Fairfield Public Schools Curriculum

Department: Science
Course: AP Physics C
Grade(s): 11, 12

AP Level / 1.5 credit
Prerequisites: Successful completion of AP Physics 1 and successful completion or concurrently enrolled in AP Calculus AB or AP Calculus BC. Teacher recommendation advised.

COURSE TITLE: AP Physics C
Course Description: AP Physics C is a two-semester, calculus-based, college-level physics course that addresses both Mechanics and Electricity and Magnetism. The Mechanics portion of the course will cover kinematics, Newton's laws of motion; work, energy, and power; systems of particlesand linear momentum; circular motion and rotation; oscillations; and gravitation. The Electricity and Magnetism topics covered include electrostatics; conductors, capacitors, and dielectrics; electrical circuits; magnetic fields; and electromagnetism. Introductory differential and integral calculus is used throughout the course. **Standards for this course are taken from the College Board Advanced Placement Physics C course description and are of three types:** ● Science Practices: The science practices enable students to establish lines of evidence and use them to develop and refine testable explanations and predictions of natural phenomena. ● Big Ideas: The key concepts and related content that define the revised AP Physics C course and exam are organized around a few underlying principles called the big ideas, which encompass the core scientific principles, theories and processes governing physical systems. ● Learning Objectives: Learning objectives provide clear and detailed articulation of what students should know and be able to do. Each learning objective is designed to help teachers integrate science practices with specific content, and to provide them with clear information about how students will be expected to demonstrate their knowledge and abilities.
FPS Academic Expectations: ***Exploring and Understanding***: Students will plan and carry out scientific investigations to explore and develop understandings of scientific concepts. ***Synthesizing and Evaluating:*** The student weighs evidence, arguments, claims and beliefs in order to critically and effectively solve problems and to justify conclusions.

Course Enduring Understanding(s): BIG IDEA 1: CHANGE Interactions produce changes in motion. BIG IDEA 2: FORCE INTERACTIONS Forces characterize interactions between objects or systems. BIG IDEA 3: FIELDS Fields predict and describe interactions. BIG IDEA 4: CONSERVATION Conservation laws constrain interactions.
Course Essential Question(s): ● How do interactions produce change in motion? ● How can interactions between objects or systems be predicted, described, and explained? ● How do universal laws of conservation govern the behavior of objects and interactions in systems?
AP Science Practices: Science Practice 1: The student can use representations and models to communicate scientific phenomena and solve scientific problems. 1.1 The student can create representations and models of natural or manmade phenomena and systems in the domain. 1.2 The student can describe representations and models of natural or manmade phenomena and systems in the domain. 1.3 The student can refine representations and models of natural or manmade phenomena and systems in the domain. 1.4 The student can use representations and models to analyze situations or solve problems qualitatively and quantitatively. 1.5 The student can re-express key elements of natural phenomena across multiple representations in the domain. Science Practice 2: The student can use mathematics appropriately 2.1 The student can justify the selection of a mathematical routine to solve problems. 2.2 The student can apply mathematical routines to quantities that describe natural phenomena. 2.3 The student can estimate numerically quantities that describe natural phenomena. Science Practice 3: The student can engage in scientific questioning to extend thinking or to guide investigations within the context of the AP course. 3.1 The student can pose scientific questions. 3.2 The student can refine scientific questions. 3.3 The student can evaluate scientific questions. Science Practice 4: The student can plan and implement data collection strategies appropriate to a particular scientific question. 4.1 The student can justify the selection of the kind of data needed to answer a particular scientific question. 4.2 The student can design a plan for collecting data to answer a particular scientific question. 4.3 The student can collect data to answer a particular scientific question. 4.4 The student can evaluate sources of data to answer a particular scientific question Science Practice 5: The student can perform data analysis and evaluation of evidence.

5.1 The student can analyze data to identify patterns or relationships.
5.2 The student can refine observations and measurements based on data analysis.
5.3 The student can evaluate the evidence provided by data sets in relation to a particular scientific question.

Science Practice 6: The student can work with scientific explanations and theories.
6.1 The student can justify claims with evidence.
6.2 The student can construct explanations of phenomena based on evidence produced through scientific practices.
6.3 The student can articulate the reasons that scientific explanations and theories are refined or replaced.
6.4 The student can make claims and predictions about natural phenomena based on scientific theories and models.
6.5 The student can evaluate alternative scientific explanations.

Science Practice 7: The student is able to connect and relate knowledge across various scales, concepts and representations in and across domains.
7.1 The student can connect phenomena and models across spatial and temporal scales.
7.2 The student can connect concepts in and across domain(s) to generalize or extrapolate in and/or across enduring understandings and/or big ideas.

UNIT 1: Kinematics

Unit Overview: Although motion is considered an accepted phenomenon because it can easily be seen, discerning—and eventually understanding—why objects move requires more observation. Unit 1 introduces students to kinematics—particularly one-dimensional, two-dimensional, and projectile motion. Students will not only learn how to define each kinematic quantity (position, velocity, acceleration, and time), but also how to distinguish between them, and how to graphically and mathematically represent the relationships among them. Kinematics serves as a foundation for various physics principles and concepts, and in the units that follow, students are expected to call upon their knowledge of kinematic quantities to describe components of motion in a variety of scenarios, such as how acceleration is addressed with Newton's third law of motion.

Enduring Understanding(s):

- There are relationships among the vector quantities of position, velocity, and acceleration for the motion of a particle along a straight line.
- There are multiple simultaneous relationships among the quantities of position, velocity, and acceleration for the motion of a particle moving in more than one dimension with or without net forces.
- A net force will change the translational motion of an object.
- The motion of some objects is constrained so that forces acting on the object cause it to move in a circular path.

Essential Question(s):

- 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?

College Board AP Unit Standards (Learning Goals):
At the conclusion of this unit, students will know and be able to:

- Calculate the components of a velocity, position, or acceleration vector in two dimensions.
- Calculate a net displacement of an object moving in two dimensions.
- 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

Unit Overview: To understand how and why objects move, students must first understand the role forces play in motion. Unit 2 investigates Newton's laws of motion, which describe the relationship among moving objects and the forces acting on them. Students will learn how forces can change the motion of an object (first law); about the relationship between force, mass, and motion (second classical mechanics, and in subsequent units, students will evolve their understanding by applying Newton's laws of motion to a variety of physicsprinciples, including the conservation of energy (Unit 3), rotation (Unit 5), simple harmonic motion (Unit 6), and the orbital motion of satellites (Unit 7).

Enduring Understanding(s):
- A net force will change the translational motion of an object.
- The motion of some objects is constrained so that forces acting on the object cause it to move in a circular path.
- There are force pairs with equal magnitude and opposite directions between any two interacting objects.

Essential Question(s):
- 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 asyou 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?

College Board AP Unit Standards (Learning Goals):
At the conclusion of this unit, students will know and be able to:

- 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 givenresistive 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

Unit Overview: Are you working hard, or hardly working? The answer depends on how you define work. In Unit 3, students will explore the relationship between work, energy, and power and will be introduced to the principle of conservation as a foundational model of physics, as well as the concept of workas an agent of change for energy. Students are not only expected to functionally define and calculate work, energy, and power, but must also be comfortable graphically and mathematically representing them. Understanding these relationships will help students make connections to other content presented in the course. For instance, students can use the concept of work to link the principles of energy transfer, forces, momentum, and certain kinematic equations.

Enduring Understanding(s):

- When a force is exerted on an object, and the energy of the object changes, then work was done on the object.
- Conservative forces internal to the system can change the potential energy of that system.
- The energy of a system can transform from one form to another without changing the total amount of energy in the system.
- The energy of an object or a system can be changed at different rates.

Essential Question(s):

- 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?

College Board AP Unit Standards (Learning Goals):
At the conclusion of this unit, students will know and be able to:

- 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.

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- 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. b. 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 largemass (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. b. 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 idealspring.
- 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
Unit Overview: Have you ever wondered how a tennis player times a return shot? Alongside skill, players must consider a number of factors to estimate how far, fast, or high their swings should be. Unit 4 introduces students to these factors through the concepts of center of mass, impulse and momentum, and the conservation of linear momentum. Students will learn the relationship between impulse and momentum via application or calculations. The conservation of linear momentum and how it's applied to collisions is also addressed. Unit 4 offers a complete picture of the motion of a system, which is explored primarily through impulse and changes in momentum. Students will further their understanding of momentum and angular momentum in Unit 7 as they begin to articulate orbital and rotational motion.

Enduring Understanding(s):	**Essential Question(s):**
● The linear motion of a system can be described by the displacement, velocity, and acceleration of its center of mass. ● An impulse exerted on an object will change the linear momentum of the object ● In the absence of an external force, the total momentum within a system can transfer from one object to another without changing the total momentum in the system.	● Why do pictures hung on a wall sometimes tilt forward? ● Why will you fall if you lean too far over a bannister 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? ● Why does a curveball take less time to reach the plate than a fastball?

College Board AP Unit Standards (Learning Goals):
At the conclusion of this unit, students will know and be able to:

- 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.
- 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.
- 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.
- Derive expressions for the conservation of momentum for a particular two-dimensional collision of two objects.

UNIT 5: Rotation	
Unit Overview: In this unit, students will investigate torque and rotational statics, kinematics, and dynamics, in addition to angular momentum and its conservation, to gain an in-depth and comprehensive understanding of rotation. Students are provided with opportunities to make connections between the content and models explored in the first four units, as well as with opportunities to demonstrate the analogy between translational and rotational kinematics. Unfortunately, when dealing with rotational motion, all the conceptual difficulties found in translational motion also have direct analogs. For example, if the angular velocity is zero, students often believe that the angular acceleration must also be zero. Astronomical phenomena (such as satellites in orbit) are explored in Unit 7 to build students' knowledge of angular momentum and its conservation.	
Enduring Understanding(s): ● When a physical system involves an extended rigid body, there are two conditions of equilibrium—a translational condition and a rotational condition. ● There are relationships among the physical properties of angular velocity, angular position, and angular acceleration. ● A net torque acting on a rigid extended body will produce rotational motion about a fixed axis. ● In the absence of an external torque, the total angular momentum of a system can transfer from one object to another within the system without changing the total angular momentum of the system.	**Essential Question(s):** ● 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?
College Board AP Unit Standards (Learning Goals): **At the conclusion of this unit, students will know and be able to:** ● Calculate the magnitude and direction of the torque associated with a given force. ● Calculate the torque on a rigid object due to gravity. ● Students should be able to analyze problems in statics, so they can: ● State the conditions for translational and rotational equilibrium of a rigid object. ● 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. ● 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. ● Students should develop skill in computing rotational inertia so they can find the rotational inertia of: ● A collection of point masses lying in a plane about an axis perpendicular to the plane. ● A thin rod of uniform density, about an arbitrary axis perpendicular to the rod.	

- A thin cylindrical shell about its axis, or an object that may be viewed as being made up of coaxial shells.
- Students should be able to state and apply the parallel-axis theorem.
- Students should understand the analogy between translational and rotational kinematics so they can 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.
- Students should be able to use the right-hand rule to associate an angular velocity vector with a rotating object.
- Students should understand the dynamics of fixed-axis rotation, so they can:
- 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 or force.
- Determine the radial and tangential acceleration of a point on a rigid object.
- Apply conservation of energy to problems of fixed-axisrotation.
- Analyze problems involving strings and massive pulleys.
- Students should understand the motion of a rigid object along a surface, so they can:
- Write down, justify and apply the relation between linear and angular velocity, or between linear and angular acceleration, for an object of circular cross-section that rolls without slipping along a fixed plane, and determine the velocity and acceleration of an arbitrary point on such an object.
- Apply the equations of translational and rotational motion simultaneously in analyzing rolling with slipping.
- Calculate the total kinetic energy of an object that is undergoing both translational and rotational motion, and apply energy conservation in analyzing such motion.
- Angular momentum and its conservation
- Students should be able to use the vector product and the right-hand rule, so they can:
- 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.
- Students should understand angular momentum conservation, so they can:
- Recognize the conditions under which the law of conservation is applicable and relate this law to one- and two-particle systems such as satellite orbits.
- 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 6: Oscillations

Unit Overview:
While earlier units focused on linear motion, Unit 6 pays close attention to the type of motion we experience when we talk or listen to music. Through the concept of oscillations, students are introduced to the model of simple harmonic motion (SHM), springs, and pendulums. Students will discover why some objects repeat their motions with a regular pattern. They will also apply the model of SHM, define the three kinematic characteristics (displacement, velocity, and acceleration),

and practice representing them graphically and mathematically. During their study of oscillations, students will gain a more in-depth understanding of motion, making them better equipped to apply their knowledge of forces and motion to waves. Students will continue to expand on circular motion in Unit 7 as they explore celestial bodies and objects.

Enduring Understanding(s):	**Essential Question(s):**
• There are certain types of forces that cause objects to repeat their motions with a regular pattern.	• How does the presence of restoring forces predict and lead to harmonic motion?

College Board AP Unit Standards (Learning Goals):
At the conclusion of this unit, students will know and be able to:

- Students should understand simple harmonic motion, so they can:
- Sketch or identify a graph of displacement as a function of time, and determine from such a graph the amplitude, period and frequency of the motion.
- Write down an appropriate expression for displacement of the form A t sin(w) or A t cos(w) 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 values.
- State and apply the relation between frequency and period.
- 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.
- Students should be able to apply their knowledge of simple harmonic motion to the case of a mass on a spring, so they can:
- 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 horizontally.
- Determine the period of oscillation for systems involving series or parallel combinations of identical springs, or springs of differing lengths.
- Students should be able to apply their knowledge of simple harmonic motion to the case of a pendulum, so they can:
- 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.

UNIT 7: Gravitation	
Unit Overview: Unit 7 investigates Newton's laws of gravity and the relationships shared between planets, satellites, and their orbits. Students will become familiar with the law of universal gravitation and how it can be applied to any pair of masses and will consider the motion of an object in orbit under the influence of gravitational forces. Additionally, students will be given opportunities to relate connected knowledge across units by applying and deriving Kepler's laws of planetary motion to circular or general orbits. Drawing such relationships will help elevate students' understanding of motion and force in various circumstances.	
Enduring Understanding(s): ● Objects of large mass will cause gravitational fields that create an interaction at a distance with other objects with mass. ● Angular momentum and total mechanical energy will not change for a satellite in an orbit.	**Essential Question(s):** ● 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?
College Board AP Unit Standards (Learning Goals): **At the conclusion of this unit, students will know and be able to:** ● 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. ● Students should know Newton's law of universal gravitation, so they can: ● 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. ● Orbits of planets and satellites ● Students should understand the motion of an object in orbit under the influence of gravitational forces, so they can:	

- 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; and 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.

UNIT 8: Electrostatics

Unit Overview:
In Unit 1, students will begin the study of electric force, which acts on all objects with a property called charge. The electric force, in contrast to gravitational force, is one of attraction or repulsion and therefore leads to different effects on objects. This knowledge will help students understand the role electrostatics has in common devices such as photocopiers, defibrillators, and printers, as well as television, radio, and radar industries. In the units that follow, students will apply their knowledge of electric charges and force to electric circuits, and how the motion of electric charges helps create magnetic fields.

Enduring Understanding(s):	Essential Question(s):
• Objects with an electric charge will interact with each other by exerting forces on each other. • Objects with an electric charge will create an electric field. • The total energy of a system composed of a collection of point charges can transfer from one form to another without changing the total amount of energy in the system. • There are laws that use symmetry and calculus to derive mathematical relationships that can be applied to physical systems containing electrostatic charge. • There are laws that use calculus and symmetry to derive mathematical relationships that can be applied to electrostatic-charge distributions.	• 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?

College Board AP Unit Standards (Learning Goals):
At the conclusion of this unit, students will know and be able to:

- Describe behavior of charges or system of chargedobjects 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 specifiedcharge 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.
- Describe the relative magnitude and direction of an electrostatic field given a diagram of equipotential lines.
- Describe characteristics of a set of equipotentiallines given in a diagram of an electric field.
- 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, and Dielectrics

Unit Overview:
Previously, students investigated why all objects have an electric charge. In Unit 2, students will examine how that charge can move through an object. Conductors, capacitors, and dielectrics are presented to demonstrate that a charge's movement is dependent on an object's material. In electronics, each of these are important based on the type of movement or desired object behavior. Additionally, this unit examines how the behavior of these elements is impacted by electric fields. Students should be provided with opportunities (laboratory investigations or activities) to describe and examine the function of each of these elements, along with capacitors. Knowledge of conductors, capacitors, and dielectrics will prepare students for understanding how electric circuits work in Unit 3 and how they behave when one or more electrical element is altered or modified.

Enduring Understanding(s):

- Excess charge on an insulated sphere or spherical shell will spread out on the entire surface of the sphere until there is no more movement of the charge because the surface is an equipotential.
- There are electrical devices that store and transfer electrostatic potential energy.
- An insulator has different properties (than a conductor) when placed in an electric field.

Essential Question(s):

- 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?

College Board AP Unit Standards (Learning Goals):
At the conclusion of this unit, students will know and be able to:

- 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.
- Describe the consequences of a conductor being an equipotential surface.
- 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.
- Describe the process of charging a conductor by induction.
- 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.
- 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 fundamentalconstants.
- 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 thecapacitor, 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.
- Calculate changes in energy, charge, or potential difference when a dielectric is inserted into an isolated charge capacitor.

UNIT 10: Electric Circuits

Unit Overview:
Whether or not they're aware, students interact with electric circuits regularly through charging their phones, powering up their laptops, or simply switching on a light. Unit 3 serves to illuminate how, and why, our various appliances function by exploring the nature and importance of electric currents, circuits, and resistance. Through activities and lab investigations, students will have opportunities to relate knowledge across the course by using the electrical components they learned about in Unit 2 and will come to discover in Unit 3 to create, modify, and analyze circuits. Students will also analyze the relationships that exist between current, resistance, and power, in addition to exploring and applying Ohm's Law and Kirchhoff's Rules.

Enduring Understanding(s):	Essential Question(s):
• The rate of charge flow through a conductor depends on the physical characteristics of the conductor • There are electrical devices that convert electrical potential energy into other forms of energy • Total energy and charge are conserved in a circuit containing resistors and a source of energy. • Total energy and charge are conserved in a circuit that includes resistors, capacitors, and a source of energy.	• 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?

College Board AP Unit Standards (Learning Goals):
At the conclusion of this unit, students will know and be able to:

- Calculate unknown quantities relating to the definition of current.
- 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 throughthe 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.
- 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.
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UNIT 11: Magnetic Fields

Unit Overview:
In previous units, students discovered that the electric field allows charged objects to interact without contact. Unit 4 introduces students to magnetism and how magnetic fields are generated, behave, and relate to electricity. Students will learn how magnetic fields impact motion and interact with other magnetic fields. Laboratory investigations and/or activities should be provided for students to apply both the Biot–Savart Law (using calculations to determine the strength of a magnetic field) and Ampère's Law (deriving mathematical relationships which relate the magnitude of the magnetic field to current). This knowledge from previous units helps students to make connections between electric fields and magnetic fields as well as between Gauss's Law and Ampère's Law.

Enduring Understanding(s):	Essential Question(s):
• 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 conductingwires depend on the directions of current in the wires?	• Charged particles moving through a magnetic field may change the direction of their motion. • A magnetic field can interact with a straight conducting wire with current. • Current-carrying conductors create magnetic fields that allow them to interact at a distance with other magnetic fields. • There are laws that use symmetry and calculus to derive mathematical relationships that are applied to physical systems containing moving charge.

College Board AP Unit Standards (Learning Goals):
At the conclusion of this unit, students will knowand be able to:

- Describe the direction of a magnetic field from theinformation given by a description of the motionor trajectory of a charged particle moving througha uniform magnetic field.
- Describe the path of different moving charged particles(i.e., of different type of charge or mass) in auniform magnetic field.
- Derive an expression for the radius of a circularpath for a charged particle of specified characteristicsmoving 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 electricand magnetic fields with a constant velocity.
- Calculate the magnitude of the magnetic force actingon a straight-line segment of a conductor with currentin a uniform magnetic field.
- Describe or indicate the direction of magnetic forcesacting on a complete conductive loop with current in a region of uniform magnetic field.
- Calculate the magnitude and direction of the net torqueexperienced by a rectangular loop of wire carryinga current in a region of a uniform magnetic field.
- Calculate the magnitude and direction of a magneticfield produced at a point near a long, straight, current-carrying wire.
- Apply the right-hand rule for magnetic field of astraight wire (or correctly use the Biot–Savart Law found in CNV-8.A.1) to deduce the direction of a magnetic field near a long, straight, current-carrying wire.
- Describe the direction of a magnetic-field vectorat 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 magneticfield on the axis of a circular loop of current ora segment of a circular loop.
- Explain how the Biot–Savart Law can be used to determine the field of a long, straight, current-carrying wireat perpendicular distances close to the wire.
- Describe the relationship of the magnetic field asa function of distance for various configurationsof current-carrying cylindrical conductors with eithera single current or multiple currents, at points inside and outside of the conductors.

UNIT 12: Electromagnetism	
Unit Overview: Throughout the course, students explored the vital roles electricity and magnetism play in our daily lives. Unit 5 examines electromagnetism through the concept of electromagnetic induction and the application of Maxwell's equations. Through activities and detailed laboratory investigations, students will study, apply, and analyze the concept of induction, as well as investigate the relationship between Faraday's Law and Lenz's Law. Additionally, students are expected to call upon their knowledge obtained in earlier units—particularly that of charges, currents, and electric and magnetic fields—to better understand Maxwell's equations and to be able to mathematically demonstrate, as well as reason with, how these fields are generated.	
Enduring Understanding(s): ● There are laws that use symmetry and calculus to derive mathematical relationships that are applied to physical systems containing moving charge. ● A changing magnetic field over time can induce current in conductors. ● Induced forces (arising from magnetic interactions) that are exerted on objects can change the kinetic energy of an object. ● In a closed circuit containing inductors and resistors, energy and charge are conserved. ● Electric and magnetic fields that change over time can mutually induce other electric and magnetic fields.	**Essential Question(s):** ● 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? ● How does Wi-Fi work?
College Board AP Unit Standards (Learning Goals): **At the conclusion of this unit, students will know and be able to:** ● 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 the 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. ● 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.
- Associate the appropriate Maxwell's equation with the appropriate physical consequence in a physical system containing a magnetic or electric field.