Michigan Merit Curriculum

Course/Credit Requirements

PHYSICS

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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

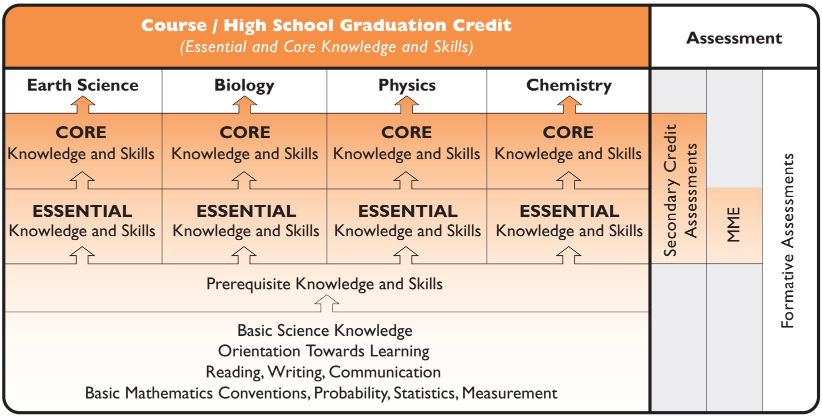
This document defines expectations for Michigan High School graduates, organized by discipline: Earth Science, Biology, Physics, and Chemistry. It defines ***useful*** and ***connected knowledge*** at four levels:

- **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.

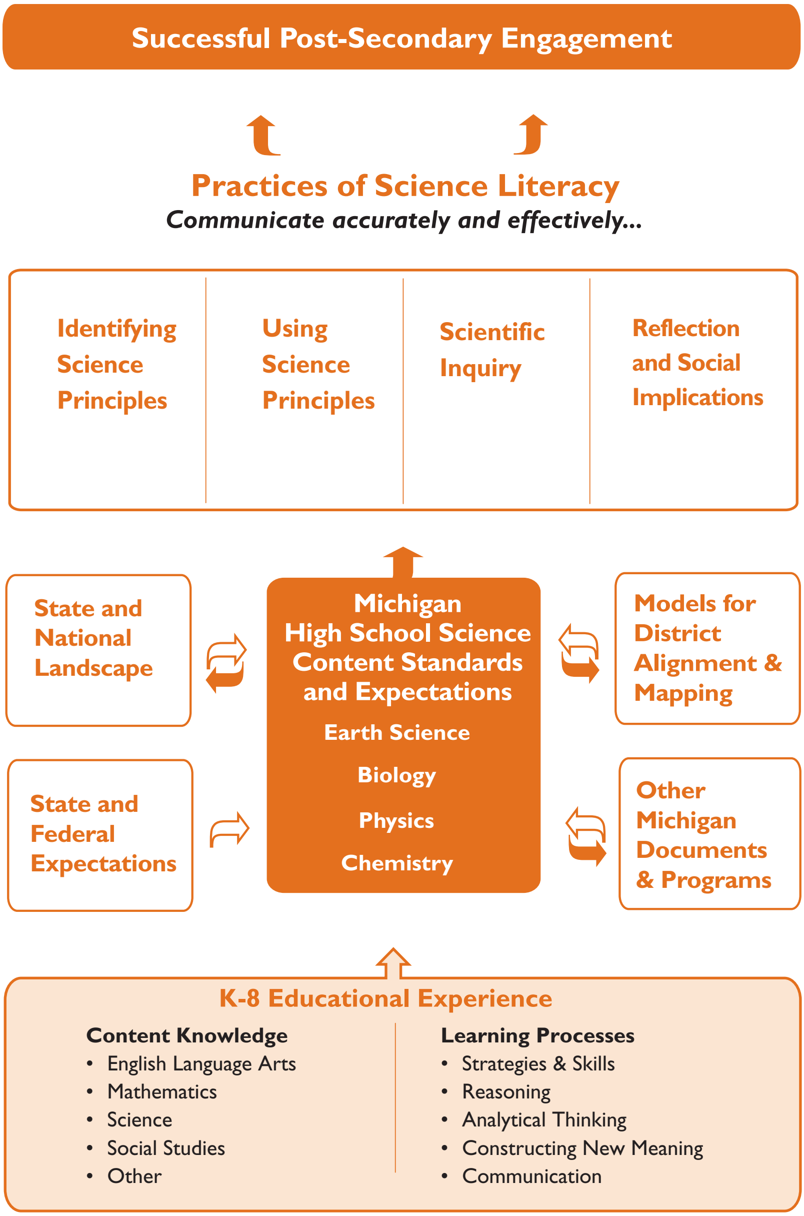
Credit for high school Earth Science, Biology, Physics, and Chemistry will be defined as meeting both essential and core subject area content expectations.



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).

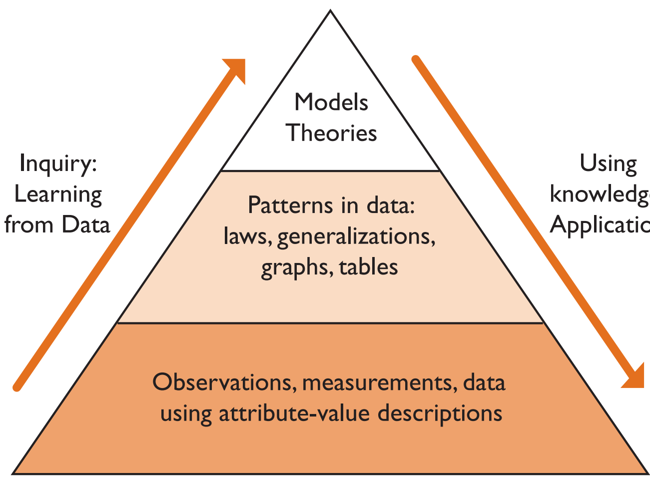


Figure 1: Knowledge and practices of model-based reasoning

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.

PHYSICS (P)

Physics is a basic science. It is a human construct to attempt to explain observations on both the macro and micro levels. Knowledge of physical principles allows understanding in other sciences and everyday experiences, (e.g., heat exchanges in the atmosphere as they relate to weather; pressure and temperature differences causing different geological formations; radiation of electromagnetic energy and how it affects photosynthesis; the behavior of light and the eye; electricity, electromagnetic waves and your cell phone; nuclear fission and power plants; atomic structure and chemical reactions).

The universe is in a state of constant change. From small particles (electrons) to the large systems (galaxies) all things are in motion. Therefore, understanding the universe requires the ability to describe and represent various types of motion. Kinematics, the description of motion, always involves measurements of position and time. The relationships between these quantities can be represented by mathematical statements, graphs, and motion maps. These representations are powerful tools that can not only describe past motions but can also predict future events.

Objects can interact with each other by direct contact (e.g., pushes or pulls, friction) or at a distance (e.g., gravity, electro-magnetism). Forces are used for describing interactions between objects. Non-zero net forces always cause changes in motion (Newton's first law). These changes can be changes in speed, direction, or both. Newton's second law summarizes relationships between net forces, masses, and changes in motion. 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).

Energy is a constant in an ever-changing world. Energy from the sun fuels electrical storms, hurricanes, tornados, and photosynthesis. In turn, the products of photosynthesis (carbohydrates and oxygen) react during respiration to fuel the life processes, such as growth and reproduction, of plants and animals. Energy is the conceptual system for explaining how the universe works and accounting for changes in matter. (NAEP) Energy is not a "thing". "Three energy-related ideas are important. One is energy transformation. All physical events involve transferring energy or changing one form of energy into another. … A second idea is the conservation of energy. … A third idea is that whenever there is a transformation of energy, some of it is likely to go into heat which is spread around and is therefore not available for use." (*Benchmarks for Science Literacy*, AAAS, 1993)

Physics Content Statement Outline

STANDARD P1 Inquiry, Reflection, and Social Implications

- P1.1 Scientific Inquiry
- P1.2 Scientific Reflection and Social Implications

STANDARD P2 Motion of Objects

- P2.1 Position –Time
- P2.2 Velocity – Time
- P2.3x Frames of Reference

STANDARD P3 Forces and Motion

- P3.1 Basic Forces in Nature
- P3.1x Forces
- P3.2 Net Forces
- P3.3 Newton's Third Law
- P3.4 Forces and Acceleration
- P3.5x Momentum
- P3.6 Gravitational Interactions
- P3.7 Electric Charges
- P3.7x Electric Charges – Interactions
- P3.p8 Magnetic Force *(prerequisite)*
- P3.8x Electromagnetic Force

STANDARD P4 Forms of Energy and Energy Transformations

- P4.1 Energy Transfer
- P4.1x Energy Transfer – Work
- P4.2 Energy Transformation
- P4.3 Kinetic and Potential Energy
- P4.3x Kinetic and Potential Energy – Calculations
- P4.4 Wave Characteristics

STANDARD P4 Forms of Energy and Energy Transformations (cont.)

P4.4x	Wave Characteristics – Calculations
P4.5	Mechanical Wave Propagation
P4.6	Electromagnetic Waves
P4.6x	Electromagnetic Propagation
P4.r7x	Quantum Theory of Waves *(recommended)*
P4.8	Wave Behavior – Reflection and Refraction
P4.8x	Wave Behavior – Diffraction, Interference, and Refraction
P4.9	Nature of Light
P4.r9x	Nature of Light – Wave-Particle Nature *(recommended)*
P4.10	Current Electricity – Circuits
P4.10x	Current Electricity – Ohm's Law, Work, and Power
P4.11x	Heat, Temperature, and Efficiency
P4.12	Nuclear Reactions
P4.12x	Mass and Energy

CONTENT EXPECTATIONS FOR PHYSICS

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.

P1.1f Predict what would happen if the variables, methods, or timing of an investigation were changed.

P1.1g Based on empirical evidence, explain and critique the reasoning used to draw a scientific conclusion or explanation.

P1.1h Design and conduct a systematic scientific investigation that tests a hypothesis. Draw conclusions from data presented in charts or tables.

P1.1i Distinguish between scientific explanations that are regarded as current scientific consensus and the emerging questions that active researchers investigate.

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.

P1.2f Critique solutions to problems, given criteria and scientific constraints.

P1.2g Identify scientific tradeoffs in design decisions and choose among alternative solutions.

P1.2h Describe the distinctions between scientific theories, laws, hypotheses, and observations.

P1.2i Explain the progression of ideas and explanations that lead to science theories that are part of the current scientific consensus or core knowledge.

P1.2j Apply science principles or scientific data to anticipate effects of technological design decisions.

P1.2k Analyze how science and society interact from a historical, political, economic, or social perspective.

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.

P2.1g Solve problems involving average speed and constant acceleration in one dimension.

P2.1h Identify the changes in speed and direction in everyday examples of circular (rotation and revolution), periodic, and projectile motions.

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.

P2.2e Use the area under a velocity-time graph to calculate the distance traveled and the slope to calculate the acceleration.

P2.2f Describe the relationship between changes in position, velocity, and acceleration during periodic motion.

P2.2g Apply the independence of the vertical and horizontal initial velocities to solve projectile motion problems.

P2.3x Frames of Reference

All motion is relative to whatever frame of reference is chosen, for there is no motionless frame from which to judge all motion.

P2.3a Describe and compare the motion of an object using different reference frames.

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" (pushes or pulls, friction) or at a distance (gravity, electromagnetism, nuclear).

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

P3.1x Forces

There are four basic forces (gravitational, electromagnetic, strong, and weak nuclear) that differ greatly in magnitude and range. Between any two charged particles, electric force is vastly greater than the gravitational force. Most observable forces (e. g., those exerted by a coiled spring or friction) may be traced to electric forces acting between atoms and molecules.

P3.1b Explain why scientists can ignore the gravitational force when measuring the net force between two electrons.

P3.1c Provide examples that illustrate the importance of the electric force in everyday life.

P3.1d Identify the basic forces in everyday interactions.

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.

P3.2d Calculate all the forces on an object on an inclined plane and describe the object's motion based on the forces using free-body diagrams.

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).

P3.3b Predict how the change in velocity of a small mass compares to the change in velocity of a large mass when the objects interact (e.g., collide).

P3.3c Explain the recoil of a projectile launcher in terms of forces and masses.

P3.3d Analyze why seat belts may be more important in autos than in buses.

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).

P3.4e Solve problems involving force, mass, and acceleration in two-dimensional projectile motion restricted to an initial horizontal velocity with no initial vertical velocity (e.g., a ball rolling off a table).

P3.4f Calculate the changes in velocity of a thrown or hit object during and after the time it is acted on by the force.

P3.4g Explain how the time of impact can affect the net force (e.g., air bags in cars, catching a ball).

P3.5x Momentum

A moving object has a quantity of motion (momentum) that depends on its velocity and mass. In interactions between objects, the total momentum of the objects does not change.

P3.5a Apply conservation of momentum to solve simple collision problems.

P3.6 Gravitational Interactions

Gravitation is an 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.

P3.6d Calculate force, masses, or distance, given any three of these quantities, by applying the Law of Universal Gravitation, given the value of G.

P3.6e Draw arrows (vectors) to represent how the direction and magnitude of a force changes on an object in an elliptical orbit.

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.

P3.7x Electric Charges — Interactions

Charged objects can attract electrically neutral objects by induction.

P3.7c Draw the redistribution of electric charges on a neutral object when a charged object is brought near.

P3.7d Identify examples of induced static charges.

P3.7e Explain why an attractive force results from bringing a charged object near a neutral object.

P3.7f Determine the new electric force on charged objects after they touch and are then separated.

P3.7g Propose a mechanism based on electric forces to explain current flow in an electric circuit.

P3.p8 Magnetic Force (prerequisite)

Magnets exert forces on all objects made of ferromagnetic materials (e.g., iron, cobalt, and nickel) as well as other magnets. This force acts at a distance. Magnetic fields accompany magnets and are related to the strength and direction of the magnetic force. *(prerequisite)*

P3.p8A Create a representation of magnetic field lines around a bar magnet and qualitatively describe how the relative strength and direction of the magnetic force changes at various places in the field. *(prerequisite)*

P3.8x Electromagnetic Force

Magnetic and electric forces are two aspects of a single electromagnetic force. Moving electric charges produce magnetic forces and moving magnets produce electric forces (e.g., electric current in a conductor).

P3.8b Explain how the interaction of electric and magnetic forces is the basis for electric motors, generators, and the production of electromagnetic waves.

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).

P4.1x Energy Transfer — Work

Work is the amount of energy transferred during an interaction. In mechanical systems, work is the amount of energy transferred as an object is moved through a distance, $W = Fd$, where d is in the same direction as F. The total work done on an object depends on the net force acting on the object and the object's displacement.

P4.1c Explain why work has a more precise scientific meaning than the meaning of work in everyday language.

P4.1d Calculate the amount of work done on an object that is moved from one position to another.

P4.1e Using the formula for work, derive a formula for change in potential energy of an object lifted a distance h.

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.

P4.2e Explain the energy transformation as an object (e.g., skydiver) falls at a steady velocity.

P4.2f Identify and label the energy inputs, transformations, and outputs using qualitative or quantitative representations in simple technological systems (e.g., toaster, motor, hair dryer) to show energy conservation.

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.

P4.3x Kinetic and Potential Energy — Calculations

The kinetic energy of an object is related to the mass of an object and its speed: $KE = \frac{1}{2} mv^2$.

P4.3d Rank the amount of kinetic energy from highest to lowest of everyday examples of moving objects.

P4.3e Calculate the changes in kinetic and potential energy in simple mechanical systems (e.g., pendulums, roller coasters, ski lifts) using the formulas for kinetic energy and potential energy.

P4.3f Calculate the impact speed (ignoring air resistance) of an object dropped from a specific height or the maximum height reached by an object (ignoring air resistance), given the initial vertical velocity.

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.

P4.4x Wave Characteristics — Calculations

Wave velocity, wavelength, and frequency are related by $v = \lambda f$. The energy transferred by a wave is proportional to the square of the amplitude of vibration and its frequency.

P4.4d Demonstrate that frequency and wavelength of a wave are inversely proportional in a given medium.

P4.4e Calculate the amount of energy transferred by transverse or compression waves of different amplitudes and frequencies (e.g., seismic waves).

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 time 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).

P4.6x Electromagnetic Propagation

Modulated electromagnetic waves can transfer information from one place to another (e.g., televisions, radios, telephones, computers and other information technology devices). Digital communication makes more efficient use of the limited electromagnetic spectrum, is more accurate than analog transmission, and can be encrypted to provide privacy and security.

P4.6e Explain why antennas are needed for radio, television, and cell phone transmission and reception.

P4.6f Explain how radio waves are modified to send information in radio and television programs, radio-control cars, cell phone conversations, and GPS systems.

P4.6g Explain how different electromagnetic signals (e.g., radio station broadcasts or cell phone conversations) can take place without interfering with each other.

P4.6h Explain the relationship between the frequency of an electromagnetic wave and its technological uses.

P4.r7x Quantum Theory of Waves *(recommended)*

Electromagnetic energy is transferred on the atomic scale in discrete amounts called quanta. The equation $E = hf$ quantifies the relationship between the energy transferred and the frequency, where h is Planck's constant. *(recommended)*

P4.r7a Calculate and compare the energy in various electromagnetic quanta (e.g., visible light, x-rays) *(recommended)*.

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).

P4.8x Wave Behavior — Diffraction, Interference, and Refraction

Waves can bend around objects (diffraction). They also superimpose on each other and continue their propagation without a change in their original properties (interference). When refracted, light follows a defined path.

P4.8c Describe how two wave pulses propagated from opposite ends of a demonstration spring interact as they meet.

P4.8d List and analyze everyday examples that demonstrate the interference characteristics of waves (e.g., dead spots in an auditorium, whispering galleries, colors in a CD, beetle wings).

P4.8e Given an angle of incidence and indices of refraction of two materials, calculate the path of a light ray incident on the boundary (Snell's Law).

P4.8f Explain how Snell's Law is used to design lenses (e.g., eye glasses, microscopes, telescopes, binoculars).

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, a 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.r9x Nature of Light — Wave-Particle Nature *(recommended)*

The dual wave-particle nature of matter and light is the foundation for modern physics. *(recommended)*

P4.r9d Describe evidence that supports the dual wave-particle nature of light. *(recommended)*

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.

P4.10x Current Electricity — Ohm's Law, Work, and Power

In circuits, the relationship between electric current, I, electric potential difference, V, and resistance, R, is quantified by $V = I R$ (Ohm's Law). Work is the amount of energy transferred during an interaction. In electrical systems, work is done when charges are moved through the circuit. Electric power is the amount of work done by an electric current in a unit of time, which can be calculated using $P = I V$.

P4.10e Explain energy transfer in a circuit, using an electrical charge model.

P4.10f Calculate the amount of work done when a charge moves through a potential difference, V.

P4.10g Compare the currents, voltages, and power in parallel and series circuits.

P4.10h Explain how circuit breakers and fuses protect household appliances.

P4.10i Compare the energy used in one day by common household appliances (e.g., refrigerator, lamps, hair dryer, toaster, televisions, music players).

P4.10j Explain the difference between electric power and electric energy as used in bills from an electric company.

P4.11x Heat, Temperature, and Efficiency

Heat is often produced as a by-product during energy transformations. This energy is transferred into the surroundings and is not usually recoverable as a useful form of energy. The efficiency of systems is defined as the ratio of the useful energy output to the total energy input. The efficiency of natural and human-made systems varies due to the amount of heat that is not recovered as useful work.

P4.11a Calculate the energy lost to surroundings when water in a home water heater is heated from room temperature to the temperature necessary to use in a dishwasher, given the efficiency of the home hot water heater.

P4.11b Calculate the final temperature of two liquids (same or different materials) at the same or different temperatures and masses that are combined.

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, or ultraviolet light).

P4.12x Mass and Energy

In nuclear reactions, a small amount of mass is converted to a large amount of energy, $E = mc^2$, where c is the speed of light in a vacuum. The amount of energy before and after nuclear reactions must consider mass changes as part of the energy transformation.

P4.12d Identify the source of energy in fission and fusion nuclear reactions.

NOTES

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