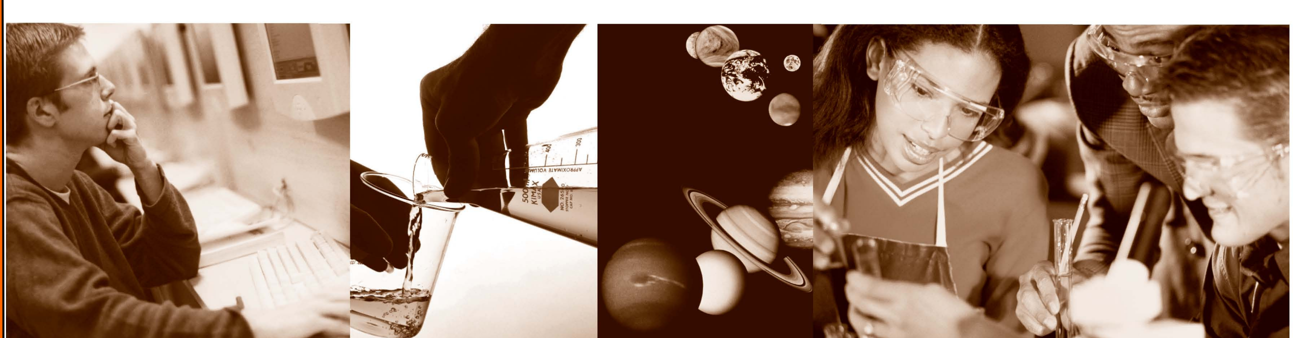
# High School Content Expectations

Companion Document



# SCIENCE

- Biology
- Chemistry
- Earth Science
- **Physics**

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MICHIGAN Department of Education

09/07

# *HSSCE Companion Document*

## OVERVIEW

The Michigan High School Science Content Expectations establish what every student is expected to know and be able to do by the end of high school and outline the parameters for receiving high school credit as recently mandated by the Merit Curriculum legislation in the state of Michigan. The Science Content Expectations Documents and the Michigan Merit Curriculum Document have raised the bar for our students, teachers and educational systems.

In an effort to support these standards and help our science teachers develop rigorous and relevant curricula to assist students in mastery, the Michigan Science Leadership Academy, in collaboration with the Michigan Mathematics and Science Center Network and the Michigan Science Teachers Association, worked in partnership with Michigan Department of Education to develop this companion document. Our goal is for each student to master the science content expectations as outlined in the merit curriculum.

This companion document is an effort to clarify and support the High School Science Content Expectations and the Michigan Merit Curriculum. The Merit Curriculum has been organized into twelve teachable units – organized around the big ideas and conceptual themes in each of the four discipline areas. The document is similar in format to the Science Assessment and Item Specifications for the 2009 National Assessment for Educational Progress (NAEP). The companion document is intended to provide boundaries to the content expectations. These boundaries are presented as "notes to teachers", not comprehensive descriptions of the full range of science content; they do not stand alone, but rather, work in conjunction with the content expectations. The boundaries use five categories of parameters:

a. **Real World Context** refers to breadth and depth of topic coverage and includes those ideas that are "common" or "familiar" to students and appear frequently in curriculum materials and in most students' experiences outside of school. This section is not intended to guide assessment, but rather, may be used as a context for assessment.
a. **Instruments, measurements, and representations** refer to instruments students are expected to use and the level of precision expected to measure, classify, and interpret phenomena or measurement. This section contains assessable information.
b. **Technical vocabulary** refers to the vocabulary for use and application of the science topics and principles that appear in the content statements and expectations. The words in this section along with those presented within the standard, content statement and content expectation comprise the assessable vocabulary.
c. **Clarification** refers to the restatement of a "key idea" or specific intent or elaboration of the content statements. It is not intended to denote a sense of content priority. The clarifications guide assessment.
d. **Instructional Examples** are included as exemplars of five different modes of instruction appropriate to the unit in which they are listed. These examples include inquiry, reflection, general instruction, enrichment and intervention strategies. These examples are intended for instructional guidance only and are not assessable.

**PHYSICS**
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## Physics Cross Reference Guide

| HSCE Code | Expectation | Clarification Unit | Instructional Example |
|---|---|---|---|
| **Standard P1** | **INQUIRY, REFLECTION, AND SOCIAL IMPLICATIONS** | | |
| **Statement P1.1** | **Scientific Inquiry** | | |
| P1.1A | Generate new questions that can be investigated in the laboratory or field. | | Lesson 9i |
| 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. | | Lesson 1i<br>Lesson 2i<br>Lesson 3i<br>Lesson 3iii<br>Lesson 5i<br>Lesson 5iv<br>Lesson 6i<br>Lesson 7i<br>Lesson 8i<br>Lesson 8iii |
| 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). | | Lesson 1i<br>Lesson 2i<br>Lesson 5i<br>Lesson 5iv<br>Lesson 8i |
| P1.1D | Identify patterns in data and relate them to theoretical models. | | Lesson 2i<br>Lesson 8i<br>Lesson 9i |
| 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. | | Lesson 3i<br>Lesson 3iii<br>Lesson 4i<br>Lesson 6i<br>Lesson 8iii<br>Lesson 11i |
| P1.1i | Distinguish between scientific explanations that are regarded as current scientific consensus and the emerging questions that active researchers investigate. | | Lesson 12i |
| **Statement P1.2** | **Scientific Reflection and Social Implications** | | |
| 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. | | Lesson 11ii<br>Lesson 11iii |

## Physics Cross Reference Guide

| HSCE Code | Expectation | Clarification Unit | Instructional Example |
|---|---|---|---|
| P1.2C | Develop an understanding of a scientific concept by accessing information from multiple sources. Evaluate the scientific accuracy and significance of the information. | | Lesson 5iii<br>Lesson 11ii |
| 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. | | Lesson 9ii<br>Lesson 12ii |
| P1.2g | Identify scientific tradeoffs in design decisions and choose among alternative solutions. | | Lesson 1ii Lesson 10i<br>Lesson 5iii Lesson 11ii<br>Lesson 8ii Lesson 11iii<br>Lesson 9ii |
| P1.2h | Describe the distinctions between scientific theories, laws, hypotheses, and observations. | | Lesson 2ii |
| 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. | | Lesson 5ii |
| P1.2j | Apply science principles or scientific data to anticipate effects of technological design decisions. | | Lesson 1ii Lesson 8ii<br>Lesson 4ii Lesson 10i<br>Lesson 6ii Lesson 11ii<br>Lesson 7ii Lesson 11iii |
| P1.2k | Analyze how science and society interact from a historical, political, economic, or social perspective. | | Lesson 3iii Lesson 8ii<br>Lesson 4iii Lesson 10ii<br>Lesson 5ii Lesson 11ii<br>Lesson 7ii Lesson 12ii |
| **Standard P2** | **MOTION OF OBJECTS** | | |
| **Statement P2.1** | **Position — Time** | | |
| P2.1A | Calculate the average speed of an object using the change of position and elapsed time. | Unit 1 | |
| P2.1B | Represent the velocities for linear and circular motion using motion diagrams (arrows on strobe pictures). | Unit 1 | |
| P2.1C | Create line graphs using measured values of position and elapsed time. | Unit 1 | |
| P2.1D | Describe and analyze the motion that a position-time graph represents, given the graph. | Unit 1 | Lesson 1iv |
| P2.1E | Describe and classify various motions in a plane as one dimensional, two dimensional, circular, or periodic. | Unit 5 | |

**Physics Cross Reference Guide**

| HSCE Code | Expectation | Clarification Unit | Instructional Example |
|---|---|---|---|
| P2.1F | Distinguish between rotation and revolution and describe and contrast the two speeds of an object like the Earth. | Unit 5 | |
| P2.1g | Solve problems involving average speed and constant acceleration in one dimension. | Unit 1 | |
| P2.1h | Identify the changes in speed and direction in everyday examples of circular (rotation and revolution), periodic, and projectile motions. | Unit 5 | Lesson 5iv |
| **Statement P2.2** | **Velocity — Time** | | |
| P2.2A | Distinguish between the variables of distance, displacement, speed, velocity, and acceleration. | Unit 1 | Lesson 1iv<br>Lesson 1v |
| P2.2B | Use the change of speed and elapsed time to calculate the average acceleration for linear motion. | Unit 1 | |
| P2.2C | Describe and analyze the motion that a velocity-time graph represents, given the graph. | Unit 1 | Lesson 1iii<br>Lesson 1iv |
| P2.2D | State that uniform circular motion involves acceleration without a change in speed. | Unit 5 | |
| P2.2e | Use the area under a velocity-time graph to calculate the distance traveled and the slope to calculate the acceleration. | Unit 1 | Lesson 1iii |
| P2.2f | Describe the relationship between changes in position, velocity, and acceleration during periodic motion. | Unit 5 | |
| P2.2g | Apply the independence of the vertical and horizontal initial velocities to solve projectile motion problems. | Unit 2 | Lesson 2i<br>Lesson 2ii<br>Lesson 2iv |
| **Statement P2.3x** | **Frames of Reference** | | |
| P2.3a | Describe and compare the motion of an object using different reference frames. | Unit 1 | |
| **Standard P3** | **FORCES AND MOTION** | | |
| **Statement P3.1** | **Basic Forces in Nature** | | |
| P3.1A | Identify the force(s) acting between objects in “direct contact” or at a distance. | Unit 3 | |
| **Statement P3.1x** | **Forces** | | |
| P3.1b | Explain why scientists can ignore the gravitational force when measuring the net force between two electrons. | Unit 9 | |

## Physics Cross Reference Guide

| HSCE Code | Expectation | Clarification Unit | Instructional Example |
|---|---|---|---|
| P3.1c | Provide examples that illustrate the importance of the electric force in everyday life. | Unit 9 | Lesson 9ii |
| P3.1d | Identify the basic forces in everyday interactions. | Unit 3 | |
| **Statement P3.2** | **Net Forces** | | |
| P3.2A | Identify the magnitude and direction of everyday forces (e.g., wind, tension in ropes, pushes and pulls, weight). | Unit 3 | Lesson 3i<br>Lesson 6v |
| P3.2B | Compare work done in different situations. | Unit 6 | |
| P3.2C | Calculate the net force acting on an object. | Unit 3 | Lesson 3i<br>Lesson 6v |
| 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. | Unit 2 | Lesson 2iii<br>Lesson 2v<br>Lesson 6v |
| **Statement P3.3** | **Newton's Third Law** | | |
| 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). | Unit 3 | Lesson 3ii<br>Lesson 3iv |
| 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). | Unit 4 | |
| P3.3c | Explain the recoil of a projectile launcher in terms of forces and masses. | Unit 4 | Lesson 4i |
| P3.3d | Analyze why seat belts may be more important in autos than in buses. | Unit 4 | |
| **Statement P3.4** | **Forces and Acceleration** | | |
| P3.4A | Predict the change in motion of an object acted on by several forces. | Unit 3 | |
| P3.4B | Identify forces acting on objects moving with constant velocity (e.g., cars on a highway). | Unit 3 | Lesson 3i<br>Lesson 3ii<br>Lesson 3iii |
| P3.4C | Solve problems involving force, mass, and acceleration in linear motion (Newton's second law). | Unit 3 | Lesson 3i<br>Lesson 3v |
| 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). | Unit 5 | Lesson 5iii<br>Lesson 5v |

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| HSCE Code | Expectation | Clarification Unit | Instructional Example |
|---|---|---|---|
| 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). | Unit 2 | Lesson 2i<br>Lesson 2ii |
| 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. | Unit 4 | Lesson 4i<br>Lesson 4iv |
| P3.4g | Explain how the time of impact can affect the net force (e.g., air bags in cars, catching a ball). | Unit 4 | Lesson 4i<br>Lesson 4iii<br>Lesson 4iv |
| **Statement P3.5x** | **Momentum** | | |
| P3.5a | Apply conservation of momentum to solve simple collision problems. | Unit 4 | Lesson 4v |
| **Statement P3.6** | **Gravitational Interactions** | | |
| P3.6A | Explain earth-moon interactions (orbital motion) in terms of forces. | Unit 5 | |
| P3.6B | Predict how the gravitational force between objects changes when the distance between them changes. | Unit 5 | Lesson 5iii |
| P3.6C | Explain how your weight on Earth could be different from your weight on another planet. | Unit 3 | |
| 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*. | Unit 5 | Lesson 5iii |
| P3.6e | Draw arrows (vectors) to represent how the direction and magnitude of a force changes on an object in an elliptical orbit. | Unit 5 | Lesson 5iii |
| **Statement P3.7** | **Electric Charges** | | |
| P3.7A | Predict how the electric force between charged objects varies when the distance between them and/or the magnitude of charges change. | Unit 9 | |
| 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. | Unit 9 | Lesson 9i<br>Lesson 9ii |

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| HSCE Code | Expectation | Clarification Unit | Instructional Example |
|---|---|---|---|
| **Statement P3.7x** | **Electric Charges — Interactions** | | |
| P3.7c | Draw the redistribution of electric charges on a neutral object when a charged object is brought near. | Unit 9 | Lesson 9ii<br>Lesson 9iv |
| P3.7d | Identify examples of induced static charges. | Unit 9 | Lesson 9ii<br>Lesson 9iii<br>Lesson 9iv |
| P3.7e | Explain why an attractive force results from bringing a charged object near a neutral object. | Unit 9 | Lesson 9iii<br>Lesson 9iv |
| P3.7f | Determine the new electric force on charged objects after they touch and are then separated. | Unit 9 | Lesson 9i<br>Lesson 9iii |
| P3.7g | Propose a mechanism based on electric forces to explain current flow in an electric circuit. | Unit 9 | |
| **Statement P3.8x** | **Electromagnetic Force** | | |
| P3.8b | Explain how the interaction of electric and magnetic forces is the basis for electric motors, generators, and the production of electromagnetic waves. | Unit 9 | Lesson 9v |
| **Standard P4** | **FORMS OF ENERGY AND ENERGY TRANSFORMATIONS** | | |
| **Statement P4.1** | **Energy Transfer** | | |
| P4.1A | Account for and represent energy into and out of systems using energy transfer diagrams. | Unit 11 | |
| 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). | Unit 12 | |
| **Statement P4.1x** | **Energy Transfer — Work** | | |
| P4.1c | Explain why work has a more precise scientific meaning than the meaning of work in everyday language. | Unit 6 | |
| P4.1d | Calculate the amount of work done on an object that is moved from one position to another. | Unit 6 | |
| P4.1e | Using the formula for work, derive a formula for change in potential energy of an object lifted a distance $h$. | Unit 6 | |

## Physics Cross Reference Guide

| HSCE Code | Expectation | Clarification Unit | Instructional Example |
|---|---|---|---|
| **Statement P4.2** | **Energy Transformation** | | |
| P4.2A | Account for and represent energy transfer and transformation in complex processes (interactions). | Unit 11 | Lesson 11iv<br>Lesson 11v |
| P4.2B | Name devices that transform specific types of energy into other types (e.g., a device that transforms electricity into motion). | Unit 11 | Lesson 11iii<br>Lesson 11iv<br>Lesson 11v |
| 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). | Unit 11 | |
| P4.2D | Explain why all the stored energy in gasoline does not transform to mechanical energy of a vehicle. | Unit 12 | Lesson 12iv |
| P4.2e | Explain the energy transformation as an object (e.g., skydiver) falls at a steady velocity. | Unit 11 | |
| 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. | Unit 11 | Lesson 11iii |
| **Statement P4.3** | **Kinetic and Potential Energy** | | |
| P4.3A | Identify the form of energy in given situations (e.g., moving objects, stretched springs, rocks on cliffs, energy in food). | Unit 6 | Lesson 6ii |
| P4.3B | Describe the transformation between potential and kinetic energy in simple mechanical systems (e.g., pendulums, roller coasters, ski lifts). | Unit 6 | |
| P4.3C | Explain why all mechanical systems require an external energy source to maintain their motion. | Unit 6 | Lesson 6ii |
| **Statement P4.3x** | **Kinetic and Potential Energy — Calculations** | | |
| P4.3d | Rank the amount of kinetic energy from highest to lowest of everyday examples of moving objects. | Unit 6 | Lesson 6iii<br>Lesson 6iv |
| 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. | Unit 6 | Lesson 6i<br>Lesson 6iii |

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| HSCE Code | Expectation | Clarification Unit | Instructional Example |
|---|---|---|---|
| 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. | Unit 6 | Lesson 6i<br>Lesson 6iii |
| **Statement P4.4** | **Wave Characteristics** | | |
| P4.4A | Describe specific mechanical waves (e.g., on a demonstration spring, on the ocean) in terms of wavelength, amplitude, frequency, and speed. | Unit 7 | Lesson 7i<br>Lesson 7iv |
| P4.4B | Identify everyday examples of transverse and compression (longitudinal) waves. | Unit 7 | |
| P4.4C | Compare and contrast transverse and compression (longitudinal) waves in terms of wavelength, amplitude, and frequency. | Unit 7 | Lesson 7ii<br>Lesson 7iv<br>Lesson 7v |
| **Statement P4.4x** | **Wave Characteristics — Calculations** | | |
| P4.4d | Demonstrate that frequency and wavelength of a wave are inversely proportional in a given medium. | Unit 7 | |
| P4.4e | Calculate the amount of energy transferred by transverse or compression waves of different amplitudes and frequencies (e.g., seismic waves). | Unit 7 | |
| **Statement P4.5** | **Mechanical Wave Propagation** | | |
| P4.5A | Identify everyday examples of energy transfer by waves and their sources. | Unit 7 | |
| P4.5B | Explain why an object (e.g., fishing bobber) does not move forward as a wave passes under it. | Unit 7 | Lesson 7v |
| P4.5C | Provide evidence to support the claim that sound is energy transferred by a wave, not energy transferred by particles. | Unit 7 | Lesson 7v |
| P4.5D | Explain how waves propagate from vibrating sources and why the intensity decreases with the square of the distance from a point source. | Unit 7 | Lesson 7ii |
| 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. | Unit 7 | |
| **Statement P4.6** | **Electromagnetic Waves** | | |
| P4.6A | Identify the different regions on the electromagnetic spectrum and compare them in terms of wavelength, frequency, and energy. | Unit 8 | Lesson 8ii<br>Lesson 8iii |
| P4.6B | Explain why radio waves can travel through space, but sound waves cannot. | Unit 8 | Lesson 8v |

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| HSCE Code | Expectation | Clarification Unit | Instructional Example |
|---|---|---|---|
| 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. | Unit 8 | Lesson 8v |
| P4.6D | Explain why we see a distant event before we hear it (e.g., lightning before thunder, exploding fireworks before the boom). | Unit 8 | |
| **Statement 4.6x** | **Electromagnetic Propagation** | | |
| P4.6e | Explain why antennas are needed for radio, television, and cell phone transmission and reception. | Unit 8 | Lesson 8ii<br>Lesson 8iii |
| 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. | Unit 8 | Lesson 8ii |
| P4.6g | Explain how different electromagnetic signals (e.g., radio station broadcasts or cell phone conversations) can take place without interfering with each other. | Unit 8 | |
| P4.6h | Explain the relationship between the frequency of an electromagnetic wave and its technological uses. | Unit 8 | Lesson 8ii |
| **Statement P4.r7x** | **Quantum Theory of Waves *(recommended)*** | | |
| P4.r7a | Calculate and compare the energy in various electromagnetic quanta (e.g., visible light, x-rays) *(recommended).* | R | |
| **Statement P4.8** | **Wave Behavior — Reflection and Refraction** | | |
| P4.8A | Draw ray diagrams to indicate how light reflects off objects or refracts into transparent media. | Unit 8 | |
| P4.8B | Predict the path of reflected light from fl at, curved, or rough surfaces (e.g., fl at and curved mirrors, painted walls, paper). | Unit 8 | |
| **Statement P4.8x** | **Wave Behavior — Diffraction, Interference, and Refraction** | | |
| P4.8c | Describe how two wave pulses propagated from opposite ends of a demonstration spring interact as they meet. | Unit 7 | Lesson 7iv |
| 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). | Unit 7 | Lesson 7iii |
| 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). | Unit 8 | |

## Physics Cross Reference Guide

| HSCE Code | Expectation | Clarification Unit | Instructional Example |
|---|---|---|---|
| P4.8f | Explain how Snell's Law is used to design lenses (e.g., eye glasses, microscopes, telescopes, binoculars). | Unit 8 | Lesson 8iv |
| **Statement P4.9** | **Nature of Light** | | |
| P4.9A | Identify the principle involved when you see a transparent object (e.g., straw, a piece of glass) in a clear liquid. | Unit 8 | |
| P4.9B | Explain how various materials reflect, absorb, or transmit light in different ways. | Unit 8 | |
| P4.9C | Explain why the image of the Sun appears reddish at sunrise and sunset. | Unit 8 | |
| **Statement P4.r9x** | **Nature of Light — Wave-Particle Nature *(recommended)*** | | |
| P4.r9d | Describe evidence that supports the dual wave particle nature of light. *(recommended)* | R | |
| **Statement P4.10** | **Current Electricity — Circuits** | | |
| P4.10A | Describe the energy transformations when electrical energy is produced and transferred to homes and businesses. | Unit 10 | Lesson 10ii |
| P4.10B | Identify common household devices that transform electrical energy to other forms of energy, and describe the type of energy transformation. | Unit 10 | Lesson 10i |
| 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. | Unit 10 | Lesson 10iv |
| P4.10D | Discriminate between voltage, resistance, and current as they apply to an electric circuit. | Unit 10 | |
| **Statement P4.10x** | **Current Electricity — Ohm's Law, Work, and Power** | | |
| P4.10e | Explain energy transfer in a circuit, using an electrical charge model. | Unit 10 | Lesson 10iv<br>Lesson 10v |
| P4.10f | Calculate the amount of work done when a charge moves through a potential difference, $V$. | Unit 10 | |
| P4.10g | Compare the currents, voltages, and power in parallel and series circuits. | Unit 10 | Lesson 10iii |
| P4.10h | Explain how circuit breakers and fuses protect household appliances. | Unit 10 | |

**Physics Cross Reference Guide**

| HSCE Code | Expectation | Clarification Unit | Instructional Example |
|---|---|---|---|
| P4.10i | Compare the energy used in one day by common household appliances (e.g., refrigerator, lamps, hair dryer, toaster, televisions, music players). | Unit 10 | |
| P4.10j | Explain the difference between electric power and electric energy as used in bills from an electric company. | Unit 10 | |
| **Statement P4.11x** | **Heat, Temperature, and Efficiency** | | |
| 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. | Unit 12 | |
| P4.11b | Calculate the final temperature of two liquids (same or different materials) at the same or different temperatures and masses that are combined. | Unit 11 | Lesson 11i |
| **Statement P4.12** | **Nuclear Reactions** | | |
| P4.12A | Describe peaceful technological applications of nuclear fission and radioactive decay. | Unit 12 | Lesson 12i<br>Lesson 12ii<br>Lesson 12v |
| P4.12B | Describe possible problems caused by exposure to prolonged radioactive decay. | Unit 12 | Lesson 12v |
| P4.12C | Explain how stars, including our Sun, produce huge amounts of energy (e.g., visible, infrared, or ultraviolet light). | Unit 12 | Lesson 12iii |
| **Statement P4.12x** | **Mass and Energy** | | |
| P4.12d | Identify the source of energy in fission and fusion nuclear reactions. | Unit 12 | Lesson 12iii |

**Units by Content Expectation**

# PHYSICS

## Unit 1: Motion

| Code | Content Expectation |
|---|---|
| *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. |
| P2.1g | Solve problems involving average speed and constant acceleration in one dimension. |
| *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. |
| P2.2e | Use the area under a velocity-time graph to calculate the distance traveled and the slope to calculate the acceleration. |
| *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. |

# PHYSICS

## Unit 1: Motion

**Big Idea (Core Concept):** The motion of an object may be described using a) motion diagrams, b) data, c) graphs, and d) mathematical functions.

**Standard(s):**
P2: Motion of Objects

**Content Statement(s):**
P2.1: Position-Time
P2.2: Velocity-Time
P2.3x: Frames of Reference

**Content Expectations: (Content Statement Clarification)**
**P2.1A**: Calculate the average speed of an object using the change of position and elapsed time.

**Clarification**: The calculation would be for average velocity (not average speed), since it involves change of position and elapsed time.

**P2.1B**: Represent the velocities for linear and circular motion using motion diagrams (arrows on strobe pictures).

**Clarification**: Motion diagrams are "strobe pictures" that illustrate the motion of an object. In a motion diagram an object is shown as multiple images where it would appear if seen at equal time intervals. Arrows (vectors) may be used to represent the size and direction of the object's displacement, velocity and/or acceleration.

**P2.1C**: Create line graphs using measured values of position and elapsed time.

**Clarification**: None.

**P2.1D**: Describe and analyze the motion that a position-time graph represents, given the graph.

**Clarification**: None.

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

**Clarification**: It is **not** expected that students will solve problems involving situations where the acceleration is changing in magnitude or direction.

**P2.2A**: Distinguish between the variables of distance, displacement, speed, velocity, and acceleration.

**Clarification**: Use of the terms vector and scalar should be applied to distinguish between the vector quantities of displacement, velocity and acceleration and the scalar quantities of distance and speed. These vector quantities have direction associated with them in addition to magnitude.

**P2.2B**: Use the change of speed and elapsed time to calculate the average acceleration for linear motion.

**Clarification**: The calculation for average acceleration would be using change in velocity (not change in speed) and elapsed time.

**P2.2C**: Describe and analyze the motion that a velocity-time graph represents, given the graph.

**Clarification**: Graphs should be limited to linear motion only.

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

**Clarification**: No calculus should be required. For the purposes of this calculation, straight-line graphs (constant slopes) with easily calculated areas should be used. The area under the velocity-time graph would represent the change in position of an object as opposed to the distance traveled.

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

**Clarification**: Descriptions and comparisons need be made only for one-dimensional motion. It is not expected that students will describe and compare the motion of an object using accelerated reference frames.

**Vocabulary**

Acceleration
Average Speed
Circular Motion
Constant Acceleration
Displacement
Frame of Reference
Function
Graph
Linear Motion
Motion
Motion diagram
Position
Relative Motion
Scalar
Speed
Time
Vector
Velocity

**Real World Context:**

A comparison can be made of the motion of a person attempting to walk at a constant velocity down a sidewalk to the motion of a person attempting to walk in a straight line with a constant acceleration. These motions can be compared to the motion of a person on a bicycle attempting to maintain a constant velocity or constant acceleration

A qualitative study of the position, velocity and acceleration of an object that is tossed straight up into the air near the surface of the earth can be made. The acceleration of the object will be constant and downward. Students often have the misconceptions that the acceleration is upward during the upward phase of the ball's flight and zero at the top of its flight.

Common examples of relative motion such as the motion observed by a person standing next to a road as a car passes compared to the motion observed by the driver of the car may be used. Also, the motion observed by the driver of a second car which has a different velocity than the first may be discussed.

**Instruments, Measurement, and Representations:**

Measures of time include hours, minutes, and seconds.

Measures of distance include centimeters, meters and kilometers.

"Freeze-frame" motion diagrams or strobe pictures with distance and time scales will be used.

Motion will be represented using tables and graphs of position versus time and of velocity versus time.

Motion will be described using calculations of average velocity and average accelerations for different parts of a journey.

Show displacement and average velocity as vectors including magnitude and direction, using arrows in a diagram format.

**Instructional Examples:**

i. Inquiry
CE: P1.1C, P1.1D

Perform a simple experiment using a ball, a ramp, and a timer (such a stopwatch or a photogate timer system). Collect data regarding the time it takes for the ball to roll down the ramp from rest to various points on the ramp. The position and time data may be graphed, and it can be determined that the ball's displacement is related to the square of the time during a constant acceleration. This relationship may be discovered without the "formula" being known beforehand.

ii. Reflection
CE: P1.2g, P1.2j

Research the effects of acceleration on the human body. Then, determine what design decisions have to be made when developing various forms of transportation (cars, aircraft, spacecraft, rollercoasters, etc.) to increase the safety of passengers.

iii. Enrichment
CE: P2.2C, P2.2e

Given objects with non-constant velocity or acceleration, graph their velocity versus time and develop at least two ways of determining the area under the resulting non-linear curve.

iv. General
CE: P2.1D, P2.2 A, P2.2 C

Using computer or calculator interfaced motion detectors, graphs of students own motion may be quickly created. The shape of position, velocity and acceleration versus time graphs can be predicted before students walk or run in front of the detector in a particular way. Also, given a particular graph, students can attempt to match that graph with their own motion.

v. Intervention
CE: P2.2A

A target bubble level can be used as an accelerometer. When the level is held horizontally, the bubble moves away from center in the direction of acceleration. Students can investigate the direction of acceleration during everyday motions. While walking or riding in a vehicle, the direction of acceleration when speeding up, slowing down, or while changing direction of motion can be determined.

**Units by Content Expectation**

# PHYSICS

## Unit 2:  2-Dimensional Motion & Forces

| Code | Content Expectation |
|---|---|
| *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. |
| P2.2g | Apply the independence of the vertical and horizontal initial velocities to solve projectile motion problems. |
| *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). |
| P3.2d | 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. |
| *P3.4* | *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. |
| P3.4e | 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). |

# PHYSICS

## Unit 2: 2-Dimensional Motion & Forces

**Big Idea (Core Concept):** The motion of an object that moves both horizontally and vertically at the same time can be analyzed with the principles of linear motion and force.

**Standard (s):**
P2: Motion of Objects
P3: Forces and Motion

**Content Statement(s):**
P2.2: Velocity-Time
P3.2: Net Forces
P3.4: Forces and Acceleration

**Content Expectations: (Content Statement Clarification)**
**P2.2g:** Apply the independence of the vertical and horizontal initial velocities to solve projectile motion problems.

**Clarification**: Only the horizontal and vertical dimensions of projectile motion are expected. These problems include projectiles with no initial vertical velocity (launched horizontally) and those launched at an angle to the horizontal. Air resistance should be ignored.

**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.

**Clarification**: Inclines should include both frictionless and friction-based systems. Inclined plane force scenarios should include ones that cause the object to be at rest, moving up a plane, and moving down a plane. Forces involve calculations; the motion involves only a description.

**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).

**Clarification**: Air resistance should be ignored.

**Vocabulary**

Position
Velocity
Average speed
Average acceleration
Vertical velocity
Horizontal velocity
Projectile motion
Projectile
Acceleration due to gravity
Proportional
Net Force
Inversely proportional
Mass
Two-dimensional projectile motion
Inclined plane
Free-body diagrams

**Real World Context:**

The use of kinematics equations for motion is extensive in this unit, as problem solving and calculations are required in each expectation. Additionally laboratory exercises with horizontally, vertically and angled projectile launches will allow application of the paper-pencil problem solving.

Sketching the motion of a projectile, teasing out the horizontal and vertical velocity vectors will help visualize the motion. Additionally adding a vector for acceleration is helpful. Velocity vs. time graphs can be completed of for the horizontal and vertical components of the projectile's motion.

**Instruments, Measurement, and Representations:**

Represent the projectile motion of an object using velocity vectors, and separating the horizontal and vertical velocity vectors. These representations should include objects projected upward at an angle and those projected horizontally from a height above ground. The entire flight of the projectile should be represented from the start of flight to the end.

Sketch the motion of a projectile on a position vs. time and velocity vs. time graph.

Complete laboratory exercises that launch projectiles vertically, horizontally and at an angle and calculate their initial velocities. Time of flight can be calculated or measured. Horizontal distance traveled can be calculated or measured.

Draw a free body diagram of the forces acting on an object on a frictionless incline plane when the object is at rest and in motion. Calculate the forces.

Draw a free body diagram of the forces acting on an object on an incline plane when the object is at rest and in motion. Calculate the forces.

Use metric measurements of mass (kilogram), velocity (meters/second), acceleration due to gravity (9.8 m/s$^2$), force (Newton), time (seconds) and distance (meters).

| Use Formulas: | Where: |
|---|---|
| $v = v_o + at$ | $\Delta x$ = displacement |
| $\Delta x = v_o t + \frac{1}{2} at^2$ | $v$ = velocity |
| $v^2 = v_o^2 + 2a\Delta x$ | $a$ = acceleration |
| $\bar{v} = \frac{\Delta x}{\Delta t}$ | $t$ = time |

**Instructional Examples:**

i. Inquiry
CE: P1.1C, P1.1D, P1.1E, P2.2g, P3.4e

Design and conduct an investigation of the factors that affect the motion of a projectile.

ii. Reflection
CE: P1.2h, P2.2g, P3.4e

Investigate the question "What is gravity?" as answered by Archimedes, Galileo, and Newton. Thinking as these historical figures, use their responses to describe the motion of a projectile.

iii. Enrichment
CE: P3.2d

Use an inclined plane to recreate Galileo's experiment to determine the acceleration due to gravity. An Internet example of an activity such as this can be found at: http://exploringdata.cqu.edu.au/ws_galil.htm

iv. General
CE: P2.2g

Given a target (cup, circular target on the ground, goal post, soccer goal) conduct the necessary experiments and calculations to determine the launch angle for the projectile (air rocket, ball, arrow) in order to hit the target.

v. Intervention
CE: P3.2d

Using an old textbook, measure the weight of the book with a spring scale or force meter. Put the book on an inclined plane. Use a spring scale or force meter to measure the forces on an object on an inclined plane—friction, normal force, force pulling it down the plane. Compare with the calculated forces using trigonometry. Measure the forces at various angles and note the motion of the book, if any.

**Units by Content Expectation**

# PHYSICS

## Unit 3: Dynamics

| Code | Content Expectation |
|---|---|
| *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. |
| P3.1d | 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). |
| P3.2C | 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). |

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

# PHYSICS

## Unit 3: Dynamics

**Big Idea (Core Concept):** When two objects interact with each other, by direct contact or at a distance, all three of Newton's Laws describe and explain that interaction.

**Standard(s):**
P3: Forces and Motion

**Content Statement(s):**
P3.1: Basic Forces in Nature
P3.1x: Forces
P3.2: Net Forces
P3.3: Newton's Third Law
P3.4: Forces and Acceleration
P3.6: Gravitational Interactions

**Content Expectations: (Content Statement Clarification)**
**P3.1A:** Identify the force(s) acting between objects in "direct contact" or at a distance.

**Clarification**: None.

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

**Clarification**: None.

**P3.2A:** Identify the magnitude and direction of everyday forces (e.g., wind, tension in ropes, pushes and pulls, weight).

**Clarification**: None.

**P3.2C:** Calculate the net force acting on an object.

**Clarification**: None.

**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).

**Clarification**: These forces are referring to 3rd Law force pairs.

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

**Clarification**: None.

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

**Clarification**: None.

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

**Clarification**: None.

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

**Clarification**: None.

**Vocabulary**

acceleration
action/reaction forces
atoms
change in direction
change in speed
contact forces
direction of a force
electric force
electromagnetic force
equal & opposite force
$F_{net}$=ma
force
forces at a distance
friction
gravitational force
inverse square law
inversely proportional
linear motion
magnitude of a force
mass
molecules
net force
Newton's First Law
Newton's Second Law
Newton's Third Law
Proportional
scalar
speed
strong nuclear force
tension
velocity

vector
weak nuclear force
weight

**Real World Context:**

When teaching about falling objects, it is useful to compare two different masses (different densities but equal volumes) falling from equal heights in approximately equal times (ignoring air resistance) and to explain how some objects fall more slowly than others when they have substantial air resistance (e.g., parachute).

Describe all the forces (action and reaction) involved in sliding a box across the floor at constant velocity, speeding up, and slowing down.

Discussion of forces should include 2nd Law pairs (forces that add up on a single object that affect its motion) and 3rd Law pairs (action-reaction forces between two objects that act on each other). It is important that these two categories of forces are distinguished as different pairs of forces.

Use examples of frictional forces that act on an object in the direction of the object's motion (traction) and that act on an object opposite the direction of motion (drag).

Examine all three Newton's Laws of Motion as they relate to contact and non-contact scenarios such as two magnets in contact with each other or just near each other.

**Clarification: A Matter of Mass (NAEP)**

"Mass is a property common to all objects. It is the amount of matter (or "stuff") in an object. Mass is measured in grams (g) or kilograms (kg) (1 kg=1000 g) using a beam or electronic balance.

Weight, on the other hand, is a measure of the force of attraction (gravitational force) between an object and Earth. Every object exerts gravitational force on every other object. The force depends on how much mass the objects have and on how far apart they are. Force and weight are measured in newtons (N) using a spring scale.

Changing an object's position (say from Earth to the moon) will change its weight, but not its mass. For example, on the surface of Earth, a cannon ball has a mass of 10 kg and a weight of 98 N. On the surface of the moon, that same cannon ball still has a mass of 10 kg, but its weight is only 16 N. So, the cannon ball weighs less on the moon than on Earth, even though nothing has been taken away. Why? Because of the moon's lesser mass and smaller radius, the force of attraction between the moon and the cannon ball is less than the force of attraction between Earth and the cannon ball. Hence, it is said that an object on the moon weighs less than the same object weighs on Earth."

**Instruments, Measurement, and Representations:**
Measures of time: hours, minutes, seconds
Measures of distance: cm, m, km
Measures of force and weight: Newtons
Measures of mass: kg, grams

Represent forces using arrows to indicate magnitude and direction of force.

Use motion diagrams with distance and time scales to show constant or changing velocity.

Use free-body diagrams on each of two interacting objects. Force diagrams with relative magnitudes can be used to compare the forces acting on each object of the pair.

Use $a=F_{net}/m$ to predict or compare accelerations or masses of objects, or the net force acting on objects.

Use free-body diagrams and equations to show qualitatively how two objects of different densities can fall in approximately equal times, if air resistance is not a major factor, and explanations of how major air resistance on an object affects the force diagram and resulting motion of the object.

Explain the relationship of distance to gravitational force: doubling (or tripling) the distance between two masses reduces the magnitude of the gravitational force to one quarter (or one ninth).

"This subtopic includes all three of Newton's Laws of Motion applied to two interacting objects. For all of the mathematical relationships/representations described in this subtopic, students having a qualitative or semi-quantitative understanding (e.g., mathematical relationships such as proportionality) is more important than calculating particular quantities.

Resolution of forces should be confined to horizontal, vertical, or inclines of 30 or 45 degrees. Resolution of perpendicular forces should result in a vector at roughly 30, 60 or 45 degrees relative to one of the "first" vectors."

For this subtopic, it is not expected that students will analyze forces in three dimensions or systems with changing mass.

__**Instructional Examples**__*:*

i. Inquiry

CE: P1.1C, P1.1h, P3.1d, P3.2A, P3.2C, P3.4B, P3.4C

Have students design an experiment to verify Newton's 2nd Law. This is a bigger challenge than it sounds initially because they must account for all forces acting on the object of their choice and then must determine whether the object is moving with constant speed or constant acceleration.

ii. Reflection

CE: P1.2k, P3.1d, P3.3A, P3.4B

Describe some of your own specific personal experiences where friction was helpful and where it was not helpful based on what you were trying to accomplish.

iii. Enrichment

CE: P1.1C, P1.1h, P3.4B

Have students design an experiment to determine the factors that affect the amount of friction between various surfaces.

iv. General

CE: P3.3A

Have students describe the reaction force when given a sentence describing one object acting on another

v. Intervention

CE: P3.4C

Have students use a spring scale to pull another student on roller blades with constant force to develop a kinesthetic understanding of the relationship between constant force and constant acceleration.

**Units by Content Expectation**

# PHYSICS

## Unit 4: Momentum

| Code | Content Expectation |
|---|---|
| *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. |
| P3.3b | 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. |
| P3.4f | 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. |

# PHYSICS

## Unit 4: Momentum

**Big Idea (Core Concept):**
Interaction between objects produces predictable motion. The product of mass times velocity is conserved in any interaction.

**Standard:**
P3: Forces and Motion

**Content Statement(s):**
P3.3: Newton's Third Law
P3.4: Forces and Acceleration
P3.5x: Momentum

**Content Expectations: (Content Statement Clarification)**
**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).

**Clarification**: Exclude momentum in two dimensions. Students having a qualitative or semi-quantitative understanding (e.g., mathematical relationships such as proportionality) is more important than calculating particular quantities.

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

**Clarification**: Explanation should include applications Newton's Third Law for forces and Newton's Second Law for masses.

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

**Clarification**: None

**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.

**Clarification**: Apply the relationship between variables described in Newton's Second Law, $F_{net} = ma$, with acceleration equal to $\Delta v/\Delta t$.

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

**Clarification**: Explanation uses the relationships described in the P3.4f clarification.

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

**Clarification**: Exclude momentum and collisions in two dimensions.

**Vocabulary**

Acceleration
Average velocity
Change in velocity
Collision
$F_{net}$=ma
Inversely proportional
Law of Conservation of Momentum
Mass
Momentum
Net Force
Newton's Second Law
Newton's Third Law
Projectile
Proportional
Vector
Velocity

**Real World Context:**

Collisions are of two main types elastic and inelastic in which momentum is always conserved. They are differentiated by the conversion of kinetic energy in the inelastic collisions to other types of energy such as heat, sound, deformation (work). In perfectly inelastic collisions the objects stick together and travel as one mass.

The formula used in Newton's Second Law (F=ma) is commonly derived from his original relationship between force, mass and changing velocity during an interaction: $F\Delta t = m\Delta v$. This is commonly referred to in high school textbooks as the impulse given to an object ($F\Delta t$) that causes a change in the object's momentum (p). Formula for change in momentum ($\Delta p = m\Delta v$).

There are numerous examples of how time of impact affects the force on an object in sports. For example, "following through" with a swing lengthens the time of impact of the force resulting in a larger change in velocity of a mass and "rolling with the punch" in boxing lessens the force by increasing the time that velocity is changed on the boxer.

Tossing an egg into a sheet or blanket illustrates how force can be minimized by increasing the time factor for the egg, therefore making the acceleration less on the mass. Contrast the throwing of the egg into a sheet with throwing the egg with a similar initial velocity into a brick wall.

**Instruments, Measurement, and Representations:**
Force is measured in Newtons, mass in kilograms, length in meters, and time in seconds.

Use the velocity and acceleration as means of describing the motion of objects as a result of an interaction.

Use average velocity as "a vector including magnitude and direction".

Draw force diagrams on each of two interacting objects; force diagrams with relative magnitudes can be used to compare the forces acting on each object of the pair.

Illustrate conservation of momentum before and after a collision with vector diagrams of the momentum (mv). Show how this relates to the velocities of the objects before and after the collision.

Use $a=F_{net}/m$ to predict or compare accelerations or masses of objects, or the net force acting on objects

Apply conservation of momentum (where momentum (p) =mv) to predict relative motions or relative masses of two interacting objects along a straight line.

Complete calculations involving the formula $F_{net}=m(\Delta v/\Delta t)$.

**Instructional Examples:**
i. Inquiry
CE: P1.1h, P3.3c, P3.4f, P3.4g

Design an experiment that would investigate the factors that affect the momentum of an air powered projectile.

ii. Reflection
CE: P1.2j

Trace the development of crash protection devices in automobiles. This includes driver, passenger and side of the vehicle air bags; bumper design; etc. Investigate how these safety devices have affected or determined the design parameters of the automobile.

iii. Enrichment
CE: P1.2k, P3.4g, P3.5a

Apply the principles of conservation of momentum and Newton's Laws as they relate to motor vehicle accident reconstruction.

iv. General:
CE: P3.4f, P3.4g

List five or more sports that use the concepts found in conservation of momentum and Newton's Second Law. Detail specific examples of how the sport is optimized using these physics principles.

v. Intervention:
CE: P3.5a

Use the "Newton's Cradle" device (5 metal balls of equal mass hanging adjacent to each other by equal length strings) visually illustrate momentum and conservation of momentum.

**Units by Content Expectation**

# PHYSICS

## Unit 5: Periodic Motion

| Code | Content Expectation |
|---|---|
| *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. |
| P2.1E | 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. |
| P2.1h | 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. |
| P2.2D | State that uniform circular motion involves acceleration without a change in speed. |
| P2.2f | Describe the relationship between changes in position, velocity, and acceleration during periodic motion. |
| *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. |
| P3.4D | 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 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. |
| P3.6d | 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. |

# PHYSICS

## Unit 5: Periodic Motion

**Big Idea (Core Concept):**
Periodic motion is the cyclic, repeating motion of an object moving back and forth along a straight line or in a cyclic type of motion.

**Standard(s):**
P2: Motion of Objects
P3: Forces and Motion

**Content Statement(s):**
P2.1: Position-Time
P2.2: Velocity-Time
P3.4: Forces and Acceleration
P3.6: Gravitational Interactions

**Content Expectations: (Content Statement Clarification)**
**P2.1E:** Describe and classify various motions in a plane as one dimensional, two dimensional, circular, or periodic.

**Clarification**: None

**P2.1F:** Distinguish between rotation and revolution and describe and contrast the two speeds of an object like the Earth.

**Clarification**: Examples include the earth rotating on its axis and revolving around the sun.

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

**Clarification**: Circular examples include a car turning a curve on a horizontal road, the earth rotating on its axis and revolving around the sun, a child on a merry-go-round. Periodic examples include the pendulum of a clock and a wave on a string. Projectile motions include the shooting of a cannon and the hitting of a baseball. Independence of horizontal and vertical motion for projectiles will be excluded.

**P2.2D:** State that uniform circular motion involves acceleration without a change in speed.

**Clarification**: Objects in uniform circular motion experience constant acceleration toward the center of the circular path.

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

**Clarification**: None.

**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).

**Clarification**: Objects in uniform circular motion experience a net force toward the center of the circular path. The magnitude of this force is constant during uniform circular motion.

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

**Clarification**: The orbit of the moon about the earth is nearly circular and may be approximated as circular motion in this context. The force that accounts for the circular motion is the force of gravitational attraction between the masses.

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

**Clarification**: The gravitational force is an "inverse r-squared" force. This means that the force of gravity between two objects diminishes such that doubling the distance results in one-forth the original force, tripling the distance results in one-ninth the original force and so on. Understanding this basic relationship is more vital than being able to use the equation.

**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.

**Clarification**: None.

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

**Clarification**: None.

**Vocabulary**
Acceleration
Average acceleration
Average speed
Circular motion
Direction
Elliptical orbit
Force
Gravitation
Inverse Square Law
Law of Universal Gravitation
Magnitude
Mass
Motion
Net force
Orbital motion
Periodic motion
Position
Projectile
Revolution
Rotation
Speed
Time
Uniform circular motion
Vector
Velocity

**Real World Context**
Understanding the ideal motion of a simple harmonic oscillator provides a basis for understanding more complex vibratory motion such as the vibration of a piano string, the vibration of the prongs of a tuning fork, the vibration of a tall building during an earthquake, the vibration of a speaker membrane as it produces sound, the oscillation of alternating household current, etc. Understanding this type of periodic motion opens the door to understanding a wide variety of disparate phenomena.

Uniform circular motion occurs all around us. The motion of a merry-go-round, a car taking a curve, the orbit of a planet (most are nearly circular), the turning of a crank shaft, the rotation of a storm cell etc., all require an understanding of the basic ideas of centripetal force and centripetal acceleration. Understanding these concepts allows an understanding of a wide range of phenomena.

The force of gravity changes with the square of the distance between the objects. This means that if the distance between two objects is doubled (multiplied by 2), the force between the objects is one quarter (divided by $2^2$) of its original value. If the distance between two objects is tripled (multiplied by 3), the force between them is one-ninth (divided by $3^2$) its original value.

**Instruments, Measurement, and Representations**
Time is measured in hours, minutes, and seconds

Distance is measured in centimeters, meters and kilometers.

Mass is measured in grams and kilograms.

Frequency is measured in oscillations/second.

Force is measured in newtons.

Arrows (vectors) are used to describe the velocity and acceleration of an object moving in a curved path.

Arrows (vectors) are used to describe the forces affecting the motion of an object moving in a curved path.

Calculations of average velocity and average accelerations for different parts of a journey are made.

Free-body diagrams on each of two interacting objects; force diagrams with relative magnitudes can be used to compare the forces acting on each object of the pair

**Instructional Examples:**
i. Inquiry
CE: P1.1C, P1.1D

An object (a small wooden block or coin) is placed on a small, round turntable with low friction bearings. Investigate at what minimum speed the turntable must be turned in order for the object to fly off the turntable. (A stopwatch may be used to time the rotations of the table). By changing the distance of the object from the center of the turntable, the effect of radius on the amount of force (in this case friction) required to keep the object on the turntable may be investigated.

ii. Reflection
CE: P1.2i, P1.2k

Research the historical scientific and social problems encountered as science moved from a geocentric to a heliocentric model for the solar system. Further, investigate the problems encountered in the shift from circular to elliptical orbits.

iii. Enrichment
CE: P1.2C, P1.2g, P3.4D, P3.6B, P3.6d, P3.6e

Research the concept of the geosynchronous orbit. Investigate its physical and technological uses. Find out what factors determine whether or not an object is in a geosynchronous orbit. Determine the amount of energy required to place an object in such an orbit.

iv. General
CE: P1.1C, P1.1 D, P2.1h

Suspend a spring vertically and place a small mass on its end. Use calculator-based (CBL) sensors or computer-based sensors to determine the points of maximum and minimum velocity and acceleration. Use stopwatches or computer-based motion sensors to determine the period of the oscillator. Investigate (qualitatively or quantitatively) the effect on the period of changing the mass, amplitude or the spring itself.

v. Intervention
CE: P3.4D

Attach a string to a constant-velocity, motorized car. Start the car moving on the floor, and, using only the string, make the car move in a circular path. It soon becomes clear that the force applied to the car must be directed toward the center of its path.

**Units by Content Expectation**

# PHYSICS

## Unit 6: Mechanical Energy

| Code | Content Expectation |
|---|---|
| *P3.2* | *Net Force -* 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). |
| P3.2B | Compare work done in different situations. |
| *P4.1x* | *Energy Transfer-Work* 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). |
| P4.1c | 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 $h$. |
| *P4.3* | *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: $KE = 1/_2$ mv2. |

| | |
|---|---|
| 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. |

# PHYSICS

## Unit 6: Mechanical Energy

**Big Idea (Core Concept):**
Doing work on an object requires transferring energy to the object resulting in a change of position and possibly a change in speed.

**Standard(s):**
P3: Forces and Motion
P4: Forms of Energy and Energy Transformations

**Content Statement(s):**
P3.2: Net Forces
P4.1x: Energy Transfer-Work
P4.3: Kinetic and Potential Energy
P4.3x: Kinetic and Potential Energy-Calculations

**Content Expectations: (Content Statement Clarification)**
**P3.2B:** Compare work done in different situations.

**Clarification**: Limit to situations involving a constant force using the formula W=Fd, where "d" is the distance an object moves in the direction *parallel* to the force. In situations where the force is not perpendicular or not parallel to the distance moved, the work done should be qualitative comparisons.

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

**Clarifications**: None.

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

**Clarification**: Include analysis a force vs. distance graph for variable or constant force situations, in addition to W = Fd calculations. Work done by forces applied at common angles (such as 30, 45, and 60 degrees) should also be addressed.

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

**Clarification**: Specifically show how the formulas W=Fd and $\Delta PE = mg\Delta h$ are related to each other.

**P4.3A:** Identify the form of energy in given situations (e.g., moving objects, stretched springs, rocks on cliffs, energy in food).

**Clarification**: The focus here is on recognizing the presence of kinetic energy and various forms of potential energy (elastic, chemical, and gravitational). Limit to the examples listed in the expectation.

**P4.3B:** Describe the transformation between potential and kinetic energy in simple mechanical systems (e.g., pendulums, roller coasters, ski lifts).

**Clarification**: These should be qualitative descriptions comparing potential and kinetic energies at various points in time using terms like increasing, decreasing, zero, maximum, minimum. Limit to the examples listed in the expectation. Ski lift energies include the work done by the machine lifting to a height, the gravitational PE, and then the kinetic energy of the moving skier.

**P4.3C:** Explain why all mechanical systems require an external energy source to maintain their motion.

**Clarification**: None.

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

**Clarification**: This will require the use of the kinetic energy formula, $KE= \frac{1}{2}mv^2$, in symbolic or numerical forms.

**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.

**Clarification**: Based on the examples listed in the expectation, this will require only the use of the kinetic energy formula, $KE= \frac{1}{2}mv^2$, the formula for gravitational potential energy, $\Delta PE=mg\Delta h$.

**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.

**Clarification**: Based on the examples listed in the expectation, this will require only the use of the kinetic energy formula, $KE= \frac{1}{2}mv^2$, the formula for gravitational potential energy, $\Delta PE=mg\Delta h$.

**Vocabulary**

$\Delta PE = mg\Delta h$
air resistance
change in direction
change in speed
direction of a force
drag
energy transfer
force
gravitational energy
gravitational potential energy
impact speed
$KE = \frac{1}{2}mv^2$
kinetic energy
magnitude of a force
mechanical systems
net force
Newton's First Law
Newtonian mechanics
pendulum
potential energy
speed
velocity
$W=Fd$
waves
work

**Real World Context**

Use pendulums, roller coasters, ski lifts to explain PE and KE

Use examples of various forms of PE such as stretched or compressed springs and rubber bands; energy stored in the chemical bonds of food, gasoline and other fuels; objects elevated above the Earth's surface

The amount of work done lifting a box, holding a box over your head, studying for a test are good ways to explain the difference between the scientific meaning and the everyday meaning of the term work.

Discuss the amount of KE and PE present at various points when bungee jumping and sky diving

Compare the KE of a moving car, a bullet fired from a gun and a freight train at rest and then moving at a speed of (for example) 40 m/s.

**Instruments, Measurement, and Representations**
Measures of time: hours, minutes, seconds
Measures of distance: cm, m, km
Measures of force and weight: Newtons
Measures of mass: kg, grams
Measures of energy: joules

All measurements of gravitational potential energies are based on an object-earth system.
Mathematical reasoning and representations:
- Qualitative comparisons of changes in potential energy with corresponding changes in kinetic energy
- Calculations of gravitational potential energy (GPE) of an object very close to Earth's surface and the change in GPE when the distance of the object from Earth's surface is increased ($GPE=mg\Delta h$)
- Calculations of kinetic energy and speed of a falling object very close to Earth's surface as the object's GPE decreases ($mg\Delta h+\Delta \frac{1}{2} mv^2=0$)

**Instructional Examples:**
i. Inquiry
CE: P1.1C, P1.1h, P4.3e, P4.3f

Design an experiment to determine the changes in the kinetic and potential energy of a bouncing ball before and after each bounce.

ii. Reflection
CE: P1.2k, P4.3A, P4.3C

Discuss the reason why lowering the speed limit saves energy

iii. Enrichment
CE: P4.3d, P4.3e, P4.3f

Calculate the gravitational potential energy, kinetic energy and elastic potential energy of a bungee jumper at one second intervals from the start of the jump

iv. General
CE: P4.3d

Develop a list of common objects in motion and have students use reasonable estimation to determine their KE's.

v. Intervention
CE: P3.2A, P3.2c, P3.2d

Have students use a spring scale to pull objects with a constant force a given distance at a constant speed and use the measured force to calculate the work done.

# PHYSICS

## Unit 7: Mechanical Waves

| Code | Content Expectation |
|---|---|
| *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 $v$ = l$f$. 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. |

| | |
|---|---|
| *P4.8x* | *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). |

# PHYSICS

## Unit 7: Mechanical Waves

**Big Idea (Core Concept)**:
Mechanical waves are vibrations in a medium that move from source to receiver, conveying energy.

**Standard:**
P4: Forms of Energy and Energy Transformations

**Content Statement(s):**
P4.4: Wave characteristics.
P4.4x: Wave Characteristics-Calculations.
P4.5: Mechanical Wave Propagation.
P4.8x: Wave Behavior—Diffraction, Interference, and Refraction

**Content Expectations: (Content Statement Clarification)**
**P4.4A:** Describe specific mechanical waves (e.g., on a demonstration spring, on the ocean) in terms of wavelength, amplitude, frequency, and speed.

**Clarification**: None.

**P4.4B:** Identify everyday examples of transverse and compression (longitudinal) waves.

**Clarification**: Examples of transverse waves: water waves, demonstration spring waves, seismic waves (S-wave). Examples of compression waves: sound waves and seismic waves (P-wave).

**P4.4C:** Compare and contrast transverse and compression (longitudinal) waves in terms of wavelength, amplitude, and frequency.

**Clarification**: Contrast and comparisons between transverse and compression (longitudinal) waves is NOT expected. Comparing and contrasting different types of transverse waves and comparing and contrasting different types of compressional waves is the expectation for this statement.

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

**Clarification**: None.

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

**Clarification**: The expectation is to *compare* the energy transferred by waves of different amplitudes and frequencies, not to *calculate*. A numerical comparison can be done using the concept given in the content statement "energy transferred by a wave is proportional to the square of the amplitude of vibration and its frequency".

**P4.5A:** Identify everyday examples of energy transfer by waves and their sources.

**Clarification**: Examples include light energy from the sun resulting in thermal energy of the Earth surfaces that results in wind, ocean currents and storms; seismic waves in the ocean creating water waves or tsunamis on the shoreline causing motion (destruction of coastal communities);and television communication involving radio waves, sound energy, light energy, electrical energy, heat energy.

**P4.5B:** Explain why an object (e.g., fishing bobber) does not move forward as a wave passes under it.

**Clarification**: None.

**P4.5C:** Provide evidence to support the claim that sound is energy transferred by a wave, not energy transferred by particles.

**Clarification**: The intent of the expectation is to instruct that sound waves involve a *transfer of energy via the particles of the medium* and that it is not the actual particles that are being transferred. (See content statement P4.5, "Waves transfer energy from one place to another without transferring mass") Sound waves are pressure waves due to particles moving closer and farther apart as a "wave" and in the process, facilitating the transfer energy from the source to the receiver. It is not the *particles* that are transferred, but the wave (energy).

**P4.5D:** Explain how waves propagate from vibrating sources and why the intensity decreases with the square of the distance from a point source.

**Clarification**: This statement does not call for calculations, but for a qualitative explanation of the decrease in intensity with distance.

**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.

**Clarification**: This is an application of content expectation P4.5D.

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

**Clarification**: Wave interference should be used describe what happens to the individual wave amplitudes when 2 waves of the same type (transverse or compression) occupy the same space at the same time.

**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).

**Clarification**: None.

**Vocabulary**

Compression (longitudinal) wave
Demonstration spring
Diffraction
Electromagnetic wave
Frequency
Hertz
Interference
Inverse square law
Inversely Proportional
Mechanical wave
Point source
Proportional
Refraction
Seismic wave
Sound wave
Superimpose
Transporting matter and/or energy
Transverse wave
Vibrations
Water wave
Wave amplitude
Wave medium
Wave propagation
Wave pulse
Wave source
Wave speed
Wave velocity
Wavelength

**Real World Context**

A demonstration spring or slinky is helpful to study the properties of waves. It is helpful to relate work done to produce the wave to the energy given to the wave. For example, applying a force and moving the spring twice the distance gives more amplitude and therefore more energy to the waves. Changing the frequency and its affect on wavelength can be visualized. Wave interference should be demonstrated with the spring or slinky. A slinky can be used to show both transverse and longitudinal waves, and to show how the speed of a wave changes in a different medium.

Wave tanks or ripple tanks or wave tables can also be used to show the properties of waves. The fishing bobber expectation can be addressed using these tools.

A recent example of wave energy transfer is the Asian Tsunami in the Indian Ocean. Use this as an example of the transfer of energy via waves from deep in the ocean to the coastline of a continent, and how the energy is transferred not the medium. Internet source: A Nova program about the physics of the Asian Tsunami,*Wave That Shook the World*, http://www.pbs.org/wgbh/nova/tsunami/.

Discuss the difference in sound transfer in solids, liquids and gases (transfer of energy by longitudinal waves in different mediums). Discuss the rationale in old western movies in which the "tracker" for the posse uses the ground to tell the location of the "outlaws".

Interference of waves involves additive amplitudes (constructive interference) or subtractive amplitudes (destructive interference). This can be demonstrated easily with a spring or string. It can also be demonstrated with a wave tank, two sound speakers at the same frequency or with laser light through double slits.

A discussion of the direction of particle vibration versus the transfer of energy when describing wave properties is appropriate. For example, the transverse wave particles and the direction of energy flow have a perpendicular relationship and the compression wave has a parallel one.

A discussion of the lack of sound in space due to the absence of a medium to transfer the energy would be appropriate.

**Instruments, Measurement, and Representations**

Sketches of the two types of waves (transverse and longitudinal) with the wavelength and amplitude labeled should be made. Include arrows showing the vibration of the particles and arrows showing the direction of energy transfer.

Use lists or flow charts of the transfer of energy from the source to the receiver in a system.

Use the wave formula ($v = \lambda f$) to make quantitative measurements of wave properties: frequency, wavelength, and speed.

Analyze graphs of waves to make quantitative measurements of wave properties: frequency, amplitude, wavelength, and speed.

Make wave diagrams (sketches) showing the result of two waves interfering with each other. Sketch an instance in which the amplitudes cancel and an instance in which the amplitudes add.

Use a demonstration spring as a model of a transverse wave.

Use a wave table or aquarium to show how a bobber does not move in the same direction as the flow of energy of the water wave.

Units of wavelength: meters (m), nanometers (nm)

Units of frequency: hertz (Hz) and megahertz (MHz)

Units of time: hours, minutes, seconds

**Instructional Examples:**

i. Inquiry
CE: P1.1C, P4.4A

Design an experiment that determines the speed of sound in air.

ii. Reflection
CE: P1.2j, P1.2k, P4.4C, P4.5D

Relate the properties of waves (speed, frequency, and wavelength) to the methods of earthquake detection. How are the detection methods based or not based on these properties? How have methods improved over time as our knowledge base has grown?

iii. Enrichment
CE: P4.8d

Study the effects of interference due to thin film interference as found in soap bubbles and on a rain slicked oily driveway.

iv. General
CE: P4.4A, P4.4C, P4.8c

Using a slinky spring and a wave demonstration spring, students generate transverse and longitudinal waves. Compare and contrast the amplitude, the speed of the wave in both mediums, and how frequency affects wavelength. Additionally, students generate waves from each end to investigate what happens when they meet.

v. Intervention
CE: P4.4C, P4.5B, P4.5C

1. *Transverse Wave Student Demo:* Students line up single file holding hands. First student raises the hand that is joined with the next student. This represents a transverse particle vibrating. The energy is transferred to the next student and so forth down the line, until the energy reaches the end, but notice the particles stayed in the same place.
2. *Longitudinal Wave Student Demo:* Students line up shoulder to shoulder. First student moves back and forth causing adjoining student to do the same and the vibration continues down the line until last student receives energy. Again, particles stay fixed, but vibration (energy) is transferred.

# PHYSICS

## Unit 8: Electromagnetic Waves

| Code | Content Expectation |
|---|---|
| *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. |

| | |
|---|---|
| *P4.8* | *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. |
| P4.8e | 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. |

# PHYSICS

## Unit 8: Electromagnetic Waves

**<u>Big Idea</u> (Core Concept):**
Electromagnetic waves transfer energy and information from place to place without a material medium, and visible light is a form of electromagnetic radiation. All electromagnetic waves move at the speed of light.

**<u>Standard(s)</u>:**
P4: Forms of Energy and Energy Transformations

**<u>Content Statement(s)</u>:**
P4.6: Electromagnetic Waves
P4.6x: Electromagnetic Propagation
P4.8: Wave Behavior-Reflection and Refraction
P4.8x: Wave Behavior — Diffraction, Interference, and Refraction
P4.9: Nature of Light

**<u>Content Expectations:</u> (Content Statement Clarification)**
**P4.6A:** Identify the different regions on the electromagnetic spectrum and compare them in terms of wavelength, frequency, and energy.

**Clarification**: knowledge of *relative* wavelengths, frequencies and energies is required. Memorization of specific values for these quantities is not called for by this expectation. (For example, it's more important to know that x-rays have much smaller wavelengths, higher frequencies and higher energies than visible light rather than learning the actual values of these quantities.)

**P4.6B:** Explain why radio waves can travel through space, but sound waves cannot.

**Clarification**: Knowledge that sound waves need a medium to transfer energy and electromagnetic waves (radio waves) do not is the expectation.

**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.

**Clarification**: None.

**P4.6D:** Explain why we see a distant event before we hear it (e.g., lightning before thunder, exploding fireworks before the boom).

**Clarification**: None.

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

**Clarification**: None.

**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.

**Clarification**: None.

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

**Clarification**: None.

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

**Clarification**: None.

**P4.8A:** Draw ray diagrams to indicate how light reflects off objects or refracts into transparent media.

**Clarification**: None.

**P4.8B:** Predict the path of reflected light from flat, curved, or rough surfaces (e.g., flat and curved mirrors, painted walls, paper).

**Clarification**: None.

**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).

**Clarification**: The use of Snell's law in problems or to explore the relationship in the lab is needed, but not a derivation the formula from first principles.

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

**Clarification**: A general explanation is required, but need not include the lens maker's equation.

**P4.9A:** Identify the principle involved when you see a transparent object (e.g., straw, a piece of glass) in a clear liquid.

**Clarification**: None.

**P4.9B:** Explain how various materials reflect, absorb, or transmit light in different ways.

**Clarification**: None.

**P4.9C:** Explain why the image of the Sun appears reddish at sunrise and sunset.

**Clarification**: None.

**Vocabulary**
Absorption
Acceleration
Analog
Angle of incidence
Angle of reflection
Angle of refraction
Antenna
Charges
Diffraction
Digital
Electric field
Electromagnetic Wave
Energy
Frequency
Incident wave
Infrared waves
Interference
Law of Reflection
Lens
Magnetic field
Microwaves
Modulation
Radio waves
Ray diagram
Reception
Reflected wave
Reflection
Refracted wave
Refraction
Snell's Law
Sound waves
Speed of light
Transmission
Ultraviolet light
Visible light
Wavelength
X-rays

**Real World Context**

Using recordings of communications between astronauts on the moon and mission control during the Apollo missions, one can identify the delay between transmission and reception and estimate the speed of EM radiation.
Delays can also be detected when a news anchor communicates with a reporter in the field via satellite.

Microwaves can be used for communication (e.g. cell phones). They can also be used to cook food. The microwave frequencies used in microwave ovens are at the resonant frequencies of water molecules. When the water molecules in food absorb this energy their kinetic energy goes up, and the food is warmer.

Melanin and sun block absorb and scatter ultraviolet radiation that can damage the nuclei of skin cells. Avoiding such damage can reduce the risk of some types of skin cancer.

X-rays are a form high frequency EM radiation that comes from the vibration of the inner shell electrons of an atom. Some X-rays may also be emitted by atomic nuclei.

**Instruments, Measurement, and Representations**

Angles are measured in degrees.

Frequency is measured in oscillations per second.

Wavelength is measured in meters and nanometers.

Velocity is measured in meters/second.

Time is measured in hours, minutes, and seconds.

Ray diagrams are used to show the path of light during reflection or refraction.

Snell's Law is used to calculate angles of refraction.

**Instructional Examples:**

i. Inquiry
CE: P1.1C, P1.1 D, P1.1 E

Given a transparent medium such as a Lucite block and a light source, data can be collected on refraction angles of light rays given a set of incident angles. A graph can be produced to help students to deduce the relationship between angles incidence and refraction.

ii. Reflection
CE: P1.2g, P1.2j, P1.2k, P4.6A, P4.6e, P4.6f, P4.6h

Research and produce a diagram of the electromagnetic spectrum. Under each form of EM radiation list its possible sources, technological/biological uses, effects/dangers to human beings and methods used to minimize negative effects.

iii. Enrichment
CE: P1.1C, P1.1h, P4.6A, P4.6e

Perform experiments to determine what it takes to block various forms of electromagnetic radiation. Given several blocking materials such as aluminum foil, paper, metal window screen, etc. attempt to block radio wave, infrared light, cell phone transmissions etc.

iv. General
CE: P4.8f

Given a set of lenses, experiment until a combination is discovered that results in a simple refracting telescope. Then, draw a ray diagram to determine how the lens combination magnifies the image.

v. Intervention
CE: P4.6B, P4.6C

Discuss the accuracy of various science fiction/fantasy movies in which sound is heard though the vacuum of space, near instantaneous communication takes place over astronomical distances, or "laser beams" are seen to be visibly traveling from one place to another.

**Units by Content Expectation**

# PHYSICS

## Unit 9: Electric Forces

| Code | Content Expectation |
|---|---|
| *P3.1x* | *Forces* Objects can interact with each other by "direct contact" (pushes or pulls, friction) or at a distance (gravity, electromagnetism, nuclear). |
| 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. |
| *P3.7* | *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. |
| *P3.8x* | *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. |

# PHYSICS

## Unit 9: Electric Forces

**Big Idea (Core Concept):**
All objects are composed of electrical charges. Certain characteristics of these charges determine the electric and magnetic forces experienced by objects that interact with each other at a distance.

**Standard(s):**
P3: Forces and Motion

**Content Statement(s):**
P3.1x: Forces
P3.7: Electric Charges
P3.7x: Electric Charges-Interactions
P3.8x: Electromagnetic Force

**Content Expectations: (Content Statement Clarification)**
**P3.1b:** Explain why scientists can ignore the gravitational force when measuring the net force between two electrons.

**Clarification**: The main point here is that for small, charged objects the electrical forces can be very much greater than the gravitational force that acts upon them.

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

**Clarification**: None.

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

**Clarification**: The emphasis here should be on a qualitative understanding of these relationships, more of a comparison or scale factor (2x, 4x larger or smaller, etc.) Actual use of the inverse square law to do calculations of electric force is not the focus of this Expectation.

**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.

**Clarification**: None.

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

**Clarification**: The redistribution of charge is the result of the movement of negative charges in an object caused by the type of charge that is brought near that object.

**P3.7d:** Identify examples of induced static charges.

**Clarification**: None.

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

**Clarification**: None.

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

**Clarification**: Note that the amount of force after they touch and are separated can vary from zero up to the amount of force that was present before they touched depending on the amount and type of charge on each object and whether or not the objects are conductors or insulators. Each of these scenarios should be addressed.

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

**Clarification**: Even though the flow of positive charge is the conventionally accepted model of flow of charge through a circuit, the movement of electrons due to electric forces will also have to be explained.

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

**Clarification**: None.

**Vocabulary**
charged object
conductor
contact forces
Coulomb's Law
direction of a force
distribution of electric charge
electric charge
electric circuit
electric force
electric generator
electric motor
electric potential
electrical current
electrically neutral
electromagnetic force
electromagnetic wave
electron
force
forces at a distance
friction
gravitational force
induction
inverse square law
inversely proportional
like charge
magnet
magnetic force
magnitude of a force
magnitude of charge
moving electrical charge
moving magnet
net force
opposite charge
proportional
proton
repel/attract
static charge
Van de Graff generator

**Real World Context**

Many of the Expectations listed in this unit are generally taught using the concepts of electric and magnetic fields. These are useful ways of explaining electric and magnetic forces at a distance. Students are expected to know and use these concepts and terminology.

The ability of a charged object to lift up a tiny piece of paper, demonstrating that between two charged particles, the electric force is larger than Earth's gravitational force

An electrophorus and an electroscope can be used to explain both charging by contact and charging by induction.

Using examples of "static cling" such as clothes from the dryer and balloons stuck to a wall is a good way to show the difference in magnitude between gravitational forces and electric forces

Electric motors and generators are good ways to explain how to utilize moving electric charges to produce magnetic forces and how to utilize changing magnetic fields produces electric forces. Both of these principles combined can be used to explain how accelerating electric charges produces electromagnetic disturbances which can be described as EM waves when these disturbances have a regular pattern.

**Instruments, Measurement, and Representations**

Measures of time: hours, minutes, seconds
Measures of distance: cm, m, km
Measures of force and weight: Newtons
Measures of mass: kg, grams
Measures of charge: coulomb

Use of arrows to represent forces of attraction or repulsion

Relationship of distance to electrical force: doubling (or tripling) the distance between two charges reduces the magnitude of the electrical force to one quarter (or one ninth).

Diagrams of charge distribution.

**Instructional Examples:**

i. Inquiry
CE: P1.1A, P1.1E, P3.7B, P3.7f

Have students investigate which types of materials and objects can build up static charge. Have them also determine which types of objects typically attract each other and which ones repel each other.

ii. Reflection
CE: P1.2f, P1.2g, P3.1c, P3.7B, P3.7c, P3.7d

Have students develop a list of common examples where the buildup of static charge can have negative effects and design ways to safely eliminate that buildup.

iii. Enrichment
CE: P3.7d, P3.7e, P3.7f

Have students build an electrophorus and construct charge distribution diagrams of the device at various steps of the charging and discharging process.

iv. General
CE: P3.7c, P3.7d, P3.7e

Make a charge distribution diagram and explain why a charged balloon sticks to the wall

v. Intervention
CE: P3.8b

Students can build their own electric motor using coils of wire and magnets. This allows them to experience, in a hands-on way, how the interaction of electric and magnetic forces is the basis for these common devices. Students can also be shown how generators and motors are really the same device just used differently by taking a motor and applying mechanical energy to it to produce electricity.

**Units by Content Expectation**

# PHYSICS

## Unit 10: Electric Current

| Code | Content Expectation |
|---|---|
| *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. |

# PHYSICS

## Unit 10: Electric Current

**Big Idea (Core Concept):**
Electrical current is used to transfer energy and to do work.

**Standard:**
P4: Forms of Energy and Energy Transformations

**Content Statement(s):**
P4.10: Current Electricity Circuits.
P4.10x: Current Electricity — Ohm's Law, Work, and Power.

**Content Expectations: (Content Statement Clarification)**
**P4.10A:** Describe the energy transformations when electrical energy is produced and transferred to homes and businesses.

**Clarification**: Describe the production of electricity by power plants that use coal, oil, natural gas and nuclear isotopes as a source of energy to heat water, producing steam that rotates a turbine that runs a generator that produces electrical energy. Production of electricity via falling water or wind (eliminating the heating of water in the transformations) should also be included.

**P4.10B:** Identify common household devices that transform electrical energy to other forms of energy, and describe the type of energy transformation.

**Clarification**: None.

**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.

**Clarification**: The use of a schematic diagram for circuit elements is not expected. Realistic sketches of circuit elements should be used. Limit circuits to individual series and parallel circuits; combination circuits are not expected.

**P4.10D:** Discriminate between voltage, resistance, and current as they apply to an electric circuit.

**Clarification**: None.

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

**Clarification**: Use of the flow of positive charge is the conventionally accepted model of flow of charge through a circuit. Limit the explanation to a simple circuit using a cell (battery) as the voltage source. Explanation should include the chemical energy of the cell, the work done by the cell, the potential energy given to the charge and the transfer of the energy as the charges moves through the resistance in the circuit.

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

**Clarification**: Since potential difference is work per unit charge, then the work done can be calculated by multiplying the potential difference (V) times the charge.

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

**Clarification**: None.

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

**Clarification**: None.

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

**Clarification**: Examples are limited to those included in this content expectation.

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

**Clarification**: Explain the difference by comparing kilowatts (kW) and kilowatt hours (kWh), the units found on electric bills. Kilowatt uses the larger metric unit for power (energy used per time interval). Kilowatt hours is a measure of the energy (power times time) using the larger metric units, kilowatt and hour.

**Vocabulary**

Amperage
Amperes
Charge
Circuit
Circuit breaker
Complete circuit
Coulomb
Electric company

Electric energy
Electric power
Electrical current
Fuse
Kilowatt hour (kWh)
Kilowatt (kW)
Load
Moving Electric Charge
Ohm
Ohm's law
Open circuit
Parallel circuit
Potential difference
Resistance
Series circuit
Short circuit
Voltage
Work
Watt

**Real World Context**

Typical ways that electrical energy is produced are coal, oil, natural gas, wind, hydroelectric, solar and nuclear. The coal, oil, natural gas and nuclear isotopes are the fuel to heat water, producing steam which drives a turbine (chemical energy to heat energy or nuclear energy to heat energy). The turbine turns a generator which produces the electricity (heat energy to mechanical energy to electrical energy). In the case of hydroelectric energy (falling water), the falling water turns a turbine which runs the generator which produces the electrical energy (potential energy to mechanical energy to electrical energy). Solar energy can be used in homes to produce electricity on a more limited basis (solar lighting or heat). This involves electromagnetic energy to heat and/or electrical energy conversions.

An example of a common device that transforms electrical energy to other forms of energy is a television which produces light, sound and heat energy.
Other devices can be used similarly as illustrations.

Although in a few textbooks it is explained electrons are the mobile charge carriers responsible for electric current in conductors such as wires, it has long been the convention to take the direction of electric current as if it were the positive charges which are moving. Because the vast majority of references use the conventional current direction, that convention will be used for the content expectations dealing with current and direction of current (positive to negative).

Home wiring is an example of parallel circuits and maximum load. Fuses or circuit breakers are used in home wiring to protect against circuit overload.

A common example of a series circuit is the flashlight.

**Instruments, Measurement, and Representations**
Diagram series and parallel circuits using pictorial representations of the circuit elements for essential expectations.

Diagram series and parallel circuits with schematic representations of a cell, resistor, wires, switch, voltmeter and ammeter for core expectations.

Measure current, voltage and resistance in series and parallel circuits with meters.

Diagram and compare complete, open and short circuits.

Use metric measurements of current (amperes), voltage (volts), resistance (ohms), power (watts) and energy (joules).

Kilowatt hours are larger units of energy used by utility companies.

Kilowatts are larger units of power.

Use utility bills from a power company.

Use formulas P = IV and V = IR to solve circuit problems.

Use the formula W = ΔVq to calculate work done.

**Instructional Examples:**
i. Inquiry
CE: P1.2g, P1.2j, P4.10B

Design and build a usable flashlight using batteries, a bulb, and common household wires.

ii. Reflection
CE: P1.2k, P4.10A

Discuss the how the use and production of electricity has impacted our society. Include developments that have had both a positive and negative effect on consumers. Brainstorm how the use and production of electricity will change 20 years from now.

iii. Enrichment
CE: P4.10g

Analyze a combination series and parallel circuit with ammeters and voltmeters.

iv. General
CE: P4.10C, P4.10e

Given a one battery, one bulb, and one wire; find four ways to light the bulb. Sketch arrangements that light and also those that do not light and draw with a colored marker the movement of charge through the circuit.

v. Intervention
CE: P4.10e

Use various kinesthetic analogies of electric circuits such as the water analogy (water flowing through pipes), the bucket brigade, and ball and ramp models (refer to NSTA Publication, *Taking Charge* by Larry E. Schafer)to show the parts of an electric circuit.

# PHYSICS

## Unit 11: Energy Transformations

| Code | Content Expectation |
|---|---|
| *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. |
| *P4.2* | *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). |
| P4.2e | 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. |
| *P4.11x* | *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. |
| P4.11b | Calculate the final temperature of two liquids (same or different materials) at the same or different temperatures and masses that are combined. |

# PHYSICS

## Unit 11: Energy Transformations

**Big Idea (Core Concept):**
Energy is constantly being transformed from one form to another. During these transformations the total amount of energy must remain constant although some energy is usually "lost" by the system in the form of heat.

**Standard(s):**
P4: Forms of Energy and Energy Transformations

**Content Statement(s):**
P4.1: Energy Transfer
P4.2: Energy Transformation
P4.11x: Heat, Temperature, and Efficiency

**Content Expectations: (Content Statement Clarification)**
**P4.1A:** Account for and represent energy into and out of systems using energy transfer diagrams.

**Clarification**: Energy transfer diagrams are flow charts that represent the movement of energy into, out of, and within a system.

**P4.2A:** Account for and represent energy transfer and transformation in complex processes (interactions).

**Clarification**: A complex process is a combination of two or more simple processes performing their energy transformations in sequence or simultaneously.

**P4.2B:** Name devices that transform specific types of energy into other types (e.g., a device that transforms electricity into motion).

**Clarification**: None.

**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).

**Clarification**: None.

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

**Clarification**: None.

**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.

**Clarification**: Label energy transfer diagrams to give simple quantitative and qualitative examples of how energy moves into and out of a system.

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

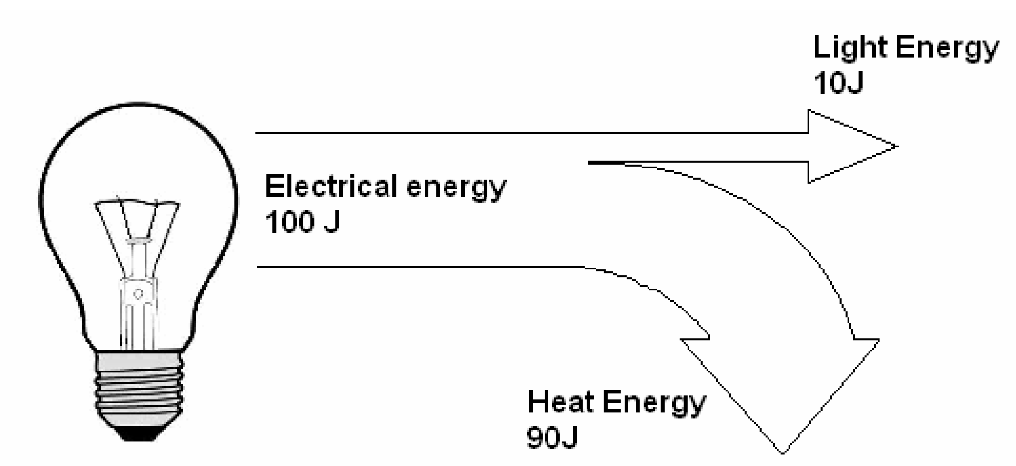
**Clarification**: This excludes any situations in which a change of phase occurs.

**Vocabulary**

Conservation of Energy
Efficiency
Electric Motor
Energy
Energy Transfer
Energy transfer diagram
Heat
Input
Output
System
Temperature
Thermal energy
Thermal equilibrium
Wave

**Real World Context**

An energy transfer diagram (see example below) can show quantitative and qualitatively how energy is transformed by simple and complex processes.



The engine of a car is an example of a complex device that ultimately changes the chemical energy of gasoline into kinetic energy, heat, sound and light.

When a car is moving at a constant velocity, energy is being transformed into heat by friction and into the motion of air by air resistance.

When a driver presses on the brake pedal, the car's kinetic energy is mostly transformed into thermal energy. This increases the temperature of the brake pads and much of this thermal energy is released to the surroundings as heat because of a temperature difference.

A simple pendulum continually transforms kinetic energy into potential energy and back again.

During a collision between two pool balls, energy leaves the system in the form of sound and heat.

When a body falls, it eventually reaches a steady velocity as gravity transforms some of its stored (potential) energy into kinetic energy. Air resistance transforms some its kinetic energy into the kinetic energy of the air which ultimately becomes heat. Friction with the air also warms the object. This is seen in dramatic terms for a spacecraft reentering the atmosphere.

Roller coasters, pendulum clocks, water waves, sound waves, nuclear reactors, interior of sun, atomic and thermonuclear reactions all represent essential ways in which energy is transformed from one form to another.

When two liquids of different temperature are combined, the final combination comes to an equilibrium temperature. This temperature is determined by the heat transferred between the two liquids. Heat transfer depends upon the mass, specific heat and initial temperature of the two liquids.

**Instruments, Measurement, and Representations**

Energy is measured in Joules

Temperature is measured in degrees Celsius

Mass is measured in grams and kilograms

The calorie is a unit of heat energy.

Use energy transfer diagrams that show the transfer and transformation of energy in simple and complex systems. An example of an energy transfer diagram would be a Rube Goldberg device.

Simple calculations relating temperature change and thermal energy measured in joules.

Mathematical reasoning and representations:

- Calculation of changes in temperatures of objects in closed systems
- Qualitative comparisons of changes in potential energy with corresponding changes in kinetic energy
- Calculations of gravitational potential energy (GPE) of an object very close to Earth's surface and the change in GPE when the distance of the object from Earth's surface is increased (GPE=mgh)
- Calculations of kinetic energy and speed of a falling object very close to Earth's surface as the object's GPE decreases ($mg\Delta h+\Delta \frac{1}{2} mv^2=0$)

**Instructional Examples:**

i. Inquiry
CE: P1.1h, P4.11b

Predict the final temperature when two liquids of different temperature are combined. They are then asked to design and conduct an experiment in determining the correctness of their prediction.

ii. Reflection
CE: P1.2B, P1.2C, P1.2g, P1.2j, P1.2k

Research alternative forms of energy such as ethanol production from corn. Comparing the energy going into the process of growing, harvesting and processing the corn, to the energy supplied by the ethanol produced, evaluate the viability of this energy source. Perform a similar analysis on wind, solar and hydrogen-based sources of energy.

iii. Enrichment
CE: P1.2B, P1.2g, P1.2j, P4.2B, P4.2f

Examine household appliances and record their power rating. This is usually displayed on the back of most microwave ovens, toasters, etc. Since power is energy per unit time, estimate how much time each appliance is used over the course of a month and calculate how much energy is used by the device per month. Also estimate the cost of per month of using the device. In the same way, compare the cost and energy usage of efficient, low wattage fluorescent light bulbs compared to the standard incandescent bulbs. Calculate the energy, cost and pollution savings if all the incandescent light bulbs in a home were replaced with their fluorescent, high efficiency counterparts.

iv. General
CE: P4.2A, P4.2B

Devise a list with many examples of technological devices that transform energy from one form (mechanical, heat, nuclear, electrical, sound, chemical, and electromagnetic) to another, and describe the input and output energies.

v. Intervention
CE: P4.2A, P4.2B

Identify the energy transformations involved in driving a car. Starting, stopping, turning, the combustion of fuel, the generation of electricity in the alternator, the electrical energy in the battery, etc. are example that may be identified.

**Units by Content Expectation**

# PHYSICS

## Unit 12:  Energy & Society

| Code | Content Expectation |
|---|---|
| *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). |
| P4.1B | 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. |
| P4.2D | Explain why all the stored energy in gasoline does not transform to mechanical energy of a vehicle. |
| *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. |
| *P4.12* | *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, $E = mc2$, 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. |

# PHYSICS

## Unit 12: Energy & Society

**Big Idea (Core Concept):**
Energy takes many forms and is able to be transformed from one form to another.

**Standard(s):**
P4: Forms of Energy and Energy Transformations

**Content Statement(s):**
P4.1: Energy Transfer
P4.2: Energy Transformation
P4.11x: Heat, Temperature, and Efficiency
P4.12: Nuclear Reactions
P4.12x: Mass and Energy

**Content Expectations: (Content Statement Clarification)**
**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).

**Clarification**: None.

**P4.2D:** Explain why all the stored energy in gasoline does not transform to mechanical energy of a vehicle.

**Clarification**: This will require an understanding of the various forms of energy that are produced and used in a vehicle as it transforms the stored energy in gasoline into mechanical energy and the various processes that produce those transformations. The efficiency of each of these processes is also necessary for this expectation.

**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.

**Clarification**: While it is common to utilize the concept of specific heat to solve problems involving the heating of water, students are not required to use or be assessed on this terminology.

**P4.12A:** Describe peaceful technological applications of nuclear fission and radioactive decay.

**Clarification**: None.

**P4.12B:** Describe possible problems caused by exposure to prolonged radioactive decay.

**Clarification**: None.

**P4.12C:** Explain how stars, including our Sun, produce huge amounts of energy (e.g., visible, infrared, or ultraviolet light).

**Clarification**: None.

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

**Clarification**: The loss of mass per nucleon needs to be addressed here for nuclear reactions that release energy. Not all fission reactions release energy and not all fusion reactions release energy. Energy is released if the mass of the parent nucleus is greater than the mass of the fission products OR if the masses of the parent nuclei are greater than the mass of the fusion product.

**Vocabulary**

atomic bonding principles
atomic configuration
atomic energy
atomic mass
atomic nuclei/nucleus
atomic number
atomic reaction
atomic weight
by-product
chemical bond
$E=mc^2$
Earth's crust
Earth's external energy sources
Earth's internal energy sources
efficiency
electromagnetic radiation
electromagnetic spectrum
energy lost
energy transfer
energy transformation
forms of energy
gasoline
heat
home hot water heater
infrared light
mass to energy conversion
matter
mechanical energy

microwave
neutron
nuclear decay rate
nuclear energy
nuclear fission
nuclear force
nuclear fusion
nuclear mass
nuclear reaction
nuclear stability
periodic table of the elements
potential energy
pressure
proton
radio wave
radioactive decay
radioactive isotope
ratio
release of energy
solar energy
speed of light
spontaneous nuclear reaction
star composition
stellar energy
stored energy
technological applications
temperature
thermal energy
total energy input
ultraviolet light
ultraviolet radiation
useful energy output
useful work
vacuum
visible light
waves
weight of subatomic particles
x-ray

**Real World Context**
Observations of nuclear energy through observations of changes in systems containing radioactive substances, such as:

- Water used to cool down nuclear reactions in nuclear power plants: observable temperature increase in the water
- Radioactive isotopes of elements: emission of alpha, beta, and gamma particles
- Thermonuclear reactions: light and charged particle emission

When teaching about radioactive decay, alpha, beta, and gamma radiation along with the concept of half-life are commonly used terminology. These are useful concepts for understanding the Expectations related to radioactive decay. However, students will not be assessed on these terms in state-wide assessments.

Various uses of nuclear medicine and the benefits/misconceptions associated with irradiated foods are great ways to teach about some of the peaceful uses of radioactive substances.

Other useful applications of nuclear physics include smoke detectors, which have nuclear components and x-ray sources which are used to detect lead paint in buildings and are used at road construction sites to determine if the roadbed is packed tightly enough.

Illnesses and medical conditions caused by exposure to radioactivity (radiation sickness, cancers, birth defects) help students understand some of the safety issues surrounding radioactive substances.

Current issues and technologies related to nuclear fission and nuclear fusion as sources of usable energy should be addressed when teaching these topics

The design and use of hot water heaters (gas, electric, LP) and their efficiencies needs to be included in this unit of instruction

**Instruments, Measurement, and Representations**
Measures of time: hours, minutes, seconds
Measures of distance: cm, m, km
Measures of force and weight: Newtons
Measures of mass: kg, grams
Measures of energy: joules
Measures of temperature: °C

Simple calculations relating temperature change and thermal energy measured in joules

Primarily verbal descriptions of evidence of energy in familiar systems, that is, if a change is observed, a form of energy is identified as a probable cause of the change

Quantitative measurements of wave properties: frequency, amplitude, wavelength, and velocity

**Instructional Examples:**

i. Inquiry
CE: P1.1i, P4.12A

In groups, students can learn about one peaceful application of radioactive decay and become experts on that application. Redistribute and jigsaw the groups back together so that each student is responsible for teaching their new group members about the one application they are the expert for.

ii. Reflection
CE: P1.2f, P1.2k, P4.12A

Have students research and present the pros and cons of nuclear power

iii. Enrichment
CE: P4.12C, P4.12d

Have students research and describe the difficulties with developing nuclear fusion into a usable source of energy.

iv. General
CE: P4.2D

Have students construct an energy flow diagram for an automobile

v. Intervention
CE: P4.12A, P4.12B

Students who are having a hard time understanding the concept of radioactive decay should develop a demonstration of their own where they have to consume or eliminate half of a chosen substance in a time period of their choosing. They then need to repeat this process as many times as possible until the substance has 'decayed'. For example, starting with a bag of cookies students might choose to eat half of the cookies every 6 minutes until they are gone.

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