ESL
SCIENCE
BUSINESS
BILINGUAL
PRESCHOOL
MATHEMATICS
LIBRARY MEDIA
SOCIAL STUDIES
WORLD LANGUAGES
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TECHNOLOGY EDUCATION
ENGLISH LANGUAGE ARTS
FINE & PERFORMING ARTS
FAMILY & CONSUMER SCIENCE
HEALTH & PHYSICAL EDUCATION

RAHWAY PUBLIC SCHOOLS

CURRICULUM & INSTRUCTION

Content Area: Science

Course: Advanced Placement Physics 1

Grade Level: 11-12

This curriculum is part of the Educational Program of Studies of the Rahway Public Schools.

ACKNOWLEDGMENTS

Jeffery Kurczeski,

Program Supervisor of 7-12 Math & Science and 9-12 Business & Technology Education

The Board acknowledges the following who contributed to the preparation of this curriculum.

Michael Keat, Science Teacher

Julie Koft, Science Teacher

Dr. Tiffany A. Beer, Director of Curriculum and Instruction

Dr. Aleya Shoieb, Superintendent of Schools

Subject/Course Title:
Advanced Placement Physics 1
Grades 11-12

Date of Board Adoption:
August 27, 2024

RAHWAY PUBLIC SCHOOLS CURRICULUM

Advanced Placement Physics 1: Grades 11-12

PACING GUIDE

Unit	Title	Pacing
1	Kinematics	3 weeks
2	Force and Translational Dynamics	5 weeks
3	Work, Energy, and Power	5 weeks
4	Linear Momentum	3 weeks
5	Torque and Rotational Dynamics	4 weeks
6	Energy and Momentum of Rotating Systems	3 weeks
7	Oscillations	2 weeks
8	Fluids	3 weeks

ACCOMMODATIONS

504 Accommodations:

- Provide scaffolded vocabulary and vocabulary lists.
- Provide extra visual and verbal cues and prompts.
- Provide adapted/alternate/excerpted versions of the text and/or modified supplementary materials.
- Provide links to audio files and utilize video clips.
- Provide graphic organizers and/or checklists.
- Provide modified rubrics.
- Provide a copy of teaching notes, especially any key terms, in advance.
- Allow additional time to complete assignments and/or assessments.
- Provide shorter writing assignments.
- Provide sentence starters.
- Utilize small group instruction.
- Utilize Think-Pair-Share structure.
- Check for understanding frequently.
- Have student restate information.
- Support auditory presentations with visuals.
- Weekly home-school communication tools (notebook, daily log, phone calls or email messages).
- Provide study sheets and teacher outlines prior to assessments.
- Quiet corner or room to calm down and relax when anxious.
- Reduction of distractions.
- Permit answers to be dictated.
- Hands-on activities.
- Use of manipulatives.
- Assign preferential seating.
- No penalty for spelling errors or sloppy handwriting.
- Follow a routine/schedule.
- Provide student with rest breaks.
- Use verbal and visual cues regarding directions and staying on task.
- Assist in maintaining agenda book.

IEP Accommodations:

- Provide scaffolded vocabulary and vocabulary lists.
- Differentiate reading levels of texts (e.g., Newsela).
- Provide adapted/alternate/excerpted versions of the text and/or modified supplementary materials.
- Provide extra visual and verbal cues and prompts.
- Provide links to audio files and utilize video clips.
- Provide graphic organizers and/or checklists.
- Provide modified rubrics.
- Provide a copy of teaching notes, especially any key terms, in advance.
- Provide students with additional information to supplement notes.
- Modify questioning techniques and provide a reduced number of questions or items on tests.
- Allow additional time to complete assignments and/or assessments.
- Provide shorter writing assignments.
- Provide sentence starters.
- Utilize small group instruction.
- Utilize Think-Pair-Share structure.
- Check for understanding frequently.
- Have student restate information.
- Support auditory presentations with visuals.
- Provide study sheets and teacher outlines prior to assessments.
- Use of manipulatives.
- Have students work with partners or in groups for reading, presentations, assignments, and analyses.
- Assign appropriate roles in collaborative work.
- Assign preferential seating.
- Follow a routine/schedule.

Gifted and Talented Accommodations:

- Differentiate reading levels of texts (e.g., Newsela).
- Offer students additional texts with higher lexile levels.
- Provide more challenging and/or more supplemental readings and/or activities to deepen understanding.
- Allow for independent reading, research, and projects.
- Accelerate or compact the curriculum.
- Offer higher-level thinking questions for deeper analysis.
- Offer more rigorous materials/tasks/prompts.
- Increase number and complexity of sources.
- Assign group research and presentations to teach the class.
- Assign/allow for leadership roles during collaborative work and in other learning activities.

ML Accommodations:

- Provide extended time.
- Assign preferential seating.
- Assign peer buddy who the student can work with.
- Check for understanding frequently.
- Provide language feedback often (such as grammar errors, tenses, subject-verb agreements, etc…).
- Have student repeat directions.
- Make vocabulary words available during classwork and exams.
- Use study guides/checklists to organize information.
- Repeat directions.
- Increase one-on-one conferencing.
- Allow student to listen to an audio version of the text.
- Give directions in small, distinct steps.
- Allow copying from paper/book.
- Give student a copy of the class notes.

	• Provide written and oral instructions. • Differentiate reading levels of texts (e.g., Newsela). • Shorten assignments. • Read directions aloud to student. • Give oral clues or prompts. • Record or type assignments. • Adapt worksheets/packets. • Create alternate assignments. • Have student enter written assignments in criterion, where they can use the planning maps to help get them started and receive feedback after it is submitted. • Allow student to resubmit assignments. • Use small group instruction. • Simplify language. • Provide scaffolded vocabulary and vocabulary lists. • Demonstrate concepts possibly through the use of visuals. • Use manipulatives. • Emphasize critical information by highlighting it for the student. • Use graphic organizers. • Pre-teach or pre-view vocabulary. • Provide student with a list of prompts or sentence starters that they can use when completing a written assignment. • Provide audio versions of the textbooks. • Highlight textbooks/study guides. • Use supplementary materials. • Give assistance in note taking • Use adapted/modified textbooks. • Allow use of computer/word processor. • Allow student to answer orally, give extended time (time-and-a-half). • Allow tests to be given in a separate location (with the ESL teacher). • Allow additional time to complete assignments and/or assessments. • Read question to student to clarify. • Provide a definition or synonym for words on a test that do not impact the validity of the exam. • Modify the format of assessments. • Shorten test length or require only selected test items. • Create alternative assessments. • On an exam other than a spelling test, don't take points off for spelling errors.

UNIT 1 OVERVIEW

Content Area: Science

Unit Title: Kinematics

Target Course/Grade Level: Advanced Placement Physics 1/Grades 11-12

Unit Summary: The world is made up of objects that are in a constant state of motion. To understand the relationships between objects, students must first understand movement. Unit 1 introduces students to the study of motion and serves as a foundation for all of AP Physics 1 by exploring the idea of acceleration and showing students how representations can be used to model and analyze scientific information as it relates to the motion of objects.

Approximate Length of Unit: 3 weeks

LEARNING TARGETS

NJ Student Learning Standards:
HS-PS2-1 Analyze data to support the claim that Newton's second law of motion describes the mathematical relationship among the net force on a macroscopic object, its mass, and its acceleration.
HS-ETS1-2 Design a solution to a complex real-world problem by breaking it down into smaller, more manageable problems that can be solved through engineering.
HS-ETS1-3 Evaluate a solution to a complex real-world problem based on prioritized criteria and trade-offs that account for a range of constraints, including cost, safety, reliability, and aesthetics, as well as possible social, cultural, and environmental impacts.

College Board Standards:
1.1.A Describe a scalar or vector quantity using magnitude and direction, as appropriate.
1.1.B Describe a vector sum in one dimension.
1.2.A Describe a change in an object's position.
1.2.B Describe the average velocity and acceleration of an object.
1.3.A Describe the position, velocity, and acceleration of an object using representations of that object's motion.
1.4.A Describe the reference frame of a given observer.
1.4.B Describe the motion of objects as measured by observers in different inertial reference frames.
1.5.A Describe the perpendicular components of a vector.
1.5.B Describe the motion of an object moving in two dimensions.

Career Readiness, Life Literacies, and Key Skills:
9.3.12.AC.1 Use vocabulary, symbols and formulas common to architecture and construction.
9.3.12.AC.6 Read, interpret and use technical drawings, documents and specifications to plan a project.
9.3.12.AC‐DES.1 Justify design solutions through the use of research documentation and analysis of data.
9.3.12.AC‐DES.2 Use effective communication skills and strategies (listening, speaking, reading, writing and graphic communications) to work with clients and colleagues.
9.3.12.ED.2 Demonstrate effective oral, written and multimedia communication in multiple formats and contexts.

9.3.12.ED‑ADM.1 Use research‑based practices to develop, communicate and enlist support for a vision of success for all learners.
9.3.12.ED‑ADM.2 Identify behaviors necessary for developing and sustaining a positive learning culture.
9.3.12.ED‑ADM.3 Create instructional programs to meet the learning organization's objectives.
9.3.12.ED‑ADM.4 Identify instructional practices that meet the learning organization's objectives.
9.3.12.ED‑ADM.5 Model leadership skills for personnel in order to improve the performance of the learning organization.
9.4.12.CI.1 Demonstrate the ability to reflect, analyze, and use creative skills and ideas
9.4.12.CT.1 Identify problem-solving strategies used in the development of an innovative product or practice
9.4.12.CT.2 Explain the potential benefits of collaborating to enhance critical thinking and problem solving
9.4.12.DC.1 Explain the beneficial and harmful effects that intellectual property laws can have on the creation and sharing of content
9.4.12.IML.3 Analyze data using tools and models to make valid and reliable claims, or to determine optimal design solutions
9.4.12.TL.2 Generate data using formula-based calculations in a spreadsheet and draw conclusions about the data.

Interdisciplinary Connections and Standards:
ELA
L.SS.11–12.1. Demonstrate command of the system and structure of the English language when writing or speaking.
L.KL.11–12.2. Apply knowledge of language to understand how language functions in different contexts, to make effective choices for meaning or style, and to comprehend more fully when reading or listening.
L.VL.11–12.3. Determine or clarify the meaning of unknown and multiple-meaning words and phrases based on grades 11–12 reading and content, including technical meanings, choosing flexibly from a range of strategies.
RI.CI.11–12.2. Determine two or more central ideas of an informational text and analyze how they are developed and refined over the course of a text, including how they interact and build on one another to provide a complex account or analysis; provide an objective summary of the text.
W.AW.11–12.1. Write arguments to support claims in an analysis of substantive topics or texts, using valid reasoning and relevant and sufficient evidence.
SL.PE.11–12.1. Initiate and participate effectively in a range of collaborative discussions (one-on-one, in groups, and teacher-led) with peers on grades 11–12 topics, texts, and issues, building on others' ideas and expressing their own clearly and persuasively.
SL.PI.11–12.4 Present information, findings and supporting evidence clearly, concisely, and logically. The content, organization, development, and style are appropriate to task, purpose, and audience.
Mathematics
MP.2 Reason abstractly and quantitatively.
MP.4 Model with mathematics.
N.Q.A.1 Use units as a way to understand problems and to guide the solution of multi-step problems; choose and interpret units consistently in formulas; choose and interpret the scale and the origin in graphs and data displays.
N.Q.A.2 Define appropriate quantities for the purpose of descriptive modeling.
N.Q.A.3 Choose a level of accuracy appropriate to limitations on measurement when reporting quantities.
A.SSE.A.1 Interpret expressions that represent a quantity in terms of its context.
A.SSE.B.3 Choose and produce an equivalent form of an expression to reveal and explain properties of the quantity represented by the expression.
A.CED.A.1 Create equations and inequalities in one variable and use them to solve problems.
A.CED.A.2 Create equations in two or more variables to represent relationships between quantities; graph equations on coordinate axes with labels and scales.
A.CED.A.4 Rearrange formulas to highlight a quantity of interest, using the same reasoning as in solving equations.

F.IF.C.7 Graph functions expressed symbolically and show key features of the graph, by hand in simple cases and using technology for more complicated cases.
S.ID.A.1 Represent data with plots on the real number line (dot plots, histograms, and box plots).

Unit Understandings:
Students will understand that…

- All forces share certain common characteristics when considered by observers in inertial reference frames.
- The acceleration of the center of mass of a system is related to the net force exerted on the system.

Unit Essential Questions:

- How can the idea of frames of reference allow two people to tell the truth yet have conflicting reports?
- How can we estimate the height of a very tall building with only a small rock and a stopwatch?
- Why might it seem like you are moving backwards when a car passes you on the highway?
- Why is the general rule for stopping your car "when you double your speed, you must give yourself four times as much distance to stop"?

Knowledge and Skills:
Students will know...

- Scalars are quantities described by magnitude only; vectors are quantities described by both magnitude and direction.
- Vectors can be visually modeled as arrows with appropriate direction and lengths proportional to their magnitude.
- Distance and speed are examples of scalar quantities, while position, displacement, velocity, and acceleration are examples of vector quantities.
- Vectors are notated with an arrow above the symbol for that quantity. Relevant equation:
  $\vec{v} = \vec{v}_0 + \vec{a}t$
- Vector notation is not required for vector components along an axis. In one dimension, the sign of the component completely describes the direction of that component. Derived equation:
  $v_x = v_{x0} + a_x t$
- When determining a vector sum in a given one-dimensional coordinate system, opposite directions are denoted by opposite signs.
- When using the object model, the size, shape, and internal configuration are ignored. The object may be treated as a single point with extensive properties such as mass and charge.
- Displacement is the change in an object's position. Relevant equation:
  $\Delta x = x - x_0$
- Averages of velocity and acceleration are calculated considering the initial and final states of an object over an interval of time.
- Average velocity is the displacement of an object divided by the interval of time in which that displacement occurs. Relevant equation:
  $\vec{v}_{avg} = \frac{\Delta \vec{x}}{\Delta t}$
- Average acceleration is the change in velocity divided by the interval of time in which that change in velocity occurs. Relevant equation:
  $\vec{a}_{avg} = \frac{\Delta \vec{v}}{\Delta t}$

- An object is accelerating if the magnitude and/or direction of the object's velocity are changing.
- Calculating average velocity or average acceleration over a very small time-interval yields a value that is very close to the instantaneous velocity or instantaneous acceleration.
- Motion can be represented by motion diagrams, figures, graphs, equations, and narrative descriptions.
- For constant acceleration, three kinematic equations can be used to describe instantaneous linear motion in one dimension. Relevant equations:

$$v_x = v_{xo} + a_x t$$

$$x = x_0 + v_{x0}t + \frac{1}{2}a_x t^2$$

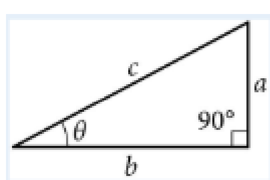
$$v_x^2 = v_{xo}^2 + 2a_x(x - x_0)$$

  Note: The equations above are written to indicate motion in the x-direction, but these equations can be used in any single dimension as appropriate.
- Near the surface of Earth, the vertical acceleration caused by the force of gravity is downward, constant, and has a measured value approximately equal to $a_g = g \cong 10 m/s^2$
- Graphs of position, velocity, and acceleration as functions of time can be used to find the relationships between those quantities.
- An object's instantaneous velocity is the rate of change of the object's position, which is equal to the slope of a line tangent to a point on a graph of the object's position as a function of time.
- An object's instantaneous acceleration is the rate of change of the object's velocity, which is equal to the slope of a line tangent to a point on a graph of the object's velocity as a function of time.
- The displacement of an object during a time interval is equal to the area under the curve of a graph of the object's velocity as a function of time (i.e., the area bounded by the function and the horizontal axis for the appropriate interval).
- The change in velocity of an object during a time interval is equal to the area under the curve of a graph of the acceleration of the object as a function of time.
- The choice of reference frame will determine the direction and magnitude of quantities measured by an observer in that reference frame.
- Measurements from a given reference frame may be converted to measurements from another reference frame.
- The observed velocity of an object results from the combination of the object's velocity and the velocity of the observer's reference frame.
- Combining the motion of an object and the motion of an observer in a given reference frame involves the addition or subtraction of vectors.
- The acceleration of any object is the same as measured from all inertial reference frames.
- Vectors can be mathematically modeled as the resultant of two perpendicular components.
- Vectors can be resolved into components using a chosen coordinate system.
- Vectors can be resolved into perpendicular components using trigonometric functions and relationships. Relevant equations:

$$\sin\theta = \frac{a}{c}$$

$$\cos\theta = \frac{b}{c}$$

$$\tan\theta = \frac{a}{b}$$



$$a^2 + b^2 = c^2$$

- Motion in two dimensions can be analyzed using one-dimensional kinematic relationships if the motion is separated into components.
- Projectile motion is a special case of two dimensional motion that has zero acceleration in one dimension and constant, nonzero acceleration in the second dimension.

Students will be able to...

- Create diagrams, tables, charts, or schematics to represent physical situations.
- Compare physical quantities between two or more scenarios or at different times and locations in a single scenario.
- Apply an appropriate law, definition, theoretical relationship, or model to make a claim.
- Justify or support a claim using evidence from experimental data, physical representations, or physical principles or laws.
- Create qualitative sketches of graphs that represent features of a model or the behavior of a physical system.
- Calculate or estimate an unknown quantity with units from known quantities, by selecting and following a logical computational pathway.
- Create quantitative graphs with appropriate scales and units, including plotting data.
- Derive a symbolic expression from known quantities by selecting and following a logical mathematical pathway.
- Predict new values or factors of change of physical quantities using functional dependence between variables.
- Create experimental procedures that are appropriate for a given scientific question.
- Make predictions about the motion of a system based on the fact that acceleration is equal to the change in velocity per unit time, and velocity is equal to the change in position per unit time.
- Create mathematical models and analyze graphical relationships for acceleration, velocity, and position of the center of mass of a system and use them to calculate properties of the motion of the center of mass of a system.

EVIDENCE OF LEARNING

Assessment:

What evidence will be collected and deemed acceptable to show that students truly "understand"?

- End of Unit Common Assessment - See folder for assessment links.
- Topic Quizzes
- AP Classroom Personal Progress Check
- Assigned Lab Reports
- Group Presentations

Learning Activities:

What differentiated learning experiences and instruction will enable all students to achieve the desired results?

- Sample Activities:
    - **Desktop Experiment Task:** Give each group a pull-back toy car. Ask students to lay out strips of paper 0.5 m apart and take a video of the car as it is released, speeds up, and slows down. Using a frame-by-frame review app to get the time each strip is passed to get

x versus t data, have students make v versus t data tables out of this, and graph both position as a function of time and velocity as a function of time.

- **Desktop Experiment Task:** Have students find the acceleration of a yo-yo as it falls and unwinds using only a meter stick and stopwatch. Then, have students draw (with correct shapes and scales) distance, speed, and acceleration versus time graphs.
- **Changing Representations:** Show a curvy x versus t graph, a v versus t graph made of connected straight-line segments, or an a versus t graph made of horizontal steps. Have students sketch the other two graphs and either walk them out along a line or move a cart on a track to demonstrate the motion (Note: The track can be tilted slightly to provide constant acceleration in either direction).
- **Changing Representations:** Have students throw/launch a ball from the second or third story of a building to the ground and measure the ball's initial height, horizontal distance, and time in the air. From this, ask students to calculate initial velocity components and draw (with scales) horizontal/ vertical position/velocity/acceleration versus time graphs.
- **Create a Plan:** Give each group a spring-loaded ball launcher and a meter stick. Have students launch the ball horizontally from a known height and then predict where it will land on the floor when fired at a given angle from the floor. Then, ask students to write their own set of lab instructions for the procedure they just performed, articulating each subtask and calculations needed to obtain their prediction.

RESOURCES

Teacher Resources:

- AP Physics 1 Course and Exam Description
- AP Classroom Resources
- College Physics: Etkina et al 1st Edition
- Flipping Physics
- PhET - Online Physics simulations
- The Physics Classroom

Equipment Needed:

- Laptop and projector
- Calculators
- Chromebooks
- Laboratory equipment for demonstrations and labs

UNIT 2 OVERVIEW

Content Area: Science

Unit Title: Force and Translational Dynamics

Target Course/Grade Level: Advanced Placement Physics 1/Grades 11-12

Unit Summary: In Unit 2, students are introduced to the concept of force, which is an interaction between two objects or systems of objects. Part of the larger study of dynamics, forces provide the context in which students analyze and come to understand a variety of physical phenomena. This understanding is accomplished by revisiting and building upon the models and representations presented in Unit 1—specifically through the introduction of the free-body diagram. Students will further analyze the effect of forces on systems when they encounter Newton's second law in rotational form in Unit 5.

Approximate Length of Unit: 5 weeks

LEARNING TARGETS

NJ Student Learning Standards:

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

HS-PS2-4 Use mathematical representations of Newton's Law of Gravitation and Coulomb's Law to describe and predict the gravitational and electrostatic forces between objects.

HS-PS2-6 Communicate scientific and technical information about why the molecular-level structure is important in the functioning of designed materials.

HS-ETS1-2 Design a solution to a complex real-world problem by breaking it down into smaller, more manageable problems that can be solved through engineering.

HS-ETS1-3 Evaluate a solution to a complex real-world problem based on prioritized criteria and trade-offs that account for a range of constraints, including cost, safety, reliability, and aesthetics, as well as possible social, cultural, and environmental impacts.

College Board Standards:

2.1.A Describe the properties and interactions of a system.

2.1.B Describe the location of a system's center of mass with respect to the system's constituent parts.

2.2.A Describe a force as an interaction between two objects or systems.

2.2.B Describe the forces exerted on an object or system using a free-body diagram.

2.3.A Describe the interaction of two objects using Newton's third law and a representation of paired forces exerted on each object.

2.4.A Describe the conditions under which a system's velocity remains constant.

2.5.A Describe the conditions under which a system's velocity changes.

2.6.A Describe the gravitational interaction between two objects or systems with mass.

2.6.B Describe situations in which the gravitational force can be considered constant.

2.6.C Describe the conditions under which the magnitude of a system's apparent weight is different from the magnitude of the gravitational force exerted on that system.

2.6.D Describe inertial and gravitational mass.
2.7.A Describe kinetic friction between two surfaces.
2.7.B Describe static friction between two surfaces.
2.8.A Describe the force exerted on an object by an ideal spring
2.9.A Describe the motion of an object traveling in a circular path.
2.9.B Describe circular orbits using Kepler's third law.

Career Readiness, Life Literacies, and Key Skills:
9.3.12.AC.1 Use vocabulary, symbols and formulas common to architecture and construction.
9.3.12.AC.6 Read, interpret and use technical drawings, documents and specifications to plan a project.
9.3.12.AC‐DES.1 Justify design solutions through the use of research documentation and analysis of data.
9.3.12.AC‐DES.2 Use effective communication skills and strategies (listening, speaking, reading, writing and graphic communications) to work with clients and colleagues.
9.3.12.ED.2 Demonstrate effective oral, written and multimedia communication in multiple formats and contexts.
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9.4.12.TL.2 Generate data using formula-based calculations in a spreadsheet and draw conclusions about the data.

Interdisciplinary Connections and Standards:
ELA
L.SS.11–12.1. Demonstrate command of the system and structure of the English language when writing or speaking.
L.KL.11–12.2. Apply knowledge of language to understand how language functions in different contexts, to make effective choices for meaning or style, and to comprehend more fully when reading or listening.
L.VL.11–12.3. Determine or clarify the meaning of unknown and multiple-meaning words and phrases based on grades 11–12 reading and content, including technical meanings, choosing flexibly from a range of strategies.
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W.AW.11–12.1. Write arguments to support claims in an analysis of substantive topics or texts, using valid reasoning and relevant and sufficient evidence.
SL.PE.11–12.1. Initiate and participate effectively in a range of collaborative discussions (one-on-one, in groups, and teacher-led) with peers on grades 11–12 topics, texts, and issues, building on others' ideas and expressing their own clearly and persuasively.
SL.PI.11–12.4 Present information, findings and supporting evidence clearly, concisely, and logically. The content, organization, development, and style are appropriate to task, purpose, and audience.
Mathematics
MP.2 Reason abstractly and quantitatively.

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

Unit Understandings:
Students will understand that…
- The internal structure of a system determines many properties of the system.
- A gravitational field is caused by an object with mass.
- The acceleration of the center of mass of a system is related to the net force exerted on the system, where $a = \frac{\Sigma F}{m}$
- A field associates a value of some physical quantity with every point in space. Field models are useful for describing interactions that occur at a distance (long-range forces), as well as a variety of other physical phenomena.

Unit Essential Questions:
- Why do we feel pulled toward Earth but not toward a pencil?
- Why is it more difficult to stop a fully loaded dump truck than a small passenger car?
- Why is it difficult to walk on ice?
- Why will a delivery truck filled with birds sitting on its floor be the same weight as a truck with the same birds flying around inside?

Knowledge and Skills:
Students will know...
- System properties are determined by the interactions between objects within the system.
- If the properties or interactions of the constituent objects within a system are not important in modeling the behavior of the macroscopic system, the system can itself be treated as a single object.
- Systems may allow interactions between constituent parts of the system and the environment, which may result in the transfer of energy or mass.
- Individual objects within a chosen system may behave differently from each other as well as from the system as a whole.
- The internal structure of a system affects the analysis of that system.
- As variables external to a system are changed, the system's substructure may change.
- For systems with symmetrical mass distributions, the center of mass is located on lines of symmetry.

- The location of a system's center of mass along a given axis can be calculated using the equation $x_{cm} = \frac{\sum_i m_i x_i}{\sum_i m_i}$
- A system can be modeled as a singular object that is located at the system's center of mass.
- Forces are vector quantities that describe the interactions between objects or systems.
  - A force exerted on an object or system is always due to the interaction of that object with another object or system.
  - An object or system cannot exert a net force on itself.
- Contact forces describe the interaction of an object or system touching another object or system and are macroscopic effects of interatomic electric forces.
- Free-body diagrams are useful tools for visualizing forces being exerted on a single object or system and for determining the equations that represent a physical situation.
- The free-body diagram of an object or system shows each of the forces exerted on the object by the environment.
- Forces exerted on an object or system are represented as vectors originating from the representation of the center of mass, such as a dot. A system is treated as though all of its mass is located at the center of mass.
- A coordinate system with one axis parallel to the direction of acceleration of the object or system simplifies the translation from free-body diagram to algebraic representation. For example, in a free-body diagram of an object on an inclined plane, it is useful to set one axis parallel to the surface of the incline.
- Newton's third law describes the interaction of two objects in terms of the paired forces that each exerts on the other.
- Interactions between objects within a system (internal forces) do not influence the motion of a system's center of mass.
- Tension is the macroscopic net result of forces that segments of a string, cable, chain, or similar system exert on each other in response to an external force.
  - An ideal string has negligible mass and does not stretch when under tension.
  - The tension in an ideal string is the same at all points within the string.
  - In a string with non negligible mass, tension may not be the same at all points within the string.
  - An ideal pulley is a pulley that has negligible mass and rotates about an axle through its center of mass with negligible friction.
- The net force on a system is the vector sum of all forces exerted on the system.
- Translational equilibrium is a configuration of forces such that the net force exerted on a system is zero.
- Newton's first law states that if the net force exerted on a system is zero, the velocity of that system will remain constant.
- Forces may be balanced in one dimension but unbalanced in another. The system's velocity will change only in the direction of the unbalanced force.
- An inertial reference frame is one from which an observer would verify Newton's first law of motion.
- Unbalanced forces are a configuration of forces such that the net force exerted on a system is not equal to zero.
- Newton's second law of motion states that the acceleration of a system's center of mass has a magnitude proportional to the magnitude of the net force exerted on the system and is in the same direction as that net force. $a_{sys} = \frac{\Sigma F_{sys}}{m_{sys}}$

- The velocity of a system's center of mass will only change if a nonzero net external force is exerted on that system.
- Newton's law of universal gravitation describes the gravitational force between two objects or systems as directly proportional to each of their masses and inversely proportional to the square of the distance between the systems' centers of mass. $F_g = G\frac{m_1 m_2}{r^2}$
  - The gravitational force is attractive.
  - The gravitational force is always exerted along the line connecting the centers of mass of the two interacting systems.
  - The gravitational force on a system can be considered to be exerted on the system's center of mass.
- A field models the effects of a noncontact force exerted on an object at various positions in space.
  - The magnitude of the gravitational field created by a system of mass M at a point in space is equal to the ratio of the gravitational force exerted by the system on a test object of mass m to the mass of the test object. $g = \frac{F_g}{m} = G\frac{M}{r^2}$
  - If the gravitational force is the only force exerted on an object, the observed acceleration of the object (in m/s2) is numerically equal to the magnitude of the gravitational field strength (in N/Kg) at that location.
- The gravitational force exerted by an astronomical body on a relatively small nearby object is called weight. $weight = F_g = mg$
- If the gravitational force between two systems' centers of mass has a negligible change as the relative position of the two systems changes, the gravitational force can be considered constant at all points between the initial and final positions of the systems.
- Near the surface of Earth, the strength of the gravitational field is g = 10 N/kg
- The magnitude of the apparent weight of a system is the magnitude of the normal force exerted on the system.
- If the system is accelerating, the apparent weight of the system is not equal to the magnitude of the gravitational force exerted on the system.
- A system appears weightless when there are no forces exerted on the system or when the force of gravity is the only force exerted on the system.
- The equivalence principle states that an observer in a noninertial reference frame is unable to distinguish between an object's apparent weight and the gravitational force exerted on the object by a gravitational field.
- Objects have inertial mass, or inertia, a property that determines how much an object's motion resists changes when interacting with another object.
- Gravitational mass is related to the force of attraction between two systems with mass.
- Inertial mass and gravitational mass have been experimentally verified to be equivalent.
- Kinetic friction occurs when two surfaces in contact move relative to each other.
  - The kinetic friction force is exerted in a direction opposite to the motion of each surface relative to the other surface.
  - The force of friction between two surfaces does not depend on the size of the surface area of contact.
- The magnitude of the kinetic friction force exerted on an object is the product of the normal force the surface exerts on the object and the coefficient of kinetic friction. $|F_{fk}| = |\mu_k F_N|$
  - The coefficient of kinetic friction depends on the material properties of the surfaces that are in contact.
  - Normal force is the perpendicular component of the force exerted on an object by the surface with which it is in contact; it is directed away from the surface.

- Static friction may occur between the contacting surfaces of two objects that are not moving relative to each other.
- Static friction adopts the value and direction required to prevent an object from slipping or sliding on a surface. $\left|F_{fs}\right| \leq \left|\mu_s F_N\right|$
    - Slipping and sliding refer to situations in which two surfaces are moving relative to each other.
    - There exists a maximum value for which static friction will prevent an object from slipping on a given surface. $\left|F_{fs,max}\right| = \left|\mu_s F_N\right|$
- The coefficient of static friction is typically greater than the coefficient of kinetic friction for a given pair of surfaces.
- An ideal spring has negligible mass and exerts a force that is proportional to the change in its length as measured from its relaxed length.
- The magnitude of the force exerted by an ideal spring on an object is given by Hooke's law: $F_s = - k\Delta x$
- The force exerted on an object by a spring is always directed toward the equilibrium position of the object–spring system.
- Centripetal acceleration is the component of an object's acceleration directed toward the center of the object's circular path.
    - The magnitude of centripetal acceleration for an object moving in a circular path is the ratio of the object's tangential speed squared to the radius of the circular path. $a_c = \frac{v^2}{r}$
    - Centripetal acceleration is directed toward the center of an object's circular path.
- Centripetal acceleration can result from a single force, more than one force, or components of forces exerted on an object in circular motion.
    - At the top of a vertical, circular loop, an object requires a minimum speed to maintain circular motion. At this point, and with this minimum speed, the gravitational force is the only force that causes the centripetal acceleration. $v = \sqrt{gr}$
    - Components of the static friction force and the normal force can contribute to the net force producing centripetal acceleration of an object traveling in a circle on a banked surface.
    - A component of tension contributes to the net force producing centripetal acceleration experienced by a conical pendulum.
- Tangential acceleration is the rate at which an object's speed changes and is directed tangent to the object's circular path.
- The net acceleration of an object moving in a circle is the vector sum of the centripetal acceleration and tangential acceleration.
- The revolution of an object traveling in a circular path at a constant speed (uniform circular motion) can be described using period and frequency.
    - The time to complete one full circular path, one full rotation, or a full cycle of oscillatory motion is defined as period, T.
    - The rate at which an object is completing revolutions is defined as frequency, f. $T = \frac{1}{f}$
    - For an object traveling at a constant speed in a circular path, the period is given by the derived equation $T = \frac{2\pi r}{v}$
- For a satellite in circular orbit around a central body, the satellite's centripetal acceleration is caused only by gravitational attraction. The period and radius of the circular orbit are related to the mass of the central body. $T^2 = \frac{4\pi^2}{GM}R^3$

Students will be able to...

- Create quantitative graphs with appropriate scales and units, including plotting data.
- Calculate or estimate an unknown quantity with units from known quantities, by selecting and following a logical computational pathway.
- Compare physical quantities between two or more scenarios or at different times and locations in a single scenario.
- Apply an appropriate law, definition, theoretical relationship, or model to make a claim.
- Create diagrams, tables, charts, or schematics to represent physical situations.
- Justify or support a claim using evidence from experimental data, physical representations, or physical principles or laws.
- Predict new values or factors of change of physical quantities using functional dependence between variables.
- Create qualitative sketches of graphs that represent features of a model or the behavior of a physical system.
- Derive a symbolic expression from known quantities by selecting and following a logical mathematical pathway.
- Create quantitative graphs with appropriate scales and units, including plotting data.
- Create experimental procedures that are appropriate for a given scientific question.
- Apply Newton's second law to systems to calculate the change in the center-of-mass velocity when an external force is exerted on the system.
- Use visual or mathematical representations of the forces between objects in a system to predict whether or not there will be a change in the center-of-mass velocity of that system.

EVIDENCE OF LEARNING

Assessment:

What evidence will be collected and deemed acceptable to show that students truly "understand"?

- End of Unit Common Assessment - See folder for assessment links.
- Topic Quizzes
- AP Classroom Personal Progress Check
- Assigned Lab Reports
- Group Presentations

Learning Activities:

What differentiated learning experiences and instruction will enable all students to achieve the desired results?

- Sample Activities:
  - **Changing Representations:** Have students consider an accelerating two-object system from everyday life (e.g., person pushes a shopping cart, car pulls a trailer). Have them draw the forces on one object, then on the other, and then the external forces exerted on the two-object system.
  - **Working Backward:** Put students in pairs. Have student A write a Newton's second law equation either with symbols or plugged-in numbers including units. Then, have student B describe a situation that the equation applies to, including the object's velocity direction and how velocity is changing, a diagram, and a free-body diagram.
  - **What, If Anything, Is Wrong?:** Have students identify some force-related problem from their homework or textbook (that requires setting up Newton's second law and maybe

more). Ask students to write out a detailed solution that has exactly one mistake in it (not a calculation error). Post everyone's problems/solutions, and then ask students to identify everyone else's errors. The last student to have their error found wins.

  - **Desktop Experiment Task:** Have students measure the coefficient of static friction of their shoe on a wood plank or metal track. Level 1: Use a spring scale. Level 2: Use a pulley, a spring, a toy bucket, and an electronic balance. Level 3: Use a protractor.
  - **Desktop Experiment Task:** Have students use the "My Solar System" PhET applet to create circular orbits of varying radii around the central star and record radius, period, and planet mass for various trials. Next, have them calculate the speed using $v = 2\pi r/ T$ and force using $F=mv^2 /r$. Using the data, have students show that gravitational force is directly proportional to the mass of each object and inversely proportional to the square of the radius.
  - **Construct an Argument:** Ask students to consider two identical objects moving in circles (or parts of circles) of different radii. Then, ask them to think of a situation where the object with the smaller radius has a greater net force and another situation where the object with the larger radius has a greater net force.
  - **Changing Representations:** Describe something a driver could be doing in a car (e.g., "turning the steering wheel to the right while pressing the brake"). Have students walk out the motion while holding out one arm representing the velocity vector and the other arm representing the acceleration vector.
  - **Predict and Explain:** Attach an object of known weight (say, 2 N) to a force sensor and cause the object to swing in a 180-degree arc. Ask students, "At the bottom, the object is neither speeding up nor slowing down, so what force is registered at the bottom?" Expect students to (incorrectly) answer, "2 N" and discuss, as a class, why this answer is incorrect.

RESOURCES

Teacher Resources:

- AP Physics 1 Course and Exam Description
- AP Classroom Resources
- College Physics: Etkina et al 1st Edition
- Flipping Physics
- PhET - Online Physics simulations
- The Physics Classroom

Equipment Needed:

- Laptop and projector
- Calculators
- Chromebooks
- Laboratory equipment for demonstrations and labs

UNIT 3 OVERVIEW

Content Area: Science

Unit Title: Work, Energy, and Power

Target Course/Grade Level: Advanced Placement Physics 1/Grades 11-12

Unit Summary: In Unit 3, students are introduced to the idea of conservation as a foundational principle of physics, along with the concept of work as the primary agent of change for energy. As in earlier units, students will once again utilize both familiar and new models and representations to analyze physical situations, now with force or energy as major components. Students will be encouraged to call upon their knowledge of content and skills in Units 1 and 2 to determine the most appropriate technique for approaching a problem and will be challenged to understand the limiting factors of each technique.

Approximate Length of Unit: 5 weeks

LEARNING TARGETS

NJ Student Learning Standards:
HS-PS2-1 Analyze data to support the claim that Newton's second law of motion describes the mathematical relationship among the net force on a macroscopic object, its mass, and its acceleration.
HS-PS3-1 Create a computational model to calculate the change in the energy of one component in a system when the change in energy of the other component(s) and energy flows in and out of the system are known.
HS-PS3-2 Develop and use models to illustrate that energy at the macroscopic scale can be accounted for as a combination of energy associated with the motions of particles (objects) and energy associated with the relative position of particles (objects).
HS-PS3-3 Design, build, and refine a device that works within given constraints to convert one form of energy into another form of energy.
HS-ETS1-2 Design a solution to a complex real-world problem by breaking it down into smaller, more manageable problems that can be solved through engineering.
HS-ETS1-3 Evaluate a solution to a complex real-world problem based on prioritized criteria and trade-offs that account for a range of constraints, including cost, safety, reliability, and aesthetics, as well as possible social, cultural, and environmental impacts.
HS-ETS1-4 Use a computer simulation to model the impact of proposed solutions to a complex real-world problem with numerous criteria and constraints on interactions within and between systems relevant to the problem.

College Board Standards:
3.1.A Describe the translational kinetic energy of an object in terms of the object's mass and velocity.
3.2.A Describe the work done on an object or system by a given force or collection of forces.
3.3.A Describe the potential energy of a system.
3.4.A Describe the energies present in a system.
3.4.B Describe the behavior of a system using conservation of mechanical energy principles.

3.4.C Describe how the selection of a system determines whether the energy of that system changes.
3.5.A Describe the transfer of energy into, out of, or within a system in terms of power.

Career Readiness, Life Literacies, and Key Skills:
9.3.12.AC.1 Use vocabulary, symbols and formulas common to architecture and construction.
9.3.12.AC.6 Read, interpret and use technical drawings, documents and specifications to plan a project.
9.3.12.AC‑DES.1 Justify design solutions through the use of research documentation and analysis of data.
9.3.12.AC‑DES.2 Use effective communication skills and strategies (listening, speaking, reading, writing and graphic communications) to work with clients and colleagues.
9.3.12.ED.2 Demonstrate effective oral, written and multimedia communication in multiple formats and contexts.
9.3.12.ED‑ADM.1 Use research‑based practices to develop, communicate and enlist support for a vision of success for all learners.
9.3.12.ED‑ADM.2 Identify behaviors necessary for developing and sustaining a positive learning culture.
9.3.12.ED‑ADM.3 Create instructional programs to meet the learning organization's objectives.
9.3.12.ED‑ADM.4 Identify instructional practices that meet the learning organization's objectives.
9.3.12.ED‑ADM.5 Model leadership skills for personnel in order to improve the performance of the learning organization.
9.4.12.CI.1 Demonstrate the ability to reflect, analyze, and use creative skills and ideas
9.4.12.CT.1 Identify problem-solving strategies used in the development of an innovative product or practice
9.4.12.CT.2 Explain the potential benefits of collaborating to enhance critical thinking and problem solving
9.4.12.DC.1 Explain the beneficial and harmful effects that intellectual property laws can have on the creation and sharing of content
9.4.12.IML.3 Analyze data using tools and models to make valid and reliable claims, or to determine optimal design solutions
9.4.12.TL.2 Generate data using formula-based calculations in a spreadsheet and draw conclusions about the data.

Interdisciplinary Connections and Standards:
ELA
L.SS.11–12.1. Demonstrate command of the system and structure of the English language when writing or speaking.
L.KL.11–12.2. Apply knowledge of language to understand how language functions in different contexts, to make effective choices for meaning or style, and to comprehend more fully when reading or listening.
L.VL.11–12.3. Determine or clarify the meaning of unknown and multiple-meaning words and phrases based on grades 11–12 reading and content, including technical meanings, choosing flexibly from a range of strategies.
RI.CI.11–12.2. Determine two or more central ideas of an informational text and analyze how they are developed and refined over the course of a text, including how they interact and build on one another to provide a complex account or analysis; provide an objective summary of the text.
W.AW.11–12.1. Write arguments to support claims in an analysis of substantive topics or texts, using valid reasoning and relevant and sufficient evidence.
SL.PE.11–12.1. Initiate and participate effectively in a range of collaborative discussions (one-on-one, in groups, and teacher-led) with peers on grades 11–12 topics, texts, and issues, building on others' ideas and expressing their own clearly and persuasively.
SL.PI.11–12.4 Present information, findings and supporting evidence clearly, concisely, and logically. The content, organization, development, and style are appropriate to task, purpose, and audience.
Mathematics
MP.2 Reason abstractly and quantitatively.
MP.4 Model with mathematics.
N.Q.A.1 Use units as a way to understand problems and to guide the solution of multi-step problems; choose and interpret units consistently in formulas; choose and interpret the scale and the origin in graphs and data displays.

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

Unit Understandings:
Students will understand that…

- Certain quantities are conserved, in the sense that the changes of those quantities in a given system are always equal to the transfer of that quantity to or from the system by all possible interactions with other systems.
- Interactions with other objects or systems can change the total energy of a system.
- A force exerted on an object can change the kinetic energy of the object.

Unit Essential Questions:

- How much money can you save by charging your cell phone at school instead of at home?
- If energy is conserved, why are we running out of it?
- Does pushing an object always change its energy?
- Why does it seem easier to carry a large box up a ramp rather than up a set of stairs?

Knowledge and Skills:
Students will know...

- An object's translational kinetic energy is given by the equation $K = \frac{1}{2}mv^2$
- Translational kinetic energy is a scalar quantity.
- Different observers may measure different values of the translational kinetic energy of an object, depending on the observer's frame of reference.
- Work is the amount of energy transferred into or out of a system by a force exerted on that system over a distance.
  - The work done by a conservative force exerted on a system is path-independent and only depends on the initial and final configurations of that system.
  - The work done by a conservative force on a system—or the change in the potential energy of the system—will be zero if the system returns to its initial configuration.
  - Potential energies are associated only with conservative forces.
  - The work done by a nonconservative force is path-dependent.
  - Examples of non-conservative forces are friction and air resistance.
- Work is a scalar quantity that may be positive, negative, or zero.
- The amount of work done on a system by a constant force is related to the components of that force and the displacement of the point at which that force is exerted.
  - Only the component of the force exerted on a system that is parallel to the displacement of the point of application of the force will change the system's total energy.
    $W = Fdcos\theta$

- The component of the force exerted on a system perpendicular to the direction of the displacement of the system's center of mass can change the direction of the system's motion without changing the system's kinetic energy.

- The work-energy theorem states that the change in an object's kinetic energy is equal to the sum of the work (net work) being done by all forces exerted on the object. $\Delta K = \sum_i W_i$
    - An external force may change the configuration of a system. The component of the external force parallel to the displacement times the displacement of the point of application of the force gives the change in kinetic energy of the system.
    - If the system's center of mass and the point of application of the force move the same distance when a force is exerted on a system, then the system may be modeled as an object, and only the system's kinetic energy can change.
    - The energy dissipated by friction is typically equated to the force of friction times the length of the path over which the force is exerted $\Delta E_{mech} = F_f d cos\theta$
- Work is equal to the area under the curve of a graph of F as a function of displacement.
- A system composed of two or more objects has potential energy if the objects within that system only interact with each other through conservative forces.
- Potential energy is a scalar quantity associated with the position of objects within a system.
- The definition of zero potential energy for a given system is a decision made by the observer considering the situation to simplify or otherwise assist in analysis.
- The potential energy of common physical systems can be described using the physical properties of that system.
    - The elastic potential energy of an ideal spring is given by the following equation, where Δx is the distance the spring has been stretched or compressed from its equilibrium length. $U_s = \frac{1}{2}k(\Delta x)^2$
    - The general form for the gravitational potential energy of a system consisting of two approximately spherical distributions of mass (e.g., moons, planets or stars) is given by the equation $U_g = - G\frac{m_1 m_2}{r}$
    - Because the gravitational field near the surface of a planet is nearly constant, the change in gravitational potential energy in a system consisting of an object with mass m and a planet with gravitational field of magnitude g when the object is near the surface of the planet may be approximated by the equation $\Delta U_g = mg\Delta y$
- The total potential energy of a system containing more than two objects is the sum of the potential energy of each pair of objects within the system.
- A system composed of only a single object can only have kinetic energy.
- A system that contains objects that interact via conservative forces or that can change its shape reversibly may have both kinetic and potential energies.
- Mechanical energy is the sum of a system's kinetic and potential energies.
- Any change to a type of energy within a system must be balanced by an equivalent change of other types of energies within the system or by a transfer of energy between the system and
- its surroundings.
- A system may be selected so that the total energy of that system is constant.
- If the total energy of a system changes, that change will be equivalent to the energy transferred into or out of the system.
- Energy is conserved in all interactions.
- If the work done on a selected system is zero and there are no nonconservative interactions within the system, the total mechanical energy of the system is constant.

- If the work done on a selected system is nonzero, energy is transferred between the system and the environment.
- Power is the rate at which energy changes with respect to time, either by transfer into or out of a system or by conversion from one type to another within a system.
- Average power is the amount of energy being transferred or converted, divided by the time it took for that transfer or conversion to occur. $P_{avg} = \frac{\Delta E}{\Delta t}$
- Because work is the change in energy of an object or system due to a force, average power is the total work done, divided by the time during which that work was done. $P_{avg} = \frac{W}{\Delta t}$
- The instantaneous power delivered to an object by the component of a constant force parallel to the object's velocity can be described with the derived equation. $P_{inst} = Fvcos\theta$

Students will be able to...

- Create diagrams, tables, charts, or schematics to represent physical situations.
- Create quantitative graphs with appropriate scales and units, including plotting data.
- Create qualitative sketches of graphs that represent features of a model or the behavior of a physical system.
- Derive a symbolic expression from known quantities by selecting and following a logical mathematical pathway.
- Calculate or estimate an unknown quantity with units from known quantities, by selecting and following a logical computational pathway.
- Compare physical quantities between two or more scenarios or at different times and locations in a single scenario.
- Predict new values or factors of change of physical quantities using functional dependence between variables.
- Create experimental procedures that are appropriate for a given scientific question.
- Apply an appropriate law, definition, theoretical relationship, or model to make a claim.
- Justify or support a claim using evidence from experimental data, physical representations, or physical principles or laws.
- Define open and closed systems for everyday situations and apply conservation concepts for energy, charge, and linear momentum to those situations.
- Make predictions about the changes in kinetic energy of an object based on considerations of the direction of the net force on the object as the object moves.
- Use net force and velocity vectors to determine qualitatively whether the kinetic energy of an object would increase, decrease, or remain unchanged.
- Use force and velocity vectors to determine qualitatively or quantitatively the net force exerted on an object and qualitatively whether the kinetic energy of that object would increase, decrease, or remain unchanged.
- Apply mathematical routines to determine the change in kinetic energy of an object given the forces on the object and the displacement of the object.
- Calculate the total energy of a system and justify the mathematical routines used in the calculation of component types of energy within the system whose sum is the total energy
- Predict changes in the total energy of a system due to changes in position and speed of objects or frictional interactions within the system.
- Make predictions about the changes in the mechanical energy of a system when a component of an external force acts parallel or antiparallel to the direction of the displacement of the center of mass.
- Apply the concepts of conservation of energy and the work-energy theorem to determine qualitatively and/or quantitatively that work done on a two-object system in linear motion will

change the kinetic energy of the center of mass of the system, the potential energy of the systems, and/or the internal energy of the system.

- Translate between a representation of a single object, which can only have kinetic energy, and a system that includes the object, which may have both kinetic and potential energies.
- Calculate the expected behavior of a system using the object model (i.e., by ignoring changes in internal structure) to analyze a situation. Then, when the model fails, the student can justify the use of conservation of energy principles to calculate the change in internal energy due to changes in internal structure because the object is actually a system.
- Describe and make qualitative and/or quantitative predictions about everyday examples of systems with internal potential energy.
- Make quantitative calculations of the internal potential energy of a system from a description or diagram of that system.
- Apply mathematical reasoning to create a description of the internal potential energy of a system from a description or diagram of the objects and interactions in that system.
- Describe and make predictions about the internal energy of systems.
- Calculate changes in kinetic energy and potential energy of a system using information from
- representations of that system.
- Design an experiment and analyze data to determine how a force exerted on an object or system does work on the object or system as it moves through a distance.
- Design an experiment and analyze graphical data in which interpretations of the area under a force distance curve are needed to determine the work done on or by the object or system.
- Predict and calculate from graphical data the energy transfer to or work done on an object or system from information about a force exerted on the object or system through a distance.
- Make claims about the interaction between a system and its environment in which the environment exerts a force on the system, thus doing work on the system and changing the energy of the system (kinetic energy plus potential energy).
- Predict and calculate the energy transfer to (i.e., the work done on) an object or system from information about a force exerted on the object or system through a distance.

EVIDENCE OF LEARNING

Assessment:
What evidence will be collected and deemed acceptable to show that students truly "understand"?

- End of Unit Common Assessment - See folder for assessment links.
- Topic Quizzes
- AP Classroom Personal Progress Check
- Assigned Lab Reports
- Group Presentations

Learning Activities:
What differentiated learning experiences and instruction will enable all students to achieve the desired results?

- **Concept-Oriented Demonstration:** Release a low friction cart (mass m) from the top of a ramp, and have students time how long it takes to reach the bottom, as well as measure the release height (h) and track length (L). Have students calculate the cart's velocity using $v=L/t$, and then calculate mgh and $\frac{1}{2} mv^2$. The two speeds are different; discuss with students what incorrect assumptions lead to the difference in speeds.

- **Desktop Experiment Task:** Divide students into groups and give each group a spring-loaded ball launcher, scale, and meter stick. Ask students to determine the spring constant of the spring in the launcher.
- **Four-Square Problem Solving:** Have students create representations of scenarios related to work and conservation of energy. First square: Provide a description, in words, of an everyday situation (e.g., "a car goes downhill, speeding up even as the brakes are pressed") along with a diagram. Second square: Draw a free-body diagram with an arrow off to the side representing the object's displacement. Third square: Create energy bar charts (initial and final). Fourth square: For each force on the free-body diagram, state whether that force performs positive or negative work and what energy transformation that force is responsible for.
- **Construct an Argument:** Ask students to consider a cart that rolls from rest down a ramp and then around a vertical loop. Have students explain why it is the case, using energy and circular motion principles, that for the cart to complete the loop without falling out, the cart must be released at a height higher than the top of the loop.
- **Working Backward:** Put students in pairs. Have student A write a conservation of energy equation (either symbolically or with numbers and units plugged in). Then, have student B describe a situation that the equation could apply to, draw a diagram, and draw energy bar charts.

RESOURCES

Teacher Resources:
- AP Physics 1 Course and Exam Description
- AP Classroom Resources
- College Physics: Etkina et al 1st Edition
- Flipping Physics
- PhET - Online Physics simulations
- The Physics Classroom

Equipment Needed:
- Laptop and projector
- Calculators
- Chromebooks
- Laboratory equipment for demonstrations and labs

UNIT 4 OVERVIEW

Content Area: Science

Unit Title: Linear Momentum

Target Course/Grade Level: Advanced Placement Physics 1/Grades 11-12

Unit Summary: Unit 4 introduces students to the relationships between force, time, impulse, and linear momentum via calculations, data analysis, designing experiments, and making predictions. Students will learn how to use new models and representations to illustrate the law of conservation of linear momentum of objects and systems while gaining proficiency using previously studied representations. Using the law of conservation of linear momentum to analyze physical situations provides students with a more complete picture of forces and opportunities to revisit misconceptions surrounding Newton's third law. Students will also have the opportunity to make connections between momentum and kinetic energy of objects or systems and see under what conditions these quantities remain constant.

Approximate Length of Unit: 3 weeks

LEARNING TARGETS

NJ Student Learning Standards:

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

HS-PS2-2 Use mathematical representations to support the claim that the total momentum of a system of objects is conserved when there is no net force on the system.

HS-PS2-3 Apply scientific and engineering ideas to design, evaluate, and refine a device that minimizes the force on a macroscopic object during a collision.

HS-ETS1-1 Analyze a major global challenge to specify qualitative and quantitative criteria and constraints for solutions that account for societal needs and wants.

HS-ETS1-2 Design a solution to a complex real-world problem by breaking it down into smaller, more manageable problems that can be solved through engineering.

HS-ETS1-3 Evaluate a solution to a complex real-world problem based on prioritized criteria and trade-offs that account for a range of constraints, including cost, safety, reliability, and aesthetics, as well as possible social, cultural, and environmental impacts.

College Board Standards:

4.1.A Describe the linear momentum of an object or system.

4.2.A Describe the impulse delivered to an object or system.

4.2.B Describe the relationship between the impulse exerted on an object or a system and the change in momentum of the object or system.

4.3.A Describe the behavior of a system using conservation of linear momentum.

4.3.B Describe how the selection of a system determines whether the momentum of that system changes.

4.4.A Describe whether an interaction between objects is elastic or inelastic.

Career Readiness, Life Literacies, and Key Skills:

9.3.12.AC.1 Use vocabulary, symbols and formulas common to architecture and construction.

9.3.12.AC.6 Read, interpret and use technical drawings, documents and specifications to plan a project.

9.3.12.AC‑DES.1 Justify design solutions through the use of research documentation and analysis of data.

9.3.12.AC‑DES.2 Use effective communication skills and strategies (listening, speaking, reading, writing and graphic communications) to work with clients and colleagues.

9.3.12.ED.2 Demonstrate effective oral, written and multimedia communication in multiple formats and contexts.

9.3.12.ED‑ADM.1 Use research‑based practices to develop, communicate and enlist support for a vision of success for all learners.

9.3.12.ED‑ADM.2 Identify behaviors necessary for developing and sustaining a positive learning culture.

9.3.12.ED‑ADM.3 Create instructional programs to meet the learning organization's objectives.

9.3.12.ED‑ADM.4 Identify instructional practices that meet the learning organization's objectives.

9.3.12.ED‑ADM.5 Model leadership skills for personnel in order to improve the performance of the learning organization.

9.4.12.CI.1 Demonstrate the ability to reflect, analyze, and use creative skills and ideas

9.4.12.CT.1 Identify problem-solving strategies used in the development of an innovative product or practice

9.4.12.CT.2 Explain the potential benefits of collaborating to enhance critical thinking and problem solving

9.4.12.DC.1 Explain the beneficial and harmful effects that intellectual property laws can have on the creation and sharing of content

9.4.12.IML.3 Analyze data using tools and models to make valid and reliable claims, or to determine optimal design solutions

9.4.12.TL.2 Generate data using formula-based calculations in a spreadsheet and draw conclusions about the data.

Interdisciplinary Connections and Standards:

ELA

L.SS.11–12.1. Demonstrate command of the system and structure of the English language when writing or speaking.

L.KL.11–12.2. Apply knowledge of language to understand how language functions in different contexts, to make effective choices for meaning or style, and to comprehend more fully when reading or listening.

L.VL.11–12.3. Determine or clarify the meaning of unknown and multiple-meaning words and phrases based on grades 11–12 reading and content, including technical meanings, choosing flexibly from a range of strategies.

RI.CI.11–12.2. Determine two or more central ideas of an informational text and analyze how they are developed and refined over the course of a text, including how they interact and build on one another to provide a complex account or analysis; provide an objective summary of the text.

W.AW.11–12.1. Write arguments to support claims in an analysis of substantive topics or texts, using valid reasoning and relevant and sufficient evidence.

SL.PE.11–12.1. Initiate and participate effectively in a range of collaborative discussions (one-on-one, in groups, and teacher-led) with peers on grades 11–12 topics, texts, and issues, building on others' ideas and expressing their own clearly and persuasively.

SL.PI.11–12.4 Present information, findings and supporting evidence clearly, concisely, and logically. The content, organization, development, and style are appropriate to task, purpose, and audience.

Mathematics

MP.2 Reason abstractly and quantitatively.

MP.4 Model with mathematics.

N.Q.A.1 Use units as a way to understand problems and to guide the solution of multi-step problems; choose and interpret units consistently in formulas; choose and interpret the scale and the origin in graphs and data displays.

N.Q.A.2 Define appropriate quantities for the purpose of descriptive modeling.

N.Q.A.3 Choose a level of accuracy appropriate to limitations on measurement when reporting quantities.

A.SSE.A.1 Interpret expressions that represent a quantity in terms of its context.

A.SSE.B.3 Choose and produce an equivalent form of an expression to reveal and explain properties of the quantity represented by the expression.
A.CED.A.1 Create equations and inequalities in one variable and use them to solve problems.
A.CED.A.2 Create equations in two or more variables to represent relationships between quantities; graph equations on coordinate axes with labels and scales.
A.CED.A.4 Rearrange formulas to highlight a quantity of interest, using the same reasoning as in solving equations.
F.IF.C.7 Graph functions expressed symbolically and show key features of the graph, by hand in simple cases and using technology for more complicated cases.
S.ID.A.1 Represent data with plots on the real number line (dot plots, histograms, and box plots).

Unit Understandings:
Students will understand that…

- A force exerted on an object can change the momentum of the object.
- Interactions with other objects or systems can change the total linear momentum of a system.
- Certain quantities are conserved, in the sense that the changes of those quantities in a given system are always equal to the transfer of that quantity to or from the system by all possible interactions with other systems.

Unit Essential Questions:

- How is the physics definition of momentum different from how momentum is used to describe things in everyday life?
- Can a person on an elevator that breaks loose and falls to the ground avoid harm by jumping at the last second?
- Why will a water balloon break when thrown on the pavement, but not break if caught carefully?
- Why is it important that cars are designed to include crumple zones?

Knowledge and Skills:
Students will know...

- Linear momentum is defined by the equation $p = mv$.
- Momentum is a vector quantity and has the same direction as the velocity.
- Momentum can be used to analyze collisions and explosions.
    - A collision is a model for an interaction where the forces exerted between the involved objects in the system are much larger than the net external force exerted on those objects during the interaction.
    - As only the initial and final states of a collision are analyzed, the object model may be used to analyze collisions.
    - An explosion is a model for an interaction in which forces internal to the system move objects within that system apart.
- The rate of change of momentum is equal to the net external force exerted on an object or system. $\Sigma F = \frac{\Delta p}{\Delta t}$
- Impulse is defined as the product of the average force exerted on a system and the time interval during which that force is exerted on the system. $J = F_{avg}\Delta t$
- Impulse is a vector quantity and has the same direction as the net force exerted on the system.
- The impulse delivered to a system by a net external force is equal to the area under the curve of a graph of the net external force exerted on the system as a function of time.
- The net external force exerted on a system is equal to the slope of a graph of the momentum of the system as a function of time.

- Change in momentum is the difference between a system's final momentum and its initial momentum. $\Delta p = p - p_0$
- The impulse–momentum theorem relates the impulse exerted on a system and the system's change in momentum. $J = F_{avg}\Delta t = \Delta p$
- Newton's second law of motion is a direct result of the impulse–momentum theorem applied to systems with constant mass. $\Sigma F = \frac{\Delta p}{\Delta t} = m\frac{\Delta v}{\Delta t} = m\bar{a}$
- A collection of objects with individual momenta can be described as one system with one center-of-mass velocity.
  - For a collection of objects, the velocity of a system's center of mass can be calculated using the equation $\bar{v}_{cm} = \frac{\Sigma p_i}{\Sigma m_i} = \frac{\Sigma(m_i v_i)}{\Sigma m_i}$.
  - The velocity of a system's center of mass is constant in the absence of a net external force.
- The total momentum of a system is the sum of the momenta of the system's constituent parts.
- In the absence of net external forces, any change to the momentum of an object within a system must be balanced by an equivalent and opposite change of momentum elsewhere within the system. Any change to the momentum of a system is due to a transfer of momentum between the system and its surroundings.
  - The impulse exerted by one object on a second object is equal and opposite to the impulse exerted by the second object on the first. This is a direct result of Newton's third law.
  - A system may be selected so that the total momentum of that system is constant.
  - If the total momentum of a system changes, that change will be equivalent to the impulse exerted on the system. $J = \Delta p$
- Correct application of conservation of momentum can be used to determine the velocity of a system immediately before and immediately after collisions or explosions.
- Momentum is conserved in all interactions.
- If the net external force on the selected system is zero, the total momentum of the system is constant.
- If the net external force on the selected system is nonzero, momentum is transferred between the system and the environment.
- An elastic collision between objects is one in which the initial kinetic energy of the system is equal to the final kinetic energy of the system.
- In an elastic collision, the final kinetic energies of each of the objects within the system may be different from their initial kinetic energies.
- An inelastic collision between objects is one in which the total kinetic energy of the system decreases.
- In an inelastic collision, some of the initial kinetic energy is not restored to kinetic energy but is transformed by nonconservative forces into other forms of energy.
- In a perfectly inelastic collision, the objects stick together and move with the same velocity after the collision.

Students will be able to...

- Create diagrams,tables, charts, or schematics to represent physical situations.
- Create quantitative graphs with appropriate scales and units, including plotting data.
- Create qualitative sketches of graphs that represent features of a model or the behavior of a physical system.

- Derive a symbolic expression from known quantities by selecting and following a logical mathematical pathway.
- Calculate or estimate an unknown quantity with units from known quantities, by selecting and following a logical computational pathway.
- Compare physical quantities between two or more scenarios or at different times and locations in a single scenario.
- Predict new values or factors of change of physical quantities using functional dependence between variables.
- Create experimental procedures that are appropriate for a given scientific question.
- Apply an appropriate law, definition, theoretical relationship, or model to make a claim.
- Justify or support a claim using evidence from experimental data, physical representations, or physical principles or laws.
- Apply the principles of conservation of momentum and restoration of kinetic energy to reconcile a situation that appears to be isolated and elastic, but in which data indicate that linear momentum and kinetic energy are not the same after the interaction, by refining a scientific question to identify interactions that have not been considered. Students will be expected to solve qualitatively and/or quantitatively for one-dimensional situations and qualitatively in two-dimensional situations.
- Apply mathematical routines appropriately to problems involving elastic collisions in one dimension and justify the selection of those mathematical routines based on conservation of momentum and restoration of kinetic energy.
- Design an experimental test of an application of the principle of the conservation of linear momentum, predict an outcome of the experiment using the principle, analyze data generated by that experiment whose uncertainties are expressed numerically, and evaluate the match between the prediction and the outcome.
- Classify a given collision situation as elastic or inelastic, justify the selection of conservation of linear momentum and restoration of kinetic energy as the appropriate principles for analyzing an elastic collision, solve for missing variables, and calculate their values.
- Qualitatively predict, in terms of linear momentum and kinetic energy, how the outcome of a collision between two objects changes depending on whether the collision is elastic or inelastic.
- Predict the velocity of the center of mass of a system when there is no interaction outside of the system but there is an interaction within the system (i.e., the student simply recognizes that interactions within asystem do not affect the center-of-mass motion of the system and is able to determine that there is no external force).

EVIDENCE OF LEARNING

Assessment:
What evidence will be collected and deemed acceptable to show that students truly "understand"?

- End of Unit Common Assessment - See folder for assessment links.
- Topic Quizzes
- AP Classroom Personal Progress Check
- Assigned Lab Reports
- Group Presentations

Learning Activities:

What differentiated learning experiences and instruction will enable all students to achieve the desired results?

- **Conflicting Contentions:** Ask students to imagine a pitcher throwing a baseball and a catcher catching it and have them debate who exerted more force on the ball (no way to know), who applied greater impulse (same for both), and who did a greater magnitude of net work on the ball (same). Repeat this process for a pitcher throwing the baseball and a batter hitting it back at the same speed.
- **Desktop Experiment Task:** Connect a spring-loaded lanyard between a cart and a force sensor, with a motion sensor on the other side of the cart. Have students take force and motion versus time data as the lanyard contracts and pulls, accelerating the cart. Show students that impulse applied to the cart equals the cart's change in momentum.
- **Construct an Argument:** Have students use momentum bar charts to explain why a dart bouncing off a cart makes the cart move faster than the dart sticking to the cart, passing through the cart, or stopping and dropping after colliding with the cart.
- **Predict and Explain/Concept-Oriented Demonstration:** Have a cart crash into a force sensor set to its highest setting in three different ways: cart sticks to sensor, cart bounces off the sensor on its hard side, and cart bounces off the sensor with its spring side. Have students predict in which case more force is registered and explain why.
- **Desktop Experiment Task:** Have two carts with different masses collide in a nonstick collision. Record the carts with a phone camera from above, with a meterstick next to the track. Have students use a frame- by-frame review app to determine the cart's initial and final speeds, whether momentum was conserved, and whether the collision was elastic.

RESOURCES

Teacher Resources:

- AP Physics 1 Course and Exam Description
- AP Classroom Resources
- <u>College Physics</u>: Etkina et al 1st Edition
- Flipping Physics
- PhET - Online Physics simulations
- The Physics Classroom

Equipment Needed:

- Laptop and projector
- Calculators
- Chromebooks
- Laboratory equipment for demonstrations and labs

UNIT 5 OVERVIEW

Content Area: Science

Unit Title: Torque and Rotational Dynamics

Target Course/Grade Level: Advanced Placement Physics 1/Grades 11-12

Unit Summary: Unit 5 reinforces the Unit 2 ideas of force and linear motion by introducing students to their rotational analogs—torque and rotational motion. Although these topics present more complex scenarios, the tools of analysis remain the same. The content and models explored in the first four units of the course set the foundation for Units 5 and 6. During their study of torque and rotational motion, students will be introduced to different ways of modeling forces. Throughout Units 5 and 6, students will compare and connect their understanding of linear and rotational motion, dynamics, energy, and momentum to develop holistic models to evaluate physical phenomena.

Approximate Length of Unit: 4 weeks

LEARNING TARGETS

NJ Student Learning Standards:
HS-PS2-1 Analyze data to support the claim that Newton's second law of motion describes the mathematical relationship among the net force on a macroscopic object, its mass, and its acceleration.
HS-ETS1-2 Design a solution to a complex real-world problem by breaking it down into smaller, more manageable problems that can be solved through engineering.
HS-ETS1-3 Evaluate a solution to a complex real-world problem based on prioritized criteria and trade-offs that account for a range of constraints, including cost, safety, reliability, and aesthetics, as well as possible social, cultural, and environmental impacts.

College Board Standards:
5.1.A Describe the rotation of a system with respect to time using angular displacement, angular velocity, and angular acceleration.
5.2.A Describe the linear motion of a point on a rotating rigid system that corresponds to the rotational motion of that point, and vice versa.
5.3.A Identify the torques exerted on a rigid system.
5.3.B Describe the torques exerted on a rigid system.
5.4.A Describe the rotational inertia of a rigid system relative to a given axis of rotation.
5.4.B Describe the rotational inertia of a rigid system rotating about an axis that does not pass through the system's center of mass.
5.5.A Describe the conditions under which a system's angular velocity remains constant.
5.6.A Describe the conditions under which a system's angular velocity changes.

Career Readiness, Life Literacies, and Key Skills:
9.3.12.AC.1 Use vocabulary, symbols and formulas common to architecture and construction.
9.3.12.AC.6 Read, interpret and use technical drawings, documents and specifications to plan a project.

9.3.12.AC‑DES.1 Justify design solutions through the use of research documentation and analysis of data.
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Mathematics
MP.2 Reason abstractly and quantitatively.
MP.4 Model with mathematics.
N.Q.A.1 Use units as a way to understand problems and to guide the solution of multi-step problems; choose and interpret units consistently in formulas; choose and interpret the scale and the origin in graphs and data displays.
N.Q.A.2 Define appropriate quantities for the purpose of descriptive modeling.
N.Q.A.3 Choose a level of accuracy appropriate to limitations on measurement when reporting quantities.
A.SSE.A.1 Interpret expressions that represent a quantity in terms of its context.
A.SSE.B.3 Choose and produce an equivalent form of an expression to reveal and explain properties of the quantity represented by the expression.
A.CED.A.1 Create equations and inequalities in one variable and use them to solve problems.

A.CED.A.2 Create equations in two or more variables to represent relationships between quantities; graph equations on coordinate axes with labels and scales.
A.CED.A.4 Rearrange formulas to highlight a quantity of interest, using the same reasoning as in solving equations.
F.IF.C.7 Graph functions expressed symbolically and show key features of the graph, by hand in simple cases and using technology for more complicated cases.
S.ID.A.1 Represent data with plots on the real number line (dot plots, histograms, and box plots).

Unit Understandings:
Students will understand that…

- A force exerted on an object can cause a torque on that object.
- Net torque causes an angular acceleration on a system such that $\alpha = \frac{\Sigma\tau}{I}$

Unit Essential Questions:

- Why does it matter where a door handle is placed?
- Why are long wrenches more effective?
- What do mobiles have in common with the Grand Canyon Skywalk?
- Why does a tightrope walker use a long pole?

Knowledge and Skills:
Students will know...

- Angular displacement is the measurement of the angle, in radians, through which a point on a rigid system rotates about a specified axis. $\Delta\theta = \theta - \theta_0$
    - A rigid system is one that holds its shape but in which different points on the system move in different directions during rotation. A rigid system cannot be modeled as an object.
    - One direction of angular displacement about an axis of rotation—clockwise or counterclockwise—is typically indicated as mathematically positive, with the other direction becoming mathematically negative.
    - If the rotation of a system about an axis may be well described using the motion of the system's center of mass, the system may be treated as a single object. For example, the rotation of Earth about its axis may be considered negligible when considering the revolution of Earth about the center of mass of the Earth–Sun system.
- Average angular velocity is the average rate at which angular position changes with respect to time. $\omega_{avg} = \frac{\Delta\theta}{\Delta t}$
- Average angular acceleration is the average rate at which the angular velocity changes with respect to time. $\alpha_{avg} = \frac{\Delta\omega}{\Delta t}$
- Angular displacement, angular velocity, and angular acceleration around one axis are analogous to linear displacement, velocity, and acceleration in one dimension and demonstrate the same mathematical relationships.
    - For constant angular acceleration, the mathematical relationships between angular displacement, angular velocity, and angular acceleration can be described with the following equations:
      $\omega = \omega_o + \alpha t$
      $\theta = \theta_o + \omega_o t + \frac{1}{2}\alpha t^2$
      $\omega^2 = \omega_o^2 + 2\alpha(\theta - \theta_o)$

- Graphs of angular displacement, angular velocity, and angular acceleration as functions of time can be used to find the relationships between those quantities.

- For a point at a distance r from a fixed axis of rotation, the linear distance traveled by the point as the system rotates through an angle $\Delta\theta$ is given by the equation $\Delta s = r\Delta\theta$.
- Derived relationships of linear velocity and of the tangential component of acceleration to their respective angular quantities are given by the following equations:
  $s = r\theta$
  $v = r\omega$
  $a = r\alpha$
- For a rigid system, all points within that system have the same angular velocity and angular acceleration.
- Torque results only from the force component perpendicular to the position vector from the axis of rotation to the point of application of the force.
- The lever arm is the perpendicular distance from the axis of rotation to the line of action of the exerted force.
- Torques can be described using force diagrams.
  - Force diagrams are similar to free-body diagrams and are used to analyze the torques exerted on a rigid system.
  - Similar to free-body diagrams, force diagrams represent the relative magnitude and direction of the forces exerted on a rigid system. Force diagrams also depict the location at which those forces are exerted relative to the axis of rotation.
- The magnitude of the torque exerted on a rigid system by a force is described by the following equation, where θ is the angle between the force vector and the position vector from the axis of rotation to the point of application of the force. $\tau = rF_{\perp} = rFsin\theta$
- Rotational inertia measures a rigid system's resistance to changes in rotation and is related to the mass of the system and the distribution of that mass relative to the axis of rotation.
- The rotational inertia of an object rotating a perpendicular distance r from an axis is described by the equation $I = mr^2$
- The total rotational inertia of a collection of objects about an axis is the sum of the rotational inertias of each object about that axis: $I_{tot} = \sum_i I_i = \sum_i mr^2$
- A rigid system's rotational inertia in a given plane is at a minimum when the rotational axis passes through the system's center of mass.
- The parallel axis theorem uses the following equation to relate the rotational inertia of a rigid system about any axis that is parallel to an axis through its center of mass: $I' = I_{cm} + Md^2$
- A system may exhibit rotational equilibrium (constant angular velocity) without being in translational equilibrium, and vice versa.
  - Free-body and force diagrams describe the nature of the forces and torques exerted on an object or rigid system.
  - Rotational equilibrium is a configuration of torques such that the net torque exerted on the system is zero. $\Sigma\tau_i = 0$
  - The rotational analog of Newton's first law is that a system will have a constant angular velocity only if the net torque exerted on the system is zero.
- A rotational corollary to Newton's second law states that if the torques exerted on a rigid system are not balanced, the system's angular velocity must be changing.
- Angular velocity changes when the net torque exerted on the object or system is not equal to zero.

- The rate at which the angular velocity of a rigid system changes is directly proportional to the net torque exerted on the rigid system and is in the same direction. The angular acceleration of the rigid system is inversely proportional to the rotational inertia of the rigid system. $\alpha_{sys} = \frac{\Sigma\tau}{I_{sys}}$
- To fully describe a rotating rigid system, linear and rotational analyses may need to be performed independently.

Students will be able to...

- Create diagrams, tables, charts, or schematics to represent physical situations.
- Create quantitative graphs with appropriate scales and units, including plotting data.
- Create qualitative sketches of graphs that represent features of a model or the behavior of a physical system.
- Derive a symbolic expression from known quantities by selecting and following a logical mathematical pathway.
- Calculate or estimate an unknown quantity with units from known quantities, by selecting and following a logical computational pathway.
- Compare physical quantities between two or more scenarios or at different times and locations in a single scenario.
- Predict new values or factors of change of physical quantities using functional dependence between variables.
- Create experimental procedures that are appropriate for a given scientific question.
- Apply an appropriate law, definition, theoretical relationship, or model to make a claim.
- Justify or support a claim using evidence from experimental data, physical representations, or physical principles or laws.
- Predict the behavior of rotational collision situations by the same processes that are used to analyze linear collision situations using an analogy between impulse and change of linear momentum and angular impulse and change of angular momentum.
- In an unfamiliar context or using representations beyond equations, justify the selection of a mathematical routine to solve for the change in angular momentum of an object caused by torques exerted on the object.
- Plan data-collection and analysis strategies designed to test the relationship between torques exerted on an object and the change in angular momentum of that object.
- Compare the torques on an object caused by various forces.
- Estimate the torque on an object caused by various forces in comparison with other situations.
- Design an experiment and analyze data testing a question about torques in a balanced rigid system.
- Calculate torques on a two-dimensional system in static equilibrium by examining a representation or model (such as a diagram or physical construction).
- Make predictions about the change in the angular velocity about an axis for an object when forces exerted on the object cause a torque about that axis.
- Plan data-collection and analysis strategies designed to test the relationship between a torque exerted on an object and the change in angular velocity of that object about an axis.
- Predict the behavior of rotational collision situations by the same processes that are used to analyze linear collision situations using an analogy between impulse and change of linear momentum and angular impulse and change of angular momentum.
- In an unfamiliar context or using representations beyond equations, justify the selection of a mathematical routine to solve for the change in angular momentum of an object caused by torques exerted on the object.
- Plan data-collection and analysis strategies designed to test the relationship between torques exerted on an object and the change in angular momentum of that object.

- Describe a representation and use it to analyze a situation in which several forces exerted on a rotating system of rigidly connected objects change the angular velocity and angular momentum of the system.
- Plan data-collection strategies designed to establish that torque, angular velocity, angular acceleration, and angular momentum can be predicted accurately when the variables are treated as being clockwise or counterclockwise with respect to a well-defined axis of rotation, and refine the research question based on the examination of data.
- Describe a model of a rotational system and use that model to analyze a situation in which angular momentum changes due to interaction with other objects or systems.
- Plan a data-collection and analysis strategy to determine the change in angular momentum of a system and relate it to interactions with other objects and systems.
- Use appropriate mathematical routines to calculate values for initial or final angular momentum, or change in angular momentum of a system, or average torque or time during which the torque is exerted in analyzing a situation involving torque and angular momentum.
- Plan a data-collection strategy designed to test the relationship between the change in angular momentum of a system and the product of the average torque applied to the system and the time interval during which the torque is exerted.
- Make qualitative predictions about the angular momentum of a system for a situation in which there is no net external torque.
- Make calculations of quantities related to the angular momentum of a system when the net external torque on the system is zero.
- Describe or calculate the angular momentum and rotational inertia of a system in terms of the locations and velocities of objects that make up the system. Use qualitative reasoning with compound objects and perform calculations with a fixed set of extended objects and point masses.

EVIDENCE OF LEARNING

Assessment:
What evidence will be collected and deemed acceptable to show that students truly "understand"?

- End of Unit Common Assessment - See folder for assessment links.
- Topic Quizzes
- AP Classroom Personal Progress Check
- Assigned Lab Reports
- Group Presentations

Learning Activities:
What differentiated learning experiences and instruction will enable all students to achieve the desired results?

- **Predict and Explain:** Spin a bike wheel (preferably with the tire removed so that it will roll on its metal rims) and release it from rest on the floor or a long table. Have students predict what will happen to the wheel's linear velocity (it will increase) and its angular velocity (it will decrease) as the wheel "peels out." Then, explain why this happens using a force diagram.
- **Create a Plan:** Have students design a walkway (of given mass) that is to be suspended from a ceiling. Have them determine the amount of force the two supports (one on each end) must be able to provide as a person (of given mass) walks across the walkway.
- **Desktop Experiment Task:** Take a hard-boiled egg and a raw egg without identifying marks or labels. Give students the task to determine which one is which. To give them a starting point, have students place the eggs on a level surface and give each egg a spin. Once each egg is

spinning lightly, have students touch each egg on the top to stop it. Students should conclude that the raw egg is noticeably more difficult to start or stop.

- **Desktop Experiment Task:** Have students allow a yo-yo to fall and unroll. Then, have them use a meter stick and stopwatch to determine its downward acceleration. Next, have them measure its mass and the radius of its axle and use that information to determine the yo-yo's rotational inertia using rotational dynamics.
- **Create a Plan:** Have students complete the necessary research to determine the rotational inertia of a human body in different configurations (e.g., arms outstretched, arms pulled in). Then, obtain footage of an ice skater spinning and pulling in their arms. Have students analyze the footage to see if angular momentum is conserved.
- **Desktop Experiment Task:** Set a meter stick on a pivot that is not set at the center of mass of the meterstick. Hang two objects off the meter stick so that the two object–meterstick system is in equilibrium. Have students observe and collect data to allow them to determine the mass of the meterstick.

RESOURCES

Teacher Resources:

- AP Physics 1 Course and Exam Description
- AP Classroom Resources
- College Physics: Etkina et al 1st Edition
- Flipping Physics
- PhET - Online Physics simulations
- The Physics Classroom

Equipment Needed:

- Laptop and projector
- Calculators
- Chromebooks
- Laboratory equipment for demonstrations and labs

UNIT 6 OVERVIEW

Content Area: Science

Unit Title: Energy and Momentum of Rotating Systems

Target Course/Grade Level: Advanced Placement Physics 1/Grades 11-12

Unit Summary: In Unit 6, students will apply their knowledge of energy and momentum to rotating systems. Similar to the approach used for translational energy and momentum concepts in Units 3 and 4, it is important that students have conceptual understanding of how angular momentum and rotational energy change due to external torque(s) on a system. Additionally, articulating the conditions under which the rotational energy and/or angular momentum of a system remains constant is foundational to working through more complex scenarios. Students will use the content and skills presented in both Units 5 and 6 to further study the motion of orbiting satellites and rolling without slipping in this unit.

Approximate Length of Unit: 3 weeks

LEARNING TARGETS

NJ Student Learning Standards:

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

HS-PS2-2 Use mathematical representations to support the claim that the total momentum of a system of objects is conserved when there is no net force on the system.

HS-PS2-3 Apply scientific and engineering ideas to design, evaluate, and refine a device that minimizes the force on a macroscopic object during a collision.

HS-PS2-4 Use mathematical representations of Newton's Law of Gravitation and Coulomb's Law to describe and predict the gravitational and electrostatic forces between objects.

HS-PS3-1 Create a computational model to calculate the change in the energy of one component in a system when the change in energy of the other component(s) and energy flows in and out of the system are known.

HS-PS3-2 Develop and use models to illustrate that energy at the macroscopic scale can be accounted for as a combination of energy associated with the motions of particles (objects) and energy associated with the relative position of particles (objects).

HS-PS3-3 Design, build, and refine a device that works within given constraints to convert one form of energy into another form of energy.

HS-ETS1-2 Design a solution to a complex real-world problem by breaking it down into smaller, more manageable problems that can be solved through engineering.

HS-ETS1-3 Evaluate a solution to a complex real-world problem based on prioritized criteria and trade-offs that account for a range of constraints, including cost, safety, reliability, and aesthetics, as well as possible social, cultural, and environmental impacts.

HS-ETS1-4 Use a computer simulation to model the impact of proposed solutions to a complex real-world problem with numerous criteria and constraints on interactions within and between systems relevant to the problem.

College Board Standards:
6.1.A Describe the rotational kinetic energy of a rigid system in terms of the rotational inertia and angular velocity of that rigid system.
6.2.A Describe the work done on a rigid system by a given torque or collection of torques.
6.3.A Describe the angular momentum of an object or rigid system.
6.3.B Describe the angular impulse delivered to an object or rigid system by a torque.
6.3.C Relate the change in angular momentum of an object or rigid system to the angular impulse given to that object or rigid system.
6.4.A Describe the behavior of a system using conservation of angular momentum.
6.4.B Describe how the selection of a system determines whether the angular momentum of that system changes.
6.5.A Describe the kinetic energy of a system that has translational and rotational motion.
6.5.B Describe the motion of a system that is rolling without slipping.
6.5.C Describe the motion of a system that is rolling while slipping.
6.6.A Describe the motions of a system consisting of two objects interacting only via gravitational forces.

Career Readiness, Life Literacies, and Key Skills:
9.3.12.AC.1 Use vocabulary, symbols and formulas common to architecture and construction.
9.3.12.AC.6 Read, interpret and use technical drawings, documents and specifications to plan a project.
9.3.12.AC‑DES.1 Justify design solutions through the use of research documentation and analysis of data.
9.3.12.AC‑DES.2 Use effective communication skills and strategies (listening, speaking, reading, writing and graphic communications) to work with clients and colleagues.
9.3.12.ED.2 Demonstrate effective oral, written and multimedia communication in multiple formats and contexts.
9.3.12.ED‑ADM.1 Use research‑based practices to develop, communicate and enlist support for a vision of success for all learners.
9.3.12.ED‑ADM.2 Identify behaviors necessary for developing and sustaining a positive learning culture.
9.3.12.ED‑ADM.3 Create instructional programs to meet the learning organization’s objectives.
9.3.12.ED‑ADM.4 Identify instructional practices that meet the learning organization’s objectives.
9.3.12.ED‑ADM.5 Model leadership skills for personnel in order to improve the performance of the learning organization.
9.4.12.CI.1 Demonstrate the ability to reflect, analyze, and use creative skills and ideas
9.4.12.CT.1 Identify problem-solving strategies used in the development of an innovative product or practice
9.4.12.CT.2 Explain the potential benefits of collaborating to enhance critical thinking and problem solving
9.4.12.DC.1 Explain the beneficial and harmful effects that intellectual property laws can have on the creation and sharing of content
9.4.12.IML.3 Analyze data using tools and models to make valid and reliable claims, or to determine optimal design solutions
9.4.12.TL.2 Generate data using formula-based calculations in a spreadsheet and draw conclusions about the data.

Interdisciplinary Connections and Standards:
ELA
L.SS.11–12.1. Demonstrate command of the system and structure of the English language when writing or speaking.
L.KL.11–12.2. Apply knowledge of language to understand how language functions in different contexts, to make effective choices for meaning or style, and to comprehend more fully when reading or listening.
L.VL.11–12.3. Determine or clarify the meaning of unknown and multiple-meaning words and phrases based on grades 11–12 reading and content, including technical meanings, choosing flexibly from a range of strategies.
RI.CI.11–12.2. Determine two or more central ideas of an informational text and analyze how they are developed and refined over the course of a text, including how they interact and build on one another to provide a complex account or analysis; provide an objective summary of the text.

W.AW.11–12.1. Write arguments to support claims in an analysis of substantive topics or texts, using valid reasoning and relevant and sufficient evidence.

SL.PE.11–12.1. Initiate and participate effectively in a range of collaborative discussions (one-on-one, in groups, and teacher-led) with peers on grades 11–12 topics, texts, and issues, building on others' ideas and expressing their own clearly and persuasively.

SL.PI.11–12.4 Present information, findings and supporting evidence clearly, concisely, and logically. The content, organization, development, and style are appropriate to task, purpose, and audience.

Mathematics

MP.2 Reason abstractly and quantitatively.

MP.4 Model with mathematics.

N.Q.A.1 Use units as a way to understand problems and to guide the solution of multi-step problems; choose and interpret units consistently in formulas; choose and interpret the scale and the origin in graphs and data displays.

N.Q.A.2 Define appropriate quantities for the purpose of descriptive modeling.

N.Q.A.3 Choose a level of accuracy appropriate to limitations on measurement when reporting quantities.

A.SSE.A.1 Interpret expressions that represent a quantity in terms of its context.

A.SSE.B.3 Choose and produce an equivalent form of an expression to reveal and explain properties of the quantity represented by the expression.

A.CED.A.1 Create equations and inequalities in one variable and use them to solve problems.

A.CED.A.2 Create equations in two or more variables to represent relationships between quantities; graph equations on coordinate axes with labels and scales.

A.CED.A.4 Rearrange formulas to highlight a quantity of interest, using the same reasoning as in solving equations.

F.IF.C.7 Graph functions expressed symbolically and show key features of the graph, by hand in simple cases and using technology for more complicated cases.

S.ID.A.1 Represent data with plots on the real number line (dot plots, histograms, and box plots).

Unit Understandings:

Students will understand that…

- A net torque exerted on a system by other objects or systems will change the angular momentum of the system.
- The angular momentum of a system is conserved.

Unit Essential Questions:

- What keeps a bicycle balanced?
- Why do planets move faster when they travel closer to the sun?
- What do satellites and projectiles have in common?
- What do ice skaters do with their arms when they want to spin faster? Why?

Knowledge and Skills:

Students will know...

- The rotational kinetic energy of an object or rigid system is related to the rotational inertia and angular velocity of the rigid system and is given by the equation $K = \frac{1}{2}I\omega^2$.
  - The rotational inertia of an object about a fixed axis can be used to show that the rotational kinetic energy of that object is equivalent to its translational kinetic energy, which is its total kinetic energy.
  - The total kinetic energy of a rigid system is the sum of its rotational kinetic energy due to its rotation about its center of mass and the translational kinetic energy due to the linear motion of its center of mass.

- A rigid system can have rotational kinetic energy while its center of mass is at rest due to the individual points within the rigid system having linear speed and, therefore, kinetic energy.
- Rotational kinetic energy is a scalar quantity.
- A torque can transfer energy into or out of an object or rigid system if the torque is exerted over an angular displacement.
- The amount of work done on a rigid system by a torque is related to the magnitude of that torque and the angular displacement through which the rigid system rotates during the interval in which that torque is exerted. $W = \tau\Delta\theta$
- Work done on a rigid system by a given torque can be found from the area under the curve of a graph of torque as a function of angular position.
- The magnitude of the angular momentum of a rigid system about a specific axis can be described with the equation $L = I\omega$.
- The magnitude of the angular momentum of an object about a given point is $L = rmv\sin\theta$
  - The selection of the axis about which an object is considered to rotate influences the determination of the angular momentum of that object.
  - The measured angular momentum of an object traveling in a straight line depends on the distance between the reference point and the object, the mass of the object, the speed of the object, and the angle between the radial distance and the velocity of the object.
- Angular impulse is defined as the product of the torque exerted on an object or rigid system and the time interval during which the torque is exerted. angular impulse = $\tau\Delta t$
- Angular impulse has the same direction as the torque exerted on the object or system.
- The angular impulse delivered to an object or rigid system by a torque can be found from the area under the curve of a graph of the torque as a function of time.
- The magnitude of the change in angular momentum can be described by comparing the magnitudes of the final and initial angular momenta of the object or rigid system: $\Delta L = L - L_0$
- A rotational form of the impulse–momentum theorem relates the angular impulse delivered to an object or rigid system and the change in angular momentum of that object or rigid system.
  - The angular impulse exerted on an object or rigid system is equal to the change in angular momentum of that object or rigid system. $\Delta L = \tau\Delta t$
  - The rotational form of the impulse– momentum theorem is a direct result of the rotational form of Newton's second law of motion for cases in which rotational inertia is constant: $\Sigma\tau = \frac{\Delta L}{\Delta t} = I\frac{\Delta\omega}{\Delta t} = I\overline{\alpha}$
- The net torque exerted on an object is equal to the slope of the graph of the angular momentum of an object as a function of time.
- The angular impulse delivered to an object is equal to the area under the curve of a graph of the net external torque exerted on an object as a function of time.
- The total angular momentum of a system about a rotational axis is the sum of the angular momenta of the system's constituent parts about that axis.
- Any change to a system's angular momentum must be due to an interaction between the system and its surroundings.
  - The angular impulse exerted by one object or system on a second object or system is equal and opposite to the angular impulse exerted by the second object or system on
  - the first. This is a direct result of Newton's third law.
  - A system may be selected so that the total angular momentum of that system is constant.
  - The angular speed of a nonrigid system may change without the angular momentum of the system changing if the system changes shape by moving mass closer to or further from the rotational axis.
  - If the total angular momentum of a system changes, that change will be equivalent to the angular impulse exerted on the system.
- Angular momentum is conserved in all interactions.

- If the net external torque exerted on a selected object or rigid system is zero, the total angular momentum of that system is constant.
- If the net external torque exerted on a selected object or rigid system is nonzero, angular momentum is transferred between the system and the environment.
- The total kinetic energy of a system is the sum of the system's translational and rotational kinetic energies. $K_{tot} = K_{trans} + K_{rot}$
- While rolling without slipping, the translational motion of a system's center of mass is related to the rotational motion of the system itself with the equations:
  $\Delta x_{cm} = r\Delta\theta$
  $v_{cm} = r\omega$
  $a_{cm} = r\alpha$
- For ideal cases, rolling without slipping implies that the frictional force does not dissipate any energy from the rolling system.
- When slipping, the motion of a system's center of mass and the system's rotational motion cannot be directly related.
- When a rotating system is slipping relative to another surface, the point of application of the force of kinetic friction exerted on the system moves with respect to the surface, so the force of kinetic friction will dissipate energy from the system.
- In a system consisting only of a massive central object and an orbiting satellite with mass that is negligible in comparison to the central object's mass, the motion of the central object itself is negligible.
- The motion of satellites in orbits is constrained by conservation laws.
  - In circular orbits, the system's total mechanical energy, the system's gravitational potential energy, and the satellite's angular momentum and kinetic energy are constant.
  - In elliptical orbits, the system's total mechanical energy and the satellite's angular momentum are constant, but the system's gravitational potential energy and the satellite's kinetic energy can each change.
  - The gravitational potential energy of a system consisting of a satellite and a massive central object is defined to be zero when the satellite is an infinite distance from the central object. $U_g = - G\frac{m_1 m_2}{r}$
- The escape velocity of a satellite is the satellite's velocity such that the mechanical energy of the satellite–central-object system is equal to zero.
  - When the only force exerted on a satellite is gravity from a central object, a satellite that reaches escape velocity will move away from the central body until its speed reaches zero at an infinite distance from the central body.
  - The escape velocity of a satellite from a central body of mass M can be derived using conservation of energy laws. $v_{esc} = \sqrt{\frac{2GM}{r}}$

Students will be able to...

- Create diagrams, tables, charts, or schematics to represent physical situations.
- Create quantitative graphs with appropriate scales and units, including plotting data.
- Create qualitative sketches of graphs that represent features of a model or the behavior of a physical system.
- Derive a symbolic expression from known quantities by selecting and following a logical mathematical pathway.
- Calculate or estimate an unknown quantity with units from known quantities, by selecting and following a logical computational pathway.

- Compare physical quantities between two or more scenarios or at different times and locations in a single scenario.
- Predict new values or factors of change of physical quantities using functional dependence between variables.
- Create experimental procedures that are appropriate for a given scientific question.
- Apply an appropriate law, definition, theoretical relationship, or model to make a claim.
- Justify or support a claim using evidence from experimental data, physical representations, or physical principles or laws.
- Articulate situations when the gravitational force is the dominant force and when the electromagnetic, weak, and strong forces can be ignored.
- Use Newton's law of gravitation to calculate the gravitational force that two objects exert on each other and use that force in contexts other than orbital motion.
- Use Newton's law of gravitation to calculate the gravitational force between two objects and use that force in contexts involving orbital motion.
- Connect the concepts of gravitational force and electric force to compare similarities and differences between the forces.
- Apply $F = mg$ to calculate the gravitational force on an object with mass m in a gravitational field of strength g in the context of the effects of a net force on objects and systems.
- Apply $g = G\,m/r^2$ to calculate the gravitational field due to an object with mass m, where the field is a vector directed toward the center of the object of mass m.
- Approximate a numerical value of the gravitational field (g) near the surface of an object from its radius and mass relative to those of Earth or other reference objects.
- Design a plan for collecting data to measure gravitational mass and to measure inertial mass and to distinguish between the two experiments.
- Evaluate, using given data, whether all the forces on a system or whether all the parts of a system have been identified.

EVIDENCE OF LEARNING

Assessment:

What evidence will be collected and deemed acceptable to show that students truly "understand"?

- End of Unit Common Assessment - See folder for assessment links.
- Topic Quizzes
- AP Classroom Personal Progress Check
- Assigned Lab Reports
- Group Presentations

Learning Activities:

What differentiated learning experiences and instruction will enable all students to achieve the desired results?

- **Desktop Experiment Task:**Have students release a yo-yo from rest, calculate its acceleration from distance and time measurements, and then determine the yo-yo's rotational inertia (which requires the yo-yo's mass and the radius at which the string connects to the yo-yo). Next, have them roll the yo-yo down a ramp and use distance and time data to construct a conservation of energy equation that can be solved for the yo-yo's rotational inertia.
- **Predict and Explain:** Allow students to play with a set of fidget spinners. Ask them to explain why it is difficult to change the plane of rotation of a spinner while it is rotating.

- **Concept-Oriented Demonstration:** Obtain a ring and a disk of equal mass and radius and load up a low-friction cart with weights to make it the same mass. "Race" the three objects from rest down identical inclines to show students the cart wins, then the disk, and then the ring. Have students explain why the objects win in this order, with forces and then with energy.
- **Ranking Tasks:** Present students with the following scenario and its accompanying three cases: A wheel rolls down an incline from rest and across a flat surface. Case 1: Tracks are rough enough that there is no slipping. Case 2: Tracks have some friction, but there is slipping. Case 3: Tracks have negligible friction. Have students rank translational kinetic energies at the end, rotational kinetic energies at the end, and total mechanical energies of the wheel at the end as three separate tasks.
  $(K_{T3} > K_{T2} > K_{T1}), (K_{R1} > K_{R2} > K_{R3}), (E_1 = E_3 > E_2)$
- **Construct an Argument:** Have students roll a hoop and a disk (of equal mass and radius) down identical ramps. Then have them explain why the disk reached the bottom in less time using energy bar charts and to-scale free-body diagrams.

RESOURCES

Teacher Resources:

- AP Physics 1 Course and Exam Description
- AP Classroom Resources
- College Physics: Etkina et al 1st Edition
- Flipping Physics
- PhET - Online Physics simulations
- The Physics Classroom

Equipment Needed:

- Laptop and projector
- Calculators
- Chromebooks
- Laboratory equipment for demonstrations and labs

UNIT 7 OVERVIEW

Content Area: Science

Unit Title: Oscillations

Target Course/Grade Level: Advanced Placement Physics 1/Grades 11-12

Unit Summary: In Unit 7, students will apply previously-encountered models and methods of analysis to simple harmonic motion. They will also be reminded that, even in new situations, the fundamental laws of physics remain the same. Because this unit is the first in which students possess all the tools of force, energy, and momentum conservation—such as energy bar charts, free-body diagrams, and momentum diagrams—scaffolding lessons will enhance student understanding of fundamental physics principles and their limitations, as they relate to oscillating systems. Students will also use the skills and knowledge they have gained to make and justify claims, as well as connect new concepts with those learned in previous topics.

Approximate Length of Unit: 2 weeks

LEARNING TARGETS

NJ Student Learning Standards:

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

HS-PS2-2 Use mathematical representations to support the claim that the total momentum of a system of objects is conserved when there is no net force on the system.

HS-PS3-1 Create a computational model to calculate the change in the energy of one component in a system when the change in energy of the other component(s) and energy flows in and out of the system are known.

HS-PS3-2 Develop and use models to illustrate that energy at the macroscopic scale can be accounted for as a combination of energy associated with the motions of particles (objects) and energy associated with the relative position of particles (objects).

HS-PS3-3 Design, build, and refine a device that works within given constraints to convert one form of energy into another form of energy.

HS-ETS1-2 Design a solution to a complex real-world problem by breaking it down into smaller, more manageable problems that can be solved through engineering.

HS-ETS1-3 Evaluate a solution to a complex real-world problem based on prioritized criteria and trade-offs that account for a range of constraints, including cost, safety, reliability, and aesthetics, as well as possible social, cultural, and environmental impacts.

College Board Standards:

7.1.A Describe simple harmonic motion.

7.2.A Describe the frequency and period of an object exhibiting SHM.

7.3.A Describe the displacement, velocity, and acceleration of an object exhibiting SHM.

7.4.A Describe the mechanical energy of a system exhibiting SHM.

Career Readiness, Life Literacies, and Key Skills:
9.3.12.AC.1 Use vocabulary, symbols and formulas common to architecture and construction.
9.3.12.AC.6 Read, interpret and use technical drawings, documents and specifications to plan a project.
9.3.12.AC‐DES.1 Justify design solutions through the use of research documentation and analysis of data.
9.3.12.AC‐DES.2 Use effective communication skills and strategies (listening, speaking, reading, writing and graphic communications) to work with clients and colleagues.
9.3.12.ED.2 Demonstrate effective oral, written and multimedia communication in multiple formats and contexts.
9.3.12.ED‐ADM.1 Use research‐based practices to develop, communicate and enlist support for a vision of success for all learners.
9.3.12.ED‐ADM.2 Identify behaviors necessary for developing and sustaining a positive learning culture.
9.3.12.ED‐ADM.3 Create instructional programs to meet the learning organization's objectives.
9.3.12.ED‐ADM.4 Identify instructional practices that meet the learning organization's objectives.
9.3.12.ED‐ADM.5 Model leadership skills for personnel in order to improve the performance of the learning organization.
9.4.12.CI.1 Demonstrate the ability to reflect, analyze, and use creative skills and ideas
9.4.12.CT.1 Identify problem-solving strategies used in the development of an innovative product or practice
9.4.12.CT.2 Explain the potential benefits of collaborating to enhance critical thinking and problem solving
9.4.12.DC.1 Explain the beneficial and harmful effects that intellectual property laws can have on the creation and sharing of content
9.4.12.IML.3 Analyze data using tools and models to make valid and reliable claims, or to determine optimal design solutions
9.4.12.TL.2 Generate data using formula-based calculations in a spreadsheet and draw conclusions about the data.

Interdisciplinary Connections and Standards:
ELA
L.SS.11–12.1. Demonstrate command of the system and structure of the English language when writing or speaking.
L.KL.11–12.2. Apply knowledge of language to understand how language functions in different contexts, to make effective choices for meaning or style, and to comprehend more fully when reading or listening.
L.VL.11–12.3. Determine or clarify the meaning of unknown and multiple-meaning words and phrases based on grades 11–12 reading and content, including technical meanings, choosing flexibly from a range of strategies.
RI.CI.11–12.2. Determine two or more central ideas of an informational text and analyze how they are developed and refined over the course of a text, including how they interact and build on one another to provide a complex account or analysis; provide an objective summary of the text.
W.AW.11–12.1. Write arguments to support claims in an analysis of substantive topics or texts, using valid reasoning and relevant and sufficient evidence.
SL.PE.11–12.1. Initiate and participate effectively in a range of collaborative discussions (one-on-one, in groups, and teacher-led) with peers on grades 11–12 topics, texts, and issues, building on others' ideas and expressing their own clearly and persuasively.
SL.PI.11–12.4 Present information, findings and supporting evidence clearly, concisely, and logically. The content, organization, development, and style are appropriate to task, purpose, and audience.
Mathematics
MP.2 Reason abstractly and quantitatively.
MP.4 Model with mathematics.
N.Q.A.1 Use units as a way to understand problems and to guide the solution of multi-step problems; choose and interpret units consistently in formulas; choose and interpret the scale and the origin in graphs and data displays.
N.Q.A.2 Define appropriate quantities for the purpose of descriptive modeling.
N.Q.A.3 Choose a level of accuracy appropriate to limitations on measurement when reporting quantities.
A.SSE.A.1 Interpret expressions that represent a quantity in terms of its context.

A.SSE.B.3 Choose and produce an equivalent form of an expression to reveal and explain properties of the quantity represented by the expression.
A.CED.A.1 Create equations and inequalities in one variable and use them to solve problems.
A.CED.A.2 Create equations in two or more variables to represent relationships between quantities; graph equations on coordinate axes with labels and scales.
A.CED.A.4 Rearrange formulas to highlight a quantity of interest, using the same reasoning as in solving equations.
F.IF.C.7 Graph functions expressed symbolically and show key features of the graph, by hand in simple cases and using technology for more complicated cases.
S.ID.A.1 Represent data with plots on the real number line (dot plots, histograms, and box plots).

Unit Understandings:
Students will understand that…

- Classically, the acceleration of an object interacting with other objects can be predicted by using $a = \frac{\Sigma F}{m}$.
- The energy of a system is conserved.

Unit Essential Questions:

- How can oscillations be used to make our lives easier and more comfortable?
- How can an astronaut be "weighed" in space?
- How could you measure the length of a long string with a stopwatch?
- What do a child on a swing, a beating heart, and a metronome have in common?

Knowledge and Skills:
Students will know...

- Simple harmonic motion is a special case of periodic motion.
- SHM results when the magnitude of the restoring force exerted on an object is proportional to that object's displacement from its equilibrium position. $ma_x = -k\Delta x$
  - A restoring force is a force that is exerted in a direction opposite to the object's displacement from an equilibrium position.
  - An equilibrium position is a location at which the net force exerted on an object or system is zero.
  - The motion of a pendulum with a small angular displacement can be modeled as simple harmonic motion because the restoring torque is proportional to the angular displacement.
- The period of SHM is related to the frequency f of the object's motion by the following equation: $T = \frac{1}{f}$
  - The period of an object - ideal spring oscillator is given by the equation $T_s = 2\pi\sqrt{\frac{m}{k}}$
  - The period of a simple pendulum displaced by a small angle is given by the equation $T_p = 2\pi\sqrt{\frac{l}{g}}$
- For an object exhibiting SHM, the displacement of that object measured from its equilibrium position can be represented by the equations $x = A\,cos(2\pi ft)$ or $x = A\,sin(2\pi ft)$
  - Minima, maxima, and zeros of displacement, velocity, and acceleration are features of harmonic motion.
  - Recognizing the positions or times at which the displacement, velocity, and acceleration for SHM have extrema or zeros can help in qualitatively describing the behavior of the motion.
- Changing the amplitude of a system exhibiting SHM will not change the period of that system.

- Properties of SHM can be determined and analyzed using graphical representations.
- The total energy of a system exhibiting SHM is the sum of the system's kinetic and potential energies. $E_{tot} = U + K$
- Conservation of energy indicates that the total energy of a system exhibiting SHM is constant.
- The kinetic energy of a system exhibiting SHM is at a maximum when the system's potential
- energy is at a minimum.
- The potential energy of a system exhibiting SHM is at a maximum when the system's kinetic energy is at a minimum.
  - The minimum kinetic energy of a system exhibiting SHM is zero.
  - Changing the amplitude of a system exhibiting SHM will change the maximum potential energy of the system and, therefore, the total energy of the system. Relevant equation for a spring–object system: $E_{tot} = \frac{1}{2}kA^2$

Students will be able to...

- Create diagrams,tables, charts, or schematics to represent physical situations.
- Create quantitative graphs with appropriate scales and units, including plotting data.
- Create qualitative sketches of graphs that represent features of a model or the behavior of a physical system.
- Derive a symbolic expression from known quantities by selecting and following a logical mathematical pathway.
- Calculate or estimate an unknown quantity with units from known quantities, by selecting and following a logical computational pathway.
- Compare physical quantities between two or more scenarios or at different times and locations in a single scenario.
- Predict new values or factors of change of physical quantities using functional dependence between variables.
- Create experimental procedures that are appropriate for a given scientific question.
- Apply an appropriate law, definition, theoretical relationship, or model to make a claim.
- Justify or support a claim using evidence from experimental data, physical representations, or physical principles or laws.
- Predict which properties determine the motion of a simple harmonic oscillator and what the dependence of the motion is on those properties.
- Design a plan and collect data in order to ascertain the characteristics of the motion of a system
- undergoing oscillatory motion caused by a restoring force
- Analyze data to identify qualitative and quantitative relationships between given values and variables (i.e., force, displacement, acceleration, velocity, period of motion, frequency, spring constant, string length, mass) associated with objects in oscillatory motion and use those data to determine the value of an unknown.
- Construct a qualitative and/or quantitative explanation of oscillatory behavior given evidence of a restoring a force.
- Calculate the expected behavior of a system using the object model (i.e., by ignoring changes in internal structure) to analyze a situation. Then, when the model fails, the student can justify the use of conservation of energy principles to calculate the change in internal energy due to changes in internal structure because the object is actually a system.
- Describe and make qualitative and/or quantitative predictions about everyday examples of systems with internal potential energy.
- Make quantitative calculations of the internal potential energy of a system from a description or diagram of that system.
- Apply mathematical reasoning to create a description of the internal potential energy of a system from a description or diagram of the objects and interactions in that system.

EVIDENCE OF LEARNING

Assessment:
What evidence will be collected and deemed acceptable to show that students truly "understand"?

- End of Unit Common Assessment - See folder for assessment links.
- Topic Quizzes
- AP Classroom Personal Progress Check
- Assigned Lab Reports
- Group Presentations

Learning Activities:
What differentiated learning experiences and instruction will enable all students to achieve the desired results?

- **Desktop Experiment Task:** Have students determine the spring constant of a spring using (1) known masses and a meterstick only and then (2) known masses and a stopwatch only.
- **Desktop Experiment Task:** Have students use a pendulum to determine the acceleration due to gravity. Ask them to refine the experiment from a single-trial calculation, to taking an average, to making a graph of linearized data.
- **Predict and Explain:** Have students make a pendulum bob oscillate with the other end of the string "clamped" between your fingers. While the bob oscillates, pull the string through your fingers so that the string length is shortened. Before doing this, ask students what will happen to the period of the oscillation and amplitude (measured in degrees), and then explain why the period decreases and the amplitude angle increases.
- **Create a Plan:** Have students choose a song and find its tempo (in beats per minute). Then, have them build a pendulum so that it swings back and forth on each beat. Next, give students a spring. Have them first find the spring's constant and then find the amount of mass necessary to make the spring-mass oscillate on each beat.
- **Construct an Argument:** A cart wiggles on a horizontal spring. A blob of clay is dropped on the cart and sticks (could be when the cart is at the center or at one end). Ask students to explain what happened to the period, total energy, amplitude of motion, and maximum speed.

RESOURCES

Teacher Resources:

- AP Physics 1 Course and Exam Description
- AP Classroom Resources
- College Physics: Etkina et al 1st Edition
- Flipping Physics
- PhET - Online Physics simulations
- The Physics Classroom

Equipment Needed:

- Laptop and projector
- Calculators

- Chromebooks
- Laboratory equipment for demonstrations and labs

UNIT 8 OVERVIEW

Content Area: Science

Unit Title: Fluids

Target Course/Grade Level: Advanced Placement Physics 1/Grades 11-12

Unit Summary: In Unit 8, students consider how the forces and conservation laws studied in Units 1 through 4 can be applied to the study of ideal fluids. Unit 8 ties together the thematic threads that have been woven throughout the course, including the interactions between systems and the conservation of fundamental quantities.

Approximate Length of Unit: 5 weeks

LEARNING TARGETS

NJ Student Learning Standards:
HS-PS3-1 Create a computational model to calculate the change in the energy of one component in a system when the change in energy of the other component(s) and energy flows in and out of the system are known.
HS-PS3-2 Develop and use models to illustrate that energy at the macroscopic scale can be accounted for as a combination of energy associated with the motions of particles (objects) and energy associated with the relative position of particles (objects).
HS-PS3-3 Design, build, and refine a device that works within given constraints to convert one form of energy into another form of energy.
HS-ETS1-2 Design a solution to a complex real-world problem by breaking it down into smaller, more manageable problems that can be solved through engineering.
HS-ETS1-3 Evaluate a solution to a complex real-world problem based on prioritized criteria and trade-offs that account for a range of constraints, including cost, safety, reliability, and aesthetics, as well as possible social, cultural, and environmental impacts.

College Board Standards:
8.1.A Describe the properties of a fluid.
8.2.A Describe the pressure exerted on a surface by a given force.
8.2.B Describe the pressure exerted by a fluid.
8.3.A Describe the conditions under which a fluid's velocity changes.
8.3.B Describe the buoyant force exerted on an object interacting with a fluid.
8.4.A Describe the flow of an incompressible fluid through a cross-sectional area by using mass conservation.
8.4.B Describe the flow of a fluid as a result of a difference in energy between two locations within the fluid–Earth system.

Career Readiness, Life Literacies, and Key Skills:
9.3.12.AC.1 Use vocabulary, symbols and formulas common to architecture and construction.
9.3.12.AC.6 Read, interpret and use technical drawings, documents and specifications to plan a project.

9.3.12.AC‑DES.1 Justify design solutions through the use of research documentation and analysis of data.
9.3.12.AC‑DES.2 Use effective communication skills and strategies (listening, speaking, reading, writing and graphic communications) to work with clients and colleagues.
9.3.12.ED.2 Demonstrate effective oral, written and multimedia communication in multiple formats and contexts.
9.3.12.ED‑ADM.1 Use research‑based practices to develop, communicate and enlist support for a vision of success for all learners.
9.3.12.ED‑ADM.2 Identify behaviors necessary for developing and sustaining a positive learning culture.
9.3.12.ED‑ADM.3 Create instructional programs to meet the learning organization's objectives.
9.3.12.ED‑ADM.4 Identify instructional practices that meet the learning organization's objectives.
9.3.12.ED‑ADM.5 Model leadership skills for personnel in order to improve the performance of the learning organization.
9.4.12.CI.1 Demonstrate the ability to reflect, analyze, and use creative skills and ideas
9.4.12.CT.1 Identify problem-solving strategies used in the development of an innovative product or practice
9.4.12.CT.2 Explain the potential benefits of collaborating to enhance critical thinking and problem solving
9.4.12.DC.1 Explain the beneficial and harmful effects that intellectual property laws can have on the creation and sharing of content
9.4.12.IML.3 Analyze data using tools and models to make valid and reliable claims, or to determine optimal design solutions
9.4.12.TL.2 Generate data using formula-based calculations in a spreadsheet and draw conclusions about the data.

Interdisciplinary Connections and Standards:
ELA
L.SS.11–12.1. Demonstrate command of the system and structure of the English language when writing or speaking.
L.KL.11–12.2. Apply knowledge of language to understand how language functions in different contexts, to make effective choices for meaning or style, and to comprehend more fully when reading or listening.
L.VL.11–12.3. Determine or clarify the meaning of unknown and multiple-meaning words and phrases based on grades 11–12 reading and content, including technical meanings, choosing flexibly from a range of strategies.
RI.CI.11–12.2. Determine two or more central ideas of an informational text and analyze how they are developed and refined over the course of a text, including how they interact and build on one another to provide a complex account or analysis; provide an objective summary of the text.
W.AW.11–12.1. Write arguments to support claims in an analysis of substantive topics or texts, using valid reasoning and relevant and sufficient evidence.
SL.PE.11–12.1. Initiate and participate effectively in a range of collaborative discussions (one-on-one, in groups, and teacher-led) with peers on grades 11–12 topics, texts, and issues, building on others' ideas and expressing their own clearly and persuasively.
SL.PI.11–12.4 Present information, findings and supporting evidence clearly, concisely, and logically. The content, organization, development, and style are appropriate to task, purpose, and audience.
Mathematics
MP.2 Reason abstractly and quantitatively.
MP.4 Model with mathematics.
N.Q.A.1 Use units as a way to understand problems and to guide the solution of multi-step problems; choose and interpret units consistently in formulas; choose and interpret the scale and the origin in graphs and data displays.
N.Q.A.2 Define appropriate quantities for the purpose of descriptive modeling.
N.Q.A.3 Choose a level of accuracy appropriate to limitations on measurement when reporting quantities.
A.SSE.A.1 Interpret expressions that represent a quantity in terms of its context.
A.SSE.B.3 Choose and produce an equivalent form of an expression to reveal and explain properties of the quantity represented by the expression.
A.CED.A.1 Create equations and inequalities in one variable and use them to solve problems.

A.CED.A.2 Create equations in two or more variables to represent relationships between quantities; graph equations on coordinate axes with labels and scales.
A.CED.A.4 Rearrange formulas to highlight a quantity of interest, using the same reasoning as in solving equations.
F.IF.C.7 Graph functions expressed symbolically and show key features of the graph, by hand in simple cases and using technology for more complicated cases.
S.ID.A.1 Represent data with plots on the real number line (dot plots, histograms, and box plots).

Unit Understandings:
Students will understand that…

- Materials have many macroscopic properties that result from the arrangement and interactions of the atoms and molecules that make up the material.
- All forces share certain common characteristics when considered by observers in inertial reference frames.

Unit Essential Questions:

- Why do some objects float while others sink?
- Why is an object's ability to float an important characteristic?
- What implications to our lives would there be if nothing floated?
- Why don't we feel the miles of air above us pushing us down?

Knowledge and Skills:
Students will know...

- Distinguishing properties of solids, liquids, and gasses stem from the varying interactions between atoms and molecules.
- A fluid is a substance that has no fixed shape.
- Fluids can be characterized by their density. Density is defined as a ratio of mass to volume. $\rho = \frac{m}{V}$.
- An ideal fluid is incompressible and has no viscosity. Pressure is defined as the magnitude of the perpendicular force component exerted per unit area over a given surface area, as described by the equation $P = \frac{F_{\perp}}{A}$.
- Pressure is a scalar quantity.
- The volume and density of a given amount of an incompressible fluid is constant regardless of the pressure exerted on that fluid.
- The absolute pressure of a fluid at a given point is equal to the sum of a reference pressure P_0, such as the atmospheric pressure P_{atm}, and the gauge pressure P_{gauge}. $P = P_0 + \rho g h$
- The gauge pressure of a vertical column of fluid is described by the equation $P_{gauge} = \rho g h$
- Newton's laws can be used to describe the motion of particles within a fluid.
- The macroscopic behavior of a fluid is a result of the internal interactions between the fluid's constituent particles and external forces exerted on the fluid.
- The buoyant force is a net upward force exerted on an object by a fluid.
- The buoyant force exerted on an object by a fluid is a result of the collective forces exerted on the object by the particles making up the fluid.
- The magnitude of the buoyant force exerted on an object by a fluid is equivalent to the weight of the fluid displaced by the object. $F_b = \rho V g$
- A difference in pressure between two locations causes a fluid to flow.
    - The rate at which matter enters a fluid-filled tube open at both ends must equal the rate at which matter exits the tube.

- The rate at which matter flows into a location is proportional to the cross- sectional area of the flow and the speed at which the fluid flows. $\frac{V}{t} = Av$

- The continuity equation for fluid flow describes conservation of mass flow rate in incompressible fluids. $A_1v_1 = A_2v_2$
- A difference in gravitational potential energies between two locations in a fluid will result in a difference in kinetic energy and pressure between those two locations that is described by conservation laws.
- Bernoulli's equation describes the conservation of mechanical energy in fluid flow. Relevant equation: $P_1 + \rho g y_1 + \frac{1}{2}\rho v_1^2 = P_2 + \rho g y_2 + \frac{1}{2}\rho v_2^2$
- Torricelli's theorem relates the speed of a fluid exiting an opening to the difference in height between the opening and the top surface of the fluid and can be derived from conservation of energy principles. $v = \sqrt{2g\Delta y}$

Students will be able to...

- Create diagrams, tables, charts, or schematics to represent physical situations.
- Create quantitative graphs with appropriate scales and units, including plotting data.
- Create qualitative sketches of graphs that represent features of a model or the behavior of a physical system.
- Derive a symbolic expression from known quantities by selecting and following a logical mathematical pathway.
- Calculate or estimate an unknown quantity with units from known quantities, by selecting and following a logical computational pathway.
- Compare physical quantities between two or more scenarios or at different times and locations in a single scenario.
- Predict new values or factors of change of physical quantities using functional dependence between variables.
- Create experimental procedures that are appropriate for a given scientific question.
- Apply an appropriate law, definition, theoretical relationship, or model to make a claim.
- Justify or support a claim using evidence from experimental data, physical representations, or physical principles or laws.
- Calculate pressure at a given depth in a fluid using $P = P_0 + \rho g h$.
- Explain the relationship between pressure, force, and area ($P = \frac{F_\perp}{A}$).
- Apply the continuity equation ($A_1v_1 = A_2v_2$) to problems involving fluid flow in pipes of varying cross-sectional area.
- Use Bernoulli's equation to analyze the behavior of fluids in motion.
- Explain phenomena such as lift on airplane wings, the Venturi effect, and fluid flow through constrictions.

EVIDENCE OF LEARNING

Assessment:
What evidence will be collected and deemed acceptable to show that students truly "understand"?

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Learning Activities:
What differentiated learning experiences and instruction will enable all students to achieve the desired results?

- **Construct an Argument** Search "pressure versus height graph" online and download a graph of air pressure as a function of elevation. Have students explain why the slope decreases with elevation (air gets less dense) and use the slope of the graph at one point to estimate the density of air at that elevation.
- **Desktop Experiment Task:** Divide students into groups. Give each group an irregularly shaped metal object (e.g., a small, inexpensive statue). Provide each group a spring scale and access to a deep sink. Have students use buoyancy principles to calculate the volume and density of the object.
- **Graph and Switch:** Have a student use a rope to raise an object 2 m from the bottom of a 3 m deep pool. Graph (with numerical scales) tension versus height of the bottom of the object above the floor of the pool for 0–4 m. Have another student determine the mass, volume, and density of the object. The shape of the graph from 1 to 3 m also determines whether the shape is a cube, sphere, or a cone pointing up or down. Ask students to switch graphs and discuss.
- **Construct an Argument:** Have students draw Bernoulli bar charts for two or more points in a flowing fluid situation. (Bars are for pressure, ρgy, and $\frac{1}{2} \rho v^2$.) Examples: water leaking out of a hole in a container, water shooting out of a hose, and drinking from a straw. Have students make and defend a claim about the pressure in two different places in the container, hose, or straw, using the bar chart as evidence.
- **Desktop Experiment Task:** Divide students into groups. Obtain a syringe (no needle) or water squirter for each group. Have each group fill it with water and squirt the water horizontally. Then, have each group determine how much pressure (for the water squirter) or force (for the syringe) was exerted to make the water come out.

RESOURCES

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