Rumson-Fair Haven Regional High School

Course: *AP Physics 1 and 2*
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Approved: September 2024

Section I: Course Description
AP Physics 1 and 2 is a second-year Physics course which encompasses the equivalent of two semesters of college-level Algebra-based Physics courses. AP Physics 1 covers topics such as Kinematics, Newton's laws of motion, Work and Energy, Momentum and Collisions, Circular Motion, Rotational Dynamics, and Fluid Mechanics. Most of this material was covered in the student's freshman-year Physics course. AP Physics 2 covers topics such as Heat and Thermodynamics, Electric Fields and forces, Electric Potential, DC Circuits, Magnetism, Optics, and Modern Physics. This course is designed for students who enjoyed and succeeded in their freshman-year Physics course. Students must be able to think critically; recall will be used in the capacity of problem solving including solution design and implementation. All assessments will require critical thinking, problem-solving, application of multiple concepts and solution fluency. Labs will run once every four-day schedule rotation. Students who demonstrate proficiency are encouraged to take both of the AP Examinations in Physics 1 and 2 offered in May.

Section II: NJSLS: New Jersey Student Learning Standards/Learning Objectives

1. ***2020 New Jersey Student Learning Standards – Science*:**
   - "Scientific and technological advances have proliferated and now permeate most aspects of life in the 21st century. It is increasingly important that all members of our society develop an understanding of scientific and engineering concepts and processes. Learning how to construct scientific explanations and how to design evidence-based solutions provides students with tools to think critically about personal and societal issues and needs. Students can then contribute meaningfully to decision-making processes, such as discussions about climate change, new approaches to health care, and innovative solutions to local and global problems."
2. ***2023 New Jersey Student Learning Standards – Mathematics:***
   - "A New Jersey education in Mathematics builds quantitatively and analytically literate citizens prepared to meet the demands of college and career, and to engage productively in an information-driven society; …A high-quality mathematics education fosters a population that…leverages data in decision-making and as a lens for discussing, analyzing, and responding to practical questions, persists to make sense of and model problems arising in everyday life, society, and the workplace, thinks critically and strategically to assess quantitative relationships and to solutions to complex problems, employs precise reasoning and constructs viable arguments to deduce conclusions, recognize false statements and assess peers' reasoning, interprets, evaluates and critiques the mathematics embedded in social, scientific and commercial systems, as well as the claims made in the private and public sectors, communicates precisely when conveying, representing, and justifying both qualitative and quantitative perspectives."
3. ***2023 New Jersey Student Learning Standards English Language Arts:***
   - A New Jersey education in English Language Arts builds readers, writers, and communicators prepared to meet the demands of college and career and to engage as productive American citizens with global responsibilities. …Students will develop the necessary skills in reading, writing, speaking, and listening that are the foundations for creative and purposeful expression in language read rich, challenging texts that build their knowledge of the world, grow their confidence and identities as readers, and develop critical thinking skills and vocabulary necessary for long-term success[; e]ngage in regular, meaningful, writing authentic tasks, exploring valued topics, writing for impact and expression, and sharing their work with others (including authentic audiences) leverage complex texts and digital media to develop comprehension, active listening, and discussion skills ground daily writing and discussion in evidence, fostering an ability to read critically, build arguments, cite evidence, and communicate ideas to contribute meaningfully as productive citizens evaluate the reliability, credibility, and perspective of authors and speakers across all forms of media express ideas and knowledge through a variety of modalities and media, and serve as effective communicators who purposefully read, write, and speak across multiple disciplines [and l]earn to persist in reading complex texts, establishing lifelong habits to read voluntarily for pleasure, for further education, for information on public policy, and for advancement in the workplace.
4. ***Standard 8.1 (Computer Science) and 8.2 (Design Thinking) of the 2020 NJSLS*:**
   - "The 'Intent and Spirit of the Computer Science and Design Thinking Standards' is to focus on deep understanding of concepts that enable students to think critically and systematically about leveraging

technology to solve local and global issues. Authentic learning experiences that enable students to apply content knowledge, integrate concepts across disciplines, develop computational thinking skills, acquire and incorporate varied perspectives, and communicate with diverse audiences about the use and effects of computing prepares New Jersey students for college and careers."

5. ***Standard 9.4 (Life Literacies and Key Skills)* of the *2020 NJSLS*:**
    - "This standard outlines key literacies and technical skills such as critical thinking, global and cultural awareness, and technology literacy* that are critical for students to develop to live and work in an interconnected global economy."
    - **Climate Change:** The state of New Jersey has mandated instruction in, "Climate Change across all content areas, leveraging the passion students have shown for this critical issue and providing them opportunities to develop a deep understanding of the science behind the changes and to explore the solutions our world desperately needs."
6. ****Amistad Law: N.J.S.A. 18A 52:16A-88:***
    - The inclusion of lessons and resources/texts dealing with the African slave trade, slavery in America, the vestiges of slavery in this country and the contributions of African-Americans to our society will be implemented in English and Social Studies courses in accordance with state law: "Every board of education shall incorporate the information regarding the contributions of African-Americans to our country in an appropriate place in the curriculum of elementary and secondary school students."
7. ****Holocaust Law: N.J.S.A. 18A 35-28:***
    - The inclusion of lessons and resources/texts that enable pupils to identify and analyze applicable theories concerning human nature and behavior; to understand that genocide is a consequence of prejudice and discrimination; and to understand that issues of moral dilemma and conscience have a profound impact on life will be implemented in English and Social Studies courses in accordance with state law: "Every board of education shall include instruction on the Holocaust and genocides in an appropriate place in the curriculum of all elementary and secondary school pupils. The instruction shall further emphasize the personal responsibility that each citizen bears to fight racism and hatred whenever and wherever it happens."
8. ****LGBT and Disabilities Law: N.J.S.A. 18A:35-4.35*:**
    - A transformative approach to the inclusion of lessons and resources/texts on the contributions and issues concerning the LGBTQ+ population and people with disabilities will be implemented across all core subjects in accordance with state law: "A board of education shall include instruction on the political, economic, and social contributions of persons with disabilities and lesbian, gay, bisexual, and transgender people, in an appropriate place in the curriculum of middle school and high school students as part of the district's implementation of the New Jersey Student Learning Standards (N.J.S.A.18A:35-4.36). A board of education shall have policies and procedures in place pertaining to the selection of instructional materials to implement the requirements of N.J.S.A. 18A:35-4.35."
9. ***Asian American and Pacific Legislation: N.J.S.A 4021/A6100:***
    - The inclusion of lessons and resources/texts on the history and contributions of Asian Americans and Pacific Islanders, will enable New Jersey's schools to provide a curriculum that reflects the diversity of our state. In accordance with state law: "A board of education shall include instruction on the history and contributions of Asian Americans and Pacific Islanders in an appropriate place in the curriculum of students in grades kindergarten through as part of the school district's implementation of the New Jersey Student Learning Standards in Social Studies."
10. Acquisition/development/refinement of the higher-order critical thinking skills aligned with the *Revised Bloom's Taxonomy of Cognitive Objectives*

Section III: Curriculum Modifications

The *AP Physics 1 and 2 Curriculum* is subject to case-by-case modifications to support/advance the needs of all students, including special education students, English language learners, gifted students and those at risk of school failure. These modifications are based on Individualized Learning Programs (IEPs), recommendations made by the district's English Language Learners (ELL) coordinator, feedback from members of the Intervention & Referral Services Team (*I&RS*) for at-risk students, and 504 Plans.

Coursework and assessments will be modified on an individual basis for students when necessary. Modifications may include but are not limited to those outlined on the Modifications/Accommodations for Science Courses chart.

Section IV: Preparation for Standardized Testing

Instruction in *AP Physics 1 and 2* is aligned with the requirements of state and national standardized assessments, including the N*JGPA, NJSLA*, the *ACT*, the *PSAT* and the *SAT*.

Section V: Curriculum Pacing Guide

Curriculum Pacing Guide	
Course Title: *AP Physics 1 and 2*	**Grade Level:** 12
Unit I: Kinematics	Weeks 1-4
Unit II: Force and Translational Dynamics	Weeks 5-7
Unit III: Work, Energy and Power	Weeks 8-9
Unit IV: Linear Momentum	Weeks 10-11
Unit V: Torque and Rotational Dynamics	Weeks 12
Unit VI: Energy and Momentum of Rotating Systems	Week 13
Unit VII: Oscillations	Weeks 14
Unit VIII: Fluids	Weeks 15
Unit IX: Thermodynamics	Weeks 16-18
Unit X: Electric Force, Field, and Potential	Weeks 19-21
Unit XI: Electric Circuits	Weeks 22-23

Unit XII: Magnetism and Electromagnetism	Weeks 24-25
Unit XIII: Geometric Optics	Weeks 26
Unit XIV: Waves, Sound, and Physical Optics	Weeks 27-28
Unit XV: Modern Physics	Weeks 29-34
Unit XVI: End of Year Project	Weeks 34-40

Section VI: Technology Skills

Students in *AP Physics 1 and 2* are required to complete the technology skills components of the curriculum:

- Collect raw data using technology
- Evaluate raw data
- Evaluate a graphical representation of raw data through the use of technology
- Analyze a graphical representation of raw data to determine relevance
- Evaluate multiple representations of data.
- Use data to make predictions.
- Operate a Vernier Interface
- Use probes and sensors correctly with the Vernier Interface

Section VII: Primary Texts and Year Long Instructional Resources

The following texts and instructional resources are employed in *AP Physics 1 and 2*:

- *College Physics* by Raymond A. Serway & Chris Vuille, 11th Edition
- AP Classroom
- *Common Sense Education* (www.commonsense.org)

Section VIII: Grading Formula and Assessment Modes

Marking period grades in *AP Physics 1 and 2* are determined via a percentage weighting model. The specific grading categories and weightings of each will be determined prior to the start of each academic year and will be published in the posted/distributed course syllabi.

Assessments in *AP Physics 1 and 2* vary greatly in format, scope/content/skills assessed, and alternative assessments, differentiation in assessments and choice will be incorporated as appropriate. Preliminary assessments of each format will be used as benchmarks and summative assessments will be created/revised collaboratively each year and planned by members of the *AP Calculus AB* instructional team to inform future learning and to measure student growth.

Section IX: Unit Templates

The following unit templates have been established for the *AP Physics 1 and 2* curriculum by the *AP Physics 1 and 2* instructional team:

Unit I: Kinematics
Unit Summary

Unit I introduces students to the study of motion and serves as a foundation for all of AP Physics 1 by beginning to explore the complex idea of acceleration and showing them how representations can be used to model and analyze scientific information as it relates to the motion of objects. By studying kinematics, students will learn to represent motion—both uniform and accelerating—in narrative, graphical, and/or mathematical forms and from different frames of reference. These representations will help students analyze the specific motion of objects and systems while also dispelling some common misconceptions they may have about motion, such as exclusively using negative acceleration to describe an object slowing down. Additionally, students will have the opportunity to go beyond their traditional understanding of mathematics. Instead of solving equations, students will use them to support their reasoning and tighten their grasp on the laws of physics. Lastly, students will begin making predictions about motion and justifying claims with evidence by exploring the relationships between the physical quantities of acceleration, velocity, position, and time. This is an important starting point for students, as these fundamental science practices will spiral throughout the course and appear in multiple units.

Standards/Core Ideas/Performance Expectations

The state standards outlined below, and established by New Jersey Department of Education, will guide instruction throughout this unit in *AP Physics 1 & 2*:

- *2020 New Jersey Student Learning Standards: Science*
  - HS-PS2-1, HS-PS2-2
- *2023 New Jersey Student Learning Standards: Mathematics*
  - MP.2, MP.4, N.Q.A.1-3, A.SSE.A.1 & B.3, A.CED.A.1-4, F-IF.C.7, S-IS.A.1, G.SRT.A.2, C.6-8
- *2023 New Jersey Student Learning Standards English Language Arts*
  - RI.CR.11–12.1., RI.CI.11–12.2., W.WR.11-12.5, W.WP.11–12.4, W.SE.11–12.6, SL.PI.11-12.4
- *2020 New Jersey Student Learning Standards: Computer Science and Design Thinking*
  - 8.1.12.DA.5-6
- *2020 New Jersey Student Learning Standards: Career Readiness, Life Literacies and Key Skills*
  - 9.4.2.CI.1-3, 9.4.12.CT.1-2, 9.4.12.TL.3

Unit Essential Questions	Unit Enduring Understandings
• What are scalars and vectors? • What is displacement? • What is average velocity? • What is average acceleration? • What are the different methods of representing motion? • What is instantaneous velocity? • What is instantaneous acceleration? • How is displacement calculated from the velocity versus time graph? • How do you describe motion in two dimensions? • What is projectile motion?	• Scalars are quantities described by magnitude only; vectors are quantities described by both magnitude and direction. • Displacement is the change in an object's position. • Average velocity is the displacement of an object divided by the interval of time in which that displacement occurs. • Average acceleration is the change in velocity divided by the interval of time in which that change in velocity occurs. • Motion can be represented by motion diagrams, figures, graphs, equations, and narrative descriptions. • 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. • 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.

Evidence of Learning

Formative & Alternative Assessments:	Benchmark & Summative Assessments:	Resources Needed:
• Classwork • Homework • Performance activities	• Quizzes (Benchmark) • Chapter Test (Benchmark)	• *College Physics by Raymond A. Serway & Chris Vuille, 11th Edition* • AP Classroom • Vernier probes and Software

• Individual student check-ins with teacher • Labs 1. Free Fall Lab 2. Projectile Motion Lab		

Unit II: Force and Translational Dynamics
Unit Summary
In Unit II, students are introduced to the term force, which is the interaction of an object with another object. Part of the larger study of dynamics, forces are used as the lens through which students analyze and come to understand a variety of physical phenomena. This is accomplished by revisiting and building upon the representations presented in Unit I, specifically the introduction to the free-body diagram. Translation, however, is key in this unit. Students must be able to portray the same object–force interactions through different graphs, diagrams, and mathematical relationships. Students will continue to make meaning from models and representations that will help them further analyze systems, the interactions between systems, and how these interactions result in change. Alongside mastering the use of specific force equations, Unit II also encourages students to derive new expressions from fundamental principles to help them make predictions in unfamiliar, applied contexts. The skill of making predictions will be nurtured throughout the course to help students craft sound scientific arguments.
Standards/Core Ideas/Performance Expectations
The state standards outlined below, and established by New Jersey Department of Education, will guide instruction throughout this unit in *AP Physics 1 and 2*: • *2020 New Jersey Student Learning Standards: Science* ○ HSN-Q.A.1-2, HS-PS2-1, HS-PS2-2, HS-PS2-3, HS-PS2-4 • *2023 New Jersey Student Learning Standards: Mathematics* ○ MP.2, MP.4, N.Q.A.1-3, A.SSE.A.1 & B.3, A.CED.A.1-4, F-IF.C.7, S-IS.A.1, G.SRT.A.2, C.6-8 • *2023 New Jersey Student Learning Standards English Language Arts* ○ RI.CR.11–12.1., RI.CI.11–12.2., W.WR.11-12.5, W.WP.11–12.4, W.SE.11–12.6, SL.PI.11-12.4 • *2020 New Jersey Student Learning Standards: Computer Science and Design Thinking* ○ 8.1.12.DA.5-6 • *2020 New Jersey Student Learning Standards: Career Readiness, Life Literacies and Key Skills* ○ 9.4.2.CI.1-3, 9.4.12.CT.1-2, 9.4.12.TL.3

Unit Essential Questions	Unit Enduring Understandings
• What are forces? • What are free-body diagrams? • When is an object in a state of equilibrium? • Under what conditions will the velocity of a system change? • What is Newton's Law of Universal Gravitation? • What is the difference between inertial and gravitational mass? • What is Newton's Third law? • What is the normal force? • What is kinetic friction? • What is static friction? • What is the relationship between frictional force and the normal force for static and kinetic friction? • What is the force exerted on an object by an ideal spring?	• Forces are vector quantities that describe the interactions between objects or systems. • 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. • An object is in a state of equilibrium when the net force on it is zero. • The velocity of a system's center of mass will only change if an on zero 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. • 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. • For every action there is an equal and opposite reaction. • 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. • Kinetic friction occurs when two surfaces in contact move relative to each other.

	- Static friction may occur between the contacting surfaces of two objects that are not moving relative to each other. - The force of friction (both static and kinetic) is directly proportional to the normal force. It also depends on the materials in the contact (coefficient of friction). - 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.

Evidence of Learning		
Formative & Alternative Assessments: - Classwork - Homework - Performance activities - Individual student check-ins with teacher - Labs: 1. Newton's Laws Lab 2. Atwood's Machine Lab	**Benchmark & Summative Assessments:** - Quizzes - Chapter Test	Resources Needed: *College Physics by Raymond A. Serway & Chris Vuille, 11th Edition* - AP Classroom - Vernier Probes and Software

Unit III: Work, Energy, and Power
Unit Summary
In Unit III, students will be introduced to the idea of conservation as a foundational model of physics, along with the concept of work as the 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 Units I–IV to determine the most appropriate technique and will be challenged to understand the limiting factors of each. Describing, creating, and using these representations will also help students grapple with common misconceptions that they may have about energy, such as whether or not a single object can "have" potential energy. A thorough understanding of these energy models will support students' ability to make predictions—and ultimately justify claims with evidence—about physical situations. This is crucial, as the mathematical models and representations used in Unit IV will mature throughout the course and appear in subsequent units.
Standards/Core Ideas/Performance Expectations
The state standards outlined below, and established by New Jersey Department of Education, will guide instruction throughout this unit in *AP Physics 1 and 2:*   *2020 New Jersey Student Learning Standards: Science*   - HS-PS2-1, HS-PS2-2, HS-PS2-3, HS-PS2-4, HS-PS3-1, HS-PS3-2, HS-PS3-3   *2023 New Jersey Student Learning Standards: Mathematics*   - MP.2, MP.4, N.Q.A.1-3, A.SSE.A.1 & B.3, A.CED.A.1-4, F-IF.C.7, S-IS.A.1   *2023 New Jersey Student Learning Standards English Language Arts*   - RI.CR.11–12.1., RI.CI.11–12.2., W.WR.11-12.5, W.WP.11–12.4, W.SE.11–12.6, SL.PI.11-12.4   *2020 New Jersey Student Learning Standards: Computer Science and Design Thinking*   8.1.12.DA.5-6   *2020 New Jersey Student Learning Standards: Career Readiness, Life Literacies and Key Skills*   9.4.2.CI.1-3, 9.4.12.CT.1-2, 9.4.12.TL.3

Unit Essential Questions	**Unit Enduring Understandings**
- What is a system? - What are open and closed systems? - What is an interaction? - What is the work done by a force? - What is kinetic energy? - How are work and kinetic energy related? - What are conservative and	- A system is an object or a collection of objects. - For an isolated or a closed system, conserved quantities are constant. An open system is one that exchanges any conserved quantity with its surroundings. - An interaction can be either a force exerted by objects outside the system or the transfer of some quantity with objects outside the system. - Work is the product of the component of the force parallel to the displacement and the displacement when the force is constant. Work (change in energy) can be found from the area under a graph of the

non-conservative forces? ● What is potential energy? ● What is the total energy of a system? ● What happens when frictional forces do work on a system? ● When will the mechanical energy of a system change? ● What is power?	magnitude of the force component parallel to the displacement versus displacement ● Energy due to movement is kinetic energy. ● The change in kinetic energy of an object is equal to the net work done on the object. ● The work done by a conservative force is independent of the path taken. The work done by a non conservative force is dependent on the path taken. ● Potential energy is due to the interaction between parts of a system via conservative forces. ● The total energy of a system is the sum of the kinetic energy, potential energy, and the internal energy of the system. ● The system will lose mechanical energy due to frictional forces in the form of thermal energy. ● Mechanical energy (the sum of kinetic and potential energy) is transferred into or out of a system when an external force does work on the system. ● Power is defined as the rate of energy transfer into, out of, or within a system.

Evidence of Learning		
Formative & Alternative Assessments: ● Classwork ● Homework ● Performance activities ● Individual student check-ins with teacher ● Labs: 1. Work-Kinetic Energy Theorem Lab 2. Mechanical Energy Conservation Lab	**Benchmark & Summative Assessments:** ● Quizzes ● Chapter Test ● Summative #1	**Resources Needed:** ● *College Physics by Raymond A. Serway & Chris Vuille, 11th Edition* ● AP Classroom ● Vernier Probes and Software

Unit IV: Linear Momentum

Unit Summary

Unit IV introduces students to the relationship between force, time, and 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 the conservation of momentum of objects and systems while simultaneously building on their knowledge of previously studied representations. Using the law of the conservation of momentum to analyze physical situations gives students a more complete picture of forces and leads them to revisit their misconceptions surrounding Newton's third law. Students will also have the opportunity to make connections between the conserved quantities of momentum and energy to determine under what conditions each quantity is conserved. It's essential that students are not only comfortable solving numerical equations (such as the speed of a system after an inelastic collision) but also confident in their ability to discuss when momentum is conserved and how the type of collision affects the outcome. Threading such connections between physical quantities is fundamental to understanding the broader relationship between this unit and the rest of the course.

Standards/Core Ideas/Performance Expectations

The state standards outlined below, and established by New Jersey Department of Education, will guide instruction throughout this unit in *AP Physics 1 and 2:*

- *2020 New Jersey Student Learning Standards: Science*
  - HS-PS2-1, HS-PS2-2, HS-PS2-3, HS-PS2-4, HS-PS2-5, HS-PS2-4, HS-PS3-1, HS-PS3-2, HS-PS3-3
- *2023 New Jersey Student Learning Standards: Mathematics*
  - MP.2, MP.4, N.Q.A.1-3, A.SSE.A.1 & B.3, A.CED.A.1-4, F-IF.C.7, S-IS.A.1, G.SRT.A.2, C.6-8
- *2023 New Jersey Student Learning Standards English Language Arts*
  - RI.CR.11–12.1., RI.CI.11–12.2., W.WR.11-12.5, W.WP.11–12.4, W.SE.11–12.6, SL.PI.11-12.4
- *2020 New Jersey Student Learning Standards: Computer Science and Design Thinking*

- 8.1.12.DA.5-6
- *2020 New Jersey Student Learning Standards: Career Readiness, Life Literacies and Key Skills*
    - 9.4.12.CI.1-3, 9.4.12.CT.1-2, 9.4.12.TL.3

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What is linear momentum?
What are the uses of linear momentum?
When will the momentum of an object change?
What is impulse?
How are force and momentum related?
What is the impulse momentum theorem?
What are open and closed systems?
Under what circumstances is linear momentum conserved?
How are collisions classified?
What quantities are conserved in elastic collisions?
What quantity/quantities are conserved in inelastic collisions?
How are velocities of objects after collisions calculated?
How might momentum be transferred to or from the system and the environment?

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Linear momentum is a vector quantity that is the product of the mass and velocity of an object.
Momentum can be used to analyze collisions and explosions.
The linear momentum of an object changes when a force acts on the object over an interval of time.
Impulse is the product of force and time when the force is constant. Impulse is a vector quantity and has the same direction as the net force exerted on the system.
The rate of change of momentum is equal to the net force exerted on an object or a system.
The impulse delivered to an object is equal to the change in momentum of the object.
For all systems under all circumstances, energy, charge, linear momentum, and angular momentum are conserved. For an isolated or a closed system, conserved quantities are constant. An open system is one that exchanges any conserved quantity with its surroundings
Under the absence of external forces, the linear momentum of a system will be conserved.
Collisions are classified into elastic and inelastic collisions based on the kinetic energy conservation.
Both, linear momentum and kinetic energy, are conserved in elastic collisions.
Only linear momentum is conserved in inelastic collisions.
Depending on the type of collision, conservation of momentum and/or kinetic energy is used to calculate velocities right after the collision.
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.

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Formative & Alternative Assessments:

Classwork
Homework
Performance activities
Individual student check-ins with teacher
Labs:

Collisions Lab
Impulse-Momentum Lab

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Benchmark & Summative Assessments:

Quizzes
Chapter Test

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Resources Needed:

College Physics by Raymond A. Serway & Chris Vuille, 11th Edition
AP Classroom
Vernier Probes and Software

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Unit V: Torque and Rotational Dynamics

Unit Summary

Unit V reinforces the Unit II 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 V and VI. During their study of torque and rotational motion, students will be introduced to different ways of modeling forces. Throughout Units V and VI, students will compare and connect their understanding of linear and rotational motion, dynamics, energy, and momentum to develop holistic models to evaluate physical phenomena.

Standards/Core Ideas/Performance Expectations

The state standards outlined below, and established by New Jersey Department of Education, will guide instruction throughout this unit in *AP Physics 1 and 2:*

- *2020 New Jersey Student Learning Standards: Science*
  - HS-PS2-1, HS-PS2-2, HS-PS2-3, HS-PS2-4
- *2023 New Jersey Student Learning Standards: Mathematics*
  - MP.2, MP.4, N.Q.A.1-3, A.SSE.A.1 & B.3, A.CED.A.1-4, F-IF.C.7, S-IS.A.1, G.SRT.A.2, C.6-8
- *2023 New Jersey Student Learning Standards English Language Arts*
  - RI.CR.11–12.1., RI.CI.11–12.2., W.WR.11-12.5, W.WP.11–12.4, W.SE.11–12.6, SL.PI.11-12.4
- *2020 New Jersey Student Learning Standards: Computer Science and Design Thinking*
  - 8.1.12.DA.5-6
- *2020 New Jersey Student Learning Standards: Career Readiness, Life Literacies and Key Skills*
  - 9.4.2.CI.1-3, 9.4.12.CT.1-2, 9.4.12.TL.3

Unit Essential Questions	Unit Enduring Understandings
• What is angular displacement? • What is angular velocity? • What is angular acceleration? • What is the linear distance traveled by a point on a rotating rigid system? • What is the linear speed of a point on a rotating rigid system? • What is the tangential acceleration of a point on a rotating rigid system? • What is torque? • How can you describe the rotational inertia of a rigid system relative to a given axis of rotation? • What is different about the rotational inertia of a rigid system rotating about an axis that does not pass through the system's center of mass? • When is an object in rotational equilibrium? • When and how can a system's angular velocity change?	• Angular displacement is the measurement of the angle, in radians, through which a point on a rigid system rotates about a specified axis. • Average angular velocity is the average rate at which angular position changes with respect to time. • Average angular acceleration is the average rate at which the angular velocity changes with respect to time. • For a point at a distance r from a fixed axis of rotation, the linear distance traveled by the point as the system rotates is the product of the radius and the angular displacement. • The speed of a point on a rotating rigid system is the product of the radius and the angular velocity of the system. • The tangential acceleration is the product of the radius and the angular acceleration of the system. • The magnitude of torque exerted on a rigid system by a force is described by the product of the lever arm and the force. • 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. For a point particle, the rotational inertia about an axis is the product of the mass of that particle and the square of the distance of the particle from the axis. • 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, which states that the rotational inertia about any axis is equal to the sum of the rotational inertia about the axis through the center of mass and the product of the mass of the object and the square of the distance between the two axes. • When the net torque on an object is zero, the object is in rotational equilibrium. • 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.

Evidence of Learning		
Formative & Alternative Assessments: • Classwork • Homework • Performance activities • Individual student check-ins with teacher	**Benchmark & Summative Assessments:** • Quizzes • Chapter Test	**Resources Needed:** • *College Physics by Raymond A. Serway & Chris Vuille, 11th Edition* • AP Classroom • Vernier Probes and Software

• Lab: Moment of Inertia Lab		

<table>
<tr><th colspan="2">Unit VI: Energy and Momentum of Rotation Systems</th></tr>
<tr><th colspan="2">Unit Summary</th></tr>
<tr><td colspan="2">Unit VI pays close attention to the type of motion we experience when we talk or listen to music. Through the concept of oscillations, students are introduced to the model of simple harmonic motion (SHM), springs, and pendulums. Students will discover why some objects repeat their motions with a regular pattern. They will also apply the model of SHM, define the three kinematic characteristics (displacement, velocity, and acceleration), and practice representing them graphically and mathematically. During their study of oscillations, students will gain a more in-depth understanding of motion, making them better equipped to apply their knowledge of forces and motion to waves.</td></tr>
<tr><th colspan="2">Standards/Core Ideas/Performance Expectations</th></tr>
<tr><td colspan="2">The state standards outlined below, and established by New Jersey Department of Education, will guide instruction throughout this unit in AP Physics 1 and 2:
• 2020 New Jersey Student Learning Standards: Science
  ○ HS-PS2-1, HS-PS2-2, HS-PS2-3, HS-PS2-4, HS-PS2-5
• 2023 New Jersey Student Learning Standards: Mathematics
  ○ MP.2, MP.4, N.Q.A.1-3, A.SSE.A.1 & B.3, A.CED.A.1-4, F-IF.C.7, S-IS.A.1, G.SRT.A.2, C.6-8
• 2023 New Jersey Student Learning Standards English Language Arts
  ○ RI.CR.11–12.1., RI.CI.11–12.2., W.WR.11-12.5, W.WP.11–12.4, W.SE.11–12.6, SL.PI.11-12.4
• 2020 New Jersey Student Learning Standards: Computer Science and Design Thinking
  ○ 8.1.12.DA.5-6
• 2020 New Jersey Student Learning Standards: Career Readiness, Life Literacies and Key Skills
  ○ 9.4.2.CI.1-3, 9.4.12.CT.1-2, 9.4.12.TL.3</td></tr>
<tr><th>Unit Essential Questions</th><th>Unit Enduring Understandings</th></tr>
<tr><td>• What is rotational kinetic energy?
• Describe the work done on a rigid system by a given torque or collection of torques.
• What is the angular momentum of an object or rigid system?
• How is the angular impulse delivered to an object or rigid system by a torque?
• How is change in angular momentum related to the angular impulse?
• Under what circumstances is the angular momentum of a system conserved?
• How does the selection of a system determine whether the angular momentum of that system changes?
• What is the kinetic energy of a system that has translational and rotational motion?
• What is the motion of a system that is rolling without slipping?
• How can you describe the motion of a system that is rolling while slipping?
• What are the motions of a system consisting of two objects interacting only via gravitational forces?</td><td>• The rotational kinetic energy of an object or rigid system is related to the rotational inertia and angular velocity of the rigid system
• 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
• Angular momentum of a rigid system about a specific axis is the product of the rotational inertia about that axis and the angular velocity about that axis. Angular momentum of an object is also the cross-product of the moment arm and the linear momentum 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.
• The angular impulse exerted on an object or rigid system is equal to the change in angular momentum of that object or rigid system.
• The angular momentum of a system is conserved whenever the net external torque on the system is zero.
• Angular momentum is conserved in all interactions.
• The total kinetic energy of a system is the sum of the system's translational and rotational kinetic energies.
• 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: $\Delta x_{cm} = r\Delta\theta$, $v_{cm} = r\omega$, $a_{cm} = r\alpha$
• When slipping, the motion of a system's center of mass and the system's rotational motion cannot be directly related.
• 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.
• In circular orbits, the system's total mechanical energy, the system's</td></tr>
</table>

● Which physical quantities are constant when satellites move in circular orbits? ● Which physical quantities are constant when satellites move in elliptical orbits? ● What is escape velocity?	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. ● Escape velocity is the minimum velocity needed by an object to free itself from the gravitational pull of a planet.

Evidence of Learning		
Formative & Alternative Assessments: ● Classwork ● Homework ● Individual student check-ins with teacher ● Performance activities ● Lab: Energy of Rotation Lab	**Benchmark & Summative Assessments:** ● Quizzes ● Chapter Test	**Resources Needed:** ● *College Physics by Raymond A. Serway & Chris Vuille, 11th Edition* ● AP Classroom ● Vernier Probes and Software

Unit VII: Oscillations

Unit Summary

In Unit VII, students will apply previously-encountered modelsandmethodsofanalysis 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.

Standards/Core Ideas/Performance Expectations

The state standards outlined below, and established by New Jersey Department of Education, will guide instruction throughout this unit in *AP Physics 1 and 2:*

- *2020 New Jersey Student Learning Standards: Science*
  - HS-PS2-1, HS-PS2-2, HS-PS2-3, HS-PS2-4
- *2023 New Jersey Student Learning Standards: Mathematics*
  - MP.2, MP.4, N.Q.A.1-3, A.SSE.A.1 & B.3, A.CED.A.1-4, F-IF.C.7, S-IS.A.1, G.SRT.A.2, C.6-8
- *2023 New Jersey Student Learning Standards English Language Arts*
  - RI.CR.11–12.1., RI.CI.11–12.2., W.WR.11-12.5, W.WP.11–12.4, W.SE.11–12.6, SL.PI.11-12.4
- *2020 New Jersey Student Learning Standards: Computer Science and Design Thinking*
  - 8.1.12.DA.5-6
- *2020 New Jersey Student Learning Standards: Career Readiness, Life Literacies and Key Skills*
  - 9.4.2.CI.1-3, 9.4.12.CT.1-2, 9.4.12.TL.3

Unit Essential Questions	Unit Enduring Understandings
● What is simple harmonic motion? ● Under what conditions will a system move simply harmonically? ● How do you define the frequency and period of an object exhibiting SHM? ● What are the displacement, velocity, and acceleration of an object exhibiting SHM? ● How do you find the mechanical energy of a system exhibiting SHM?	● 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. ● The period of SHM is related to the frequency f of the object's motion by the following equation: $T = 1/f$. ● The displacement, velocity, and acceleration can each be described by sinusoidal functions of time. ● The total energy of a system exhibiting SHM is the sum of the system's kinetic and potential energies. 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 and vice versa.

<table>
<tr><th colspan="3">Evidence of Learning</th></tr>
<tr><td>Formative & Alternative Assessments:
● Classwork
● Homework
● Individual student check-ins with teacher
● Performance activities
1. Simple and Compound Pendulum Lab
2. Mass-Spring SHM lab</td><td>Benchmark & Summative Assessments:
● Quizzes
● Chapter Test
● Summative 2</td><td>Resources Needed:
● College Physics by Raymond A. Serway & Chris Vuille, 11th Edition
● AP Classroom
● Vernier Probes and Software</td></tr>
</table>

<table>
<tr><th colspan="2">Unit VIII: Fluids</th></tr>
<tr><th colspan="2">Unit Summary</th></tr>
<tr><td colspan="2">In Unit VIII, students consider how the forces and conservation laws studied in Units I through IV can be applied to the study of ideal fluids. UnitVIII ties together the thematic threads that have been woven throughout the course, including the interactions between systems and the conservation of fundamental quantities.</td></tr>
<tr><th colspan="2">Standards/Core Ideas/Performance Expectations</th></tr>
<tr><td colspan="2">The state standards outlined below, and established by New Jersey Department of Education, will guide instruction throughout this unit in AP Physics 1 and 2:
● 2020 New Jersey Student Learning Standards: Science
○ HS-PS2-1, HS-PS2-2, HS-PS2-3, HS-PS2-4, HS-PS2-5
● 2023 New Jersey Student Learning Standards: Mathematics
○ MP.2, MP.4, N.Q.A.1-3, A.SSE.A.1 & B.3, A.CED.A.1-4, F-IF.C.7, S-IS.A.1, G.SRT.A.2, C.6-8
● 2023 New Jersey Student Learning Standards English Language Arts
○ RI.CR.11–12.1., RI.CI.11–12.2., W.WR.11-12.5, W.WP.11–12.4, W.SE.11–12.6, SL.PI.11-12.4
● 2020 New Jersey Student Learning Standards: Computer Science and Design Thinking
○ 8.1.12.DA.5-6
● 2020 New Jersey Student Learning Standards: Career Readiness, Life Literacies and Key Skills
○ 9.4.2.CI.1-3, 9.4.12.CT.1-2, 9.4.12.TL.3</td></tr>
<tr><th>Unit Essential Questions</th><th>Unit Enduring Understandings</th></tr>
<tr><td>● What are the properties of a fluid?
● How do you define pressure?
● How is pressure exerted by a fluid?
● What is the absolute pressure of a fluid?
● What is the buoyant force exerted on an object interacting with a fluid?
● What determines the flow of an incompressible fluid through a cross-sectional area using mass conservation?
● How is the flow of a fluid affected by a difference in energy between two locations within the fluid Earth system?</td><td>● A fluid is a substance that has no fixed shape. Fluids can be characterized by their density. 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.
● The pressure exerted by a fluid is the result of the entirety of the interactions between the fluid's constituent particles and surface with which those particles interact.
● The absolute pressure of a fluid at a given point is equal to the sum of a reference pressure, such as the atmospheric pressure, and the gauge pressure, which is the pressure due to the fluid.
● The buoyant force is a net upward force exerted on an object by fluid and is equivalent to the weight of the fluid displaced by the object.
● The rate at which matter enters a fluid-filled tube open at both ends must equal the rate at which matter exits the tube.
● 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.</td></tr>
</table>

<table>
<tr><th colspan="3">Evidence of Learning</th></tr>
<tr><td>Formative & Alternative Assessments:
● Classwork</td><td>Benchmark & Summative Assessments:
● Quizzes</td><td>Resources Needed:
● College Physics by Raymond A. Serway & Chris Vuille, 11th</td></tr>
</table>

● Homework ● Individual student check-ins with teacher ● Performance activities ● Lab: PHET Fluid Pressure and Flow Lab	● Chapter Test	*Edition* ● AP Classroom ● Vernier Probes and Software

Unit IX: Thermodynamics	
Unit Summary	
In Unit IX, students investigate what they cannot see by examining the properties of ideal gases. This unit's focus is the study of relationships and change, so it is important that students can discuss—and describe mathematically—what happens when a physical scenario changes, such as the consequences of heating or cooling a system. Students will use the first law of thermodynamics and PV diagrams to represent and analyze thermodynamic processes. Thermal energy transfer and material properties such as specific heat and thermal conductivity will be studied. Unit IX also acquaints students with the second law of thermodynamics, including entropy.	
Standards/Core Ideas/Performance Expectations	

The state standards outlined below, and established by New Jersey Department of Education, will guide instruction throughout this unit in *AP Physics 1 and 2:*
● *2020 New Jersey Student Learning Standards: Science*
  ○ HS-PS2-1, HS-PS2-2, HS-PS2-3, HS-PS2-4, HS-PS3-4
● *2023 New Jersey Student Learning Standards: Mathematics*
  ○ MP.2, MP.4, N.Q.A.1-3, A.SSE.A.1 & B.3, A.CED.A.1-4, F-IF.C.7, S-IS.A.1
● *2023 New Jersey Student Learning Standards English Language Arts*
  ○ RI.CR.11–12.1., RI.CI.11–12.2., W.WR.11-12.5, W.WP.11–12.4, W.SE.11–12.6, SL.PI.11-12.4
● *2020 New Jersey Student Learning Standards: Computer Science and Design Thinking*
  ○ 8.1.12.DA.5-6
● *2020 New Jersey Student Learning Standards: Career Readiness, Life Literacies and Key Skills*
  ○ 9.4.2.CI.1-3, 9.4.12.CT.1-2, 9.4.12.TL.3	

Unit Essential Questions	**Unit Enduring Understandings**
● What determines the pressure of a gas? ● What is temperature? ● What is an ideal gas? ● How does heat flow between two systems in thermal contact due to temperature differences of those two systems? ● What makes up the internal energy of a system? ● What is the first law of thermodynamics? ● What is the work done on a system? ● How do you calculate the work done on a gas from a PV diagram? ● What determines the energy required to change the temperature of an object by a certain amount? ● What is the specific heat of a material? ● What determines the rate at which energy is transferred by	● Atoms in a gas collide with and exert forces on other atoms in the gas and with the container in which the gas is contained. The pressure exerted by a gas on a surface is the ratio of the sum of the magnitudes of the perpendicular components of the forces exerted by the gas's atoms on the surface to the area of the surface. Pressure exists throughout the gas itself, not just at the boundary between the gas and the container. ● The temperature of a system characterized by the average kinetic energy of the atoms within that system. ● The classical model of an ideal gas assumes that the instantaneous velocities of atoms are random, the volumes of the atoms are negligible compared to the total volume occupied by the gas, the atoms collide elastically, and the only appreciable forces on the atoms are those that occur during collisions. An ideal gas is one in which the relationships between pressure, volume, the number of moles or number of atoms, and temperature of a gas can be modeled using the equation $PV=nRT$. ● Two systems are in thermal contact if the systems may transfer energy by thermal processes. The thermal processes by which energy may be transferred between systems at different temperatures are conduction, convection, and radiation. Thermal equilibrium results when no net energy is transferred by thermal processes between two systems in thermal contact with each other. ● The internal energy of a system is the sum of the kinetic energy of the objects that make up the system and the potential energy of the configuration of those objects.An ideal gas does not have potential energy.

conduction through a given material? ● What is entropy?	● The first law of thermodynamics is a restatement of conservation of energy that accounts for energy transferred into or out of a system by work, heating, or cooling. ● The work done on a system by a constant or average external pressure that changes the volume of that system (for example, a piston compressing a gas in a container) is defined as $W = -P\Delta V$. ● The absolute value of the work done on a gas when the gas expands or compresses is equal to the area underneath the curve of a plot of pressure vs. volume for the gas. ● The amount of energy required to change the temperature of a material is related to the material's specific heat. ● The specific heat of a material is an intrinsic property of that material that depends on the arrangement and interactions of the atoms that make up the material. ● The rate at which energy is transferred by conduction through a given material is related to the thermal conductivity, the physical dimensions of the material, and the temperature difference across the material. ● Entropy can be qualitatively described as the tendency of energy to spread or the unavailability of some of the system's energy to do work. The second law of thermodynamics states that the total entropy of an isolated system can never decrease and is constant only when all processes the system undergoes are reversible.

Evidence of Learning		
Formative & Alternative Assessments: ● Classwork ● Homework ● Individual student check-ins with teacher ● Performance activities ● Lab: Boyle's Law Lab	**Benchmark & Summative Assessments:** ● Quizzes ● Chapter Test	**Resources Needed:** ● *College Physics by Raymond A. Serway & Chris Vuille, 11th Edition* ● AP Classroom ● Vernier Probes and Software

Unit X: Electric Force, Field, and Potential

Unit Summary

Unit X begins the study of electrostatic phenomena at a fundamental level, introducing students to the model of field forces. Despite the topical shift from gasses to charged particles, this unit continues the study of interactions and change. Unit X reinforces the idea that interactions can be described by forces, and that the electric force, like the other forces introduced in AP Physics 1, can be described with Newton's laws. Students are encouraged to apply fundamental physics principles studied in AP Physics 1 when learning about fields (gravitational and electric) and the forces experienced by objects in a field.

Standards/Core Ideas/Performance Expectations

The state standards outlined below, and established by New Jersey Department of Education, will guide instruction throughout this unit in *AP Physics 1 and 2:*

- *2020 New Jersey Student Learning Standards: Science*
  - HS-PS2-1, HS-PS2-3, HS-PS2-4, HS-PS2-5, HS-PS3-5
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  - MP.2, MP.4, N.Q.A.1-3, A.SSE.A.1 & B.3, A.CED.A.1-4, F-IF.C.7, S-IS.A.1, G.SRT.A.2, C.6-8
- *2023 New Jersey Student Learning Standards English Language Arts*
  - RI.CR.11–12.1., RI.CI.11–12.2., W.WR.11-12.5, W.WP.11–12.4, W.SE.11–12.6, SL.PI.11-12.4
- *2020 New Jersey Student Learning Standards: Computer Science and Design Thinking*
  - 8.1.12.DA.5-6
- *2020 New Jersey Student Learning Standards: Career Readiness, Life Literacies and Key Skills*
  - 9.4.2.CI.1-3, 9.4.12.CT.1-2, 9.4.12.TL.3

Unit Essential Questions	**Unit Enduring Understandings**

• What is the electric force that results from the interactions between charged objects or systems? • What are the traits of the electric and gravitational forces that result from interactions between charged objects with mass? • What determines the electric permittivity of a material or medium? • What is the difference between conductors and insulators? • What is the conservation of charge? • What is grounding? • How is an electric field produced by a charged object or configuration of point charges? • How are electric fields generated by charged conductors or insulators? • What is the electric potential energy of a system? • How is the electric potential affected due to a configuration of charged objects? • What is the relationship between electric potential and electric field? • What are isolines and how are they related to the electric field vector map? • What are the physical properties of a parallel-plate capacitor? • What is capacitance? • How is an electric field created between the plates of a capacitor? • How are changes in energy in a system affected by a difference in electric potential between two locations?	• Coulomb's law describes the electrostatic force between two charged objects as directly proportional to the magnitude of each of the charges and inversely proportional to the square of the distance between the objects. The direction of the electrostatic force depends on the signs of the charges of the interacting objects and is parallel to the line of separation between the objects. • Electrostatic forces can be attractive or repulsive, while gravitational forces are always attractive. For any two objects that have mass and electric charge, the magnitude of the gravitational force is usually much smaller than the magnitude of the electrostatic force. Gravitational forces dominate at larger scales even though they are weaker than electrostatic forces, because systems at large scales tend to be electrically neutral. • Electric permittivity is a measurement of the degree to which a material or medium is polarized in presence of an electric field. The permittivity of matter has a value different from that of free space that arises from the matter's composition and arrangement. • Conductors are made from electrically conducting materials in which charge carriers move easily; insulators are made from electrically nonconducting materials in which charge carriers cannot move easily. • Any change to a system's net charge is due to a transfer of charge between the system and its surroundings. The charging of a system typically involves the transfer of electrons to and from the system. • Grounding involves electrically connecting a charged system to a much larger and approximately neutral system (e.g., Earth). • The electric field at a given point is the ratio of the electric force exerted on a test charge at that point to the charge of the test charge. An electric field points away from isolated positive charges and toward isolated negative charges. The net electric field at a given location is the vector sum of individual electric fields created by nearby charged objects. • While in electrostatic equilibrium, the excess charge of a solid conductor is distributed on the surface of the conductor, and the electric field within the conductor is zero. • While in electrostatic equilibrium, the excess charge of an insulator is distributed throughout the interior of the insulator as well as at the surface, and the electric field within the insulator may have a non zero value. • The electric potential energy of a system of two point charges equals the amount of work required for an external force to bring the point charges to their current positions from infinitely far away. The total electric potential energy of a system can be determined by finding the sum of the electric potential energies of the individual interactions between each pair of charged objects in the system. • Electric potential describes the electric potential energy per unit charge at a point in space. The electric potential due to multiple point charges can be determined by the principle of scalar superposition of the electric potential due to each of the point charges. • The average electric field between two points in space is equal to the electric potential difference between the two points divided by the distance between the two points. • Equipotential lines represent lines of equal electric potential in space. These lines are also referred to as isolines of electric potential. Isolines are perpendicular to electric field vectors. • A parallel-plate capacitor consists of two separated parallel conducting surfaces that can hold equal amounts of charge with opposite signs. • Capacitance relates the magnitude of the charge stored on each plate to the electric potential difference created by the separation of those charges.

	• The electric field between two charged parallel plates with uniformly distributed electric charge,such as in a parallel-plate capacitor, is constant in both magnitude and direction, except near the edges of the plates. • When a charged object moves between two locations with different electric potentials, the resulting change in the electric potential energy of the object-field system is given by the following equation $\Delta U = q\Delta V$. The movement of a charged object between two points with different electric potentials results in a change in kinetic energy of the object consistent with the conservation of energy.

Evidence of Learning		
Formative & Alternative Assessments: • Classwork • Homework • Individual student check-ins with teacher • Performance activities • Lab: Van de Graff Generator Lab	**Benchmark & Summative Assessments:** • Quizzes • Chapter Test	**Resources Needed:** • *College Physics by Raymond A. Serway & Chris Vuille, 11th Edition* • AP Classroom • Vernier Probes and Software

Unit XI: Electric Circuits
Unit Summary
Unit XI revisits the behavior of charged particles to deepen students' understanding of the law of conservation of energy and its application to electric circuits. This unit requires more than calculating currents, resistances, and potential differences in a simple circuit. For example, students must be able to articulate the impact of a light bulb being removed from a circuit. They should also practice designing an experiment, for example, to test if a light bulb is ohmic or justify how and why circuit elements in series and parallel affect the properties of a circuit. In Unit XII, students will expand their investigations of the similarities and differences between electric and magnetic fields.
Standards/Core Ideas/Performance Expectations
The state standards outlined below, and established by New Jersey Department of Education, will guide instruction throughout this unit in *AP Physics 1 and 2:* • *2020 New Jersey Student Learning Standards: Science* ○ HS-PS2-1, HS-PS2-2, HS-PS2-3, HS-PS2-4, HS-PS2-5, HS-PS3-5 • *2023 New Jersey Student Learning Standards: Mathematics* ○ MP.2, MP.4, N.Q.A.1, N.Q.A.2, N.Q.A.3, A.SSE.A.1, A.SSE.B.3, A.CED.A.1, A.CED.A.2, A.CED.A.4, F-IF.C.7, S-IS.A.1 • *2023 New Jersey Student Learning Standards English Language Arts* ○ RI.CR.11–12.1., RI.CI.11–12.2., W.WR.11-12.5, W.WP.11–12.4, W.SE.11–12.6, SL.PI.11-12.4 • *2020 New Jersey Student Learning Standards: Computer Science and Design Thinking* ○ 8.1.12.DA.5-6 • *2020 New Jersey Student Learning Standards: Career Readiness, Life Literacies and Key Skills* ○ 9.4.2.CI.1-3, 9.4.12.CT.1-2, 9.4.12.TL.3

Unit Essential Questions	Unit Enduring Understandings
• What is current? • What is the direction of the flow of current? • What is a circuit? • What is the resistance of an object using physical properties of that object? • What is resistivity? • What is Ohm's Law? • How is energy transferred into, out of, or within an electric	• Current is the rate at which charge passes through a cross-sectional area of a wire. • Although current is not a vector quantity, it does have a direction. The direction of current is associated with what the motion of positive charge would be but not with any coordinate system in space. • A circuit is composed of electrical loops, which may include circuit elements such as wires, batteries, resistors, lightbulbs, capacitors, switches, ammeters, and voltmeters. A closed electrical loop is a closed path through which charges may flow. • Resistance is a measure of the degree to which an object opposes the movement of electric charge. The resistance of a resistor with uniform

circuit, in terms of power? ● How can you find the equivalent resistance of multiple resistors connected in a circuit? ● What are ideal batteries and wires? ● How do you measure current in a circuit? ● How do you measure the potential difference in a circuit? ● How do you apply Kirchhoff's loop rule to a circuit? ● How do you apply Kirchhoff's junction rule? ● What is the equivalent capacitance of multiple capacitors? ● How does a circuit behave with different combinations of resistors and capacitors?	geometry is proportional to its resistivity and length and is inversely proportional to its cross-sectional area. ● Resistivity is a fundamental property of a material that depends on its atomic and molecular structure and quantifies how strongly the material opposes the motion of electric charge. ● Ohm's law relates current, resistance, and potential difference across a conductive element of a circuit. Materials that obey Ohm's law have constant resistance for all currents and are called ohmic materials. ● The rate at which energy is transferred, converted, or dissipated by a circuit element depends on the current in the element and the electric potential difference across it. The brightness of a bulb increases with power, so power can be used to qualitatively predict the brightness of bulbs in a circuit. ● Circuit elements may be connected in series and/or in parallel. The equivalent resistance of a set of resistors in series is the sum of the individual resistances. The inverse of the equivalent resistance of a set of resistors connected in parallel is equal to the sum of the inverses of the individual resistances. ● Ideal batteries have negligible internal resistance. Ideal wires have negligible resistance. ● Ammeters are used to measure current at a specific point in a circuit. Ammeters must be connected in series with the element in which current is being measured. Ideal ammeters have zero resistance so that they do not affect the current in the element that they are in series with. ● Voltmeters are used to measure electric potential difference between two points in a circuit. Voltmeters must be connected in parallel with the element across which potential difference is being measured. Ideal voltmeters have infinite resistance so that no charge flows through them. ● Energy changes in simple electrical circuits may be represented in terms of charges moving through electric potential differences within circuit elements. Kirchhoff's loop rule states that the sum of potential differences across all circuit elements in a single closed loop must equal zero. ● Kirchhoff's junction rule is a consequence of the conservation of electric charge. Kirchhoff's junction rule states that the total amount of charge entering a junction per unit time must equal the total amount of charge exiting that junction per unit time. ● The inverse of the equivalent capacitance of a set of capacitors connected in series is equal to the sum of the inverses of the individual capacitances. The equivalent capacitance of a set of capacitors in parallel is the sum of the individual capacitances. ● Immediately after being placed in a circuit, an uncharged capacitor acts like a wire, and charge can easily flow to or from the plates of the capacitor. As a capacitor discharges, the amount of charge on the capacitor, the potential difference across the capacitor,and the current in the circuit branch in which the capacitor is located all decrease until a steady state is reached.

Evidence of Learning		
Formative & Alternative Assessments: ● Classwork ● Homework ● Individual student check-ins with teacher ● Performance activities ● Labs:	**Benchmark & Summative Assessments:** ● Quizzes ● Chapter Test	**Resources Needed:** ● *College Physics by Raymond A. Serway & Chris Vuille, 11th Edition* ● AP Classroom ● Vernier Probes and Software

1. Ohm's Law Lab 2. Series and Parallel Circuits Lab 3. Capacitors Lab		

Unit XII: Magnetism and Electromagnetism	
Unit Summary	
In Unit XII, students will build upon their knowledge of electrostatic forces, fields, free charges, and circuits by exploring the relationships between moving charges, the magnetic fields they generate, and the magnetic forces that act on other moving charges in those fields. Students will discover the natural symmetry between electricity and magnetism and how electromagnetic induction powers technology in modern society.	
Standards/Core Ideas/Performance Expectations	
The state standards outlined below, and established by New Jersey Department of Education, will guide instruction throughout this unit in *AP Physics 1 and 2:* ● *2020 New Jersey Student Learning Standards: Science* ○ HS-PS2-1, HS-PS2-2, HS-PS2-3, HS-PS2-4, HS-PS2-5, HS-PS3-5 ● *2023 New Jersey Student Learning Standards: Mathematics* ○ MP.2, MP.4, N.Q.A.1-3, A.SSE.A.1 & B.3, A.CED.A.1-4, F-IF.C.7, S-IS.A.1, G.SRT.A.2, C.6-8 ● *2023 New Jersey Student Learning Standards English Language Arts* ○ RI.CR.11–12.1., RI.CI.11–12.2., W.WR.11-12.5, W.WP.11–12.4, W.SE.11–12.6, SL.PI.11-12.4 ● *2020 New Jersey Student Learning Standards: Computer Science and Design Thinking* ○ 8.1.12.DA.5-6 ● *2020 New Jersey Student Learning Standards: Career Readiness, Life Literacies and Key Skills* ○ 9.4.2.CI.1-3, 9.4.12.CT.1-2, 9.4.12.TL.3	
Unit Essential Questions	**Unit Enduring Understandings**
● What is a magnetic field? ● What is the nature of magnetic field lines? ● What is the magnetic behavior of a material as a result of the configuration of magnetic dipoles in the material? ● What is the difference between ferromagnetic and paramagnetic materials? ● What is the magnetic permeability of a material? ● How is a magnetic field produced by moving charged objects? ● What is the force exerted on moving charged objects by a magnetic field? ● What is the Hall Effect? ● How is a magnetic field produced by a long current carrying wire? ● How is the magnetic field due to two or more current carrying conductors determined? ● What is the force exerted on a current-carrying wire by a magnetic field? ● What is magnetic flux?	● A magnetic field is a vector field that can be used to determine the magnetic force exerted on moving electric charges, electric currents, or magnetic materials. ● Magnetic field lines form closed loops. Magnetic fields in a bar magnet form closed loops,with the external magnetic field pointing away from one end(defined as the north pole) and returning to the other end (defined as the southpole). ● Magnetic dipoles result from the circular or rotational motion of electric charges. In magnetic materials, this can be the motion of electrons. Permanent magnetism and induced magnetism are system properties that both result from the alignment of magnetic dipoles within a system. The magnitude of the magnetic field from a magnetic dipole decreases with increasing distance from the dipole. ● Ferromagnetic materials such as iron, nickel, and cobalt can be permanently magnetized by an external field that causes the alignment of magnetic domains or atomic magnetic dipoles.Paramagnetic materials such as aluminum, titanium, and magnesium interact weakly with an external magnetic field, in that the magnetic dipoles of the material do not remain aligned after the external field is removed. ● Magnetic permeability is a measurement of the amount of magnetization in a material in response to an external magnetic field. The permeability of matter has values different from that of free space and arises from the matter's composition and arrangement. ● A single moving charged object produces a magnetic field at any point which depends on the object's velocity and the distance between the point and the object. The direction of the magnetic field is perpendicular to both the velocity and the position vector from the object to that point and it is determined by the right-hand rule. ● The magnitude of the force exerted by a magnetic field on a moving

● What is Faraday's Law? ● What is Lenz's Law?	charged object is proportional to the magnitude of the charge, the magnitude of the charged object's velocity, and the magnitude of the magnetic field andalso depends on the angle between the velocity and magnetic field vectors. The direction of the force exerted by a magnetic field on a moving charged object is perpendicular to both the direction of the magnetic field and the velocity of the charge,as defined by the right-hand rule. ● The Hall effect describes the potential difference created in a conductor by an external magnetic field that has a component perpendicular to the direction of charges moving in the conductor. ● The magnetic field vectors around a long, straight, current-carrying wire are tangent to concentric circles centered on that wire. The field has no component toward, away from, or parallel to the long, straight, current-carrying wire. At a point in space, the magnitude of the magnetic field due to a long,straight,current carrying wire is proportional to the magnitude of the current in the wire and inversely proportional to the perpendicular distance from the central axis of the wire to the point. ● The magnetic field at a location near two or more current-carrying wires can be determined using vector addition principles. ● A magnetic field may exert a force on a current carrying wire. The magnitude of the force exerted by a magnetic field on a current-carrying wire is proportional to the current, the length of the portion of the wire within the magnetic and the magnitude of the magnetic field, and also depends on the angle between the direction of the current in the wire and the direction of the magnetic field. The direction of the force is determined by the right-hand rule. ● Magnetic flux is a description of the amount of the component of a magnetic field that is perpendicular to a cross-sectional area. Magnetic flux through a surface is proportional to the magnitude of the component of the magnetic field perpendicular to the surface and to the cross-sectional area of the surface. ● Faraday's law describes the relationship between changing magnetic flux and the resulting induced emf in a system. ● Lenz's law is used to determine the direction of an induced emf resulting from a changing magnetic flux. An induced emf generates a current that creates a magnetic field that opposes the change in magnetic flux.

Evidence of Learning		
Formative & Alternative Assessments: ● Classwork ● Homework ● Individual student check-ins with teacher ● Performance activities ● Lab: Magnetic Field in a Slinky Lab	**Benchmark & Summative Assessments:** ● Quizzes ● Chapter Test ● Summative 3	**Resources Needed:** ● *College Physics by Raymond A. Serway & Chris Vuille, 11th Edition* ● AP Classroom ● Vernier Probes and Software

Unit XIII: Geometric Optics
Unit Summary
Unit XIII demonstrates another distinct shift in both content and the models used to analyze physical scenarios. In this unit, students will be introduced to the different ways of thinking about and modeling light. This unit will focus on using the ray model of light to determine the images formed by mirrors as a result of reflection and the images formed by lenses as a result of refraction. Students will be challenged to confront their misconceptions about light, including why objects are not always located where they are seen.
Standards/Core Ideas/Performance Expectations

The state standards outlined below, and established by New Jersey Department of Education, will guide instruction throughout this unit in *AP Physics 1 and 2:*

- *2020 New Jersey Student Learning Standards: Science*
    - HS-PS2-1, HS-PS2-2, HS-PS2-3, HS-PS2-4
- *2023 New Jersey Student Learning Standards: Mathematics*
    - MP.2, MP.4, N.Q.A.1-3, A.SSE.A.1 & B.3, A.CED.A.1-4, F-IF.C.7, S-IS.A.1, G.SRT.A.2, C.6-8
- *2023 New Jersey Student Learning Standards English Language Arts*
    - RI.CR.11–12.1., RI.CI.11–12.2., W.WR.11-12.5, W.WP.11–12.4, W.SE.11–12.6, SL.PI.11-12.4
- *2020 New Jersey Student Learning Standards: Computer Science and Design Thinking*
    - 8.1.12.DA.5-6
- *2020 New Jersey Student Learning Standards: Career Readiness, Life Literacies and Key Skills*
    - 9.4.2.CI.1-3, 9.4.12.CT.1-2, 9.4.12.TL.3

Unit Essential Questions	Unit Enduring Understandings
• How can light be described as a ray? • How does light reflect from a surface? • What is the difference between real and virtual images? • What is the image formed by a plane mirror? • What is the image formed by a concave mirror? • How is light refected between two media? • What is total internal reflection? • Under what circumstances will a real image be formed by a lens? • Under what circumstances will a virtual image be formed by a lens? • What type of image is formed by a converging lens? • What type of image is formed by a diverging lens? • What are ray diagrams?	• A light ray is a straight line that is perpendicular to the wavefront of a light wave and points in the direction of travel of the wave. • Light that is incident on a surface can be reflected. The law of reflection states that the angle between the incident ray and the normal (the line perpendicular to the surface) is equal to the angle between the reflected ray and the normal. Diffuse reflection is the reflection of light from a rough surface and results in light reflected in many different directions, because the line normal to the surface varies over the area over which the light is incident. Specular reflection is the reflection of light from a smooth surface and results in light uniformly reflected from the surface, because the line normal to the surface has an approximately constant direction over the area the light strikes. • A real image is formed by a mirror when light rays emanating from a common point are reflected and then intersect at a common point. A virtual image is formed by a mirror when reflected light rays diverge such that they appear to have originated from a common point. • The image formed by a plane mirror is the same size as the object, is the same distance behind the mirror as the object is in front of the mirror, and is always virtual. • The image formed by a concave mirror can be real or virtual depending on the location of the object from the mirror. • Refraction is the change in direction of a light ray as the ray passes from one medium into another. Refraction is a result of the speed of light changing when light enters a new medium • Total internal reflection may occur when light passes from one medium into another medium with a lower index of refraction. • A real image is formed by a lens when light rays originating from a common point are refracted such that they intersect at another common point. • A virtual image is formed by a lens when refracted light rays diverge such that they appear to have originated from a common point. • The image formed by a converging lens can be real or virtual, enlarged or reduced or the same size, depending on the location of the object from the lens. • The image formed by a diverging lens is always virtual and smaller in size compared with the object. • Ray diagrams can be used to determine the location, type, size,and orientation of images formed by lenses. The three principal rays are typically used to find the images formed by lenses.The principal rays are 1) the ray parallel to the principal axis, 2) the ray that passes through the center of the lens where the principal axis intersects the lens, and 3) the ray that passes through the focal point of the lens.

Evidence of Learning		
Formative & Alternative Assessments: ● Classwork ● Homework ● Individual student check-ins with teacher ● Performance activities ● Lab: Images Lab (formed by thin lenses and concave mirrors)	**Benchmark & Summative Assessments:** ● Quizzes ● Chapter Test	**Resources Needed:** ● *College Physics by Raymond A. Serway & Chris Vuille, 11th Edition* ● AP Classroom ● Vernier Probes and Software

Unit XIV: Waves, Sound, and Physical Optics	
Unit Summary	
In Unit XIV, students will investigate the behavior of waves, including a focused look at sound waves. The study of waves includes ways to quantify a wave, such as amplitude, wavelength, period, frequency, and wave speed, and how light can be modeled as a wave. This unit will also address the concepts of diffraction and interference, polarization, the Doppler effect, and thin-film interference. The end of Unit XIV leaves an open question of whether light should be considered a wave or a particle, which will be further studied in Unit XV.	
Standards/Core Ideas/Performance Expectations	
The state standards outlined below, and established by New Jersey Department of Education, will guide instruction throughout this unit in *AP Physics 1 and 2:* ● *2020 New Jersey Student Learning Standards: Science* ○ HS-PS2-1, HS-PS2-2, HS-PS2-3, HS-PS2-4, HS-PS2-5 ● *2023 New Jersey Student Learning Standards: Mathematics* ○ MP.2, MP.4, N.Q.A.1-3, A.SSE.A.1 & B.3, A.CED.A.1-4, F-IF.C.7, S-IS.A.1, G.SRT.A.2, C.6-8 ● *2023 New Jersey Student Learning Standards English Language Arts* ○ RI.CR.11–12.1., RI.CI.11–12.2., W.WR.11-12.5, W.WP.11–12.4, W.SE.11–12.6, SL.PI.11-12.4 ● *2020 New Jersey Student Learning Standards: Computer Science and Design Thinking* ○ 8.1.12.DA.5-6 ● *2020 New Jersey Student Learning Standards: Career Readiness, Life Literacies and Key Skills* ○ 9.4.2.CI.1-3, 9.4.12.CT.1-2, 9.4.12.TL.3	
Unit Essential Questions	**Unit Enduring Understandings**

● What are waves? ● What is a wave pulse? ● What is the difference between mechanical and electromagnetic waves? ● What does the speed of a wave in a string depend on? ● What is the difference between transverse and longitudinal waves? ● What are sound waves? ● What does the loudness of sound depend on? ● What are the physical properties of a periodic wave? ● What is the relation between speed, wavelength, and frequency of a periodic wave? ● How does a wave interact with a boundary? ● What is the polarization of waves? ● What are the properties of an electromagnetic wave? ● What are the properties of a wave based on the relative motion between the source of the wave and the observer of the wave? ● What is wave interference? ● What occurs when two or more wave pulses or waves overlap? ● What is the difference between constructive and destructive interference? ● What is the phenomenon of beats? ● What are the properties of a standing wave? ● What is the behavior of a wave and the diffraction pattern resulting from a wave passing through a single opening? ● What is the behavior of a wave and the diffraction pattern resulting from the wave passing through a double slit? ● What is the behavior of a wave and the diffraction pattern resulting from the wave passing through a diffraction grating? ● How does the phase change of a reflected ray at a boundary? ● What is thin film interference?	● Waves transfer energy between two locations without transferring matter between those locations. ● A wave pulse is a single disturbance that transfers energy without transferring matter between two locations. ● Mechanical waves or wave pulses require a medium in which to propagate. Electromagnetic waves or wave pulses do not require a medium in which to propagate. ● The speed at which a wave pulse or wave propagates along a string is dependent upon the tension in the string, and the mass per length of the string. ● In a transverse wave, the direction of the disturbance is perpendicular to the direction of propagation of the wave. In a longitudinal wave, the direction of the disturbance is parallel to the direction of propagation of the wave. ● Sound waves are modeled as mechanical longitudinal waves. The regions of high and low pressure in a sound wave are called compressions and rarefactions, respectively. In a given medium, the speed of sound waves increases with the temperature of the medium. ● The loudness of a sound increases with increasing amplitude. The amplitude of a longitudinal pressure wave may be determined by the maximum increase or decrease in pressure from equilibrium pressure. ● Periodic waves have regular repetitions that can be described using period and frequency. The period is the time for one complete oscillation of the wave. The frequency is the rate at which the wave repeats. ● For a periodic wave, the wavelength is proportional to the wave's speed and inversely proportional to the wave's frequency. ● A wave that travels from one medium to another can be transmitted or reflected, depending on the properties of the boundary separating the two media. A wave traveling from one medium to another (for example, a wave traveling between low-mass and high-mass strings) will result in reflected and transmitted waves. A reflected wave is inverted if the transmitted wave travels into a medium in which the speed of the wave decreases. A reflected wave is not inverted if the transmitted wave travels into a medium in which the speed of the wave increases. The frequency of a wave does not change when it travels from one medium to another. ● Transverse waves that are reflected from a surface, refracted through a medium, or pass through specific openings may be polarized. Longitudinal waves cannot be polarized. Polarization of a wave may result in a reduction of the wave's intensity. ● Electromagnetic waves are transverse waves which do no require a medium through which to propagate and consist of oscillating electric and magnetic fields that are mutually perpendicular. ● The Doppler effect describes the relationship between the rest frequency of a wave source, the observed frequency of the source, and the relative velocity of the source and the observer. For a wave source moving at the same velocity as the observer, the observed frequency is equal to the rest frequency. For a wave source moving toward an observer, the observed frequency is greater than the rest frequency. For a wave source moving away from an observer, the observed frequency is less than the rest frequency. ● Wave interference is the interaction of two or more wave pulses or waves. ● When two or more wave pulses or waves interact with each other, they travel through each other and overlap rather than bouncing off each other, and the resulting displacement can be determined by adding the individual displacements. This is called superposition. ● When the displacements of the superposed wave pulses or waves are in the same direction, the interaction is called constructive interference. When

	the displacements of the superposed wave pulses or waves are in opposite directions, the interaction is called destructive interference. ● Beats arise from the addition of two waves of slightly different frequency. The beat frequency is the difference in the frequencies of the two waves. Tuning forks are devices that are commonly used to demonstrate beat frequencies. ● Standing waves can result from interference between two waves that are confined to a region and traveling in opposite directions. Standing waves have nodes and antinodes. A node is a point on the standing wave where the amplitude is always zero. An antinode is a point on the standing wave where the amplitude is always at maximum. The possible wavelengths of a standing wave are determined by the size and boundary conditions of the region to which it is confined. Common regions where standing waves can form include pipes with open or closed ends, as well as strings with fixed or loose ends. A standing wave with the longest possible wavelength is called the fundamental or first harmonic. The second-longest wavelength is typically called the second harmonic, the third longest wavelength is called the third harmonic, and so on. However, for a standing wave with a node at one end and an antinode at the other end, only odd harmonics can be established. ● Diffraction is the spreading of a wave around the edges of an obstacle or through an opening. It is most pronounced when the size of the opening is comparable to the wavelength of the wave. Diffraction of multiple wavefronts through a single opening leads to observable interference patterns. The diffraction pattern produced by a wave passing through an opening depends on the shape of the opening. ● The pattern resulting from monochromatic light incident on two slits a distance d apart is caused by a combination of wave diffraction and wave interference. When only considering wave interference, a double slit creates a pattern of uniformly spaced maxima. When considering wave interference and wave diffraction, a double slit creates an interference pattern of maxima and minima superimposed within the envelope created by single-slit diffraction. ● A diffraction grating is a collection of evenly spaced parallel slits or openings that produce an interference pattern that is the combination of numerous diffraction patterns superimposed on each other. When white light is incident on a diffraction grating, the center maximum is white and the higher-order maxima disperse white light into a rainbow of colors, with the longest-wavelength light (red) appearing farthest from the central maximum. ● The phase change of a reflected ray depends on the relative indices of refraction of the materials with which the ray interacts. A phase change of 180 degrees occurs when a light ray is reflected from a medium with a greater index of refraction than the medium through which the ray is traveling. No phase change occurs when a light ray is reflected from a medium with a lower index of refraction than the medium through which the ray is traveling. The phase of a wave does not change when it is refracted as it passes from one medium into another. ● Thin-film interference occurs when light interacts with a medium whose thickness is comparable to the light's wavelength. The interactions between the initial reflected light and the light exiting the thin film after being reflected from the second interface exhibit wave interference behavior, resulting in a single wave that is the sum of the two interacting waves. The amount of constructive or destructive interference between the two reflected waves depends on the relationship between the thickness of

	the film,the wavelength of light, any phase shifts, and the angle at which the incident light strikes the film.

Evidence of Learning		
Formative & Alternative Assessments: ● Classwork ● Homework ● Individual student check-ins with teacher ● Performance activities ● Lab: Diffraction Lab	**Benchmark & Summative Assessments:** ● Quizzes ● Chapter Test	**Resources Needed:** ● *College Physics by Raymond A. Serway & Chris Vuille, 11th Edition* ● AP Classroom ● Vernier Probes and Software

Unit XV: Modern Physics

Unit Summary

Unit 1XV lays the groundwork for the study of modern physics by resolving the conflicts and unanswered questions from Units XIII and XIV. While Unit XV introduces new models and representations (such as energy level diagrams), students will make connections between this unit's content, the fundamental principles of physics, principles of conservation, and models and representations used earlier in the course. These connections will help students make predictions about a variety of phenomena—including radioactive decay rates or nuclear reaction types—and make and justify claims with evidence. Students will also revisit the wave particle duality of light through their investigations of phenomena such as the photoelectric effect.

Standards/Core Ideas/Performance Expectations

The state standards outlined below, and established by New Jersey Department of Education, will guide instruction throughout this unit in *AP Physics 1 and 2:*

- *2020 New Jersey Student Learning Standards: Science*
  - HS-PS2-1, HS-PS2-2, HS-PS2-3, HS-PS2-4
- *2023 New Jersey Student Learning Standards: Mathematics*
  - MP.2, MP.4, N.Q.A.1-3, A.SSE.A.1 & B.3, A.CED.A.1-4, F-IF.C.7, S-IS.A.1, G.SRT.A.2, C.6-8
- *2023 New Jersey Student Learning Standards English Language Arts*
  - RI.CR.11–12.1., RI.CI.11–12.2., W.WR.11-12.5, W.WP.11–12.4, W.SE.11–12.6, SL.PI.11-12.4
- *2020 New Jersey Student Learning Standards: Computer Science and Design Thinking*
  - 8.1.12.DA.5-6
- *2020 New Jersey Student Learning Standards: Career Readiness, Life Literacies and Key Skills*
  - 9.4.2.CI.1-3, 9.4.12.CT.1-2, 9.4.12.TL.3

Unit Essential Questions	Unit Enduring Understandings
● What are the properties and behavior of an object that exhibits both particle-like and wave-like behavior? ● What are the properties of an atom? ● What is the Bohr model of the atom? ● How are photons emitted or absorbed by atoms? ● What is the difference between emission spectrum and absorption spectrum? ● What is binding energy? ● What is a blackbody? ● How is electromagnetic radiation emitted by an object due to its temperature? ● What is the photoelectric effect?	● In quantum theory, fundamental particles can exhibit both particle-like and wave-like behavior. Light can be modeled both as a wave and as discrete particles, called photons. Particles can demonstrate wave properties, as shown by variation of Young's double-slit experiment. Quantum theory is necessary to describe systems where the de Broglie wavelength is comparable to the size of the system. ● Atoms have internal structure. Atoms consist of a small, positively charged nucleus surrounded by one or more negatively charged electrons. The nucleus of an atom is made up of protons and neutrons. ● In the Bohr model of the atom, electrons are modeled as moving around the nucleus in circular orbits determined by the electron's charge and mass, as well as the electric force between the electron and the nucleus. The standing wave model of electrons accounts for the existence of specific allowed energy states of an electron in an atom, because the electron orbit's circumference must be an integer multiple of the electron's de Broglie wavelength. ● Energy transfer occurs when photons are absorbed or emitted by an atom, which is modeled as a system consisting of a nucleus and an electron. Energy can only be absorbed or emitted by an atom if the

● What interactions occur between photons and matter using the photoelectric effect? ● What interactions occur between photons and matter using Compton scattering? ● What physical properties constrain the behavior of interacting nuclei, subatomic particles, and nucleons? ● What is the difference between nuclear fusion and fission? ● How is the radioactive decay of a given sample of material consisting of a finite number of nuclei described?. ● How do individual nuclei decay?	amount of energy being absorbed or emitted corresponds to the energy difference between two atomic energy states. Transitions between two energy states of an atom correspond to the absorption or emission of a photon of a single frequency and, therefore, a single wavelength. ● An emission spectrum can be used to determine the elements in a source of light. An absorption spectrum can be used to determine the elements composing a substance by observing what light the substance has absorbed. ● Binding energy is the energy required to remove an electron from an atom, causing the atom to become ionized. An atom in the lowest energy level (ground state) will require the greatest amount of energy to remove the electron from the atom. ● A black body is an idealized model of matter that absorbs all radiation that falls on the body. If the body is in equilibrium at a constant temperature, then it must in turn emit energy. ● A blackbody will emit a continuous spectrum that only depends on the body's temperature. The radiation emitted by a blackbody is often modeled by plotting intensity per unit wavelength as a function of wavelength. The peak wavelength emitted by a blackbody (the wavelength at which the blackbody emits the greatest amount of radiation per unit wavelength) decreases with increasing temperature, as described by Wien's law. The rate at which energy is emitted (power) by a blackbody is proportional to the surface area of the body and to the temperature of the body raised to the fourth power, as described by the Stefan Boltzmann law. ● The photoelectric effect is the emission of electrons when electromagnetic radiation is incident upon a photoactive material. ● The emission of electrons via the photoelectric effect requires a minimum frequency of incident light, called the threshold frequency. Light that is incident on a material and is at the threshold frequency or higher will induce electron emission, regardless of the number of photons that strike the material. The energy of the emitted electrons is not dependent on the number of photons that are incident upon the material, which provides evidence that light is a collection of discrete, quantized energy packets called photons. The maximum kinetic energy of an emitted electron is related to the frequency of the incident light and the work function of the material. ● In Compton scattering, a photon interacts with a free electron. The Compton effect is when a photon that emerges from the interaction has a lower energy and longer wavelength than the incoming photon. The magnitude of the change is related to the direction of the photon after the collision. Compton scattering provides evidence that light is a collection of discrete, quantized energy packets called photons. ● The strong force is exerted at nuclear scales and dominates the interactions of nucleons (protons or neutrons). Possible nuclear reactions and the behavior of the constituent particles of a nuclear reaction is constrained by laws of conservation of energy, energy-mass equivalence, and conservation of momentum. ● Nuclear fusion is the process by which two or more smaller nuclei combine to form a larger nucleus, as well as subatomic particles. Nuclear fission is the process by which the nucleus of an atom splits into two or more smaller nuclei, as well as subatomic particles. ● Radioactive decay is the spontaneous transformation of a nucleus into one or more different nuclei. The time at which an individual nucleus undergoes radioactive decay is indeterminable, but decay rates can be described using probability.

	• Nuclei can undergo radioactive decay via alpha decay, beta-minus decay, beta-plus decay, and gamma decay. Alpha decay occurs when a nucleus ejects an alpha particle. Beta-minus decay occurs when a neutron changes to a proton by emitting an electron and antineutrino. Beta-plus decay occurs when a proton changes to a neutron by emitting a positron and neutrino. Gamma decay occurs after a nucleus has undergone alpha or beta decay and the excited nucleus decays to a lower energy state by emitting a photon.

Evidence of Learning		
Formative & Alternative Assessments: • Classwork • Homework • Individual student check-ins with teacher • Performance activities • Lab: PHET Photoelectric Simulation Lab	**Benchmark & Summative Assessments:** • Released AP Questions	**Resources Needed:** • *College Physics by Raymond A. Serway & Chris Vuille, 11th Edition* • AP Classroom • Vernier Probes and Software

Unit XVI: Project		
Unit Summary		
Students will research a topic of their choosing in the field of science or engineering and will prepare a presentation to share with their class.		
Standards/Core Ideas/Performance Expectations		

The state standards outlined below, and established by New Jersey Department of Education, will guide instruction throughout this unit in *AP Physics 1 and 2:*
• *2020 New Jersey Student Learning Standards: Science*
  ○ HS-PS2-1, HS-PS2-2, HS-PS2-3, HS-PS2-4, HS-PS2-5
• *2023 New Jersey Student Learning Standards: Mathematics*
  ○ MP.2, MP.4, N.Q.A.1-3, A.SSE.A.1 & B.3, A.CED.A.1-4, F-IF.C.7, S-IS.A.1, G.SRT.A.2, C.6-8
• *2023 New Jersey Student Learning Standards English Language Arts*
  ○ RI.CR.11–12.1., RI.CI.11–12.2., W.WR.11-12.5, W.WP.11–12.4, W.SE.11–12.6, SL.PI.11-12.4
• *2020 New Jersey Student Learning Standards: Computer Science and Design Thinking*
  ○ 8.1.12.DA.5-6
• *2020 New Jersey Student Learning Standards: Career Readiness, Life Literacies and Key Skills*
  ○ 9.4.2.CI.1-3, 9.4.12.CT.1-2, 9.4.12.TL.3		

Unit Essential Questions	**Unit Enduring Understandings**	
• What field of science or engineering does the student find interesting?	• Students will pick a topic that they find interesting and will explore it further.	
Evidence of Learning		
Formative & Alternative Assessments: • Classwork • Homework • Individual student check-ins with teacher • Performance activities	**Benchmark & Summative Assessments:** • Final Project	**Resources Needed:** • *College Physics by Raymond A. Serway & Chris Vuille, 11th Edition* • AP Classroom • Vernier Probes and Software

Section X: Unit Reflection

The *AP Physics 1 and 2* instructional team must confer upon the completion of each instructional unit in the *AP Physics 1 and 2* curriculum and rate the degrees to which the instructional units meet performance criteria established by the New Jersey Department of Education using the Unit Reflection Form. Completed unit reflection forms must be submitted to the Department Supervisor for approval upon completion of curriculum implementation with a complementing list of suggested modifications to the *AP Physics 1 and 2* curriculum.

Unit Reflection Form: *AP Physics 1 and 2*			
Lesson Activities:	**Strongly**	**Moderately**	**Weakly**
Foster student use of technology as a tool to develop critical thinking, creativity and innovation skills;			
Are challenging and require higher order thinking and problem-solving skills;			
Allow for student choice;			
Provide scaffolding for acquiring targeted knowledge/skills;			
Integrate modern, global perspectives, especially those regarding diversity, genocide, global issues, and historical ones regarding racial relations;			
Integrate 21st century skills;			
Provide opportunities for interdisciplinary connection and transfer of knowledge and skills;			
Are varied to address different student learning styles and preferences;			
Are differentiated based on student needs;			
Are student-centered with teacher acting as a facilitator and co-learner during the teaching and learning process;			
Provide means for students to demonstrate knowledge and skills and progress in meeting learning goals and objectives;			
Provide opportunities for student reflection and self-assessment;			
Provide data to inform and adjust instruction to better meet the varying needs of learners.			

Appendix
Writing Instruction and the RFH Community

Writing instruction should happen across the RFH Community. Writing across the curriculum is a philosophy that advances the belief that writing is a method of learning. Since all departments are committed to helping students learn, writing must be used as a methodology to advance student learning.

Each academic discipline has its own unique conventions, formats and structures. It is the responsibility of each department to agree upon domain-specific writing praxes, model them for students, and require them to utilize them on a consistent basis. Students must understand that acceptable writing in one domain may not be acceptable writing in another area. The development of domain-specific writing skills supports the overall development of the student writer because all writing is grounded in the writing situation: audience, context, purpose, subject, and writer. Representatives from the academic disciplines must share their domain-specific writing praxes with each other, identify intersections, and determine how to address perceived gaps that limit student learning.

Students must experience writing situations that help them learn how to think creatively and critically and communicate effectively in the academic disciplines. Writing instruction, regardless of the academic discipline, must always reinforce student understanding of the writing situation. When students experience writing situations, they must study examples of domain-specific writing in order to understand how writers communicate in discipline-related contexts. This does not mean information embedded in textbooks. Domain-specific writing is writing that is used to inform and influence readers as it draws them into an established circle of discourse. Students must use these non-fiction texts to develop the close reading skills that will shape their own writing. Focused engagement with domain-specific writing should not be limited to basic reading comprehension and topical understanding. It must also include the analysis of the writing situation that is represented in the text: audience, context, purpose, subject, and writer. The close reading of well-written texts—regardless of the domain—will show students the importance of writing mechanics, diction, and syntax. The development of close reading skills will also help the students grow in terms of their ability to construct and advance independent and original claims that are well-supported by evidence. Domain-specific writing is grounded in positioning of claims and the effective use of evidence.

The final written product is important; nevertheless, the learning that results in this production must not be devalued. The writing process is not limited to the basic steps of planning, drafting, revising, and editing/proofreading. It is a complex sequence of critical and creative thinking and writing that leads to the production of a text that provides evidence of learning and understanding. Students must ultimately develop the ability to self-assess the effectiveness of their writing as a representation of the writing situation. Without the use of models that evidence learning and understanding, students will not develop the ability to self-assess their own work—the true outcome of the writing process.

What types of writing situations should RFH students engage in?

RFH students should engage in writing situations across the curriculum that require them to:

- write to improve mechanical proficiency, diction usage, and syntactical sophistication
- write to narrate, describe, and reflect
- write to summarize and report
- write to classify and define
- write to explain how process leads to an outcome
- write to compare, contrast and evaluate
- write to speculate on cause and effect
- write to propose solutions and solve problems
- write to analyze

These writing situations should be positioned in a coordinated, developmental sequence that extends across the academic disciplines.

Upon Completion of Grade 12, RFH students must be ready to transition to the following writing situations:

- write to analyze
- write to persuade (argument)

The core focus of first-year college writing courses are analysis and argument. These courses orient the students to the demands and expectations of writing for the academic culture of college. At colleges/universities with carefully coordinated writing programs, students must demonstrate proficiency in analysis and argument before they transition to upper level courses that require them to engage in the following writing situation:

- write to investigate (research)