

# High School Content Expectations



## ESSENTIAL SCIENCE

- Earth Science
- Biology
- Physics
- Chemistry

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# Welcome to Michigan's High School Science Essential Content Standards and Expectations

The Michigan High School Content Expectations for Science and the Michigan Merit Curriculum Course Credit Requirements define useful and connected knowledge at four levels: prerequisite, essential, core, and recommended. This essential science document defines assessable content for the Michigan Merit Exam. It includes all standards, essential content statements and essential expectations for Earth Science, Biology, Physics, and Chemistry.

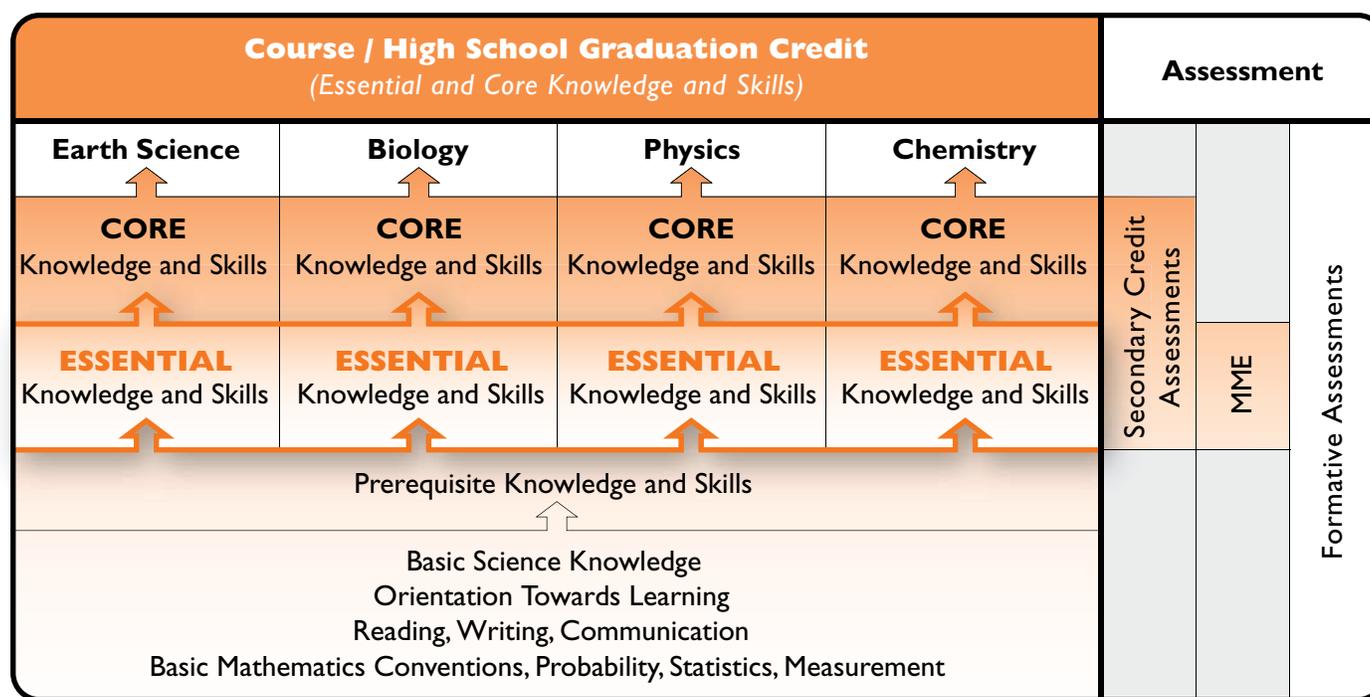
Earth Science	Biology	Physics	Chemistry
<b>STANDARDS</b> (and number of Essential Content Statements in each standard)			
E1 Inquiry, Reflection, and Social Implications (2) E2 Earth Systems (4) E3 The Solid Earth (4) E4 The Fluid Earth (3) E5 Earth in Space and Time (4)	B1 Inquiry, Reflection, and Social Implications (2) B2 Organization and Development of Living Systems (5) B3 Interdependence of Living Systems and the Environment (5) B4 Genetics (3) B5 Evolution and Biodiversity (2)	P1 Inquiry, Reflection, and Social Implications (2) P2 Motion of Objects (2) P3 Forces and Motion (6) P4 Forms of Energy and Energy Transformations (10)	C1 Inquiry, Reflection, and Social Implications (2) C2 Forms of Energy (1) C3 Energy Transfer and Conservation (2) C4 Properties of Matter (5) C5 Changes in Matter (5)

## Useful and Connected Knowledge for All Students

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

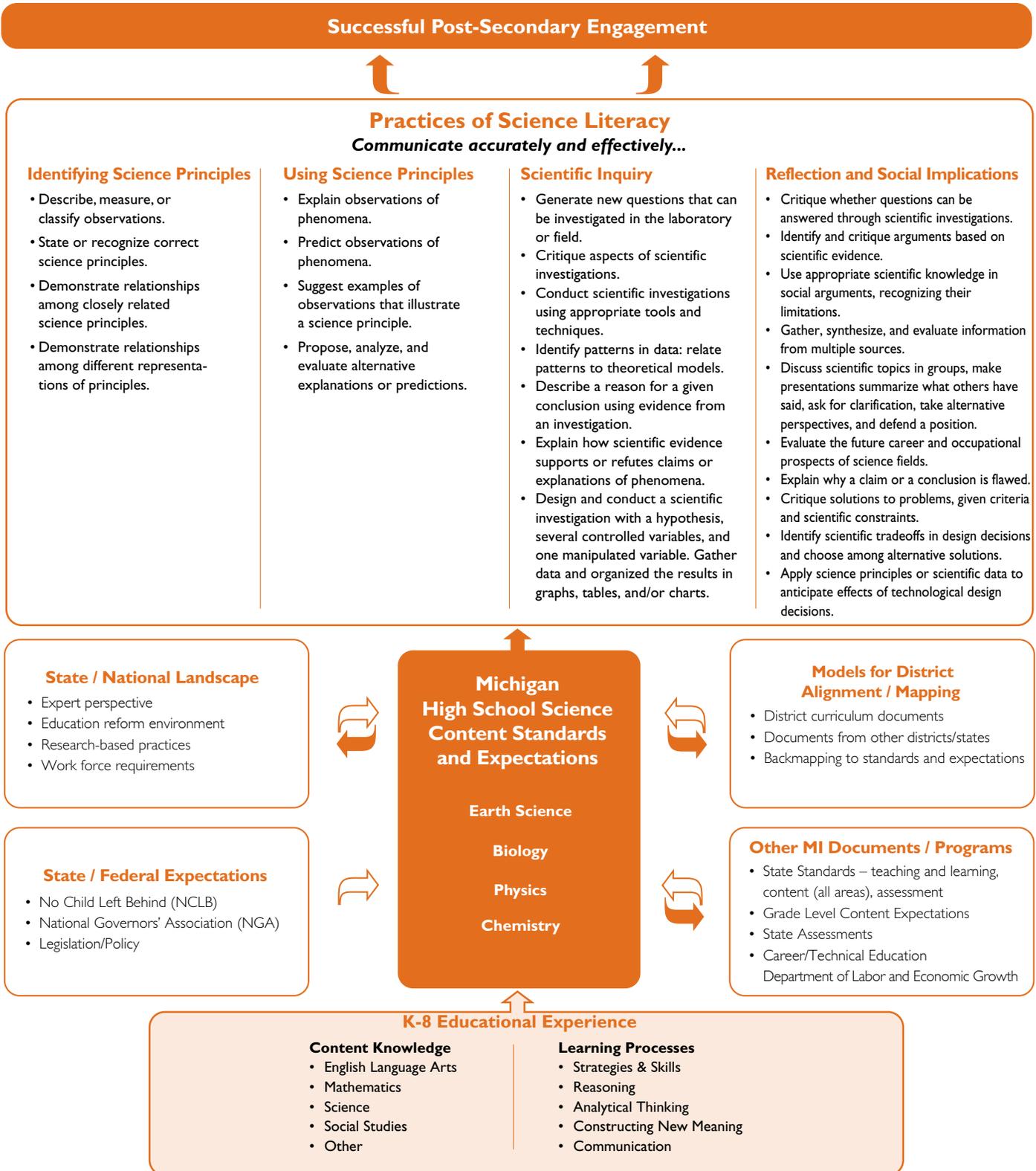
- **Essential knowledge** — Useful and connected knowledge for all high school graduates, regardless of what courses they take in high school. Essential expectation codes include an upper case letter (e.g., **E2.1A**). Essential content knowledge and performance expectations are required for graduation and are assessable on the Michigan Merit Exam (MME) and can also be assessed with formative assessments.

## High School Science Overview



# 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.



This chart includes talking points for professional development.

## 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.**

### 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.

**This document includes only Essential content statements.**

1. **Prerequisite science content** that all students should bring as a prerequisite to high school science classes. Prerequisite content statement codes include a “p” and are organized by topic [e.g., **E3.p1 Landforms and Soils (prerequisite)**].
2. **Essential science content** that all high school graduates should master. Essential content and expectations are organized by topic (e.g., **E2.1 Earth Systems Overview**).
3. **Core science content** that high school graduates need for more advanced study in the discipline and for some kinds of work. Core content and expectations are organized by topic (e.g., **B2.2x Proteins**); “x” designates a core topic).
4. **Recommended science content** that is desirable as preparation for more advanced study in the discipline, but is not required for credit. Content and expectations labeled as recommended represent extensions of the core. Recommended content statement codes include an “r” and an “x”; expectations include an “r” and a lower case letter (e.g., **P4.r9x Nature of Light; P4.r9a**).

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

### Performance Expectations

Performance expectations are derived from the intersection of content statements and practices—if the content statements from the Earth Sciences, Biology, Physics, and Chemistry are the columns of a table and the practices (Identifying Science Principles, Using Science Principles, Using Scientific Inquiry, Reflection and Social Implications) are the rows, the cells of the table are inhabited by performance expectations.

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.”

# EARTH SCIENCE

## **Essential Content Statements**

*(and number of Essential Content Expectations for each statement)*

### **OUTLINE**

#### **STANDARD E1: Inquiry, Reflection, and Social Implications**

- E1.1 Scientific Inquiry (5)
- E1.2 Scientific Reflection and Social Implications (5)

#### **STANDARD E2: Earth Systems**

- E2.1 Earth Systems Overview (3)
- E2.2 Energy in Earth Systems (4)
- E2.3 Biogeochemical Cycles (1)
- E2.4 Resources and Human Impacts on Earth Systems (2)

#### **STANDARD E3: Solid Earth**

- E3.1 Advanced Rock Cycle (2)
- E3.2 Interior of the Earth (3)
- E3.3 Plate Tectonics Theory (3)
- E3.4 Earthquakes and Volcanoes (3)

#### **STANDARD E4: Fluid Earth**

- E4.1 Hydrogeology (3)
- E4.2 Oceans and Climate (2)
- E4.3 Severe Weather (6)

#### **STANDARD E5: The Earth in Space and Time**

- E5.1 The Earth in Space (1)
- E5.2 The Sun (4)
- E5.3 Earth History and Geologic Time (4)
- E5.4 Climate Change (4)



## STANDARD EI: 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.*

### EI.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.

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

**EI.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.

**EI.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).

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

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

### EI.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.

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

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

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

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

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

## STANDARD E2: EARTH SYSTEMS

*Students describe the interactions within and between Earth systems. Students will explain how both fluids (water cycle) and solids (rock cycle) move within Earth systems and how these movements form and change their environment. They will describe the relationship between physical process and human activities and use this understanding to demonstrate an ability to make wise decisions about land use.*

### E2.1 Earth Systems Overview

The Earth is a system consisting of four major interacting components: geosphere (crust, mantle, and core), atmosphere (air), hydrosphere (water), and biosphere (the living part of Earth). Physical, chemical, and biological processes act within and among the four components on a wide range of time scales to continuously change Earth's crust, oceans, atmosphere, and living organisms. Earth elements move within and between the lithosphere, atmosphere, hydrosphere, and biosphere as part of geochemical cycles.

**E2.1A** Explain why the Earth is essentially a closed system in terms of matter.

**E2.1B** Analyze the interactions between the major systems (geosphere, atmosphere, hydrosphere, biosphere) that make up the Earth.

**E2.1C** Explain, using specific examples, how a change in one system affects other Earth systems.

### E2.2 Energy in Earth Systems

Energy in Earth systems can exist in a number of forms (e.g., thermal energy as heat in the Earth, chemical energy stored as fossil fuels, mechanical energy as delivered by tides) and can be transformed from one state to another and move from one reservoir to another. Movement of matter and its component elements, through and between Earth's systems, is driven by Earth's internal (radioactive decay and gravity) and external (Sun as primary) sources of energy. Thermal energy is transferred by radiation, convection, and conduction. Fossil fuels are derived from plants and animals of the past, are nonrenewable, and, therefore, are limited in availability. All sources of energy for human consumption (e.g., solar, wind, nuclear, ethanol, hydrogen, geothermal, hydroelectric) have advantages and disadvantages.

**E2.2A** Describe the Earth's principal sources of internal and external energy (e.g., radioactive decay, gravity, solar energy).

**E2.2B** Identify differences in the origin and use of renewable (e.g., solar, wind, water, biomass) and nonrenewable (e.g., fossil fuels, nuclear [U-235]) sources of energy.

**E2.2C** Describe natural processes in which heat transfer in the Earth occurs by conduction, convection, and radiation.

**E2.2D** Identify the main sources of energy to the climate system.

### E2.3 Biogeochemical Cycles

The Earth is a system containing essentially a fixed amount of each stable chemical atom or element. Most elements can exist in several different states and chemical forms; they move within and between the geosphere, atmosphere, hydrosphere, and biosphere as part of the Earth system. The movements can be slow or rapid. Elements and compounds have significant impacts on the biosphere and have important impacts on human health.

**E2.3A** Explain how carbon exists in different forms such as limestone (rock), carbon dioxide (gas), carbonic acid (water), and animals (life) within Earth systems and how those forms can be beneficial or harmful to humans.

### E2.4 Resources and Human Impacts on Earth Systems

The Earth provides resources (including minerals) that are used to sustain human affairs. The supply of nonrenewable natural resources is limited and their extraction and use can release elements and compounds into Earth systems. They affect air and water quality, ecosystems, landscapes, and may have effects on long-term climate. Plans for land use and long-term development must include an understanding of the interactions between Earth systems and human activities.

**E2.4A** Describe renewable and nonrenewable sources of energy for human consumption (electricity, fuels), compare their effects on the environment, and include overall costs and benefits.

**E2.4B** Explain how the impact of human activities on the environment (e.g., deforestation, air pollution, coral reef destruction) can be understood through the analysis of interactions between the four Earth systems.

## STANDARD E3: THE SOLID EARTH

*Students explain how scientists study and model the interior of the Earth and its dynamic nature. They use the theory of plate tectonics, the unifying theory of geology, to explain a wide variety of Earth features and processes and how hazards resulting from these processes impact society.*

### E3.1 Advanced Rock Cycle

Igneous, metamorphic, and sedimentary rocks are indicators of geologic and environmental conditions and processes that existed in the past. These include cooling and crystallization, weathering and erosion, sedimentation and lithification, and metamorphism. In some way, all of these processes are influenced by plate tectonics, and some are influenced by climate.

**E3.1A** Discriminate between igneous, metamorphic, and sedimentary rocks and describe the processes that change one kind of rock into another.

**E3.1B** Explain the relationship between the rock cycle and plate tectonics theory in regard to the origins of igneous, sedimentary, and metamorphic rocks.

### E3.2 Interior of the Earth

The Earth can also be subdivided into concentric layers based on their physical characteristics: (lithosphere, asthenosphere, lower mantle, outer core, and inner core). The crust and upper mantle compose the rigid lithosphere (plates) that moves over a “softer” asthenosphere (part of the upper mantle). The magnetic field of the Earth is generated in the outer core. The interior of the Earth cannot be directly sampled and must be modeled using data from seismology.

**E3.2A** Describe the interior of the Earth (in terms of crust, mantle, and inner and outer cores) and where the magnetic field of the Earth is generated.

**E3.2B** Explain how scientists infer that the Earth has interior layers with discernable properties using patterns of primary (*P*) and secondary (*S*) seismic wave arrivals.

**E3.2C** Describe the differences between oceanic and continental crust (including density, age, composition).

### E3.3 Plate Tectonics Theory

The Earth’s crust and upper mantle make up the lithosphere, which is broken into large mobile pieces called tectonic plates. The plates move at velocities in units of centimeters per year as measured using the global positioning system (GPS). Motion histories are determined with calculations that relate rate, time, and distance of offset geologic features. Oceanic plates are created at mid-ocean ridges by magmatic activity and cooled until they sink back into the Earth at subduction zones. At some localities, plates slide by each other. Mountain belts are formed both by continental collision and as a result of subduction. The outward flow of heat from Earth’s interior provides the driving energy for plate tectonics.

**E3.3A** Explain how plate tectonics accounts for the features and processes (sea floor spreading, mid-ocean ridges, subduction zones, earthquakes and volcanoes, mountain ranges) that occur on or near the Earth’s surface.

**E3.3B** Explain why tectonic plates move using the concept of heat flowing through mantle convection, coupled with the cooling and sinking of aging ocean plates that result from their increased density.

**E3.3C** Describe the motion history of geologic features (e.g., plates, Hawaii) using equations relating rate, time, and distance.

### E3.4 Earthquakes and Volcanoes

Plate motions result in potentially catastrophic events (earthquakes, volcanoes, tsunamis, mass wasting) that affect humanity. The intensity of volcanic eruptions is controlled by the chemistry and properties of the magma. Earthquakes are the result of abrupt movements of the Earth. They generate energy in the form of body and surface waves.

**E3.4A** Use the distribution of earthquakes and volcanoes to locate and determine the types of plate boundaries.

**E3.4B** Describe how the sizes of earthquakes and volcanoes are measured or characterized.

**E3.4C** Describe the effects of earthquakes and volcanic eruptions on humans.

## STANDARD E4: THE FLUID EARTH

*Students explain how the ocean and atmosphere move and transfer energy around the planet. They also explain how these movements affect climate and weather and how severe weather impacts society. Students explain how long term climatic changes (glaciers) have shaped the Michigan landscape. They also explain features and processes related to surface and ground- water and describe the sustainability of systems in terms of water quality and quantity.*

### E4.1 Hydrogeology

Fresh water moves over time between the atmosphere, hydrosphere (surface water, wetlands, rivers, and glaciers), and geosphere (groundwater). Water resources are both critical to and greatly impacted by humans. Changes in water systems will impact quality, quantity, and movement of water. Natural surface water processes shape the landscape everywhere and are affected by human land use decisions.

- E4.1A** Compare and contrast surface water systems (lakes, rivers, streams, wetlands) and groundwater in regard to their relative sizes as Earth's freshwater reservoirs and the dynamics of water movement (inputs and outputs, residence times, sustainability).
- E4.1B** Explain the features and processes of groundwater systems and how the sustainability of North American aquifers has changed in recent history (e.g., the past 100 years) qualitatively using the concepts of recharge, residence time, inputs, and outputs.
- E4.1C** Explain how water quality in both groundwater and surface systems is impacted by land use decisions.

### E4.2 Oceans and Climate

Energy from the sun and the rotation of the Earth control global atmospheric circulation. Oceans redistribute matter and energy around the Earth through currents, waves, and interaction with other Earth systems. Ocean currents are controlled by prevailing winds, changes in water density, ocean topography, and the shape and location of landmasses. Oceans and large lakes (e.g., Great Lakes) have a major effect on climate and weather because they are a source of moisture and a large reservoir of heat. Interactions between oceanic circulation and the atmosphere can affect regional climates throughout the world.

- E4.2A** Describe the major causes for the ocean's surface and deep water currents, including the prevailing winds, the Coriolis effect, unequal heating of the earth, changes in water temperature and salinity in high latitudes, and basin shape.
- E4.2B** Explain how interactions between the oceans and the atmosphere influence global and regional climate. Include the major concepts of heat transfer by ocean currents, thermohaline circulation, boundary currents, evaporation, precipitation, climatic zones, and the ocean as a major CO<sub>2</sub> reservoir.

### E4.3 Severe Weather

Tornadoes, hurricanes, blizzards, and thunderstorms are severe weather phenomena that impact society and ecosystems. Hazards include downbursts (wind shear), strong winds, hail, lightning, heavy rain, and flooding. The movement of air in the atmosphere is due to differences in air density resulting from variations in temperature. Many weather conditions can be explained by fronts that occur when air masses meet.

- E4.3A** Describe the various conditions of formation associated with severe weather (thunderstorms, tornadoes, hurricanes, floods, waves, and drought).
- E4.3B** Describe the damage resulting from, and the social impact of thunderstorms, tornadoes, hurricanes, and floods.
- E4.3C** Describe severe weather and flood safety and mitigation.
- E4.3D** Describe the seasonal variations in severe weather.
- E4.3E** Describe conditions associated with frontal boundaries that result in severe weather (thunderstorms, tornadoes, and hurricanes).
- E4.3F** Describe how mountains, frontal wedging (including dry lines), convection, and convergence form clouds and precipitation.

## STANDARD E5: THE EARTH IN SPACE AND TIME

*Students explain theories about how the Earth and universe formed and evolved over a long period of time. Students predict how human activities may influence the climate of the future.*

### E5.1 The Earth in Space

Scientific evidence indicates the universe is orderly in structure, finite, and contains all matter and energy. Information from the entire light spectrum tells us about the composition and motion of objects in the universe. Early in the history of the universe, matter clumped together by gravitational attraction to form stars and galaxies. According to the Big Bang theory, the universe has been continually expanding at an increasing rate since its formation about 13.7 billion years ago.

**E5.1A** Describe the position and motion of our solar system in our galaxy and the overall scale, structure, and age of the universe.

### E5.2 The Sun

Stars, including the Sun, transform matter into energy in nuclear reactions. When hydrogen nuclei fuse to form helium, a small amount of matter is converted to energy. Solar energy is responsible for life processes and weather as well as phenomena on Earth. These and other processes in stars have led to the formation of all the other chemical elements.

**E5.2A** Identify patterns in solar activities (sunspot cycle, solar flares, solar wind).

**E5.2B** Relate events on the Sun to phenomena such as auroras, disruption of radio and satellite communications, and power grid disturbances.

**E5.2C** Describe how nuclear fusion produces energy in the Sun.

**E5.2D** Describe how nuclear fusion and other processes in stars have led to the formation of all the other chemical elements.

### E5.3 Earth History and Geologic Time

The solar system formed from a nebular cloud of dust and gas 4.6 Ga (billion years ago). The Earth has changed through time and has been affected by both catastrophic (e.g., earthquakes, meteorite impacts, volcanoes) and gradual geologic events (e.g., plate movements, mountain building) as well as the effects of biological evolution (formation of an oxygen atmosphere). Geologic time can be determined through both relative and absolute dating.

**E5.3A** Explain how the solar system formed from a nebula of dust and gas in a spiral arm of the Milky Way Galaxy about 4.6 Ga (billion years ago).

**E5.3B** Describe the process of radioactive decay and explain how radioactive elements are used to date the rocks that contain them.

**E5.3C** Relate major events in the history of the Earth to the geologic time scale, including formation of the Earth, formation of an oxygen atmosphere, rise of life, Cretaceous-Tertiary (K-T) and Permian extinctions, and Pleistocene ice age.

**E5.3D** Describe how index fossils can be used to determine time sequence.

### E5.4 Climate Change

Atmospheric gases trap solar energy that has been reradiated from the Earth's surface (the greenhouse effect). The Earth's climate has changed both gradually and catastrophically over geological and historical time frames due to complex interactions between many natural variables and events. The concentration of greenhouse gases (especially carbon dioxide) has increased due to human industrialization, which has contributed to a rise in average global atmospheric temperatures and changes in the biosphere, atmosphere, and hydrosphere. Climates of the past are researched, usually using indirect indicators, to better understand and predict climate change.

**E5.4A** Explain the natural mechanism of the greenhouse effect, including comparisons of the major greenhouse gases (water vapor, carbon dioxide, methane, nitrous oxide, and ozone).

**E5.4B** Describe natural mechanisms that could result in significant changes in climate (e.g., major volcanic eruptions, changes in sunlight received by the earth, and meteorite impacts).

**E5.4C** Analyze the empirical relationship between the emissions of carbon dioxide, atmospheric carbon dioxide levels, and the average global temperature over the past 150 years.

**E5.4D** Based on evidence of observable changes in recent history and climate change models, explain the consequences of warmer oceans (including the results of increased evaporation, shoreline and estuarine impacts, oceanic algae growth, and coral bleaching) and changing climatic zones (including the adaptive capacity of the biosphere).

# BIOLOGY

## **Essential Content Statements**

*(and number of Essential Content Expectations for each statement)*

### **OUTLINE**

#### **STANDARD B1: Inquiry, Reflection, and Social Implications**

- B1.1 Scientific Inquiry (5)
- B1.2 Scientific Reflection and Social Implications (5)

#### **STANDARD B2: Organization and Development of Living Systems**

- B2.1 Transformation of Matter and Energy in Cells (3)
- B2.2 Organic Molecules (5)
- B2.3 Maintaining Environmental Stability (3)
- B2.4 Cell Specialization (3)
- B2.5 Living Organism Composition (4)

#### **STANDARD B3: Interdependence of Living Systems and the Environment**

- B3.1 Photosynthesis and Respiration (4)
- B3.2 Ecosystems (3)
- B3.3 Element Recombination (1)
- B3.4 Changes in Ecosystems (3)
- B3.5 Populations (3)

#### **STANDARD B4: Genetics**

- B4.1 Genetics and Inherited Traits (2)
- B4.2 DNA (5)
- B4.3 Cell Division – Mitosis and Meiosis (3)

#### **STANDARD B5: Evolution and Biodiversity**

- B5.1 Theory of Evolution (2)
- B5.3 Natural Selection (3)



## STANDARD BI: 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.*

### B1.1 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.

- B1.1A** Generate new questions that can be investigated in the laboratory or field.
- B1.1B** 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.
- B1.1C** 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).
- B1.1D** Identify patterns in data and relate them to theoretical models.
- B1.1E** Describe a reason for a given conclusion using evidence from an investigation.

### B1.2 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.

- B1.2A** Critique whether or not specific questions can be answered through scientific investigations.
- B1.2B** Identify and critique arguments about personal or societal issues based on scientific evidence.
- B1.2C** Develop an understanding of a scientific concept by accessing information from multiple sources. Evaluate the scientific accuracy and significance of the information.
- B1.2D** Evaluate scientific explanations in a peer review process or discussion format.
- B1.2E** Evaluate the future career and occupational prospects of science fields.

## STANDARD B2: ORGANIZATION AND DEVELOPMENT OF LIVING SYSTEMS

*Students describe the general structure and function of cells. They can explain that all living systems are composed of cells and that organisms may be unicellular or multicellular. They understand that cells are composed of biological macromolecules and that the complex processes of the cell allow it to maintain a stable internal environment necessary to maintain life. They make predictions based on these understandings.*

### B2.1 Transformation of Matter and Energy in Cells

In multicellular organisms, cells are specialized to carry out specific functions such as transport, reproduction, or energy transformation.

- B2.1A** Explain how cells transform energy (ultimately obtained from the sun) from one form to another through the processes of photosynthesis and respiration. Identify the reactants and products in the general reaction of photosynthesis.
- B2.1B** Compare and contrast the transformation of matter and energy during photosynthesis and respiration.
- B2.1C** Explain cell division, growth, and development as a consequence of an increase in cell number, cell size, and/or cell products.

### B2.2 Organic Molecules

There are four major categories of organic molecules that make up living systems: carbohydrates, fats, proteins, and nucleic acids.

- B2.2A** Explain how carbon can join to other carbon atoms in chains and rings to form large and complex molecules.
- B2.2B** Recognize the six most common elements in organic molecules (C, H, N, O, P, S).
- B2.2C** Describe the composition of the four major categories of organic molecules (carbohydrates, lipids, proteins, and nucleic acids).
- B2.2D** Explain the general structure and primary functions of the major complex organic molecules that compose living organisms.
- B2.2E** Describe how dehydration and hydrolysis relate to organic molecules.

### B2.3 Maintaining Environmental Stability

The internal environment of living things must remain relatively constant. Many systems work together to maintain stability. Stability is challenged by changing physical, chemical, and environmental conditions as well as the presence of disease agents.

- B2.3A** Describe how cells function in a narrow range of physical conditions, such as temperature and pH (acidity), to perform life functions.
- B2.3B** Describe how the maintenance of a relatively stable internal environment is required for the continuation of life.
- B2.3C** Explain how stability is challenged by changing physical, chemical, and environmental conditions as well as the presence of disease agents.

### B2.4 Cell Specialization

In multicellular organisms, specialized cells perform specialized functions. Organs and organ systems are composed of cells and function to serve the needs of cells for food, air, and waste removal. The way in which cells function is similar in all living organisms.

- B2.4A** Explain that living things can be classified based on structural, embryological, and molecular (relatedness of DNA sequence) evidence.
- B2.4B** Describe how various organisms have developed different specializations to accomplish a particular function and yet the end result is the same (e.g., excreting nitrogenous wastes in animals, obtaining oxygen for respiration).
- B2.4C** Explain how different organisms accomplish the same result using different structural specializations (gills vs. lungs vs. membranes).

## B2.5 Living Organism Composition

All living or once-living organisms are composed of carbohydrates, lipids, proteins, and nucleic acids. Carbohydrates and lipids contain many carbon-hydrogen bonds that also store energy.

- B2.5A** Recognize and explain that macromolecules such as lipids contain high energy bonds.
- B2.5B** Explain how major systems and processes work together in animals and plants, including relationships between organelles, cells, tissues, organs, organ systems, and organisms. Relate these to molecular functions.
- B2.5C** Describe how energy is transferred and transformed from the Sun to energy-rich molecules during photosynthesis.
- B2.5D** Describe how individual cells break down energy-rich molecules to provide energy for cell functions.

## STANDARD B3: INTERDEPENDENCE OF LIVING SYSTEMS AND THE ENVIRONMENT

*Students describe the processes of photosynthesis and cellular respiration and how energy is transferred through food webs. They recognize and analyze the consequences of the dependence of organisms on environmental resources and the interdependence of organisms in ecosystems.*

### B3.1 Photosynthesis and Respiration

Organisms acquire their energy directly or indirectly from sunlight. Plants capture the Sun's energy and use it to convert carbon dioxide and water to sugar and oxygen through the process of photosynthesis. Through the process of cellular respiration, animals are able to release the energy stored in the molecules produced by plants and use it for cellular processes, producing carbon dioxide and water.

- B3.1A** Describe how organisms acquire energy directly or indirectly from sunlight.
- B3.1B** Illustrate and describe the energy conversions that occur during photosynthesis and respiration.
- B3.1C** Recognize the equations for photosynthesis and respiration and identify the reactants and products for both.
- B3.1D** Explain how living organisms gain and use mass through the processes of photosynthesis and respiration.

### B3.2 Ecosystems

The chemical elements that make up the molecules of living things pass through food webs and are combined and recombined in different ways. At each link in an ecosystem, some energy is stored in newly made structures, but much is dissipated into the environment as heat. Continual input of energy from sunlight keeps the process going.

- B3.2A** Identify how energy is stored in an ecosystem.
- B3.2B** Describe energy transfer through an ecosystem, accounting for energy lost to the environment as heat.
- B3.2C** Draw the flow of energy through an ecosystem. Predict changes in the food web when one or more organisms are removed.

### B3.3 Element Recombination

As matter cycles and energy flows through different levels of organization of living systems—cells, organs, organisms, and communities—and between living systems and the physical environment, chemical elements are recombined in different ways. Each recombination results in storage and dissipation of energy into the environment as heat. Matter and energy are conserved in each change.

- B3.3A** Use a food web to identify and distinguish producers, consumers, and decomposers and explain the transfer of energy through trophic levels.

### **B3.4 Changes in Ecosystems**

Although the interrelationships and interdependence of organisms may generate biological communities in ecosystems that are stable for hundreds or thousands of years, ecosystems always change when climate changes or when one or more new species appear as a result of migration or local evolution. The impact of the human species has major consequences for other species.

- B3.4A** Describe ecosystem stability. Understand that if a disaster such as flood or fire occurs, the damaged ecosystem is likely to recover in stages of succession that eventually result in a system similar to the original one.
- B3.4B** Recognize and describe that a great diversity of species increases the chance that at least some living organisms will survive in the face of cataclysmic changes in the environment.
- B3.4C** Examine the negative impact of human activities.

### **B3.5 Populations**

Populations of living things increase and decrease in size as they interact with other populations and with the environment. The rate of change is dependent upon relative birth and death rates.

- B3.5A** Graph changes in population growth, given a data table.
- B3.5B** Explain the influences that affect population growth.
- B3.5C** Predict the consequences of an invading organism on the survival of other organisms.

## **STANDARD B4: GENETICS**

*Students recognize that the specific genetic instructions for any organism are contained within genes composed of DNA molecules located in chromosomes. They explain the mechanism for the direct production of specific proteins based on inherited DNA. Students diagram how occasional modifications in genes and the random distribution of genes from each parent provide genetic variation and become the raw material for evolution. Content Statements, Performances, and Boundaries*

### **B4.1 Genetics and Inherited Traits**

Hereditary information is contained in genes, located in the chromosomes of each cell. Cells contain many thousands of different genes. One or many genes can determine an inherited trait of an individual, and a single gene can influence more than one trait. Before a cell divides, this genetic information must be copied and apportioned evenly into the daughter cells.

- B4.1A** Draw and label a homologous chromosome pair with heterozygous alleles highlighting a particular gene location.
- B4.1B** Explain that the information passed from parents to offspring is transmitted by means of genes that are coded in DNA molecules. These genes contain the information for the production of proteins.

### **B4.2 DNA**

The genetic information encoded in DNA molecules provides instructions for assembling protein molecules. Genes are segments of DNA molecules. Inserting, deleting, or substituting DNA segments can alter genes. An altered gene may be passed on to every cell that develops from it. The resulting features may help, harm, or have little or no effect on the offspring's success in its environment.

- B4.2A** Show that when mutations occur in sex cells, they can be passed on to offspring (inherited mutations), but if they occur in other cells, they can be passed on to descendant cells only (noninherited mutations).
- B4.2B** Recognize that every species has its own characteristic DNA sequence.
- B4.2C** Describe the structure and function of DNA.
- B4.2D** Predict the consequences that changes in the DNA composition of particular genes may have on an organism (e.g., sickle cell anemia, other).
- B4.2E** Propose possible effects (on the genes) of exposing an organism to radiation and toxic chemicals.

### **B4.3 Cell Division — Mitosis and Meiosis**

Sorting and recombination of genes in sexual reproduction results in a great variety of possible gene combinations from the offspring of any two parents.

- B4.3A** Compare and contrast the processes of cell division (mitosis and meiosis), particularly as those processes relate to production of new cells and to passing on genetic information between generations.
- B4.3B** Explain why only mutations occurring in gametes (sex cells) can be passed on to offspring.
- B4.3C** Explain how it might be possible to identify genetic defects from just a karyotype of a few cells.

## **STANDARD B5: EVOLUTION AND BIODIVERSITY**

*Students recognize that evolution is the result of genetic changes that occur in constantly changing environments. They can explain that modern evolution includes both the concepts of common descent and natural selection. They illustrate how the consequences of natural selection and differential reproduction have led to the great biodiversity on Earth.*

### **B5.1 Theory of Evolution**

The theory of evolution provides a scientific explanation for the history of life on Earth as depicted in the fossil record and in the similarities evident within the diversity of existing organisms.

- B5.1A** Summarize the major concepts of natural selection (differential survival and reproduction of chance inherited variants, depending on environmental conditions).
- B5.1B** Describe how natural selection provides a mechanism for evolution.

### **B5.3 Natural Selection**

Evolution is the consequence of natural selection, the interactions of (1) the potential for a population to increase its numbers, (2) the genetic variability of offspring due to mutation and recombination of genes, (3) a finite supply of the resources required for life, and (4) the ensuing selection from environmental pressure of those organisms better able to survive and leave offspring.

- B5.3A** Explain how natural selection acts on individuals, but it is populations that evolve. Relate genetic mutations and genetic variety produced by sexual reproduction to diversity within a given population.
- B5.3B** Describe the role of geographic isolation in speciation.
- B4.3C** Give examples of ways in which genetic variation and environmental factors are causes of evolution and the diversity of organisms.

# PHYSICS

## **Essential Content Statements**

*(and number of Essential Content Expectations for each statement)*

### **OUTLINE**

#### **STANDARD P1: Inquiry, Reflection, and Social Implications**

- P1.1 Scientific Inquiry (5)
- P1.2 Scientific Reflection and Social Implications (5)

#### **STANDARD P2: Motion of Objects**

- P2.1 Position — Time (6)
- P2.2 Velocity — Time (4)

#### **STANDARD P3: Forces and Motion**

- P3.1 Basic Forces in Nature (1)
- P3.2 Net Forces (3)
- P3.3 Newton's Third Law (1)
- P3.4 Forces and Acceleration (4)
- P3.6 Gravitational Interactions (3)
- P3.7 Electric Charges (2)

#### **STANDARD P4: Forms of Energy and Energy Transformations**

- P4.1 Energy Transfer (2)
- P4.2 Energy Transformation (4)
- P4.3 Kinetic and Potential Energy (3)
- P4.4 Wave Characteristics (3)
- P4.5 Mechanical Wave Propagation (5)
- P4.6 Electromagnetic Waves (4)
- P4.8 Wave Behavior – Reflection and Refraction (2)
- P4.9 Nature of Light (3)
- P4.10 Current Electricity – Circuits (4)
- P4.12 Nuclear Reactions (3)



## STANDARD P1: 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.*

### P1.1 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.

- P1.1A** Generate new questions that can be investigated in the laboratory or field.
- P1.1B** 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.
- P1.1C** 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).
- P1.1D** Identify patterns in data and relate them to theoretical models.
- P1.1E** Describe a reason for a given conclusion using evidence from an investigation.

### P1.2 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.

- P1.2A** Critique whether or not specific questions can be answered through scientific investigations.
- P1.2B** Identify and critique arguments about personal or societal issues based on scientific evidence.
- P1.2C** Develop an understanding of a scientific concept by accessing information from multiple sources. Evaluate the scientific accuracy and significance of the information.
- P1.2D** Evaluate scientific explanations in a peer review process or discussion format.
- P1.2E** Evaluate the future career and occupational prospects of science fields.

## STANDARD P2: MOTION OF OBJECTS

*The universe is in a state of constant change. From small particles (electrons) to the large systems (galaxies) all things are in motion. Therefore, for students to understand the universe they must describe and represent various types of motion. Kinematics, the description of motion, always involves measurements of position and time. Students must describe the relationships between these quantities using mathematical statements, graphs, and motion maps. They use these representations as powerful tools to not only describe past motions but also predict future events.*

### P2.1 Position — Time

An object's position can be measured and graphed as a function of time. An object's speed can be calculated and graphed as a function of time.

- P2.1A** Calculate the average speed of an object using the change of position and elapsed time.
- P2.1B** Represent the velocities for linear and circular motion using motion diagrams (arrows on strobe pictures).
- P2.1C** Create line graphs using measured values of position and elapsed time.
- P2.1D** Describe and analyze the motion that a position-time graph represents, given the graph.
- P2.1E** Describe and classify various motions in a plane as one dimensional, two dimensional, circular, or periodic.
- P2.1F** Distinguish between rotation and revolution and describe and contrast the two speeds of an object like the Earth.

### P2.2 Velocity — Time

The motion of an object can be described by its position and velocity as functions of time and by its average speed and average acceleration during intervals of time.

- P2.2A** Distinguish between the variables of distance, displacement, speed, velocity, and acceleration.
- P2.2B** Use the change of speed and elapsed time to calculate the average acceleration for linear motion.
- P2.2C** Describe and analyze the motion that a velocity-time graph represents, given the graph.
- P2.2D** State that uniform circular motion involves acceleration without a change in speed.

## STANDARD P3: FORCES AND MOTION

*Students identify interactions between objects either as being by direct contact (e.g., pushes or pulls, friction) or at a distance (e.g., gravity, electromagnetism), and to use forces to describe interactions between objects. They recognize that non-zero net forces always cause changes in motion (Newton's first law). These changes can be changes in speed, direction, or both. Students use Newton's second law to summarize relationships among and solve problems involving net forces, masses, and changes in motion (using standard metric units). They explain that whenever one object exerts a force on another, a force equal in magnitude and opposite in direction is exerted back on it (Newton's third law).*

### P3.1 Basic Forces in Nature

Objects can interact with each other by "direct contact" (e.g., pushes or pulls, friction) or at a distance (e.g., gravity, electromagnetism, nuclear).

- P3.1A** Identify the force(s) acting between objects in "direct contact" or at a distance.

### P3.2 Net Forces

Forces have magnitude and direction. The net force on an object is the sum of all the forces acting on the object. Objects change their speed and/or direction only when a net force is applied. If the net force on an object is zero, there is no change in motion (Newton's First Law).

- P3.2A** Identify the magnitude and direction of everyday forces (e.g., wind, tension in ropes, pushes and pulls, weight).
- P3.2B** Compare work done in different situations.
- P3.2C** Calculate the net force acting on an object.

### P3.3 Newton's Third Law

Whenever one object exerts a force on another object, a force equal in magnitude and opposite in direction is exerted back on the first object.

**P3.3A** Identify the action and reaction force from examples of forces in everyday situations (e.g., book on a table, walking across the floor, pushing open a door).

### P3.4 Forces and Acceleration

The change of speed and/or direction (acceleration) of an object is proportional to the net force and inversely proportional to the mass of the object. The acceleration and net force are always in the same direction.

**P3.4A** Predict the change in motion of an object acted on by several forces.

**P3.4B** Identify forces acting on objects moving with constant velocity (e.g., cars on a highway).

**P3.4C** Solve problems involving force, mass, and acceleration in linear motion (Newton's second law).

**P3.4D** Identify the force(s) acting on objects moving with uniform circular motion (e.g., a car on a circular track, satellites in orbit).

### P3.6 Gravitational Interactions

Gravitation is a universal attractive force that a mass exerts on every other mass. The strength of the gravitational force between two masses is proportional to the masses and inversely proportional to the square of the distance between them.

**P3.6A** Explain earth-moon interactions (orbital motion) in terms of forces.

**P3.6B** Predict how the gravitational force between objects changes when the distance between them changes.

**P3.6C** Explain how your weight on Earth could be different from your weight on another planet.

### P3.7 Electric Charges

Electric force exists between any two charged objects. Oppositely charged objects attract, while objects with like charge repel. The strength of the electric force between two charged objects is proportional to the magnitudes of the charges and inversely proportional to the square of the distance between them (Coulomb's Law).

**P3.7A** Predict how the electric force between charged objects varies when the distance between them and/or the magnitude of charges change.

**P3.7B** Explain why acquiring a large excess static charge (e.g., pulling off a wool cap, touching a Van de Graaff generator, combing) affects your hair.

## STANDARD P4: FORMS OF ENERGY AND ENERGY TRANSFORMATIONS

*Energy is a useful conceptual system for explaining how the universe works and accounting for changes in matter. Energy is not a "thing." Students develop several energy-related ideas: First, they keep track of energy during transfers and transformations, and account for changes using energy conservation. Second, they identify places where energy is apparently lost during a transformation process, but is actually spread around to the environment as thermal energy and therefore not easily recoverable. Third, they identify the means of energy transfers: collisions between particles, or waves.*

### P4.1 Energy Transfer

Moving objects and waves transfer energy from one location to another. They also transfer energy to objects during interactions (e.g., sunlight transfers energy to the ground when it warms the ground; sunlight also transfers energy from the Sun to the Earth).

**P4.1A** Account for and represent energy into and out of systems using energy transfer diagrams.

**P4.1B** Explain instances of energy transfer by waves and objects in everyday activities (e.g., why the ground gets warm during the day, how you hear a distant sound, why it hurts when you are hit by a baseball).

## P4.2 Energy Transformation

Energy is often transformed from one form to another. The amount of energy before a transformation is equal to the amount of energy after the transformation. In most energy transformations, some energy is converted to thermal energy.

- P4.2A** Account for and represent energy transfer and transformation in complex processes (interactions).
- P4.2B** Name devices that transform specific types of energy into other types (e.g., a device that transforms electricity into motion).
- P4.2C** Explain how energy is conserved in common systems (e.g., light incident on a transparent material, light incident on a leaf, mechanical energy in a collision).
- P4.2D** Explain why all the stored energy in gasoline does not transform to mechanical energy of a vehicle

## P4.3 Kinetic and Potential Energy

Moving objects have kinetic energy. Objects experiencing a force may have potential energy due to their relative positions (e.g., lifting an object or stretching a spring, energy stored in chemical bonds). Conversions between kinetic and gravitational potential energy are common in moving objects. In frictionless systems, the decrease in gravitational potential energy is equal to the increase in kinetic energy or vice versa.

- P4.3A** Identify the form of energy in given situations (e.g., moving objects, stretched springs, rocks on cliffs, energy in food).
- P4.3B** Describe the transformation between potential and kinetic energy in simple mechanical systems (e.g., pendulums, roller coasters, ski lifts).
- P4.3C** Explain why all mechanical systems require an external energy source to maintain their motion.

## P4.4 Wave Characteristics

Waves (mechanical and electromagnetic) are described by their wavelength, amplitude, frequency, and speed.

- P4.4A** Describe specific mechanical waves (e.g., on a demonstration spring, on the ocean) in terms of wavelength, amplitude, frequency, and speed.
- P4.4B** Identify everyday examples of transverse and compression (longitudinal) waves.
- P4.4C** Compare and contrast transverse and compression (longitudinal) waves in terms of wavelength, amplitude, and frequency.

## P4.5 Mechanical Wave Propagation

Vibrations in matter initiate mechanical waves (e.g., water waves, sound waves, seismic waves), which may propagate in all directions and decrease in intensity in proportion to the distance squared for a point source. Waves transfer energy from one place to another without transferring mass.

- P4.5A** Identify everyday examples of energy transfer by waves and their sources.
- P4.5B** Explain why an object (e.g., fishing bobber) does not move forward as a wave passes under it.
- P4.5C** Provide evidence to support the claim that sound is energy transferred by a wave, not energy transferred by particles.
- P4.5D** Explain how waves propagate from vibrating sources and why the intensity decreases with the square of the distance from a point source.
- P4.5E** Explain why everyone in a classroom can hear one person speaking, but why an amplification system is often used in the rear of a large concert auditorium.

## P4.6 Electromagnetic Waves

Electromagnetic waves (e.g., radio, microwave, infrared, visible light, ultraviolet, x-ray) are produced by changing the motion (acceleration) of charges or by changing magnetic fields. Electromagnetic waves can travel through matter, but they do not require a material medium. (That is, they also travel through empty space.) All electromagnetic waves move in a vacuum at the speed of light. Types of electromagnetic radiation are distinguished from each other by their wavelength and energy.

- P4.6A Identify the different regions on the electromagnetic spectrum and compare them in terms of wavelength, frequency, and energy.
- P4.6B Explain why radio waves can travel through space, but sound waves cannot.
- P4.6C Explain why there is a delay between the time we send a radio message to astronauts on the moon and when they receive it.
- P4.6D Explain why we see a distant event before we hear it (e.g., lightning before thunder, exploding fireworks before the boom).

## P4.8 Wave Behavior — Reflection and Refraction

The laws of reflection and refraction describe the relationships between incident and reflected/refracted waves.

- P4.8A Draw ray diagrams to indicate how light reflects off objects or refracts into transparent media.
- P4.8B Predict the path of reflected light from flat, curved, or rough surfaces (e.g., flat and curved mirrors, painted walls, paper).

## P4.9 Nature of Light

Light interacts with matter by reflection, absorption, or transmission.

- P4.9A Identify the principle involved when you see a transparent object (e.g., straw, piece of glass) in a clear liquid.
- P4.9B Explain how various materials reflect, absorb, or transmit light in different ways.
- P4.9C Explain why the image of the Sun appears reddish at sunrise and sunset.

## P4.10 Current Electricity — Circuits

Current electricity is described as movement of charges. It is a particularly useful form of energy because it can be easily transferred from place to place and readily transformed by various devices into other forms of energy (e.g., light, heat, sound, and motion). Electrical current (amperage) in a circuit is determined by the potential difference (voltage) of the power source and the resistance of the loads in the circuit.

- P4.10A Describe the energy transformations when electrical energy is produced and transferred to homes and businesses.
- P4.10B Identify common household devices that transform electrical energy to other forms of energy, and describe the type of energy transformation.
- P4.10C Given diagrams of many different possible connections of electric circuit elements, identify complete circuits, open circuits, and short circuits and explain the reasons for the classification.
- P4.10D Discriminate between voltage, resistance, and current as they apply to an electric circuit.

## P4.12 Nuclear Reactions

Changes in atomic nuclei can occur through three processes: fission, fusion, and radioactive decay. Fission and fusion can convert small amounts of matter into large amounts of energy. Fission is the splitting of a large nucleus into smaller nuclei at extremely high temperature and pressure. Fusion is the combination of smaller nuclei into a large nucleus and is responsible for the energy of the Sun and other stars. Radioactive decay occurs naturally in the Earth's crust (rocks, minerals) and can be used in technological applications (e.g., medical diagnosis and treatment).

- P4.12A Describe peaceful technological applications of nuclear fission and radioactive decay.
- P4.12B Describe possible problems caused by exposure to prolonged radioactive decay.
- P4.12C Explain how stars, including our Sun, produce huge amounts of energy (e.g., visible, infrared, ultraviolet light).

# CHEMISTRY

## **Essential Content Statements**

*(and number of Essential Content Expectations for each statement)*

### **OUTLINE**

#### **STANDARD C1: Inquiry, Reflection, and Social Implications**

- C1.1 Scientific Inquiry (5)
- C1.2 Scientific Reflection and Social Implications (5)

#### **STANDARD C2: Forms of Energy**

- C2.2 Molecules in Motion (2)

#### **STANDARD C3: Energy Transfer and Conservation**

- C3.3 Heating Impacts (2)
- C3.4 Endothermic and Exothermic Reactions (2)

#### **STANDARD C4: Properties of Matter**

- C4.2 Nomenclature (2)
- C4.3 Properties of Substances (2)
- C4.8 Atomic Structure (4)
- C4.9 Periodic Table (1)
- C4.10 Neutral Atoms, Ions, and Isotopes (2)

#### **STANDARD C5: Changes in Matter**

- C5.2 Chemical Changes (3)
- C5.4 Phase Change/Diagrams (2)
- C5.5 Chemical Bonds — Trends (2)
- C5.7 Acids and Bases (5)
- C5.8 Carbon Chemistry (3)



## STANDARD CI: 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.

### C1.2 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.

## 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.

### 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.

## 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.

### 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.

### C3.4 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.

## 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.

### 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.

### C4.3 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.

### C4.8 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.

### C4.9 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.

### C4.10 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.

## 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.*

### 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.

### C5.4 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.

### C5.5 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.

### C5.7 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.

### C5.8 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.



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