Michigan Physics High School Content Expectations

Approved by the State Board of Education, October, 2006

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

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

Objects can interact with each other by direct contact (e.g., pushes or pulls, friction) or at a distance (e.g., gravity, electromagnetism). Forces are used for describing interactions between objects. Non-zero net forces always cause changes in motion (Newton's fi rst law). These changes can be changes in speed, direction, or both. Newton's second law summarizes relationships between net forces, masses, and changes in motion. Whenever one object exerts a force on another, a force equal in magnitude and opposite in direction is exerted back on it (Newton's third law).

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

STANDARD P1: INQUIRY, REFLECTION, AND SOCIAL IMPLICATIONS

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

Essential	Core and Recommended
P1.1 Scientific Inquiry Science is a way of understanding nature. Scientific research may begin by generating new scientific questions that can be answered through replicable scientific investigations that are logically developed and conducted systematically. Scientific conclusions and explanations result from careful analysis of empirical evidence and the use of logical reasoning. Some questions in science are addressed through indirect rather than direct observation, evaluating the consistency of new evidence with results predicted by models of natural processes. Results from investigations are communicated in reports that are scrutinized through a peer review process.	
P1.1A Generate new questions that can be investigated in the laboratory or field. **P1.1B** Evaluate the uncertainties or validity of scientific conclusions using an understanding of sources of measurement error, the challenges of controlling variables, accuracy of data analysis, logic of argument, logic of experimental design, and/or the dependence on underlying assumptions. **P1.1C** Conduct scientific investigations using appropriate tools and techniques (e.g., selecting an instrument that measures the desired quantity–length, volume, weight, time interval, temperature–with the appropriate level of precision). **P1.1D** Identify patterns in data and relate them to theoretical models. **P1.1E** Describe a reason for a given conclusion using evidence from an investigation.	**P1.1f** Predict what would happen if the variables, methods, or timing of an investigation were changed. **P1.1g** Based on empirical evidence, explain and critique the reasoning used to draw a scientific conclusion or explanation. **P1.1h** Design and conduct a systematic scientific investigation that tests a hypothesis. Draw conclusions from data presented in charts or tables. **P1.1i** Distinguish between scientific explanations that are regarded as current scientific consensus and the emerging questions that active researchers investigate.

P1.2 Scientific Reflection and Social Implications	
The integrity of the scientific process depends on scientists and citizens understanding and respecting the "Nature of Science." Openness to new ideas, skepticism, and honesty are attributes required for good scientific practice. Scientists must use logical reasoning during investigation design, analysis, conclusion, and communication. Science can produce critical insights on societal problems from a personal and local scale to a global scale. Science both aids in the development of technology and provides tools for assessing the costs, risks, and benefits of technological systems. Scientific conclusions and arguments play a role in personal choice and public policy decisions. New technology and scientific discoveries have had a major infl uence in shaping human history. Science and technology continue to offer diverse and significant career opportunities.	
P1.2A Critique whether or not specific questions can be answered through scientific investigations. **P1.2B** Identify and critique arguments about personal or societal issues based on scientific evidence. **P1.2C** Develop an understanding of a scientific concept by accessing information from multiple sources.Evaluate the scientific accuracy and significance of the information. **P1.2D** Evaluate scientific explanations in a peer review process or discussion format. **P1.2E** Evaluate the future career and occupational prospects of science fields.	**P1.2f** Critique solutions to problems, given criteria and scientific constraints. **P1.2g** Identify scientific tradeoffs in design decisions and choose among alternative solutions. **P1.2h** Describe the distinctions between scientific theories, laws, hypotheses, and observations. **P1.2i** Explain the progression of ideas and explanations that lead to science theories that are part of the current scientific consensus or core knowledge. **P1.2j** Apply science principles or scientific data to anticipate effects of technological design decisions. **P1.2k** Analyze how science and society interact from a historical, political, economic, or social perspective.

STANDARD P2: MOTION OF OBJECTS

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

P2.1 Position — Time An object's position can be measured and graphed as a function of time. An object's speed can be calculated and graphed as a function of time. **P2.1A** Calculate the average speed of an object using the change of position and elapsed time. **P2.1B** Represent the velocities for linear and circular motion using motion diagrams (arrows on strobe pictures). **P2.1C** Create line graphs using measured values of position and elapsed time. **P2.1D** Describe and analyze the motion that a position-time graph represents, given the graph. **P2.1E** Describe and classify various motions in a plane as one dimensional, two dimensional, circular, or periodic. **P2.1F** Distinguish between rotation and revolution and describe and contrast the two speeds of an object like the Earth.	**P2.1g** Solve problems involving average speed and constant acceleration in one dimension. **P2.1h** Identify the changes in speed and direction in everyday examples of circular (rotation and revolution), periodic, and projectile motions.
P2.2 Velocity — Time The motion of an object can be described by its position and velocity as functions of time and by its average speed and average acceleration during intervals of time. **P2.2A** Distinguish between the variables of distance, displacement, speed, velocity, and acceleration. **P2.2B** Use the change of speed and elapsed time to calculate the average acceleration for linear motion. **P2.2C** Describe and analyze the motion that a velocity-time graph represents, given the graph. **P2.2D** State that uniform circular motion involves acceleration without a change in speed.	**P2.2e** Use the area under a velocity-time graph to calculate the distance traveled and the slope to calculate the acceleration. **P2.2f** Describe the relationship between changes in position, velocity, and acceleration during periodic motion. **P2.2g** Apply the independence of the vertical and horizontal initial velocities to solve projectile motion problems.
	P2.3x Frames of Reference All motion is relative to whatever frame of reference is chosen, for there is no motionless frame from which to judge all motion. **P2.3a** Describe and compare the motion of an object using different reference frames.

STANDARD P3: FORCES AND MOTION

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

P3.1 Basic Forces in Nature Objects can interact with each other by "direct contact" (e.g., pushes or pulls, friction) or at a distance (e.g., gravity, electromagnetism, nuclear). **P3.1A** Identify the force(s) acting between objects in "direct contact" or at a distance.	**P3.1x Forces** There are four basic forces (gravitational, electromagnetic, strong, and weak nuclear) that differ greatly in magnitude and range. Between any two charged particles, electric force is vastly greater than the gravitational force. Most observable forces (e.g., those exerted by a coiled spring or friction) may be traced to electric forces acting between atoms and molecules. **P3.1b** Explain why scientists can ignore the gravitational force when measuring the net force between two electrons. **P3.1c** Provide examples that illustrate the importance of the electric force in everyday life. **P3.1d** Identify the basic forces in everyday interactions.
P3.2 Net Forces Forces have magnitude and direction. The net force on an object is the sum of all the forces acting on the object. Objects change their speed and/or direction only when a net force is applied. If the net force on an object is zero, there is no change in motion (Newton's First Law). **P3.2A** Identify the magnitude and direction of everyday forces (e.g., wind, tension in ropes, pushes and pulls, weight). **P3.2B** Compare work done in different situations. **P3.2C** Calculate the net force acting on an object.	**P3.2d** Calculate all the forces on an object on an inclined plane and describe the object's motion based on the forces using free-body diagrams.
P3.3 Newton's Third Law Whenever one object exerts a force on another object, a force equal in magnitude and opposite in direction is exerted back on the first object. **P3.3A** Identify the action and reaction force from examples of forces in everyday situations (e.g., book on a table, walking across the fl oor, pushing open a door).	**P3.3b** Predict how the change in velocity of a small mass compares to the change in velocity of a large mass when the objects interact (e.g., collide). **P3.3c** Explain the recoil of a projectile launcher in terms of forces and masses. **P3.3d** Analyze why seat belts may be more important in autos than in buses.

P3.4 Forces and Acceleration The change of speed and/or direction (acceleration) of an object is proportional to the net force and inversely proportional to the mass of the object. The acceleration and net force are always in the same direction. **P3.4A** Predict the change in motion of an object acted on by several forces. **P3.4B** Identify forces acting on objects moving with constant velocity (e.g., cars on a highway). **P3.4C** Solve problems involving force, mass, and acceleration in linear motion (Newton's second law). **P3.4D** Identify the force(s) acting on objects moving with uniform circular motion (e.g., a car on a circular track, satellites in orbit).	**P3.4e** Solve problems involving force, mass, and acceleration in two-dimensional projectile motion restricted to an initial horizontal velocity with no initial vertical velocity (e.g., ball rolling off a table). **P3.4f** Calculate the changes in velocity of a thrown or hit object during and after the time it is acted on by the force. **P3.4g** Explain how the time of impact can affect the net force (e.g., air bags in cars, catching a ball).
	P3.5x Momentum A moving object has a quantity of motion (momentum) that depends on its velocity and mass. In interactions between objects, the total momentum of the objects does not change. **P3.5a** Apply conservation of momentum to solve simple collision problems.
P3.6 Gravitational Interactions Gravitation is a universal attractive force that a mass exerts on every other mass. The strength of the gravitational force between two masses is proportional to the masses and inversely proportional to the square of the distance between them. **P3.6A** Explain earth-moon interactions (orbital motion) in terms of forces. **P3.6B** Predict how the gravitational force between objects changes when the distance between them changes. **P3.6C** Explain how your weight on Earth could be different from your weight on another planet.	**P3.6d** Calculate force, masses, or distance, given any three of these quantities, by applying the Law of Universal Gravitation, given the value of *G*. **P3.6e** Draw arrows (vectors) to represent how the direction and magnitude of a force changes on an object in an elliptical orbit.

P3.7 Electric Charges	P3.7x Electric Charges — Interactions
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.	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 fl ow in an electric circuit.
P3.p8 Magnetic Force (prerequisite)	**P3.8x Electromagnetic Force**
Magnets exert forces on all objects made of ferromagnetic materials (e.g., iron, cobalt, and nickel) as well as other magnets. This force acts at a distance. Magnetic fields accompany magnets and are related to the strength and direction of the magnetic force. *(prerequisite)* **P3.p8A** Create a representation of magnetic field lines around a bar magnet and qualitatively describe how the relative strength and direction of the magnetic force changes at various places in the field. *(prerequisite)*	Magnetic and electric forces are two aspects of a single electromagnetic force. Moving electric charges produce magnetic forces and moving magnets produce electric forces (e.g., electric current in a conductor). **P3.8b** Explain how the interaction of electric and magnetic forces is the basis for electric motors, generators, and the production of electromagnetic waves.

STANDARD P4: FORMS OF ENERGY AND ENERGY TRANSFORMATIONS

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

P4.1 Energy Transfer Moving objects and waves transfer energy from one location to another. They also transfer energy to objects during interactions (e.g., sunlight transfers energy to the ground when it warms the ground; sunlight also transfers energy from the Sun to the Earth). **P4.1A** Account for and represent energy into and out of systems using energy transfer diagrams. **P4.1B** Explain instances of energy transfer by waves and objects in everyday activities (e.g., why the ground gets warm during the day, how you hear a distant sound, why it hurts when you are hit by a baseball).	**P4.1x Energy Transfer — Work** Work is the amount of energy transferred during an interaction. In mechanical systems, work is the amount of energy transferred as an object is moved through a distance, $W = F\,d$, where d is in the same direction as F. The total work done on an object depends on the net force acting on the object and the object's displacement. **P4.1c** Explain why work has a more precise scientific meaning than the meaning of work in everyday language. **P4.1d** Calculate the amount of work done on an object that is moved from one position to another. **P4.1e** Using the formula for work, derive a formula for change in potential energy of an object lifted a distance h.
P4.2 Energy Transformation Energy is often transformed from one form to another. The amount of energy before a transformation is equal to the amount of energy after the transformation. In most energy transformations, some energy is converted to thermal energy. **P4.2A** Account for and represent energy transfer and transformation in complex processes (interactions). **P4.2B** Name devices that transform specific types of energy into other types (e.g., a device that transforms electricity into motion). **P4.2C** Explain how energy is conserved in common systems (e.g., light incident on a transparent material, light incident on a leaf, mechanical energy in a collision). **P4.2D** Explain why all the stored energy in gasoline does not transform to mechanical energy of a vehicle.	**P4.2e** Explain the energy transformation as an object (e.g., skydiver) falls at a steady velocity. **P4.2f** Identify and label the energy inputs, transformations, and outputs using qualitative or quantitative representations in simple technological systems (e.g., toaster, motor, hair dryer) to show energy conservation.

P4.3 Kinetic and Potential Energy Moving objects have kinetic energy. Objects experiencing a force may have potential energy due to their relative positions (e.g., lifting an object or stretching a spring, energy stored in chemical bonds). Conversions between kinetic and gravitational potential energy are common in moving objects. In frictionless systems, the decrease in gravitational potential energy is equal to the increase in kinetic energy or vice versa. **P4.3A** Identify the form of energy in given situations (e.g., moving objects, stretched springs, rocks on cliffs, energy in food). **P4.3B** Describe the transformation between potential and kinetic energy in simple mechanical systems (e.g., pendulums, roller coasters, ski lifts). **P4.3C** Explain why all mechanical systems require an external energy source to maintain their motion.	**P4.3x Kinetic and Potential Energy — Calculations** The kinetic energy of an object is related to the mass of an object and its speed: $KE = 1/2\ mv^2$. **P4.3d** Rank the amount of kinetic energy from highest to lowest of everyday examples of moving objects. **P4.3e** Calculate the changes in kinetic and potential energy in simple mechanical systems (e.g., pendulums, roller coasters, ski lifts) using the formulas for kinetic energy and potential energy. **P4.3f** Calculate the impact speed (ignoring air resistance) of an object dropped from a specific height or the maximum height reached by an object (ignoring air resistance), given the initial vertical velocity.
P4.4 Wave Characteristics Waves (mechanical and electromagnetic) are described by their wavelength, amplitude, frequency, and speed. **P4.4A** Describe specific mechanical waves (e.g., on a demonstration spring, on the ocean) in terms of wavelength, amplitude, frequency, and speed. **P4.4B** Identify everyday examples of transverse and compression (longitudinal) waves. **P4.4C** Compare and contrast transverse and compression (longitudinal) waves in terms of wavelength, amplitude, and frequency.	**P4.4x Wave Characteristics — Calculations** Wave velocity, wavelength, and frequency are related by $v = \lambda f$. The energy transferred by a wave is proportional to the square of the amplitude of vibration and its frequency. **P4.4d** Demonstrate that frequency and wavelength of a wave are inversely proportional in a given medium. **P4.4e** Calculate the amount of energy transferred by transverse or compression waves of different amplitudes and frequencies (e.g., seismic waves).
P4.5 Mechanical Wave Propagation Vibrations in matter initiate mechanical waves (e.g., water waves, sound waves, seismic waves), which may propagate in all directions and decrease in intensity in proportion to the distance squared for a point source. Waves transfer energy from one place to another without transferring mass. **P4.5A** Identify everyday examples of energy transfer by waves and their sources. **P4.5B** Explain why an object (e.g., fishing bobber) does not move forward as a wave passes under it. **P4.5C** Provide evidence to support the claim that sound is energy transferred by a wave, not energy transferred by particles. **P4.5D** Explain how waves propagate from vibrating sources and why the intensity decreases with the square of the distance from a point source. **P4.5E** Explain why everyone in a classroom can hear one person speaking, but why an amplification system is often used in the rear of a large concert auditorium.	

P4.6 Electromagnetic Waves	P4.6x Electromagnetic Propagation
Electromagnetic waves (e.g., radio, microwave, infrared, visible light, ultraviolet, x-ray) are produced by changing the motion (acceleration) of charges or by changing magnetic fields. Electromagnetic waves can travel through matter, but they do not require a material medium. (That is, they also travel through empty space.) All electromagnetic waves move in a vacuum at the speed of light. Types of electromagnetic radiation are distinguished from each other by their wavelength and energy. **P4.6A** Identify the different regions on the electromagnetic spectrum and compare them in terms of wavelength, frequency, and energy. **P4.6B** Explain why radio waves can travel through space, but sound waves cannot. **P4.6C** Explain why there is a delay between the time we send a radio message to astronauts on the moon and when they receive it. **P4.6D** Explain why we see a distant event before we hear it (e.g., lightning before thunder, exploding fireworks before the boom).	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, radiocontrol cars, cell phone conversations, and GPS systems. **P4.6g** Explain how different electromagnetic signals (e.g., radio station broadcasts or cell phone conversations) can take place without interfering with each other. **P4.6h** Explain the relationship between the frequency of an electromagnetic wave and its technological uses. **P4.r7x Quantum Theory of Waves *(recommended)*** Electromagnetic energy is transferred on the atomic scale in discrete amounts called quanta. The equation $E = h f$ quantifies the relationship between the energy transferred and the frequency, where h is Planck's constant. *(recommended)* **P4.r7h** Calculate and compare the energy in various electromagnetic quanta (e.g., visible light, x-rays). *(recommended)*
P4.8 Wave Behavior — Reflection and Refraction The laws of refl ection and refraction describe the relationships between incident and reflected/refracted waves. **P4.8A** Draw ray diagrams to indicate how light reflects off objects or refracts into transparent media. **P4.8B** Predict the path of reflected light from flat, curved, or rough surfaces (e.g., flat and curved mirrors, painted walls, paper).	**P4.8x Wave Behavior — Diffraction, Interference, and Refraction** Waves can bend around objects (diffraction). They also superimpose on each other and continue their propagation without a change in their original properties (interference). When refracted, light follows a defined path. **P4.8c** Describe how two wave pulses propagated from opposite ends of a demonstration spring interact as they meet. **P4.8d** List and analyze everyday examples that demonstrate the interference characteristics of waves (e.g., dead spots in an auditorium, whispering galleries, colors in a CD, beetle wings). **P4.8e** Given an angle of incidence and indices of refraction of two materials, calculate the path of a light ray incident on the boundary (Snell's Law). **P4.8f** Explain how Snell's Law is used to design lenses (e.g., eye glasses, microscopes, telescopes, binoculars).

P4.9 Nature of Light Light interacts with matter by reflection, absorption, or transmission. **P4.9A** Identify the principle involved when you see a transparent object (e.g., straw, piece of glass) in a clear liquid. **P4.9B** Explain how various materials reflect, absorb, or transmit light in different ways. **P4.9C** Explain why the image of the Sun appears reddish at sunrise and sunset.	**P4.r9x Nature of Light — Wave-Particle Nature *(recommended)*** The dual wave-particle nature of matter and light is the foundation for modern physics. *(recommended)* **P4.r9d** Describe evidence that supports the dual wave - particle nature of light. *(recommended)*
P4.10 Current Electricity — Circuits Current electricity is described as movement of charges. It is a particularly useful form of energy because it can be easily transferred from place to place and readily transformed by various devices into other forms of energy (e.g., light, heat, sound, and motion). Electrical current (amperage) in a circuit is determined by the potential difference (voltage) of the power source and the resistance of the loads in the circuit. **P4.10A** Describe the energy transformations when electrical energy is produced and transferred to homes and businesses. **P4.10B** Identify common household devices that transform electrical energy to other forms of energy, and describe the type of energy transformation. **P4.10C** Given diagrams of many different possible connections of electric circuit elements, identify complete circuits, open circuits, and short circuits and explain the reasons for the classification. **P4.10D** Discriminate between voltage, resistance, and current as they apply to an electric circuit.	**P4.10x Current Electricity — Ohm's Law, Work, and Power** In circuits, the relationship between electric current, I, electric potential difference, V, and resistance, R, is quantified by $V = I R$ (Ohm's Law). Work is the amount of energy transferred during an interaction. In electrical systems, work is done when charges are moved through the circuit. Electric power is the amount of work done by an electric current in a unit of time, which can be calculated using $P = I V$. **P4.10e** Explain energy transfer in a circuit, using an electrical charge model. **P4.10f** Calculate the amount of work done when a charge moves through a potential difference, V. **P4.10g** Compare the currents, voltages, and power in parallel and series circuits. **P4.10h** Explain how circuit breakers and fuses protect household appliances. **P4.10i** Compare the energy used in one day by common household appliances (e.g., refrigerator, lamps, hair dryer, toaster, televisions, music players). **P4.10j** Explain the difference between electric power and electric energy as used in bills from an electric company.

	P4.11x Heat, Temperature, and Efficiency Heat is often produced as a by-product during energy transformations. This energy is transferred into the surroundings and is not usually recoverable as a useful form of energy. The efficiency of systems is defined as the ratio of the useful energy output to the total energy input. The efficiency of natural and human-made systems varies due to the amount of heat that is not recovered as useful work. **P4.11a** Calculate the energy lost to surroundings when water in a home water heater is heated from room temperature to the temperature necessary to use in a dishwasher, given the efficiency of the home hot water heater. **P4.11b** Calculate the final temperature of two liquids (same or different materials) at the same or different temperatures and masses that are combined.
P4.12 Nuclear Reactions Changes in atomic nuclei can occur through three processes: fission, fusion, and radioactive decay. Fission and fusion can convert small amounts of matter into large amounts of energy. Fission is the splitting of a large nucleus into smaller nuclei at extremely high temperature and pressure. Fusion is the combination of smaller nuclei into a large nucleus and is responsible for the energy of the Sun and other stars. Radioactive decay occurs naturally in the Earth's crust (rocks, minerals) and can be used in technological applications (e.g., medical diagnosis and treatment). **P4.12A** Describe peaceful technological applications of nuclear fission and radioactive decay. **P4.12B** Describe possible problems caused by exposure to prolonged radioactive decay. **P4.12C** Explain how stars, including our Sun, produce huge amounts of energy (e.g., visible, infrared, ultraviolet light).	**P4.12x Mass and Energy** In nuclear reactions, a small amount of mass is converted to a large amount of energy, $E = mc^2$, where c is the speed of light in a vacuum. The amount of energy before and after nuclear reactions must consider mass changes as part of the energy transformation. **P4.12d** Identify the source of energy in fission and fusion nuclear reactions.