SCHOOL DISTRICT OF THE CHATHAMS

AP Physics C
Grades 11 & 12
Full Year

Course Overview

AP Physics C: Mechanics is a calculus-based, college-level physics course. It covers kinematics; Newton's laws of motion; work, energy, and power; systems of particles and linear momentum; circular motion and rotation; oscillations; and gravitation.

AP Physics C: Electricity and Magnetism is a calculus-based, college level physics course, especially appropriate for students planning to specialize or major in physical science or engineering. The course explores topics such as electrostatics; conductors, capacitors, and dielectrics; electric circuits; magnetic fields; and electromagnetism. Introductory differential and integral calculus are used throughout the course.

New Jersey Student Learning Standards

The New Jersey Student Learning Standards (NJSLS) can be located at www.nj.gov/education/cccs/2020/.

Physical Science:
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.
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 scientific and engineering ideas to design, evaluate, and refine a device that minimizes the force on a macroscopic object during a collision.
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-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-PS3-1 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 motions of particles (objects) and energy associated with the relative positions 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-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.
HS-PS4-1 Use mathematical representations to support a claim regarding relationships among the frequency, wavelength, and speed of waves traveling in various media.
HS-PS4-2 Evaluate questions about the advantages of using a digital transmission and storage of information.

HS-PS4-3 Evaluate the claims, evidence, and reasoning behind the idea that electromagnetic radiation can be described either by a wave model or a particle model, and that for some situations one model is more useful than the other.
HS-PS4-4 Evaluate the validity and reliability of claims in published materials of the effects that different frequencies of electromagnetic radiation have when absorbed by matter.
HS-PS4-5 Communicate technical information about how some technological devices use the principles of wave behavior and wave interactions with matter to transmit and capture information and energy.

Earth and Space Science:
HS- ETS1-2 Design a solution to a complex real-world problem by breaking it down into smaller, more manageable problems that can be solved through engineering.
HS-ESS1-4 Use mathematical or computational representations to predict the motion of orbiting objects in the solar system

Technology Standards
9.4.12.IML.7: Develop an argument to support a claim regarding a current workplace or societal/ethical issue such as climate change (e.g., NJSLSA.W1, 7.1.AL.PRSNT.4).
9.4.12.TL.2: Generate data using formula-based calculations in a spreadsheet and draw conclusions about the data.
9.4.12.TL.3: Analyze the effectiveness of the process and quality of collaborative environments.

21st Century Integration | NJSLS 9
9.3.ST-ET.1 Use STEM concepts and processes to solve problems involving design and/or production.
9.3.ST.2 Use technology to acquire, manipulate, analyze and report data.

Career Ready Practices
CRP8. Utilize critical thinking to make sense of problems and persevere in solving them.
CRP2. Apply appropriate academic and technical skills.
CRP4. Communicate clearly and effectively and with reason.

Interdisciplinary Connections
English Language Arts:
Reading
- RST.9-10.8 Assess the extent to which the reasoning and evidence in a text support the author's claim or a recommendation for solving a scientific or technical problem.
- RST.11-12.1 Cite specific textual evidence to support analysis of science and technical texts, attending to important distinctions the author makes and to any gaps or inconsistencies in the account. (HS-PS2-1)
- RST.11-12.7 Integrate and evaluate multiple sources of information presented in diverse formats and media (e.g., quantitative data, video, multimedia) in order to address a question or solve a problem.

Writing
- WHST.11-12.7 Conduct short as well as more sustained research projects to answer a question (including a self-generated question) or solve a problem; narrow or broaden the inquiry when appropriate; synthesize multiple sources on the subject, demonstrating understanding of the subject under investigation.
- WHST.11-12.8 Gather relevant information from multiple authoritative print and digital sources, using advanced searches effectively; assess the strengths and limitations of each source in terms of the specific task, purpose, and audience; integrate information into the text selectively to maintain

the flow of ideas, avoiding plagiarism and overreliance on any one source and following a standard format for citation.

- WHST.11-12.9 Draw evidence from informational texts to support analysis, reflection, and research.

Speaking and Listening

- SL.11-12.5 Make strategic use of digital media (e.g., textual, graphical, audio, visual, and interactive elements) in presentations to enhance understanding of findings, reasoning, and evidence and to add interest.

Mathematics:

- HSN.Q.A.1 Use units as a way to understand problems and to guide the solution of multi-step problems; choose and interpret units consistently in formulas; choose and interpret the scale and the origin in graphs and data displays.
- HSN.Q.A.2 Define appropriate quantities for the purpose of descriptive modeling.
- HSN.Q.A.3 Choose a level of accuracy appropriate to limitations on measurement when reporting quantities.
- HSA.CED.A.1 Create equations and inequalities in one variable and use them to solve problems.
- HSA.CED.A.2 Create equations in two or more variables to represent relationships between quantities; graph equations on coordinate axes with labels and scales.
- HSA.CED.A.4 Rearrange formulas to highlight a quantity of interest, using the same reasoning as in solving equations.
- HSA.SSE.A.1 Interpret expressions that represent a quantity in terms of its context.
- HSA.SSE.B.3 Choose and produce an equivalent form of an expression to reveal and explain properties of the quantity represented by the expression.
- HSF-IF.C.7 Graph functions expressed symbolically and show key features of the graph, by hand in simple cases and using technology for more complicated cases.
- HSS-IS.A.1 Represent data with plots on the real number line (dot plots, histograms, and box plots).

Units of Study

Unit 1: Kinematics *(~10 days)*

- When descending a hill on your bike, why do you roll faster the farther you go?
- Why should you throw a stone higher if you want it to go farther?

Unit 2: Newton's Laws of Motion *(~10 days)*

- Why does the swirling motion continue after you've stopped stirring a cup of coffee or tea?
- If you apply the same amount of "push" to a car as you would a shopping cart, why doesn't it move?
- Why will the sun set tomorrow in nearly the same place that it set today?
- Why must you push backward to make a skateboard move forward?

Unit 3: Work, Energy, and Power *(~15 days)*

- Why is no work done when you push against a wall, but work is done when you coast down a hill?
- Why does a stretched rubber band return to its original length?
- Why is it easier to walk up a flight of steps, rather than run, when the gravitational potential energy of the system is the same?

Unit 4: Systems of Particles and Linear Momentum *(~15 days)*

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- Why do pictures hung on a wall sometimes tilt forward?
- Why will you fall if you lean too far over a banister or ledge?
- Why does water move a ship forward when its propellers push water backward?
- Why are cannon barrels so much longer and heavier than cannonballs?

Unit 5: Rotation *(~15 days)*
- Why does a curveball take less time to reach the plate than a fastball?
- Why is it easier to balance a bicycle when it's in motion?
- How can you increase your swing on a swing set without being pushed?

Unit 6: Oscillations *(~8 days)*
- How can you increase your swing on a swing set without being pushed?

Unit 7: Gravitation *(~8 days)*
- How does the moon stay in orbit despite its great distance from the Earth?
- Why is navigation technology dependent on the orbits of Earth's artificial satellites?

Unit 8: Electrostatics *(~25 days)*
- Why does your hair stand up after brushing it with a plastic comb?
- How does a charged rubber rod bend a stream of water?
- How is the kinematics of charged particles used in old televisions?
- Why is it sometimes necessary to shield against electric fields?
- How are maps of voltage and topographical maps related?
- Why can a bird land on a high voltage wire and not be electrocuted?

Unit 9: Conductors, Capacitors, Dielectrics *(~12 days)*
- Why is the electric potential in the conductor connecting two resistors in series constant?
- Why is the electric field everywhere perpendicular to surfaces of constant electric potential?
- Why does water in a microwave oven become warm while aluminum foil sparks?
- Why are capacitors used as circuit elements shaped like cylinders?

Unit 10: Electric Circuits *(~15 days)*
- How does the wiring design for a house allow for electricity to still be on in some rooms when others have none due to a circuit breaker being flipped?
- Why do warming light bulbs take several minutes to shine bright?
- Why doesn't the electric company charge for electrons used?
- How does touching a conductor to a capacitor before removing it from a circuit protect you?

Unit 11: Magnetic Fields *(~10 days)*
- Why are large-scale, charged-particle accelerators in the shape of a circle?
- How does a guitar pick up work?
- Why does a current deflect the needle of a compass?
- Why does the deflection of a pair of parallel conducting wires depend on the directions of current in the wires?

Unit 12: Electromagnetism *(~10 days)*
- How does an electric motor work?
- How does pushing the button at the door produce a sound inside the house?
- How does an antenna work?
- How does the digital recording in your MP3 player generate sound waves in your headphones?

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- How does Wi-Fi work?

Learning Objectives/Discipline Standards of Practice

<u>Learning Objectives</u>

Unit 1: Kinematics

- Determine the appropriate expressions for velocity and position as a function of time for an object accelerating uniformly in one dimension with given initial conditions.
- Calculate unknown variables of motion such as acceleration, velocity, or positions for an object undergoing uniformly accelerated motion in one dimension.
- Calculate values such as average velocity or minimum or maximum velocity for an object in uniform acceleration.
- Determine functions of position, velocity, and acceleration that are consistent with each other, for the motion of an object with a nonuniform acceleration.
- Describe the motion of an object in terms of the consistency that exists between position and time, velocity and time, and acceleration and time.
- Calculate the components of a velocity, position, or acceleration vector in two dimensions.
- Calculate a net displacement of an object moving in two dimensions. c. Calculate a net change in velocity of an object moving in two dimensions.
- Calculate an average acceleration vector for an object moving in two dimensions.
- Calculate a velocity vector for an object moving relative to another object (or frame of reference) that moves with a uniform velocity.
- Describe the velocity vector for one object relative to a second object with respect to its frame of reference
- Derive an expression for the vector position, velocity, or acceleration of a particle, at some point in its trajectory, using a vector expression or using two simultaneous equations.
- Calculate kinematic quantities of an object in projectile motion, such as displacement, velocity, speed, acceleration, and time, given initial conditions of various launch angles, including a horizontal launch at some point in its trajectory.
- Describe the motion of an object in two-dimensional motion in terms of the consistency that exists between position and time, velocity and time, and acceleration and time

Unit 2: Newton's Laws of Motion

- Describe an object (either in a state of equilibrium or acceleration) in different types of physical situations such as inclines, falling through air resistance, Atwood machines, or circular tracks)
- Explain Newton's first law in qualitative terms and apply the law to many different physical situations.
- Calculate a force of unknown magnitude acting on an object in equilibrium.
- Calculate the acceleration of an object moving in one dimension when a single constant force (or a net constant force) acts on the object during a known interval of time.
- Calculate the average force acting on an object moving in a plane with a velocity vector that is changing over a specified time interval.
- Describe the trajectory of a moving object that experiences a constant force in a direction perpendicular to its initial velocity vector.
- Derive an expression for the net force on an object in translational motion.
- Derive a complete Newton's second law statement (in the appropriate direction) for an object in various physical dynamic situations (e.g., mass on incline, mass in elevator, strings/pulleys, or Atwood machines).
- Calculate a value for an unknown force acting on an object accelerating in a dynamic situation (e.g., inclines, Atwood machines, falling with air resistance, pulley systems, mass in elevator, etc.)

- Describe the relationship between frictional force and the normal force for static friction and for kinetic friction.
- Explain when to use the static frictional relationship versus the kinetic frictional relationship in different physical situations (e.g., object sliding on surface or object not slipping on incline)
- Describe the direction of frictional forces (static or kinetic) acting on an object under various physical situations
- Derive expressions that relate mass, forces, or angles of inclines for various slipping conditions with friction.
- Calculate the value for the static frictional force for an object in various dynamic situations (e.g., an object at rest on truck bed, an object at rest on incline, or an object pinned to a horizontal surface).
- Derive an expression for the motion of an object freely falling with a resistive drag force (or moving horizontally subject to a resistive horizontal force).
- Describe the acceleration, velocity, or position in relation to time for an object subject to a resistive force (with different initial conditions, i.e., falling from rest or projected vertically)
- Calculate the terminal velocity of an object moving vertically under the influence of a resistive force of a given relationship.
- Derive a differential equation for an object in motion subject to a specified resistive force.
- Derive an expression for a time-dependent velocity function for an object moving under the influence of a given resistive force (with given initial conditions).
- Derive expressions for the acceleration or position of an object moving under the influence of a given resistive force
- Calculate the velocity of an object moving in a horizontal circle with a constant speed, when subject to a known centripetal force.
- Calculate relationships among the radius of a circle, the speed of an object (or period of revolution), and the magnitude of centripetal acceleration for an object moving in uniform circular motion.
- Explain how a net force in the centripetal direction can be a single force, more than one force, or even components of forces that are acting on an object moving in circular motion.
- Describe forces that are exerted on objects undergoing horizontal circular motion, vertical circular motion, or horizontal circular motion on a banked curve.
- Describe forces that are acting on different objects traveling in different circular paths.
- Describe the direction of the velocity and acceleration vector for an object moving in two dimensions, circular motion, or uniform circular motion.
- Calculate the resultant acceleration for an object that changes its speed as it moves in a circular path.
- Derive expressions relating centripetal force to the minimum speed or maximum speed of an object moving in a vertical circular path.
- Derive expressions relating the centripetal force to the maximum speed of an object or minimum speed of an object moving in a circular path on a banked surface with friction.
- Describe the forces of interaction between two objects (Newton's third law).
- Describe pairs of forces that occur in a physical system due to Newton's third law.
- Describe the forces that occur between two (or more) objects accelerating together (e.g., in contact or connected by light strings, springs, or cords).
- Derive expressions that relate the acceleration of multiple connected masses moving in a system (e.g., Atwood machines) connected by light strings with tensions (and pulleys).

Unit 3: Work, Energy, and Power

- Calculate work done by a given force (constant or as a given function F(x)) on an object that undergoes a specified displacement.
- Describe the work done on an object as the result of the scalar product between force and displacement.

- Explain how the work done on an object by an applied force acting on an object can be negative or zero.
- Calculate a value for work done on an object from a force versus position graph.
- Calculate the change in kinetic energy due to the work done on an object or a system by a single force or multiple forces.
- Calculate the net work done on an object that undergoes a specified change in speed or change in kinetic energy.
- Calculate changes in an object's kinetic energy or changes in speed that result from the application of specified forces.
- Compare conservative and dissipative forces.
- Describe the role of a conservative force or a dissipative force in a dynamic system.
- Explain how the general relationship between potential energy functions and conservative forces is used to determine relationships between the two physical quantities.
- Derive an expression that represents the relationship between a conservative force acting in a system on an object to the potential energy of the system using the methods of calculus.
- Describe the force within a system and the potential energy of a system.
- Derive the expression for the potential energy function of an ideal spring.
- Derive an expression for the potential energy function of a nonideal spring that has a nonlinear relationship with position.
- Calculate the potential energy of a system consisting of an object in a uniform gravitational field.
- Derive an expression for the gravitational potential energy of a system consisting of a satellite or large mass (e.g., an asteroid) and the Earth at a great distance from the Earth.
- Describe physical situations in which mechanical energy of an object in a system is converted to other forms of energy in the system.
- Describe physical situations in which the total mechanical energy of an object in a system changes or remains constant
- Describe kinetic energy, potential energy, and total energy in relation to time (or position) for a "conservative" mechanical system.
- Calculate unknown quantities (e.g., speed or positions of an object) that are in a conservative system of connected objects, such as the masses in an Atwood machine, masses connected with pulley/ string combinations, or the masses in a modified Atwood machine.
- Calculate unknown quantities, such as speed or positions of an object that is under the influence of an ideal spring.
- Calculate unknown quantities, such as speed or positions of an object that is moving under the influence of some other non-constant one dimensional force.
- Derive expressions such as positions, heights, angles, and speeds for an object in vertical circular motion or pendulum motion in an arc.
- Derive an expression for the rate at which a force does work on an object.
- Calculate the amount of power required for an object to maintain a constant acceleration.
- Calculate the amount of power required for an object to be raised vertically at a constant rate

Unit 4: Systems of Particles and Linear Momentum

- Calculate the center of mass of a system of point masses or a system of regular symmetrical objects.
- Calculate the center of mass of a thin rod of nonuniform density using integration.
- Describe the motion of the center of the mass of a system for various situations.
- Explain the difference between the terms "center of gravity" and "center of mass," and identify physical situations when these terms have identical positions and when they have different positions.
- Calculate the total momentum of an object or a system of objects.
- Calculate relationships between mass, velocity, and linear momentum of a moving object

- Calculate the quantities of force, time of collision, mass, and change in velocity from an expression relating impulse to change in linear momentum for a collision of two objects.
- Describe relationships between a system of objects' individual momenta and the velocity of the center of mass of the system of objects.
- Calculate the momentum change in a collision using a force versus time graph for a collision.
- Calculate the change in momentum of an object given a nonlinear function, F(t), for a net force acting on the object.
- Calculate the velocity of one part of a system after an explosion or a collision of the system.
- Calculate energy changes in a system that undergoes a collision or an explosion.
- Calculate the changes of momentum and kinetic energy as a result of a collision between two objects.
- Describe the quantities that are conserved in a collision. CON-4.D Calculate the speed of the center of mass of a system.
- Calculate the changes in speeds, changes in velocities, changes in kinetic energy, or changes in momenta of objects in all types of collisions (elastic or inelastic) in one dimension, given the initial conditions of the objects. b. Derive expressions for the conservation of momentum for a particular collision in one dimension.
- Calculate the changes in speeds, changes in velocities, changes in kinetic energy, or changes in momenta of objects involved in a two-dimensional collision (including an elastic collision), given the initial conditions of the objects. b. Derive expressions for the conservation of momentum for a particular two-dimensional collision of two objects.

Unit 5: Rotation

- Explain the differences in the moments of inertia between different objects such as rings, discs, spheres, or other regular shapes by applying the general definition of moment of inertia (rotational inertia) of a rigid body.
- Derive the moment of inertia, using calculus, of a thin rod of nonuniform density about an arbitrary axis perpendicular to the rod.
- Derive the moments of inertia of an extended rigid body for different rotational axes (parallel to an axis that goes through the object's center of mass) if the moment of inertia is known about an axis through the object's center of mass.
- Explain how the angular kinematic relationships for uniform angular acceleration are directly analogous to the relationships for uniformly and linearly accelerated motion.
- Calculate unknown quantities such as angular positions, displacement, angular speeds, or angular acceleration of a rigid body in uniformly accelerated motion, given initial conditions.
- Calculate unknown quantities such as angular positions, displacement, angular velocity, or rotational kinetic energy of a rigid body rotating with a specified non-uniform angular acceleration.
- Calculate the translational kinematic quantities from an object's rotational kinematic quantities for objects that are rolling without slipping.
- Describe the complete analogy between fixed axis rotation and linear translation for an object subject to a net torque.
- Describe the net torque experienced by a rigid extended body in situations such as, but not limited to, rolling down inclines, pulled along horizontal surfaces by external forces, a pulley system (with rotational inertia), simple pendulums, physical pendulums, and rotating bars.
- Derive expressions for physical systems such as Atwood machines, pulleys with rotational inertia, or strings connecting discs or strings connecting multiple pulleys that relate linear or translational motion characteristics to the angular motion characteristics of rigid bodies in the system that are— rolling and rotating
- Derive expressions using energy conservation principles for physical systems such as rolling bodies on inclines, Atwood machines, pendulums, physical pendulums, and systems with massive

pulleys that relate linear or angular motion characteristics to initial conditions (such as height or position) or properties of rolling body (such as moment of inertia or mass).

- Calculate the angular momentum vector of a linearly translating particle about a defined stationary point of reference.
- a. b. Explain how a one- or two-particle system (rotating object or satellite orbits) may have a change in angular velocity when other properties of the system change (such as radius or inertia).
- Calculate changes in angular velocity of a rotating rigid body when the moment of inertia of the body changes during the motion (such as a satellite in orbit).
- Calculate the increase or decrease in angular momentum of a rigid body when a point mass particle has a collision with the rigid body.
- Calculate the changes of angular momentum of each disc in a rotating system of two rotating discs that collide with each other inelastically about a common rotational axis.

Unit 6: Oscillations

- Describe the general behavior of a spring mass system in SHM in qualitative terms.
- Describe the relationship between the phase angle and amplitude in an SHM system
- a. Describe the displacement in relation to time for a mass-spring system in SHM.
- Identify the period, frequency, and amplitude of the SHM in a mass spring system from the features of a plot.
- Describe each of the three kinematic characteristics of a spring-mass system in SHM in relation to time (displacement, velocity, and acceleration). For a spring mass system in SHM—
- Derive a differential equation to describe Newton's second law for a spring-mass system in SHM or for the simple pendulum.
- Calculate the position, velocity, or acceleration of a spring-mass system in SHM at any point in time or at any known position from the initial conditions and known spring constant and mass.
- Derive the expression for the period of oscillation for various physical systems oscillating in SHM.
- Calculate the mechanical energy of an oscillating system. Show that this energy is conserved in an ideal SHM spring-mass system.
- Describe the effects of changing the amplitude of a spring-mass system.
- Describe the kinetic energy as a function of time (or position), potential energy as a function of time (or position), and total mechanical energy as a function of time (or position) for a spring-mass system in SHM, identifying important features of the oscillating system and where these features occur.
- Explain how the model of SHM can be used to determine characteristics of motion for other physical systems that can exhibit this behavior.
- Describe a linear relationship between the period of a system oscillating in SHM and physical constants of the system.

Unit 7: Gravitation

- Calculate the magnitude of the gravitational force between two large spherically symmetrical masses.
- Calculate the value for g or gravitational acceleration on the surface of the Earth (or some other large planetary object) and at other points outside of the Earth.
- Describe the motion in a qualitative way of an object under the influence of a variable gravitational force, such as in the case where an object falls toward the Earth's surface when dropped from distances much larger than the Earth's radius.
- Calculate quantitative properties (such as period, speed, radius of orbit) of a satellite in circular orbit around a planetary object.
- Derive Kepler's third law for the case of circular orbits.
- Describe a linear relationship to verify Kepler's third law.
- Calculate the gravitational potential energy and the kinetic energy of a satellite/ Earth system in which the satellite is in circular orbit around the earth.

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- Derive the relationship of total mechanical energy of a satellite/earth system as a function of radial position.
- Calculate positions, speeds, or energies of a satellite launched straight up from the planet's surface, or a satellite that is projected straight toward the planet's surface, using energy principles.
- Describe elliptical satellite orbits using Kepler's three laws of planetary motion.
- Calculate the orbital distances and velocities of a satellite in elliptical orbit using the conservation of angular momentum. b. Calculate the speeds of a satellite in elliptical orbit at the two extremes of the elliptical orbit (perihelion and aphelion).

Unit 8: Electrostatics

- Describe behavior of charges or system of charged objects interacting with each other.
- Explain and/or describe the behavior of a neutral object in the presence of a charged object or a system of charges.
- Calculate the net electrostatic force on a single point charge due to other point charges.
- Calculate unknown quantities such as the force acting on a specified charge or the distances between charges in a system of static point charges.
- Determine the motion of a charged object of specified charge and mass under the influence of an electrostatic force.
- Using the definition of electric field, unknown quantities (such as charge, force, field, and direction of field) can be calculated in an electrostatic system of a point charge or an object with a charge in a specified electric field.
- Describe and calculate the electric field due to a single point charge.
- Describe and calculate the electric field due to a dipole or a configuration of two or more static-point charges.
- Explain or interpret an electric field diagram of a system of charges.
- Sketch an electric-field diagram of a single point charge, a dipole, or a collection of static-point charges.
- Determine the qualitative nature of the motion of a charged particle of specified charge and mass placed in a uniform electric field.
- Sketch the trajectory of a known charged particle placed in a known uniform electric field
- Calculate the value of the electric potential in the vicinity of one or more point charges.
- Mathematically represent the relationships between the electric charge, the difference in electric potential, and the work done (or electrostatic potential energy lost or gained) in moving a charge between two points in a known electric field.
- Calculate the electrostatic potential energy of a collection of two or more point charges held in a static configuration.
- Calculate the amount of work needed to assemble a configuration of point charges in some known static configuration.
- Calculate the potential difference between two points in a uniform electric field and determine which point is at the higher potential
- Calculate the work done or changes in kinetic energy (or changes in speed) of a charged particle when it is moved through some known potential difference.
- a. Describe the relative magnitude and direction of an electrostatic field given a diagram of equipotential lines.
- Describe characteristics of a set of equipotential lines given in a diagram
- Use the general relationship between electric field and electric potential to calculate the relationships between the magnitude of electric field or the potential difference as a function of position.
- Use integration techniques to calculate a potential difference between two points on a line, given the electric field as a function of position on that line.
- State and apply the general definition of electric flux.

- Calculate the electric flux through an arbitrary area or through a geometric shape (e.g., cylinder, sphere).
- Calculate the flux through a rectangular area when the electric field is perpendicular to the rectangle and is a function of one position coordinate only
- Qualitatively apply Gauss's Law to a system of charges or charged region to determine characteristics of the electric field, flux, or charge contained in the system.
- State and use Gauss's Law in integral form to derive unknown electric fields for planar, spherical, or cylindrically symmetrical charge distributions.
- Using appropriate mathematics (which may involve calculus), calculate the total charge contained in lines, surfaces, or volumes when given a linear-charge density, a surface-charge density, or a volume-charge density of the charge configuration.
- Use Gauss's Law to calculate an unknown charge density or total charge on surface in terms of the electric field near the surface.
- Qualitatively describe electric fields around symmetrically (spherically, cylindrically, or planar) charged distributions.
- Describe the general features of an electric field due to symmetrically shaped charged distributions.
- Describe the general features of an unknown charge distribution, given other features of the system.
- Derive expressions for the electric field of specified charge distributions using integration and the principle of superposition. Examples of such charge distributions include a uniformly charged wire, a thin ring of charge (along the axis of the ring), and a semicircular or part of a semicircular arc.
- . Identify and qualitatively describe situations in which the direction and magnitude of the electric field can be deduced from symmetry considerations and understanding the general behavior of certain charge distributions.
- Describe an electric field as a function of distance for the different types of symmetrical charge distributions.
- Derive expressions for the electric potential of a charge distribution using integration and the principle of superposition.
- Describe electric potential as a function of distance for the different types of symmetrical charge distributions.
- Identify regions of higher and lower electric potential by using a qualitative (or quantitative) argument to apply to the charged region of space.

Unit 9: Conductors, Capacitors, Dielectrics

- Recognize that the excess charge on a conductor in electrostatic equilibrium resides entirely on the surface of a conductor.
- Describe the consequence of the law of electrostatics and that it is responsible for the other law of conductors (that states there is an absence of an electric field inside of a conductor).
- Explain why a conducting surface must be an equipotential surface.
- b.Describe the consequences of a conductor being an equipotential surface.
- c. Explain how a change to a conductor's charge density due to an external electric field will not change the electric-field value inside the conductor.
- a. Describe the process of charging a conductor by induction.
- b. Describe the net charge residing on conductors during the process of inducing a charge on an electroscope/conductor.
- Explain how a charged object can attract a neutral conductor
- Describe the concept of electrostatic shielding.

- For charged conducting spheres or spherical shells, describe the electric field with respect to position. b. For charged conducting spheres or spherical shells, describe the electric potential with respect to position.
- Calculate the electric potential on the surfaces of two charged conducting spheres when connected by a conducting wire.
- Apply the general definition of capacitance to a capacitor attached to a charging source.
- Calculate unknown quantities such as charge, potential difference, or capacitance for physical system with a charged capacitor
- Use the relationship for stored electrical potential energy for a capacitor.
- Calculate quantities such as charge, potential difference, capacitance, and potential energy of a physical system with a charged capacitor.
- Explain how a charged capacitor, which has stored energy, may transfer that energy into other forms of energy.
- Derive an expression for a parallel-plate capacitor in terms of the geometry of the capacitor and fundamental constants.
- Describe the properties of a parallel-plate capacitor in terms of the electric field between the plates, the potential difference between the plates, the charge on the plates, and distance of separation between the plates.
- Calculate physical quantities such as charge, potential difference, electric field, surface area, and distance of separation for a physical system that contains a charged parallel-plate capacitor.
- Explain how a change in the geometry of a capacitor will affect the capacitance value.
- Apply the relationship between the electric field between the capacitor plates and the surface-charge density on the plates.
- Derive expressions for the energy stored in a parallel plate capacitor or the energy per volume of the capacitor.
- Describe the consequences to the physical system of a charged capacitor when a conduction slab is inserted between the plates or when the conducting plates are moved closer or farther apart.
- Calculate unknown quantities such as charge, potential difference, charge density, electric field, and stored energy when a conducting slab is placed in between the plates of a charged capacitor or when the plates of a charged capacitor are moved closer or farther apart.
- Derive expressions for a cylindrical capacitor or a spherical capacitor in terms of the geometry of the capacitor and fundamental constants.
- Calculate physical quantities such as charge, potential difference, electric field, surface area, and distance of separation for a physical system that contains a charged capacitor.
- Describe and/or explain the physical properties of an insulating material when the insulator is placed in an external electric field.
- Explain how a dielectric inserted in between the plates of a capacitor will affect the properties of the capacitor, such as potential difference, electric field between the plates, and charge on the capacitor.
- Use the definition of the capacitor to describe changes in the capacitance value when a dielectric is inserted between the plates. FIE-2.D a. Calculate changes in energy, charge, or potential difference when a dielectric is inserted into an isolated charge capacitor.

Unit 10: Electric Circuits

- Calculate unknown quantities relating to the definition of current.
- Describe the relationship b. Apply Ohm's Law
- Explain how the properties of a conductor affect resistance.
- Calculate the resistance of a conductor of known resistivity and geometry
- Describe the relationship between the electric field strength through a conductor and the current density within the conductor.

- Using the microscopic definition of current in a conductor, describe the properties of the conductor and the idea of "drift velocity."
- Derive the expression for resistance of a conductor of uniform cross-sectional area in terms of its dimensions and resistivity
- Derive expressions that relate current, voltage, and resistance to the rate at which heat is produced in a resistor.
- Calculate the amount of heat produced in a resistor given a known time interval and the circuit characteristics
- Identify parallel or series arrangement in a circuit containing multiple resistors.
- Calculate equivalent resistances for a network of resistors that can be considered a combination of series and parallel arrangements.
- Calculate relationships between the potential difference, current, resistance, and power dissipation for any part of a circuit, given some of the characteristics of the circuit (i.e., battery voltage or current in the battery, or a resistor or branch of resistors).
- Describe a circuit diagram that will properly produce a given current and a given potential difference across a specified component in the circuit.
- Calculate the terminal voltage and the internal resistance of a battery of specified EMF and known current through the battery.
- Calculate a single unknown current, potential difference, or resistance in a multi-loop circuit using Kirchhoff's Rules
- Describe the proper use of an ammeter and a voltmeter in an experimental circuit and correctly demonstrate or identify these methods in a circuit diagram.
- Calculate the potential differences across specified capacitors arranged in a series in a circuit. C
- Calculate the stored charge in a system of capacitors and on individual capacitors arranged in series or in parallel
- Calculate the potential difference across a capacitor in a circuit arrangement containing capacitors, resistors, and an energy source under steady-state conditions
- In transient circuit conditions (i.e., RC circuits), calculate the time constant of a circuit containing resistors and capacitors arranged in series.
- Derive expressions using calculus to describe the time dependence of the stored charge or potential difference across the capacitor, or the current or potential difference across the resistor in an RC circuit when charging or discharging a capacitor.
- Describe stored charge or potential difference across a capacitor or current, or potential difference of a resistor in a transient RC circuit.
- Describe the behavior of the voltage or current behavior over time for a circuit that contains resistors and capacitors in a multi-loop arrangement.
- Calculate expressions that determine electrical potential energy stored in a capacitor as a function of time in a transient RC circuit.
- Describe the energy transfer in charging or discharging a capacitor in an RC circuit

Unit 11: Magnetic Fields

- Describe the direction of a magnetic field from the information given by a description of the motion or trajectory of a charged particle moving through a uniform magnetic field.
- Describe the path of different moving charged particles (i.e., of different type of charge or mass) in a uniform magnetic field. CHG-1.C Derive an expression for the radius of a circular path for a charged particle of specified characteristics moving in a specified magnetic field.
- Explain why the magnetic force acting on a moving charge particle does not work on the moving charged particle.
- Describe the conditions under which a moving charged particle can move through a region of crossed electric and magnetic fields with a constant velocity

- . Calculate the magnitude of the magnetic force acting on a straight-line segment of a conductor with current in a uniform magnetic field.
- a. Describe or indicate the direction of magnetic forces acting on a complete conductive loop with current in a region of uniform magnetic field
- Calculate the magnitude and direction of the net torque experienced by a rectangular loop of wire carrying a current in a region of a uniform magnetic field.
- Calculate the magnitude and direction of a magnetic field produced at a point near a long, straight, current carrying wire.
- Apply the right-hand rule for magnetic field of a straight wire (or correctly use the Biot–Savart Law found in to deduce the direction of a magnetic field near a long, straight, current carrying wire.
- Describe the direction of a magnetic-field vector at various points near multiple long, straight, current carrying wires.
- Calculate an unknown current value or position value, given a specified magnetic field at a point due to multiple long, straight, current-carrying wires.
- Derive the expression for the magnitude of magnetic field on the axis of a circular loop of current or a segment of a circular loop.
- Explain how the Biot–Savart Law can be used to determine the field of a long, straight, current-carrying wire at perpendicular distances close to the wire.
- Describe the relationship of the magnetic field as a function of distance for various configurations of current-carrying cylindrical conductors with either a single current or multiple currents, at points inside and outside of the conductors.

Unit 12: Electromagnetism

- Calculate the magnetic flux of a non-uniform magnetic field that may have a magnitude that varies over one coordinate through a specified rectangular loop that is oriented perpendicularly to the field.
- Describe which physical situations with a changing magnetic field and a conductive loop will create an induced current in the loop.
- Describe the direction of an induced current in a conductive loop that is placed in a changing magnetic field.
- Describe the induced current magnitudes and directions for a conductive loop moving through a specified region of space containing a uniform magnetic field.
- Calculate the magnitude and direction of induced EMF and induced current in a conductive loop (or conductive bar) when the magnitude of either the field or area of loop is changing at a constant rate.
- Calculate the magnitude and direction of induced EMF and induced current in a conductive loop (or conductive bar) when a physical quantity related to magnetic field or area is changing with a specified non-linear function of time. Induced currents arise in a conductive loop (or long wire) when there is a change in magnetic flux occurring through the loop. This change is defined by Faraday's Law.
- Lenz's Law is the relationship that allows the direction of the induced current to be determined. The law states that any induced EMF and current induced in a conductive loop will create an induced current and induced magnetic field to oppose the direction change in external flux.
- Lenz's Law is essentially a law relating to conservation of energy in a system and has mechanical consequences.
- Derive expressions for the induced EMF (or current) through a closed conductive loop with a time-varying magnetic field directed either perpendicularly through the loop or at some angle oriented relative to the magnetic-field direction.
- Describe the relative magnitude and direction of induced currents in a conductive loop with a time-varying magnetic field.

- Write a differential equation and calculate the terminal velocity for the motion of a conductive bar (in a closed electrical loop) falling through a magnetic field or moving through a field due to other physical mechanisms.
- Describe the mechanical consequences of changing an electrical property (such as resistance) or a mechanical property (such as length/area) of a conductive loop as it moves through a uniform magnetic field
- Calculate the stored electrical energy in an inductor that has a steady state current.
- Describe currents or potential differences with respect to time across resistors or inductors in a simple circuit containing resistors and an inductor, either in series or a parallel arrangement
- Explain how a changing b. Associate the appropriate Maxwell's equation with the appropriate physical consequence in a physical system containing a magnetic or electric field

<u>Discipline Specific Standards of Practice</u>
AP Physics C
- Visual Representations
  - Analyze and/or use [non narrative/nonmathematical] representations of physical situations, excluding graphs.
- Question and Method
  - Determine scientific questions and methods.
- Representing Data and Phenomena
  - Create visual representations or models of physical situations.
- Data Analysis
  - Analyze quantitative data represented in graphs.
- Theoretical Relationships
  - Determine the effects on a quantity when another quantity or the physical situation changes.
- Mathematical Routines
  - Solve problems of physical situations using mathematical relationships.
- Argumentation
  - Develop an explanation or scientific argument.

Science and Engineering Practices
- Plan and Carryout and Investigation
  - Identify or pose a testable question based on observations, data or a model
- Constructing Explanations and Designing Solutions
- Using Mathematics and Computational Thinking
  - Using data to evaluate a hypothesis
  - Perform mathematical equations in the curriculum
- Analyzing and Interpreting Data
- Developing and Using Models
  - Describe characteristics of a biological concept, process or model represented visually
- Engaging in Argument from Evidence
  - Making a scientific claim
  - Provide reasoning to justify a claim by connecting evidence to biological theories
- Asking Questions and Defining Problems
- Obtaining, Evaluating, and Communicating Information

Crosscutting Concepts
- Structure and Function
- Stability and Change
- Systems and System Models
- Energy and Matter

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- Scale, Proportion, and Quantity
- Cause and effect

Instructional Resources and Materials
Whole class resources have been identified with an asterisk.

Resources
- *Fundamental Physics* Halliday, Resnick, Walker 9th edition

Materials
- Various PASCO probeware
- Desktop computers with PASCO 850 Interface
- Various lab & demonstration equipment

Benchmark Tasks
- Unit 1 Labs
  - Projectiles launched from accelerating cart
- Unit 2 Labs
  - Forces/Friction
- Unit 3 Labs:
  - Atwood machine
- Unit 4 Labs:
  - Collisions in 2D
- Unit 5 Labs:
  - Centripetal force
- Unit 6 Labs
  - Hooke's Law for cart on an incline
- Unit 7 Labs
  - Kepler's Laws
- Unit 8
  - Electrostatics
- Unit 9
  - Parallel plate capacitor
- Unit 10
  - Resistance of Play Doh
- Unit 11
  - Electric Potential
- Unit 12
  - EMF of a C-cell

Assessment Strategies
Assessment is designed to measure a student's mastery of a course standard and learning objective. Assessment can be used for both instructional purposes (formative assessment) and for evaluative purposes (summative assessment).

The following is a general list of the many forms of assessment that may take in learning.
- Tests
- Quizzes

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- Laboratory Investigations
- Unit Assessments
- Projects
    - Physics Olympics
    - Conqueror of the Hill

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