Physics

INTRODUCTION AND SYLLABUS

COURSE DESCRIPTION

Physics is a high school level course, which satisfies the Ohio Core science graduation requirements of Ohio Revised Code Section 3313.603. This section of Ohio law requires three units of science. Each course should include inquiry-based laboratory experience that engages students in asking valid scientific questions and gathering and analyzing information.

Physics elaborates on the study of the key concepts of motion, forces and energy as they relate to increasingly complex systems and applications that will provide a foundation for further study in science and scientific literacy.

Students engage in investigations to understand and explain motion, forces and energy in a variety of inquiry and design scenarios that incorporate scientific reasoning, analysis, communication skills and real-world applications.

COURSE CONTENT

The following information may be taught in any order; there is no ODE-recommended sequence.

P.M: MOTION

P.M.1: Motion Graphs
- Position vs. time
- Velocity vs. time
- Acceleration vs. time

P.M.2: Problem Solving
- Using graphs (average velocity, instantaneous velocity, acceleration, displacement, change in velocity)
- Uniform acceleration including free fall (initial velocity, final velocity, time, displacement, acceleration, average velocity)

P.M.3: Projectile Motion
- Independence of horizontal and vertical motion
- Problem-solving involving horizontally launched projectiles

P.F: FORCES, MOMENTUM AND MOTION

P.F.1: Newton's laws applied to complex problems
P.F.2: Gravitational force and fields
P.F.3: Elastic forces
P.F.4: Friction force (static and kinetic)
P.F.5: Air resistance and drag
P.F.6: Forces in two dimensions
- Adding vector forces
- Motion down inclines
- Centripetal forces and circular motion

P.F.7: Momentum, impulse and conservation of momentum

P.E: ENERGY

P.E.1: Gravitational potential energy
P.E.2: Energy in springs
P.E.3: Work and power
P.E.4: Conservation of energy
P.E.5: Nuclear energy

P.W: WAVES

P.W.1: Wave properties
- Conservation of energy
- Reflection
- Refraction
- Interference
- Diffraction

P.W.2: Light phenomena
- Ray diagrams (propagation of light)
- Law of reflection (equal angles)
- Snell's law
- Diffraction patterns
- Wave—particle duality of light
- Visible spectrum of color

P.EM: ELECTRICITY AND MAGNETISM

P.EM.1: Charging objects (friction, contact and induction)
P.EM.2: Coulomb's law
P.EM.3: Electric fields and electric potential energy
P.EM.4: DC circuits

- Ohm's law
- Series circuits
- Parallel circuits
- Mixed circuits
- Applying conservation of charge and energy (junction and loop rules)

P.EM.5: Magnetic fields
P.EM.6: Electromagnetic interactions

NATURE OF SCIENCE HIGH SCHOOL

Nature of Science
One goal of science education is to help students become scientifically literate citizens able to use science as a way of knowing about the natural and material world. All students should have sufficient understanding of scientific knowledge and scientific processes to enable them to distinguish what is science from what is not science and to make informed decisions about career choices, health maintenance, quality of life, community and other decisions that impact both themselves and others.

Categories	High School
Scientific Inquiry, Practice and Applications All students must use these scientific processes with appropriate laboratory safety techniques to construct their knowledge and understanding in all science content areas.	• Identify questions and concepts that guide scientific investigations. • Design and conduct scientific investigations using a variety of methods and tools to collect empirical evidence, observing appropriate safety techniques. • Use technology and mathematics to improve investigations and communications. • Formulate and revise explanations and models using logic and scientific evidence (critical thinking). • Recognize and analyze explanations and models. • Communicate and support scientific arguments.

Science is a Way of Knowing
Science assumes the universe is a vast single system in which basic laws are consistent. Natural laws operate today as they did in the past and they will continue to do so in the future. Science is both a body of knowledge that represents a current understanding of natural systems and the processes used to refine, elaborate, revise and extend this knowledge.
	• Various science disciplines use diverse methods to obtain evidence and do not always use the same set of procedures to obtain and analyze data (i.e., there is no one scientific method).
	  ○ Make observations and look for patterns.
	  ○ Determine relevant independent variables affecting observed patterns.
	  ○ Manipulate an independent variable to affect a dependent variable.
	  ○ Conduct an experiment with controlled variables based on a question or hypothesis.
	  ○ Analyze data graphically and mathematically.
	• Science disciplines share common rules of evidence used to evaluate explanations about natural phenomenon by using empirical standards, logical arguments and peer reviews.
	  ○ Empirical standards include objectivity, reproducibility and honest and ethical reporting of findings.
	  ○ Logical arguments should be evaluated with open-mindedness, objectivity and skepticism.
	• Science arguments are strengthened by multiple lines of evidence supporting a single explanation.
	• The various scientific disciplines have practices, methods, and modes of thinking that are used in the process of developing new science knowledge and critiquing existing knowledge.

Science is a Human Endeavor Science has been, and continues to be, advanced by individuals of various races, genders, ethnicities, languages, abilities, family backgrounds and incomes.	• Science depends on curiosity, imagination, creativity and persistence. • Individuals from different social, cultural and ethnic backgrounds work as scientists and engineers. • Science and engineering are influenced by technological advances and society; technological advances and society are influenced by science and engineering. • Science and technology might raise ethical, social and cultural issues for which science, by itself, does not provide answers and solutions.
Scientific Knowledge is Open to Revision in Light of New Evidence Science is not static. Science is constantly changing as we acquire more knowledge.	• Science can advance through critical thinking about existing evidence. • Science includes the process of comparing patterns of evidence with current theory. • Some science knowledge pertains to probabilities or tendencies. • Science should carefully consider and evaluate anomalies (persistent outliers) in data and evidence. • Improvements in technology allow us to gather new scientific evidence.

*Adapted from Appendix H – Understanding the Scientific Enterprise: The Nature of Science in the Next Generation Science Standards

Physics continued

P.M: MOTION
P.M.1: Motion graphs

- Position vs. time
- Velocity vs. time
- Acceleration vs. time

CONTENT ELABORATION: MOTION

In physical science, the concepts of position, displacement, velocity and acceleration were introduced and straight-line motion involving either uniform velocity or uniform acceleration was investigated and represented in position vs. time graphs, velocity vs. time graphs, motion diagrams and data tables.

In this course, acceleration vs. time graphs are introduced and more complex graphs are considered that have both positive and negative displacement values and involve motion that occurs in stages (e.g., an object accelerates then moves with constant velocity). Symbols representing acceleration are added to motion diagrams and mathematical analysis of motion becomes increasingly more complex. Motion is explored through investigation and experimentation. Motion detectors and computer graphing applications can be used to collect and organize data. Computer simulations and video analysis can be used to analyze motion with greater precision.

P.M.1: Motion graphs
Instantaneous velocity for an accelerating object can be determined by calculating the slope of the tangent line for some specific instant on a position vs. time graph. Instantaneous velocity will be the same as average velocity for conditions of constant velocity, but this is rarely the case for accelerating objects. The position vs. time graph for objects increasing in speed will become steeper as they progress and the position vs. time graph for objects decreasing in speed will become less steep.

On a velocity vs. time graph, objects increasing in speed will slope away from the x-axis and objects decreasing in speed will slope toward the x-axis. The slope of a velocity vs. time graph indicates the acceleration so the graph will be a straight line (not necessarily horizontal) when the acceleration is constant. Acceleration is positive for objects speeding up in a positive direction or objects slowing down in a negative direction. Acceleration is negative for objects slowing down in a positive direction or speeding up in a negative direction. These are not concepts that should be memorized, but can be developed from analyzing the definition of acceleration and the conditions under which acceleration would have these signs.

The word "deceleration" should not be used since it provides confusion between slowing down and negative acceleration. The area under the curve for a velocity vs. time graph gives the change in position (displacement) but the absolute position cannot be determined from a velocity vs. time graph. Objects moving with uniform acceleration will have a horizontal line on an acceleration vs. time graph. This line will be at the x-axis for objects that are either standing still or moving with constant velocity. The area under the curve of an acceleration vs. time graph gives the change in velocity for the object, but the displacement, position and the absolute velocity cannot be determined from an acceleration vs. time graph. The details about motion graphs should not be taught as rules to memorize, but rather as generalizations that can be developed from interpreting the graphs.

P.M.2: Problem solving
Many problems can be solved from interpreting graphs and charts as detailed in the motion graphs section. In addition, when acceleration is constant, average velocity can be calculated by taking the average of the initial and final instantaneous velocities ($v_{avg} = (v_f - v_i)/2$). This relationship does not hold true when the acceleration changes. The equation can be used in conjunction with other kinematic equations to solve increasingly complex problems, including those involving free fall with negligible air resistance in which objects fall with uniform acceleration. Near the surface of Earth, in the absence of other forces, the acceleration of freely falling objects is 9.81 m/s^2. Assessments of motion problems, including projectile motion, will not include problems that require the quadratic equation to solve.

P.M.3: Projectile motion
When an object has both horizontal and vertical components of motion, as in a projectile, the components act independently of each other. For a projectile in the absence of air resistance, this means that horizontally, the projectile will continue to travel at constant speed just like it would if there were no vertical motion. Likewise, vertically the object will accelerate just as it would without any horizontal motion. Problem solving will be limited to solving for the range, time, initial height, initial velocity or final velocity of horizontally launched projectiles with negligible air resistance. While it is not inappropriate to explore more complex projectile problems, it must not be done at the expense of other parts of the curriculum.

EXPECTATIONS FOR LEARNING

The content in the standards needs to be taught in ways that incorporate the nature of science and engage students in scientific thought processes. Where possible, real-world data and problem- and project-based experiences should be utilized. *Ohio's Cognitive Demands* relate to current understanding and research about the ways people learn and are important aspects to the overall understanding of science concepts. Care should be taken to provide students opportunities to engage in all four types of thinking. Additionally, lessons need to be designed so that they incorporate the concepts described in the *Nature of Science*.

VISIONS INTO PRACTICE: CLASSROOM EXAMPLES

This section provides guidance for developing classroom tasks that go beyond traditional approaches to instruction. It is a springboard for generating innovative ideas to address the cognitive demands. A variety of activities are presented so that teachers can select those that best meet the needs of their students. This is not an all-inclusive checklist and is not intended to cover every aspect of the standards. **These activities are suggestions and are not mandatory.**

Designing technological/engineering solutions using science concepts	Demonstrating science knowledge	Interpreting and communicating science concepts	Recalling accurate science
P.M.1: Motion graphs			
	Construct a method to measure the changing velocity of an object falling from a height of at least 5.0 m and that of an object rising into the air for at least 5.0 m.	Given a position vs. time graph or velocity vs. time graph write a driving scenario that fits the graph given. Given a position vs. time graph, velocity vs. time graph or acceleration vs. time graph sketch the other two corresponding graphs.	Determine the collision point for two constant velocity buggies traveling at different velocities and moving towards each other. Create a position vs. time graph from given data and determine the velocity of an object at two different times. Use that data to determine the average acceleration of the object during that interval of time. Given a velocity vs. time graph showing quadrants I and IV, label portions of the graph where acceleration is positive or negative and describe the motion of the object as increasing or decreasing by relating slope of the line to sign of acceleration. This clarifies the misconception of negative acceleration always indicating that an object is slowing down. Given unlabeled graphs with a variety of shapes (e.g., constant positive slope, increasing positive slope, zero slope), give an example for an object that would produce a graph for each of the relevant motion graphs.

Designing technological/engineering solutions using science concepts	Demonstrating science knowledge	Interpreting and communicating science concepts	Recalling accurate science
P.M.2: Problem solving			
	Use a constant velocity buggy and an accelerating cart to investigate the simultaneous motion of two objects. Collect data individually on the motion of each object as it travels down a ramp. Use the data to make a prediction for when the accelerating object will overtake the constant velocity object if released at a specified later time. Test your prediction. Compare predictions with actual results and provide possible explanations for any discrepancies. Investigate the motion of a freely falling body using either a ticker timer or a motion detector. Use mathematical analysis to determine a value for "g." Compare the experimental value to known values of "g." Suggest sources of error and possible improvements to the experiment.	Using kinematic equations, solve simultaneous equations to determine when an accelerating object will overtake an object moving at constant velocity (e.g., the police officer and speeder problem). Consider constraints such as the maximum velocity the accelerating object can travel and reaction times if applicable. Experimentally determine reaction time or velocity of a jump using kinematic equations and data collected in class (e.g., distance a ruler drops before catching, height of jump, time in air).	Use the kinematic equations to solve for unknown quantities regarding an accelerated body in one dimension. Solve for information in one part of a problem and use the results to solve for information in subsequent parts.

Designing technological/engineering solutions using science concepts	Demonstrating science knowledge	Interpreting and communicating science concepts	Recalling accurate science
P.M.3: Projectile motion			
	Design an experiment to collect data that will determine the launch velocity of a projectile launcher. Use the data to predict the range of the projectile at a given angle and attempt to hit a target with a projectile. Then, describe any assumptions made (e.g., neglecting air resistance, accounting for any uncertainty in the measurements).	Predict the range of a ball rolling off a table by measuring the speed of the ball on the table and determining the time the ball will take to fall by measuring the height of the table. Using a target placed on the floor, determine how accurate predictions were. Then, identify sources of uncertainty in measurements and explain the effect these had on experimental results.	Solve problems involving horizontal projectiles and recognize that the horizontal velocity does not affect the time that a horizontal projectile will spend in the air.
Investigation of motion			
Given a ramp and a low-friction rolling cart, investigate accelerated motion. Design a procedure to collect relevant position vs. time data for the rolling cart and create a graph of the data. Use the position vs. time graph to determine the acceleration of the rolling cart, either by taking the slope of the graph at various times to determine the velocity and then graphing the velocity values to get a velocity vs. time graph and taking the slope of the graph or by linearizing the data and making use of appropriate kinematics equations.	Given a toy car that travels at a constant velocity, collect data to determine the velocity of the car from a position vs. time graph. The speeds of the cars can be varied by replacing a battery with an aluminum cylinder of the same length or a wooden dowel wrapped in aluminum foil.	Predict where a rolling cart and a constant velocity car will be at the same position on a ramp. Make this prediction by graphing the data for both cars on the same coordinate grid and using algebraic analysis of the data obtained from the previous parts (e.g., the acceleration of the rolling cart and the velocity of the car). Test the prediction and analyze any sources of uncertainty.	

Physics continued

P.F: FORCES, MOMENTUM AND MOTION
P.F.1: Newton's laws applied to complex problems
P.F.2: Gravitational force and fields
P.F.3: Elastic forces
P.F.4: Friction force (static and kinetic)
P.F.5: Air resistance and drag
P.F.6: Forces in two dimensions

- Adding vector forces
- Motion down inclines
- Centripetal forces and circular motion

P.F.7: Momentum, impulse and conservation of momentum

CONTENT ELABORATION: FORCES, MOMENTUM AND MOTION

In earlier grades, Newton's laws of motion were introduced, gravitational forces and fields were described conceptually, the gravitational force (weight) acting on objects near Earth's surface was calculated, and friction forces and drag were addressed conceptually and quantified from force diagrams. The forces required for circular motion were introduced conceptually. In this course, Newton's laws of motion are applied to mathematically describe and predict the effects of forces on more complex systems of objects and to analyze falling objects that experience significant air resistance.

Gravitational forces are studied as a universal phenomenon and gravitational field strength is quantified. Elastic forces and a more detailed look at friction are included. At the atomic level, contact forces are actually due to the forces between the charged particles of the objects that appear to be touching. These electric forces are responsible for friction forces, normal forces and other contact forces. Air resistance and drag are explained using the particle nature of matter. Projectile motion is introduced and circular motion is quantified. The vector properties of momentum and impulse are introduced and used to analyze elastic and inelastic collisions between objects. Analysis of experimental data collected in laboratory investigations is used to study forces and momentum. This can include the use of force probes and computer software to collect and analyze data.

P.F.1: Newton's laws applied to complex problems
Newton's laws of motion, especially the third law, can be used to solve complex problems that involve systems of many objects that move together as one (e.g., an Atwood machine). The equation $a = F_{net}/m$ that was introduced in physical science can be used to solve more complex problems involving systems of objects and situations involving forces that must themselves be quantified (e.g., gravitational forces, elastic forces, friction forces).

P.F.2: Gravitational force and fields
Gravitational interactions are very weak compared to other interactions and are difficult to observe unless one of the objects is extremely massive (e.g., the sun, planets, moons). The force law for gravitational interaction states that the strength of the gravitational force is proportional to the product of the two masses and inversely proportional to the square of the distance between the centers of the masses, $F_g = (G \cdot m_1 \cdot m_2)/r^2$. The proportionality constant, G, is called the universal gravitational constant and has a value of $6.674 \cdot 10^{-11}\ m^3/(kg \cdot s^2)$. Problem solving may involve calculating the net force for an object between two massive objects (e.g., Earth-moon system, planet-sun system) or calculating the position of such an object given the net force.

The strength of an object's (i.e., the source's) gravitational field at a certain location, g, is given by the gravitational force per unit of mass experienced by another object placed at that location, $g = F_g/m$. Comparing this equation to Newton's second law can be used to explain why all objects on Earth's surface accelerate at the same rate in the absence of air resistance. While the gravitational force from another object can be used to determine the field strength at a particular location, the field of the object is always there, even if the object is not interacting with anything else. The field direction is toward the center of the source. Given the gravitational field strength at a certain location, the gravitational force between the source of that field and any object at that location can be calculated. Greater gravitational field strengths result in larger gravitational forces on masses placed in the field. Gravitational fields can be represented by field diagrams obtained by plotting field arrows at a series of locations. Field line diagrams are excluded from this course. Distinctions between gravitational and inertial masses are excluded.

A scale indicates weight by measuring the normal force between the object and the surface supporting it. The reading on the scale accurately measures the weight if the system is not accelerating. However, if the scale is used in an accelerating system, as in an elevator, the reading on the scale does not equal the actual weight. The scale reading can be referred to as the "apparent weight." This apparent weight in accelerating elevators can be explained and calculated using force diagrams and Newton's laws.

P.F.3: Elastic forces
Elastic materials stretch or compress in proportion to the load they support. The mathematical model for the force that a linearly elastic object exerts on another object is $F_{elastic} = k\Delta x$, where Δx is the displacement of the object from its relaxed position. The direction of the elastic force is always toward the relaxed position of the elastic object. The constant of proportionality, k, is the same for compression and extension and depends on the "stiffness" of the elastic object.

P.F.4: Friction force (static and kinetic)
The amount of kinetic friction between two objects depends on the electric forces between the atoms of the two surfaces sliding past each other. It also depends upon the magnitude of the normal force that pushes the two surfaces together. This can be represented mathematically as $F_k = \mu_k F_N$, where μ_k is the coefficient of kinetic friction that depends upon the materials of which the two surfaces are made.

Sometimes friction forces can prevent objects from sliding past each other, even when an external force is applied parallel to the two surfaces that are in contact. This is called static friction, which is mathematically represented by $F_s \leq \mu_s F_N$. The maximum amount of static friction possible depends on the types of materials that make up the two surfaces and the magnitude of the normal force pushing the objects together, $F_{smax} = \mu_s F_N$. As long as the external net force is less than or equal to the maximum force of static friction, the objects will not move relative to one another. In this case, the actual static friction force acting on the object will be equal to the net external force acting on the object, but in the opposite direction. If the external net force exceeds the maximum static friction force for the object, the objects will move relative to each other and the friction between them will no longer be static friction, but will be kinetic friction.

P.F.5: Air resistance and drag
Liquids have more drag than gases. When an object pushes on the particles in a fluid, the fluid particles can push back on the object according to Newton's third law and cause a change in motion of the object. This is how helicopters experience lift and how swimmers propel themselves forward. Forces from fluids are quantified using Newton's second law and force diagrams. Factors that affect air resistance and drag and the determination of terminal velocity may be included.

P.F.6: Forces in two dimensions

- Adding vector forces
- Motion down inclines
- Centripetal forces and circular motion

Net forces will be calculated for force vectors with directions between 0° and 360° or a certain angle from a reference (e.g., 37° above the horizontal). Vector addition can be done with trigonometry or by drawing scaled diagrams. Problems can be solved for objects sliding down inclines. The net force, final velocity, time, displacement and acceleration can be calculated. Inclines will either be frictionless or the force of friction will already be quantified. Calculations of friction forces down inclines from the coefficients of friction and the normal force will not be addressed in this course.

An object moves at constant speed in a circular path when there is a constant net force that is always directed at right angles to the direction of motion toward the center of the circle. In this case, the net force causes an acceleration that shows up as a change in direction. If the force is removed, the object will continue in a straight-line path. The nearly circular orbits of planets and satellites result from the force of gravity. Centripetal acceleration is directed toward the center of the circle and can be calculated by the equation $a_c = v^2/r$, where v is the speed of the object and r is the radius of the circle. This expression for acceleration can be substituted into Newton's second law to calculate the centripetal force. Since the centripetal force is a net force, it can be equated to friction (unbanked curves), gravity, elastic force, etc., to perform more complex calculations.

P.F.7: Momentum, impulse and conservation of momentum

Momentum, p, is a vector quantity that is directly proportional to the mass, m, and the velocity, v, of the object. Momentum is in the same direction the object is moving and can be mathematically represented by the equation p = mv. The conservation of linear momentum states that the total (net) momentum before an interaction in a closed system is equal to the total momentum after the interaction. In a closed system, linear momentum is always conserved for elastic, inelastic and totally inelastic collisions. While total energy is conserved for any collision, in an elastic collision, the kinetic energy also is conserved. Given the initial motions of two objects, qualitative predictions about the change in motion of the objects due to a collision can be made. Problems can be solved for the initial or final velocities of objects involved in inelastic and totally inelastic collisions. Momentum may be dealt with in two dimensions conceptually, but at this level calculations should be limited to only one dimension. Coefficients of restitution are beyond the scope of this course.

Impulse, Δp, is the total momentum transfer into or out of a system. Any momentum transfer is the result of interactions with objects outside the system and is directly proportional to both the average net external force acting on the system, F_{avg}, and the time interval of the interaction, t. It can mathematically be represented by $\Delta p = p_f - p_i = F_{avg}\,\Delta t$. This equation can be used to justify why momentum changes due to the external force of friction can be ignored when the time of interaction is extremely short. Average force, initial or final velocity, mass or time interval can be calculated in multi-step word problems. For objects that experience a given impulse (e.g., a truck coming to a stop), a variety of force/time combinations are possible. The time could be small, which would require a large force (e.g., the truck crashing into a brick wall to a sudden stop). Conversely, the time could be extended which would result in a much smaller force (e.g., the truck applying the brakes for a long period of time).

EXPECTATIONS FOR LEARNING

The content in the standards needs to be taught in ways that incorporate the nature of science and engage students in scientific thought processes. Where possible, real-world data and problem- and project-based experiences should be utilized. *Ohio's Cognitive Demands* relate to current understanding and research about the ways people learn and are important aspects to the overall understanding of science concepts. Care should be taken to provide students opportunities to engage in all four types of thinking. Additionally, lessons need to be designed so that they incorporate the concepts described in the *Nature of Science*.

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Designing technological/engineering solutions using science concepts	Demonstrating science knowledge	Interpreting and communicating science concepts	Recalling accurate science
P.F.1: Newton's laws applied to complex problems			
	Plan and conduct an investigation using an Atwood machine. Vary one of the masses to determine the effect it has on the acceleration of the system. This can be accomplished by measuring the time for one mass to fall a known distance and using kinematics equations to solve for the acceleration or by measuring the acceleration using smart pulleys and computer data logging if it is available. Then, state the relationship mathematically and verify the numerical values from data.	Draw free body diagrams for objects and use them to apply Newton's Second Law to solve for the acceleration of a mass. Design a demonstration for one of Newton's Laws and present the demonstration to the class. The demonstration should provide clear evidence for the law and sufficient data should be collected to support claims. Have classmates critique the demonstration and provide suggested improvements. Calculate the drag force (air resistance) on coffee filters by dropping different quantities and analyzing the experimental data. Determine the factors that affect terminal velocity.	Solve for the acceleration of a mass that is acted upon by multiple forces acting in one dimension. Solve problems for both horizontal and vertical acceleration. **Note:** *Once friction and elastic forces are introduced, these concepts should be integrated into students learning experiences.*
P.F.2: Gravitational forces and fields			
	Use the Phet Gravity Force Lab to investigate the relationship between masses of objects, distance between them and gravitational force. Verify the force law for gravitational interaction using values from the simulation.		Solve problems using the equation for universal gravitation (e.g., determine the net force on a mass at a point between Earth and another stellar object, determine why the gravitational force between two people is negligible, determine the value for g from the equation and Newton's Second Law).

Designing technological/engineering solutions using science concepts	Demonstrating science knowledge	Interpreting and communicating science concepts	Recalling accurate science
P.F.3: Elastic forces			
Construct a bungee jump apparatus to safely drop a fragile object (e.g., flour bag) to within a specified distance of the ground from an appropriate height, using calculations alone to determine length and strength of bungee cord required. After construction, test bungees to compare elastic force and gravitational force on the object and use data to critique and modify designs.	Plan and conduct a scientific investigation to determine the relationship between the force exerted on a spring and the amount it stretches. Represent the data graphically. Analyze the data to determine patterns and trends and model the relationship with a mathematical equation. Describe the relationship in words and support the conclusion with experimental evidence.	Draw a free body diagram that shows the forces acting on a mass that is hanging from a spring. Draw the forces acting on a mass that is attached to an ideal spring that is not stretched in the vertical direction and is then released. Diagrams can be drawn at the initial position, the equilibrium position, the maximum stretched distance, and at the points halfway between equilibrium and the ends of the motion. The forces and the motion of the spring should only be discussed qualitatively at this point.	Calculate the force on a mass that is hanging in equilibrium by relating the force of gravity and the force applied by the spring.

Designing technological/engineering solutions using science concepts	Demonstrating science knowledge	Interpreting and communicating science concepts	Recalling accurate science
P.F.4: Friction forces (static and kinetic)			
	Plan and conduct an investigation to determine the coefficient of kinetic friction between two surfaces. Collect sufficient relevant data and analyze the data graphically to determine the value for the coefficient of kinetic friction. Then, compare the value to either the accepted value of kinetic friction when possible or to the results of other students and discuss any differences and sources of uncertainty in measurements. Conduct an investigation to measure the coefficient of static friction between two surfaces by changing variables such as mass, incline and types of surfaces. Design an investigation to support or refute the claim that speed or surface area affects the value for the force of friction between two surfaces. Present experimental designs and results to the class and allow others to question the design and the validity of the results.		Solve problems involving calculations of the force of kinetic friction between two surfaces. Problems should include objects moving at constant velocity, objects that are accelerating due to an external force other than friction, and situations where friction is the only force acting on an object to slow it to a stop. Kinematic equations may be included to allow students to determine stopping distance or time for an object to slide to a stop. Draw free body diagrams in conjunction with these problems.

Designing technological/engineering solutions using science concepts	Demonstrating science knowledge	Interpreting and communicating science concepts	Recalling accurate science
P.F.5: Air resistance and drag			
			Determine the magnitude of the air resistance or drag acting on an object when provided with all other forces and the acceleration. Represent the force of air resistance in free body diagrams.
P.F.6: Forces in two dimensions			
	Investigate the relationship between acceleration and the angle of the incline for an object accelerating down an incline in the absence of friction using a low friction cart. Investigate the relationship between acceleration and mass of the object. This can be done at a fixed angle with or without the presence of frictional force. Discuss why no relationships exist. Collect data to investigate the relationship between the speed of an object moving in a circular path and the force needed to keep the object moving in that path. Plot a graph of force vs. velocity and analyze the relationship.	Draw a free-body diagram for an object that is accelerating along a horizontal surface under the influence of a force that acts at a known angle to the horizontal. Use the free-body diagram to solve for the acceleration of the object. The object may be acted on by friction and subject to more than one external force. Use a free-body diagram and trigonometry or scale diagrams to determine the acceleration of an object accelerating down a frictionless incline. Make use of kinematic equations to solve for the time to slide down the incline, the final velocity, or the length of the incline when the appropriate information is provided.	Solve for the components of a force that is at an angle to a known reference. Add force components that act at right angles. Both can be done using either trigonometry or by drawing scale diagrams. Solve problems involving an object accelerating down an incline with a known force of friction. Use kinematic equations to solve for the time to slide down the incline, the final velocity, or the length of the incline when the appropriate information is provided. Solve problems involving objects moving in circular motion (e.g., satellites orbiting planets, cars driving around horizontal curves, planes flying in horizontal and vertical circles). Identify what force is providing the necessary centripetal force for each situation.

Designing technological/engineering solutions using science concepts	Demonstrating science knowledge	Interpreting and communicating science concepts	Recalling accurate science
P.F.7: Momentum, impulse and conservation of momentum			
Research a stretch of road where there are many accidents. Evaluate potential causes related to laws of motion and propose a design change to the road to reduce the number of accidents. Design a system to safely stop a vehicle. Construct a working model that allows a raw egg mounted on the front of a vehicle to remain whole when the vehicle stops before impacting a wall. Test components and systems to collect and analyze data. Use data to refine designs and retest. Use a design portfolio to keep track of trials and revisions to the design throughout the process. Discuss advantages and disadvantages of various braking systems.		Research the effect of snow, rain and ice on the coefficients of friction between tires and the road and use this knowledge to create a presentation for other students on the importance of driving appropriately for the road conditions. Present data using posters to display in the school to raise awareness among the students about the effects that changes in weather conditions can have on driving.	

Physics continued

P.E: ENERGY
P.E.1: Gravitational potential energy
P.E.2: Energy in springs
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P.E.4: Conservation of energy
P.E.5: Nuclear energy

CONTENT ELABORATION: ENERGY

In Physical Science, the role of strong nuclear forces in radioactive decay, half-lives, fission and fusion, and mathematical problem solving involving kinetic energy, gravitational potential energy, energy conservation and work (when the force and displacement were in the same direction) were introduced. In this course, the concept of gravitational potential energy is understood from the perspective of a field, elastic potential energy is introduced and quantified, nuclear processes are explored further, and the concept of mass-energy equivalence is introduced. The concept of work is expanded, power is introduced and the principle of conservation of energy is applied to increasingly complex situations. Energy is explored by analyzing data gathered in scientific investigations. Computers and probes can be used to collect and analyze data.

P.E.1: Gravitational potential energy
When two attracting masses interact, the kinetic energies of both objects change but neither is acting as the energy source or the receiver. Instead, the energy is transferred into or out of the gravitational field around the system as gravitational potential energy. A single mass does not have gravitational potential energy. Only the system of attracting masses can have gravitational potential energy. When two masses are moved farther apart, energy is transferred into the field as gravitational potential energy. When two masses are moved closer together, gravitational potential energy is transferred out of the field.

P.E.2: Energy in springs
The approximation for the change in the potential elastic energy of an elastic object (e.g., a spring) is $\Delta E_{elastic} = ½ k \Delta x^2$ where Δx is the distance the elastic object is stretched or compressed from its relaxed length.

P.E.3: Work and power
Work can be calculated for situations in which the force and the displacement are at angles to one another using the equation $W = F\Delta x(\cos\theta)$ where W is the work, F is the force, Δx is the displacement, and θ is the angle between the force and the displacement. This means when the force and the displacement are at right angles, no work is done and no energy is transferred between the objects. Such is the case for circular motion.

The rate of energy change or transfer is called power (P) and can be mathematically represented by $P = \Delta E/\Delta t$ or $P = W/\Delta t$. Power is a scalar property. The unit of power is the watt (W), which is equivalent to one joule of energy transferred in one second (J/s).

P.E.4: Conservation of energy
The total initial energy of the system and the energy entering the system are equal to the total final energy of the system and the energy leaving the system. Although the various forms of energy appear very different, each can be measured in a way that makes it possible to keep track of how much of one form is converted into another. Situations involving energy transformations can be represented with verbal or written descriptions, energy diagrams and mathematical equations. Translations can be made between these representations.

The conservation of energy principle applies to any defined system and time interval within a situation or event in which there are no nuclear changes that involve mass-energy equivalency. The system and time interval may be defined to focus on one particular aspect of the event. The defined system and time interval may then be changed to obtain information about different aspects of the same event.

P.E.5: Nuclear energy
Alpha, beta, gamma and positron emission each have different properties and result in different changes to the nucleus. The identity of new elements can be predicted for radioisotopes that undergo alpha or beta decay. Nuclear reactions, such as fission and fusion, are accompanied by large energy changes that are much greater than those that accompany chemical reactions. Nuclear fission reactions are used as a controlled source of energy in nuclear power plants. There are advantages and disadvantages of generating electricity from fission and fusion. During nuclear interactions, the transfer of energy out of a system is directly proportional to the change in mass of the system as expressed by $E = mc^2$, which is known as the equation for mass-energy equivalence. A very small loss in mass is accompanied by a release of a large amount of energy. In nuclear processes such as nuclear decay, fission and fusion, the mass of the product is less than the mass of the original nuclei. The missing mass appears as energy. This energy can be calculated for fission and fusion when given the masses of the particle(s) formed and the masses of the particle(s) that interacted to produce them.

EXPECTATIONS FOR LEARNING

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VISIONS INTO PRACTICE: CLASSROOM EXAMPLES

This section provides guidance for developing classroom tasks that go beyond traditional approaches to instruction. It is a springboard for generating innovative ideas to address the cognitive demands. A variety of activities are presented so that teachers can select those that best meet the needs of their students. This is not an all-inclusive checklist and is not intended to cover every aspect of the standards. **These activities are suggestions and are not mandatory.**

Designing technological/engineering solutions using science concepts	Demonstrating science knowledge	Interpreting and communicating science concepts	Recalling accurate science
P.E.1: Gravitational potential energy			
Design a gravity-fed water system, connecting concepts of rise/fall to gravitational potential energy. Evaluate the system's real-world function compared to predicted performance, considering factors affecting performance (e.g., effects of pipe diameter). Use data to critique designs and propose changes for reconstruction.			Solve problems involving gravitational potential energy. Use problems that involve objects near the surface of Earth as well as objects that have a large distance between their centers of mass, such as a satellite orbiting Earth.

Designing technological/engineering solutions using science concepts	Demonstrating science knowledge	Interpreting and communicating science concepts	Recalling accurate science
P.E.2: Energy in springs			
Attempt to measure/calculate k values for a variety of bungee shock cords. Then construct a bungee jump apparatus to safely drop a fragile object (ex. flour bag, egg) to within a specified distance of the ground from an appropriate height, using calculations alone to determine length and strength of bungee cord required. After construction, compare elastic force and gravitational force on the object and use data to critique designs and propose changes for reconstruction.		Referring to a force vs. distance graph for a spring, interpret what the slope of the line represents (the spring constant, k, measured in N/m) and what the area under the line represents (the energy stored in the spring in joules).	Calculate the amount of energy stored in a spring that is stretched or compressed a certain distance. Referring to a force vs. distance graph, recognize that the force of a spring is changing as a spring oscillates.
P.E.3: Work and power			
	Plan an investigation into the rate at which work can be done by a student. Choose a task that does work on a system (e.g., running up a flight of stairs, raising a mass a certain distance) and measure the amount of work done by the student. Calculate each student's average power. Compare the values for the power and discuss possible reasons for differences obtained by similar tasks performed by different students.	Compare the use of a horizontal force, the use of a force angled above the horizontal, and a force at the same angle below the horizontal to determine which situation transfers the greatest total amount of energy to the system, both with and without friction present.	Solve problems determining the work done on an object by a force that acts at an angle to the displacement of the object. Use free body diagrams to solve for unknown forces. Solve problems determining the rate at which energy is added or removed from an object or a system of objects. Calculations should be limited to calculations involving the average power or the instantaneous power delivered to an object moving at a constant velocity.

Designing technological/engineering solutions using science concepts	Demonstrating science knowledge	Interpreting and communicating science concepts	Recalling accurate science
P.E.4: Conservation of energy			
Investigate a system that transforms mechanical energy to determine the average force of friction on the system and refine the system to improve its efficiency. Compare the efficiency of the system before and after student refinements.	Plan and conduct an investigation into an existing system that transforms mechanical energy from one form into another. Determine an unknown quantity or value associated with the system (e.g., spring constant of a rubber band, mass of an unknown object), and make measurements to calculate the unknown quantity. The value for the unknown quantity can be measured directly and compared to the experimentally determined value. Uncertainties in measurement and assumptions made by the students should be included. Design a method to predict where an object sliding down a ramp onto a flat surface will stop. Determine what data and calculations are needed to make accurate predictions. Collect the necessary data and make predictions for a variety of objects. Compare predictions to actual stopping points. Identify assumptions and other factors that account for discrepancies.	Solve problems using the principle of energy conservation to determine information about a system, such as the final velocity of a mass or the height an object will obtain. These problems should require the use of free body diagrams and the application of Newton's Laws to solve for unknown forces and may include multiple forms of energy transformations (e.g., initial elastic potential energy transformed into kinetic and gravitational potential energy). External forces, such as friction, should be included in problems.	Draw diagrams or graphs to represent energy flow into or out of a system.

Designing technological/engineering solutions using science concepts	Demonstrating science knowledge	Interpreting and communicating science concepts	Recalling accurate science
P.E.5: Nuclear energy			
		Predict the products of a given decay process or identify the decay process given the reactants and products.	From given reactions, calculate the masses of the reactants and the products to find the mass defect and hence the energy released in fission and fusion reactions.
Energy transformation system			
Design a system to complete a task, such as raising a mass a certain distance or compressing a spring or a spring-loaded lever. Use the smallest amount of initial energy to complete the task. Test and refine the design to minimize energy transferred out of the system.	Investigate each energy transformation in the system and take measurements to provide data to calculate the amount of energy present. Calculate energy before and after each transformation. Estimates for energy lost at each transformation should be recorded throughout the design process.	For each of the transformations in the system describe the type of energy and show how values for the energy present, lost and remaining at each step in the process were determined.	Identify the energy present before and after each transformation in the system and accurately calculate the amount of energy present at each step in the process.
Nuclear power plant			
Research consequences of using nuclear energy as a source of electrical energy production in a particular area. Choose to support or oppose the construction of a nuclear power plant in that area. Identify design changes that could be incorporated to a nuclear power plant that would make it more suitable for use in the area.		Research concepts such as nuclear waste storage, decay series, energy production from fossil fuels, and other related concepts to provide scientific evidence for the recommendation. Present and explain the scientific evidence.	Relate the scientific principles associated with electrical energy production through nuclear fission to the argument for or against construction of a nuclear power plant.

Physics continued

P.W: WAVES
P.W.1: Wave properties

- Conservation of energy
- Reflection
- Refraction
- Interference
- Diffraction

P.W.2: Light phenomena

- Ray diagrams (propagation of light)
- Law of reflection (equal angles)
- Snell's law
- Diffraction patterns
- Wave—particle duality of light
- Visible spectrum of color

CONTENT ELABORATION: WAVES

In earlier grades, the electromagnetic spectrum and basic properties (wavelength, frequency, amplitude) and behaviors of waves (absorption, reflection, transmission, refraction, interference, diffraction) were introduced. In this course, conservation of energy is applied to waves and the measurable properties of waves (wavelength, frequency, amplitude) are used to mathematically describe the behavior of waves (index of refraction, law of reflection, single- and double-slit diffraction). The wavelet model of wave propagation and interactions is not addressed in this course. Waves are explored experimentally in the laboratory. This may include, but is not limited to, water waves, waves in springs, the interaction of light with mirrors, lenses, barriers with one or two slits and diffraction gratings.

P.W.1: Wave properties
When a wave reaches a barrier or a new medium, a portion of its energy is reflected at the boundary and a portion of the energy passes into the new medium. Some of the energy that passes to the new medium may be absorbed by the medium and transformed to other forms of energy, usually thermal energy, and some continues as a wave in the new medium. Some of the energy may also be dissipated and no longer be part of the wave since it has been transformed into thermal energy or transferred out of the system due to the interaction of the system with surrounding objects. Usually all of these processes occur simultaneously, but the total amount of energy must remain constant.

When waves bounce off barriers (reflection), the angle at which a wave approaches the barrier (angle of incidence) equals the angle at which the wave reflects off the barrier (angle of reflection). When a wave travels from a two-dimensional (e.g., surface water, seismic waves) or three-dimensional (e.g., sound, electromagnetic waves) medium into another medium in which the wave travels at a different speed, both the speed and the wavelength of the transferred wave change. Depending on the angle between the wave and the boundary, the direction of the wave can also change, resulting in refraction. The amount of bending of waves around barriers or small openings (diffraction) increases with decreasing wavelength. When the wavelength is smaller than the obstacle or opening, no noticeable diffraction occurs. Standing waves and interference patterns between two sources are included in this topic. As waves pass through a single or double slit, diffraction patterns are created with alternating lines of constructive and destructive interference. The diffraction patterns demonstrate predictable changes as the width of the slit(s), spacing between the slits and/or the wavelength of waves passing through the slits changes.

P.W.2: Light phenomena
The path of light waves can be represented with ray diagrams to show reflection and refraction through converging lenses, diverging lenses and plane mirrors. Since light is a wave, the law of reflection applies. Snell's law, $n_1\sin\theta_1 = n_2\sin\theta_2$, quantifies refraction in which n is the index of refraction of the medium and θ is the angle the wave enters or leaves the medium as measured from the normal line. The index of refraction of a material can be calculated by the equation $n = c/v$,

where n is the index of refraction of a material, v is the speed of light through the material, and c is the speed of light in a vacuum. Diffraction patterns of light are addressed, including patterns from diffraction gratings.

There are two models of how radiant energy travels through space at the speed of light. One model is that the radiation travels in discrete packets of energy called photons that are continuously emitted from an object in all directions. The energy of these photons is directly proportional to the frequency of the electromagnetic radiation. This particle-like model is called the photon model of light energy transfer. A second model is that radiant energy travels like a wave that spreads out in all directions from a source. This wave-like model is called the electromagnetic wave model of light energy transfer. Strong scientific evidence supports both the particle-like model and wave-like model. Depending on the problem scientists are trying to solve, either the particle-like model or the wave-like model of radiant energy transfer is used. Students are not required to know the details of the evidence that supports either model at this level.

Humans can only perceive a very narrow portion of the electromagnetic spectrum. Radiant energy from the sun or a light bulb filament is a mixture of all the colors of light (visible light spectrum). The different colors correspond to different radiant energies. When white light hits an object, the pigments in the object reflect one or more colors in all directions and absorb the other colors.

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Designing technological/engineering solutions using science concepts	Demonstrating science knowledge	Interpreting and communicating science concepts	Recalling accurate science
P.W.1: Wave properties			
Design a parabolic cooker using principles of ray reflection to design the apparatus. After construction and testing, evaluate the success of the design and examine where performance departs from plan.	Plan and conduct an investigation of wave diffraction. Use single or double slit diffraction to experimentally investigate light waves.	Solve problems related to constructive and destructive interference between two waves. Graphically represent the locations where constructive and destructive interference are occurring based on the path of each wave. Calculate the distances mathematically.	Solve problems involving standing waves on strings and in open and closed pipes. Explain the conditions required for standing waves to occur. Calculate the frequency of a standing wave of a given harmonic.

Designing technological/engineering solutions using science concepts	Demonstrating science knowledge	Interpreting and communicating science concepts	Recalling accurate science
P.W.2: Light phenomena			
	Investigate the image formed by a lens. Experimentally determine the focal length of a lens. Investigate the images formed by the lens using a light source placed different distances from the lens (e.g., inside the focal length, outside the focal length, twice the focal length). Experimentally determine the wavelength of a laser using diffraction through a single slit, a double slit, or a diffraction grating.	Draw ray diagrams for light reflecting off plane, concave and convex mirrors to determine the location of the image formed. Describe the properties of the image that is formed using diagrams and calculations. Draw ray diagrams for light refracting through a boundary of two translucent media. Use the diagrams and calculations to describe the properties of the image. Compare images for converging and diverging lenses.	Solve problems to determine the location and properties of an image formed by various mirrors and lenses. Compare the wave model of light to the particle model. Solve refraction problems using Snell's Law to find the index of refraction for a medium.
Laser maze			
Design a laser maze. Present mazes and challenge other students to solve them.	Use mirrors to direct a beam of light or a laser around obstacles. Use calculations to determine placement of mirrors to hit a target. Diagram the placement of mirrors to be used and test their placement. Refine and update the path diagram as needed.		Accurately apply the law of reflection to correctly predict the path of light reflecting from a mirror.
Index of refraction			
	Plan and conduct an investigation to determine the index of refraction of a substance. Determine a procedure to collect sufficient and relevant data. Use the data to calculate the index of refraction. Check the calculated value against the theoretical index of refraction (if known).		Select relevant data to collect in order to determine the index of refraction of a substance.

Physics continued

P.EM: ELECTRICITY AND MAGNETISM
P.EM.1: Charging objects (friction, contact and induction)
P.EM.2: Coulomb's law
P.EM.3: Electric fields and electric potential energy
P.EM.4: DC circuits

- Ohm's law
- Series circuits
- Parallel circuits
- Mixed circuits
- Applying conservation of charge and energy (junction and loop rules)

P.EM.5: Magnetic fields
P.EM.6: Electromagnetic interactions

CONTENT ELABORATION: ELECTRICITY AND MAGNETISM

In earlier grades, electric and magnetic potential energy were treated conceptually. The relative number of subatomic particles present in charged and neutral objects, attraction and repulsion between electrical charges and attraction and repulsion between magnetic poles were explored. The concept of fields to conceptually explain forces at a distance was introduced and the concepts of current, potential difference (voltage) and resistance were used to explain circuits. Additionally, connections between electricity and magnetism were made as observed in electromagnets, motors and generators. In this course, the details of electrical and magnetic forces and energy are further explored and can be used as additional examples of energy and forces affecting motion.

P.EM.1: Charging objects (friction, contact and induction)
For all methods of charging neutral objects, one object/system ends up with a surplus of positive charge and the other object/system ends up with the same amount of surplus of negative charge. This supports the law of conservation of charge that states that charges cannot be created or destroyed. Tracing the movement of electrons for each step in different ways of charging objects (rubbing together two neutral materials to charge by friction; charging by contact and by induction) can explain the differences between them. When an electrical conductor is charged, the charge "spreads out" over the surface. When an electrical insulator is charged, the excess or deficit of electrons on the surface is localized to a small area of the insulator.

There can be electrical interactions between charged and neutral objects. Metal conductors have a lattice of fixed positively charged metal ions surrounded by a "sea" of negatively charged electrons that flow freely within the lattice. If the neutral object is a metal conductor, the free electrons in the metal are attracted toward or repelled away from the charged object. As a result, one side of the conductor has an excess of electrons and the opposite side has an electron deficit. This separation of charges on the neutral conductor can result in a net attractive force between the neutral conductor and the charged object. When a charged object is near a neutral insulator, the electron cloud of each insulator atom shifts position slightly so it is no longer centered on the nucleus. The separation of charge is very small, much less than the diameter of the atom. Still, this small separation of charges for billions of neutral insulator particles can result in a net attractive force between the neutral insulator and the charged object.

P.EM.2: Coulomb's law
Two charged objects, which are small compared to the distance between them, can be modeled as point charges. The forces between point charges are proportional to the product of the charges and inversely proportional to the square of the distance between the point charges [$F_e = (k_e\, q_1\, q_2)/r^2$]. Problems may be solved for the electric force, the amount of charge on one of the two objects or the distance between the two objects. Problems may also be solved for three- or four-point charges in a line if the vector sum of the forces is zero. This can be explored experimentally through computer simulations. Electric forces acting within and between atoms are vastly stronger than the gravitational forces acting between the atoms. However, gravitational forces are only attractive and can accumulate in massive objects to produce a large and noticeable effect. Conversely, electric forces are both attractive and repulsive and tend to cancel each other out.

P.EM.3: Electric fields and electric potential energy
The strength of the electrical field of a charged object at a certain location is given by the electric force per unit charge experienced by another charged object placed at that location, $E = F_e/q$. This equation can be used to calculate the electric field strength, the electric force or the electric charge. However, the electric field is always there, even if the object is not interacting with anything else. The direction of the electric field at a certain location is parallel to the direction of the electrical force on a positively charged object at that location. The electric field caused by a collection of charges is equal to the vector sum of the electric fields caused by the individual charges (superposition of charge). This topic can be explored experimentally through computer simulations. Greater electric field strengths result in larger electric forces on electrically charged objects placed in the field. Electric fields can be represented by field diagrams obtained by plotting field arrows at a series of locations. Electric field diagrams for a dipole, two-point charges (both positive, both negative, one positive and one negative) and parallel capacitor plates are included. Field line diagrams are excluded from this course.

The concept of electric potential energy can be understood from the perspective of an electric field. When two attracting or repelling charges interact, the kinetic energies of both objects change but neither is acting as the energy source or the receiver. Instead, the energy is transferred into or out of the electric field around the system as electric potential energy. A single charge does not have electric potential energy. Only the system of attracting or repelling charges can have electric potential energy. When the distance between the attracting or repelling charges changes, there is a change in the electric potential energy of the system. When two opposite charges are moved farther apart or two like charges are moved close together, energy is transferred into the field as electric potential energy. When two opposite charges are moved closer together or two like charges are moved farther apart, electric potential energy is transferred out of the field. When a charge is transferred from one object to another, work is required to separate the positive and negative charges. If there is no change in kinetic energy and no energy is transferred out of the system, the work increases the electric potential energy of the system.

P.EM.4: DC circuits
Once a circuit is switched on, the current and potential difference are experienced almost instantaneously in all parts of the circuit even though the electrons are only moving at speeds of a few centimeters per hour in a current-carrying wire. It is the electric field that travels instantaneously through all parts of the circuit, moving the electrons that are already present in the wire. Since electrical charge is conserved, in a closed system such as a circuit, the current flowing into a branch point junction must equal the total current flowing out of the junction (junction rule).

Resistance is measured in ohms and has different cumulative effects when added to series and parallel circuits. The potential difference, or voltage (ΔV), across an energy source is the potential energy difference (ΔE) supplied by the energy source per unit charge (q) ($\Delta V = \Delta E/q$). The electric potential difference across a resistor is the product of the current and the resistance ($\Delta V = I R$). In this course, only ohmic resistors will be studied. When potential difference vs. current is plotted for an ohmic resistor, the graph will be a straight line and the value of the slope will be the resistance. Since energy is conserved for any closed loop, the energy put into the system by the battery must equal the energy that is transformed by the resistors. For circuits with resistors in series, this means that $V_{battery} = \Delta V_1 + \Delta V_2 + \Delta V_3 + \ldots$. The rate of energy transfer (power) across each resistor is equal to the product of the current through and the voltage drop across each resistor ($P = \Delta V I$) and $P_{battery} = I \Delta V_1 + I \Delta V_2 + I \Delta V_3 + \ldots = I\Delta V_{battery}$. Equations should be understood conceptually and used to calculate the current or potential difference at different locations of a parallel, series or mixed circuit. However, the names of the laws (e.g., Ohm's law,) are not the focus. Opportunities for measuring and analyzing current, voltage and resistance in parallel, series and mixed circuits should be provided. This can be done with traditional laboratory equipment and through computer simulations.

P.EM.5: Magnetic fields
The direction of the magnetic field at any point in space is the equilibrium direction of the north end of a compass placed at that point. Magnetic fields can be represented by field diagrams obtained by plotting field arrows at a series of locations. Field line diagrams are excluded from this course. Calculations for the magnetic field strength are not required at this grade level, but it is important to note that greater magnetic fields result in larger magnetic forces on magnetic objects or moving charges placed in the field. In this course, the concept of magnetic fields will not be addressed mathematically.

P.EM.6: Electromagnetic interactions
Magnetic forces are very closely related to electric forces. Even though they appear to be distinct from each other, they are thought of as different aspects of a single electromagnetic force. A flow of charged particles (including an electric current) creates a magnetic field around the moving particles or the current carrying wire. Motion in a nearby magnet is evidence of this field. Electric currents in Earth's interior give Earth an extensive magnetic field, which is detected from the orientation of compass needles. The motion of electrically charged particles in atoms produces magnetic fields. Usually these magnetic fields in an atom are randomly oriented and therefore cancel each other out. In magnetic materials, the subatomic magnetic fields are aligned, resulting in a macroscopic magnetic field.

A moving charged particle interacts with a magnetic field. The magnetic force that acts on a moving charged particle in a magnetic field is perpendicular to both the magnetic field and to the direction of motion of the charged particle. The magnitude of the magnetic force depends on the speed of the moving particle, the magnitude of the charge of the particle, the strength of the magnetic field, and the angle between the velocity and the magnetic field. There is no magnetic force on a particle moving parallel to the magnetic field. Calculations of the magnetic force acting on moving particles are not required at this grade level. Moving charged particles in magnetic fields typically follow spiral trajectories since the force is perpendicular to the motion.

A changing magnetic field creates an electric field. If a closed conducting path, such as a wire, is in the vicinity of a changing magnetic field, a current may flow through the wire. A changing magnetic field can be created in a closed loop of wire if the magnet and the wire move relative to one another. This can cause a current to be induced in the wire. The strength of the current depends upon the strength of the magnetic field, the velocity of the relative motion and the number of loops in the wire. Calculations for current induced in a wire or coil of wire is not required at this level. A changing electric field creates a magnetic field and a changing magnetic field creates an electric field. Thus, radiant energy travels in electromagnetic waves produced by changing the motion of charges or by changing magnetic fields. Therefore, electromagnetic radiation is a pattern of changing electric and magnetic fields that travel at the speed of light.

The interplay of electric and magnetic forces is the basis for many modern technologies that convert mechanical energy to electrical energy (generators) or electrical energy to mechanical energy (electric motors) as well as devices that produce or receive electromagnetic waves. Therefore, coils of wire and magnets are found in many electronic devices including speakers, microphones, generators and electric motors. The interactions between electricity and magnetism should be explored in the laboratory setting. Experiments with the inner workings of motors, generators and electromagnets can be conducted. Current technologies using these principles can be explored.

EXPECTATIONS FOR LEARNING

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Designing technological/engineering solutions using science concepts	Demonstrating science knowledge	Interpreting and communicating science concepts	Recalling accurate science
P.EM.1: Charging objects			
Investigate alternative solutions to reduce static electricity in clothing tossed in a dryer.		Describe and draw diagrams to explain the process of polarization and the attraction of a charged object and a neutral object in terms of the movement of electrons (e.g., balloon sticking to a wall, balance a meter stick on a golf ball and cause rotation with a charged balloon).	State the differences between conductors and insulators in terms of electron movement through the materials. Describe how electrons move in an electroscope and how the electroscope indicates charge. Represent the methods of charging in a graphic organizer, chart or drawing.
P.EM.2: Coulomb's law			
	Investigate, in the lab or with a computer simulation, electrostatic repulsion and attraction. Devise two procedures to investigate the effects charge and distance have on the magnitude and direction of the force.		Cite the similarities and differences between the equation for gravitational and for electrical force (Coulomb's Law). Solve problems using Coulomb's Law to determine the net force on a charge due to two charges that are not collinear. Explain the relationship between force and distance using a graphical representation.

Designing technological/engineering solutions using science concepts	Demonstrating science knowledge	Interpreting and communicating science concepts	Recalling accurate science
P.EM.3: Electric fields and electric potential energy			
	Use a computer simulation to investigate the effect of charges on the electric field at a point in space and the effect of an external field on a charged particle. Determine the relationships.	Compare Earth's gravitational field with an electric field in terms of when potential energy is increasing and decreasing. Explore the Millikan Oil Drop Experiment. Apply the idea of equilibrium to electrical and gravitational forces.	Solve problems about the force on a charged particle in a constant electric field. Use Newton's Laws, kinematic equations and equations for work and kinetic energy to calculate the acceleration of the particle, the final velocity of the particle and the change in energy of the particle. Describe the relationship between potential energy and electric fields. Draw the field lines for a positive charge, a negative charge, a dipole and two parallel plates of charge.
P.EM.4: DC circuits			
	Use a source of constant voltage to plan and conduct an investigation to determine the relationship between the current and the resistance in a simple DC circuit. Analyze the results mathematically and graphically. Form a claim about the relationship between the current and resistance and support the claim with evidence from the investigation.	Solve problems involving complex circuits with arrangements of resistors in both parallel and series to determine the equivalent resistance of the entire circuit as well as the current, the potential difference, or rate of energy dissipated in individual resistors in the circuit. Compare different types of string lights to explore what type of circuits are involved, how blinker bulbs work and how bulbs that are unlit complete a circuit.	Solve problems involving resistors in series and in parallel to determine the current, potential difference, or rate of energy dissipated in individual resistors in the circuit.
P.EM.5: Magnetic fields			
		Use a small compass to map the magnetic field around a bar magnet, horseshoe magnet and circular magnet. Explain why the shape of the fields is different.	

Designing technological/engineering solutions using science concepts	Demonstrating science knowledge	Interpreting and communicating science concepts	Recalling accurate science
P.EM.6: Electromagnetic interactions			
Design and build a generator that will convert mechanical energy into electrical energy and light three flashlight bulbs. Draw a labeled design plan and write a paper explaining in detail, and in terms of electromagnetic induction, how the details of the design allow the generator to work. Test the generator in an electric circuit. If it cannot supply the electrical energy to light three flashlight bulbs in a series, redesign the generator. Design an electromagnetic motor with a limitation on the amount of materials used in construction. Test the design and redesign the motor based on the findings from the testing process.	Investigate the production of a magnetic field by a current carrying wire. Develop and test a hypothesis about the relationship between an independent variable (e.g., amount of current) and the strength of the generated magnetic field. Using a galvanometer connected to a solenoid and a magnet, design and conduct an investigation to determine when current is induced and what variables affect the strength of the current.	Apply Newton's Laws to predict the shape of the path followed by a charged particle moving in a magnetic field. Draw the path and predict the shape for heavier and lighter particles as well as particles with different charge. Predict the direction of a magnetic field in a current carrying wire. Use a compass and wire demonstration device to check the prediction.	State the factors that affect the force on a moving charged particle in a magnetic field and determine the path taken by the charged particle. Use the right-hand rules to determine the direction of a charged particle in a magnetic field. Discuss the benefits and origins of Earth's magnetic field.
Determining unknown resistance			
	Plan and conduct an investigation to determine the resistance of an unknown resistor. Unanticipated effects on measurements should be accounted for (e.g., internal resistance of the battery or power supply) and assumptions made should be explained (e.g., assuming the resistance of the wires can be ignored or that a voltmeter has an infinite impedance). Experimental design should be checked for safety before conducting the experiment.	Draw a circuit diagram of the experimental design before conducting the experiment, labeling the elements of the circuit.	Calculate the resistance of the resistor, using either an average of the data or by graphing the data and analyzing it.