Richmond Public Schools
Department of Curriculum and Instruction
Curriculum Pacing and Resource Guide

Course Title/ Course #: Physics / 2900

Start day: 1

Meetings: 180 days

Course Description

The Physics standards emphasize a more complex understanding of experimentation, the analysis of data, and the use of reasoning and logic to evaluate evidence. The use of mathematics, including algebra and trigonometry, is important, but conceptual understanding of physical systems remains a primary concern. Students build on basic physical science principles by exploring in-depth the nature and characteristics of energy and its dynamic interaction with matter. Key areas covered by the standards include force and motion, energy transformations, wave phenomena and the electromagnetic spectrum, electricity, fields, and non-Newtonian physics. The standards stress the practical application of physics in other areas of science, technology, engineering, and mathematics. The effects of physics on our world are investigated through the study of critical, contemporary global topics.

Pacing Resources Assessments MP1

Time Frame	Standards of Learning	Units/ Topics/ Concepts	Resources	Assessments
1 week	**PH.1a-g**	**Scientific Investigation**	Gizmos • Free Fall Tower • Pendulum Clock Physics Science Fair Project Ideas (Sciencebuddies.com) Physics Science Fair Project Ideas (education.com) Science Fair Project Guide	Pretest: Physics Baseline Cornerstone Assessment (LENS Project) PALS – Performance Assessments • Friction Force • Speed and Collisions • Electric Energy • A Cut Above the Rest • Radioactive Decay • Electric Circuits Throughout the course, students should be

				participating in every step of the "scientific process," including: • proposing scientific questions hypotheses • designing experiments • making measurements using appropriate tools and technology safely • determining and appropriately communicating measurement accuracy and precision • drawing reasonable conclusions from analyzed data • Using simulations when necessary to model physical systems Practices for Scientific Investigation: Kindergarten-Physics Progression Students use actual scientific tools (balances, spring scales, graduated cylinders, meter sticks, etc.) to make scientific measurements of "known" quantities (i.e. pre-measured by the teacher). Students are expected to record measurements with appropriate significant figures, complete calculations using appropriate significant figures, and complete error analysis when needed.
1 week	**PH.1a-g**; **PH.3a-e**	**Scientific Reasoning and Logic**	NOVA ScienceNOW: Newton's Dark Secrets (running time: 51:15) • Newton's Dark Secrets Classroom Guide NOVA ScienceNOW: Einstein's Big Idea (running time: 1:48:58) • Einstein's Big Idea Classroom Guide NOVA ScienceNOW: The Fabric of the Cosmos (4 full episodes, each ~50 min.)	Students may complete a research paper on a specific paradigm shift in physics, including social as well as scientific context and implications. Students may choose a particular physicist, historical or modern, and complete a biographical project on that person. Given a series of hypothetical or actual ideas or belief systems, students can be asked to identify whether each fits the "nature of science" or not.

			• Fabric of the Cosmos Worksheets NOVA ScienceNOW: The Elegant Universe (3 full episodes, each ~50 min.) • The Elegant Universe Classroom Guide NOVA ScienceNOW: Big Bang Machine (running time: 53:10)	If not, students can explain what aspect(s) of the nature of science is not adhered to by that particular idea. Given any of the NOVA ScienceNOW videos listed at left, students may write a paper or prepare a presentation why each embodies (or fails to embody) each aspect of the nature of science.

3 weeks	**PH. 1a-g; PH.2a-d; PH.5a**	**Data Analysis/ Graphing; Linear Motion**	Gizmos • Unit Conversions • Unit Conversions 2 (Sci Notation and Sig Figs) • Slope - Activity B • Correlation • Distance-Time Graphs • Distance-Time and Velocity-Time Graphs Activities and Labs • Motion on a Ramp • Seeing Motion PhET Simulations • The Moving Man Physics Lab Online: Introductory Mathematics (examples, lab exercises, practice problems, and worksheets) Physics Lab Online: Kinematics – Graphs Physics Lab Online: Kinematics - Equations The Physics Classroom • Habits of an Effective Problem Solver • Tutorial: 1-D Kinematics • Interactives: 1-D Kinematics • Problem Set: 1-D Kinematics Khan Academy: Displacement, Velocity, and Time	Use http://www.problem-attic.com/ to create a multiple choice or free response quiz or test. Given a displacement-time or velocity-time graph, students write a story that accurately reflects the motion shown in the graph. Alternatively, they may create a motion-time graph based on a provided story. Students may complete a graph-matching exercise using motion detectors and probeware, in which they must move in a certain way in order to reproduce a provided motion graph. Given a particular measurement and necessary equivalencies, students can use dimensional analysis methods to convert it to another unit. Skills may include: • metric-to-metric conversions • standard-to-metric conversions • derived-to-base units Students can use manual or digital methods to determine a best-fit line from hypothetical or actual data points, and then use the equation for this line to make predictions. Solve problems involving displacement, velocity, acceleration, and time in one dimension.
2 weeks	**PH. 1 a-g; PH.4a-b; PH.5a**	**Application/ Acceleration, Velocity, Displacement, Time**	2 weeks	PH. 1 a-g; PH.2e

			Gizmos • Vectors • Adding Vectors Physics Lab Online: Vectors The Physics Classroom • Tutorial: Vectors – Motion and Forces in Two Dimensions • Interactives: Vectors and Projectiles • Problem Set: Vectors and Projectiles • Problem Set: Vectors and Forces in 2D Khan Academy: Two-Dimensional Motion (1st video)	Use http://www.problem-attic.com/ to create a multiple choice or free response quiz or test. Students should be able to demonstrate the following skills with fluency: • add/subtract vectors in one dimension • resolve a vector into its horizontal and vertical components • combine horizontal and vertical vectors into one resultant vector Given a story, students may represent the motion described in the story using vectors. Alternatively, students may write a story based on a series of motion vectors. Resolve vector diagrams involving displacement and velocity into their components along perpendicular axes.

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Pacing Resources Assessments MP2				
Time Frame	**Standards of Learning**	**Units/ Topics/ Concepts**	**Resources**	**Assessments**
2 weeks	**PH. 1 a-g; PH.5b-c**	**Circular Motion/ Projectile Motion**	Gizmos • Uniform Circular Motion • Shoot the Monkey • Golf Range PhET Simulations • Gravity and Orbits • Ladybug Revolution • Projectile Motion • Ladybug Motion 2D • Motion in 2D Physics Lab Online: Projectiles Physics Lab Online: Uniform Circular Motion The Physics Classroom: • Tutorial: Circular Motion and Satellite Motion • Tutorial: Vectors – Motion and Forces in Two Dimensions • Interactives: Vectors and Projectiles • Interactives: Circular and Satellite Motion • Problem Set: Vectors and Projectiles • Problem Set: Circular Motion and Gravitation Khan Academy: Two-Dimensional Motion Khan Academy: Optimal Angle for a Projectile Khan Academy: Centripetal Acceleration	Use http://www.problem-attic.com/ to create a multiple choice or free response quiz or test. Students may explain, verbally or in writing, the role of centripetal force and acceleration in circular motion, including an explanation of the invalidity of “centrifugal” forces. Students may explain, verbally or in writing, the independence of horizontal and vertical components of motion in a projectile’s trajectory. After students have an understanding of Newton’s Laws of Motion, students may explain how these laws, especially the 1st and 2nd, apply to circular and/or projectile motion. Students may complete poster-size diagram of circular motion, including labels for centripetal force, centripetal acceleration, and tangential velocity vectors, radius, the trajectory an object would take if the centripetal force disappeared, and key equations. Students may complete a poster-size diagram of projectile motion, including labels for the apex, range, initial velocity vector components, gravity, and velocity

				vectors during flight. Key questions may also be included. Solve problems involving displacement, velocity, acceleration, and time in one and two dimensions (only constant acceleration). Draw vector diagrams of a projectile's motion. Find range, trajectory, height of the projectile, and time of flight (uniform gravitational field, no air resistance). Distinguish between centripetal and centrifugal force. Solve problems related to free-falling objects, including 2-D motion. Describe the forces involved in circular motion.
3 weeks	**PH. 1 a-g; PH.5d-f**	**Newton's Laws/ Gravitation/ Planetary Motion**	Gizmos • Force and Fan Carts • Fan Cart Physics • Orbital Motion - Kepler's Laws • Gravitational Force • Gravity Pitch • Weight and Mass The Concord Consortium • Forces - Equal and Opposite PhET Simulations • Forces and Motion: Basics • Forces and Motion • Gravity and Orbits • My Solar System • Forces in 1 Dimension	Use http://www.problem-attic.com/ to create a multiple choice or free response quiz or test. PALS – Performance Assessments • Friction Force In writing, verbally, and/or using vector diagrams, students may explain qualitatively how forces produce the motion of familiar situations or videos of less familiar ones (such as the launching of a rocket). Solve problems involving force (F), mass (m), and acceleration (a).

			• Lunar Lander • Gravity Force Lab • Friction Physics Lab Online: Dynamics Physics Lab Online: Gravitation The Physics Classroom • Tutorial: Newton's Laws • Interactives: Newton's Laws • Problem Set: Vectors and Forces in 2D • Problem Set: Newton's Laws of Motion • Problem Set: Circular Motion and Gravitation Khan Academy: Forces and Newton's Laws of Motion Khan Academy: Newton's Law of Gravitation	Solve problems using Newton's Law of Universal Gravitation. Solve problems involving multiple forces, using free-body diagrams.
2 weeks	**PH. 1 a-g; PH.5g**	**Energy, Work, Power**	Gizmos • Pulley Lab • Energy Conversion in a System PhET Simulations • Energy Skate Park: Basics Physics Lab Online: Work and Energy The Physics Classroom • Tutorial: Work, Energy, and Power • Interactives: Work and Energy Khan Academy: Work and Energy	Use http://www.problem-attic.com/ to create a multiple choice or free response quiz or test. In groups, students can complete (and compete in) the Strongman Lab to determine how to accurately measure the force required, work performed, and power generated in a variety of physical activities. Editable versions of the lab handout may be found online by Googling "Strongman Lab." Solve problems involving mechanical work, power, and energy.

1 week	**PH.1-5**	**Review and Semester Exam**	Bozeman Science Review Videos (Units 1 – 5)	Use http://www.problem-attic.com/ to create a multiple choice or free response semester exam. To demonstrate student growth, students may once again complete the Physics Baseline Cornerstone Assessment (LENS Project)

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Pacing Resources Assessments MP3				
Time Frame	**Standards of Learning**	**Units/ Topics/ Concepts**	**Resources**	**Assessments**
3 weeks	**PH. 1 a-g; PH.6a-c; PH.7a-b**	**Energy (PE and KE, Momentum/ Collisions), Energy Conversion to Work Application**	Gizmos • Potential Energy on Shelves • Roller Coaster Physics • Inclined Plane - Sliding Objects • Air Track • Pulley Lab • Energy Conversion in a System • Inclined Plane - Simple Machine The Concord Consortium • Heat and Light from Electricity • Elastic Collisions • Gravity Rules in the Skatepark PhET Simulations • Energy Skate Park • Energy Forms and Changes Physics Lab Online: Momentum The Physics Classroom • Tutorial: Momentum and its Conservation • Tutorial: Work, Energy, and Power • Interactives: Momentum and Collisions • Interactives: Work and Energy NOVA ScienceNOW: Einstein's Big Idea (running time: 1:48:58) • Einstein's Big Idea Classroom Guide Khan Academy: Work and Energy Khan Academy: Momentum	Use http://www.problem-attic.com/ to create a multiple choice or free response quiz or test. PALS – Performance Assessments • Speed and Collisions • A Cut Above the Rest Solve problems involving mechanical work, power, and energy. Provide and explain examples of how energy can be converted from potential energy to kinetic energy and the reverse, such as in the case of roller coasters or bouncing objects. Provide and explain examples showing linear momentum is the product of mass and velocity, and is conserved in a closed system, including during elastic and inelastic collisions. Students may explain the significance of Einstein's famous $E=mc^2$ equation qualitatively, as well as use it to calculate the energy contained in any object with a known mass. Solve elastic and inelastic collision problems. Illustrate that energy can be transformed from one form to another, using examples from everyday life and technology. For example, students may write a paragraph, a script, or a poem describing the energy forms and transformations taking place in common objects, such as a flashlight.

				Calculate efficiency by identifying the useful energy in a process. For example, students may directly measure the energy input and output of various types of lightbulbs using probeware (or use appropriate specifications from the packaging) to compare efficiencies. Qualitatively identify the various energy transformations in simple demonstrations.
3 weeks	**PH. 1 a-g; PH.8a-c**	**Waves (Light and Sound), Characteristics & Fundamentals**	Gizmos • Pendulum Clock • Energy of a Pendulum • Period of a Pendulum • Longitudinal Waves • Ripple Tank • Laser Reflection • Sound Beats and Sine Waves • Simple Harmonic Motion The Concord Consortium • Complex Sounds and Instruments (link to application is near the bottom of the right-hand list of activities) • Ripple Tank • The Shape of Sound Waves (link to application is at the bottom of the right-hand list of activities) PhET Simulations • Pendulum Lab • Wave Interference • Sound • Refraction • Wave on a String Physics Lab Online: Waves and Sound	Use http://www.problem-attic.com/ to create a multiple choice or free response quiz or test. Identify examples of and differentiate between transverse and longitudinal waves, using simulations and/or models. Illustrate period, wavelength, and amplitude on a graphic representation of a wave, possibly on a poster or flyer. Solve problems involving frequency, period, wavelength, and velocity. Distinguish between superimposed waves that are in-phase and those that are out-of-phase. Graphically illustrate reflection and refraction of a wave when it encounters a change in medium or a boundary. Graphically illustrate constructive and destructive interference. Identify a standing wave, using a string.

			The Physics Classroom • Tutorial: Waves • Tutorial: Sound Waves and Music • Interactives: Waves and Sound • Problem Set: Wave Basics • Problem Set: Sound and Music Khan Academy: Harmonic Motion Khan Academy: Introduction to Waves Khan Academy: Sound	
2 weeks	**PH. 1 a-g; PH.9a-c**	**Light Waves/ Frequencies and Wavelengths**	Gizmos • Doppler Shift • Herschel Experiment • Photoelectric Effect The Concord Consortium • Interference with Light PhET Simulations • Radio Waves & Electromagnetic Fields • Microwaves Physics Lab Online: Interference and Diffraction The Physics Classroom • Tutorial: Light Waves and Color • Problem Set: Light Waves Khan Academy: The Doppler Effect Khan Academy: Light Waves	Use http://www.problem-attic.com/ to create a multiple choice or free response quiz or test. Demonstrate (using probeware) and describe (in writing) the change in observed frequency of waves due to the motion of a source or a receiver (the Doppler effect). Students may complete research projects on specific technologies that use one or more waves in the electromagnetic spectrum, explaining how waves with specific frequencies/wavelengths are used in the technology. Students may produce a poster or other display of the electromagnetic spectrum with common human applications mapped out along the spectrum and specific types of waves identified.

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Pacing Resources Assessments MP4				
Time Frame	**Standards of Learning**	**Units/ Topics/ Concepts**	**Resources**	**Assessments**
2 weeks	**PH. 1 a-g; PH.10a-b**	**Forces/ Coulomb's Law/Newton's Universal Gravitation, Technological Applications**	Gizmos • Gravitational Force • Coulomb Force (Static) • Pith Ball Lab • Electromagnetic Induction • Magnetic Induction The Concord Consortium • Electrostatics PhET Simulations • My Solar System • Gravity Force Lab • Faraday's Electromagnetic Lab • Balloons and Static Electricity • Magnets and Electromagnets • Generator • Faraday's Law • Simplified MRI Physics Lab Online: Gravitation Physics Lab Online: Electrostatics Physics Lab Online: Induction The Physics Classroom • Tutorial: Static Electricity • Tutorial: Circular Motion and Satellite Motion • Interactives: Static Electricity • Interactives: Circular and Satellite Motion • Problem Set: Circular Motion and Gravitation • Problem Set: Static Electricity	Use http://www.problem-attic.com/ to create a multiple choice or free response quiz or test. Solve problems using Newton's Law of Universal Gravitation. Describe the attractive or repulsive forces between objects relative to their forces and distance between them (Coulomb's law). Describe the attraction of particles (Newton's Law of Universal Gravitation). Describe the effect of a uniform magnetic field on a moving electrical charge (magnetic induction). Students may explain graphically or in writing the basic principles behind a motor and/or an electric generator.

			Khan Academy: Newton's Law of Gravitation Khan Academy: Charge and Electric Field Khan Academy: Magnetism	
2 weeks	**PH. 1 a-g; PH.11a-d**	**Circuits/ Ohm's Law, Series and Parallel Circuits, AC and DC**	Gizmos • Circuits • Advanced Circuits • Circuit Builder The Concord Consortium • Current in a Simple Circuit • Voltage in a Simple Circuit PhET Simulations • Circuit Construction Kit (DC Only) • Circuit Construction Kit (AC & DC) • Ohm's Law • Battery-Resistor Circuit • Battery Voltage Physics Lab Online: DC Circuits The Physics Classroom • Tutorial: Current Electricity • Interactives: Electric Circuits • Problem Set: Electric Circuits Khan Academy: Circuits	Use http://www.problem-attic.com/ to create a multiple choice or free response quiz or test. PALS – Performance Assessments • Electric Energy • Electric Circuits Recognize a series and a parallel circuit and assemble simple circuits composed of batteries and resistors in series and in parallel. Apply Ohm's law to a series and a parallel circuit and solve simple circuits using Ohm's law. Calculate the dissipated power of a circuit element. Recognize that DC power is supplied by batteries and that AC power is supplied by electrical wall sockets.
2 weeks	**PH. 1 a-g; PH.12a-j**	**Nanotechnology & Modern Physics**	Gizmos • Photoelectric Effect • Nuclear Decay PhET Simulations • Nuclear Fission • Photoelectric Effect • Quantum Wave Interference	Use http://www.problem-attic.com/ to create a multiple choice or free response quiz or test. Explain that the motion of objects traveling near or approaching the speed of light does not follow Newtonian mechanics but must be

			• Blackbody Spectrum Physics Lab Online: Modern Physics NOVA ScienceNOW: The Fabric of the Cosmos (4 full episodes, each ~50 min.) • Fabric of the Cosmos Worksheets NOVA ScienceNOW: The Elegant Universe (3 full episodes, each ~50 min.) • The Elegant Universe Classroom Guide NOVA ScienceNOW: Big Bang Machine (running time: 53:10) National Nanotechnology Infrastructure Newtork: Classroom Activities and Curriculum Materials	treated within the theory of relativity. Describe the relationship between the Big Bang theory timeline and particle physics. Describe the structure of the atomic nucleus, including quarks. Provide examples of technologies used to explore the nanoscale through research projects and presentations. PALS – Performance Assessments • Radioactive Decay
2 weeks	**PH.1-12**	**Review and Final Exam**	Bozeman Science Review Videos (Units 1 – 10)	60 Questions Physics Students Should Know (Conceptual, by Paul Hewitt)

Science Standards of Learning

Curriculum Framework 2010

Physics

Board of Education
Commonwealth of Virginia

Virginia Department of Education
P.O. Box 2120
Richmond, Virginia 23218-2120
http://www.doe.virginia.gov

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The 2010 *Science Curriculum Framework* can be found in PDF and Microsoft Word file formats on the Virginia Department of Education's Web site at http://www.doe.virginia.gov.

Virginia *Science Standards of Learning* Curriculum Framework 2010
Introduction

The *Science Standards of Learning* Curriculum Framework amplifies the *Science Standards of Learning for Virginia Public Schools* and defines the content knowledge, skills, and understandings that are measured by the Standards of Learning tests. The Science Curriculum Framework provides additional guidance to school divisions and their teachers as they develop an instructional program appropriate for their students. It assists teachers as they plan their lessons by identifying essential understandings and defining the essential content knowledge, skills, and processes students need to master. This supplemental framework delineates in greater specificity the minimum content that all teachers should teach and all students should learn.

School divisions should use the *Science Curriculum Framework* as a resource for developing sound curricular and instructional programs. This framework should not limit the scope of instructional programs. Additional knowledge and skills that can enrich instruction and enhance students' understanding of the content identified in the Standards of Learning should be included as part of quality learning experiences.

The Curriculum Framework serves as a guide for Standards of Learning assessment development. Assessment items may not and should not be a verbatim reflection of the information presented in the Curriculum Framework. Students are expected to continue to apply knowledge and skills from Standards of Learning presented in previous grades as they build scientific expertise.

The Board of Education recognizes that school divisions will adopt a K–12 instructional sequence that best serves their students. The design of the Standards of Learning assessment program, however, requires that all Virginia school divisions prepare students to demonstrate achievement of the standards for elementary and middle school by the time they complete the grade levels tested. The high school end-of-course Standards of Learning tests, for which students may earn verified units of credit, are administered in a locally determined sequence.

Each topic in the *Science Standards of Learning* Curriculum Framework is developed around the Standards of Learning. The format of the Curriculum Framework facilitates teacher planning by identifying the key concepts, knowledge and skills that should be the focus of instruction for each standard. The Curriculum Framework is divided into two columns: Understanding the Standard (K-5); Essential Understandings (middle and high school); and Essential Knowledge, Skills, and Processes. The purpose of each column is explained below.

Understanding the Standard (K-5)
This section includes background information for the teacher. It contains content that may extend the teachers' knowledge of the standard beyond the current grade level. This section may also contain suggestions and resources that will help teachers plan instruction focusing on the standard.

Essential Understandings (middle and high school)
This section delineates the key concepts, ideas and scientific relationships that all students should grasp to demonstrate an understanding of the Standards of Learning.

Essential Knowledge, Skills and Processes (K-12)
Each standard is expanded in the Essential Knowledge, Skills, and Processes column. What each student should know and be able to do in each standard is outlined. This is not meant to be an exhaustive list nor a list that limits what is taught in the classroom. It is meant to be the key knowledge and skills that define the standard.

Standard PH.1

PH.1 The student will plan and conduct investigations using experimental design and product design processes. Key concepts include
a) the components of a system are defined;
b) instruments are selected and used to extend observations and measurements;
c) information is recorded and presented in an organized format;
d) the limitations of the experimental apparatus and design are recognized;
e) the limitations of measured quantities are recognized through the appropriate use of significant figures or error ranges;
f) models and simulations are used to visualize and explain phenomena, to make predictions from hypotheses, and to interpret data; and
g) appropriate technology, including computers, graphing calculators, and probeware, is used for gathering and analyzing data and communicating results.

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Essential Understandings

The concepts developed in this standard include the following:

- Appropriate instruments are used to measure position, time, mass, force, volume, temperature, motion, fields, electric current, and potential.
- No measurement is complete without a statement about its uncertainty.
- Experimental records, including experimental diagrams, data, and procedures, are kept concurrently with experimentation.
- Tables, spreadsheets, and graphs are used to interpret, organize, and clarify experimental observations, possible explanations, and models for phenomena being observed.
- Accuracy is the difference between the accepted value and the measured value.
- Precision is the spread of repeated measurements.
- Results of calculations or analyses of data are reported in appropriate numbers of significant digits.
- Data are organized into tables and graphed when involving dependent and independent variables.

Essential Knowledge and Skills

In order to meet this standard, it is expected that students will

- measure and record position, time, mass, force, volume, temperature, motion, fields, and electric current and potential, using appropriate technology.
- determine accuracy of measurement by comparing the experimental averages and the theoretical value.
- determine precision of measurement using range or standard deviation.
- follow safe practices in all laboratory procedures.
- use simulations to model physical phenomena.
- draw conclusions and provide reasoning using supporting data.

Standard PH.2

PH.2	The student will investigate and understand how to analyze and interpret data. Key concepts include a) a description of a physical problem is translated into a mathematical statement in order to find a solution; b) relationships between physical quantities are determined using the shape of a curve passing through experimentally obtained data; c) the slope of a linear relationship is calculated and includes appropriate units; d) interpolated, extrapolated, and analyzed trends are used to make predictions; and e) situations with vector quantities are analyzed utilizing trigonometric or graphical methods. Back to CPR MP1

Essential Understandings	Essential Knowledge and Skills
The concepts developed in this standard include the following: • Mathematics is a tool used to model and describe phenomena. • Graphing and dimensional analysis are used to reveal relationships and other important features of data. • Predictions are made from trends based on the data. • The shape of the curve fit to experimentally obtained data is used to determine the relationship of the plotted quantities. • All experimental data do not follow a linear relationship. • The area under the curve of experimentally obtained data is used to determine related physical quantities. • Not all quantities add arithmetically. Some must be combined using trigonometry. These quantities are known as vectors. • Physical phenomena or events can often be described in mathematical terms (as an equation or inequality).	In order to meet this standard, it is expected that students will • recognize linear and nonlinear relationships from graphed data. • where appropriate, draw a straight line through a set of experimental data points and determine the slope and/or area under the curve. • use dimensional analysis to verify appropriate units. • combine vectors into resultants utilizing trigonometric or graphical methods. • resolve vectors into components utilizing trigonometric or graphical methods.

Standard PH.3

<table>
<tr><td colspan="2">PH.3 The student will investigate and demonstrate an understanding of the nature of science, scientific reasoning, and logic. Key concepts include
a) analysis of scientific sources to develop and refine research hypotheses;
b) analysis of how science explains and predicts relationships;
c) evaluation of evidence for scientific theories;
d) examination of how new discoveries result in modification of existing theories or establishment of new paradigms; and
e) construction and defense of a scientific viewpoint.
Back to CPR MP1</td></tr>
<tr><th>Essential Understandings</th><th>Essential Knowledge and Skills</th></tr>
<tr><td>The concepts developed in this standard include the following:
• The nature of science refers to the foundational concepts that govern the way scientists formulate explanations about the natural world. The nature of science includes the following concepts
a) the natural world is understandable;
b) science is based on evidence - both observational and experimental;
c) science is a blend of logic and innovation;
d) scientific ideas are durable yet subject to change as new data are collected;
e) science is a complex social endeavor; and
f) scientists try to remain objective and engage in peer review to help avoid bias.
• Experimentation may support a hypothesis, falsify it, or lead to new discoveries.
• The hypothesis may be modified based upon data and analysis.
• A careful study of prior reported research is a basis for the formation of a research hypothesis.
• A theory is a comprehensive and effective explanation, which is well supported by experimentation and observation, of a set of phenomena.
• Science is a human endeavor relying on human qualities, such as reasoning, insight, energy, skill, and creativity as well as intellectual honesty, tolerance of ambiguity, skepticism, and openness to new ideas.</td><td>In order to meet this standard, it is expected that students will
• identify and explain the interaction between human nature and the scientific process.
• identify examples of a paradigm shift (e.g., quantum mechanics).</td></tr>
</table>

Standard PH.4

<table>
<tr><td colspan="2">PH.4 The student will investigate and understand how applications of physics affect the world. Key concepts include
a) examples from the real world; and
b) exploration of the roles and contributions of science and technology.
Back to CPR MP1</td></tr>
<tr><th>Essential Understandings</th><th>Essential Knowledge and Skills</th></tr>
<tr><td>The concepts developed in this standard include the following:
• Discoveries in physics, both theoretical and experimental, have resulted in advancements in communication, medicine, engineering, transportation, commerce, exploration, and technology.
• Journals, books, the Internet, and other sources are used in order to identify key contributors and their contributions to physics as well as their impact on the real world.</td><td>In order to meet this standard, it is expected that students will
• be aware of real-world applications of physics, and the importance of physics in the advancement of various fields, such as medicine, engineering, technology, etc.</td></tr>
</table>

Standard PH.5

PH.5	The student will investigate and understand the interrelationships among mass, distance, force, and time through mathematical and experimental processes. Key concepts include a) linear motion; b) uniform circular motion; c) projectile motion; d) Newton’s laws of motion; e) gravitation; f) planetary motion; and g) work, power, and energy.

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Essential Understandings	Essential Knowledge and Skills
The concepts developed in this standard include the following: • Newton’s three laws of motion are the basis for understanding the mechanical universe. • Linear motion graphs include - displacement (d) vs. time (t) - velocity (v) vs. time (t) - acceleration (a) vs. time (t) • Position, displacement, velocity, and acceleration are vector quantities. • Motion is described in terms of position, displacement, time, velocity, and acceleration. • Velocity is the change in displacement divided by the change in time. A straight-line, position-time graph indicates constant velocity. The slope of a displacement-time graph is the velocity. • Forces are interactions that can cause objects to accelerate. When one object exerts a force on a second object, the second exerts a force on the first that is equal in magnitude but opposite in direction. • An object with no net force acting on it is stationary or moves with constant velocity. • Acceleration is the change in velocity divided by the change in time. A straight-line, velocity-time graph indicates constant acceleration. A horizontal-line, velocity-time graph indicates zero acceleration. The slope of a velocity-time graph is the acceleration.	In order to meet this standard, it is expected that students will • qualitatively explain motion in terms of Newton’s Laws. • solve problems involving force (F), mass (m), and acceleration (a). • construct and analyze displacement (d) vs. time (t), velocity (v) vs. time (t), and acceleration (a) vs. time (t) graphs. • solve problems involving displacement, velocity, acceleration, and time in one and two dimensions (only constant acceleration). • resolve vector diagrams involving displacement and velocity into their components along perpendicular axes. • draw vector diagrams of a projectile’s motion. Find range, trajectory, height of the projectile, and time of flight (uniform gravitational field, no air resistance). • distinguish between centripetal and centrifugal force. • solve problems related to free-falling objects, including 2-D motion. • solve problems using Newton’s Law of Universal Gravitation. • solve problems involving multiple forces, using free-body diagrams. • solve problems involving mechanical work, power, and energy. • describe the forces involved in circular motion.

Standard PH.5

<table>
<tr><td colspan="2">PH.5 The student will investigate and understand the interrelationships among mass, distance, force, and time through mathematical and experimental processes. Key concepts include
a) linear motion;
b) uniform circular motion;
c) projectile motion;
d) Newton's laws of motion;
e) gravitation;
f) planetary motion; and
g) work, power, and energy.
Back to CPR MP1 Back to CPR MP2</td></tr>
<tr><th>Essential Understandings</th><th>Essential Knowledge and Skills</th></tr>
<tr><td>• The acceleration of a body is directly proportional to the net force on it and inversely proportional to its mass.
• In a uniform vertical gravitational field with negligible air resistance, horizontal and vertical components of the motion of a projectile are independent of one another with constant horizontal velocity and constant vertical acceleration.
• An object moving along a circular path with a constant speed experiences an acceleration directed toward the center of the circle.
• The force that causes an object to move in a circular path is directed centripetally, toward the center of the circle. The object's inertia is sometimes falsely characterized as a centrifugal or outward-directed force.
• Weight is the gravitational force acting on a body.
• Newton's Law of Universal Gravitation can be used to determine the force between objects separated by a known distance, and describes the force that determines the motion of celestial objects. The total force on a body can be represented as a vector sum of constituent forces.
• For a constant force acting on an object, the impulse by that force is the product of the force and the time the object experiences the force. The impulse also equals the change in momentum of the object.
• Work is the mechanical transfer of energy to or from a system and is the product of a force at the point of application and the parallel component of the object's displacement. The net work on a system equals its</td><td></td></tr>
</table>

Standard PH.5

PH.5	The student will investigate and understand the interrelationships among mass, distance, force, and time through mathematical and experimental processes. Key concepts include a) linear motion; b) uniform circular motion; c) projectile motion; d) Newton's laws of motion; e) gravitation; f) planetary motion; and g) work, power, and energy.

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Essential Understandings	Essential Knowledge and Skills
change in velocity. • Forces within a system transform energy from one form to another with no change in the system's total energy. • For a constant force acting on an object, the work done by that force is the product of the force and the distance the object moves in the direction of the force. The net work performed on an object equals its change in kinetic energy. • Power is the rate of doing work.	

Standard PH.6

PH.6	The student will investigate and understand that quantities including mass, energy, momentum, and charge are conserved. Key concepts include a) kinetic and potential energy; b) elastic and inelastic collisions; and c) mass/energy equivalence. Back to CPR MP1 Back to CPR MP3

Essential Understandings	Essential Knowledge and Skills
The concepts developed in this standard include the following: • Kinetic energy is the energy of motion. Potential energy is the energy due to an object's position or state. • Total energy and momentum are conserved. • For elastic collisions, total momentum and total kinetic energy are conserved. For inelastic collisions, total momentum is conserved and some kinetic energy is transformed to other forms of energy. • Electrical charge moves through electrical circuits and is conserved. • In some systems the conservation of mass and energy must take into account the principle of mass/energy equivalence.	In order to meet this standard, it is expected that students will • provide and explain examples of how energy can be converted from potential energy to kinetic energy and the reverse. • provide and explain examples showing linear momentum is the product of mass and velocity, and is conserved in a closed system.

Standard PH.7

PH.7	The student will investigate and understand that energy can be transferred and transformed to provide usable work. Key concepts include a) transfer and storage of energy among systems including mechanical, thermal, gravitational, electromagnetic, chemical, and nuclear systems; and b) efficiency of systems. Back to CPR MP1 Back to CPR MP3

Essential Understandings	Essential Knowledge and Skills
The concepts developed in this standard include the following: • Energy can be transformed from one form to another. • Efficiency is the ratio of output work to input work.	In order to meet this standard, it is expected that students will • illustrate that energy can be transformed from one form to another, using examples from everyday life and technology. • calculate efficiency by identifying the useful energy in a process. • qualitatively identify the various energy transformations in simple demonstrations.

Standard PH.8

PH.8	The student will investigate and understand wave phenomena. Key concepts include a) wave characteristics; b) fundamental wave processes; and c) light and sound in terms of wave models. Back to CPR MP1 Back to CPR MP3

Essential Understandings	Essential Knowledge and Skills
The concepts developed in this standard include the following: • Mechanical waves transport energy as a traveling disturbance in a medium. • In a transverse wave, particles of the medium oscillate in a direction perpendicular to the direction the wave travels. • In a longitudinal wave, particles of the medium oscillate in a direction parallel to the direction the wave travels. • Wave velocity equals the product of the frequency and the wavelength. • For small angles of oscillation, a pendulum exhibits simple harmonic motion. • Frequency and period are reciprocals of each other. • Waves are reflected and transmitted when they encounter a change in medium or a boundary. • The overlapping of two or more waves results in constructive or destructive interference. • When source and observer are in relative motion, a shift in frequency occurs (Doppler effect). • Sound is a longitudinal mechanical wave that travels through matter. • Light is a transverse electromagnetic wave that can travel through matter as well as a vacuum. • Reflection is the change of direction of the wave in the original medium. • Refraction is the change of direction of the wave at the boundary between two media. • Diffraction is the spreading of a wave around a barrier or an aperture.	In order to meet this standard, it is expected that students will • identify examples of and differentiate between transverse and longitudinal waves, using simulations and/or models. • illustrate period, wavelength, and amplitude on a graphic representation of a wave. • solve problems involving frequency, period, wavelength, and velocity. • distinguish between superimposed waves that are in-phase and those that are out-of-phase. • graphically illustrate reflection and refraction of a wave when it encounters a change in medium or a boundary. • graphically illustrate constructive and destructive interference. • identify a standing wave, using a string.

Standard PH.8

<table>
<tr><td colspan="2">PH.8 The student will investigate and understand wave phenomena. Key concepts include
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Back to CPR MP1 Back to CPR MP3</td></tr>
<tr><th>Essential Understandings</th><th>Essential Knowledge and Skills</th></tr>
<tr><td>• The pitch of a note is determined by the frequency of the sound wave.
• The color of light is determined by the frequency of the light wave.
• As the amplitude of a sound wave increases, the loudness of the sound increases.
• As the amplitude of a light wave increases, the intensity of the light increases.
• Electromagnetic waves can be polarized by reflection or transmission.
• Polarizing filters allow light oriented in one direction (or component of) to pass through.</td><td></td></tr>
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Standard PH.9

PH.9	The student will investigate and understand that different frequencies and wavelengths in the electromagnetic spectrum are phenomena ranging from radio waves through visible light to gamma radiation. Key concepts include a) the properties, behaviors, and relative size of radio waves, microwaves, infrared, visible light, ultraviolet, X-rays, and gamma rays; b) wave/particle dual nature of light; and c) current applications based on the respective wavelengths.

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Essential Understandings	Essential Knowledge and Skills
The concepts developed in this standard include the following: • Frequency, wavelength, and energy vary across the entire electromagnetic spectrum. • The long wavelength, low frequency portion of the electromagnetic spectrum is used for communication (e.g., radio, TV, cellular phone). • Medium wavelengths (infrared) are used for heating and remote control devices. • Visible light comprises a relatively narrow portion of the electromagnetic spectrum. • Ultraviolet (UV) wavelengths (shorter than the visible spectrum) are ionizing radiation and can cause damage to humans. UV is responsible for sunburn, and can be used for sterilization and fluorescence. • X-rays and gamma rays are the highest frequency (shortest wavelength) and are used primarily for medical purposes. These wavelengths are also ionizing radiation and can cause damage to humans.	In order to meet this standard, it is expected that students will • describe the change in observed frequency of waves due to the motion of a source or a receiver (the Doppler effect). • identify common uses for radio waves, microwaves, X-rays and gamma rays.

Standard PH.10

PH.10	The student will investigate and understand how to use the field concept to describe the effects of gravitational, electric, and magnetic forces. Key concepts include a) inverse square laws (Newton's law of universal gravitation and Coulomb's law); and b) technological applications. Back to CPR MP4

Essential Understandings	Essential Knowledge and Skills
The concepts developed in this standard include the following: • The electrostatic force (Coulomb's law) can be either repulsive or attractive, depending on the sign of the charges. • The gravitational force (Newton's Law of Gravitation) is always an attractive force. • The force found from Newton's Law of Gravitation and in Coulomb's law is dependent on the inverse square of the distance between two objects. • The interaction of two particles at a distance can be described as a two-step process that occur simultaneously: the creation of a field by one of the particles and the interaction of the field with the second particle. • The force a magnetic field exerts on a moving electrical charge has a direction perpendicular to both the velocity and field directions. Its magnitude is dependent on the velocity of the charge, the magnitude of the charge, and the strength of the magnetic field.	In order to meet this standard, it is expected that students will • describe the attractive or repulsive forces between objects relative to their forces and distance between them (Coulomb's law). • describe the attraction of particles (Newton's Law of Universal Gravitation). • describe the effect of a uniform magnetic field on a moving electrical charge.

Standard PH.11

PH.11	The student will investigate and understand how to diagram, construct, and analyze basic electrical circuits and explain the function of various circuit components. Key concepts include a) Ohm's law; b) series, parallel, and combined circuits; c) electrical power; and d) alternating and direct currents.

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Essential Understandings	Essential Knowledge and Skills
The concepts developed in this standard include the following: • Current is the rate at which charge moves through a circuit element. • Electric potential difference (voltage) in a circuit provides the energy that drives the current. • Elements in a circuit are positioned relative to other elements either in series or parallel. • According to Ohm's law, the resistance of an element equals the voltage across the element divided by the current through the element. • Potential difference (voltage) is the change in electrical potential energy per unit charge across that element. • The dissipated power of a circuit element equals the product of the voltage across that element and the current through that element. • In a DC (direct current) circuit, the current flows in one direction, whereas in an AC (alternating current) circuit, the current switches direction several times per second (60Hz in the U.S.).	In order to meet this standard, it is expected that students will • recognize a series and a parallel circuit. • apply Ohm's law to a series and a parallel circuit. • assemble simple circuits composed of batteries and resistors in series and in parallel. • solve simple circuits using Ohm's law. • calculate the dissipated power of a circuit element. • recognize that DC power is supplied by batteries and that AC power is supplied by electrical wall sockets.

Standard PH.12

PH.12	The student will investigate and understand that extremely large and extremely small quantities are not necessarily described by the same laws as those studied in Newtonian physics. Key concepts may include a) wave/particle duality; b) wave properties of matter; c) matter/energy equivalence; d) quantum mechanics and uncertainty; e) relativity; f) nuclear physics; g) solid state physics; h) nanotechnology; i) superconductivity; and j) radioactivity.

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Essential Understandings	Essential Knowledge and Skills
The concepts developed in this standard include the following: • For processes that are important on the atomic scale, objects exhibit both wave characteristics (e.g., interference) as well as particle characteristics (e.g., discrete amounts and a fixed definite number of electrons per atom). • Nuclear physics is the study of the interaction of the protons and neutrons in the atom's nucleus. • The nuclear force binds protons and neutrons in the nucleus. Fission is the breakup of heavier nuclei to lighter nuclei. Fusion is the combination of lighter nuclei to heavier nuclei. • Dramatic examples of mass-energy transformation are the fusion of hydrogen in the sun, which provides light and heat for Earth, and the fission process in nuclear reactors that provide electricity. • Natural radioactivity is the spontaneous disintegration of unstable nuclei. Alpha, beta, and gamma rays are different emissions associated with radioactive decay. • The special theory of relativity predicts that energy and matter can be converted into each other. • Objects cannot travel faster than the speed of light. • The atoms and molecules of many substances in the natural world, including most metals and minerals, bind together in regular arrays to	In order to meet this standard, it is expected that students will • explain that the motion of objects traveling near or approaching the speed of light does not follow Newtonian mechanics but must be treated within the theory of relativity. • describe the relationship between the Big Bang theory timeline and particle physics. • describe the structure of the atomic nucleus, including quarks. • provide examples of technologies used to explore the nanoscale.

Standard PH.12

PH.12	The student will investigate and understand that extremely large and extremely small quantities are not necessarily described by the same laws as those studied in Newtonian physics. Key concepts may include a) wave/particle duality; b) wave properties of matter; c) matter/energy equivalence; d) quantum mechanics and uncertainty; e) relativity; f) nuclear physics; g) solid state physics; h) nanotechnology; i) superconductivity; and j) radioactivity.

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Essential Understandings	Essential Knowledge and Skills
form crystals. The structure of these crystals is important in determining the properties of these materials (appearance, hardness, etc.). • Certain materials at very low temperatures exhibit the property of zero resistance called superconductivity. • Electrons in orbitals can be treated as standing waves in order to model the atomic spectrum. • Quantum mechanics requires an inverse relationship between the measurable location and the measurable momentum of a particle. The more accurately one determines the position of a particle, the less accurately the momentum can be known, and vice versa. This is known as the Heisenberg uncertainty principle. • Matter behaves differently at nanometer scale (size and distance) than at macroscopic scale.	