Summit High School
Summit, NJ

Grade Level/Content Area: 12th Grade AP® Physics C
Length of Course: 1 year
(Revised Summer 2017)

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Table of Contents

Course Description

About this document

Course Pacing Guide

Content Curriculum
- **Newtonian Mechanics**
  - Unit 1: Kinematics
  - Unit 2: Dynamics
  - Unit 3: Energy and Momentum
  - Unit 4: Rotation
  - Unit 5: Oscillations and Gravitation
- **Electricity and Magnetism**
  - Unit 6: Electrostatics, conductors, capacitors and dielectrics
  - Unit 7: Electrical circuits
  - Unit 8: Magnetic fields and Electromagnetism

Texts and Resources

Course Description: Advanced Placement Physics C is designed for the student with exceptional aptitude for and interest in mathematics and the physical sciences. We utilize guided inquiry and student-centered learning to engage the development of critical and analytical thinking skills. The course will address all of the basic concepts covered in the first part of the regular level physics course but to a depth equal to that of a first year college course for students majoring in engineering or the physical sciences. The first part of the course (approx 18 weeks) covers mechanics, while the second part (approx 14 weeks) covers electricity and magnetism.

Topics covered are in keeping with the suggested syllabus of the College Board. Students will understand how physics principles and concepts are developed from observations and data and, whenever possible, will develop these principles on the basis of experimentation. The Mechanics portion of the course covers classical Newtonian mechanics: kinematics, dynamics, work & energy, momentum, rotational motion, oscillations and gravitation. The Electricial & Magnetism part covers classical electrodynamics up to Maxwell: electrostatics, electronic devices, circuits, magnetostatics, and electromagnetism. Descriptive physics is included in the study of these areas and serves to help the students understand how ordinary physical phenomena are included in everyday activities. After the AP examination students will study special topics and projects, such as special relativity, a design challenge, and/or a science book report.

About this document: What follows is a guide to the course content and practices. Included are “Big Ideas”, “Essential Questions”, “Enduring Understandings”, “Proficiencies”, and Examples of Outcomes and Assessments as they appear in the classroom. Although this course is not officially aligned with Next Generation Science Standards, we have included relevant standards within the document to reflect areas of coverage. Most of the Big Ideas come from the Science and Engineering Practices; many of the Enduring Understandings come from the Crosscutting concepts; and many of the Proficiencies come from the Disciplinary Core Ideas. Otherwise the document is largely adapted from the official AP Physics C Objective outline. Please note that it is impossible to cover everything that is listed in any give year, as time and schedule constraints require teachers to pick and choose. Rather, what follows can be thought of as a list of potential topics, activities, and assessments from which to choose for a successful school year.

Course Pacing Guide

Weeks	Unit	Key Topics
Summer assignment	Kinematics review	1-D Motion, equations of kinematics, calculus applications, motion graphs, freefall
Weeks 1-3	Kinematics	Vectors, Projectiles, 2-D Motion, uniform and nonuniform circular motion Relative Motion
Weeks 4-6	Dynamics	Newton's Laws, Friction, Applications, Centripetal force, Air Drag
Weeks 7-11	Energy and Momentum	Work and energy, energy conservation, Power, Momentum and impulse, momentum conservation, center of mass
Weeks 12-15	Rotation	Angular kinematics, dynamics, moment of inertia, rotational energy, angular momentum and conservation
Weeks 16-18	Oscillations and Gravitation	Simple harmonic motion, harmonic oscillators, pendulums, Universal gravitation, Kepler's Laws, gravitational potential energy and orbital applications
Weeks 19-23	Electrostatics, conductors, capacitors and dielectrics	Charging methods, Gauss's Law, electric potential, conductors in equilibrium, conductors and applications, dielectric properties
Weeks 24-26	Circuits	Current, Power, series and parallel circuits, complex circuits, Kirchoff's Laws and applications, RC circuits
Weeks 27-30	Magnetic fields and Electromagnetism	Lorentz forces, Hall effect, Ferromagnetism, Magnetism of current carrying wires and loops, solenoids, Ampere's Law and applications, Faraday and Lenz's Law, induction and applications, Maxwell's equations
Weeks 31-32	AP Exam Review	
Weeks 33-34	AP Exams	

Weeks 35-39	Post-AP exam assignments	Special relativity, design projects, book reports

Content Curriculum: Newtonian Mechanics
Unit 1
Kinematics

NGSS Standards: N/A	
Big Ideas: from *Science and Engineering Practices* Plan and conduct an investigation individually and collaboratively to produce data to serve as the basis for evidence, and in the design: decide on types, how much, and accuracy of data needed to produce reliable measurements and consider limitations on the precision of the data (e.g., number of trials, cost, risk, time), and refine the design accordingly. Analyze data using tools, technologies, and/or models (e.g., computational, mathematical) in order to make valid and reliable scientific claims or determine an optimal design solution. Use mathematical representations of phenomena to describe explanations. Theories and laws provide explanations in science. Laws are statements or descriptions of the relationships among observable phenomena. Develop and use a model based on evidence to illustrate the relationships between systems or between components of a system. Create a computational model or simulation of a phenomenon, designed device, process, or system. A scientific theory is a substantiated explanation of some aspect of the natural world, based on a body of facts that have been repeatedly confirmed through observation and experiment and the science community validates each theory before it is accepted. If new evidence is discovered that the theory does not accommodate, the theory is generally modified in light of this new evidence.	
Essential Questions	**Enduring Understandings**

What provocative questions will foster inquiry, understanding, and transfer of learning?	*What will students understand about the big ideas?*
How would you quantitatively describe the motion of a fighter jet landing on a carrier deck in a way that would help designers and pilots? How would you estimate the arrival time of your commute with knowledge of the different speed limits and starts and stops along the way? As the space shuttle lands and slows to a stop, is it accurate to say that it is “accelerating”? When fragments of rock are ejected from a volcano, what factors determine which will land farthest from the volcano? What information would a bee need to specify to tell other bees the location of a flowerbed? Why must a sailboat “tack” back and forth across the wind during a journey and how is it able to move against a wind? How did film crews achieve the effect of weightlessness in scenes of “Apollo 13”?	From NGSS Crosscutting concepts: Patterns ● Different patterns may be observed at each of the scales at which a system is studied and can provide evidence for causality in explanations of phenomena. Cause and Effect ● Empirical evidence is required to differentiate between cause and correlation and make claims about specific causes and effects. ● Systems can be designed to cause a desired effect. ● Cause and effect relationships can be suggested and predicted for complex natural and human designed systems by examining what is known about smaller scale mechanisms within the system. Systems and System Models ● When investigating or describing a system, the boundaries and initial conditions of the system need to be defined. ● Models can be used to predict the behavior of a system, but these predictions have limited precision and reliability due to the assumptions and approximations inherent in models. Scale, Proportion, and Quantity ● The significance of a phenomenon is dependent on the scale, proportion, and quantity at which it occurs. ● Algebraic thinking is used to examine scientific data and predict the effect of a change in one variable on another (e.g., linear growth vs. exponential growth).

	Influence of Science, Engineering and Technology on Society and the Natural World ● Modern civilization depends on major technological systems. Engineers continuously modify these technological systems by applying scientific knowledge and engineering design practices to increase benefits while decreasing costs and risks. Interdependence of Science, Engineering, and Technology ● Science and engineering complement each other in the cycle known as research and development (R&D). Many R&D projects may involve scientists, engineers, and others with wide ranges of expertise. Scientific Knowledge Assumes an Order and Consistency in Natural Systems ● Science assumes the universe is a vast single system in which basic laws are consistent. ● Scientific knowledge is based on the assumption that natural laws operate today as they did in the past and they will continue to do so in the future. From AP Physics C Objectives Students will understand… a. the general relationship among position, velocity and acceleration for the motion of a particle along a straight line b. the special case of motion with constant acceleration c. how to deal with situations in which acceleration is a specified function of velocity and time d. how to add, subtract and resolve displacement and velocity vectors

	e. the general motion of a particle in two dimensions f. The motion of projectiles in a uniform gravitational field

Areas of Focus: Proficiencies (Cumulative Progress Indicators)	**Examples, Outcomes, Assessments**
From NGSS Disciplinary Core Ideas: N/A ____ From AP Physics C Objectives Students can... a. given a graph of one of the kinematics quantities, position, velocity, or acceleration, as a function of time, recognize in what time intervals the other two are positive, negative, or zero and identify or sketch a graph of each as a function of time; determine the other two as a function of time, and find when these quantities are zero or achieve their maximum and minimum values. b. write down expressions for velocity and position as functions of time, and identify or sketch graphs of these quantities; use the standard kinematics equations to solve problems involving 1-D motion with constant acceleration. c. write an appropriate differential equation and solve it for v(t) by separation of variables, incorporating correctly a given initial value of v d. determine components of a vector along two specified, mutually perpendicular axes; determine the net displacement of a particle or the location of a particle relative to another; determine the change in velocity of a particle or the velocity of one particle relative to another e. given functions x(t) and y(t) which describe general motion, determine the components, magnitude and direction	**Instructional Focus:** ● Mathematical derivation of key formulas and concepts ● Problem solving techniques and strategies ● Hands-on exploration of unit topics ● Comparison of theoretical simplifications to real-world complexities ● Real-world applications and connections to individual student interests ● Measurement techniques and error analysis ● Calculus applications ● Preparation for AP exam **Sample Assessments:** ● Daily assignments and homework quizzes ● Collaborative projects ● Multiple choice items from textbook test banks and released AP exams ● Free response problems from released AP exams ● Unit Exam ● Lab: Graph matching ● Lab: Galileo and the Inclined Plane ● Lab: Projectile launch challenge **Instructional Strategies:** **Interdisciplinary Connections** ● Astronomy: Relative distances and velocities. ● History: Knowledge of velocity, distance and time allowed the ancient

of the particle's velocity and acceleration as functions of time f. write down expressions for the horizontal and vertical components of velocity and position as a function of time, and sketch or identify graphs of these components; use these expressions in analyzing the motion of a projectile that is projected with an arbitrary initial velocity	Greeks to accurately estimate the circumference of the Earth ● History: biographical sketch of Galileo ● Mathematics: algebraic manipulation of single variable equations (average speed, wave equation); arithmetic calculations ● Math: Calculations of energies, velocities, forces at various points in a roller coaster. ● Math: Numerical integration of kinematic data to yield physical constants. ● Math: Numerical integration of a force and time graph to yield impulse. ● Forensic Science: determining initial speeds and positions of vehicles before an automobile collision. **Technology Integration** ● Use of computer spreadsheet software programs (Excel, Graphical Analysis, etc) to analyze data graphically ● Using infrared photogate timing devices to measure velocity ● Use computers to collect data on fast moving objects ● Use motion sensors, photo gates, and video cameras to record motion data ● Use computers to store motion data, and calculate velocities and acceleration **Media Literacy Integration** ● Often our metal images of famous scientists are formed from information presented in classroom movies. Sometimes this information is inaccurate or misleading. ● We need to consider the credentials of the "experts" who speak in educational media. **Global Perspectives** ● Explore travel distances and velocities of various modes of transportation.

	• Explore travel distances and velocities of peoples from various societies today and in the past. • Explore travel direction, distances and velocities of oil from the 2010 Gulf Oil Spill. • Explore the concept of planetary travel to the Moon, Mars, and beyond.

Unit 2
Dynamics

NGSS standards:

HS-PS2-1 Analyze data to support the claim that Newton's second law of motion describes the mathematical relationship among the net force on a macroscopic object, its mass, and its acceleration.

Big Ideas: from *Science and Engineering Practices*

Plan and conduct an investigation individually and collaboratively to produce data to serve as the basis for evidence, and in the design: decide on types, how much, and accuracy of data needed to produce reliable measurements and consider limitations on the precision of the data (e.g., number of trials, cost, risk, time), and refine the design accordingly.

Analyze data using tools, technologies, and/or models (e.g., computational, mathematical) in order to make valid and reliable scientific claims or determine an optimal design solution.

Use mathematical representations of phenomena to describe explanations.

Apply scientific ideas to solve a design problem, taking into account possible unanticipated effects.

Theories and laws provide explanations in science.

Laws are statements or descriptions of the relationships among observable phenomena.

Develop and use a model based on evidence to illustrate the relationships between systems or between components of a system.

Create a computational model or simulation of a phenomenon, designed device, process, or system.

Design, evaluate, and/or refine a solution to a complex real-world problem, based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and tradeoff considerations.

A scientific theory is a substantiated explanation of some aspect of the natural world, based on a body of facts that have been repeatedly confirmed through observation and experiment and the science community validates each theory before it is accepted. If new evidence is discovered that the theory does not accommodate, the theory is generally modified in light of this new evidence.

Essential Questions *What provocative questions will foster inquiry, understanding, and transfer of learning?*	**Enduring Understandings** *What will students understand about the big ideas?*
How is it possible for a single person to support the vertical weight of an airship and what property makes it impossible to abruptly change its horizontal motion? When a horse pulls a buggy, and the action force of the horse pulling on the buggy is equal to the reaction force of the buggy pulling on the horse, how is it possible for the system to move at all? Why is it possible to juggle when riding in a moving airplane? How could an airplane passenger determine the rate of acceleration down the runway with only a shoelace, a wedding ring, and a camera? What factors determine how fast a car can go around a corner without skidding? How do airplanes receive lift? What factors determine the maximum falling speed of a skydiver?	From NGSS Crosscutting concepts: Patterns ● Different patterns may be observed at each of the scales at which a system is studied and can provide evidence for causality in explanations of phenomena. Cause and Effect ● Empirical evidence is required to differentiate between cause and correlation and make claims about specific causes and effects. ● Systems can be designed to cause a desired effect. ● Cause and effect relationships can be suggested and predicted for complex natural and human designed systems by examining what is known about smaller scale mechanisms within the system. Systems and System Models ● When investigating or describing a system, the boundaries and initial conditions of the system need to be defined. ● Models can be used to predict the behavior of a system, but these predictions have limited precision and reliability due to the assumptions and approximations inherent in models. Scale, Proportion, and Quantity ● The significance of a phenomenon is dependent on the scale, proportion, and quantity at which it occurs. ● Algebraic thinking is used to examine scientific data and predict the effect of a change in one

	variable on another (e.g., linear growth vs. exponential growth). Influence of Science, Engineering and Technology on Society and the Natural World ● Modern civilization depends on major technological systems. Engineers continuously modify these technological systems by applying scientific knowledge and engineering design practices to increase benefits while decreasing costs and risks. Interdependence of Science, Engineering, and Technology ● Science and engineering complement each other in the cycle known as research and development (R&D). Many R&D projects may involve scientists, engineers, and others with wide ranges of expertise. Scientific Knowledge Assumes an Order and Consistency in Natural Systems ● Science assumes the universe is a vast single system in which basic laws are consistent. ● Scientific knowledge is based on the assumption that natural laws operate today as they did in the past and they will continue to do so in the future. From AP Physics C Objectives: Students will understand… a. static objects or objects moving with constant velocity have a balance of forces and are dynamically equivalent b. the relation between the force that acts on an object and the resulting change in the object's velocity

<table>
<tr><td></td><td>c. how Newton's second law applies to an object subject to forces such as gravity, the pull of strings or contact forces
d. how to analyze general dynamics situations
e. the significance of the coefficient of friction
f. the effect of drag forces on the motion of an object
g. the significance of Newton's third law
h. how to apply Newton's third law
i. that tension in a light string passing over a massless pulley is constant
j. that some problems in dynamics lead to two or three simultaneous equations</td></tr>
<tr><th>Areas of Focus: Proficiencies
(Cumulative Progress Indicators)</th><th>Examples, Outcomes, Assessments</th></tr>
<tr><td>From NGSS DCI:
PS2.A: Forces and Motion
● Newton's second law accurately predicts changes in the motion of macroscopic objects. (HS-PS2-1)
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Furthermore students will…
a. be able to analyze situations in which a particle remains at rest, or moves with constant velocity, under the influence of several forces
b. calculate, for an object moving in 1-D, the velocity change that results when a constant force acts over a specified time interval; the velocity change that results when a changing force F(t) acts over a specified time interval; determine, for an object moving in a plane whose velocity vector undergoes a specified change over a specified time interval, the average force that acted on the object
c. draw a well-labeled, free-body diagram showing all real forces that act on the object; write down the vector equation</td><td>Instructional Focus:
● Mathematical derivation of key formulas and concepts
● Problem solving techniques and strategies
● Hands-on exploration of unit topics
● Comparison of theoretical simplifications to real-world complexities
● Real-world applications and connections to individual student interests
● Measurement techniques and error analysis
● Calculus applications
● Preparation for AP exam

Sample Assessments:
● Daily assignments and homework quizzes
● Collaborative projects
● Multiple choice: items from textbook test banks and released AP exams
● Free response problems from released AP exams
● Unit Exam
● Lab: Connected bodies</td></tr>
</table>

that results from applying Newton's Second Law to the object, and take components of this equation along appropriate axes d. analyze situations in which an object moves with specified acceleration under the influence of one or more forces and determine the magnitude and direction of the net force, or of one of the forces that makes up the net force, such as motion up or down with constant acceleration e. write down the relationship between the normal and frictional forces on a surface; analyze situations in which an object moves along a rough inclined plane or horizontal surface; analyze under what circumstances an object will start to slip or to calculate the magnitude of the force of static friction f. find the terminal velocity of an object moving vertically under the influence of a retarding force dependent on velocity; describe qualitatively, with the aid of graphs, the acceleration, velocity and displacement of such a particle when it is released from rest or is projected vertically with specified initial velocity; use Newton's Second Law to write a differential equation for the velocity of the object as a function of time; use the method of separation of variables to derive the equation for the velocity as a function of time from the differential equation; derive an expression for the acceleration as a function of time for an object falling under the influence of drag forces g. identify the force pairs and the objects on which they act and state the magnitude and direction of each force h. apply Newton's third law in analyzing the force of contact between two objects that accelerate together along a horizontal or vertical line, or between	● Lab: Whirligig (uniform circular motion) ● Lab: Measurement of Pasco cart spring constant with computer integration **Instructional Strategies:** **Interdisciplinary Connections** ● History: to put Isaac Newton's 1687 magnum opus, *The Principia*, into its historical context ● Biology: Discuss the maximum boundaries of acceleration on the human body, particularly in roller coasters, airplanes, and spaceships. ● Biological basis of roller coaster design constraints – g-forces. **Technology Integration** ● Collect force data using computer based lab probeware ● Use motion and force sensors to determine frictional forces. ● Use of computer spreadsheet software programs (Excel, Graphical Analysis, etc) to analyze data graphically **Media Literacy Integration** ● Articles published in magazines are significantly different from articles published in peer reviewed scholarly journals. ● Scientifically literate students should be able to identify the critical difference between the two types of media. **Global Perspectives** ● The laws of mechanics—equivalent throughout the universe—transcend geographical and cultural borders. ● Inertia and relative motion as a reference frame phenomena--metaphor for Point of View ● Historical background of Newton's life and work

two surfaces that slide across one another i. analyze the motion of a system of two objects joined by a string j. solve problems in which application of Newton's laws leads to two or three simultaneous linear equations involving unknown forces or accelerations	

Unit 3
Energy and Momentum

NGSS Standards:
HS-PS3-1 Create a computational model to calculate the change in the energy of one component in a system when the change in energy of the other component(s) and energy flows in and out of the system are known **HS-PS3-2** Develop and use models to illustrate that energy at the macroscopic scale can be accounted for as a combination of energy associated with the motion of particles (objects) and energy associated with the relative position of particles (objects). **HS-PS3-3** Design, build, and refine a device that works within given constraints to convert one form of energy into another form of energy. **HS-PS2-2** Use mathematical representations to support the claim that the total momentum of a system of objects is conserved when there is no net force on the system. **HS-PS2-3** Apply science and engineering ideas to design, evaluate, and refine a device that minimizes the force on a macroscopic object during a collision.*
Big Ideas: from *Science and Engineering Practices* Plan and conduct an investigation individually and collaboratively to produce data to serve as the basis for evidence, and in the design: decide on types, how much, and accuracy of data needed to produce reliable measurements and consider limitations on the precision of the data (e.g., number of trials, cost, risk, time), and refine the design accordingly. Analyze data using tools, technologies, and/or models (e.g., computational, mathematical) in order to make valid and reliable scientific claims or determine an optimal design solution. Use mathematical representations of phenomena to describe explanations. Apply scientific ideas to solve a design problem, taking into account possible unanticipated effects.

Theories and laws provide explanations in science. Laws are statements or descriptions of the relationships among observable phenomena. Develop and use a model based on evidence to illustrate the relationships between systems or between components of a system. Create a computational model or simulation of a phenomenon, designed device, process, or system. Design, evaluate, and/or refine a solution to a complex real-world problem, based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and tradeoff considerations. A scientific theory is a substantiated explanation of some aspect of the natural world, based on a body of facts that have been repeatedly confirmed through observation and experiment and the science community validates each theory before it is accepted. If new evidence is discovered that the theory does not accommodate, the theory is generally modified in light of this new evidence.

Essential Questions *What provocative questions will foster inquiry, understanding, and transfer of learning?*	**Enduring Understandings** *What will students understand about the big ideas?*
When a pole-vaulter springs over the bar, what energy transformations are involved? Why do “fish ladders” help salmon in their journey over a dam? In the carnival “Ring the Bell” attraction, what is the best strategy to win the game? When a high diver dives into the water, what energy transformations are involved? How does energy conservation help roller coaster designers know how high up the cars must be when they start their descent to negotiate a loop-the-loop? What is more dangerous: being tackled by a lightweight football player moving	From the NGSS Crosscutting concepts: Patterns ● Different patterns may be observed at each of the scales at which a system is studied and can provide evidence for causality in explanations of phenomena. Cause and Effect ● Empirical evidence is required to differentiate between cause and correlation and make claims about specific causes and effects. ● Systems can be designed to cause a desired effect. ● Cause and effect relationships can be suggested and predicted for complex natural and human designed systems by examining

quickly or by a player of twice the speed moving half as fast? What principles govern the behavior of rockets? Do golfers benefit from more massive clubs? Why does an airbag protect passengers during a car crash?	what is known about smaller scale mechanisms within the system. Systems and System Models ● When investigating or describing a system, the boundaries and initial conditions of the system need to be defined. ● Models can be used to predict the behavior of a system, but these predictions have limited precision and reliability due to the assumptions and approximations inherent in models. Scale, Proportion, and Quantity ● The significance of a phenomenon is dependent on the scale, proportion, and quantity at which it occurs. ● Algebraic thinking is used to examine scientific data and predict the effect of a change in one variable on another (e.g., linear growth vs. exponential growth). Energy and Matter ● Changes of energy and matter in a system can be described in terms of energy and matter flows into, out of, and within that system. ● Energy cannot be created or destroyed—only moves between one place and another place, between objects and/or fields, or between systems. Influence of Science, Engineering and Technology on Society and the Natural World ● Modern civilization depends on major technological systems. Engineers continuously modify these technological systems by applying scientific knowledge and engineering design practices to increase benefits while decreasing costs and risks.

	Interdependence of Science, Engineering, and Technology ● Science and engineering complement each other in the cycle known as research and development (R&D). Many R&D projects may involve scientists, engineers, and others with wide ranges of expertise. Scientific Knowledge Assumes an Order and Consistency in Natural Systems ● Science assumes the universe is a vast single system in which basic laws are consistent. ● Scientific knowledge is based on the assumption that natural laws operate today as they did in the past and they will continue to do so in the future. From the AP Physics C Objectives: Students will understand… a. the definition of work, including when it is positive, negative, and zero b. how to apply the work-energy theorem c. the concept of a conservative force d. the concept of potential energy e. the concepts of mechanical energy and total energy f. the principle of energy conservation g. that some situations require the application of conservation of energy and Newton's Laws h. the definition of power i. the technique for finding center of mass j. the relation between center of mass velocity and linear momentum and between center of mass acceleration and net external force for a system of particles k. the definition of center of gravity l. impulse and linear momentum m. linear momentum conservation n. frames of reference

Areas of Focus: Proficiencies (Cumulative Progress Indicators)	Examples, Outcomes, Assessments
From the NGSS DCI's: **PS3.A: Definitions of Energy** ● Energy is a quantitative property of a system that depends on the motion and interactions of matter and radiation within that system. That there is a single quantity called energy is due to the fact that a system's total energy is conserved, even as, within the system, energy is continually transferred from one object to another and between its various possible forms. (HS-PS3-1),(HS-PS3-2) ● At the macroscopic scale, energy manifests itself in multiple ways, such as in motion, sound, light, and thermal energy. (HS-PS3-2) (HS-PS3-3) ● These relationships are better understood at the microscopic scale, at which all of the different manifestations of energy can be modeled as a combination of energy associated with the motion of particles and energy associated with the configuration (relative position of the particles). In some cases the relative position energy can be thought of as stored in fields (which mediate interactions between particles). This last concept includes radiation, a phenomenon in which energy stored in fields moves across space. (HS-PS3-2) **PS3.B: Conservation of Energy and Energy Transfer**	**Instructional Focus:** ● Mathematical derivation of key formulas and concepts ● Problem solving techniques and strategies ● Hands-on exploration of unit topics ● Comparison of theoretical simplifications to real-world complexities ● Real-world applications and connections to individual student interests ● Measurement techniques and error analysis ● Calculus applications ● Preparation for AP exam **Sample Assessments:** ● Daily assignments and homework quizzes ● Collaborative projects ● Multiple choice: items from textbook test banks and released AP exams ● Free response problems from released AP exams ● Unit Exam ● Lab: Spring constant of projectile launcher ● Lab: Ballistic pendulum ● Lab: Cut pendulum ● Lab: the Centerpoint (explosions) ● Lab: Inelastic Collisions ● Lab: 2-D Elastic collisions **Instructional Strategies:** **Interdisciplinary Connections** ● Math: Calculations of energies, velocities, forces at various points in a roller coaster. ● Math: Numerical integration of kinematic data to yield physical constants.

• Conservation of energy means that the total change of energy in any system is always equal to the total energy transferred into or out of the system. (HS-PS3-1) • Energy cannot be created or destroyed, but it can be transported from one place to another and transferred between systems. (HS-PS3-1),(HS-PS3-4) • Mathematical expressions, which quantify how the stored energy in a system depends on its configuration (e.g. relative positions of charged particles, compression of a spring) and how kinetic energy depends on mass and speed, allow the concept of conservation of energy to be used to predict and describe system behavior. (HS-PS3-1) • The availability of energy limits what can occur in any system. (HS-PS3-1) • Uncontrolled systems always evolve toward more stable states—that is, toward more uniform energy distribution (e.g., water flows downhill, objects hotter than their surrounding environment cool down). (HS-PS3-4) **PS3.C: Relationship Between Energy and Forces** • When two objects interacting through a field change relative position, the energy stored in the field is changed. (HS-PS3-5) **PS3.D: Energy in Chemical Processes** • Although energy cannot be destroyed, it can be converted to	• Social studies: how does the existence of high concentrations of potential energy (oil) effect global politics? • Astronomy: Supernova and other explosions. • Biology: energy transfers and effects in biological systems and ecosystems **Technology Integration** • Use computer simulations to observe and create unique energy transfer systems. • Use of computer spreadsheet software programs (Excel, Graphical Analysis, etc) to analyze data graphically • Mining internet for data on worldwide energy use and savings • Collection of lab data through computerized probeware • Collection of force, impulse, and momentum data with computers and probeware • Use of precision timing photogates • Simulations of idealized collision events **Media Literacy Integration** • Articles published in magazines are significantly different from articles published in peer reviewed scholarly journals. • Scientifically literate students should be able to identify the critical difference between the two types of media. **Global Perspectives** • Compare and contrast classroom energy transformations with those within our solar system, our galaxy, and the universe. • Investigate the geopolitical effects of energy policy • Energy as a unifying concept • Explore the concept of planetary travel to the Moon, Mars, and beyond using concepts of impulse and momentum.

less useful forms—for example, to thermal energy in the surrounding environment. (HS-PS3-3),(HS-PS3-4) **PS2.A: Forces and Motion** ● Momentum is defined for a particular frame of reference; it is the mass times the velocity of the object. (HS-PS2-2) ● If a system interacts with objects outside itself, the total momentum of the system can change; however, any such change is balanced by changes in the momentum of objects outside the system. (HS-PS2-2),(HS-PS2-3) From the AP Physics C Objectives: a. calculate the work done by a specified constant force on an object that undergoes a specified displacement; relate the work done by a force to the area under a graph of the force as a function of position, and calculate this work in the case where the force is a linear function of position; use integration to calculate the work performed by a changing force on an object that undergoes a specified displacement in one dimension; use the scalar product operation to calculate the work performed by a specified constant force on an object that undergoes a displacement in a plane b. calculate the change in kinetic energy or speed that results from performing a specified amount of work on an object; calculate the work performed by the net force, on an object that undergoes a specified change in speed or kinetic energy; apply the theorem to determine the change in an object's kinetic energy and speed that results from the	● Momentum conservation as a universal law

application of specified forces, or to determine the force that is required in order to bring an object to rest in a specified distance c. state alternative definitions of "conservative force" and explain why these definitions are equivalent; describe examples of conservative forces and non-conservative forces d. state the general relationship between force and potential energy and explain why potential energy can be associated only with conservative forces; calculate a potential energy function associated with a specified 1-D force function; calculate the magnitude and direction of a 1-D force when given the potential energy function for the force; write an expression for the force exerted by an ideal spring and for the potential energy of a stretched or compressed spring; calculate the potential energy of one or more objects in a uniform gravitational field e. state and apply the relation between the work performed on an object by non-conservative forces and the change in an object's mechanical energy; describe and identify situations in which mechanical energy is converted to other forms of energy; analyze situations in which an object's mechanical energy is changed by friction or by a specified externally applied force f. identify situations in which mechanical energy is or is not conserved; apply conservation of energy in analyzing the motion of systems of connected objects, such as an Atwood's machine; apply conservation of energy in analyzing the motion of objects that move under the influence of springs; apply conservation of energy in analyzing the motion of objects that	

move under the influence of other non-constant one-dimensional forces g. recognize and solve problems that call for application both of conservation of energy and Newton's Laws h. calculate the power required to maintain the motion of an object with constant acceleration; calculate the work performed by a force that supplies constant power or the average power supplied by a force that performs a specified amount of work i. relate the radius of the circle and the speed or rate of revolution of the particle to the magnitude of the centripetal acceleration; describe the direction of the particle's velocity and acceleration at any instant during the motion; determine the components of the velocity and acceleration vectors at any instant, and sketch or identify graphs of these quantities; analyze motion in a horizontal circle; analyze motion in a vertical circle j. calculate the magnitude and direction of the torque associated with a given force; calculate the torque on a rigid object due to gravity k. state the conditions for translational and rotational equilibrium and apply these conditions in analyzing the equilibrium of a rigid object under the combined influence of a number of coplanar forces applied at different locations l. determine by inspection which of a set of symmetrical objects of equal mass has the greatest rotational inertia; determine by what factor an object's rotational inertia changes if all its dimensions are increased by the same factor m. find the rotational inertia of a collection of point masses lying in a plane perpendicular to the plane, a thin rod of uniform density, about an	

arbitrary axis perpendicular to it, and a thin cylindrical shell about its axis or an object that might be viewed as being made up of coaxial shells n. apply the parallel axis theorem o. write and apply relations among the angular acceleration, angular velocity, and angular displacement of an object that rotates about a fixed axis with constant angular acceleration p. use the right hand rule for angular velocities q. describe in detail the analogy between fixed-axis rotation and straight-line translation; determine the angular acceleration with which a rigid object is accelerated about a fixed axis when subjected to a specified external torque; determine the radial and tangential acceleration of a point on a rigid object; apply conservation of energy to problems of fixed-axis pulleys; analyze problems involving strings and massive pulleys r. write down, justify, and apply the relation between linear and angular velocity and acceleration for an objecting rolling without slipping; apply the equations of translational and rotational motion simultaneously; calculate the total kinetic energy of an object that is undergoing both translational and rotational motion and apply energy conservation s. calculate the torque of a specified force about an arbitrary origin; calculate the angular momentum vector for a moving particle; calculate the angular momentum vector for a rotating rigid object in simple cases where this vector lies parallel to the angular velocity vector t. recognize the conditions under which the law of conservation is applicable and relate this law to 1 and 2 particle systems such as satellite systems; state	

the relation between net external torque and angular momentum and identify situations in which angular momentum is conserved; analyze problems in which the moment of inertia of an object is changed as it rotates freely about a fixed axis; analyze a collision between a moving particle and a rigid object that can rotate about a fixed axis or about its center of mass.	

Unit 4
Rotation

NGSS Standards: N/A
Big Ideas: *Science and Engineering Practices* Plan and conduct an investigation individually and collaboratively to produce data to serve as the basis for evidence, and in the design: decide on types, how much, and accuracy of data needed to produce reliable measurements and consider limitations on the precision of the data (e.g., number of trials, cost, risk, time), and refine the design accordingly. Analyze data using tools, technologies, and/or models (e.g., computational, mathematical) in order to make valid and reliable scientific claims or determine an optimal design solution. Use mathematical representations of phenomena to describe explanations. Theories and laws provide explanations in science. Laws are statements or descriptions of the relationships among observable phenomena. Develop and use a model based on evidence to illustrate the relationships between systems or between components of a system. Create a computational model or simulation of a phenomenon, designed device, process, or system. A scientific theory is a substantiated explanation of some aspect of the natural world, based on a body of facts that have been repeatedly confirmed through observation and experiment and the science community validates each theory before it is accepted. If new evidence is discovered that the theory does not accommodate, the theory is generally modified in light of this new evidence.

Essential Questions *What provocative questions will foster inquiry, understanding, and transfer of learning?*	**Enduring Understandings** *What will students understand about the big ideas?*
Why must CD/DVD players adjust their speed depending on what track is being used at the time?	From the NGSS Crosscutting concepts: Patterns ● Different patterns may be observed at each of the scales at which a system is studied and can provide

How could you design a bowling ball return that stops the ball's' rotation? How does a rotating merry-go-round speed up when its riders move toward the center? In what sense do different parts of a bicycle wheel move at different speeds? How can a gymnast, figure skater, or acrobat change their rotational speed without touching the ground? When dying stars become pulsars, how do they obtain such great rotational speeds?	evidence for causality in explanations of phenomena. Cause and Effect ● Empirical evidence is required to differentiate between cause and correlation and make claims about specific causes and effects. ● Systems can be designed to cause a desired effect. ● Cause and effect relationships can be suggested and predicted for complex natural and human designed systems by examining what is known about smaller scale mechanisms within the system. Systems and System Models ● When investigating or describing a system, the boundaries and initial conditions of the system need to be defined. ● Models can be used to predict the behavior of a system, but these predictions have limited precision and reliability due to the assumptions and approximations inherent in models. Scale, Proportion, and Quantity ● The significance of a phenomenon is dependent on the scale, proportion, and quantity at which it occurs. ● Algebraic thinking is used to examine scientific data and predict the effect of a change in one variable on another (e.g., linear growth vs. exponential growth). Energy and Matter ● Changes of energy and matter in a system can be described in terms of energy and matter flows into, out of, and within that system. ● Energy cannot be created or destroyed—only moves between one place and another place,

	between objects and/or fields, or between systems. Influence of Science, Engineering and Technology on Society and the Natural World ● Modern civilization depends on major technological systems. Engineers continuously modify these technological systems by applying scientific knowledge and engineering design practices to increase benefits while decreasing costs and risks. Interdependence of Science, Engineering, and Technology ● Science and engineering complement each other in the cycle known as research and development (R&D). Many R&D projects may involve scientists, engineers, and others with wide ranges of expertise. Scientific Knowledge Assumes an Order and Consistency in Natural Systems ● Science assumes the universe is a vast single system in which basic laws are consistent. ● Scientific knowledge is based on the assumption that natural laws operate today as they did in the past and they will continue to do so in the future. From the AP Physics C Objectives: Students will understand… a. the uniform circular motion of a particle b. the concept of torque c. how to analyze statics problems d. a qualitative understanding of rotational inertia e. how to compute rotational inertia f. the parallel-axis theorem

	g. the analogy between translational and rotational kinematics h. how to associate an angular velocity vector with a rotating object i. the dynamics of fixed-axis rotation j. the motion of a rigid object along a surface k. how to use the vector product and right-hand rule l. angular momentum conservation
Areas of Focus: Proficiencies (Cumulative Progress Indicators)	**Examples, Outcomes, Assessments**
From the NGSS DCI's: **PS3.B: Conservation of Energy and Energy Transfer** ● Conservation of energy means that the total change of energy in any system is always equal to the total energy transferred into or out of the system. (HS-PS3-1) ● Energy cannot be created or destroyed, but it can be transported from one place to another and transferred between systems. (HS-PS3-1),(HS-PS3-4) ● Mathematical expressions, which quantify how the stored energy in a system depends on its configuration (e.g. relative positions of charged particles, compression of a spring) and how kinetic energy depends on mass and speed, allow the concept of conservation of energy to be used to predict and describe system behavior. (HS-PS3-1) ● The availability of energy limits what can occur in any system. (HS-PS3-1) ● Uncontrolled systems always evolve toward more stable states—that is, toward more	**Instructional Focus:** ● Mathematical derivation of key formulas and concepts ● Problem solving techniques and strategies ● Hands-on exploration of unit topics ● Comparison of theoretical simplifications to real-world complexities ● Real-world applications and connections to individual student interests ● Measurement techniques and error analysis ● Calculus applications ● Preparation for AP exam **Sample Assessments:** ● Daily assignments and homework quizzes ● Collaborative projects ● Multiple choice: items from textbook test banks and released AP exams ● Free response problems from released AP exams ● Unit Exam ● Lab: the Rolling Projectile ● Lab: Moment of inertia of Rod and Point masses ● Lab: Rotational Collision **Instructional Strategies:**

uniform energy distribution (e.g., water flows downhill, objects hotter than their surrounding environment cool down). (HS-PS3-4) **PS3.D: Energy in Chemical Processes** ● Although energy cannot be destroyed, it can be converted to less useful forms—for example, to thermal energy in the surrounding environment. (HS-PS3-3),(HS-PS3-4) From the AP Physics C Objectives: a. relate the radius of the circle and the speed or rate of revolution of the particle to the magnitude of the centripetal acceleration; describe the direction of the particle's velocity and acceleration at any instant during the motion; determine the components of the velocity and acceleration vectors at any instant, and sketch or identify graphs of these quantities; analyze motion in a horizontal circle; analyze motion in a vertical circle b. calculate the magnitude and direction of the torque associated with a given force; calculate the torque on a rigid object due to gravity c. state the conditions for translational and rotational equilibrium and apply these conditions in analyzing the equilibrium of a rigid object under the combined influence of a number of coplanar forces applied at different locations d. determine by inspection which of a set of symmetrical objects of equal mass has the greatest rotational inertia; determine by what factor an object's rotational inertia changes if all its dimensions are increased by the same factor	**Interdisciplinary Connections** ● Biology: Discuss rotational motion and schemes of artificial gravity in space travel. **Technology Integration** ● Computer and probeware collection of data in rotational laboratory experiments ● Use of computer spreadsheet software programs (Excel, Graphical Analysis, etc) to analyze data graphically **Media Literacy Integration** ● Articles published in magazines are significantly different from articles published in peer reviewed scholarly journals. ● Scientifically literate students should be able to identify the critical difference between the two types of media. **Global Perspectives** ● Rotating space stations with simulated gravity as unified international effort ● Dynamics of the rotation and revolution of Earth in space

e. find the rotational inertia of a collection of point masses lying in a plane perpendicular to the plane, a thin rod of uniform density, about an arbitrary axis perpendicular to it, and a thin cylindrical shell about its axis or an object that might be viewed as being made up of coaxial shells f. apply the parallel axis theorem g. write and apply relations among the angular acceleration, angular velocity, and angular displacement of an object that rotates about a fixed axis with constant angular acceleration h. use the right hand rule for angular velocities i. describe in detail the analogy between fixed-axis rotation and straight-line translation; determine the angular acceleration with which a rigid object is accelerated about a fixed axis when subjected to a specified external torque; determine the radial and tangential acceleration of a point on a rigid object; apply conservation of energy to problems of fixed-axis pulleys; analyze problems involving strings and massive pulleys j. write down, justify, and apply the relation between linear and angular velocity and acceleration for an objecting rolling without slipping; apply the equations of translational and rotational motion simultaneously; calculate the total kinetic energy of an object that is undergoing both translational and rotational motion and apply energy conservation k. calculate the torque of a specified force about an arbitrary origin; calculate the angular momentum vector for a moving particle; calculate the angular momentum vector for a rotating rigid object in simple cases where this vector lies parallel to the angular velocity vector	

l. recognize the conditions under which the law of conservation is applicable and relate this law to 1 and 2 particle systems such as satellite systems; state the relation between net external torque and angular momentum and identify situations in which angular momentum is conserved; analyze problems in which the moment of inertia of an object is changed as it rotates freely about a fixed axis; analyze a collision between a moving particle and a rigid object that can rotate about a fixed axis or about its center of mass.	

Unit 5
Oscillations and Gravitation

NGSS Standards:
HS-PS2-4 Use mathematical representations of Newton's Law of Gravitation and Coulomb's Law to describe and predict the gravitational and electrostatic forces between objects. **HS-ESS1-4** Use mathematical or computational representations to predict the motion of orbiting objects in the solar system

Big Ideas: *Science and Engineering Practices*
Plan and conduct an investigation individually and collaboratively to produce data to serve as the basis for evidence, and in the design: decide on types, how much, and accuracy of data needed to produce reliable measurements and consider limitations on the precision of the data (e.g., number of trials, cost, risk, time), and refine the design accordingly. Analyze data using tools, technologies, and/or models (e.g., computational, mathematical) in order to make valid and reliable scientific claims or determine an optimal design solution. Use mathematical representations of phenomena to describe explanations. Theories and laws provide explanations in science. Laws are statements or descriptions of the relationships among observable phenomena. Develop and use a model based on evidence to illustrate the relationships between systems or between components of a system. Create a computational model or simulation of a phenomenon, designed device, process, or system. A scientific theory is a substantiated explanation of some aspect of the natural world, based on a body of facts that have been repeatedly confirmed through observation and experiment and the science community validates each theory before it is accepted. If new evidence is discovered that the theory does not accommodate, the theory is generally modified in light of this new evidence.

Essential Questions	Enduring Understandings

What provocative questions will foster inquiry, understanding, and transfer of learning?	*What will students understand about the big ideas?*
If the pendulum in a mechanical clock reduces the amplitudes of its oscillations, how does it continue to keep good time? What causes horizontal ridges along dirt roads? If the gravitational attraction on the moon is stronger than the Sun than the Earth, why does the Moon orbit the Earth? How did the Tacoma Narrows bridge collapse? How is a falling apple like the Moon? Why do space shuttle astronauts feel "weightless"? What factors determine whether dying stars become white dwarfs, neutron stars, or black holes?	From the NGSS Crosscutting concepts: Patterns ● Different patterns may be observed at each of the scales at which a system is studied and can provide evidence for causality in explanations of phenomena. Cause and Effect ● Empirical evidence is required to differentiate between cause and correlation and make claims about specific causes and effects. ● Systems can be designed to cause a desired effect. ● Cause and effect relationships can be suggested and predicted for complex natural and human designed systems by examining what is known about smaller scale mechanisms within the system. Systems and System Models ● When investigating or describing a system, the boundaries and initial conditions of the system need to be defined. ● Models can be used to predict the behavior of a system, but these predictions have limited precision and reliability due to the assumptions and approximations inherent in models. Scale, Proportion, and Quantity ● The significance of a phenomenon is dependent on the scale, proportion, and quantity at which it occurs. ● Algebraic thinking is used to examine scientific data and predict the effect of a change in one variable on another (e.g., linear growth vs. exponential growth).

	Energy and Matter ● Changes of energy and matter in a system can be described in terms of energy and matter flows into, out of, and within that system. ● Energy cannot be created or destroyed—only moves between one place and another place, between objects and/or fields, or between systems. Influence of Science, Engineering and Technology on Society and the Natural World ● Modern civilization depends on major technological systems. Engineers continuously modify these technological systems by applying scientific knowledge and engineering design practices to increase benefits while decreasing costs and risks. Interdependence of Science, Engineering, and Technology ● Science and engineering complement each other in the cycle known as research and development (R&D). Many R&D projects may involve scientists, engineers, and others with wide ranges of expertise. Scientific Knowledge Assumes an Order and Consistency in Natural Systems ● Science assumes the universe is a vast single system in which basic laws are consistent. ● Scientific knowledge is based on the assumption that natural laws operate today as they did in the past and they will continue to do so in the future. From the AP Physics C Objectives: Students will understand…

	a. the definition of simple harmonic motion b. how to apply knowledge of SHM to the case of a mass on a spring c. how to apply knowledge of SHM to the case of simple, physical, and torsional pendulums d. Newton's Law of Universal Gravitation e. the motion of an object in orbit under the influence of gravitational forces
Areas of Focus: Proficiencies (Cumulative Progress Indicators)	**Examples, Outcomes, Assessments**
From the NGSS DCI's: **PS2.B: Types of Interactions** ● Newton's law of universal gravitation and Coulomb's law provide the mathematical models to describe and predict the effects of gravitational and electrostatic forces between distant objects. (HS-PS2-4) ● Forces at a distance are explained by fields (gravitational, electric, and magnetic) permeating space that can transfer energy through space. Magnets or electric currents cause magnetic fields; electric charges or changing magnetic fields cause electric fields. (HS-PS2-4),(HS-PS2-5) **ESS1.B: Earth and the Solar System** ● Kepler's laws describe common features of the motions of orbiting objects, including their elliptical paths around the sun. Orbits may change due to the gravitational effects from, or collisions with, other objects in the solar system. (HS-ESS1-4) Furthermore students will… a. sketch or identify a graph of displacement as a function of time, and	**Instructional Focus:** ● Mathematical derivation of key formulas and concepts ● Problem solving techniques and strategies ● Hands-on exploration of unit topics ● Comparison of theoretical simplifications to real-world complexities ● Real-world applications and connections to individual student interests ● Measurement techniques and error analysis ● Calculus applications ● Preparation for AP exam **Sample Assessments:** ● Daily assignments and homework quizzes ● Collaborative projects ● Multiple choice: items from textbook test banks and released AP exams ● Free response problems from released AP exams ● Unit Exam ● Lab: Galileo's Pendulum ● Lab: Physical Pendulums ● Lab: Mass on a spring **Instructional Strategies:** **Interdisciplinary Connections** ● History: Galileo's use of a pendulum to measure time enabled much more

determine from such a graph the amplitude, period and frequency of the motion; write down an appropriate expression for displacement to describe the motion; find an expression for velocity as a function of time; state the relations between acceleration, velocity and displacement, and identify points in the motion where these quantities are zero or achieve their greatest positive and negative value; state and apply the relation between frequency and period; recognize that a system that obeys a differential equation must execute simple harmonic motion, and determine the frequency and period of such motion; state how the total energy of an oscillating system depends on the amplitude of the motion, sketch or identify a graph of kinetic or potential energy as a function of time, and identify points in the motion where this energy is all potential or all kinetic; calculate the kinetic and potential energies of an oscillating system as functions of time, sketch or identify graphs of these functions, and prove that the sum of kinetic and potential energy is constant; calculate the maximum displacement or velocity of a particle that moves in simple harmonic motion with specified initial position and velocity; develop a qualitative understanding of resonance so they can identify situations in which a system will resonate in response to a sinusoidal external force b. derive the expression for the period of oscillation of a mass on a spring; apply the expression for the period of oscillation of a mass on a spring; analyze problems in which a mass hangs from a spring and oscillates vertically; analyze problems in which a mass attached to a spring oscillates	accurate naval navigation and exploration. ● Historical background of Kepler's life and works and relationship with Tycho Brahe **Technology Integration** ● Computer/probeware of data collection in pendulum and spring experiments ● Use of computer spreadsheet software programs (Excel, Graphical Analysis, etc) to analyze data graphically ● Use of real current Mercury orbit data from NASA online ● Computer simulations of orbits **Media Literacy Integration** ● Articles published in magazines are significantly different from articles published in peer reviewed scholarly journals. ● Scientifically literate students should be able to identify the critical difference between the two types of media. **Global Perspectives** ● Space exploration as an international cooperative effort ● The laws of mechanics—equivalent throughout the universe—transcend geographical and cultural borders

horizontally; determine the period of oscillation for systems involving series or parallel combinations of identical springs, or springs of differing lengths c. derive the expression for the period of a simple pendulum; apply the expression for the period of a simple pendulum; state what approximation must be made in deriving the period; analyze the motion of a torsional pendulum or physical pendulum in order to determine the period of small oscillations d. determine the force that one spherically symmetrical mass exerts on another; determine the strength of the gravitational field at a specified point outside a spherically symmetrical mass; describe the gravitational force inside and outside a uniform sphere, and calculate how the field at the surface depends on the radius and density of the sphere e. for a circular orbit: recognize that the motion does not depend on the object's mass; describe qualitatively how the velocity, period of revolution and centripetal acceleration depend upon the radius of the orbit; derive expressions for the velocity and period of revolution in such an orbit; derive Kepler's Third Law for the case of circular orbits; derive and apply the relations among kinetic energy, potential energy and total energy for such an orbit; for a general orbit: state Kepler's three laws of planetary motion and use them to describe in qualitative terms the motion of an object in an elliptical orbit; apply conservation of angular momentum to determine the velocity and radial distance at any point	

in the orbit; apply angular momentum conservation and energy conservation to relate the speeds of an object at the two extremes of an elliptical orbit; apply energy conservation in analyzing the motion of an object that is projected straight up from a planet's surface or that is projected directly toward the planet from far above the surface	

Content Curriculum: Electricity and Magnetism
Unit 6
Electrostatics, conductors, capacitors, dielectrics

NGSS Standards:
HS-PS2-4 Use mathematical representations of Newton's Law of Gravitation and Coulomb's Law to describe and predict the gravitational and electrostatic forces between objects.
Big Ideas: *Science and Engineering Practices* Plan and conduct an investigation individually and collaboratively to produce data to serve as the basis for evidence, and in the design: decide on types, how much, and accuracy of data needed to produce reliable measurements and consider limitations on the precision of the data (e.g., number of trials, cost, risk, time), and refine the design accordingly. Analyze data using tools, technologies, and/or models (e.g., computational, mathematical) in order to make valid and reliable scientific claims or determine an optimal design solution. Use mathematical representations of phenomena to describe explanations. Theories and laws provide explanations in science. Laws are statements or descriptions of the relationships among observable phenomena. Develop and use a model based on evidence to illustrate the relationships between systems or between components of a system. Create a computational model or simulation of a phenomenon, designed device, process, or system. A scientific theory is a substantiated explanation of some aspect of the natural world, based on a body of facts that have been repeatedly confirmed through observation and experiment and the science community validates each theory before it is accepted. If new evidence is discovered that the theory does not accommodate, the theory is generally modified in light of this new evidence.

Essential Questions *What provocative questions will foster inquiry, understanding, and transfer of learning?*	**Enduring Understandings** *What will students understand about the big ideas?*

What electrical properties of water make it a good solvent? How can modern electronics in an operating room cause a bacterial contamination? How do lightning rods work? How are thunderclouds similar to rubbing your socks on your carpet and receiving a shock? In what real-world situations are electric shocks dangerous? What caused some burn-victim hospital unit gurneys to catch fire? How do car airbags know when to inflate? How does a camera flash work? How does a defibrillator work?	From the NGSS Crosscutting Concepts: Patterns ● Different patterns may be observed at each of the scales at which a system is studied and can provide evidence for causality in explanations of phenomena. Cause and Effect ● Empirical evidence is required to differentiate between cause and correlation and make claims about specific causes and effects. ● Systems can be designed to cause a desired effect. ● Cause and effect relationships can be suggested and predicted for complex natural and human designed systems by examining what is known about smaller scale mechanisms within the system. Systems and System Models ● When investigating or describing a system, the boundaries and initial conditions of the system need to be defined. ● Models can be used to predict the behavior of a system, but these predictions have limited precision and reliability due to the assumptions and approximations inherent in models. Scale, Proportion, and Quantity ● The significance of a phenomenon is dependent on the scale, proportion, and quantity at which it occurs. ● Algebraic thinking is used to examine scientific data and predict the effect of a change in one variable on another (e.g., linear growth vs. exponential growth). Energy and Matter ● Changes of energy and matter in a system can be described in terms of

	energy and matter flows into, out of, and within that system. • Energy cannot be created or destroyed—only moves between one place and another place, between objects and/or fields, or between systems. Influence of Science, Engineering and Technology on Society and the Natural World • Modern civilization depends on major technological systems. Engineers continuously modify these technological systems by applying scientific knowledge and engineering design practices to increase benefits while decreasing costs and risks. Interdependence of Science, Engineering, and Technology • Science and engineering complement each other in the cycle known as research and development (R&D). Many R&D projects may involve scientists, engineers, and others with wide ranges of expertise. Scientific Knowledge Assumes an Order and Consistency in Natural Systems • Science assumes the universe is a vast single system in which basic laws are consistent. • Scientific knowledge is based on the assumption that natural laws operate today as they did in the past and they will continue to do so in the future. From the AP Physics C Objectives: Students will understand… a. the concept of electric charge b. Coulomb's law c. the electric field concept

	d. the concept of electric potential e. the relationship between electric field and electric flux f. Gauss's Law g. the principle of superposition h. the fields of highly symmetric charge distributions i. the nature of electric fields in and around conductors j. induced charge and electrostatic shielding k. the definition and function of capacitance l. the physics of a parallel plate capacitors and cylindrical and spherical capacitors m. the behavior of dielectrics
Areas of Focus: Proficiencies (Cumulative Progress Indicators)	**Examples, Outcomes, Assessments**
From the NGSS DCI's: **PS2.B: Types of Interactions** ● Newton's law of universal gravitation and Coulomb's law provide the mathematical models to describe and predict the effects of gravitational and electrostatic forces between distant objects. (HS-PS2-4) ● Forces at a distance are explained by fields (gravitational, electric, and magnetic) permeating space that can transfer energy through space. Magnets or electric currents cause magnetic fields; electric charges or changing magnetic fields cause electric fields. (HS-PS2-4),(HS-PS2-5) **PS3.B: Conservation of Energy and Energy Transfer** ● Conservation of energy means that the total change of energy in any system is always equal to the total energy transferred into or out of the system. (HS-PS3-1)	**Instructional Focus:** ● Mathematical derivation of key formulas and concepts ● Problem solving techniques and strategies ● Hands-on exploration of unit topics ● Comparison of theoretical simplifications to real-world complexities ● Real-world applications and connections to individual student interests ● Measurement techniques and error analysis ● Calculus applications ● Preparation for AP exam **Sample Assessments:** ● Daily assignments and homework quizzes ● Collaborative projects ● Multiple choice: items from textbook test banks and released AP exams ● Free response problems from released AP exams

• Energy cannot be created or destroyed, but it can be transported from one place to another and transferred between systems. (HS-PS3-1),(HS-PS3-4) • Mathematical expressions, which quantify how the stored energy in a system depends on its configuration (e.g. relative positions of charged particles, compression of a spring) and how kinetic energy depends on mass and speed, allow the concept of conservation of energy to be used to predict and describe system behavior. (HS-PS3-1) • The availability of energy limits what can occur in any system. (HS-PS3-1) • Uncontrolled systems always evolve toward more stable states—that is, toward more uniform energy distribution (e.g., water flows downhill, objects hotter than their surrounding environment cool down). (HS-PS3-4) **PS3.C: Relationship Between Energy and Forces** • When two objects interacting through a field change relative position, the energy stored in the field is changed. (HS-PS3-5) Furthermore students will… a. describe the types of charge and the attraction and repulsion of charges; describe polarization and induced charges b. calculate the magnitude and direction of the force on a positive or negative	• Unit Exam • Lab: Static Electricity Stations lab • Lab: Electroscopes • Lab: Electric Field Mapping (Pasco, metal ink) • Virtual Lab: Electric fields around charges • Virtual Lab: Electric field hockey • Lab: Capacitor in series and parallel lab • Lab: Van de Graaff conductor demonstrations **Instructional Strategies:** **Interdisciplinary Connections** • Social studies: historical and cultural context of Franklin, Coulomb, Volta, Ampere • Engineering: operation of grounds, lightning rods, etc. • Meteorology: electrodynamics of thunderstorms • Health: physiological effects of electrical charge • Math: Calculus integration methods for solving capacitance and potential of common capacitor geometries • Math: application of Gauss's law to justify physics of conducting bodies **Technology Integration** • Computer/probeware of data collection in electric charge experiments • Use of computer spreadsheet software programs (Excel, Graphical Analysis, etc) to analyze data graphically • Internet-based research of electric charge in thunderstorms and lightning • Computer simulations of different geometries of capacitors **Media Literacy Integration** • Articles published in magazines are significantly different from articles published in peer reviewed scholarly journals.

charge due to other specified point charges; analyze the motion of a particle of specified charge and mass under the influence of an electrostatic force c. define it in terms of the force on a test charge; describe and calculate the electric field of a single point charge; calculate the magnitude and direction of the electric field produced by two or more point charges; calculate the magnitude and direction of the force on a positive or negative charge placed in a specified field; interpret an electric field diagram; analyze the motion of a particle of specified charge and mass in a uniform electric field d. determine the electric potential in the vicinity of one or more point charges; calculate the electrical work done on a charge or use conservation of energy to determine the speed of a charge that moves through a specified potential difference; determine the direction and approximate magnitude of the electric field at various positions given a sketch of equipotentials; calculate the potential difference between two points in a uniform electric field, and state which point is at the higher potential; calculate how much work is required to move a test charge from one location to another in the field of fixed point charges; calculate the electrostatic potential energy of a system of two or more point charges, and calculate how much work is required to establish the charge system; use integration to determine electric potential difference between two points on a line, given electric field strength as a function of position along that line; state the general relationship between field and potential, and define	● Scientifically literate students should be able to identify the critical difference between the two types of media. **Global Perspectives** ● Association of lightning and associated electrical phenomena with intercontinental weather systems ● International historical context of 18^{th} and 19^{th} century electricians ● Ancient understanding of electrical forces, from which the word “electron” is derived ● Importance of electronics to modern global economy ● Cultural and historical context of 18^{th} century discoveries related to capacitors

and apply the concept of a conservative electric field e. calculate the flux of an electric field through an arbitrary surface or of a field uniform in magnitude over a Gaussian surface and perpendicular to it; calculate the flux of the electric field through a rectangle when the field is perpendicular to the rectangle and a function of one coordinate only; state and apply the relationship between flux and lines of force f. state the law in integral form, and apply it qualitatively to relate flux and electric charge for a specified surface; apply the law, along with symmetry arguments, to determine the electric field for a planar, spherical or cylindrically symmetric charge distribution; apply the law to determine the charge density or total charge on a surface in terms of the electric field near the surface g. the electric field of a straight, uniformly charged wire; the electric field and potential on the axis of a thin ring of charge, or at the center of a circular arc of charge; the electric potential on the axis of a uniformly charged disk h. identify situations in which the direction of the electric field produced by a charge distribution can be deduced from symmetry considerations; describe qualitatively the patterns and variation with distance of the electric field of oppositely-charged parallel plates, a long, uniformly-charged wire, or thin cylindrical or spherical shell; use superposition to determine the fields of parallel charged planes, coaxial cylinders or concentric spheres; derive expressions for electric potential as a function of position	

i. explain the mechanics responsible for the absence of electric field inside a conductor, and know that all excess charge must reside on the surface of the conductor; explain why a conductor must be an equipotential, and apply this principle in analyzing what happens when conductors are connected by wires; show that all excess charge on a conductor must reside on its surface and that the field outside the conductor must be perpendicular to the surface; students should be able to describe and sketch a graph of the electric field and potential inside and outside a charged conducting sphere j. describe the process of charging by induction; explain why a neutral conductor is attracted to a charged object; explain why there can be no electric field in a charge-free region completely surrounded by a single conductor, and recognize consequences of this result; explain why the electric field outside a closed conducting surface cannot depend on the precise location of charge in the space enclosed by the conductor, and identify consequences of this result k. relate stored charge and voltage for a capacitor; relate voltage, charge and stored energy for a capacitor; recognize situations in which energy stored in a capacitor is converted to other forms l. describe the electric field inside the capacitor, and relate the strength of this field to the potential difference between the plates and the plate separation; relate the electric field to the density of the charge on the plates; derive an expression for the capacitance of a parallel-plate capacitor; determine how changes in dimension will affect the value of the capacitance; derive and apply expressions for the energy stored in a parallel-plate capacitor and for the	

energy density in the field between the plates; analyze situations in which capacitor plates are moved apart or moved closer together, or in which a conducting slab is inserted between capacitor plates, either with a battery connected between the plates or with the charge on the plates held fixed m. describe how the insertion of a dielectric between the plates of a charged parallel-plate capacitor affects its capacitance and the field strength and voltage between the plates; analyze situations in which a dielectric slab is inserted between the plates of a capacitor	

Unit 7
Circuits

<table>
<tr><th colspan="2">NGSS Standards:</th></tr>
<tr><td colspan="2"> Big Ideas: Science and Engineering Practices
Plan and conduct an investigation individually and collaboratively to produce data to serve as the basis for evidence, and in the design: decide on types, how much, and accuracy of data needed to produce reliable measurements and consider limitations on the precision of the data (e.g., number of trials, cost, risk, time), and refine the design accordingly.
Analyze data using tools, technologies, and/or models (e.g., computational, mathematical) in order to make valid and reliable scientific claims or determine an optimal design solution.
Use mathematical representations of phenomena to describe explanations.
Apply scientific ideas to solve a design problem, taking into account possible unanticipated effects.
Theories and laws provide explanations in science.
Laws are statements or descriptions of the relationships among observable phenomena.
Develop and use a model based on evidence to illustrate the relationships between systems or between components of a system.
Create a computational model or simulation of a phenomenon, designed device, process, or system.
Design, evaluate, and/or refine a solution to a complex real-world problem, based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and tradeoff considerations.
A scientific theory is a substantiated explanation of some aspect of the natural world, based on a body of facts that have been repeatedly confirmed through observation and experiment and the science community validates each theory before it is accepted. If new evidence is discovered that the theory does not accommodate, the theory is generally modified in light of this new evidence. </td></tr>
<tr><th>Essential Questions</th><th>Enduring Understandings</th></tr>
</table>

What provocative questions will foster inquiry, understanding, and transfer of learning?	*What will students understand about the big ideas?*
Why does a flashlight dim over time? Where should you go when caught outdoors during a thunderstorm? If individual electrons drift through a conducting wire very slowly, why do light bulbs come on immediately when the switch is thrown? How do you jumpstart a car battery? How do computers work?	From the NGSS Crosscutting concepts: Patterns ● Different patterns may be observed at each of the scales at which a system is studied and can provide evidence for causality in explanations of phenomena. Cause and Effect ● Empirical evidence is required to differentiate between cause and correlation and make claims about specific causes and effects. ● Systems can be designed to cause a desired effect. ● Cause and effect relationships can be suggested and predicted for complex natural and human designed systems by examining what is known about smaller scale mechanisms within the system. Systems and System Models ● When investigating or describing a system, the boundaries and initial conditions of the system need to be defined. ● Models can be used to predict the behavior of a system, but these predictions have limited precision and reliability due to the assumptions and approximations inherent in models. Scale, Proportion, and Quantity ● The significance of a phenomenon is dependent on the scale, proportion, and quantity at which it occurs. ● Algebraic thinking is used to examine scientific data and predict the effect of a change in one variable on another (e.g., linear growth vs. exponential growth).

	Energy and Matter ● Changes of energy and matter in a system can be described in terms of energy and matter flows into, out of, and within that system. ● Energy cannot be created or destroyed—only moves between one place and another place, between objects and/or fields, or between systems. Influence of Science, Engineering and Technology on Society and the Natural World ● Modern civilization depends on major technological systems. Engineers continuously modify these technological systems by applying scientific knowledge and engineering design practices to increase benefits while decreasing costs and risks. Interdependence of Science, Engineering, and Technology ● Science and engineering complement each other in the cycle known as research and development (R&D). Many R&D projects may involve scientists, engineers, and others with wide ranges of expertise. Scientific Knowledge Assumes an Order and Consistency in Natural Systems ● Science assumes the universe is a vast single system in which basic laws are consistent. ● Scientific knowledge is based on the assumption that natural laws operate today as they did in the past and they will continue to do so in the future. From the AP Physics C Objectives: Students will understand…

	a. the definition of electric current b. conductivity, resistivity, and resistance c. the behavior of series and parallel combinations of resistors d. the properties of ideal and real batteries e. Ohm's law and Kirchoff's rules f. the properties of voltmeters and ammeters g. the initial and steady state behavior of capacitors connected in series and parallel h. the discharging or charging of a capacitor through a resistor
Areas of Focus: Proficiencies (Cumulative Progress Indicators)	**Examples, Outcomes, Assessments**
From the NGSS DCI's: **PS3.A: Definitions of Energy** ● "Electrical energy" may mean energy stored in a battery or energy transmitted by electric currents. *(secondary to HS-PS2-5)* From the AP Physics C Objectives: a. relate the magnitude and direction of the current to the rate of flow of positive and negative charge b. relate current and voltage for a resistor; write the relationship between electric field strength and current density in a conductor, and describe, in terms of the drift velocity of electrons, why such a relationship is plausible; describe how the resistance of a resistor depends upon its length and cross-sectional area, and apply this result in comparing current flow in resistors of different material or different geometry; derive an expression for the resistance of a resistor of uniform cross-section in terms of its dimensions and the resistivity of the material from which it is constructed; derive expressions that relate the current, voltage and	**Instructional Focus:** ● Mathematical derivation of key formulas and concepts ● Problem solving techniques and strategies ● Hands-on exploration of unit topics ● Comparison of theoretical simplifications to real-world complexities ● Real-world applications and connections to individual student interests ● Measurement techniques and error analysis ● Calculus applications ● Preparation for AP exam **Sample Assessments:** ● Daily assignments and homework quizzes ● Collaborative projects ● Multiple choice: items from textbook test banks and released AP exams ● Free response problems from released AP exams ● Unit Exam ● Lab: Resistors ● Lab: Ohm's Law ● Lab: Series and Parallel Circuits

resistance to the rate at which heat is produced when current passes through a resistor; apply the relationships for the rate of heat production in a resistor c. identify on a circuit diagram whether resistors are in series or in parallel; determine the ratio of the voltages across resistors connected in series or the ratio of the currents through resistors connected in parallel; calculate the equivalent resistance of a network of resistors that can be broken down into series and parallel combinations; calculate the voltage, current and power dissipation for any resistor in such a network of resistors connected to a single power supply; design a simple series-parallel circuit that produces a given current through and potential difference across one specified component, and draw a diagram for the circuit using conventional symbols d. calculate the terminal voltage of a battery of specified emf and internal resistance from which a known current is flowing; calculate the rate at which a battery is supplying energy to a circuit or is being charged up by a circuit e. determine a single unknown current, voltage or resistance; set up and solve simultaneous equations to determine two unknown currents f. state whether the resistance of each is high or low; identify or show correct methods of connecting meters into circuits in order to measure voltage or current; assess qualitatively the effect of finite meter resistance on a circuit into which these meters are connected g. calculate the equivalent capacitance of a series or parallel combination;	● Lab: RC Circuit ● Lab: Voltage Divider **Instructional Strategies:** **Interdisciplinary Connections** ● Fluids: extended analogy of current flowing through wires and water flowing through pipes ● Social studies: historical context of pioneers of electrical circuits, such as Kirchoff, Ohm, etc. ● Health: safety with electrical circuits and currents ● Math: methods of solving systems of linear equations **Technology Integration** ● Computer/probeware data collection and analysis for simple and complex circuit labs, including RC circuits ● Computer web-based simulations of simple circuits ● Realization that complex electrical circuits are merely combinations of simple elements studies in class **Media Literacy Integration** ● Articles published in magazines are significantly different from articles published in peer reviewed scholarly journals. ● Scientifically literate students should be able to identify the critical difference between the two types of media. **Global Perspectives** ● The internet, made possible through principles of electrical circuits, as a unifying international system ● Importance of electronics for the modern global economy

describe how stored charge is divided between capacitors connected in parallel; determine the ratio of voltages for capacitors connected in series; calculate the voltage or stored charge, under steady-state conditions, for a capacitor connected to a circuit consisting of a battery and resistors h. calculate and interpret the time constant of the circuit; sketch or identify graphs of stored charge or voltage for the capacitor, or of current or voltage for the resistor, and indicate on the graph the significance of the time constant; write expressions to describe the time dependence of the stored charge or voltage for the capacitor, or of the current or voltage for the resistor; analyze the behavior of circuits containing several capacitors and resistors, including analyzing or sketching graphs that correctly indicate how voltages and currents vary with time	

Unit 8
Magnetic Fields and Electromagnetism

NGSS Standards: **HS-PS2-5** Plan and conduct an investigation to provide evidence that an electric current can produce a magnetic field and that a changing magnetic field can produce an electric current. **HS-PS3-5** Develop and use a model of two objects interacting through electric or magnetic fields to illustrate the forces between objects and the changes in energy of the objects due to the interaction.	
Big Ideas: *Science and Engineering Practices* Plan and conduct an investigation individually and collaboratively to produce data to serve as the basis for evidence, and in the design: decide on types, how much, and accuracy of data needed to produce reliable measurements and consider limitations on the precision of the data (e.g., number of trials, cost, risk, time), and refine the design accordingly. Analyze data using tools, technologies, and/or models (e.g., computational, mathematical) in order to make valid and reliable scientific claims or determine an optimal design solution. Use mathematical representations of phenomena to describe explanations. Theories and laws provide explanations in science. Laws are statements or descriptions of the relationships among observable phenomena. Develop and use a model based on evidence to illustrate the relationships between systems or between components of a system. Create a computational model or simulation of a phenomenon, designed device, process, or system. A scientific theory is a substantiated explanation of some aspect of the natural world, based on a body of facts that have been repeatedly confirmed through observation and experiment and the science community validates each theory before it is accepted. If new evidence is discovered that the theory does not accommodate, the theory is generally modified in light of this new evidence.	
Essential Questions	**Enduring Understandings**

What provocative questions will foster inquiry, understanding, and transfer of learning?	*What will students understand about the big ideas?*
How can magnetic fields create a high-energy beam of neutrons for use in cancer patients? What causes the aurora borealis? Why do the auroras take place primarily or exclusively near Earth's poles? Where does Earth's magnetic field come from, and why is it essential to life? Why are only some metals magnetic? How does a tube television work? How do MRIs work? How do brain scientists measure brain activity? Why must a magnetic credit card be moved through a reader rather than sitting still? How could an MRI burn a patient? How do motors, generators, and transformers work? Why do we largely depend on alternating current power?	From the NGSS Crosscutting concepts: Patterns ● Different patterns may be observed at each of the scales at which a system is studied and can provide evidence for causality in explanations of phenomena. Cause and Effect ● Empirical evidence is required to differentiate between cause and correlation and make claims about specific causes and effects. ● Systems can be designed to cause a desired effect. ● Cause and effect relationships can be suggested and predicted for complex natural and human designed systems by examining what is known about smaller scale mechanisms within the system. Systems and System Models ● When investigating or describing a system, the boundaries and initial conditions of the system need to be defined. ● Models can be used to predict the behavior of a system, but these predictions have limited precision and reliability due to the assumptions and approximations inherent in models. Scale, Proportion, and Quantity ● The significance of a phenomenon is dependent on the scale, proportion, and quantity at which it occurs. ● Algebraic thinking is used to examine scientific data and predict the effect of a change in one variable on another (e.g., linear growth vs. exponential growth).

	Energy and Matter ● Changes of energy and matter in a system can be described in terms of energy and matter flows into, out of, and within that system. ● Energy cannot be created or destroyed—only moves between one place and another place, between objects and/or fields, or between systems. Influence of Science, Engineering and Technology on Society and the Natural World ● Modern civilization depends on major technological systems. Engineers continuously modify these technological systems by applying scientific knowledge and engineering design practices to increase benefits while decreasing costs and risks. Interdependence of Science, Engineering, and Technology ● Science and engineering complement each other in the cycle known as research and development (R&D). Many R&D projects may involve scientists, engineers, and others with wide ranges of expertise. Scientific Knowledge Assumes an Order and Consistency in Natural Systems ● Science assumes the universe is a vast single system in which basic laws are consistent. ● Scientific knowledge is based on the assumption that natural laws operate today as they did in the past and they will continue to do so in the future. From the AP Physics C Objectives: Students will understand…

	a. the force experienced by a charged particle in a magnetic field b. the force exerted on a current-carrying wire in a magnetic field c. the magnetic field produced by a long straight current-carrying wire d. the Biot-Savart law e. the statement and application of Ampere's Law in integral form f. the concept of magnetic flux g. Faraday's law and Lenz's law h. the mechanical consequences of electromagnetic forces i. the concept of inductance j. the transient and steady-state behavior of DC circuits containing resistors and inductors k. Maxwell's equations
Areas of Focus: Proficiencies (Cumulative Progress Indicators)	**Examples, Outcomes, Assessments**
From the NGSS DCI's: **PS2.B: Types of Interactions** ● Newton's law of universal gravitation and Coulomb's law provide the mathematical models to describe and predict the effects of gravitational and electrostatic forces between distant objects. (HS-PS2-4) ● Forces at a distance are explained by fields (gravitational, electric, and magnetic) permeating space that can transfer energy through space. Magnets or electric currents cause magnetic fields; electric charges or changing magnetic fields cause electric fields. (HS-PS2-4),(HS-PS2-5) Furthermore students will… a. calculate the magnitude and direction of the force in terms of q, **v**, and **B**, and	**Instructional Focus:** ● Mathematical derivation of key formulas and concepts ● Problem solving techniques and strategies ● Hands-on exploration of unit topics ● Comparison of theoretical simplifications to real-world complexities ● Real-world applications and connections to individual student interests ● Measurement techniques and error analysis ● Calculus applications ● Preparation for AP exam **Sample Assessments:** ● Daily assignments and homework quizzes ● Collaborative projects ● Multiple choice: items from textbook test banks and released AP exams

explain why the magnetic force can perform no work; deduce the direction of a magnetic field from information about the forces experienced by charged particles moving through that field; describe the paths of charged particles moving in uniform magnetic fields; derive and apply the formula for the radius of the circular path of a charge that moves perpendicular to a uniform magnetic field; describe under what conditions particles will move with constant velocity through crossed electric and magnetic fields b. calculate the magnitude and direction of the force on a straight segment of current- carrying wire in a uniform magnetic field; indicate the direction of magnetic forces on a current-carrying loop of wire in a magnetic field, and determine how the loop will tend to rotate as a consequence of these forces; calculate the magnitude and direction of the torque experienced by a rectangular loop of wire carrying a current in a magnetic field c. calculate the magnitude and direction of the field at a point in the vicinity of such a wire; use superposition to determine the magnetic field produced by two long wires; calculate the force of attraction or repulsion between two long current-carrying wires d. deduce the magnitude and direction of the contribution to the magnetic field made by a short straight segment of current-carrying wire; derive and apply the expression for the magnitude of **B** on the axis of a circular loop of current e. state Ampere's law precisely; use Ampere's law, plus symmetry arguments and the right-hand rule, to	● Free response problems from released AP exams ● Unit exam ● Lab: Tangent Galvanometer ● Lab: Electromagnets (nails, wire, iron filings) ● Lab: Building DC motors ● Lab: Measuring transformers **Instructional Strategies:** **Interdisciplinary Connections** ● Math: Calculus integration techniques to describe magnetic field geometries ● Social studies: worldwide discoveries associated with magnetism ● Math: mathematical comparison of derivative and integral forms of Maxwell's equations ● Social studies: historical context of electromagnetic inventions associated with Edison, Westinghouse, and Tesla ● Social studies: historical context of theoretical contributions of Faraday and Maxwell ● Social studies: geopolitical ramifications of energy production associated with electromagnetic devices **Technology Integration** ● Computer/probeware data collection and analysis of magnetic field experiments ● Computer simulations of Earth's magnetic field and magnetic fields around electrical currents ● Computer simulations of motors, generators, and transformers ● Computer and probeware based data collection in electromagnetic experiments **Media Literacy Integration** ● Articles published in magazines are significantly different from articles

relate magnetic field strength to current for planar or cylindrical symmetries; apply the superposition principle so they can determine the magnetic field produced by combinations of the configurations listed above f. calculate the flux of a uniform magnetic field through a loop of arbitrary orientation; use integration to calculate the flux of a non-uniform magnetic field, whose magnitude is a function of one coordinate, through a rectangular loop perpendicular to the field g. recognize situations in which changing flux through a loop will cause an induced emf or current in the loop; calculate the magnitude and direction of the induced emf and current in a loop of wire or a conducting bar under the following conditions: the magnitude of a related quantity such as magnetic field or area of the loop is changing at a constant rate; the magnitude of a related quantity such as magnetic field or area of the loop is a specified non-linear function of time h. analyze the forces that act on induced currents so they can determine the mechanical consequences of those forces i. calculate the magnitude and sense of the emf in an inductor through which a specified changing current is flowing; derive and apply the expression for the self-inductance of a long solenoid j. apply Kirchhoff's rules to a simple *LR* series circuit to obtain a differential equation for the current as a function of time; solve the differential equation obtained for the current as a function of time through the battery, using separation of variables; calculate the initial transient currents and final steady state currents through any part of a simple series and parallel circuit containing an inductor and one or more	published in peer reviewed scholarly journals. ● Scientifically literate students should be able to identify the critical difference between the two types of media. **Global Perspectives** ● Importance of the magnetic field of Earth for all life on Earth ● Multicultural context of magnetic field discoveries: China, Greece, etc. ● Energy production via electromagnetic devices and related cultural context

resistors; sketch graphs of the current through or voltage across the resistors or inductor in a simple series and parallel circuit; calculate the rate of change of current in the inductor as a function of time; calculate the energy stored in an inductor that has a steady current flowing through it k. associate each of Maxwell’s equations with its implications.	

Texts and Resources

Adopted Course textbook:

Young and Freedman. University Physics, 14th Edition. Pearson Education, 2015.

Supplemental resources:

Serway and Beichner. PHYSICS For Scientists and Engineers, Fifth Edition. Thomson Learning, 2000.

Tipler and Mosca. Physics for Scientists and Engineers, Fifth Edition. W.H. Freeman and Co, 2004.

Physics C Course Description. The College Board, Fall 2011.

Halliday, Resnick, and Walker. Fundamentals of Physics, 7th Edition. John Wiley & Sons, 2005.

Serway and Faughn. College Physics, 7th Edition. Brooks Cole, 2005.

Halliday, Resnick and Krane. Physics, Fifth Edition. John Wiley & Sons, 2002.

Chabay and Sherwood. Matter & Interactions 1 and 2, Second Edition. John Wiley & Sons, 2007.

AP Physics C Course Description and Outline.

Next Generation Science Standards. https://www.nextgenscience.org/

"Video Encyclopedia of Physics Demonstrations". The Education Group. http://www.physicsdemos.com

MIT Open CourseWare Physics.

"The Mechanical Universe and Beyond". Annenberg Foundation. http://www.learner.org/resources/series42.html