PISCATAWAY TOWNSHIP SCHOOLS

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AP Physics C: Mechanics

Content Area: Science
Grade Span: 11-12
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COURSE OVERVIEW

Description

The AP Physics course is a full year, 7.5 credit course encompassing the College Board requirements for Physics C: Mechanics. 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 course will apply calculus to topics in kinematics, dynamics, energy, momentum, and circular, rotational physics, simple harmonic motion, and universal gravitation . 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.

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.

Scope and Sequence

Unit	Topic	Length
Unit 1	Kinematics	6 blocks
Unit 2	Dynamics	20 blocks
Unit 3	Momentum	18 blocks
Unit 4	Energy	17 blocks
Unit 5	Rotational Physics	36 blocks
Unit 6	Simple Harmonic Motion, Universal Gravitation, and Kepler's Laws	20 blocks

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

UNIT 1: 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. Students will also learn how vectors are represented and used, and how to solve problems about motion in a plane.
Recommended Pacing
6 blocks
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 **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.
- 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 object's 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?
- How can motion be modeled in multiple dimensions to solve real world problems and make predictions?

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.
- 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:

- 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

  $v = v_o + at$
  $x = x_o + v_o t + ½ at^2$
  $v_f^2 = v_o^2 + 2a(x - x_o)$
  to solve problems in one-dimensional motion with constant acceleration.
- 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.

UNIT 2: DYNAMICS

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

20 blocks

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, Â $\mathbf{F} = \mathbf{F}_{net} = m\mathbf{a}$, 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 object's 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, one 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 analyzing 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.

UNIT 3: MOMENTUM

Summary and Rationale
In this unit students will learn to use concepts of impulse and momentum in one and two dimensions.
Recommended Pacing
18 blocks
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 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.

UNIT 4: 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

17 blocks

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 in 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.

UNIT 5: ROTATIONAL PHYSICS

Summary and Rationale
In this unit students will learn to understand and apply the physics of rotation.
Recommended Pacing
36 blocks
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.

UNIT 6: SIMPLE HARMONIC MOTION, UNIVERSAL GRAVITATION, & KEPLER'S LAWS

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
20 blocks
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 $d^2 x / dt^2 = -w^2 x$ 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.

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