Teresa M. Rafferty
Superintendent of Schools

Dr. Frank Ranelli
Assistant Superintendent

Advanced Placement Physics

Content Area: Science
Grade Span: 11-12
Revised by: Elizabeth Eibling
Presented by: Gita Manchanda
Approval date:

Piscataway Township Schools
1515 Stelton Road
Piscataway, NJ 08854-1332
732 572-2289, ext. 2561
Fax 732 572-1540
www.piscatawayschools.org

COURSE OVERVIEW

Description

The second year physics program is intended to strengthen the background obtained by students who took the first year physics course. This course is taught at an accelerated pace in order to strictly follow the national advanced placement physics curriculum. Upon completion of this course students are expected to take the Physics "C" advanced placement exams for Mechanics, and Electricity and Magnetism. Students are required to have a strong foundation in calculus.

Goals

To provide students with learning opportunities that are designed to build scientific literacy, critical thinking, problem solving and analytical skills through the process of inquiry and problem solving in physics. To prepare students for the College Board AP Physic C Mechanics test and the AP Physics C Electromagnetism test.

Scope and Sequence

Unit	Topic	Length
	Mechanics	
Unit 1	One Dimensional Kinematics	1 cycle
Unit 2	Vectors and Two Dimensional Motion	1.5 cycles
Unit 3	Newtonian Mechanics	2 cycles
Unit 4	Conservation of Energy	1.5 cycles
Unit 5	Impulse and Momentum	1.5 cycles
Unit 6	Rotary Motion and Torque	3 cycles
Unit 7	Simple Harmonic Motion	1.5 cycles
	Electricity and Magnetism	
Unit 8	Electrostatic Fields and Forces	3 cycles
Unit 9	Electric Potential and Capacitance	1.5 cycles
Unit 10	Resistance and DC Circuits	2 cycles
Unit 11	Magnetism	1.5 cycles
Unit 12	Electromagnetism	2 cycles

Resources

Core Text:

- Knight, Randall. 2017. *Physics for Scientists and Engineers A Strategic Approach with Modern Physics Fourth Edition AP Edition,* Boston, MA: Pearson Education, Inc. **ISBN**-13: 978-0-134-11065-3

Suggested Resources:

- AP College Board approved resources
- www.physicsclassroom.com
- Phet Simulations www.phet.colorado.edu/en/simulations/category/physics
- Gizmos www.explorelearning.com/index.cfm?method=cuser.dsploginjoin

ALL UNITS: INSTRUCTIONAL FOCUS

Summary and Rationale

The AP Physics course is a full year course encompassing the College Board requirements for Physics C for both Mechanics and Electricity & Magnetism. Students are expected to have completed the Honors level first year Physics course, or the Academic Physics course (but only with the recommendation of the Academic Physics instructor.) Students should be enrolled in a Calculus course, or should have already taken calculus.

In this course, advanced level topics will be explored as well as the review of the fundamental topics which will be covered in greater depth and detail. The mechanics portion of the course will apply calculus to topics in kinematics, dynamics, energy, momentum, and circular and rotational motion. The electricity & magnetism portion of this course calculus to develop concepts and will introduce students to electrostatics, electric circuits, magnetic fields, and electromagnetism. Concepts and skills are introduced, refined and reinforced in a student centered, inquiry based learning environment. Problem solving and technical reading are two of the outside activities required for the successful development of these topics. The course makes use of both technology and traditional methods to collect and analyze data. Because our school year extends through most of June, some hands-on lab work and projects will take place after the AP exam, but most will be interspersed throughout the course where appropriate.

The course provides students with the opportunity to earn AP college credit for a calculus based physics course.

State Standards

Standard
A. Kinematics (including vectors, vector algebra, components of vectors, coordinate systems, displacement, velocity, and acceleration)

1. Motion in one dimension

a) Students should understand the general relationships among position, velocity, and acceleration for the motion of a particle along a straight line, so that:

(1) Given a graph of one of the kinematic quantities, position, velocity, or acceleration, as a function of time, they can recognize in what time intervals the other two are positive, negative, or zero, and can identify or sketch a graph of each as a function of time.

(2) Given an expression for one of the kinematic quantities, position, velocity, or acceleration, as a function of time, they can determine the other two as a function of time, and find when these quantities are zero or achieve their maximum and minimum values.

b) Students should understand the special case of motion with constant acceleration, so they can:

(1) Write down expressions for velocity and position as functions of time, and identify or sketch graphs of these quantities.

(2) Use the equations $v = v_o + at$, $x = x_o + v_o t + \frac{1}{2}at^2$, and $v^2 = v_o^2 + 2a\Delta x$ to solve problems involving one-dimensional motion with constant acceleration.

c) Students should know how to deal with situations in which acceleration is a specified function of velocity and time so they can write an appropriate differential equation and solve it for *u(t)* by separation of variables, incorporating correctly a given initial value of *u*.

2. Motion in two dimensions, including projectile motion

a) Students should be able to add, subtract, and resolve displacement and velocity vectors, so they can:
(1) Determine components of a vector along two specified, mutually perpendicular axes.
(2) Determine the net displacement of a particle or the location of a particle relative to another.
(3) Determine the change in velocity of a particle or the velocity of one particle relative to another.
b) Students should understand the general motion of a particle in two dimensions so that, given functions $x(t)$ and $y(t)$ which describe this motion, they can determine the components, magnitude, and direction of the particle's velocity and acceleration as functions of time.
c) Students should understand the motion of projectiles in a uniform gravitational field, so they can:
(1) Write down expressions for the horizontal and vertical components of velocity and position as functions of time, and sketch or identify graphs of these components.
(2) Use these expressions in analyzing the motion of a projectile that is projected with an arbitrary initial velocity.
Standard **B. Newton's laws of motion**
1. Static equilibrium (first law)
Students should be able to analyze situations in which a particle remains at rest, or moves with constant velocity, under the influence of several forces.
2. Dynamics of a single particle (second law)
a) Students should understand the relation between the force that acts on an object and the resulting change in the object's velocity, so they can:
(1) Calculate, for an object moving in one dimension, the velocity change that results when a constant force F acts over a specified time interval.
(2) Calculate, for an object moving in one dimension, the velocity change that results when a force $F(t)$ acts over a specified time interval.
(3) Determine, for an object moving in a plane whose velocity vector undergoes a specified change over a specified time interval, the average force that acted on the object.
b) Students should understand how Newton's Second Law, $\hat{A}\mathbf{F} = \mathbf{F}_{net} = m\mathbf{a}$, applies to an object subject to forces such as gravity, the pull of strings, or contact forces, so they can:
(1) Draw a well-labeled, free-body diagram showing all real forces that act on the object.
(2) Write down the vector equation that results from applying Newton's Second Law to the object, and take components of this equation along appropriate axes.
c) Students should be able to analyze situations in which an object moves with specified acceleration under the influence of one or more forces so they can determine the magnitude and direction of the net force, or of one of the forces that makes up the net force, such as motion up or down with constant acceleration.
d) Students should understand the significance of the coefficient of friction, so they can:
(1) Write down the relationship between the normal and frictional forces on a surface.
(2) Analyze situations in which an object moves along a rough inclined plane or

horizontal surface.
(3) Analyze under what circumstances an object will start to slip, or to calculate the magnitude of the force of static friction.
e) Students should understand the effect of drag forces on the motion of an object, so they can:
(1) Find the terminal velocity of an object moving vertically under the influence of a retarding force dependent on velocity.
(2) Describe qualitatively, with the aid of graphs, the acceleration, velocity, and displacement of such a particle when it is released from rest or is projected vertically with specified initial velocity.
(3) Use Newton's Second Law to write a differential equation for the velocity of the object as a function of time.
(4) Use the method of separation of variables to derive the equation for the velocity as a function of time from the differential equation that follows from Newton's Second Law.
(5) Derive an expression for the acceleration as a function of time for an object falling under the influence of drag forces.
3. Systems of two or more objects (third law)
a) Students should understand Newton’s Third Law so that, for a given system, they can identify the force pairs and the objects on which they act, and state the magnitude and direction of each force.
b) Students should be able to apply Newton’s Third Law in analyzing the force of contact between two objects that accelerate together along a horizontal or vertical line, or between two surfaces that slide across one another.
c) Students should know that the tension is constant in a light string that passes over a massless pulley and should be able to use this fact in analyzing the motion of a system of two objects joined by a string.
d) Students should be able to solve problems in which application of Newton’s laws leads to two or three simultaneous linear equations involving unknown forces or accelerations.
Standard **C. Work, energy, power**
1. Work and the work-energy theorem
a) Students should understand the definition of work, including when it is positive, negative, or zero, so they can:
(1) Calculate the work done by a specified constant force on an object that undergoes a specified displacement.
(2) Relate the work done by a force to the area under a graph of force as a function of position, and calculate this work in the case where the force is a linear function of position.
(3) Use integration to calculate the work performed by a force $F(x)$ on an object that undergoes a specified displacement in one dimension.
(4) Use the scalar product operation to calculate the work performed by a specified constant force F on an object that undergoes a displacement in a plane.
b) Students should understand and be able to apply the work-energy theorem, so they can:
(1) Calculate the change in kinetic energy or speed that results from performing a specified amount of work on an object.

(2) Calculate the work performed by the net force, or by each of the forces that make up the net force, on an object that undergoes a specified change in speed or kinetic energy.
(3) Apply the theorem to determine the change in an object's kinetic energy and speed that results from the application of specified forces, or to determine the force that is required in order to bring an object to rest in a specified distance.
2. Forces and potential energy
a) Students should understand the concept of a conservative force, so they can:
(1) State alternative definitions of "conservative force" and explain why these definitions are equivalent.
(2) Describe examples of conservative forces and non-conservative forces.
b) Students should understand the concept of potential energy, so they can:
(1) State the general relation between force and potential energy, and explain why potential energy can be associated only with conservative forces.
(2) Calculate a potential energy function associated with a specified one-dimensional force $F(x)$.
(3) Calculate the magnitude and direction of a one-dimensional force when given the potential energy function $U(x)$ for the force.
(4) Write an expression for the force exerted by an ideal spring and for the potential energy of a stretched or compressed spring.
(5) Calculate the potential energy of one or more objects in a uniform gravitational field.
3. Conservation of energy
a) Students should understand the concepts of mechanical energy and of total energy, so they can:
(1) State and apply the relation between the work performed on an object by non-conservative forces and the change in an object's mechanical energy.
(2) Describe and identify situations in which mechanical energy is converted to other forms of energy.
(3) Analyze situations in which an object's mechanical energy is changed by friction or by a specified externally applied force.
b) Students should understand conservation of energy, so they can:
(1) Identify situations in which mechanical energy is or is not conserved.
(2) Apply conservation of energy in analyzing the motion of systems of connected objects, such as an Atwood's machine.
(3) Apply conservation of energy in analyzing the motion of objects that move under the influence of springs.
(4) Apply conservation of energy in analyzing the motion of objects that move under the influence of other non-constant one-dimensional forces.
c) Students should be able to recognize and solve problems that call for application both of conservation of energy and Newton's Laws.
4. Power Students should understand the definition of power, so they can:

a) Calculate the power required to maintain the motion of an object with constant acceleration (e.g., to move an object along a level surface, to raise an object at a constant rate, or to overcome friction for an object that is moving at a constant speed).
b) Calculate the work performed by a force that supplies constant power, or the average power supplied by a force that performs a specified amount of work.
Standard **D. Systems of particles, linear momentum**
1. Center of mass
a) Students should understand the technique for finding center of mass, so they can:
(1) Identify by inspection the center of mass of a symmetrical object.
(2) Locate the center of mass of a system consisting of two such objects.
(3) Use integration to find the center of mass of a thin rod of non-uniform density
b) Students should be able to understand and apply the relation between center-of- mass velocity and linear momentum, and between center-of-mass acceleration and net external force for a system of particles.
c) Students should be able to define center of gravity and to use this concept to express the gravitational potential energy of a rigid object in terms of the position of its center of mass.
2. Impulse and momentum Students should understand impulse and linear momentum, so they can:
a) Relate mass, velocity, and linear momentum for a moving object, and calculate the total linear momentum of a system of objects.
b) Relate impulse to the change in linear momentum and the average force acting on an object.
c) State and apply the relations between linear momentum and center-of-mass motion for a system of particles.
d) Calculate the area under a force versus time graph and relate it to the change in momentum of an object.
e) Calculate the change in momentum of an object given a function $F(t)$ for the net force acting on the object.
3. Conservation of linear momentum, collisions
a) Students should understand linear momentum conservation, so they can:
(1) Explain how linear momentum conservation follows as a consequence of Newton's Third Law for an isolated system.
(2) Identify situations in which linear momentum, or a component of the linear momentum vector, is conserved.
(3) Apply linear momentum conservation to one-dimensional elastic and inelastic collisions and two-dimensional completely inelastic collisions.
(4) Apply linear momentum conservation to two-dimensional elastic and inelastic collisions.
(5) Analyze situations in which two or more objects are pushed apart by a spring or other agency, and calculate how much energy is released in such a process.
b) Students should understand frames of reference, so they can:
(1) Analyze the uniform motion of an object relative to a moving medium such as a flowing stream.

(2) Analyze the motion of particles relative to a frame of reference that is accelerating horizontally or vertically at a uniform rate.
Standard **E. Circular motion and rotation**
1. Uniform circular motion Students should understand the uniform circular motion of a particle, so they can:
a) Relate the radius of the circle and the speed or rate of revolution of the particle to the magnitude of the centripetal acceleration.
b) Describe the direction of the particle's velocity and acceleration at any instant during the motion.
c) Determine the components of the velocity and acceleration vectors at any instant, and sketch or identify graphs of these quantities.
d) Analyze situations in which an object moves with specified acceleration under the influence of one or more forces so they can determine the magnitude and direction of the net force, or of one of the forces that makes up the net force, in situations such as the following:
(1) Motion in a horizontal circle (e.g., mass on a rotating merry-go-round, or car rounding a banked curve).
(2) Motion in a vertical circle (e.g., mass swinging on the end of a string, cart rolling down a curved track, rider on a Ferris wheel).
2. Torque and rotational statics
a) Students should understand the concept of torque, so they can:
(1) Calculate the magnitude and direction of the torque associated with a given force.
(2) Calculate the torque on a rigid object due to gravity.
b) Students should be able to analyze problems in statics, so they can:
(1) State the conditions for translational and rotational equilibrium of a rigid object.
(2) 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.
c) Students should develop a qualitative understanding of rotational inertia, so they can:
(1) Determine by inspection which of a set of symmetrical objects of equal mass has the greatest rotational inertia.
(2) Determine by what factor an object's rotational inertia changes if all its dimensions are increased by the same factor.
d) Students should develop skill in computing rotational inertia so they can find the rotational inertia of:
(1) A collection of point masses lying in a plane about an axis perpendicular to the plane.
(2) A thin rod of uniform density, about an arbitrary axis perpendicular to the rod.
(3) A thin cylindrical shell about its axis, or an object that may be viewed as being made up of coaxial shells.
e) Students should be able to state and apply the parallel-axis theorem.

3. Rotational kinematics and dynamics
a) 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.
b) Students should be able to use the right-hand rule to associate an angular velocity vector with a rotating object.
c) Students should understand the dynamics of fixed-axis rotation, so they can:
(1) Describe in detail the analogy between fixed-axis rotation and straight-line translation.
(2) Determine the angular acceleration with which a rigid object is accelerated about a fixed axis when subjected to a specified external torque or force.
(3) Determine the radial and tangential acceleration of a point on a rigid object.
(4) Apply conservation of energy to problems of fixed-axis rotation.
(5) Analyze problems involving strings and massive pulleys.
e) Students should understand the motion of a rigid object along a surface, so they can:
(1) 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.
(2) Apply the equations of translational and rotational motion simultaneously in analyzing rolling with slipping.
(3) Calculate the total kinetic energy of an object that is undergoing both translational and rotational motion, and apply energy conservation in analyzing such motion.
4. Angular momentum and its conservation
a) Students should be able to use the vector product and the right-hand rule, so they can:
(1) Calculate the torque of a specified force about an arbitrary origin.
(2) Calculate the angular momentum vector for a moving particle.
(3) Calculate the angular momentum vector for a rotating rigid object in simple cases where this vector lies parallel to the angular velocity vector.
d) Students should understand angular momentum conservation, so they can:
(1) 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.
(2) State the relation between net external torque and angular momentum, and identify situations in which angular momentum is conserved.
(3) Analyze problems in which the moment of inertia of an object is changed as it rotates freely about a fixed axis.
(4) Analyze a collision between a moving particle and a rigid object that can rotate about a fixed axis or about its center of mass.
Standard **F. Oscillations and Gravitation**

1. Simple harmonic motion (dynamics and energy relationships) Students should understand simple harmonic motion, so they can:		
	a)	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.
	b)	Write down an appropriate expression for displacement of the form A sin (wt) or A cos (wt) to describe the motion.
	c)	Find an expression for velocity as a function of time.
	d)	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.
	e)	State and apply the relation between frequency and period.
	f)	Recognize that a system that obeys a differential equation of the form $d^2x/dt^2 = -w^2x$ must execute simple harmonic motion, and determine the frequency and period of such motion.
	g)	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.
	h)	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.
	i)	Calculate the maximum displacement or velocity of a particle that moves in simple harmonic motion with specified initial position and velocity.
	j)	Develop a qualitative understanding of resonance so they can identify situations in which a system will resonate in response to a sinusoidal external force.
2. Mass on a spring Students should be able to apply their knowledge of simple harmonic motion to the case of a mass on a spring, so they can:		
	a)	Derive the expression for the period of oscillation of a mass on a spring.
	b)	Apply the expression for the period of oscillation of a mass on a spring.
	c)	Analyze problems in which a mass hangs from a spring and oscillates vertically.
	d)	Analyze problems in which a mass attached to a spring oscillates horizontally.
	e)	Determine the period of oscillation for systems involving series or parallel combinations of identical springs, or springs of differing lengths.
3. Pendulum and other oscillations Students should be able to apply their knowledge of simple harmonic motion to the case of a pendulum, so they can:		
	a)	Derive the expression for the period of a simple pendulum.
	b)	Apply the expression for the period of a simple pendulum.
	c)	State what approximation must be made in deriving the period.
	d)	Analyze the motion of a torsional pendulum or physical pendulum in order to determine the period of small oscillations.
4. Newton's law of gravity Students should know Newton's Law of Universal Gravitation, so they can:		

a) Determine the force that one spherically symmetrical mass exerts on another.
b) Determine the strength of the gravitational field at a specified point outside a spherically symmetrical mass.
c) 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.
5. Orbits of planets and satellites Students should understand the motion of an object in orbit under the influence of gravitational forces, so they can:
a) For a circular orbit:
(1) 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.
(2) Derive Kepler's Third Law for the case of circular orbits.
(3) Derive and apply the relations among kinetic energy, potential energy, and total energy for such an orbit.
b) For a general orbit:
(1) 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.
(2) Apply conservation of angular momentum to determine the velocity and radial distance at any point in the orbit.
(3) Apply angular momentum conservation and energy conservation to relate the speeds of an object at the two extremes of an elliptical orbit.
(4) 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.
III. ELECTRICITY AND MAGNETISM
Standard **A. Electrostatics**
1. Charge and Coulomb's Law
a) Students should understand the concept of electric charge, so they can:
(1) Describe the types of charge and the attraction and repulsion of charges.
(2) Describe polarization and induced charges.
b) Students should understand Coulomb's Law and the principle of superposition, so they can:
(1) Calculate the magnitude and direction of the force on a positive or negative charge due to other specified point charges.
(2) Analyze the motion of a particle of specified charge and mass under the influence of an electrostatic force.
2. Electric field and electric potential (including point charges)
a) Students should understand the concept of electric field, so they can:

(1) Define it in terms of the force on a test charge.
(2) Describe and calculate the electric field of a single point charge.
(3) Calculate the magnitude and direction of the electric field produced by two or more point charges.
(4) Calculate the magnitude and direction of the force on a positive or negative charge placed in a specified field.
(5) Interpret an electric field diagram.
(6) Analyze the motion of a particle of specified charge and mass in a uniform electric field.
b) Students should understand the concept of electric potential, so they can:
(1) Determine the electric potential in the vicinity of one or more point charges.
(2) Calculate the electrical work done on a charge or use conservation of energy to determine the speed of a charge that moves through a specified potential difference.
(3) Determine the direction and approximate magnitude of the electric field at various positions given a sketch of equipotentials.
(4) Calculate the potential difference between two points in a uniform electric field, and state which point is at the higher potential.
(5) Calculate how much work is required to move a test charge from one location to another in the field of fixed point charges.
(6) Calculate the electrostatic potential energy of a system of two or more point charges, and calculate how much work is required to establish the charge system.
(7) Use integration to determine electric potential difference between two points on a line, given electric field strength as a function of position along that line.
(8) State the general relationship between field and potential, and define and apply the concept of a conservative electric field.
3. Gauss's law
a) Students should understand the relationship between electric field and electric flux, so they can:
(1) Calculate the flux of an electric field through an arbitrary surface or of a field uniform in magnitude over a Gaussian surface and perpendicular to it.
(2) Calculate the flux of the electric field through a rectangle when the field is perpendicular to the rectangle and a function of one coordinate only.
(3) State and apply the relationship between flux and lines of force.
b) Students should understand Gauss's Law, so they can:
(1) State the law in integral form, and apply it qualitatively to relate flux and electric charge for a specified surface.
(2) Apply the law, along with symmetry arguments, to determine the electric field for a planar, spherical, or cylindrically symmetric charge distribution.
(3) Apply the law to determine the charge density or total charge on a surface in terms of the electric field near the surface.
4. Fields and potentials of other charge distributions

a) Students should be able to use the principle of superposition to calculate by integration:
(1) The electric field of a straight, uniformly charged wire.
(2) The electric field and potential on the axis of a thin ring of charge, or at the center of a circular arc of charge.
(3) The electric potential on the axis of a uniformly charged disk.
b) Students should know the fields of highly symmetric charge distributions, so they can:
(1) Identify situations in which the direction of the electric field produced by a charge distribution can be deduced from symmetry considerations.
(2) Describe qualitatively the patterns and variation with distance of the electric field of:
(a) Oppositely-charged parallel plates.
(b) A long, uniformly-charged wire, or thin cylindrical or spherical shell.
(3) Use superposition to determine the fields of parallel charged planes, coaxial cylinders, or concentric spheres.
(4) Derive expressions for electric potential as a function of position in the above cases.
Standard **B. Conductors, capacitors, dielectrics**
1. Electrostatics with conductors
a) Students should understand the nature of electric fields in and around conductors, so they can:
(1) Explain the mechanics responsible for the absence of electric field inside a conductor, and know that all excess charge must reside on the surface of the conductor.
(2) Explain why a conductor must be an equipotential, and apply this principle in analyzing what happens when conductors are connected by wires.
(3) Show that all excess charge on a conductor must reside on its surface and that the field outside the conductor must be perpendicular to the surface.
b) Students should be able to describe and sketch a graph of the electric field and potential inside and outside a charged conducting sphere.
c) Students should understand induced charge and electrostatic shielding, so they can:
(1) Describe the process of charging by induction.
(2) Explain why a neutral conductor is attracted to a charged object.
(3) Explain why there can be no electric field in a charge-free region completely surrounded by a single conductor, and recognize consequences of this result.
(4) Explain why the electric field outside a closed conducting surface cannot depend on the precise location of charge in the space enclosed by the conductor, and identify consequences of this result.
2. Capacitors
a) Students should understand the definition and function of capacitance, so they can:

(1) Relate stored charge and voltage for a capacitor.
(2) Relate voltage, charge, and stored energy for a capacitor.
(3) Recognize situations in which energy stored in a capacitor is converted to other forms.
b) Students should understand the physics of the parallel-plate capacitor, so they can:
(1) Describe the electric field inside the capacitor, and relate the strength of this field to the potential difference between the plates and the plate separation.
(2) Relate the electric field to the density of the charge on the plates.
(3) Derive an expression for the capacitance of a parallel-plate capacitor.
(4) Determine how changes in dimension will affect the value of the capacitance.
(5) Derive and apply expressions for the energy stored in a parallel-plate capacitor and for the energy density in the field between the plates.
(6) Analyze situations in which capacitor plates are moved apart or moved closer together, or in which a conducting slab is inserted between capacitor plates, either with a battery connected between the plates or with the charge on the plates held fixed.
c) Students should understand cylindrical and spherical capacitors, so they can:
(1) Describe the electric field inside each.
(2) Derive an expression for the capacitance of each.
3. Dielectrics Students should understand the behavior of dielectrics, so they can:
a) Describe how the insertion of a dielectric between the plates of a charged parallel- plate capacitor affects its capacitance and the field strength and voltage between the plates.
b) Analyze situations in which a dielectric slab is inserted between the plates of a capacitor.
Standard **C. Electric circuits**
1. Current, resistance, power
a) Students should understand the definition of electric current, so they can relate the magnitude and direction of the current to the rate of flow of positive and negative charge.
b) Students should understand conductivity, resistivity, and resistance, so they can:
(1) Relate current and voltage for a resistor.
(2) Write the relationship between electric field strength and current density in a conductor, and describe, in terms of the drift velocity of electrons, why such a relationship is plausible.
(3) Describe how the resistance of a resistor depends upon its length and cross-sectional area, and apply this result in comparing current flow in resistors of different material or different geometry.
(4) Derive an expression for the resistance of a resistor of uniform cross-section in terms of its dimensions and the resistivity of the material from which it is constructed.

(5) Derive expressions that relate the current, voltage, and resistance to the rate at which heat is produced when current passes through a resistor.
(6) Apply the relationships for the rate of heat production in a resistor.
2. Steady-state direct current circuits with batteries and resistors only
a) Students should understand the behavior of series and parallel combinations of resistors, so they can:
(1) Identify on a circuit diagram whether resistors are in series or in parallel.
(2) Determine the ratio of the voltages across resistors connected in series or the ratio of the currents through resistors connected in parallel.
(3) Calculate the equivalent resistance of a network of resistors that can be broken down into series and parallel combinations.
(4) Calculate the voltage, current, and power dissipation for any resistor in such a network of resistors connected to a single power supply.
(5) Design a simple series-parallel circuit that produces a given current through and potential difference across one specified component, and draw a diagram for the circuit using conventional symbols.
b) Students should understand the properties of ideal and real batteries, so they can:
(1) Calculate the terminal voltage of a battery of specified emf and internal resistance from which a known current is flowing.
(2) Calculate the rate at which a battery is supplying energy to a circuit or is being charged up by a circuit.
c) Students should be able to apply Ohm's law and Kirchhoff's rules to direct-current circuits, in order to:
(1) Determine a single unknown current, voltage, or resistance.
(2) Set up and solve simultaneous equations to determine two unknown currents.
d) Students should understand the properties of voltmeters and ammeters, so they can:
(1) State whether the resistance of each is high or low.
(2) Identify or show correct methods of connecting meters into circuits in order to measure voltage or current.
(3) Assess qualitatively the effect of finite meter resistance on a circuit into which these meters are connected.
3. Capacitors in circuits
a) Students should understand the $t = 0$ and steady-state behavior of capacitors connected in series or in parallel, so they can:
(1) Calculate the equivalent capacitance of a series or parallel combination.
(2) Describe how stored charge is divided between capacitors connected in parallel.
(3) Determine the ratio of voltages for capacitors connected in series.
(4) Calculate the voltage or stored charge, under steady-state conditions, for a capacitor connected to a circuit consisting of a battery and resistors.
b) Students should understand the discharging or charging of a capacitor through a resistor, so they can:

(1) Calculate and interpret the time constant of the circuit.
(2) Sketch or identify graphs of stored charge or voltage for the capacitor, or of current or voltage for the resistor, and indicate on the graph the significance of the time constant.
(3) Write expressions to describe the time dependence of the stored charge or voltage for the capacitor, or of the current or voltage for the resistor.
(4) Analyze the behavior of circuits containing several capacitors and resistors, including analyzing or sketching graphs that correctly indicate how voltages and currents vary with time.
Standard **D. Magnetic Fields**
1. Forces on moving charges in magnetic fields Students should understand the force experienced by a charged particle in a magnetic field, so they can:
a) Calculate the magnitude and direction of the force in terms of *q*, **v**, and, **B**, and explain why the magnetic force can perform no work.
b) Deduce the direction of a magnetic field from information about the forces experienced by charged particles moving through that field.
c) Describe the paths of charged particles moving in uniform magnetic fields.
d) Derive and apply the formula for the radius of the circular path of a charge that moves perpendicular to a uniform magnetic field.
e) Describe under what conditions particles will move with constant velocity through crossed electric and magnetic fields.
2. Forces on current-carrying wires in magnetic fields Students should understand the force exerted on a current-carrying wire in a magnetic field, so they can:
a) Calculate the magnitude and direction of the force on a straight segment of current- carrying wire in a uniform magnetic field.
b) Indicate the direction of magnetic forces on a current-carrying loop of wire in a magnetic field, and determine how the loop will tend to rotate as a consequence of these forces.
c) Calculate the magnitude and direction of the torque experienced by a rectangular loop of wire carrying a current in a magnetic field.
3. Fields of long current-carrying wires Students should understand the magnetic field produced by a long straight current-carrying wire, so they can:
a) Calculate the magnitude and direction of the field at a point in the vicinity of such a wire.
b) Use superposition to determine the magnetic field produced by two long wires.
c) Calculate the force of attraction or repulsion between two long current-carrying wires.
4. Biot-Savart law and Ampere's law
a) Students should understand the Biot-Savart Law, so they can:
(1) Deduce the magnitude and direction of the contribution to the magnetic field made by a short straight segment of current-carrying wire.
(2) Derive and apply the expression for the magnitude of **B** on the axis of a circular loop of current.

b) Students should understand the statement and application of Ampere's Law in integral form, so they can:
(1) State the law precisely.
(2) Use Ampere's law, plus symmetry arguments and the right-hand rule, to relate magnetic field strength to current for planar or cylindrical symmetries.
c) Students should be able to apply the superposition principle so they can determine the magnetic field produced by combinations of the configurations listed above.
Standard **E. Electromagnetism**
1. Electromagnetic induction (including Faraday's law and Lenz's law)
a) Students should understand the concept of magnetic flux, so they can:
(1) Calculate the flux of a uniform magnetic field through a loop of arbitrary orientation.
(2) Use integration to calculate the flux of a non-uniform magnetic field, whose magnitude is a function of one coordinate, through a rectangular loop perpendicular to the field.
b) Students should understand Faraday's law and Lenz's law, so they can:
(1) Recognize situations in which changing flux through a loop will cause an induced emf or current in the loop.
(2) Calculate the magnitude and direction of the induced emf and current in a loop of wire or a conducting bar under the following conditions:
(a) The magnitude of a related quantity such as magnetic field or area of the loop is changing at a constant rate.
(b) The magnitude of a related quantity such as magnetic field or area of the loop is a specified non-linear function of time.
c) Students should be able to analyze the forces that act on induced currents so they can determine the mechanical consequences of those forces.
2. Inductance (including *LR* and *LC* circuits)
a) Students should understand the concept of inductance, so they can:
(1) Calculate the magnitude and sense of the emf in an inductor through which a specified changing current is flowing.
(2) Derive and apply the expression for the self-inductance of a long solenoid.
b) Students should understand the transient and steady state behavior of DC circuits containing resistors and inductors, so they can:
(1) Apply Kirchhoff's rules to a simple *LR* series circuit to obtain a differential equation for the current as a function of time.
(2) Solve the differential equation obtained in (1) for the current as a function of time through the battery, using separation of variables.
(3) Calculate the initial transient currents and final steady state currents through any part of a simple series and parallel circuit containing an inductor and one or more resistors.
(4) Sketch graphs of the current through or voltage across the resistors or inductor in a simple series and parallel circuit.

(5) Calculate the rate of change of current in the inductor as a function of time.
(6) Calculate the energy stored in an inductor that has a steady current flowing through it.
3. Maxwell's equations Students should be familiar with Maxwell's equations so they can associate each equation with its implications.
Standard **LABORATORY AND EXPERIMENTAL SITUATIONS** These objectives overlay the content objectives, and are assessed in the context of those objectives.
1. Design experiments Students should understand the process of designing experiments, so they can:
a) Describe the purpose of an experiment or a problem to be investigated.
b) Identify equipment needed and describe how it is to be used.
c) Draw a diagram or provide a description of an experimental setup.
d) Describe procedures to be used, including controls and measurements to be taken.
2. Observe and measure real phenomena Students should be able to make relevant observations, and be able to take measurements with a variety of instruments (cannot be assessed via paper-and-pencil examinations).
3. Analyze data Students should understand how to analyze data, so they can:
a) Display data in graphical or tabular form.
b) Fit lines and curves to data points in graphs.
c) Perform calculations with data.
d) Make extrapolations and interpolations from data.
4. Analyze errors Students should understand measurement and experimental error, so they can:
a) Identify sources of error and how they propagate.
b) Estimate magnitude and direction of errors.
c) Determine significant digits.
d) Identify ways to reduce error.
5. Communicate results Students should understand how to summarize and communicate results, so they can:
a) Draw inferences and conclusions from experimental data.
b) Suggest ways to improve experiment.
c) Propose questions for further study.

UNIT 1: One Dimensional Kinematics

Summary and Rationale
In this unit students will learn the fundamental concepts of motion and how to solve problems about motion in a straight line.
Recommended Pacing
1 Cycle (5 instructional days)
State Standards
Standard: A. Kinematics (including vectors, vector algebra, components of vectors, coordinate systems, displacement, velocity, and acceleration)
1. Motion in one dimension
a) Students should understand the general relationships among position, velocity, and acceleration for the motion of a particle along a straight line, so that:
(1) Given a graph of one of the kinematic quantities, position, velocity, or acceleration, as a function of time, they can recognize in what time intervals the other two are positive, negative, or zero, and can identify or sketch a graph of each as a function of time.
(2) Given an expression for one of the kinematic quantities, position, velocity, or acceleration, as a function of time, they can determine the other two as a function of time, and find when these quantities are zero or achieve their maximum and minimum values.
b) Students should understand the special case of motion with constant acceleration, so they can:
(1) Write down expressions for velocity and position as functions of time, and identify or sketch graphs of these quantities.
(2) Use the equations $v = v_o + at$, $x = x_o + v_o t + \frac{1}{2}at^2$, and $v^2 = v_o^2 + 2a\Delta x$ to solve problems involving one-dimensional motion with constant acceleration.
c) Students should know how to deal with situations in which acceleration is a specified function of velocity and time so they can write an appropriate differential equation and solve it for *u(t)* by separation of variables, incorporating correctly a given initial value of *u*.
Standard **LABORATORY AND EXPERIMENTAL SITUATIONS** These objectives overlay the content objectives, and are assessed in the context of those objectives.
1. Design experiments Students should understand the process of designing experiments, so they can:
a) Describe the purpose of an experiment or a problem to be investigated.
b) Identify equipment needed and describe how it is to be used.
c) Draw a diagram or provide a description of an experimental setup.
d) Describe procedures to be used, including controls and measurements to be taken.
2. Observe and measure real phenomena Students should be able to make relevant observations, and be able to take measurements with a variety of instruments (cannot be assessed via paper-and-pencil examinations).

3. Analyze data

Students should understand how to analyze data, so they can:

a) Display data in graphical or tabular form.

b) Fit lines and curves to data points in graphs.

c) Perform calculations with data.

d) Make extrapolations and interpolations from data.

4. Analyze errors

Students should understand measurement and experimental error, so they can:

a) Identify sources of error and how they propagate.

b) Estimate magnitude and direction of errors.

c) Determine significant digits.

d) Identify ways to reduce error.

5. Communicate results

Students should understand how to summarize and communicate results, so they can:

a) Draw inferences and conclusions from experimental data.

b) Suggest ways to improve experiment.

c) Propose questions for further study.

Instructional Focus

Unit Enduring Understandings

- Mathematical models describe physical phenomena and can be used to predict real world events.
- Uncertainty analysis gives measurements a range that can be used to disprove or fail to disprove predictions.

Unit Essential Questions

- How can an objects motion and change in motion in one dimension be represented verbally, graphically, and mathematically?
- How is data collected and interpreted in an experiment?
- What is the difference between a prediction and a hypothesis?

Objectives

Students will know:

- Models for one dimensional kinematics
- Understand the general relationships among position, velocity, and acceleration for the motion of a particle along a straight line.
- Understand the special case of motion with constant acceleration.

Students will be able to:

- Given a graph of position as a function of time, they can recognize in what time intervals velocity or acceleration is positive, negative or zero, and can sketch a graph of velocity as a function of time.
- Given a graph of velocity as a function of time, they can recognize in what time intervals acceleration is positive, negative or zero, and can sketch graphs of position and acceleration as functions of time.

- Write down expressions for velocity and position as functions of time, and identify or sketch the graphs of these quantities.
- Use the equations

  $v = v_o + at$

  $x = x_o + v_ot + ½ at^2$

  $v_f^2 = v_o^2 + 2a(x - x_o)$

  to solve problems in one-dimensional motion with constant acceleration.

Resources

Core Text:

- Knight, Randall. 2017. *Physics for Scientists and Engineers A Strategic Approach with Modern Physics Fourth Edition AP Edition,* Boston, MA: Pearson Education, Inc. **ISBN**-13: 978-0-134-11065-3

Suggested Resources:

- AP College Board approved resources
- www.physicsclassroom.com
- Phet Simulations www.phet.colorado.edu/en/simulations/category/physics
- Gizmos www.explorelearning.com/index.cfm?method=cuser.dsploginjoin

UNIT 2: Vectors and Two Dimensional Motion

Summary and Rationale

In this unit students will learn how vectors are represented and used, and how to solve problems about motion in a plane.

Recommended Pacing

1.5 Cycles (8 instructional days)

State Standards

Standard: A. Kinematics (including vectors, vector algebra, components of vectors, coordinate systems, displacement, velocity, and acceleration)

2. Motion in two dimensions, including projectile motion

a) Students should be able to add, subtract, and resolve displacement and velocity vectors, so they can:

(1) Determine components of a vector along two specified, mutually perpendicular axes.

(2) Determine the net displacement of a particle or the location of a particle relative to another.

(3) Determine the change in velocity of a particle or the velocity of one particle relative to another.

b) Students should understand the general motion of a particle in two dimensions so that, given functions $x(t)$ and $y(t)$ which describe this motion, they can determine the components, magnitude, and direction of the particle's velocity and acceleration as functions of time.
c) Students should understand the motion of projectiles in a uniform gravitational field, so they can:
(1) Write down expressions for the horizontal and vertical components of velocity and position as functions of time, and sketch or identify graphs of these components.
(2) Use these expressions in analyzing the motion of a projectile that is projected with an arbitrary initial velocity.
Standard **LABORATORY AND EXPERIMENTAL SITUATIONS** These objectives overlay the content objectives, and are assessed in the context of those objectives.
1. Design experiments Students should understand the process of designing experiments, so they can:
a) Describe the purpose of an experiment or a problem to be investigated.
b) Identify equipment needed and describe how it is to be used.
c) Draw a diagram or provide a description of an experimental setup.
d) Describe procedures to be used, including controls and measurements to be taken.
2. Observe and measure real phenomena Students should be able to make relevant observations, and be able to take measurements with a variety of instruments (cannot be assessed via paper-and-pencil examinations).
3. Analyze data Students should understand how to analyze data, so they can:
a) Display data in graphical or tabular form.
b) Fit lines and curves to data points in graphs.
c) Perform calculations with data.
d) Make extrapolations and interpolations from data.
4. Analyze errors Students should understand measurement and experimental error, so they can:
a) Identify sources of error and how they propagate.
b) Estimate magnitude and direction of errors.
c) Determine significant digits.
d) Identify ways to reduce error.
5. Communicate results Students should understand how to summarize and communicate results, so they can:
a) Draw inferences and conclusions from experimental data.
b) Suggest ways to improve experiment.
c) Propose questions for further study.

Instructional Focus

Unit Enduring Understandings

- Mathematical models describe physical phenomena and can be used to predict real world events.
- Multiple experiments can be used to verify an experimentally measured quantity.
- The same basic principles govern the motion of all objects.
- Motion in the x- direction is independent of motion in the y- direction.

Unit Essential Questions

- What is the best way to investigate?
- How can an objects motion and change in motion in one dimension be represented verbally, graphically, and mathematically?
- How can motion be modeled in multiple dimensions to solve real world problems and make predictions?

Objectives

Students will know:

- Vector mathematics
- Models for two dimensional motion
- Understand the general motion of projectiles in a uniform gravitational field.
- Understand the uniform circular motion of a particle.

Students will be able to:

- Represent displacement, velocity and acceleration as vectors.
- Calculate the component of a vector along a specified axis, or resolve a vector into components along two specified mutually perpendicular axes.
- Add vectors in order to find the net displacement of a particle that undergoes successive straight line displacements.
- Subtract displacement vectors in order to find the location of one particle relative to another, or calculate the average velocity of a particle.
- Add or subtract velocity vectors in order to calculate the velocity change or average acceleration of a particle, or the velocity of one particle relative to another.
- Write down expressions for the horizontal and vertical components of velocity and position as functions of time, and sketch or identify graphs of their components.
- Use these expressions in analyzing the motion of a projectile that is projected above level ground with a specified initial velocity.
- Relate the radius of the circle and the speed or rate of revolution of the particle to the magnitude of the centripetal acceleration.
- Describe the direction of the particle's velocity and acceleration at any instant during the motion.
- Determine the components of the velocity and acceleration vectors at any instant, and sketch or identify graphs of these quantities.

Resources

Core Text:

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Suggested Resources:

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- Gizmos www.explorelearning.com/index.cfm?method=cuser.dsploginjoin
- Projectile Motion Lab

UNIT 3: Newtonian Mechanics

Summary and Rationale

In this unit students will learn about the connections between force and motion, to solve linear force and motion problems, and to solve problems about motion in two dimensions.

Recommended Pacing

2 Cycles (11 instructional days)

State Standards

Standard
B. Newton's laws of motion

1. Static equilibrium (first law)

Students should be able to analyze situations in which a particle remains at rest, or moves with constant velocity, under the influence of several forces.

2. Dynamics of a single particle (second law)

a) Students should understand the relation between the force that acts on an object and the resulting change in the object's velocity, so they can:

(1) Calculate, for an object moving in one dimension, the velocity change that results when a constant force F acts over a specified time interval.

(2) Calculate, for an object moving in one dimension, the velocity change that results when a force $F(t)$ acts over a specified time interval.

(3) Determine, for an object moving in a plane whose velocity vector undergoes a specified change over a specified time interval, the average force that acted on the object.

b) Students should understand how Newton's Second Law, $\Sigma \mathbf{F} = \mathbf{F}_{net} = m\mathbf{a}$, applies to an object subject to forces such as gravity, the pull of strings, or contact forces, so they can:

(1) Draw a well-labeled, free-body diagram showing all real forces that act on the object.

(2) Write down the vector equation that results from applying Newton's Second Law to the object, and take components of this equation along appropriate axes.

c) Students should be able to analyze situations in which an object moves with specified acceleration under the influence of one or more forces so they can determine the magnitude and direction of the net force, or of one of the forces that makes up the net force, such as motion up or down with constant acceleration.

d) Students should understand the significance of the coefficient of friction, so they can:

(1) Write down the relationship between the normal and frictional forces on a surface.
(2) Analyze situations in which an object moves along a rough inclined plane or horizontal surface.
(3) Analyze under what circumstances an object will start to slip, or to calculate the magnitude of the force of static friction.
e) Students should understand the effect of drag forces on the motion of an object, so they can:
(1) Find the terminal velocity of an object moving vertically under the influence of a retarding force dependent on velocity.
(2) Describe qualitatively, with the aid of graphs, the acceleration, velocity, and displacement of such a particle when it is released from rest or is projected vertically with specified initial velocity.
(3) Use Newton's Second Law to write a differential equation for the velocity of the object as a function of time.
(4) Use the method of separation of variables to derive the equation for the velocity as a function of time from the differential equation that follows from Newton's Second Law.
(5) Derive an expression for the acceleration as a function of time for an object falling under the influence of drag forces.
3. Systems of two or more objects (third law)
a) Students should understand Newton's Third Law so that, for a given system, they can identify the force pairs and the objects on which they act, and state the magnitude and direction of each force.
b) Students should be able to apply Newton's Third Law in analyzing the force of contact between two objects that accelerate together along a horizontal or vertical line, or between two surfaces that slide across one another.
c) Students should know that the tension is constant in a light string that passes over a massless pulley and should be able to use this fact in analyzing the motion of a system of two objects joined by a string.
d) Students should be able to solve problems in which application of Newton's laws leads to two or three simultaneous linear equations involving unknown forces or accelerations.
Standard **LABORATORY AND EXPERIMENTAL SITUATIONS** These objectives overlay the content objectives, and are assessed in the context of those objectives.
1. Design experiments Students should understand the process of designing experiments, so they can:
a) Describe the purpose of an experiment or a problem to be investigated.
b) Identify equipment needed and describe how it is to be used.
c) Draw a diagram or provide a description of an experimental setup.
d) Describe procedures to be used, including controls and measurements to be taken.
2. Observe and measure real phenomena Students should be able to make relevant observations, and be able to take measurements with a variety of instruments (cannot be assessed via paper-and-pencil examinations).
3. Analyze data Students should understand how to analyze data, so they can:

a)	Display data in graphical or tabular form.
b)	Fit lines and curves to data points in graphs.
c)	Perform calculations with data.
d)	Make extrapolations and interpolations from data.
4. Analyze errors Students should understand measurement and experimental error, so they can:	
a)	Identify sources of error and how they propagate.
b)	Estimate magnitude and direction of errors.
c)	Determine significant digits.
d)	Identify ways to reduce error.
5. Communicate results Students should understand how to summarize and communicate results, so they can:	
a)	Draw inferences and conclusions from experimental data.
b)	Suggest ways to improve experiment.
c)	Propose questions for further study.

Instructional Focus

Unit Enduring Understandings

- Mathematical models describe physical phenomena and can be used to predict real world events.
- The same basic principles govern the motion of all objects.
- Only the net external force affects an objects motion.

Unit Essential Questions

- What causes a change in motion?
- How can forces on a system be described, verbally, pictorially, graphically and mathematically?
- What are the forces exerted between two objects or systems that interact?
- What conditions are necessary for an object to travel in a circular path?

Objectives

Students will know:

- Understand the relationship between the force that acts on a body and the resulting change in the body's velocity so that one can calculate, for a body moving in one direction, the velocity change that results when a constant force F acts over a specified time interval.
- Understand how Newton's Second Law, F = ma, applies to a body subject to forces such as gravity, the pull of strings, or contact forces, so that one can draw a well labeled diagram showing all real forces that act on the body.
- Understand the significance of the coefficient of friction so that one can write down the relation between the normal and frictional forces on a surface.
- Understand Newton's Third Law so that, for a given force, they can identify the body on which the reaction force acts and state the magnitude and direction of this reaction.

Students will be able to:

- Analyze situations in which a particle remains at rest, or moves with constant velocity, under the influence of several forces.
- Determine, for a body moving in a plane whose velocity vector undergoes a specified change over a specified time interval the average force that acted on the body.
- Write down the vector equation that results from applying Newton's Second Law to the body, and take the components of this equation along appropriate axes.
- Analyze situations in which a body moves with a specified acceleration under the influence of one or more forces so that they can determine the magnitude and direction of the net force, or some of the forces that make up the net force, in situations such as the following:
    - Motion up or down with constant acceleration
    - Motion in a horizontal circle
    - Motion in a vertical circle
- Analyze situations in which a body slides down a rough inclined plane or is pulled or pushed across a rough surface.
- Analyze static situations involving friction to determine under what circumstances a body will start to slip, or to calculate the magnitude of the force of static friction.
- Know that the tension is constant in a light string that passes over a massless pulley and should be able to use this fact in analyze the motion of a system of two bodies joined by a string.
- Apply Newton's Third Law in analyzing the force of contact between two bodies that accelerate together along a horizontal or vertical line, or between two surfaces that slide across one another.

Resources

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- Gizmos www.explorelearning.com/index.cfm?method=cuser.dsploginjoin
- Air Resistance Lab

UNIT 4: Conservation of Energy

Summary and Rationale

In this unit students will learn how energy is transferred and transformed and will develop an understanding of energy and its conservation.

Recommended Pacing

1.5 Cycles (7 instructional days)

State Standards

Standard **C. Work, energy, power**
1. Work and the work-energy theorem
a) Students should understand the definition of work, including when it is positive, negative, or zero, so they can:
(1) Calculate the work done by a specified constant force on an object that undergoes a specified displacement.
(2) Relate the work done by a force to the area under a graph of force as a function of position, and calculate this work in the case where the force is a linear function of position.
(3) Use integration to calculate the work performed by a force $F(x)$ on an object that undergoes a specified displacement in one dimension.
(4) Use the scalar product operation to calculate the work performed by a specified constant force F on an object that undergoes a displacement in a plane.
b) Students should understand and be able to apply the work-energy theorem, so they can:
(1) Calculate the change in kinetic energy or speed that results from performing a specified amount of work on an object.
(2) Calculate the work performed by the net force, or by each of the forces that make up the net force, on an object that undergoes a specified change in speed or kinetic energy.
(3) Apply the theorem to determine the change in an object's kinetic energy and speed that results from the application of specified forces, or to determine the force that is required in order to bring an object to rest in a specified distance.
2. Forces and potential energy
a) Students should understand the concept of a conservative force, so they can:
(1) State alternative definitions of "conservative force" and explain why these definitions are equivalent.
(2) Describe examples of conservative forces and non-conservative forces.
b) Students should understand the concept of potential energy, so they can:
(1) State the general relation between force and potential energy, and explain why potential energy can be associated only with conservative forces.
(2) Calculate a potential energy function associated with a specified one-dimensional force $F(x)$.
(3) Calculate the magnitude and direction of a one-dimensional force when given the potential energy function $U(x)$ for the force.
(4) Write an expression for the force exerted by an ideal spring and for the potential energy of a stretched or compressed spring.
(5) Calculate the potential energy of one or more objects in a uniform gravitational field.
3. Conservation of energy
a) Students should understand the concepts of mechanical energy and of total energy, so they can:
(1) State and apply the relation between the work performed on an object by non-conservative forces and the change in an object's mechanical energy.

(2) Describe and identify situations in which mechanical energy is converted to other forms of energy.
(3) Analyze situations in which an object's mechanical energy is changed by friction or by a specified externally applied force.
b) Students should understand conservation of energy, so they can:
(1) Identify situations in which mechanical energy is or is not conserved.
(2) Apply conservation of energy in analyzing the motion of systems of connected objects, such as an Atwood's machine.
(3) Apply conservation of energy in analyzing the motion of objects that move under the influence of springs.
(4) Apply conservation of energy in analyzing the motion of objects that move under the influence of other non-constant one-dimensional forces.
c) Students should be able to recognize and solve problems that call for application both of conservation of energy and Newton's Laws.
4. Power Students should understand the definition of power, so they can:
a) Calculate the power required to maintain the motion of an object with constant acceleration (e.g., to move an object along a level surface, to raise an object at a constant rate, or to overcome friction for an object that is moving at a constant speed).
b) Calculate the work performed by a force that supplies constant power, or the average power supplied by a force that performs a specified amount of work.
Standard **LABORATORY AND EXPERIMENTAL SITUATIONS** These objectives overlay the content objectives, and are assessed in the context of those objectives.
1. Design experiments Students should understand the process of designing experiments, so they can:
a) Describe the purpose of an experiment or a problem to be investigated.
b) Identify equipment needed and describe how it is to be used.
c) Draw a diagram or provide a description of an experimental setup.
d) Describe procedures to be used, including controls and measurements to be taken.
2. Observe and measure real phenomena Students should be able to make relevant observations, and be able to take measurements with a variety of instruments (cannot be assessed via paper-and-pencil examinations).
3. Analyze data Students should understand how to analyze data, so they can:
a) Display data in graphical or tabular form.
b) Fit lines and curves to data points in graphs.
c) Perform calculations with data.
d) Make extrapolations and interpolations from data.
4. Analyze errors Students should understand measurement and experimental error, so they can:

a)	Identify sources of error and how they propagate.
b)	Estimate magnitude and direction of errors.
c)	Determine significant digits.
d)	Identify ways to reduce error.

5. Communicate results

Students should understand how to summarize and communicate results, so they can:

a)	Draw inferences and conclusions from experimental data.
b)	Suggest ways to improve experiment.
c)	Propose questions for further study.

Instructional Focus

Unit Enduring Understandings

- Mathematical models describe physical phenomena and can be used to predict real world events.
- Energy is a conserved quantity.
- Energy conservation sets fundamental limits on the exploitation of our physical environment.
- Work is the process by which the energy is a system is changed.

Unit Essential Questions

- How do you identify a system and external objects interacting with the system?
- How can conservation of energy in a system be represented verbally, physically, graphically and mathematically?
- How are changes in energy in a non-uniform field determined?

Objectives

Students will know:

- Models of conservation of energy
- Understand the definition of work so that one can calculate the work done by a specified constant force on a body that undergoes a specified displacement.
- Understand the definition of work so that one can calculate the work when force and displacement are not parallel.
- Understand the work-energy theorem so that one can calculate the change in kinetic energy or speed that results from performing a specified amount of work on a body.
- Understand the concept of potential energy so that one can write an expression for the force exerted by an ideal spring and for the potential energy stored in a stretched or compressed spring.
- Understand conservation of energy so that one can identify situations in which mechanical energy is or is not conserved.
- Understand the definition of power so that one can calculate the power required to maintain the motion of a body with constant acceleration.
- Understand and be able to perform Vector Dot Products.

Students will be able to:

- Relate the work done by a force to the area under a graph of force as a function of position, and calculate this work in the case where the force is a linear function of position.

- Calculate the work performed by the net force, or by each of the forces that makes up the net force, on a body that undergoes a specified change in speed or kinetic energy.
- Apply the theorem to determine the change in a body's kinetic energy and speed that result from the application of specified forces, or to determine the force that is required in order to bring a body to rest in a specified distance.
- Calculate the potential energy of a single body in a uniform gravitational field.
- Apply conservation of energy in analyzing the motion of bodies that are moving in a gravitational field and are subject to constraints imposed by strings or surfaces.
- Apply conservation of energy in analyzing the motion of bodies that move under the influence of springs.
- Calculate the work performed by a force that supplies constant power, or the average power supplied by a force that performs a specified amount of work.

Resources

Core Text:

- Knight, Randall. 2017. *Physics for Scientists and Engineers A Strategic Approach with Modern Physics Fourth Edition AP Edition,* Boston, MA: Pearson Education, Inc. **ISBN**-13: 978-0-134-11065-3

Suggested Resources:

- AP College Board approved resources
- www.physicsclassroom.com
- Phet Simulations www.phet.colorado.edu/en/simulations/category/physics
- Gizmos www.explorelearning.com/index.cfm?method=cuser.dsploginjoin

UNIT 5: Impulse and Momentum

Summary and Rationale

In this unit students will learn to use concepts of impulse and momentum in one and two dimensions.

Recommended Pacing

1.5 Cycles (7 instructional days)

State Standards

Standard
D. Systems of particles, linear momentum

1. Center of mass

a) Students should understand the technique for finding center of mass, so they can:

(1) Identify by inspection the center of mass of a symmetrical object.

(2) Locate the center of mass of a system consisting of two such objects.

(3) Use integration to find the center of mass of a thin rod of non-uniform density

b) Students should be able to understand and apply the relation between center-of- mass velocity and linear momentum, and between center-of-mass acceleration and net external force for a system of particles.
c) Students should be able to define center of gravity and to use this concept to express the gravitational potential energy of a rigid object in terms of the position of its center of mass.
2. Impulse and momentum Students should understand impulse and linear momentum, so they can:
a) Relate mass, velocity, and linear momentum for a moving object, and calculate the total linear momentum of a system of objects.
b) Relate impulse to the change in linear momentum and the average force acting on an object.
c) State and apply the relations between linear momentum and center-of-mass motion for a system of particles.
d) Calculate the area under a force versus time graph and relate it to the change in momentum of an object.
e) Calculate the change in momentum of an object given a function $F(t)$ for the net force acting on the object.
3. Conservation of linear momentum, collisions
a) Students should understand linear momentum conservation, so they can:
(1) Explain how linear momentum conservation follows as a consequence of Newton's Third Law for an isolated system.
(2) Identify situations in which linear momentum, or a component of the linear momentum vector, is conserved.
(3) Apply linear momentum conservation to one-dimensional elastic and inelastic collisions and two-dimensional completely inelastic collisions.
(4) Apply linear momentum conservation to two-dimensional elastic and inelastic collisions.
(5) Analyze situations in which two or more objects are pushed apart by a spring or other agency, and calculate how much energy is released in such a process.
b) Students should understand frames of reference, so they can:
(1) Analyze the uniform motion of an object relative to a moving medium such as a flowing stream.
(2) Analyze the motion of particles relative to a frame of reference that is accelerating horizontally or vertically at a uniform rate.
Standard **LABORATORY AND EXPERIMENTAL SITUATIONS** These objectives overlay the content objectives, and are assessed in the context of those objectives.
1. Design experiments Students should understand the process of designing experiments, so they can:
a) Describe the purpose of an experiment or a problem to be investigated.
b) Identify equipment needed and describe how it is to be used.
c) Draw a diagram or provide a description of an experimental setup.
d) Describe procedures to be used, including controls and measurements to be taken.
2. Observe and measure real phenomena

Students should be able to make relevant observations, and be able to take measurements with a variety of instruments (cannot be assessed via paper-and-pencil examinations).
3. Analyze data Students should understand how to analyze data, so they can:
a) Display data in graphical or tabular form.
b) Fit lines and curves to data points in graphs.
c) Perform calculations with data.
d) Make extrapolations and interpolations from data.
4. Analyze errors Students should understand measurement and experimental error, so they can:
a) Identify sources of error and how they propagate.
b) Estimate magnitude and direction of errors.
c) Determine significant digits.
d) Identify ways to reduce error.
5. Communicate results Students should understand how to summarize and communicate results, so they can:
a) Draw inferences and conclusions from experimental data.
b) Suggest ways to improve experiment.
c) Propose questions for further study.

Instructional Focus

Unit Enduring Understandings

- Mathematical models describe physical phenomena and can be used to predict real world events.
- The total momentum in a closed system remains constant.

Unit Essential Questions

- How is the center of mass of a system determined?
- How do you identify a system and external objects interacting with the system?
- How can conservation of momentum in a system be represented verbally, physically, graphically and mathematically?
- What is the difference between elastic and inelastic collisions?
- What affects the impulse on a system and how does impulse affect the momentum of a system?

Objectives

Students will know:

- Models of impulse and momentum
- Understand impulse and linear momentum so that one can relate mass, velocity, and linear momentum for a moving body, and calculate the total linear momentum of a system of bodies.
- Understand linear momentum conservation so that one can identify situations in which linear momentum, or a component of the linear momentum vector, is conserved.

- Understand the concept of Center of Mass in order to properly apply conservation of momentum to extended bodies.

Students will be able to:

- Relate impulse to the change in linear momentum and the average force acting on a body.
- Apply linear momentum conservation to determine the final velocity when two bodies that are moving along the same line, or at right angles, collide and stick together, and calculate how much kinetic energy is lost in such a situation.

Resources

Core Text:

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Suggested Resources:

- AP College Board approved resources
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- Phet Simulations www.phet.colorado.edu/en/simulations/category/physics
- Gizmos www.explorelearning.com/index.cfm?method=cuser.dsploginjoin
- Momentum and Collisions Lab
- Impulse Lab

UNIT 6: Rotary Motion and Torque

Summary and Rationale

In this unit students will learn to understand and apply the physics of rotation.

Recommended Pacing

3 Cycles (16 instructional days)

State Standards

Standard
E. Circular motion and rotation

1. Uniform circular motion

Students should understand the uniform circular motion of a particle, so they can:

a) Relate the radius of the circle and the speed or rate of revolution of the particle to the magnitude of the centripetal acceleration.

b) Describe the direction of the particle's velocity and acceleration at any instant during the motion.

c) Determine the components of the velocity and acceleration vectors at any instant, and sketch or identify graphs of these quantities.

d) Analyze situations in which an object moves with specified acceleration under the influence of one or more forces so they can determine the magnitude and direction of the net force, or of one of the forces that makes up the net force, in situations such as the following:
(1) Motion in a horizontal circle (e.g., mass on a rotating merry-go-round, or car rounding a banked curve).
(2) Motion in a vertical circle (e.g., mass swinging on the end of a string, cart rolling down a curved track, rider on a Ferris wheel).
2. Torque and rotational statics
a) Students should understand the concept of torque, so they can:
(1) Calculate the magnitude and direction of the torque associated with a given force.
(2) Calculate the torque on a rigid object due to gravity.
b) Students should be able to analyze problems in statics, so they can:
(1) State the conditions for translational and rotational equilibrium of a rigid object.
(2) 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.
c) Students should develop a qualitative understanding of rotational inertia, so they can:
(1) Determine by inspection which of a set of symmetrical objects of equal mass has the greatest rotational inertia.
(2) Determine by what factor an object's rotational inertia changes if all its dimensions are increased by the same factor.
d) Students should develop skill in computing rotational inertia so they can find the rotational inertia of:
(1) A collection of point masses lying in a plane about an axis perpendicular to the plane.
(2) A thin rod of uniform density, about an arbitrary axis perpendicular to the rod.
(3) A thin cylindrical shell about its axis, or an object that may be viewed as being made up of coaxial shells.
e) Students should be able to state and apply the parallel-axis theorem.
3. Rotational kinematics and dynamics
a) 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.
b) Students should be able to use the right-hand rule to associate an angular velocity vector with a rotating object.
c) Students should understand the dynamics of fixed-axis rotation, so they can:
(1) Describe in detail the analogy between fixed-axis rotation and straight-line translation.
(2) Determine the angular acceleration with which a rigid object is accelerated about a fixed axis when subjected to a specified external torque or force.

(3) Determine the radial and tangential acceleration of a point on a rigid object.
(4) Apply conservation of energy to problems of fixed-axis rotation.
(5) Analyze problems involving strings and massive pulleys.
d) Students should understand the motion of a rigid object along a surface, so they can:
(1) 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.
(2) Apply the equations of translational and rotational motion simultaneously in analyzing rolling with slipping.
(3) Calculate the total kinetic energy of an object that is undergoing both translational and rotational motion, and apply energy conservation in analyzing such motion.
4. Angular momentum and its conservation
a) Students should be able to use the vector product and the right-hand rule, so they can:
(1) Calculate the torque of a specified force about an arbitrary origin.
(2) Calculate the angular momentum vector for a moving particle.
(3) Calculate the angular momentum vector for a rotating rigid object in simple cases where this vector lies parallel to the angular velocity vector.
b) Students should understand angular momentum conservation, so they can:
(1) 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.
(2) State the relation between net external torque and angular momentum, and identify situations in which angular momentum is conserved.
(3) Analyze problems in which the moment of inertia of an object is changed as it rotates freely about a fixed axis.
(4) Analyze a collision between a moving particle and a rigid object that can rotate about a fixed axis or about its center of mass.
Standard **LABORATORY AND EXPERIMENTAL SITUATIONS** These objectives overlay the content objectives, and are assessed in the context of those objectives.
1. Design experiments Students should understand the process of designing experiments, so they can:
a) Describe the purpose of an experiment or a problem to be investigated.
b) Identify equipment needed and describe how it is to be used.
c) Draw a diagram or provide a description of an experimental setup.
d) Describe procedures to be used, including controls and measurements to be taken.
2. Observe and measure real phenomena Students should be able to make relevant observations, and be able to take measurements with a variety of instruments (cannot be assessed via paper-and-pencil examinations).

3. Analyze data

Students should understand how to analyze data, so they can:

a) Display data in graphical or tabular form.

b) Fit lines and curves to data points in graphs.

c) Perform calculations with data.

d) Make extrapolations and interpolations from data.

4. Analyze errors

Students should understand measurement and experimental error, so they can:

a) Identify sources of error and how they propagate.

b) Estimate magnitude and direction of errors.

c) Determine significant digits.

d) Identify ways to reduce error.

5. Communicate results

Students should understand how to summarize and communicate results, so they can:

a) Draw inferences and conclusions from experimental data.

b) Suggest ways to improve experiment.

c) Propose questions for further study.

Instructional Focus

Unit Enduring Understandings

- Mathematical models describe physical phenomena and can be used to predict real world events.
- Rotating systems can be expressed using rotational and translational quantities.
- Mass distribution affects rotational motion.

Unit Essential Questions

- What physical variables affect the rotational inertia of a system of objects?
- How can rotational energies, rotational momentums, and torques exerted on a system be represented verbally, physically, graphically, and mathematically?
- How does a net external torque exerted on a system affect the rotational motion of that system?
- How can the conservation of energy model be revised to analyze phenomena with rotational motion in open and closed systems?
- How can the conservation of momentum model be revised to analyze phenomena with rotational motion in open and closed systems?
- How does the vector nature of angular momentum and torque impact our understanding of the physical world?
- What is the difference between a cross product and a dot product? How can dot and cross products be used to mathematically describe phenomena?

Objectives

Students will know:

- Models of rotary motion and torque

- Understand that a change in direction requires force and that the force must total mv^2/r.
- Use free body diagrams to identify and calculate the forces causing circular motion including both horizontal circular motion and vertical circular motion.
- Understand the concepts and quantities involved in rotary motion (angular position, speed, acceleration).
- Understand the concept of torque so that one can calculate the magnitude and size of the torque associated with a given force.
- Understand and apply the concept of center of mass.
- Understand angular momentum conservation so that one 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 or the Bohr atom.
- Understand the motion of a body in orbit under the influence of gravitational forces so that one can:
    - Apply conservation of angular momentum, for a general orbit, to determine the velocity and radial distance to any point in the orbit.
    - Apply angular momentum conservation and energy conservation, for a general orbit, to relate the speeds of a body at the two extremes of an elliptical orbit.

Students will be able to:

- Define and differentiate between translational, circular, and rotational motion.
- Differentiate between tangential speed and angular velocity.
- Solve kinematics problems involving rotary motion.
- Calculate the torque on a rigid body due to gravity.
- Analyze problems in statics so that one can state the conditions for translational and rotational equilibrium of a rigid body.
- Apply these conditions in analyzing the equilibrium of a rigid body under the combined influence of a number of coplanar forces applied at different locations.

Resources

Core Text:

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Suggested Resources:

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- Phet Simulations www.phet.colorado.edu/en/simulations/category/physics
- Gizmos www.explorelearning.com/index.cfm?method=cuser.dsploginjoin
- Rotational Statics Lab
- Lost in Translation Lab (Rotational energy and projectile motion Lab)

UNIT 7: Simple Harmonic Motion

Summary and Rationale

In this unit students will learn about systems that oscillate in simple harmonic motion and Universal Gravitation. Applications will include the study of Keplar's Laws and planetary motion.
Recommended Pacing
1.5 Cycles (7 instructional days)
State Standards
Standard **F. Oscillations and Gravitation**
1. Simple harmonic motion (dynamics and energy relationships) Students should understand simple harmonic motion, so they can:
a) 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.
b) Write down an appropriate expression for displacement of the form $A \sin(wt)$ or $A \cos(wt)$ to describe the motion.
c) Find an expression for velocity as a function of time.
d) 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.
e) State and apply the relation between frequency and period.
f) Recognize that a system that obeys a differential equation of the form $d^2x / dt^2 = -w^2 x$ must execute simple harmonic motion, and determine the frequency and period of such motion.
g) 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.
h) 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.
i) Calculate the maximum displacement or velocity of a particle that moves in simple harmonic motion with specified initial position and velocity.
j) Develop a qualitative understanding of resonance so they can identify situations in which a system will resonate in response to a sinusoidal external force.
2. Mass on a spring Students should be able to apply their knowledge of simple harmonic motion to the case of a mass on a spring, so they can:
a) Derive the expression for the period of oscillation of a mass on a spring.
b) Apply the expression for the period of oscillation of a mass on a spring.
c) Analyze problems in which a mass hangs from a spring and oscillates vertically.
d) Analyze problems in which a mass attached to a spring oscillates horizontally.
e) Determine the period of oscillation for systems involving series or parallel combinations of identical springs, or springs of differing lengths.
3. Pendulum and other oscillations Students should be able to apply their knowledge of simple harmonic motion to the case of a pendulum, so they can:

a) Derive the expression for the period of a simple pendulum.
b) Apply the expression for the period of a simple pendulum.
c) State what approximation must be made in deriving the period.
d) Analyze the motion of a torsional pendulum or physical pendulum in order to determine the period of small oscillations.
4. Newton's law of gravity Students should know Newton's Law of Universal Gravitation, so they can:
a) Determine the force that one spherically symmetrical mass exerts on another.
b) Determine the strength of the gravitational field at a specified point outside a spherically symmetrical mass.
c) 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.
5. Orbits of planets and satellites Students should understand the motion of an object in orbit under the influence of gravitational forces, so they can:
a) For a circular orbit:
(1) 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.
(2) Derive Kepler's Third Law for the case of circular orbits.
(3) Derive and apply the relations among kinetic energy, potential energy, and total energy for such an orbit.
b) For a general orbit:
(1) 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.
(2) Apply conservation of angular momentum to determine the velocity and radial distance at any point in the orbit.
(3) Apply angular momentum conservation and energy conservation to relate the speeds of an object at the two extremes of an elliptical orbit.
(4) 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.
Standard **LABORATORY AND EXPERIMENTAL SITUATIONS** These objectives overlay the content objectives, and are assessed in the context of those objectives.
1. Design experiments Students should understand the process of designing experiments, so they can:
a) Describe the purpose of an experiment or a problem to be investigated.
b) Identify equipment needed and describe how it is to be used.
c) Draw a diagram or provide a description of an experimental setup.
d) Describe procedures to be used, including controls and measurements to be taken.

2. Observe and measure real phenomena

Students should be able to make relevant observations, and be able to take measurements with a variety of instruments (cannot be assessed via paper-and-pencil examinations).

3. Analyze data

Students should understand how to analyze data, so they can:

a) Display data in graphical or tabular form.

b) Fit lines and curves to data points in graphs.

c) Perform calculations with data.

d) Make extrapolations and interpolations from data.

4. Analyze errors

Students should understand measurement and experimental error, so they can:

a) Identify sources of error and how they propagate.

b) Estimate magnitude and direction of errors.

c) Determine significant digits.

d) Identify ways to reduce error.

5. Communicate results

Students should understand how to summarize and communicate results, so they can:

a) Draw inferences and conclusions from experimental data.

b) Suggest ways to improve experiment.

c) Propose questions for further study.

Instructional Focus

Unit Enduring Understandings

- Mathematical models describe physical phenomena and can be used to predict real world events.
- Physical systems undergoing simple harmonic motion are characterized by the sinusoidal nature of the mathematical models representing the physical variables of that system.
- Gravitational interactions are exerted between all objects with mass.

Unit Essential Questions

- How can a system undergoing simple harmonic motion be represented verbally, physically, graphically and mathematically?
- How does simple harmonic motion relate to circular motion?
- How are maximum and minimum energies determined for an oscillating system?
- What physical variables determine the magnitude of gravitational interaction between objects?
- How is the gravitational field determined in the space around and through an object with mass?
- How can the orbits of planets be expressed as a function of the rotational period and the orbital radius?

Objectives

Students will know:

- Models of simple harmonic motion, circular motion and universal gravitation

- Understand the kinematics of simple harmonic motion so that one 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.
- Understand the motion of a body in orbit under the influence of gravitational forces.

Students will be able to:

- Identify points in the motion where the velocity is zero or achieves its maximum positive or negative value.
- State qualitatively the relation between acceleration and displacement in simple harmonic motion.
- Identify the points where the acceleration is zero or achieves its greatest positive or negative value.
- State and apply the relation between frequency and period for simple harmonic motion.
- State how the total energy of an oscillating system depends on the amplitude of the motion, sketch or identify a graph of kinetic or potential energy as a function of time, and identify the points in the motion where this energy is all potential or all kinetic.
- Apply their knowledge of simple harmonic motion to the case of mass on a spring, so that one can apply the expression for the period of oscillation of a mass on a spring.
- Apply their knowledge of simple harmonic motion to the case of a pendulum, so that one can apply the expression for the period of a simple pendulum and state what approximation must be made in deriving the period.
- Know Newton's Law of Gravitation so that one 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.
- Recognize, for a circular orbit, that the motion does not depend on the body'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.
- Apply conservation of angular momentum, for a general orbit, to determine the velocity and radial distance to any point in the orbit.
- Apply angular momentum conservation and energy conservation, for a general orbit, to relate the speeds of a body at the two extremes of an elliptical orbit.

Resources

Core Text:

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Suggested Resources:

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- Phet Simulations www.phet.colorado.edu/en/simulations/category/physics
- Gizmos www.explorelearning.com/index.cfm?method=cuser.dsploginjoin
- Physical Pendulum Lab
- Gravitation and Planetary motion Lab

UNIT 8: Electric Fields and Forces

Summary and Rationale
In this unit students will learn that electrical phenomena are based on charges, forces and fields, and how to calculate and use electric fields.
Recommended Pacing
2.5 Cycles (12 instructional days)
State Standards
Standard **A. Electrostatics**
1. Charge and Coulomb's Law
a) Students should understand the concept of electric charge, so they can:
(1) Describe the types of charge and the attraction and repulsion of charges.
(2) Describe polarization and induced charges.
b) Students should understand Coulomb's Law and the principle of superposition, so they can:
(1) Calculate the magnitude and direction of the force on a positive or negative charge due to other specified point charges.
(2) Analyze the motion of a particle of specified charge and mass under the influence of an electrostatic force.
2. Electric field and electric potential (including point charges)
a) Students should understand the concept of electric field, so they can:
(1) Define it in terms of the force on a test charge.
(2) Describe and calculate the electric field of a single point charge.
(3) Calculate the magnitude and direction of the electric field produced by two or more point charges.
(4) Calculate the magnitude and direction of the force on a positive or negative charge placed in a specified field.
(5) Interpret an electric field diagram.
(6) Analyze the motion of a particle of specified charge and mass in a uniform electric field.
b) Students should understand the concept of electric potential, so they can:
(1) Determine the electric potential in the vicinity of one or more point charges.
(2) Calculate the electrical work done on a charge or use conservation of energy to determine the speed of a charge that moves through a specified potential difference.
(3) Determine the direction and approximate magnitude of the electric field at various positions given a sketch of equipotentials.
(4) Calculate the potential difference between two points in a uniform electric field, and state which point is at the higher potential.

(5) Calculate how much work is required to move a test charge from one location to another in the field of fixed point charges.
(6) Calculate the electrostatic potential energy of a system of two or more point charges, and calculate how much work is required to establish the charge system.
(7) Use integration to determine electric potential difference between two points on a line, given electric field strength as a function of position along that line.
(8) State the general relationship between field and potential, and define and apply the concept of a conservative electric field.
3. Gauss's law
a) Students should understand the relationship between electric field and electric flux, so they can:
(1) Calculate the flux of an electric field through an arbitrary surface or of a field uniform in magnitude over a Gaussian surface and perpendicular to it.
(2) Calculate the flux of the electric field through a rectangle when the field is perpendicular to the rectangle and a function of one coordinate only.
(3) State and apply the relationship between flux and lines of force.
b) Students should understand Gauss's Law, so they can:
(1) State the law in integral form, and apply it qualitatively to relate flux and electric charge for a specified surface.
(2) Apply the law, along with symmetry arguments, to determine the electric field for a planar, spherical, or cylindrically symmetric charge distribution.
(3) Apply the law to determine the charge density or total charge on a surface in terms of the electric field near the surface.
4. Fields and potentials of other charge distributions
a) Students should be able to use the principle of superposition to calculate by integration:
(1) The electric field of a straight, uniformly charged wire.
(2) The electric field and potential on the axis of a thin ring of charge, or at the center of a circular arc of charge.
(3) The electric potential on the axis of a uniformly charged disk.
b) Students should know the fields of highly symmetric charge distributions, so they can:
(1) Identify situations in which the direction of the electric field produced by a charge distribution can be deduced from symmetry considerations.
(2) Describe qualitatively the patterns and variation with distance of the electric field of:
(a) Oppositely-charged parallel plates.
(b) A long, uniformly-charged wire, or thin cylindrical or spherical shell.
(3) Use superposition to determine the fields of parallel charged planes, coaxial cylinders, or concentric spheres.
(4) Derive expressions for electric potential as a function of position in the above cases.

Standard **LABORATORY AND EXPERIMENTAL SITUATIONS** These objectives overlay the content objectives, and are assessed in the context of those objectives.
1. Design experiments Students should understand the process of designing experiments, so they can:
a) Describe the purpose of an experiment or a problem to be investigated.
b) Identify equipment needed and describe how it is to be used.
c) Draw a diagram or provide a description of an experimental setup.
d) Describe procedures to be used, including controls and measurements to be taken.
2. Observe and measure real phenomena Students should be able to make relevant observations, and be able to take measurements with a variety of instruments (cannot be assessed via paper-and-pencil examinations).
3. Analyze data Students should understand how to analyze data, so they can:
a) Display data in graphical or tabular form.
b) Fit lines and curves to data points in graphs.
c) Perform calculations with data.
d) Make extrapolations and interpolations from data.
4. Analyze errors Students should understand measurement and experimental error, so they can:
a) Identify sources of error and how they propagate.
b) Estimate magnitude and direction of errors.
c) Determine significant digits.
d) Identify ways to reduce error.
5. Communicate results Students should understand how to summarize and communicate results, so they can:
a) Draw inferences and conclusions from experimental data.
b) Suggest ways to improve experiment.
c) Propose questions for further study.

Instructional Focus

Unit Enduring Understandings

- The fundamental physical laws enable us to explain, predict and control force, matter and energy.
- Physical laws governing various phenomena are similar.
- All objects with charge generate an electric field.
- Electric charge is a property of an object or system that affects its interactions with other objects or systems containing charge.

Unit Essential Questions

- How can we quantitatively predict what will happen when electrical forces act on an object?
- Why and how do objects become charged?
- How does understanding electric fields and shielding help us analyze and understand electrical phenomena?

Objectives

Students will know:

- Models for electrostatic fields and forces
- Understand the concept of electric field in terms of the force on a test charge.
- Understand Coulomb's Law and the principle of superposition to determine the force that acts between specified point charges, and describe the electric field of a single point charge.
- Understand the nature of electric fields in and around conductors to explain the mechanics responsible for the absence of electric field inside a conductor, and why all excess charge must reside on the surface of the conductor.
- Understand induced charge and electrostatic shielding to describe qualitatively the process of charging by induction.
- Understand and apply Gauss' Law to determine the electric field caused by an enclosed charge.

Students will be able to:

- Calculate the magnitude and direction of the force on a positive or negative charge placed in a specified field.
- Given a diagram on which electric field is represented by flux lines, determine the direction of the field at a given point, identify locations where the field is strong and where it is weak, and identify where positive and negative charges must be present.
- Analyze the motion of a particle of specified charge and mass in a uniform electric field.
- Use vector addition to determine the electric field produced by two or more point charges.
- Determine the direction of the force on a charged particle bought near an uncharged or grounded conductor.
- Describe and sketch a graph of the electric field inside and outside a charged conducting sphere.

Resources

Core Text:

- Knight, Randall. 2017. *Physics for Scientists and Engineers A Strategic Approach with Modern Physics Fourth Edition AP Edition,* Boston, MA: Pearson Education, Inc. **ISBN**-13: 978-0-134-11065-3

Suggested Resources:

- AP College Board approved resources
- www.physicsclassroom.com
- Phet Simulations www.phet.colorado.edu/en/simulations/category/physics
- Gizmos www.explorelearning.com/index.cfm?method=cuser.dsploginjoin
- Electric Fields Lab

UNIT 9: Electric Potential and Capacitance

Summary and Rationale

In this unit students will learn to use electric potential and electric potential energy and how the electric potential is related to the electric field.
Recommended Pacing
1.5 Cycles (7 instructional days)
State Standards
Standard **B. Conductors, capacitors, dielectrics**
1. Electrostatics with conductors
a) Students should understand the nature of electric fields in and around conductors, so they can:
(1) Explain the mechanics responsible for the absence of electric field inside a conductor, and know that all excess charge must reside on the surface of the conductor.
(2) Explain why a conductor must be an equipotential, and apply this principle in analyzing what happens when conductors are connected by wires.
(3) Show that all excess charge on a conductor must reside on its surface and that the field outside the conductor must be perpendicular to the surface.
b) Students should be able to describe and sketch a graph of the electric field and potential inside and outside a charged conducting sphere.
c) Students should understand induced charge and electrostatic shielding, so they can:
(1) Describe the process of charging by induction.
(2) Explain why a neutral conductor is attracted to a charged object.
(3) Explain why there can be no electric field in a charge-free region completely surrounded by a single conductor, and recognize consequences of this result.
(4) Explain why the electric field outside a closed conducting surface cannot depend on the precise location of charge in the space enclosed by the conductor, and identify consequences of this result.
2. Capacitors
a) Students should understand the definition and function of capacitance, so they can:
(1) Relate stored charge and voltage for a capacitor.
(2) Relate voltage, charge, and stored energy for a capacitor.
(3) Recognize situations in which energy stored in a capacitor is converted to other forms.
b) Students should understand the physics of the parallel-plate capacitor, so they can:
(1) Describe the electric field inside the capacitor, and relate the strength of this field to the potential difference between the plates and the plate separation.
(2) Relate the electric field to the density of the charge on the plates.
(3) Derive an expression for the capacitance of a parallel-plate capacitor.
(4) Determine how changes in dimension will affect the value of the capacitance.

(5) Derive and apply expressions for the energy stored in a parallel-plate capacitor and for the energy density in the field between the plates.
(6) Analyze situations in which capacitor plates are moved apart or moved closer together, or in which a conducting slab is inserted between capacitor plates, either with a battery connected between the plates or with the charge on the plates held fixed.
c) Students should understand cylindrical and spherical capacitors, so they can:
(1) Describe the electric field inside each.
(2) Derive an expression for the capacitance of each.
3. Dielectrics Students should understand the behavior of dielectrics, so they can:
a) Describe how the insertion of a dielectric between the plates of a charged parallel- plate capacitor affects its capacitance and the field strength and voltage between the plates.
b) Analyze situations in which a dielectric slab is inserted between the plates of a capacitor.
Standard **LABORATORY AND EXPERIMENTAL SITUATIONS** These objectives overlay the content objectives, and are assessed in the context of those objectives.
1. Design experiments Students should understand the process of designing experiments, so they can:
a) Describe the purpose of an experiment or a problem to be investigated.
b) Identify equipment needed and describe how it is to be used.
c) Draw a diagram or provide a description of an experimental setup.
d) Describe procedures to be used, including controls and measurements to be taken.
2. Observe and measure real phenomena Students should be able to make relevant observations, and be able to take measurements with a variety of instruments (cannot be assessed via paper-and-pencil examinations).
3. Analyze data Students should understand how to analyze data, so they can:
a) Display data in graphical or tabular form.
b) Fit lines and curves to data points in graphs.
c) Perform calculations with data.
d) Make extrapolations and interpolations from data.
4. Analyze errors Students should understand measurement and experimental error, so they can:
a) Identify sources of error and how they propagate.
b) Estimate magnitude and direction of errors.
c) Determine significant digits.
d) Identify ways to reduce error.

5. Communicate results

Students should understand how to summarize and communicate results, so they can:

a) Draw inferences and conclusions from experimental data.

b) Suggest ways to improve experiment.

c) Propose questions for further study.

Instructional Focus

Unit Enduring Understandings

- The fundamental physical laws enable us to explain, predict and control force, matter and energy.
- Physical laws governing various phenomena are similar.
- A potential difference has to be maintained in order to move charges between two points.

Unit Essential Questions

- How can we control and use electrical energy?
- How are electric potential and electric energy different?
- Why and how do objects become charged?
- How can a system with electric potential be represented verbally, pictorially, graphically and mathematically?
- How does understanding electric potential help us analyze and understand electrical phenomena?
- What does the capacitance of a circuit depend on?

Objectives

Students will know:

- Models for electrostatic potential and capacitance
- Understand the concept of electric potential so that one can calculate the electric work done on a positive or negative charge that moves through a specified potential difference.
- Know the potential function for a point charge so they can determine the electric potential in the vicinity of one or more point charges.
- Understand induced charge and electrostatic shielding so they can describe qualitatively the process of charging by induction.
- Know the definition of capacitance so they can relate stored charge and voltage for a capacitor.
- Understand energy storage in capacitors so that one can relate voltage, charge, and stored energy for a capacitor.
- Understand the physics of the parallel- plate capacitor so that one can describe the electric field inside the capacitor, and relate the strength of this field to the potential difference between the plates and plate separation.
- Understand the behavior of capacitors connected in series or in parallel so that one can calculate the equivalent capacitance of a series or parallel combination.

Students will be able to:

- Given a sketch of equipotentials for a charge configuration, determine the direction and approximate magnitude of the electric field at various positions.
- Apply conservation of energy to determine the speed of a charged particle that has been accelerated through a specified potential difference.
- Calculate the potential difference between two points in a uniform electric field, and state which is at a higher potential.

- Describe and sketch a graph of the electric potential inside and outside a charged conducting sphere.
- Recognize situations in which energy stored in a capacitor is converted to other forms.
- Determine how changes in dimension and/or dielectric will affect the value of the capacitance.
- Describe how stored charge is divided between two capacitors connected in parallel.
- Determine the ratio of voltages for two capacitors connected in series.

Resources

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- Electric Potential Lab

UNIT 10: Resistance and DC Circuits

Summary and Rationale

In this unit students will learn how and why charge moves through a wire as a current, and the fundamental physical properties that govern electric circuits.

Recommended Pacing

2 Cycles (10 instructional days)

State Standards

Standard
C. Electric circuits

1. Current, resistance, power

a) Students should understand the definition of electric current, so they can relate the magnitude and direction of the current to the rate of flow of positive and negative charge.

b) Students should understand conductivity, resistivity, and resistance, so they can:

(1) Relate current and voltage for a resistor.

(2) Write the relationship between electric field strength and current density in a conductor, and describe, in terms of the drift velocity of electrons, why such a relationship is plausible.

(3) Describe how the resistance of a resistor depends upon its length and cross-

sectional area, and apply this result in comparing current flow in resistors of different material or different geometry.
(4) Derive an expression for the resistance of a resistor of uniform cross-section in terms of its dimensions and the resistivity of the material from which it is constructed.
(5) Derive expressions that relate the current, voltage, and resistance to the rate at which heat is produced when current passes through a resistor.
(6) Apply the relationships for the rate of heat production in a resistor.
2. Steady-state direct current circuits with batteries and resistors only
a) Students should understand the behavior of series and parallel combinations of resistors, so they can:
(1) Identify on a circuit diagram whether resistors are in series or in parallel.
(2) Determine the ratio of the voltages across resistors connected in series or the ratio of the currents through resistors connected in parallel.
(3) Calculate the equivalent resistance of a network of resistors that can be broken down into series and parallel combinations.
(4) Calculate the voltage, current, and power dissipation for any resistor in such a network of resistors connected to a single power supply.
(5) Design a simple series-parallel circuit that produces a given current through and potential difference across one specified component, and draw a diagram for the circuit using conventional symbols.
b) Students should understand the properties of ideal and real batteries, so they can:
(1) Calculate the terminal voltage of a battery of specified emf and internal resistance from which a known current is flowing.
(2) Calculate the rate at which a battery is supplying energy to a circuit or is being charged up by a circuit.
c) Students should be able to apply Ohm's law and Kirchhoff's rules to direct-current circuits, in order to:
(1) Determine a single unknown current, voltage, or resistance.
(2) Set up and solve simultaneous equations to determine two unknown currents.
d) Students should understand the properties of voltmeters and ammeters, so they can:
(1) State whether the resistance of each is high or low.
(2) Identify or show correct methods of connecting meters into circuits in order to measure voltage or current.
(3) Assess qualitatively the effect of finite meter resistance on a circuit into which these meters are connected.
3. Capacitors in circuits
a) Students should understand the $t = 0$ and steady-state behavior of capacitors connected in series or in parallel, so they can:
(1) Calculate the equivalent capacitance of a series or parallel combination.
(2) Describe how stored charge is divided between capacitors connected in parallel.

(3) Determine the ratio of voltages for capacitors connected in series.
(4) Calculate the voltage or stored charge, under steady-state conditions, for a capacitor connected to a circuit consisting of a battery and resistors.
b) Students should understand the discharging or charging of a capacitor through a resistor, so they can:
(1) Calculate and interpret the time constant of the circuit.
(2) Sketch or identify graphs of stored charge or voltage for the capacitor, or of current or voltage for the resistor, and indicate on the graph the significance of the time constant.
(3) Write expressions to describe the time dependence of the stored charge or voltage for the capacitor, or of the current or voltage for the resistor.
(4) Analyze the behavior of circuits containing several capacitors and resistors, including analyzing or sketching graphs that correctly indicate how voltages and currents vary with time.
Standard **LABORATORY AND EXPERIMENTAL SITUATIONS** These objectives overlay the content objectives, and are assessed in the context of those objectives.
1. Design experiments Students should understand the process of designing experiments, so they can:
a) Describe the purpose of an experiment or a problem to be investigated.
b) Identify equipment needed and describe how it is to be used.
c) Draw a diagram or provide a description of an experimental setup.
d) Describe procedures to be used, including controls and measurements to be taken.
2. Observe and measure real phenomena Students should be able to make relevant observations, and be able to take measurements with a variety of instruments (cannot be assessed via paper-and-pencil examinations).
3. Analyze data Students should understand how to analyze data, so they can:
a) Display data in graphical or tabular form.
b) Fit lines and curves to data points in graphs.
c) Perform calculations with data.
d) Make extrapolations and interpolations from data.
4. Analyze errors Students should understand measurement and experimental error, so they can:
a) Identify sources of error and how they propagate.
b) Estimate magnitude and direction of errors.
c) Determine significant digits.
d) Identify ways to reduce error.
5. Communicate results

	Students should understand how to summarize and communicate results, so they can:
a)	Draw inferences and conclusions from experimental data.
b)	Suggest ways to improve experiment.
c)	Propose questions for further study.

Instructional Focus

Unit Enduring Understandings

- The fundamental physical laws enable us to explain, predict and control force, matter and energy.
- Physical laws governing various phenomena are similar.
- Electricity is a form of energy that can be transformed by moving electric charges and doing work in various devices.

Unit Essential Questions

- How can we control and use electrical energy?
- How do conservation of energy and conservation of charge affect how circuits behave?
- How can current flow be determined when various circuit components are connected in a circuit?

Objectives

Students will know:

- Models for resistance and DC circuits
- Understand the definition of electric current so they can relate the magnitude and direction of the current in a wire or ionized medium to the rate of flow of positive and negative charge.
- Understand conductivity, resistivity, and resistance so that one can relate current and voltage for a resistor.
- Understand the behavior of series and parallel combinations of resistors so that one can identify on a circuit diagram resistors that are in series or in parallel.
- Understand the properties of ideal and real batteries so they can calculate the terminal voltage of a battery of specified emf and internal resistance from which a known current is flowing.
- Understand the properties of voltmeters and ammeters so that one can state whether the resistance of each is high or low.

Students will be able to:

- Describe how the resistance of a resistor depends on its length and cross-sectional area.
- Apply the relations for the rate of heat production in a resistor.
- Determine the ratio of the voltage across resistors connected in series or the ratio of the currents through resistors connected in parallel.
- Calculate the equivalent resistance of two or more resistors connected in series or in parallel, or of a network of resistors that can be broken down into series and parallel combinations.
- Calculate the voltage, current, and power dissipation for any resistor in such a network of resistors connected to a single battery.
- Design a simple series-parallel circuit that produces a given current and terminal voltage for one specified component, and draw a diagram for the circuit using conventional symbols.
- Apply Ohm’s Law and Kirchoff’s rules to direct current circuits in order to determine a single unknown current, voltage, or resistance.
- Identify or show correct methods of connecting meters into circuits in order to measure current or voltage.

- Calculate the voltage or stored charge, under steady-state conditions, for a capacitor connected to a circuit consisting of a battery and resistors.
- Develop skill in analyzing the behavior of circuits containing several capacitors and resistors so they can determine voltages and currents immediately after a switch has been closed and also after steady-state conditions have been established.

Resources

Core Text:

- Knight, Randall. 2017. *Physics for Scientists and Engineers A Strategic Approach with Modern Physics Fourth Edition AP Edition,* Boston, MA: Pearson Education, Inc. **ISBN**-13: 978-0-134-11065-3

Suggested Resources:

- AP College Board approved resources
- www.physicsclassroom.com
- Phet Simulations www.phet.colorado.edu/en/simulations/category/physics
- Gizmos www.explorelearning.com/index.cfm?method=cuser.dsploginjoin
- Parallel and series circuits lab
- RC Circuit Lab

UNIT 11: Magnetism

Summary and Rationale

In this unit students will learn about magnetism and magnetic fields.

Recommended Pacing

1.5 Cycles (7 instructional days)

State Standards

Standard
D. Magnetic Fields

1. Forces on moving charges in magnetic fields
Students should understand the force experienced by a charged particle in a magnetic field, so they can:

a) Calculate the magnitude and direction of the force in terms of q, **v**, and, **B**, and explain why the magnetic force can perform no work.

b) Deduce the direction of a magnetic field from information about the forces experienced by charged particles moving through that field.

c) Describe the paths of charged particles moving in uniform magnetic fields.

d) Derive and apply the formula for the radius of the circular path of a charge that moves perpendicular to a uniform magnetic field.

e) Describe under what conditions particles will move with constant velocity through crossed electric and magnetic fields.

2. Forces on current-carrying wires in magnetic fields
Students should understand the force exerted on a current-carrying wire in a magnetic field, so they can:

a) Calculate the magnitude and direction of the force on a straight segment of current- carrying wire in a uniform magnetic field.
b) Indicate the direction of magnetic forces on a current-carrying loop of wire in a magnetic field, and determine how the loop will tend to rotate as a consequence of these forces.
c) Calculate the magnitude and direction of the torque experienced by a rectangular loop of wire carrying a current in a magnetic field.
3. Fields of long current-carrying wires Students should understand the magnetic field produced by a long straight current-carrying wire, so they can:
a) Calculate the magnitude and direction of the field at a point in the vicinity of such a wire.
b) Use superposition to determine the magnetic field produced by two long wires.
c) Calculate the force of attraction or repulsion between two long current-carrying wires.
4. Biot-Savart law and Ampere's law
a) Students should understand the Biot-Savart Law, so they can:
(1) Deduce the magnitude and direction of the contribution to the magnetic field made by a short straight segment of current-carrying wire.
(2) Derive and apply the expression for the magnitude of **B** on the axis of a circular loop of current.
b) Students should understand the statement and application of Ampere's Law in integral form, so they can:
(1) State the law precisely.
(2) Use Ampere's law, plus symmetry arguments and the right-hand rule, to relate magnetic field strength to current for planar or cylindrical symmetries.
c) Students should be able to apply the superposition principle so they can determine the magnetic field produced by combinations of the configurations listed above.
Standard **LABORATORY AND EXPERIMENTAL SITUATIONS** These objectives overlay the content objectives, and are assessed in the context of those objectives.
1. Design experiments Students should understand the process of designing experiments, so they can:
a) Describe the purpose of an experiment or a problem to be investigated.
b) Identify equipment needed and describe how it is to be used.
c) Draw a diagram or provide a description of an experimental setup.
d) Describe procedures to be used, including controls and measurements to be taken.
2. Observe and measure real phenomena Students should be able to make relevant observations, and be able to take measurements with a variety of instruments (cannot be assessed via paper-and-pencil examinations).
3. Analyze data Students should understand how to analyze data, so they can:
a) Display data in graphical or tabular form.

b) Fit lines and curves to data points in graphs.

c) Perform calculations with data.

d) Make extrapolations and interpolations from data.

4. Analyze errors

Students should understand measurement and experimental error, so they can:

a) Identify sources of error and how they propagate.

b) Estimate magnitude and direction of errors.

c) Determine significant digits.

d) Identify ways to reduce error.

5. Communicate results

Students should understand how to summarize and communicate results, so they can:

a) Draw inferences and conclusions from experimental data.

b) Suggest ways to improve experiment.

c) Propose questions for further study.

Instructional Focus

Unit Enduring Understandings

- The fundamental physical laws enable us to explain, predict and control force, matter and energy.
- Physical laws governing various phenomena are similar.
- A moving charge creates a magnetic field.

Unit Essential Questions

- How we can control and use magnetic fields?
- How do moving charges and magnetic fields interact?
- How can interactions between moving charges and magnetic fields be represented verbally, pictorially, and mathematically?

Objectives

Students will know:

- Models of magnetism
- Understand the force experienced by a charged particle in a magnetic field so that one can calculate the magnitude and direction of the force in terms of q, v, and B, and explain why the magnetic force can perform no work.
- Understand the force experienced by a current in a magnetic field so that one can calculate the magnitude and direction of the force on a straight segment of current-carrying wire in a uniform magnetic field.
- Understand the magnetic field produced by a long straight current-carrying wire so that one can calculate the magnitude and direction of the magnetic field at a point in the vicinity of such a wire, using Ampere's Law.

Students will be able to:

- Deduce the direction of a magnetic field from information about the forces experienced by charged particles moving through that field.

- State and apply the formula for the radius of the circular path of a charge that moves perpendicular to a uniform magnetic field, and derive this formula from Newton's Second Law and the magnetic force law.
- Describe the most general path possible for a charged particle moving in a uniform magnetic field and describe the motion of a particle that enters a uniform magnetic field moving with a specified initial velocity.
- Describe quantitatively under what conditions particles will move with constant velocity through crossed electric and magnetic fields.
- Indicate the direction of the magnetic forces on a current-carrying loop of wire in a magnetic field, and determine how the loop will tend to rotate as a consequence of these forces.
- Use superposition to determine the magnetic field produced by two long wires.
- Calculate the force of attraction or repulsion between two long current-carrying wires.
- Determine the magnetic field at a point in the vicinity of a non-straight current carrying wire, by integrating the Biot-Savart law for the particular geometry of the wire.

Resources

Core Text:

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Suggested Resources:

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- Gizmos www.explorelearning.com/index.cfm?method=cuser.dsploginjoin

UNIT 12: Electromagnetism

Summary and Rationale

In this unit students will learn what electromagnetic induction is and how it is used.

Recommended Pacing

8 instructional days approximately 2 Cycles Cycles 20-21

State Standards

Standard
E. Electromagnetism

1. Electromagnetic induction (including Faraday's law and Lenz's law)

a) Students should understand the concept of magnetic flux, so they can:

(1) Calculate the flux of a uniform magnetic field through a loop of arbitrary orientation.

(2) Use integration to calculate the flux of a non-uniform magnetic field, whose

magnitude is a function of one coordinate, through a rectangular loop perpendicular to the field.
b) Students should understand Faraday’s law and Lenz’s law, so they can:
(1) Recognize situations in which changing flux through a loop will cause an induced emf or current in the loop.
(2) Calculate the magnitude and direction of the induced emf and current in a loop of wire or a conducting bar under the following conditions:
(a) The magnitude of a related quantity such as magnetic field or area of the loop is changing at a constant rate.
(b) The magnitude of a related quantity such as magnetic field or area of the loop is a specified non-linear function of time.
c) Students should be able to analyze the forces that act on induced currents so they can determine the mechanical consequences of those forces.
2. Inductance (including *LR* and *LC* circuits)
a) Students should understand the concept of inductance, so they can:
(1) Calculate the magnitude and sense of the emf in an inductor through which a specified changing current is flowing.
(2) Derive and apply the expression for the self-inductance of a long solenoid.
b) Students should understand the transient and steady state behavior of DC circuits containing resistors and inductors, so they can:
(1) Apply Kirchhoff's rules to a simple *LR* series circuit to obtain a differential equation for the current as a function of time.
(2) Solve the differential equation obtained in (1) for the current as a function of time through the battery, using separation of variables.
(3) Calculate the initial transient currents and final steady state currents through any part of a simple series and parallel circuit containing an inductor and one or more resistors.
(4) Sketch graphs of the current through or voltage across the resistors or inductor in a simple series and parallel circuit.
(5) Calculate the rate of change of current in the inductor as a function of time.
(6) Calculate the energy stored in an inductor that has a steady current flowing through it.
3. Maxwell’s equations Students should be familiar with Maxwell’s equations so they can associate each equation with its implications.
Standard **LABORATORY AND EXPERIMENTAL SITUATIONS** These objectives overlay the content objectives, and are assessed in the context of those objectives.
1. Design experiments Students should understand the process of designing experiments, so they can:
a) Describe the purpose of an experiment or a problem to be investigated.
b) Identify equipment needed and describe how it is to be used.
c) Draw a diagram or provide a description of an experimental setup.

d)	Describe procedures to be used, including controls and measurements to be taken.
2. Observe and measure real phenomena Students should be able to make relevant observations, and be able to take measurements with a variety of instruments (cannot be assessed via paper-and-pencil examinations).	
3. Analyze data Students should understand how to analyze data, so they can:	
a)	Display data in graphical or tabular form.
b)	Fit lines and curves to data points in graphs.
c)	Perform calculations with data.
d)	Make extrapolations and interpolations from data.
4. Analyze errors Students should understand measurement and experimental error, so they can:	
a)	Identify sources of error and how they propagate.
b)	Estimate magnitude and direction of errors.
c)	Determine significant digits.
d)	Identify ways to reduce error.
5. Communicate results Students should understand how to summarize and communicate results, so they can:	
a)	Draw inferences and conclusions from experimental data.
b)	Suggest ways to improve experiment.
c)	Propose questions for further study.

Instructional Focus

Unit Enduring Understandings

- Magnetic flux causes a current in a conductor.

Unit Essential Questions

- How are electric and magnetic fields related?
- How can a system with a changing magnetic field be represented verbally, pictorially, and mathematically?

Objectives

Students will know:

- Understand the concept of magnetic flux so they can calculate the flux of a uniform magnetic field through a loop of arbitrary orientation.
- Understand Faraday's Law and Lenz's Law so that one can recognize situations in which changing flux through a loop will cause an induced EMF or current in the loop.
- Understand how Maxwell synthesized the understandings that had been achieved in Electro-magnetic theory, closed some open issues and provided a comprehensive set of equations which describe electrostatics and magnetism, how the field interact and propagate at light speed.

Students will be able to:

- Calculate the magnitude and direction of the induced EMF and current in general cases of wire loops.

Resources

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- Gizmos www.explorelearning.com/index.cfm?method=cuser.dsploginjoin
- LRC Circuit Lab

After AP exams students will complete experimental investigations and projects pertaining to the College Board Standards for AP Physics C.