Physical Setting/ Physics

Core Curriculum

THE UNIVERSITY OF THE STATE OF NEW YORK THE STATE EDUCATION DEPARTMENT

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CONTENTS

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Physical Setting/ Physics

Core Curriculum

PREFACE

This *Physical Setting/Physics Core Curriculum* is intended to be a catalyst for significant change in the teaching of high school physics. The primary focus of the classroom experience should be on the development of higher order process skills. The content becomes the context and the vehicle for the teaching of these skills rather than an end in itself.

This *Physical Setting/Physics Core Curriculum* has been written to assist teachers and supervisors as they prepare curriculum, instruction, and assessment for the physics content and process skills of the New York State *Learning Standards for Mathematics, Science, and Technology.* This core curriculum, including the skills section, should be seen as part of a continuum that elaborates the science content of Standard 4. The *Learning Standards for Mathematics, Science, and Technology* identifies key ideas and performance indicators. This document should serve as the basis for local curriculum development by providing insight for the interpretation and implementation of the core understandings. Key ideas are broad, unifying, general statements of what students need to know. The performance indicators for each key idea are statements of what students should be able to do to provide evidence that they understand the key idea. As part of this continuum, this core curriculum presents major understandings and skills that give specific detail to the concepts underlying each performance indicator.

This core curriculum guide is *not* a syllabus. It addresses the content and process skills as applied to the rigor and relevancy to be assessed by the in the Physical Setting / Physics Regents Examination. The focus of the examination is the application of skills to real-world situations. The core curriculum has been prepared with the assumption that the content as outlined in the *Learning Standards for Mathematics, Science, and Technology* at the elementary and intermediate levels has been taught previously. This is a guide for the preparation of commencement-level curriculum, instruction, and assessment, the final stage in a K–12 continuum of science education. Teachers should recognize that what is found in this document (including the core content and skills sections) is the ***minimum*** content to be assessed. Teachers are expected to provide for horizontal and vertical enrichment. This core curriculum has specifically been constructed to permit the exploration of the richness of physics. Time has deliberately been built into the year to permit students to examine these topics in greater depth or investigate new areas of physics. This time facilitates the inclusion of experiences supporting analysis, inquiry, interconnectedness, and problem solving. The focus on conceptual understanding in the guide is consistent with the approaches recommended in the *National Science Education Standards* and *Benchmarks of Science Literacy: Project 2061.*

Misconceptions greatly influence learning. Students may internalize new ideas, but if the learning is incorporated into incorrect assumptions or ideas, the learning is superficial and of doubtful value. Educational research has shown that students typically learn best by moving from the concrete to the abstract; learning is enhanced through the use of manipulatives and hands-on activities. Teachers can dramatically influence learning by providing constructive feedback and by maintaining appropriately rigorous expectations.

Science for All Americans: Project 2061 makes several recommendations that foster effective science teaching. The use of inquiry is central to scientific thought and therefore an extremely powerful teaching tool in the physics classroom. Real-world questions to focus the attention of the student, active student involvement, and the collection and use of evidence are essential components of effective science teaching. Since science is a collaborative process, the use of teams (cooperative learning groups) is encouraged. It is important to encourage curiosity and to support academic growth, especially for female and minority students who have been underrepresented in physics.

It is essential that instruction focus on student understandings, mathematical relationships, processes, mechanisms, and the application of concepts. Students, in attaining scientific literacy, will be able to provide explanations in their own words, exhibiting creative problem solving, reasoning, and informed decision making. Future assessments will access students' ability to explain, analyze, and interpret physics processes and phenomena and generate science inquiry. The general nature of the statements in this guide will encourage the teaching of science understanding instead of emphasizing the memorization of facts. The major understandings in this guide permit teachers a large degree of flexibility, making rich and creative instruction possible, and allowing for multifaceted assessment.

The order of presentation and numbering of all statements in this guide are not meant to indicate any recommended sequence of instruction. Ideas have not been prioritized, nor have they been organized to indicate teaching time allotments or test weighting. Teachers are encouraged to find and elaborate for students the conceptual cross-linkages that interconnect many of the key ideas to each other and to other mathematics, science, and technology learning standards.

Historical Context:

> *If I have seen further it is by standing on the shoulders of giants.*
>
> — Sir Isaac Newton,
> From a letter to Robert Hooke,
> dated 5 February 1676.

Throughout history new understandings of real-world phenomena resulted from extensions of the work of previous generations. Newton's statement reflects his belief that his work in mechanics and calculus would have been impossible without the solid foundation established by both his colleagues and predecessors. All physics courses should foster an appreciation of the major developments that significantly contributed to advancements in the field.

Greek Origins

The foundations of physics can be traced back to the ancient Greeks (600–200 BC), who sought order within the physical events that were understood as either chaotic or mystical. The idea of atoms as the fundamental particles of matter had a major influence over much of the scientific investigation that occurred over the course of the next few centuries.

The Foundations of Mechanics

On the macroscopic level, the significance of air resistance on falling objects was established. The enunciation of the Three Laws of Planetary Motion applied mathematical relationships at the planetary level. Sir Isaac Newton, using this new vantage point, concluded that a new force, gravity, was the basis for general laws of motion as well as universal gravitation. Newton, concurrently with Leibniz, developed calculus as a tool for the solution of problems within physics.

Subatomic Investigations

On a microscopic level, a relationship between electricity and magnetism was demonstrated by the induction of voltage in a conductor passing through a magnetic field. Electrolysis was explored; studies established a proportionality between current and the mass of a substance generated at an electrode. Radium was discovered; the existence of three types of radiation—alpha, beta, and gamma rays—was demonstrated. Evidence for both a wave nature and a quantum nature of light was generated during the latter half of the 19th century. The birth of quantum mechanics is fundamental to understanding the ability of light to exhibit both particle and wave characteristics.

Cosmic Developments

Observations at the cosmic scale continued as a red shift in the light reaching us from distant galaxies was discovered; the implications of an expanding universe intrigued scientists around the world. The understanding of gravity was refined early in the 20th century when Albert Einstein introduced both special and general theories of relativity. Einstein's proposal that space and time are intimately and indivisibly linked fostered a spate of activity in theoretical physics.

The Transistor Age

The development of the computer is clearly a significant event in the history of science. The invention of transistors spirited in a second generation of mini-computers and a wide range of electronic devices and applications.

The laws of physics apply from the subatomic through the cosmic levels, an idea whose development can be traced through the history of the science. The contributions of Democritus, Galileo, Kepler, Newton, Faraday, Maxwell, Planck, Curie, Hubble, Einstein, Heisenberg, Schrödinger, Feynman, Bardeen, Brattain, and Shockley provide insights to pivotal moments in our field. The physics of today is based upon the achievements of the past. Students should appreciate the significance of these accomplishments and teachers should foster this appreciation.

Laboratory Requirements: The use of scientific inquiry is critical to understanding science concepts and the development of explanations of natural phenomena. As a prerequisite for admission to the Physical Setting/Physics Regents Examination students must have successfully completed a minimum of 1200 minutes of hands-on laboratory experience with satisfactory laboratory reports on file. Due to the strong emphasis on student development of laboratory skills, a minimum of 280 minutes/week of class and laboratory time is recommended.

Prior to the written portion of the Regents examination, students will be required to complete laboratory performance tasks during which concepts and skills from Standards 1, 2, 4, 6, and 7 will be assessed.

The Laboratory Setting: Laboratory safety dictates that a minimum amount of space be provided for each individual student. According to the National Science Teachers Association and the American Association of Physics Teachers, recommended space considerations include:

- A minimum of 60 ft^2/pupil (5.6m^2) which is equivalent to 1440 ft^2 (134m^2) to accommodate a class of 24 safely in a combination laboratory/classroom.

Or,

- A minimum of 45 ft^2/pupil (4.2m^2) which is equivalent to 1080 ft^2 (101m^2) to accommodate a class of 24 safely in a stand-alone laboratory.

It is recommended that each school district comply with local, State, and federal codes and regulations regarding facilities and fire and safety issues.

Systems of Units: SI (International System) units are used in this core curriculum. SI units are a logical extension of the metric system. The SI system begins with seven fundamental units, from which all other units are derived. In addition to the standard fundamental and derived units of the SI system (kilogram, meter, joule, volt), other units commonly used in physics (centimeter, kilometer) are also employed.

Uncertainty of Measurements and Significant Figures: It is an important concept in physics that all measurements contain some uncertainty. The reporting of such data uses significant figures to inform the reader of the uncertainty of the measurement. When these values are used in calculations, it is vital that answers to such calculations are not misleading, and hence, rules for addition, subtraction, multiplication, and division should be followed.

PROCESS SKILLS
BASED ON STANDARDS 1, 2, 6, AND 7

Science process skills should be based on a series of discoveries. Students learn most effectively when they have a central role in the discovery process. To that end, Standards 1, 2, 6, and 7 incorporate in the Physical Setting/ Physics Core Curriculum *a student-centered, problem-solving approach to physics. It should be a goal of the instructor to encourage science process skills that will provide students with the background and curiosity to investigate important issues in the world around them.*

This section denotes the types and depth of the process skills the students should practice throughout the school year. These process skills are an integral part of all core-based curricula. This implies that students should already have a foundation in these skills. The physics teacher reinforces these process skills by creating new situations for the student to investigate in the context of physics. During assessments, students will be presented with new situations to analyze and new problems to solve using these process skills.

In the same vein of facilitating student learning within an authentic context, students will be expected to apply the SI (International System) system of units. SI units are used in this core curriculum. The SI system begins with fundamental units, from which all other units are derived. In addition to the standard fundamental and derived units of the SI system (such as kilogram, meter, joule, and volt), other units such as centimeters and kilometers are commonly employed.

Quantity	Fundamental Units	Symbol
length	meter	m
mass	kilogram	kg
time	second	s
electric current	ampere	A
temperature	kelvin	K
amount	mole	mol
luminous intensity	candela	cd

Note: the use of e.g. *denotes examples which may be used for in-depth study. The terms* for example *and* such as *denote material which is testable. Items in paranthesis denote further definition of the word(s) preceding the item and are testable.*

STANDARD 1
Analysis, Inquiry, and Design

MATHEMATICAL ANALYSIS:

STANDARD 1—Analysis, Inquiry, and Design
Students will use mathematical analysis, scientific inquiry, and engineering design, as appropriate, to pose questions, seek answers, and develop solutions.

Key Idea 1:
Abstraction and symbolic representation are used to communicate mathematically.
M1.1 Use algebraic and geometric representations to describe and compare data.
- use scaled diagrams to represent and manipulate vector quantities
- represent physical quantities in graphical form
- construct graphs of real-world data (scatter plots, line or curve of best fit)
- manipulate equations to solve for unknowns
- use dimensional analysis to confirm algebraic solutions

Key Idea 2:
Deductive and inductive reasoning are used to reach mathematical conclusions.
M2.1 Use deductive reasoning to construct and evaluate conjectures and arguments, recognizing that patterns and relationships in mathematics assist them in arriving at these conjectures and arguments.
- interpret graphs to determine the mathematical relationship between the variables

STANDARD 1 Analysis, Inquiry, and Design MATHEMATICAL ANALYSIS: continued	*Key Idea 3:* Critical thinking skills are used in the solution of mathematical problems. M3.1 Apply algebraic and geometric concepts and skills to the solution of problems. • explain the physical relevance of properties of a graphical representation of real-world data, e.g., slope, intercepts, area under the curve

STANDARD 1
Analysis, Inquiry, and Design

SCIENTIFIC INQUIRY:

Key Idea 1:

The central purpose of scientific inquiry is to develop explanations of natural phenomena in a continuing, creative process.

- develop extended visual models and mathematical formulations to represent an understanding of natural phenomena
- clarify ideas through reasoning, research, and discussion
- evaluate competing explanations and overcome misconceptions

Key Idea 2:

Beyond the use of reasoning and consensus, scientific inquiry involves the testing of proposed explanations involving the use of conventional techniques and procedures and usually requiring considerable ingenuity.

S2.1 Devise ways of making observations to test proposed explanations.
- design an experiment to investigate the relationship between physical phenomena

S2.2 Refine research ideas through library investigations, including electronic information retrieval and reviews of the literature, and through peer feedback obtained from review and discussion.

S2.3 Develop and present proposals including formal hypotheses to test explanations; i.e., predict what should be observed under specific conditions if the explanation is true.

S2.4 Carry out a research plan for testing explanations, including selecting and developing techniques, acquiring and building apparatus, and recording observations as necessary. (*Note: This could apply to many activities from simple investigations to long-term projects.*)

Key Idea 3:

The observations made while testing proposed explanations, when analyzed using conventional and invented methods, provide new insights into phenomena.

S3.1 Use various means of representing and organizing observations (e.g., diagrams, tables, charts, graphs, and equations) and insightfully interpret the organized data.
- use appropriate methods to present scientific information (e.g., lab reports, posters, research papers, or multimedia presentations)
- identify possible sources of error in data collection and explain their effects on experimental results

S3.2 Apply statistical analysis techniques when appropriate to test if chance alone explains the result.
- examine collected data to evaluate the reliability of experimental results, including percent error, range, standard deviation, line of best fit, and the use of the correct number of significant digits

S3.3 Assess correspondence between the predicted result contained in the hypothesis and the actual result, and reach a conclusion as to whether or not the explanation on which the prediction was based is supported.

S3.4 Based on the results of the test and through public discussion, revise the explanation and contemplate additional research. (*Note: Public discussion may include lab partners, lab groups, classes, etc.*)

STANDARD 1 **Analysis, Inquiry, and Design** **ENGINEERING DESIGN:**	*Key Idea 1:* Engineering design is an iterative process involving modeling and optimization (finding the best solution within given constraints) which is used to develop technological solutions to problems within given constraints. (*Note: The design process could apply to activities from simple investigations to long-term projects.*) T1.1 Students engage in the following steps of a design process: § initiate and carry out a thorough investigation of an unfamiliar situation and identify needs and opportunities for technological invention or innovation § identify, locate, and use a wide range of information resources, and document through notes and sketches how findings relate to the problem § generate creative solutions, break ideas into significant functional elements, and explore possible refinements; predict possible outcomes, using mathematical and functional modeling techniques; choose the optimal solution to the problem, clearly documenting ideas against design criteria and constraints; and explain how human understandings, economics, ergonomics, and environmental considerations have influenced the solution § develop work schedules and working plans which include optimal use and cost of materials, processes, time, and expertise; construct a model of the solution, incorporating developmental modifications while working to a high degree of quality (craftsmanship) § devise a test of the solution according to the design criteria and perform the test; record, portray, and logically evaluate performance test results through quantitative, graphic, and verbal means. Use a variety of creative verbal and graphic techniques effectively and persuasively to present conclusions, predict impacts and new problems, and suggest and pursue modifications

STANDARD 2

Students will access, generate, process, and transfer information, using appropriate technologies.

STANDARD 2 **INFORMATION SYSTEMS:**	*Key Idea 1:* Information technology is used to retrieve, process, and communicate information as a tool to enhance learning. 1.1 Understand and use the more advanced features of word processing, spreadsheets, and database software. 1.2 Prepare multimedia presentations demonstrating a clear sense of audience and purpose. (*Note: Multimedia may include posters, slides, images, presentation software, etc.*) • extend knowledge of physical phenomena through independent investigation, e.g., literature review, electronic resources, library research • use appropriate technology to gather experimental data, develop models, and present results 1.3 Access, select, collate, and analyze information obtained from a wide range of sources such as research databases, foundations, organizations, national libraries, and electronic communication networks, including the Internet. • use knowledge of physics to evaluate articles in the popular press on contemporary scientific topics 1.4 Utilize electronic networks to share information.

STANDARD 2 **INFORMATION SYSTEMS:** **continued**	1.5 Model solutions to a range of problems in mathematics, science, and technology, using computer simulation software. • use software to model and extend classroom and laboratory experiences, recognizing the differences between the model used for understanding and real-world behavior *Key Idea 2:* Knowledge of the impacts and limitations of information systems is essential to its effective and ethical use. *Key Idea 3:* Information technology can have positive and negative impacts on society, depending upon how it is used.

STANDARD 6—Interconnectedness: Common Themes

Students will understand the relationships and common themes that connect mathematics, science, and technology and apply the themes to these and other areas of learning.

STANDARD 6 **Interconnectedness: Common Themes** **SYSTEMS THINKING:**	*Key Idea 1:* Through systems thinking, people can recognize the commonalities that exist among all systems and how parts of a system interrelate and combine to perform specific functions. 1.1 Define boundary conditions when doing systems analysis to determine what influences a system and how it behaves.

STANDARD 6 **Interconnectedness: Common Themes** **MODELS:**	*Key Idea 2:* Models are simplified representations of objects, structures, or systems used in analysis, explanation, interpretation, or design. 2.1 Revise a model to create a more complete or improved representation of the system. 2.2 Collect information about the behavior of a system and use modeling tools to represent the operation of the system. • use observations of the behavior of a system to develop a model 2.3 Find and use mathematical models that behave in the same manner as the processes under investigation. • represent the behavior of real-world systems, using physical and mathematical models 2.4 Compare predictions to actual observations, using test models. • validate or reject a model based on collated experimental data • predict the behavior of a system, using a model

STANDARD 6 Interconnectedness: Common Themes MAGNITUDE AND SCALE:	*Key Idea 3:* The grouping of magnitudes of size, time, frequency, and pressures or other units of measurement into a series of relative order provides a useful way to deal with the immense range and the changes in scale that affect the behavior and design of systems. 3.1 Describe the effects of changes in scale on the functioning of physical, biological, or designed systems. 3.2 Extend their use of powers of ten notation to understanding the exponential function and performing operations with exponential factors. • estimate quantitative results, using orders of magnitude • simplify calculations by using scientific notation

STANDARD 6 Interconnectedness: Common Themes EQUILIBRIUM AND STABILITY:	*Key Idea 4:* Equilibrium is a state of stability due either to a lack of change (static equilibrium) or a balance between opposing forces (dynamic equilibrium). 4.1 Describe specific instances of how disturbances might affect a system's equilibrium, from small disturbances that do not upset the equilibrium to larger disturbances (threshold level) that cause the system to become unstable. 4.2 Cite specific examples of how dynamic equilibrium is achieved by equality of change in opposing directions.

STANDARD 6 Interconnectedness: Common Themes PATTERNS OF CHANGE:	*Key Idea 5:* Identifying patterns of change is necessary for making predictions about future behavior and conditions. 5.1 Use sophisticated mathematical models, such as graphs and equations of various algebraic or trigonometric functions. • predict the behavior of physical systems, using mathematical models such as graphs and equations 5.2 Search for multiple trends when analyzing data for patterns, and identify data that do not fit the trends. • deduce patterns from the organization and presentation of data • identify and develop models, using patterns in data

STANDARD 6 Interconnectedness: Common Themes OPTIMIZATION:	*Key Idea 6:* In order to arrive at the best solution that meets criteria within constraints, it is often necessary to make trade-offs. • determine optimal solutions to problems that can be solved using quantitative methods

STANDARD 7—Interdisciplinary Problem Solving

Students will apply the knowledge and thinking skills of mathematics, science, and technology to address real-life problems and make informed decisions.

STANDARD 7 **Interdisciplinary Problem Solving** **CONNECTIONS:**	*Key Idea 1:* The knowledge and skills of mathematics, science, and technology are used together to make informed decisions and solve problems, especially those relating to issues of science/technology/society, consumer decision making, design, and inquiry into phenomena. • address real-world problems, using scientific methodology

STANDARD 7 **Interdisciplinary Problem Solving** **STRATEGIES:**	*Key Idea 2:* Solving interdisciplinary problems involves a variety of skills and strategies, including effective work habits; gathering and processing information; generating and analyzing ideas; realizing ideas; making connections among the common themes of mathematics, science, and technology; and presenting results. • collect, analyze, interpret, and present data, using appropriate tools • If students participate in an extended, culminating mathematics, science, and technology project, then students should: § work effectively § gather and process information § generate and analyze ideas § observe common themes § realize ideas § present results

PROCESS SKILLS
BASED ON STANDARD 4

Science process skills should be based on a series of discoveries. Students learn most effectively when they have a central role in the discovery process. To that end, Standards 1, 2, 6, and 7 incorporate a student-centered, problem-solving approach to physics. This list is not intended to be an all-inclusive list of the content or skills that teachers are expected to incorporate into their curriculum. It should be a goal of the instructor to encourage science process skills that will provide students with the background and curiosity to investigate important issues in the world around them.

Note: the use of e.g. *denotes examples which may be used for in-depth study. The terms* for example *and* such as *denote material which is testable. Items in paranthesis denote further definition of the word(s) preceding the item and are testable.*

STANDARD 4—The Physical Setting
Students will understand and apply scientific concepts, principles, and theories pertaining to the physical setting and living environment and recognize the historical development of ideas in science.

STANDARD 4
The Physical Setting

Key Idea 4:
Energy exists in many forms, and when these forms change energy is conserved.

4.1 Observe and describe transmission of various forms of energy.

- i. describe and explain the exchange between potential energy, kinetic energy, and internal energy for simple mechanical systems, such as a pendulum, a roller coaster, a spring, a freely falling object
- ii. predict velocities, heights, and spring compressions based on energy conservation
- iii. determine the energy stored in a spring
- iv. determine the factors that affect the period of a pendulum
- v. observe and explain energy conversions in real-world situations
- vi. recognize and describe conversions among different forms of energy in real or hypothetical devices such as a motor, a generator, a photocell, a battery
- vii. compare the power developed when the same work is done at different rates
- viii. measure current and voltage in a circuit
- ix. use measurements to determine the resistance of a circuit element
- x. interpret graphs of voltage versus current
- xi. measure and compare the resistance of conductors of various lengths and cross-sectional areas
- xii. construct simple series and parallel circuits
- xiii. draw and interpret circuit diagrams which include voltmeters and ammeters
- xiv. predict the behavior of lightbulbs in series and parallel circuits
- xv. map the magnetic field of a permanent magnet, indicating the direction of the field between the N (north-seeking) and S (south-seeking) poles

4.3 Explain variations in wavelength and frequency in terms of the source of the vibrations that produce them, e.g., molecules, electrons, and nuclear particles.

- i. compare the characteristics of two transverse waves such as amplitude, frequency, wavelength, speed, period, and phase
- ii. draw wave forms with various characteristics
- iii. identify nodes and antinodes in standing waves
- iv. differentiate between transverse and longitudinal waves
- v. determine the speed of sound in air
- vi. predict the superposition of two waves interfering constructively and destructively
- vii. observe, sketch, and interpret the behavior of wave fronts as they reflect, refract, and diffract
- viii. draw ray diagrams to represent the reflection and refraction of waves
- ix. determine empirically the index of refraction of a transparent medium

STANDARD 4 The Physical Setting continued	*Key Idea 5:* Energy and matter interact through forces that result in changes in motion. 5.1 Explain and predict different patterns of motion of objects (e.g., linear and uniform circular motion, velocity and acceleration, momentum and inertia). i. construct and interpret graphs of position, velocity, or acceleration versus time ii. determine and interpret slopes and areas of motion graphs iii. determine the acceleration due to gravity near the surface of Earth iv. determine the resultant of two or more vectors graphically or algebraically v. draw scaled force diagrams using a ruler and a protractor vi. resolve a vector into perpendicular components both graphically and algebraically vii. sketch the theoretical path of a projectile viii. use vector diagrams to analyze mechanical systems (equilibrium and non-equilibrium) ix. verify Newton's Second Law for linear motion x. determine the coefficient of friction for two surfaces xi. verify Newton's Second Law for uniform circular motion xii. verify conservation of momentum xiii. determine a spring constant 5.3 Compare energy relationships within an atom's nucleus to those outside the nucleus. i. interpret energy-level diagrams ii. correlate spectral lines with an energy-level diagram

STANDARD 4: The Physical Setting

Students will understand and apply scientific concepts, principles, and theories pertaining to the physical setting and living environment and recognize the historical development of ideas in science.

Key Idea 4:

Energy exists in many forms, and when these forms change energy is conserved.

The law of conservation of energy provides one of the basic keys to understanding the universe. The fundamental tenet of this law is that the total mass-energy of the universe is constant; however, energy can be transferred in many ways. Historically, scientists have treated the law of conservation of matter and energy separately. All energy can be classified as either kinetic or potential. When work is done on or by a system, the energy of the system changes. This relationship is known as the work-energy theorem.

Energy may be transferred by matter or by waves. Waves transfer energy without transferring mass. Most of the information scientists gather about the universe is derived by detecting and analyzing waves. This process has been enhanced through the use of digital analysis. Types of waves include mechanical and electromagnetic. All waves have the same characteristics and exhibit certain behaviors, subject to the constraints of conservation of energy.

Note: the use of e.g. *denotes examples which may be used for in-depth study. The terms* for example *and* such as *denote material which is testable. Items in paranthesis denote further definition of the word(s) preceding the item and are testable.*

PERFORMANCE INDICATOR 4.1

Students can observe and describe transmission of various forms of energy.

Major Understandings:

4.1a All energy transfers are governed by the law of conservation of energy.*

4.1b Energy may be converted among mechanical, electromagnetic, nuclear, and thermal forms.

4.1c Potential energy is the energy an object possesses by virtue of its position or condition. Types of potential energy include gravitational* and elastic*.

4.1d Kinetic energy* is the energy an object possesses by virtue of its motion.

4.1e In an ideal mechanical system, the sum of the macroscopic kinetic and potential energies (mechanical energy) is constant.*

4.1f In a nonideal mechanical system, as mechanical energy decreases there is a corresponding increase in other energies such as internal energy.*

4.1g When work* is done on or by a system, there is a change in the total energy* of the system.

4.1h Work done against friction results in an increase in the internal energy of the system.

4.1i Power* is the time-rate at which work is done or energy is expended.

(Note: Items with asterisks* require quantitative treatment per the Reference Table for Physics. Asterisks following individual words refer to the preceding word or phrase only; asterisks appearing after the final period of a sentence refer to all concepts or ideas presented in the sentence.)

PERFORMANCE INDICATOR 4.1

continued

4.1j Energy may be stored in electric* or magnetic fields. This energy may be transferred through conductors or space and may be converted to other forms of energy.

4.1k Moving electric charges produce magnetic fields. The relative motion between a conductor and a magnetic field may produce a potential difference in the conductor.

4.1l All materials display a range of conductivity. At constant temperature, common metallic conductors obey Ohm's Law*.

4.1m The factors affecting resistance in a conductor are length, cross-sectional area, temperature, and resistivity.*

4.1n A circuit is a closed path in which a current* can exist. (*Note: Use conventional current.*)

4.1o Circuit components may be connected in series* or in parallel*. Schematic diagrams are used to represent circuits and circuit elements.

4.1p Electrical power* and energy* can be determined for electric circuits.

PERFORMANCE INDICATOR 4.3

Students can explain variations in wavelength and frequency in terms of the source of the vibrations that produce them, e.g., molecules, electrons, and nuclear particles.

Major Understandings:

4.3a An oscillating system produces waves. The nature of the system determines the type of wave produced.

4.3b Waves carry energy and information without transferring mass. This energy may be carried by pulses or periodic waves.

4.3c The model of a wave incorporates the characteristics of amplitude, wavelength,* frequency*, period*, wave speed*, and phase.

4.3d Mechanical waves require a material medium through which to travel.

4.3e Waves are categorized by the direction in which particles in a medium vibrate about an equilibrium position relative to the direction of propagation of the wave, such as transverse and longitudinal waves.

4.3f Resonance occurs when energy is transferred to a system at its natural frequency.

4.3g Electromagnetic radiation exhibits wave characteristics. Electromagnetic waves can propagate through a vacuum.

4.3h When a wave strikes a boundary between two media, reflection*, transmission, and absorption occur. A transmitted wave may be refracted.

4.3i When a wave moves from one medium into another, the wave may refract due to a change in speed. The angle of refraction (measured with respect to the normal) depends on the angle of incidence and the properties of the media (indices of refraction).*

4.3j The absolute index of refraction is inversely proportional to the speed of a wave.*

PERFORMANCE INDICATOR 4.3

continued

4.3k All frequencies of electromagnetic radiation travel at the same speed in a vacuum.*

4.3l Diffraction occurs when waves pass by obstacles or through openings. The wavelength of the incident wave and the size of the obstacle or opening affect how the wave spreads out.

4.3m When waves of a similar nature meet, the resulting interference may be explained using the Principle of Superposition. Standing waves are a special case of interference.

4.3n When a wave source and an observer are in relative motion, the observed frequency of the waves traveling between them is shifted (Doppler effect).

Key Idea 5:

Energy and matter interact through forces that result in changes in motion.

Introduction: Fundamental forces govern all the interactions of the universe. The interaction of masses is determined by the gravitational force; the interaction of charges is determined by the electro-weak force; the interaction between particles in the nucleus is controlled by the strong force. Changes in the motion of an object require a force. Newton's laws can be used to explain and predict the motion of an object.

On the atomic level, the quantum nature of the fundamental forces becomes evident. Models of the atom have been developed to incorporate wave-particle duality, quantization, and the conservation laws. These models have been modified to reflect new observations; they continue to evolve.

Everyday experiences are manifestations of patterns that repeat themselves from the subnuclear to the cosmic level. Models that are used at each level reflect these patterns. The future development of physics is likely to be derived from these realms.

PERFORMANCE INDICATOR 5.1

Students can explain and predict different patterns of motion of objects (e.g., linear and uniform circular motion, velocity and acceleration, momentum and inertia).

Major Understandings:

5.1a Measured quantities can be classified as either vector or scalar.

5.1b A vector may be resolved into perpendicular components.*

5.1c The resultant of two or more vectors, acting at any angle, is determined by vector addition.

5.1d An object in linear motion may travel with a constant velocity* or with acceleration*. *(Note: Testing of acceleration will be limited to cases in which acceleration is constant.)*

5.1e An object in free fall accelerates due to the force of gravity.* Friction and other forces cause the actual motion of a falling object to deviate from its theoretical motion. *(Note: Initial velocities of objects in free fall may be in any direction.)*

5.1f The path of a projectile is the result of the simultaneous effect of the horizontal and vertical components of its motion; these components act independently.

5.1g A projectile's time of flight is dependent upon the vertical components of its motion.

PERFORMANCE INDICATOR 5.1

continued

5.1h The horizontal displacement of a projectile is dependent upon the horizontal component of its motion and its time of flight.

5.1i According to Newton's First Law, the inertia of an object is directly proportional to its mass. An object remains at rest or moves with constant velocity, unless acted upon by an unbalanced force.

5.1j When the net force on a system is zero, the system is in equilibrium.

5.1k According to Newton's Second Law, an unbalanced force causes a mass to accelerate*.

5.1l Weight is the gravitational force with which a planet attracts a mass*. The mass of an object is independent of the gravitational field in which it is located.

5.1m The elongation or compression of a spring depends upon the nature of the spring (its spring constant) and the magnitude of the applied force.*

5.1n Centripetal force* is the net force which produces centripetal acceleration.* In uniform circular motion, the centripetal force is perpendicular to the tangential velocity.

5.1o Kinetic friction* is a force that opposes motion.

5.1p The impulse* imparted to an object causes a change in its momentum*.

5.1q According to Newton's Third Law, forces occur in action/reaction pairs. When one object exerts a force on a second, the second exerts a force on the first that is equal in magnitude and opposite in direction.

5.1r Momentum is conserved in a closed system.* *(Note: Testing will be limited to momentum in one dimension.)*

5.1s Field strength* and direction are determined using a suitable test particle. *(Notes: 1)Calculations are limited to electrostatic and gravitational fields. 2)The gravitational field near the surface of Earth and the electrical field between two oppositely charged parallel plates are treated as uniform.)*

5.1t Gravitational forces are only attractive, whereas electrical and magnetic forces can be attractive or repulsive.

5.1u The inverse square law applies to electrical* and gravitational* fields produced by point sources.

PERFORMANCE INDICATOR 5.3

Students can compare energy relationships within an atom's nucleus to those outside the nucleus.

Major Understandings:

5.3a States of matter and energy are restricted to discrete values (quantized).

5.3b Charge is quantized on two levels. On the atomic level, charge is restricted to multiples of the elementary charge (charge on the electron or proton). On the subnuclear level, charge appears as fractional values of the elementary charge (quarks).

5.3c On the atomic level, energy is emitted or absorbed in discrete packets called photons.*

5.3d The energy of a photon is proportional to its frequency.*

5.3e On the atomic level, energy and matter exhibit the characteristics of both waves and particles.

5.3f Among other things, mass-energy and charge are conserved at all levels (from subnuclear to cosmic).

5.3g The Standard Model of Particle Physics has evolved from previous attempts to explain the nature of the atom and states that:

- atomic particles are composed of subnuclear particles
- the nucleus is a comglomeration of quarks which manifest themselves as protons and neutrons
- each elementary particle has a corresponding antiparticle

5.3h Behaviors and characteristics of matter, from the microscopic to the cosmic levels, are manifestations of its atomic structure. The macroscopic characteristics of matter, such as electrical and optical properties, are the result of microscopic interactions.

5.3i The total of the fundamental interactions is responsible for the appearance and behavior of the objects in the universe.

5.3j The fundamental source of all energy in the universe is the conversion of mass into energy.*

APPENDIX A
Standards 1, 2, 6, & 7 Checklist

The Standards 1, 2, 6, & 7 Process Skills Checklist is intended to be a tool for curriculum development. These process skills should be incorporated into all core-based science curricula. These skills are not tied to specific content in the core, but should be practiced throughout the school year. During assessments, students will be presented with new situations to analyze and new problems to solve using these process skills.

Standard 1: Analysis, Inquiry, and Design

Students will use mathematical analysis, scientific inquiry, and engineering design, as appropriate, to pose questions, seek answers, and develop solutions.

Mathematical Analysis

Skill	✓	Comment
Key Idea 1: Abstraction and symbolic representation are used to communicate mathematically.		
M1.1 Use algebraic and geometric representations to describe and compare data.		
• Use scaled diagrams to represent and manipulate vector quantities.		
• Represent physical quantities in graphical form.		
• Construct graphs of real-world data (scatter plots, line or curve of best fit).		
• Manipulate equations to solve for unknowns.		
• Use dimensional analysis to confirm algebraic solutions.		
Key Idea 2: Deductive and inductive reasoning are used to reach mathematical conclusions.		
M2.1 Use deductive reasoning to construct and evaluate conjectures and arguments, recognizing that patterns and relationships in mathematics assist them in arriving at these conjectures and arguments.		
• Interpret graphs of real world data to determine the mathematical relationship between the variables.		
Key Idea 3: Critical thinking skills are used in the solution of mathematical problems.		
M3.1 Apply algebraic and geometric concepts and skills to the solution of problems.		
• Explain the physical relevance of properties of a graphical representation of real-world data, e.g., slope, intercepts, area under the curve.		

Scientific Inquiry

Skill	✓	Comment
Key Idea 1: The central purpose of scientific inquiry is to develop explanations of natural phenomena in a continuing, creative process. Students:		
• develop extended visual models and mathematical formulations to represent an understanding of natural phenomena		
• clarify ideas through reasoning, research, and discussion		
• evaluate competing explanations and overcome misconceptions		
Key Idea 2: Beyond the use of reasoning and consensus, scientific inquiry involves the testing of proposed explanations involving the use of conventional techniques and procedures and usually requiring considerable ingenuity. Students:		
S2.1 Devise ways of making observations to test proposed explanations.		
• Design an experiment to investigate the relationship between physical phenomena.		
S2.2 Refine research ideas through library investigations, including electronic information retrieval and reviews of the literature, and through peer feedback obtained from review and discussion.		
S2.3 Develop and present proposals including formal hypotheses to test explanations; i.e., predict what should be observed under specific conditions if the explanation is true.		
S2.4 Carry out a research plan for testing explanations, including selecting and developing techniques, acquiring and building apparatus, and recording observations as necessary. (*Note: This could apply to many activities from simple investigations to long-term projects.*)		
Key Idea 3: The observations made while testing proposed explanations, when analyzed using conventional and invented methods, provide new insights into phenomena. Students:		
S3.1 Use various means of representing and organizing observations (e.g., diagrams, tables, charts, graphs, equations, and matrices) and insightfully interpret the organized data.		
• Use appropriate methods to present scientific information (e.g., lab reports, posters, research papers, or multimedia presentations).		
• Identify possible sources of error in data collection and explain their effects on experimental results.		
S3.2 Apply statistical analysis techniques when appropriate to test if chance alone explains the result.		
• Examine collected data to evaluate the reliability of experimental results, including percent error, range, standard deviation, line of best fit, and the use of the correct number of significant digits.		
S3.3 Assess correspondence between the predicted result contained in the hypothesis and the actual result, and reach a conclusion as to whether or not the explanation on which the prediction was based is supported.		
S3.4 Based on results of the test and through public discussion, they revise the explanation and contemplate additional research. (*Note: Public discussion may include lab partners, lab groups, classes, etc.*)		

Engineering Design

Skill	✓	Comment
Key Idea 1: Engineering design is an iterative process involving modeling and optimization (finding the best solution within given constraints) which is used to develop technological solutions to problems within given constraints. Students:		
T1.1 Engage in the following steps of a design process:		
• Initiate and carry out a thorough investigation of an unfamiliar situation and identify needs and opportunities for technological invention or innovation.		
• Identify, locate, and use a wide range of information resources, and document through notes and sketches how findings relate to the problem.		
• Generate creative solutions, break ideas into significant functional elements, and explore possible refinements; predict possible outcomes, using mathematical and functional modeling techniques; choose the optimal solution to the problem, clearly documenting ideas against design criteria and constraints; and explain how human understandings, economics, ergonomics, and environmental considerations have influenced the solution.		
• Develop work schedules and working plans which include optimal use and cost of materials, processes, time, and expertise; construct a model of the solution, incorporating developmental modifications while working to a high degree of quality (craftsmanship).		
• Devise a test of the solution according to the design criteria and perform the test; record, portray, and logically evaluate performance test results through quantitative, graphic, and verbal means. Use a variety of creative verbal and graphic techniques effectively and persuasively to present conclusions, predict impacts and new problems, and suggest and pursue modifications.		

Standard 2: Information Systems

Students will access, generate, process, and transfer information, using appropriate technologies.

Skill	✓	Comment
Key Idea 1: Information technology is used to retrieve, process, and communicate information technology as a tool to enhance learning. Students:		
1.1 Understand and use the more advanced features of word processing, spreadsheets, and database software.		
1.2 Prepare multimedia presentations demonstrating a clear sense of audience and purpose.		
• Extend knowledge of physical phenomena through independent investigation, e.g., literature review, electronic resources, library research.		
• Use appropriate technology to gather experimental data, develop models, and present results.		
1.3 Access, select, collate, and analyze information obtained from a wide range of sources such as research databases, foundations, organizations, national libraries, and electronic communication networks, including the Internet.		
• Use knowledge of physics to evaluate articles in the popular press on contemporary scientific topics.		
1.4 Utilize electronic networks to share information.		
1.5 Model solutions to a range of problems in mathematics, science, and technology, using computer simulation software.		
• Use software to model and extend classroom and laboratory experiences, recognizing the differences between the model used for understanding and real-world behavior.		
Key Idea 2: Knowledge of the impacts and limitations of information systems is essential to its effective and ethical use.		
Key Idea 3: Information technology can have positive and negative impacts on society, depending on how it is used.		

Standard 6: Interconnectedness: Common Themes

Students will understand the relationships and common themes that connect mathematics, science, and technology and apply the themes to these and other areas.

Systems Thinking

Skill	✓	Comment
Key Idea 1: Through systems thinking, people can recognize the commonalities that exist among all systems and how parts of a system interrelate and combine to perform specific functions. Students:		
1.1 Define boundary conditions when doing systems analysis to determine what influences a system and how it behaves.		

Models

Skill	✓	Comment
Key Idea 2: Models are simplified representations of objects, structures, or systems used in analysis, explanation, interpretation, or design. Students:		
2.1 Revise a model to create a more complete or improved representation of the system.		
2.2 Collect information about the behavior of a system and use modeling tools to represent the operation of the system.		
• Observations of the behavior of a system can be used to develop a model.		
2.3 Find and use mathematical models that behave in the same manner as the processes under investigation.		
• Physical and mathematical models represent the behavior of real-world systems.		
2.4 Compare predictions to actual observations, using test models.		
• Experimental data can be collected to either validate or reject a model.		
• A model can be used to predict the behavior of a system.		

Magnitude and Scale

Skill	✓	Comment
Key Idea 3: The grouping of magnitudes of size, time, frequency, and pressures or other units of measurement into a series of relative order provides a useful way to deal with the immense range and the changes in scale that affect the behavior and design of systems. Students:		
3.1 Describe the effects of changes in scale on the functioning of physical, biological, or designed systems.		
3.2 Extend their use of powers of ten notation to understanding the exponential function and performing operations with exponential factors.		
• Orders of magnitude are used to estimate quantitative results.		
• Scientific notation is used to simplify calculations.		

Equilibrium and Stability

Skill	✓	Comment
Key Idea 4: Equilibrium is a state of stability due either to a lack of changes (static equilibrium) or a balance between opposing forces (dynamic equilibrium). Students:		
4.1 Describe specific instances of how disturbances might affect a system's equilibrium, from small disturbances that do not upset the equilibrium to larger disturbances (threshold level) that cause the system to become unstable.		
4.2 Cite specific examples of how dynamic equilibrium is achieved by equality of change in opposing directions.		

Patterns of Change

Skill	✓	Comment
Key Idea 5: Identifying patterns of change is necessary for making predictions about future behavior and conditions. Students:		
5.1 Use sophisticated mathematical models, such as graphs and equations of various algebraic or trigonometric functions.		
• Mathematical models such as graphs and equations can be used to predict the behavior of physical systems.		
5.2 Search for multiple trends when analyzing data for patterns, and identify data that do not fit the trends.		
• Patterns can be deduced from the organization and presentation of the data.		
• Patterns in data can be used to identify and develop models.		

Optimization

Skill	✓	Comment
Key Idea 6: In order to arrive at the best solution that meets criteria within constraints, it is often necessary to make trade-offs. Students:		
• Determine optimal solutions to problems that can be solved using quantitative methods.		

Standard 7: Interdisciplinary Problem Solving

Students will apply the knowledge and thinking skills of mathematics, science, and technology to address real-life problems and make informed decisions.

Connections

Skill	✓	Comment
Key Idea 1: The knowledge and skills of mathematics, science, and technology are used together to make informed decisions and solve problems, especially those relating to issues of science/technology/society, consumer decision making, design, and inquiry into phenomena.		
• Physics can be used in solving problems on many scales, e.g., local, national, and global.		
• Scientific methodology is used to solve real-world problems.		

Strategies

Skill	✓	Comment
Key Idea 2: Solving interdisciplinary problems involves a variety of skills and strategies, including effective work habits; gathering and processing information; generating and analyzing ideas; realizing ideas; making connections among the common themes of mathematics, science, and technology; and presenting results.		
• Collect, analyze, interpret, and present data, using appropriate tools.		
• If students participate in an extended, culminating mathematics, science, and technology project, then the students should:		
§ work effectively		
§ gather and process information		
§ generate and analyze ideas		
§ observe common themes		
§ realize ideas		
§ present results		

APPENDIX B
Standard 4 Process Skills Checklist

The Standard 4 Process Skills Checklist is intended to be a tool for curriculum development. These process skills should be incorporated into core-based physics curricula. These skills are tied to specific content in the core. During assessments, students will be presented with new situations to analyze and new problems to solve using these process skills.

Mechanics

The student will be able to:	✓	Comment
construct and interpret graphs of position, velocity, or acceleration versus time		
determine and interpret slopes and areas of motion graphs		
determine the acceleration due to gravity near the surface of the Earth		
determine the resultant of two or more vectors graphically or algebraically		
resolve a vector into perpendicular components: graphically and algebraically		
sketch the theoretical path of a projectile		
use vector diagrams to analyze mechanical systems (equilibrium and nonequilibrium)		
verify Newton's Second Law for linear motion		
determine the coefficient of friction for two surfaces		
verify Newton's Second Law for uniform circular motion		
verify conservation of momentum		
determine a spring constant		

Energy

The student will be able to:	✓	Comment
describe and explain the exchange between potential energy, kinetic energy, and internal energy for simple mechanical systems, such as a pendulum, a roller coaster, a spring, a freely falling object		
predict velocities, heights, and spring compressions based on energy conservation		
determine the energy stored in a spring		
observe and explain energy conversions in real-world situations		
recognize and describe conversions among different forms of energy in real or hypothetical devices such as a motor, a generator, a photocell, a battery		
compare the power developed when the same work is done at different rates		
determine the factors that affect the period of a pendulum		

Electricity and Magnetism

The student will be able to:	✓	Comment
measure current and voltage in a circuit		
use measurements to determine the resistance of a circuit element		
interpret graphs of voltage versus current		
measure and compare the resistance of conductors of various lengths and cross-sectional areas		
construct simple series and parallel circuits		
draw and interpret circuit diagrams which include voltmeters and ammeters		
predict the behavior of lightbulbs in series and parallel circuits		
map the magnetic field of a permanent magnet, indicating the direction of the field between the N (north-seeking) and S (south-seeking) poles		

Waves

The student will be able to:	✓	Comment
compare the characteristics of two transverse waves such as amplitude, frequency, wavelength, speed, period, and phase		
draw wave forms with various characteristics		
identify nodes and antinodes in standing waves		
differentiate between transverse and longitudinal waves		
identify nodes and aninnodes in standing waves		
determine the speed of sound in air		
predict the superposition of two waves interfering constructively and destructively (indicating nodes, antinodes, and standing waves)		
observe, sketch, and interpret the behavior of wave fronts as they reflect, refract, and diffract		
draw ray diagrams to represent the reflection and refraction of waves		
determine empirically the index of refraction of a transparent medium		

Modern Physics

The student will be able to:	✓	Comment
interpret energy-level diagrams		
correlate spectral lines with an energy-level diagram		

APPENDIX C
Process Skills Connections

The process skills connections table has been designed to assist teachers in curriculum writing and lesson planning. Real-world connections have been identified only to assist teachers in planning and are not meant to limit the scope of the content connections or to link these connections to any assessment.

Mechanics

Process Skills (The student will be able to…)	*Core Reference*	*Real-World Application*
construct and interpret graphs of position, velocity, or acceleration -ing versus time (5.1i)	4.1e, 4.1f, 5.1d	Global Positioning Systems (GPS), track and field
determine and interpret slopes and areas of motion graphs (5.1ii)	4.1e, 4.1f, 5.1d, 5.1e, 5.1f, 5.1i	mathematical slopes, calculus
determine the acceleration due to gravity near the surface of the Earth (5.1iii)	5.1e, 5.1l, 5.1p, 5.1t	weights, bungee jumping, skydiving
determine the resultant of two or more vectors graphically or algebraically (5.1iv)	5.1b-d, 5.1p-t	navigation (e.g., boats, planes, …)
draw scaled force diagrams, using a ruler and a protractor (5.1v)	5.1b-d, 5.1p-t	building design (stress analysis), cranes, picture hangers
resolve a vector into perpendicular components: graphically and algebraically (5.1vi)	5.1b-d, 5.1p-t	push lawn mower, amusement park wave swing
sketch the theoretical path of a projectile (5.1vii)	5.1f-h	tennis, soccer, golf, archery
use vector diagrams to analyze mechanical systems (equilibrium and nonequilibrium) (5.1viii)	5.1b-d, 5.1p-s	cars, elevators, tightrope walker, apparent weightlessness (micro-gravity)
verify Newton's Second Law for linear motion (5.1ix)	5.1i	space shuttle, cruise control
determine the coefficient of friction for two surfaces (5.1x)	4.1f-h, 5.1e	skidding on driving surfaces, ice skating, Teflon surfaces, sledding
verify Newton's Second Law for uniform circular motion (5.1xi)	5.1i, 5.1n	amusement park rides (e.g., merry-go-rounds)

Energy

Process Skills (The student will be able to…)	***Core Reference***	***Real-World Application***
verify conservation of momentum (5.1xii)	5.1p-r	car crashes, balls, bats
determine a spring constant (5.1xiii)	5.1m	car suspension systems, rubber bands, spring scales
describe and explain the exchange between potential energy, kinetic energy, and internal energy for simple mechanical systems, such as a pendulum, a roller coaster, a spring, a freely falling object (4.1i)	4.1a-j	skiing, skateboarding
predict velocities, heights, and spring compressions based on energy conservation (4.1ii)	4.1c, 4.1e, 4.1f, 4.1g	diving board, trampoline
determine the energy stored in a spring (4.1iii)	4.1c, 4.1e	ballpoint pen, pop-up toys
observe and explain energy conversions in real-world situations (4.1v)	4.1b	hydroelectric power, solar power, Sun, engines
recognize and describe conversions among different forms of energy in real or hypothetical devices such as a motor, a generator, a photocell, a battery (4.1vi)	4.1a-g	solar-powered calculator, electric fan, heat pumps, air conditioners, Peltier devices
compare the power developed when the same work is done at different rates (4.1vii)	4.1i	elevators, running versus walking up stairs, motorcycles versus tractor-trailers
determine the factors that affect the period of a pendulum (4.1iv)	4.1c, 4.1d, 4.1e, 4.1f, 4.1g	Pirate Ship and Sky Coaster (amusement park rides), grandfather clock, swing

Electricity and Magnetism

Process Skills (The student will be able to…)	***Core Reference***	***Real-World Application***
measure current and voltage in a circuit (4.1viii)	4.1l, 4.1m, 4.1p	transformers, power supplies, battery testers, power meters, multimeters
use measurements to determine the resistance of a circuit element (4.1ix)	4.1l, 4.1m, 4.1p	dimmer switches, volume controls, temperature controls (potentiometers)
interpret graphs of voltage versus current (4.1x)	4.1l, 4.1m, 4.1p	power meters, soundboard meters
measure and compare the resistance of conductors of various lengths and cross-sectional areas (4.1xi)	4.1m, 4.1o	toasters, hair dryers, power transmission lines
construct simple series and parallel circuits (4.1xii)	4.1n, 4.1o, 4.1p	household wiring, jumper cables, fuses, and circuit breakers
draw and interpret circuit diagrams which include voltmeters and ammeters (4.1xiii)	4.1n, 4.1o	schematic plans
predict the behavior of lightbulbs in series and parallel circuits (4.1xiv)	4.1n, 4.1o, 4.1p	holiday lights, flashlights
map the magnetic field of a permanent magnet, indicating the direction of the field between the N (north-seeking) and S (south-seeking) poles (4.1xv)	5.1u	compass, magnets, magnetic storage media (e.g., floppy disks, hard drives, tapes)

Waves

Process Skills (The student will be able to…)	***Core Reference***	***Real-World Application***
compare the characteristics of two transverse waves such as amplitude, frequency, wavelength, speed, period, and phase (4.3i)	4.3a-e	stadium waves, electromagnetic waves, S-waves (secondary earthquake waves)
draw wave forms with various characteristics (4.3ii)	4.3a, 4.3e, 4.3f	oscilloscopes
identify nodes and antinodes in standing waves (4.3iii)	4.3f	guitar string (vibrating stretched wire), pipe organ (vibrating air column)
differentiate between transverse and longitudinal waves (4.3iv)	4.3a-f	polarized sunglasses, liquid crystal displays (e.g., computer screens, watches, calculator), speakers, 3-D movies
determine the speed of sound in air (4.3v)	4.3c	echoes
predict the superposition of two waves interfering constructively and destructively (indicating nodes, antinodes, and standing waves) (4.3vi)	4.3c, 4.3f	stereo speakers, surround sound, iridescence (e.g., butterfly wings, soap bubbles), Tacoma Narrows Bridge, beats, electronic tuners
observe, sketch, and interpret the behavior of wave fronts as they reflect, refract, and diffract (4.3vii)	4.3h-k	ocean waves, amusement park wave pools, harbor waves, pond ripples, ultrasonic cleaners (standing waves)
draw ray diagrams to represent the reflection and refraction of waves (4.3viii)	4.3h-k	barcode scanners, mirrors
determine empirically the index of refraction of a transparent medium (4.3ix)	4.3j	diamonds, spearfishing, lenses

Modern Physics

Process Skills (The student will be able to…)	*Core Reference*	*Real-World Application*
interpret energy-level diagrams (5.3i)	4.3f, 5.3a-g	black light posters, lasers
correlate spectral lines with an energy-level diagram (5.3ii)	4.3f, 5.3a-g	neon lights, street lights

APPENDIX D
Performance Indicator Correlation Matrix

Mechanics

Sequence	*Performance Indicators*	*Core Reference*	*Skills* *(The student should be able to)*
I.1	Measured quantities can be classified as either vector or scalar.	5.1a	
I.2	An object in linear motion may travel with a constant velocity* or with acceleration*. *(Note: Testing of acceleration will be limited to cases in which acceleration is constant.)*	5.1d	5.1i, 5.1ii, 5.1iv, 5.1v, 5.1vi, 5.1viii
I.3	An object in free fall accelerates due to the force of gravity*. Friction and other forces cause the actual motion of a falling object to deviate from its theoretical motion. *(Note: Initial velocities of objects in free fall may be in any direction.)*	5.1e	5.1i, 5.1ii, 5.1iii, 5.1x
I.4	The resultant of two or more vectors, acting at any angle, is determined by vector addition.	5.1c	5.1iv, 5.1v, 5.1vi, 5.1viii
I.5	A vector may be resolved into perpendicular components.*	5.1b	5.1iv, 5.1v, 5.1vi, 5.1viii
I.6	The path of a projectile is the result of the simultaneous effect of the horizontal and vertical components of its motion; these components act independently.	5.1f	5.1i, 5.1ii, 5.1vii
I.7	A projectile's time of flight is dependent upon the vertical components of its motion.	5.1g	5.1vii
I.8	The horizontal displacement of a projectile is dependent upon the horizontal component of its motion and its time of flight.	5.1h	5.1vii
I.9	According to Newton's First Law, the inertia of an object is directly proportional to its mass. An object remains at rest or moves with constant velocity, unless acted upon by an unbalanced force.	5.1i	5.1i, 5.1ii, 5.1ix, 5.1xi
I.10	When the net force on a system is zero, the system is in equilibrium.	5.1j	
I.11	According to Newton's Second Law, an unbalanced force causes a mass to accelerate*.	5.1k	
I.12	Weight is the gravitational force with which a planet attracts a mass.* The mass of an object is independent of the gravitational field in which it is located.	5.1l	5.1iii
I.13	Kinetic friction* is a force that opposes motion.	5.1o	

Mechanics continued

Sequence	*Performance Indicators*	*Core Reference*	*Skills* *(The student should be able to)*
I.14	Centripetal force* is the net force which produces centripetal acceleration*. In uniform circular motion, the centripetal force is perpendicular to the tangential velocity.	5.1n	5.1xi
I.15	The impulse* imparted to an object causes a change in its momentum*.	5.1p	5.1iii, 5.1iv, 5.1v, 5.1vi, 5.1viii, 5.1xiii
I.16	The elongation or compression of a spring depends upon the nature of the spring (its spring constant) and the magnitude of the applied force.*	5.1m	5.1xiii
I.17	According to Newton's Third Law, forces occur in action/reaction pairs. When one object exerts a force on a second, the second exerts a force on the first that is equal in magnitude and opposite in direction.	5.1q	5.1iv, 5.1v, 5.1vi, 5.1viii, 5.1xii
I.18	Momentum is conserved in a closed system.* *(Note: Testing will be limited to momentum in one dimension.)*	5.1r	5.1iv, 5.1v, 5.1vi, 5.1viii 5.1xii
I.19	Gravitational forces are only attractive, whereas electrical and magnetic forces can be attractive or repulsive.	5.1t	5.1iii, 5.1iv, 5.1v, 5.1vi
I.20	The inverse square law applies to electrical* and gravitational* fields produced by point sources.	5.1u	4.1xv
I.21	Field strength* and direction are determined using a suitable test particle. *(Notes: 1)Calculations are limited to electrostatic and gravitational fields. 2)The gravitational field near the surface of Earth and the electrical field between two oppositely charged parallel plates are treated as uniform.)*	5.1s	5.1iv, 5.1v, 5.1vi, 5.1viii

Energy

Sequence	*Performance Indicators*	*Core Reference*	*Skills* *(The student should be able to)*
II.1	When work* is done on or by a system, there is a change in the total energy* of the system.	4.1g	4.1i, 4.1ii, 4.1iv, 4.1vi, 5.1x
II.2	Work done against friction results in an increase in the internal energy of the system.	4.1h	4.1i, 5.1x
II.3	Power* is the time-rate at which work is done or energy is expended.	4.1j	4.1i, 4.1vii
II.4	All energy transfers are governed by the law of conservation of energy.*	4.1a	4.1i, 4.1vi
II.5	Energy may be converted among mechanical, electromagnetic, nuclear, and thermal forms.	4.1b	4.1i, 4.1v, 4.1vi
II.6	Potential energy is the energy an object possesses by virtue of its position or condition. Types of potential energy are gravitational* and elastic.*	4.1c	4.1i, 4.1ii, 4.1iii, 4.1iv, 4.1vi
II.7	Kinetic energy* is the energy an object possesses by virtue of its motion.	4.1d	4.1i, 4.1iv, 4.1vi
II.8	In an ideal mechanical system, the sum of the macroscopic kinetic and potential energies (mechanical energy) is constant.*	4.1e	4.1i, 4.1ii, 4.1iii, 4.1vi, 5.1i, 5.1ii
II.9	In a nonideal mechanical system, as mechanical energy decreases there is a corresponding increase in other energies such as internal energy.*	4.1f	4.1i, 4.1ii, 4.1iv, 4.1vi, 5.1i, 5.1ii, 5.1x

Electricity and Magnetism

Sequence	*Performance Indicators*	*Core Reference*	*Skills (The student should be able to)*
III.1	Gravitational forces are only attractive, whereas electrical and magnetic forces can be attractive or repulsive.	5.1t	
III.2	The inverse square law applies to electrical* and gravitational* fields produced by point sources.	5.1u	
III.3	Energy may be stored in electric* or magnetic fields. This energy may be transferred through conductors or space and may be converted to other forms of energy.	4.1j	4.1i
III.4	The factors affecting resistance in a conductor are length, cross-sectional area, temperature, and resistivity.*	4.1m	4.1viii, 4.1ix, 4.1x, 4.1xi
III.5	All materials display a range of conductivity. At constant temperature, common metallic conductors obey Ohm's Law*.	4.1l	4.1viii, 4.1ix, 4.1x
III.6	A circuit is a closed path in which a current* can exist. *(Note: Use conventional current.)*	4.1n	4.1xii, 4.1xiii, 4.1xiv
III.7	Electrical power* and energy* can be determined for electric circuits.	4.1p	4.1viii, 4.1ix, 4.1x, 4.1xii, 4.1xiv
III.8	Circuit components may be connected in series* or in parallel.* Schematic diagrams are used to represent circuits and circuit elements.	4.1o	4.1xi, 4.1xii, 4.1xiii, 4.1xiv
III.9	Moving electric charges produce magnetic fields. The relative motion between a conductor and a magnetic field may produce a potential difference in the conductor.	4.1k	

Waves

Sequence	*Performance Indicators*	*Core Reference*	*Skills (The student should be able to)*
IV.1	An oscillating system produces waves. The nature of the system determines the type of wave produced.	4.3a	4.3i, 4.3ii, 4.3iv
IV.2	Waves carry energy and information without transferring mass. This energy may be carried by pulses or periodic waves.	4.3b	4.3i, 4.3iv
IV.3	Waves are categorized by the direction in which particles in a medium vibrate about an equilibrium position relative to the direction of propagation of the wave such as transverse and longitudinal waves.	4.3e	4.3i, 4.3ii, 4.3iv
IV.4	Mechanical waves require a material medium through which to travel.	4.3d	4.3i, 4.3iv
IV.5	The model of a wave incorporates the characteristics of amplitude, wavelength*, frequency*, period*, wave speed*, and phase.	4.3c	4.3i, 4.3iv, 4.3v, 4.3vi
IV.6	Electromagnetic radiation exhibits wave characteristics. Electromagnetic waves can propagate through a vacuum.	4.3g	
IV.7	All frequencies of electromagnetic radiation travel at the same speed in a vacuum.*	4.3k	4.3vii, 4.3viii
IV.8	When a wave strikes a boundary between two media, reflection*, transmission, and absorption occur. A transmitted wave may be refracted.	4.3h	4.3vii, 4.3viii
IV.9	When a wave moves from one medium into another, the wave may refract due to a change in speed. The angle of refraction (measured with respect to the normal) depends on the angle of incidence and the properties of the media (indices of refraction).*	4.3i	4.3vii, 4.3viii
IV.10	The absolute index of refraction is inversely proportional to the speed of a wave.*	4.3j	4.3vii, 4.3viii, 4.3vix
IV.11	When waves of a similar nature meet, the resulting interference may be explained using the Principle of Superposition. Standing waves are a special case of interference.	4.3m	
IV.12	Resonance occurs when energy is transferred to a system at its natural frequency.	4.3f	4.3ii, 4.3iii, 4.3iv, 4.3vi, 5.3i, 5.3ii
IV.13	Diffraction occurs when waves pass by obstacles or through openings. The wavelength of the incident wave and the size of the obstacle or opening affect how the wave spreads out.	4.3l	
IV.14	When a wave source and an observer are in relative motion, the observed frequency of the waves traveling between them is shifted (Doppler effect).	4.3n	

Modern Physics

Sequence	*Performance Indicators*	*Core Reference*	*Skills* (*The student should be able to*)
V.1	States of matter and energy are restricted to discrete values (quantized).	5.3a	
V.2	Charge is quantized on two levels. On the atomic level, charge is restricted to the elementary charge (charge on an electron or proton). On the subnuclear level charge appears as fractional values of the elementary charge (quarks).	5.3b	
V.3	On the atomic level, energy is emitted or absorbed in discrete packets called photons.*	5.3c	
V.4	The energy of a photon is proportional to its frequency.*	5.3d	
V.5	On the atomic level, energy and matter exhibit the characteristics of both waves and particles.	5.3e	
V.6	Among other things, mass-energy and charge are conserved at all levels (from subnuclear to cosmic).	5.3f	
V.7	The Standard Model of Particle Physics has evolved from previous attempts to explain the nature of the atom and states that: 1. Atomic particles are composed of subnuclear particles. 2. The nucleus is a conglomeration of quarks which manifest themselves as protons and neutrons. 3. Each elementary particle has a corresponding antiparticle.	5.3g	
V.8	Behaviors and characteristics of matter, from the microscopic to the cosmic levels, are manifestations of its atomic structure. The macroscopic characteristics of matter, such as electrical and optical properties, are the result of microscopic interactions.	5.3h	
V.9	The total of the fundamental interactions is responsible for the appearance and behavior of the objects in the universe.	5.3i	
V.10	The fundamental source of all energy in the universe is the conversion of mass into energy.*	5.3j	