SCIENCE CURRICULUM

AP Physics 1: Algebra Based
Course Description

The AP Physics 1 curriculum is written in accordance to College Board requirements. AP Physics 1: Algebra-Based is a one-year course equivalent to the first semester introductory, algebra-based, college physics course. It provides students with the opportunity to foster greater depth of conceptual understanding through the use of inquiry-based instructional practices. It focuses on enduring, conceptual understandings of foundational physics principles: Newtonian mechanics (including rotational motion); work, energy, and power; mechanical waves and sound; and introductory, simple circuits.

This approach will enable students to spend less time on mathematical routines and more time engaged in inquiry-based learning of essential concepts, and it will help them develop the critical thinking and reasoning skills necessary to engage in the science practices used throughout their study of algebra-based AP Physics and subsequent course work in science disciplines. Having a deep understanding of physics principles implies the ability to reason about physical phenomena using important science process skills such as explaining causal relationships, applying and justifying the use of mathematical routines, designing experiments, analyzing data and making connections across multiple topics within the course. As such, it pairs the core essential knowledge with the fundamental scientific reasoning skills necessary for authentic scientific inquiry. The result will be readiness for the study of advanced topics in subsequent college courses — a goal of every AP course.

The science practices enable students to establish lines of evidence and use them to develop and refine testable explanations and predictions of natural phenomena. Because content, inquiry and reasoning are equally important in AP Physics, each learning objective described in the concept outline combines content with inquiry and reasoning skills described in the science practices.

PREREQUISITES:

There are no prerequisite courses. Students should have completed geometry and be concurrently taking Algebra II or an equivalent course. Although the Physics 1 course includes basic use of trigonometric functions, this understanding can be gained either in the concurrent math course or in the AP Physics 1 course itself.

THE LABORATORY REQUIREMENT
This course requires that 25 percent of the instructional time be spent in hands-on laboratory work, with an emphasis on inquiry-based investigations that provide students with opportunities to demonstrate the foundational physics principles and apply all seven science practices defined in the course framework.

<table>
<thead>
<tr>
<th>PACING CHART</th>
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</thead>
<tbody>
<tr>
<td><strong>Unit</strong></td>
</tr>
<tr>
<td>Unit 1</td>
</tr>
<tr>
<td>Unit 2</td>
</tr>
</tbody>
</table>
| Unit 3 | Conservative Laws:  
3.i. Circular Motion and Gravitation.  
3.iii. Momentum.  
3.iv. Simple Harmonic Motion.  
3.v. Torque and Rotational Motion.  
3.vii. DC Circuits. | 22 Weeks:  
4 Weeks  
3 Weeks  
3 Weeks  
3 Weeks  
3 Weeks  
2 Weeks |
| Unit 4 | Mechanical Waves and Sound | 2 Weeks |

**The AP Physics 1: Algebra-Based Course Framework**

Based on the Understanding by Design (Wiggins and McTighe) model, the AP Physics 1 course framework is intended to provide a clear and detailed description of the course requirements necessary for student success. The framework specifies what students must know, be able to do, and understand, and encourages instruction that allows students to make connections across domains through a broader way of thinking about the physical world. This course framework is structured around six “big ideas” of physics, which encompass core scientific principles, theories, and processes of the discipline:
Big Idea 1: Objects and systems have properties such as mass and charge. Systems may have internal structure.
Big Idea 2: Fields existing in space can be used to explain interactions.
Big Idea 3: The interactions of an object with other objects can be described by forces.
Big Idea 4: Interactions between systems can result in changes in those systems.
Big Idea 5: Changes that occur as a result of interactions are constrained by conservation laws.
Big Idea 6: Waves can transfer energy and momentum from one location to another without the permanent transfer of mass and serve as a mathematical model for the description of other phenomena.

Overview
The AP Science Practices explicitly articulate the behaviors in which students need to engage in order to achieve conceptual understanding in the course. The science practices enable students to establish lines of evidence and use them to develop and refine testable explanations and predictions of natural phenomena. Because content, inquiry, and reasoning are equally important in AP Physics, each learning objective described in the content outline combines content with inquiry and reasoning skills described in the science practices.

The content outline in this framework contains the key concepts and related content that define the course, topically arranged into 10 content areas: Kinematics; Dynamics; Circular Motion and Gravitation; Energy; Momentum; Simple Harmonic Motion; Torque and Rotational Motion; Electric Charge and Electric Force; DC Circuits; and Mechanical Waves and Sound. These content areas are presented in a tabular format. The components of the content outline are as follows:

- **Big ideas:** Each content area begins with a list of the particular big ideas that are the main focus points for the topic covered.
- **Enduring understandings:** The first column of the table lists the enduring understandings. These are the long-term takeaways related to the big ideas that a student should retain after exploring the content and skills. These understandings are expressed as generalizations that specify what a student will come to understand about the key concepts in each content area. Enduring understandings are numbered to correspond with the appropriate big idea.
- **Learning objectives:** Aligned to the right of each enduring understanding are the corresponding learning objectives. The learning objectives convey what a student needs to be able to do in order to develop the enduring understandings. The learning objectives serve as targets of assessment for each course. Learning objectives are numbered to correspond with the appropriate big idea and enduring understanding (e.g., LO 5.F.1.1 is from Big Idea 5, Enduring Understanding 5.F, and is the first learning objective aligned to that EU). The science practices that align to the learning objective are also designated within brackets (e.g., [SP 2.1, 2.2, 7.2]).
- **Essential knowledge:** Aligned to the right of each learning objective are the corresponding essential knowledge statements. These statements describe the facts and basic concepts that a student should know and be able to recall in order to demonstrate mastery of each learning objective. Relevant equations from the AP Physics 1 Equations and Constants tables (Appendix C) are provided to show where they are applicable. Since these equations are provided to students at the exam, students do not need to memorize them, but they do need to know...
when and how to use them in the correct context. Essential knowledge statements are numbered to correspond with the appropriate big idea, enduring understanding, and learning objective.

- Boundary statements: These statements provide guidance to teachers regarding the content boundaries for the AP Physics 1 and 2 courses. These statements help articulate the contextual differences of how the same big ideas and enduring understandings are applied in each course. Boundary statements appear at the end of essential knowledge statements where appropriate.

**Science Practices for AP Physics**
The science practices that follow capture important aspects of the work that scientists engage in, at the level of competence expected of AP Physics students. AP Physics teachers will see within the learning objectives how these practices are integrated with the course content, and they will be able to design instruction with these practices in mind.

Science Practice 1: The student can use representations and models to communicate scientific phenomena and solve scientific problems:

1.1 The student can create representations and models of natural or man-made phenomena and systems in the domain.
1.2 The student can describe representations and models of natural or man-made phenomena and systems in the domain.
1.3 The student can refine representations and models of natural or man-made phenomena and systems in the domain.
1.4 The student can use representations and models to analyze situations or solve problems qualitatively and quantitatively.
1.5 The student can reexpress key elements of natural phenomena across multiple representations in the domain.

Science Practice 2: The student can use mathematics appropriately. Physicists commonly use mathematical representations to describe and explain phenomena as well as to solve problems:

2.1 The student can justify the selection of a mathematical routine to solve problems.
2.2 The student can apply mathematical routines to quantities that describe natural phenomena.
2.3 The student can estimate numerically quantities that describe natural phenomena.

Science Practice 3: The student can engage in scientific questioning to extend thinking or to guide investigations within the context of the AP course:

3.1 The student can pose scientific questions.
3.2 The student can refine scientific questions.
3.3 The student can evaluate scientific questions.

Science Practice 4: The student can plan and implement data collection strategies appropriate for a particular scientific question:
4.1 The student can justify the selection of the kind of data needed to answer a particular scientific question.
4.2 The student can design a plan for collecting data to answer a particular scientific question.
4.3 The student can collect data to answer a particular scientific question.
4.4 The student can evaluate sources of data to answer a particular scientific question.

Science Practice 5: The student can perform data analysis and evaluation of evidence

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

Science Practice 6: The student can work with scientific explanations and theories.

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

Science Practice 7: The student is able to connect and relate knowledge across various scales, concepts, and representations in and across domains.

7.1 The student can connect phenomena and models across spatial and temporal scales.
7.2 The student can connect concepts in and across domain(s) to generalize or extrapolate in and/or across enduring understandings and/or big ideas.
<table>
<thead>
<tr>
<th>Standards</th>
</tr>
</thead>
<tbody>
<tr>
<td>8.1.2.A.1, 8.1.2.A.2, 8.1.2.A.3, 8.1.2.A.5, 8.1.2.B.1, 8.1.2.C.1, 8.1.2.D.1, 8.1.2.E.1, 8.1.2.F.1</td>
</tr>
</tbody>
</table>

- **Technology Operations and Concepts**: Create professional documents (e.g., newsletter, personalized learning plan, business letter or flyer) using advanced features of a word processing program.
  
  Example: Create a lab report using word processing tools that includes graphs generated in a spreadsheet program.

- **Creativity and Innovation**: Synthesize and publish information about a local or global issue or event on a collaborative, web-based service.
  
  Example: Create a vlog regarding a relevant topic.

- **Communication and Collaboration**: Participate in an online learning community with learners from other countries to understand their perspectives on a global problem or issue, and propose possible solutions.
  
  Example: Participate in an Empatico.org project with students from another country.

- **Digital Citizenship**: Model appropriate online behaviors related to cyber safety, cyber bullying, cyber security, and cyber ethics.
  
  Example: Use social media platforms, such as diigo.com appropriately.

- **Research and Information Literacy**: Gather and analyze findings using data collection technology to produce a possible solution for a content-related or real-world problem.
  
  Example: Use Vernier probeware to gather data and report out findings.

- **Critical Thinking, Problem Solving, and Decision-Making**: Use an electronic authoring tool in collaboration with learners from other countries to evaluate and summarize the perspectives of other cultures about a current event or contemporary figure.
  
  Example: Participate in an Empatico.org project with students from another country.
Career Ready Practices

<table>
<thead>
<tr>
<th>Standards</th>
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</thead>
<tbody>
<tr>
<td>CRP1, CRP2, CRP3, CRP4, CRP5, CRP6, CRP7, CRP8, CRP9, CRP10, CRP11, CRP12</td>
</tr>
</tbody>
</table>

Career Ready Practices describe the career-ready skills that all educators in all content areas should seek to develop in their students. They are practices that have been linked to increase college, career, and life success. Career Ready Practices should be taught and reinforced in all career exploration and preparation programs with increasingly higher levels of complexity and expectation as a student advances through a program of study.

**CRP1. Act as a responsible and contributing citizen and employee**

Career-ready individuals understand the obligations and responsibilities of being a member of a community, and they demonstrate this understanding every day through their interactions with others. They are conscientious of the impacts of their decisions on others and the environment around them. They think about the near-term and long-term consequences of their actions and seek to act in ways that contribute to the betterment of their teams, families, community and workplace. They are reliable and consistent in going beyond the minimum expectation and in participating in activities that serve the greater good.

Ex. Engage in classroom discussion using agreed upon norms to ensure that all voices are heard and valued.

**CRP4. Communicate clearly and effectively and with reason.**

Career-ready individuals communicate thoughts, ideas, and action plans with clarity, whether using written, verbal, and/or visual methods. They communicate in the workplace with clarity and purpose to make maximum use of their own and others’ time. They are excellent writers; they master conventions, word choice, and organization, and use effective tone and presentation skills to articulate ideas. They are skilled at interacting with others; they are active listeners and speak clearly and with purpose. Career-ready individuals think about the audience for their communication and prepare accordingly to ensure the desired outcome.

Ex. Present findings from a lab investigation in a poster session.

**CRP5. Consider the environmental, social and economic impacts of decisions.**

Career-ready individuals understand the interrelated nature of their actions and regularly make decisions that positively impact and/or mitigate negative impact on other people, organization, and the environment. They are aware of and utilize new technologies, understandings, procedures, materials, and regulations affecting the nature of their work as it relates to the impact on the social condition, the environment and the profitability of the organization.

Ex. Engage in a project where environmental, social and economic impacts must be taken into consideration in the design, marketing and execution of the plan.

**CRP7. Employ valid and reliable research strategies.**

Career-ready individuals are discerning in accepting and using new information to make decisions, change practices or inform strategies. They use
reliable research process to search for new information. They evaluate the validity of sources when considering the use and adoption of external information or practices in their workplace situation.
Ex. Utilize a variety of sources to ensure that research accounts for possible bias.

CRP8. Utilize critical thinking to make sense of problems and persevere in solving them.
Career-ready individuals readily recognize problems in the workplace, understand the nature of the problem, and devise effective plans to solve the problem. They are aware of problems when they occur and take action quickly to address the problem; they thoughtfully investigate the root cause of the problem prior to introducing solutions. They carefully consider the options to solve the problem. Once a solution is agreed upon, they follow through to ensure the problem is solved, whether through their own actions or the actions of others.
Ex. Use the design thinking approach to get to the root of a problem before proposing potential solutions.

CRP11. Use technology to enhance productivity.
Career-ready individuals find and maximize the productive value of existing and new technology to accomplish workplace tasks and solve workplace problems. They are flexible and adaptive in acquiring new technology. They are proficient with ubiquitous technology applications. They understand the inherent risks-personal and organizational-of technology applications, and they take actions to prevent or mitigate these risks.
Ex. Utilize probeware and other technological tools to gather data, as well as applications such as Excel to analyze data and share findings.

CRP12. Work productively in teams while using cultural global competence.
Career-ready individuals positively contribute to every team, whether formal or informal. They apply an awareness of cultural difference to avoid barriers to productive and positive interaction. They find ways to increase the engagement and contribution of all team members. They plan and facilitate effective team meetings.
Ex. Participate in working teams that draw on the skills of all members and use consensus driven decision making.
**WIDA Proficiency Levels:** At the given level of English language proficiency, English language learners will process, understand, produce or use

<table>
<thead>
<tr>
<th>Level</th>
<th>Characteristics</th>
</tr>
</thead>
</table>
| **6- Reaching** | - Specialized or technical language reflective of the content areas at grade level  
- A variety of sentence lengths of varying linguistic complexity in extended oral or written discourse as required by the specified grade level  
- Oral or written communication in English comparable to proficient English peers |
| **5- Bridging** | - Specialized or technical language of the content areas  
- A variety of sentence lengths of varying linguistic complexity in extended oral or written discourse, including stories, essays or reports  
- Oral or written language approaching comparability to that of proficient English peers when presented with grade level material. |
| **4- Expanding** | - Specific and some technical language of the content areas  
- A variety of sentence lengths of varying linguistic complexity in oral discourse or multiple, related sentences or paragraphs  
- Oral or written language with minimal phonological, syntactic or semantic errors that may impede the communication, but retain much of its meaning, when presented with oral or written connected discourse, with sensory, graphic or interactive support |
| **3- Developing** | - General and some specific language of the content areas  
- Expanded sentences in oral interaction or written paragraphs  
- Oral or written language with phonological, syntactic or semantic errors that may impede the communication, but retain much of its meaning, when presented with oral or written, narrative or expository descriptions with sensory, graphic or interactive support |
| **2- Beginning** | - General language related to the content area  
- Phrases or short sentences  
- Oral or written language with phonological, syntactic, or semantic errors that often impede the communication when presented with one to multiple-step commands, directions, or a series of statements with sensory, graphic or interactive support |
| **1- Entering** | - Pictorial or graphic representation of the language of the content areas  
- Words, phrases or chunks of language when presented with one-step commands directions, WH-, choice or yes/no questions, or statements with sensory, graphic or interactive support |
Language Development Supports For English Language Learners To Increase Comprehension and Communication Skills

<table>
<thead>
<tr>
<th>Environment</th>
<th>Sensory Supports*</th>
<th>Graphic Supports*</th>
<th>Interactive Supports*</th>
<th>Verbal and Textual Supports</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Welcoming and stress-free</td>
<td>Integrates learning centers and games in a meaningful way</td>
<td>In a whole group</td>
<td>Labeling</td>
</tr>
<tr>
<td></td>
<td>Respectful of linguistic and cultural diversity</td>
<td>Provides opportunities to practice and refine receptive and productive skills in English as a new language</td>
<td>In a small group</td>
<td>Students’ native language</td>
</tr>
<tr>
<td></td>
<td>Honors students’ background knowledge</td>
<td>Integrates meaning and purposeful tasks/activities that:</td>
<td>With a partner such as Turn-and-Talk</td>
<td>Modeling</td>
</tr>
<tr>
<td></td>
<td>Sets clear and high expectations</td>
<td>○ Are accessible by all students through multiple entry points</td>
<td>In pairs as a group (first, two pairs work independently, then they form a group of four)</td>
<td>Repetitions</td>
</tr>
<tr>
<td></td>
<td>Includes routines and norms</td>
<td>○ Are relevant to students’ lives and cultural experiences</td>
<td>In triads</td>
<td>Paraphrasing</td>
</tr>
<tr>
<td></td>
<td>Is thinking-focused vs. answer-seeking</td>
<td>○ Build on prior mathematical learning</td>
<td>Cooperative learning structures such as Think-Pair-Share</td>
<td>Summarizing</td>
</tr>
<tr>
<td></td>
<td>Offers multiple modalities to engage in content learning and to demonstrate understanding</td>
<td>○ Demonstrate high cognitive demand</td>
<td>Interactive websites or software</td>
<td>Guiding questions</td>
</tr>
<tr>
<td></td>
<td>Includes explicit instruction of specific language targets</td>
<td>○ Offer multiple strategies for solutions</td>
<td>With a mentor or coach</td>
<td>Clarifying questions</td>
</tr>
<tr>
<td></td>
<td>Provides participation techniques to include all learners</td>
<td>○ Allow for a language learning experience in addition to content</td>
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</tbody>
</table>

BUILDING EQUITY IN YOUR TEACHING PRACTICE

How do the essential questions highlight the connection between the big ideas of the unit and equity in your teaching practice?

**CONTENT INTEGRATION**
Teachers use examples and content from a variety of cultures & groups.

This unit / lesson is connected to other topics explored with students.

There are multiple viewpoints reflected in the content of this unit / lesson.

The materials and resources are reflective of the diverse identities and experiences of students.

The content affirms students, as well as exposes them to experiences other than their own.

**KNOWLEDGE CONSTRUCTION**
Teachers help students understand how knowledge is created and influenced by cultural assumptions, perspectives & biases.

This unit / lesson provides context to the history of privilege and oppression.

This unit / lesson addresses power relationships.

This unit / lesson help students to develop research and critical thinking skills.

This curriculum creates windows and mirrors* for students.

**PREJUDICE REDUCTION**
Teachers implement lessons and activities to assert positive images of ethnic groups & improve intergroup relations.

This unit / lesson help students question and unpack biases & stereotypes.

This unit / lesson help students examine, research and question information and sources.

The curriculum encourage discussion and understanding about the groups of people being represented.

This unit / lesson challenges dominant perspectives.

**EQUITABLE PEDAGOGY**
Teachers modify techniques and methods to facilitate the academic achievement of students from diverse backgrounds.

The instruction has been modified to meet the needs of each student.

Students feel respected and their cultural identities are valued.

Additional supports have been provided for students to become successful and independent learners.

Opportunities are provided for student to reflect on their learning and provide feedback.

**EMPOWERING SCHOOL CULTURE**
Using the other four dimensions to create a safe and healthy educational environment for all.

There are opportunities for students to connect with the community.

My classroom is welcoming and supportive for all students?

I am aware of and sensitive to the needs of my students and their families.

There are effective parent communication systems established. Parents can talk to me about issues as they arise in my classroom.

### Culturally Relevant Pedagogy Examples

- Use students’ life experiences as cultural reference to examples in instructions, such as their music, places in their respective countries, foods, and even choice vocabularies.
- Make posters representing content examples in cultural expressions.
- Develop an asset mapping of the community to harness the partnerships from the community. Ex. invite parents to attend classroom events such as presentation of projects.
- Explore ways to tie local resources to things in the classroom. Ex. community members as guest speakers.
- Value parents by keeping websites updated with current events in the classroom/school.
- Have guest speakers of various cultural backgrounds from industry to present to our students.
- Use textbooks or articles from diverse writers.
- Use adaptive learning to refocus content for each student on an individual basis, with the help of technology.
- Project based learning involves an open end approach that allows students to work alone or collaboratively on engaging, intricate curriculum related challenges.
- Empower students to tell their stories and reflect upon their similarities and differences to your own: Where are the places of common experience, and where are the places where we need to employ empathy.
- Challenge other teachers to become culturally aware of their students.
- Empower, engage and stimulate students as they are put at the center of the learning process.
- Employ experiential learning activities to develop knowledge and skills through direct, firsthand experiences.
- Seek opportunities for professional development on diversity issues.
- Employ inquiry based learning, which encourages students’ authentic questions, ideas and analyses.

### Differentiated Instruction
<table>
<thead>
<tr>
<th><strong>Time/General</strong></th>
<th><strong>Processing</strong></th>
<th><strong>Comprehension</strong></th>
<th><strong>Recall</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Extra time for assigned tasks</td>
<td>Extra Response time</td>
<td>Precise step-by-step directions</td>
<td>Teacher-made checklist</td>
</tr>
<tr>
<td>Adjust length of assignment</td>
<td>Have students verbalize steps</td>
<td>Short manageable tasks</td>
<td>Use visual graphic organizers</td>
</tr>
<tr>
<td>Timeline with due dates for reports and projects</td>
<td>Repeat, clarify or reword directions</td>
<td>Brief and concrete directions</td>
<td>Reference resources to promote independence</td>
</tr>
<tr>
<td>Communication system between home and school</td>
<td>Mini-breaks between tasks</td>
<td>Provide immediate feedback</td>
<td>Visual and verbal reminders</td>
</tr>
<tr>
<td>Provide lecture notes/outline</td>
<td>Provide a warning for transitions</td>
<td>Small group instruction</td>
<td>Graphic organizers</td>
</tr>
<tr>
<td></td>
<td>Reading partners</td>
<td>Emphasize multi-sensory learning</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Assistive Technology</strong></th>
<th><strong>Tests/Quizzes/Grading</strong></th>
<th><strong>Behavior/Attention</strong></th>
<th><strong>Organization</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Computer/whiteboard</td>
<td>Extended time</td>
<td>Consistent daily structured routine</td>
<td>Individual daily planner</td>
</tr>
<tr>
<td>Tape recorder</td>
<td>Study guides</td>
<td>Simple and clear classroom rules</td>
<td>Display a written agenda</td>
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<tr>
<td>Spell-checker</td>
<td>Shortened tests</td>
<td>Frequent feedback</td>
<td>Note-taking assistance</td>
</tr>
<tr>
<td>Audio-taped books</td>
<td>Read directions aloud</td>
<td></td>
<td>Color code materials</td>
</tr>
</tbody>
</table>
### Interdisciplinary Connections

#### English Language Arts

- Cite specific textual evidence to support analysis of science and technical texts. (MS-LS1-4),(MS-LS1-5) **RST.6-8.1**
- Determine the central ideas or conclusions of a text; provide an accurate summary of the text distinct from prior knowledge or opinions. (MS-LS1-4),(MS-LS1-5) **RST.6-8.2**
- Trace and evaluate the argument and specific claims in a text, distinguishing claims that are supported by reasons and evidence from claims that are not. (MS-LS1-4) **RI.6.8**
- Write arguments focused on discipline content. (MS-LS1-4) **WHST.6-8.1**
- Write informative/explanatory texts to examine a topic and convey ideas, concepts, and information through the selection, organization, and analysis of relevant content. (MS-LS1-5) **WHST.6-8.2**
- Draw evidence from informational texts to support analysis, reflection, and research. (MS-LS1-5) **WHST.6-8.9**

#### Mathematics

- Understand that a set of data collected to answer a statistical question has a distribution which can be described by its center, spread, and overall shape. (MS-LS1-4),(MS-LS1-5) **6.SP.A.2**
- Summarize numerical data sets in relation to their context. (MS-LS1-4),(MS-LS1-5) **6.SP.B.4**

### Differentiated Instruction

<table>
<thead>
<tr>
<th>Accommodate Based on Students’ Individual Needs: Strategies</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Leveled Text</td>
</tr>
<tr>
<td>• Chunking text</td>
</tr>
<tr>
<td>• Choice Board/Menu</td>
</tr>
<tr>
<td>• Tiered Instruction</td>
</tr>
<tr>
<td>• Small group instruction</td>
</tr>
<tr>
<td>• Sentence starters/frames</td>
</tr>
<tr>
<td>• Writing scaffolds</td>
</tr>
<tr>
<td>• Tangible items/pictures (i.e., to facilitate vocabulary acquisition)</td>
</tr>
<tr>
<td>• Use of oral assessment</td>
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<tr>
<td>• Tiered learning centers</td>
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<tr>
<td>• Tiered questioning</td>
</tr>
<tr>
<td>• Data-driven student partnerships</td>
</tr>
</tbody>
</table>
Enrichment

Accommodate Based on Students Individual Needs: Strategies

The goal of Enrichment is to provide learners the opportunity to participate in extension activities that are differentiated and augment the district’s curriculum. Teachers are to accommodate based on student individual needs.

- Show a high degree of intellectual, creative and/or artistic ability and demonstrate this ability in multiple ways.
- Pose questions and exhibit sincere curiosity about principles and how things work.
- The ability to grasp concepts and make real world and cross-curricular connections.
- Generate theories and hypotheses and pursue methods of inquiry.
- Produce products that express insight, creativity, and excellence.
- Possess exceptional leadership skills.
- Evaluate vocabulary
- Elevate Text Complexity
- Inquiry based assignments and projects
- Independent student options
- Tiered/Multi-level activities
- Purposeful Learning Center
- Open-ended activities and projects
- Form and build on learning communities
- Providing pupils with experiences outside the ‘regular’ curriculum
- Altering the pace the student uses to cover regular curriculum in order to explore topics of interest in greater depth/breadth within their own grade level.
- A higher quality of work than the norm for the given age group.
- The promotion of a higher level of thinking and making connections.
- The inclusion of additional subject areas and/or activities (cross-curricular).
- Using supplementary materials in addition to the normal range of resources.
### Assessments

#### Required District/State Assessments

Participating in the AP Course Audit Schools wishing to offer AP courses must participate in the AP Course Audit.

Participation in the AP Course Audit requires the online submission of two documents: the AP Course Audit form and the teacher’s syllabus.

The AP Course Audit form is submitted by the AP teacher and the school principal (or designated administrator) to confirm awareness and understanding of the curricular and resource requirements. The syllabus, detailing how course requirements are met, is submitted by the AP teacher for review by college faculty.

AP Physics 1 Examination

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#### Suggested Formative/Summative Classroom Assessments

- Short constructed response questions
- Multiple Choice questions
- Quizzes
- Journals
- Essays
- Quick writes
- Summative chapter test
- Projects
- Portfolio
- Exit Slips
- Graphic Organizers
- Presentations (incorporating Web 2.0 tools)
- Homework
- Anecdotal Notes
- Student Conferencing
## New Jersey Student Learning Standards (NJSLS)

### NJSLS: HS-PS1  Matter and Its Interactions

Students who demonstrate understanding can:

**HS-PS1-1.** Use the periodic table as a model to predict the relative properties of elements based on the patterns of electrons in the outermost energy level of atoms. [Clarification Statement: Examples of properties that could be predicted from patterns could include reactivity of metals, types of bonds formed, numbers of bonds formed, and reactions with oxygen.] [Assessment Boundary: Assessment is limited to main group elements. Assessment does not include quantitative understanding of ionization energy beyond relative trends.]

**HS-PS1-2.** Construct and revise an explanation for the outcome of a simple chemical reaction based on the outermost electron states of atoms, trends in the periodic table, and knowledge of the patterns of chemical properties. [Clarification Statement: Examples of chemical reactions could include the reaction of sodium and chlorine, of carbon and oxygen, or of carbon and hydrogen.] [Assessment Boundary: Assessment is limited to chemical reactions involving main group elements and combustion reactions.]

**HS-PS1-3.** Plan and conduct an investigation to gather evidence to compare the structure of substances at the bulk scale to infer the strength of electrical forces between particles. [Clarification Statement: Emphasis is on understanding the strengths of forces between particles, not on naming specific intermolecular forces (such as dipole-dipole). Examples of particles could include ions, atoms, molecules, and networked materials (such as graphite). Examples of bulk properties of substances could include the melting point and boiling point, vapor pressure, and surface tension.] [Assessment Boundary: Assessment does not include Raoult’s law calculations of vapor pressure.]

**HS-PS1-4.** Develop a model to illustrate that the release or absorption of energy from a chemical reaction system depends upon the changes in total bond energy. [Clarification Statement: Emphasis is on the idea that a chemical reaction is a system that affects the energy change. Examples of models could include molecular-level drawings and diagrams of reactions, graphs showing the relative energies of reactants and products, and representations showing energy is conserved.] [Assessment Boundary: Assessment does not include calculating the total bond energy changes during a chemical reaction from the bond energies of reactants and products.]

**HS-PS1-5.** Apply scientific principles and evidence to provide an explanation about the effects of changing the temperature or concentration of the reacting particles on the rate at which a reaction occurs. [Clarification Statement: Emphasis is on student reasoning that focuses on the number and energy of collisions between molecules.] [Assessment Boundary: Assessment is limited to simple reactions in which there are only two reactants; evidence from temperature, concentration, and rate data; and qualitative relationships between rate and temperature.]

**HS-PS1-6.** Refine the design of a chemical system by specifying a change in conditions that would produce increased amounts of products at equilibrium.* [Clarification Statement: Emphasis is on the application of Le Chatelier’s Principle and on refining designs of chemical reaction systems.]
systems, including descriptions of the connection between changes made at the macroscopic level and what happens at the molecular level. Examples of designs could include different ways to increase product formation including adding reactants or removing products. [Assessment Boundary: Assessment is limited to specifying the change in only one variable at a time. Assessment does not include calculating equilibrium constants and concentrations.]

HS-PS1-7. Use mathematical representations to support the claim that atoms, and therefore mass, are conserved during a chemical reaction. [Clarification Statement: Emphasis is on using mathematical ideas to communicate the proportional relationships between masses of atoms in the reactants and the products, and the translation of these relationships to the macroscopic scale using the mole as the conversion from the atomic to the macroscopic scale. Emphasis is on assessing students’ use of mathematical thinking and not on memorization and rote application of problem-solving techniques.] [Assessment Boundary: Assessment does not include complex chemical reactions.]

HS-PS1-8. Develop models to illustrate the changes in the composition of the nucleus of the atom and the energy released during the processes of fission, fusion, and radioactive decay. [Clarification Statement: Emphasis is on simple qualitative models, such as pictures or diagrams, and on the scale of energy released in nuclear processes relative to other kinds of transformations.] [Assessment Boundary: Assessment does not include quantitative calculation of energy released. Assessment is limited to alpha, beta, and gamma radioactive decays.]

**HS2 Motion and Stability**

Forces and Interactions Students who demonstrate understanding can:

HS-PS2-1. Analyze data to support the claim that Newton’s second law of motion describes the mathematical relationship among the net force on a macroscopic object, its mass, and its acceleration. [Clarification Statement: Examples of data could include tables or graphs of position or velocity as a function of time for objects subject to a net unbalanced force, such as a falling object, an object sliding down a ramp, or a moving object being pulled by a constant force.] [Assessment Boundary: Assessment is limited to one-dimensional motion and to macroscopic objects moving at non-relativistic speeds.]

HS-PS2-2. Use mathematical representations to support the claim that the total momentum of a system of objects is conserved when there is no net force on the system. [Clarification Statement: Emphasis is on the quantitative conservation of momentum in interactions and the qualitative meaning of this principle.] [Assessment Boundary: Assessment is limited to systems of two macroscopic bodies moving in one dimension.]

HS-PS2-3. Apply scientific and engineering ideas to design, evaluate, and refine a device that minimizes the force on a macroscopic object during a collision.* [Clarification Statement: Examples of evaluation and refinement could include determining the success of the device at protecting an object from damage and modifying the design to improve it. Examples of a device could include a football helmet or a parachute.] [Assessment Boundary: Assessment is limited to qualitative evaluations and/or algebraic manipulations.]
HS-PS2-4. Use mathematical representations of Newton’s Law of Gravitation and Coulomb’s Law to describe and predict the gravitational and electrostatic forces between objects. [Clarification Statement: Emphasis is on both quantitative and conceptual descriptions of gravitational and electric fields.] [Assessment Boundary: Assessment is limited to systems with two objects.]

HS-PS2-5. Plan and conduct an investigation to provide evidence that an electric current can produce a magnetic field and that a changing magnetic field can produce an electric current. [Assessment Boundary: Assessment is limited to designing and conducting investigations with provided materials and tools.]

HS-PS2-6. Communicate scientific and technical information about why the molecular-level structure is important in the functioning of designed materials.* [Clarification Statement: Emphasis is on the attractive and repulsive forces that determine the functioning of the material. Examples could include why electrically conductive materials are often made of metal, flexible but durable materials are made up of long chained molecules, and pharmaceuticals are designed to interact with specific receptors.] [Assessment Boundary: Assessment is limited to provided molecular structures of specific designed materials.]

HS-PS3  Energy
Students who demonstrate understanding can:

HS-PS3-1. Create a computational model to calculate the change in the energy of one component in a system when the change in energy of the other component(s) and energy flows in and out of the system are known. [Clarification Statement: Emphasis is on explaining the meaning of mathematical expressions used in the model.] [Assessment Boundary: Assessment is limited to basic algebraic expressions or computations; to systems of two or three components; and to thermal energy, kinetic energy, and/or the energies in gravitational, magnetic, or electric fields.]

HS-PS3-2. Develop and use models to illustrate that energy at the macroscopic scale can be accounted for as a combination of energy associated with the motions of particles (objects) and energy associated with the relative position of particles (objects). [Clarification Statement: Examples of phenomena at the macroscopic scale could include the conversion of kinetic energy to thermal energy, the energy stored due to position of an object above the earth, and the energy stored between two electrically-charged plates. Examples of models could include diagrams, drawings, descriptions, and computer simulations.]

HS-PS3-3. Design, build, and refine a device that works within given constraints to convert one form of energy into another form of energy.* [Clarification Statement: Emphasis is on both qualitative and quantitative evaluations of devices. Examples of devices could include Rube Goldberg devices, wind turbines, solar cells, solar ovens, and generators. Examples of constraints could include use of renewable energy forms and efficiency.] [Assessment Boundary: Assessment for quantitative evaluations is limited to total output for a given input. Assessment is limited to devices constructed with materials provided to students.]
HS-PS3-4. Plan and conduct an investigation to provide evidence that the transfer of thermal energy when two components of different temperature are combined within a closed system results in a more uniform energy distribution among the components in the system (second law of thermodynamics). [Clarification Statement: Emphasis is on analyzing data from student investigations and using mathematical thinking to describe the energy changes both quantitatively and conceptually. Examples of investigations could include mixing liquids at different initial temperatures or adding objects at different temperatures to water.] [Assessment Boundary: Assessment is limited to investigations based on materials and tools provided to students.]

HS-PS3-5. Develop and use a model of two objects interacting through electric or magnetic fields to illustrate the forces between objects and the changes in energy of the objects due to the interaction. [Clarification Statement: Examples of models could include drawings, diagrams, and texts, such as drawings of what happens when two charges of opposite polarity are near each other.] [Assessment Boundary: Assessment is limited to systems containing two objects.]

HS-PS4 Waves and Their Applications in Technologies for Information Transfer
Students who demonstrate understanding can:
HS-PS4-1. Use mathematical representations to support a claim regarding relationships among the frequency, wavelength, and speed of waves traveling in various media. [Clarification Statement: Examples of data could include electromagnetic radiation traveling in a vacuum and glass, sound waves traveling through air and water, and seismic waves traveling through the earth.] [Assessment Boundary: Assessment is limited to algebraic relationships and describing those relationships qualitatively.]

HS-PS4-2. Evaluate questions about the advantages of using a digital transmission and storage of information. [Clarification Statement: Examples of advantages could include that digital information is stable because it can be stored reliably in computer memory, transferred easily, and copied and shared rapidly. Disadvantages could include issues of easy deletion, security, and theft.]

HS-PS4-3. Evaluate the claims, evidence, and reasoning behind the idea that electromagnetic radiation can be described either by a wave model or a particle model, and that for some situations one model is more useful than the other. [Clarification Statement: Emphasis is on how the experimental evidence supports the claim and how a theory is generally modified in light of new evidence. Examples of a phenomenon could include resonance, interference, diffraction, and photoelectric effect.] [Assessment Boundary: Assessment does not include using quantum theory.]

HS-PS4-4. Evaluate the validity and reliability of claims in published materials of the effects that different frequencies of electromagnetic radiation have when absorbed by matter. [Clarification Statement: Emphasis is on the idea that photons associated with different frequencies of light have different energies, and the damage to living tissue from electromagnetic radiation depends on the energy of the radiation. Examples of published materials could include trade books, magazines, web resources, videos, and other passages that may reflect bias.] [Assessment Boundary:
Assessment is limited to qualitative descriptions.]

HS-PS4-5. Communicate technical information about how some technological devices use the principles of wave behavior and wave interactions with matter to transmit and capture information and energy.* [Clarification Statement: Examples could include solar cells capturing light and converting it to electricity; medical imaging; and communications technology.] [Assessment Boundary: Assessments are limited to qualitative information. Assessments do not include band theory.]

**HS-ETS1 Engineering Design**

Students who demonstrate understanding can:

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

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

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

HS-ETS1-4. Use a computer simulation to model the impact of proposed solutions to a complex real-world problem with numerous criteria and constraints on interactions within and between systems relevant to the problem.
The Advanced Placement Program® (AP®) enables students to pursue college-level studies while still in high school. Through more than 30 courses, each culminating in a rigorous exam, AP provides willing and academically prepared students with the opportunity to earn college credit and/or advanced placement. Taking AP courses also demonstrates to college admission officers that students have sought out the most rigorous course work available to them. Each AP course is modeled upon a comparable college course, and college and university faculty play a vital role in ensuring that AP courses align with college-level standards. Talented and dedicated AP teachers help AP students in classrooms around the world develop and apply the content knowledge and skills they will need later in college. Each AP course concludes with a college-level assessment developed and scored by college and university faculty as well as experienced AP teachers. AP Exams are an essential part of the AP experience, enabling students to demonstrate their mastery of college-level course work. Most four-year colleges and universities in the United States and universities in more than 60 countries recognize AP in the admission process and grant students credit, placement, or both on the basis of successful AP Exam scores. Visit www.collegeboard.org/apcreditpolicy to view AP credit and placement policies at more than 1,000 colleges and universities. Performing well on an AP Exam means more than just the successful completion of a course; it is a gateway to success in college. Research consistently shows that students who receive a score of 3 or higher on AP Exams typically experience greater academic success in college and have higher graduation rates than their non-AP peers. Additional AP studies are available at www.collegeboard.org/research.

Offering AP Courses and Enrolling Students This AP Course and Exam Description details the essential information required to understand the objectives and expectations of an AP course. The AP Program unequivocally supports the principle that each school implements its own curriculum that will enable students to develop the content knowledge and skills described here. Schools wishing to offer AP courses must participate in the AP Course Audit, a process through with AP teachers’ syllabi are reviewed by college faculty. The AP Course Audit was created to provide teachers and administrators with clear guidelines on curricular and resource requirements for AP courses and to help colleges and universities validate courses marked “AP” on students’ transcripts. This process ensures that AP teachers’ syllabi meet or exceed the curricular and resource expectations that college and secondary school faculty have established for college-level courses. For more information on the AP Course Audit, visit www.collegeboard.org/apcourseaudit. The College Board strongly encourages educators to make equitable access a guiding principle for their AP programs by giving all willing and academically prepared students the opportunity to participate in AP. We encourage the elimination of barriers that restrict access to AP for students from ethnic, racial, and socioeconomic groups that have been traditionally underserved. The College Board also believes that all students should have access to academically challenging course work before they enroll in AP classes, which can prepare them for AP success. It is only through a commitment to equitable preparation and access that true equity and excellence can be achieved.

AP courses and exams are designed by committees of college faculty and expert AP teachers who ensure that each AP subject reflects and assesses college-level expectations. A list of each subject’s current AP Development Committee members is available on apcentral.collegeboard.org. AP Development Committees define the scope and expectations of the course, articulating through a course framework what students should know and be able to do upon completion of the AP course. Their work is informed by data collected from a range of colleges and universities to ensure that
AP coursework reflects current scholarship and advances in the discipline. The AP Development Committees are also responsible for drawing clear and well-articulated connections between the AP course and AP Exam — work that includes designing and approving exam specifications and exam questions. The AP Exam development process is a multi-year endeavor; all AP Exams undergo extensive review, revision, piloting, and analysis to ensure that questions are high quality and fair and that there is an appropriate spread of difficulty across the questions. Throughout AP course and exam development, the College Board gathers feedback from various stakeholders in both secondary schools and higher education institutions. This feedback is carefully considered to ensure that AP courses and exams are able to provide students with a college-level learning experience and the opportunity to demonstrate their qualifications for advanced placement.

The exam scoring process, like the course and exam development process, relies on the expertise of both AP teachers and college faculty. While multiple-choice questions are scored by machine, the free-response questions are scored by thousands of college faculty and expert AP teachers at the annual AP Reading. AP Exam Readers are thoroughly trained, and their work is monitored throughout the Reading for fairness and consistency. In each subject, a highly respected college faculty member fills the role of Chief Reader, who, with the help of AP readers in leadership positions, maintains the accuracy of the scoring standards. Scores on the free-response questions are weighted and combined with the results of the computerscored multiple-choice questions, and this raw score is converted into a composite AP score of 5, 4, 3, 2, or 1. The score-setting process is both precise and labor intensive, involving numerous psychometric analyses of the results of a specific AP Exam in a specific year and of the particular group of students who took that exam. Additionally, to ensure alignment with college-level standards, part of the score-setting process involves comparing the performance of AP students with the performance of students enrolled in comparable courses in colleges throughout the United States. In general, the AP composite score points are set so that the lowest raw score need to earn an AP score of 5 is equivalent to the average score among college students earning grades of A in the college course. Similarly, AP Exam scores of 4 are equivalent to college grades of A−, B+, and B. AP Exam scores of 3 are equivalent to college grades of B−, C+, and C.

The extensive work done by college faculty and AP teachers in the development of the course and the exam and throughout the scoring process ensures that AP Exam scores accurately represent students’ achievement in the equivalent college course. While colleges and universities are responsible for setting their own credit and placement policies, AP scores signify how qualified students are to receive college credit or placement:

**AP Score Qualification**

5 Extremely well qualified
4 Well qualified
3 Qualified
2 Possibly qualified
1 No recommendation
### Big Idea 3: The interactions of an object with other objects can be described by forces.

### Big Idea 4: Interactions between systems can result in changes in those systems.

**Enduring Understanding:**
- 3.A: All forces share certain common characteristics when considered by observers in inertial reference frames.
- 4.A: The acceleration of the center of mass of a system is related to the net force exerted on the system, where 
  \[ \ddot{a} = \sum \frac{F}{m}. \]

<table>
<thead>
<tr>
<th>NJDOE Student Learning Objective</th>
<th>Skills, Strategies &amp; Concepts</th>
<th>Essential Understandings/Questions</th>
<th>Tasks/Activities</th>
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<tbody>
<tr>
<td>3.A.1.1: The student is able to express the motion of an object using narrative, mathematical, and graphical representations. [SP 1.5, 2.1, 2.2]</td>
<td>Concepts of vectors having both magnitude and direction.</td>
<td>3.A.1: An observer in a particular reference frame can describe the motion of an object using such quantities as position, displacement, distance, velocity, speed, and acceleration.</td>
<td>Velocity of a Nonaccelerating Object What’s Your Reaction Time:</td>
</tr>
<tr>
<td>3.A.1.2: The student is able to design an experimental investigation of the motion of an object. [SP 4.2]</td>
<td>Speed</td>
<td>velocity</td>
<td></td>
</tr>
<tr>
<td>3.A.1.3: The student is able to analyze experimental data describing the motion of an object and is able to express the results of the analysis using narrative,</td>
<td>Distance</td>
<td>displacement</td>
<td></td>
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<tr>
<td></td>
<td>Mass</td>
<td>weight</td>
<td></td>
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<tr>
<td></td>
<td>Vectors: Vectors are mathematical representations that show the direction and magnitude of certain physical quantities. The use of vector mathematics</td>
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<td>Initial Velocity of a Popper Toy Horizontally Launched Projectile Challenge</td>
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<td>Initial Velocity of a Toy Dart Launched at an angle</td>
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<td>Acceleration Due to Gravity Giancoli</td>
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is necessary to add, subtract, or perform certain vector products. The Pythagorean theorem and the trigonometric functions can be useful in determining unknown quantities with vector addition.

Velocity and Acceleration Kinematic equations are relationships between velocity, acceleration, time, and position. Velocity measures the rate of change of position with time. The acceleration of an object is the rate of change of velocity with time. Displacement, position, velocity, and acceleration are vector quantities. The measurement of these quantities also depends on a frame of reference being defined. The following kinematics equations model the mathematical relationships between position, velocity, acceleration, and time for constant acceleration motion. The relationship between velocity and time for constant acceleration in one dimension is represented by the following equation: Where represents the final velocity of the object after accelerating over a time interval \( t \) from an initial velocity \( u \). The symbol represents the acceleration in the x-direction (or any one dimension) and \( t \) represents the elapsed time or time interval.

Apply the laws of motion equations to various situations:

\[ v = u + at \]
\[ d = ut + \frac{1}{2} at^2 \]

Acceleration is the rate of change of velocity with time. Changes in each property are expressed by subtracting initial values from final values. Relevant Equations:

\[ a_x = \frac{\Delta v}{\Delta t} \]
\[ \Delta \theta = \frac{\Delta \theta}{\Delta t} \]

- c. A choice of reference frame determines the direction and the magnitude of each of these quantities.
- d. There are three fundamental interactions or forces in nature: the gravitational force, the electroweak force, and the strong force. The fundamental forces determine both the structure of objects and the motion of objects.
- e. In inertial reference frames, forces are detected by their influence on the motion (specifically the velocity) of an object. So force, like velocity, is a
For uniform acceleration:
\[ v^2 = u^2 + 2ad \]

<table>
<thead>
<tr>
<th>Concepts of graphs:</th>
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</thead>
<tbody>
<tr>
<td>( S ) vs ( t )</td>
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<tr>
<td>( V ) vs ( t )</td>
</tr>
<tr>
<td>Constant velocity</td>
</tr>
<tr>
<td>Constant acceleration</td>
</tr>
<tr>
<td>Uniform acceleration.</td>
</tr>
</tbody>
</table>

Relate \( y = mx + b \) to \( v = u + at \)
\[ d = ut + \frac{1}{2}at^2 \] is a quadratic equation.

For falling objects,
\[ a = g \]
\[ v = u + gt \]
\[ d = ut + \frac{1}{2}gt^2 \]
\[ v^2 = u^2 + 2gd \]

A force vector has magnitude and direction. When multiple forces are exerted on an object, the vector sum of these forces, referred to as the net force, causes a change in the motion of the object. The acceleration of the object is proportional to the net force.

f. The kinematic equations only apply to constant acceleration situations. Circular motion and projectile motion are both included. Circular motion is further covered in Content Area 3. The three kinematic equations describing linear motion with constant acceleration in one and two dimensions are:
\[ v_x = v_{x0} + a_x t \]
\[ x = x_0 + v_{x0} t + \frac{1}{2}a_x t^2 \]
\[ v_x^2 = v_{x0}^2 + 2a_x (x-x_0) \]

g. For rotational motion there are analogous quantities such as angular
4.A.1.1 The student is able to use representations of the center of mass of an isolated two-object system to analyze the motion of the system qualitatively and semiquantitatively. [SP 1.2, 1.4, 2.3, 6.4]

Application of the formulas:

\[ v_x = v_{x0} + a_x t \]
\[ x = x_0 + v_{x0} t + \frac{1}{2} a_x t^2 \]
\[ v_x^2 = v_{x0}^2 + 2a_x (x - x_0) \]

4.A.2.1: The student is able to make predictions about the motion of a system based on the fact that acceleration is equal to the change in velocity per unit time, and velocity is equal to the change in position per unit time. [SP 6.4]

Application of the formulas:

\[ v_x = v_{x0} + a_x t \]
\[ x = x_0 + v_{x0} t + \frac{1}{2} a_x t^2 \]
\[ v_x^2 = v_{x0}^2 + 2a_x (x - x_0) \]

4.A.2.3: The student is able to create mathematical models and analyze graphical relationships for acceleration, velocity, and position of the center of mass of a system and use them to calculate position, angular velocity, and angular acceleration. The kinematic equations describing angular motion with constant angular acceleration are:

\[ \theta = \theta_0 + \omega_0 t + \frac{1}{2} \alpha t^2 \]
\[ \omega = \omega_0 + \alpha t \]
\[ \omega^2 = \omega_0^2 + 2\alpha (\theta - \theta_0) \]

Circular motion is included, and is further discussed in Content Area 3.

4.A.1: The linear motion of a system can be described by the displacement, velocity, and acceleration of its center of mass. a. The variables \( x \), \( v \), and \( a \) all refer to the center-of-mass quantities.

Relevant Equations:

\[ v_x = v_{x0} + a_x t \]
\[ x = x_0 + v_{x0} t + \frac{1}{2} a_x t^2 \]
\[ v_x^2 = v_{x0}^2 + 2a_x (x - x_0) \]
properties of the motion of the center of mass of a system. [SP 1.4, 2.2]

\[
\begin{align*}
\vec{a} &= \frac{\sum \vec{F}}{m_{\text{system}}} \\
\vec{v}_{\text{avg}} &= \frac{\Delta \vec{x}}{\Delta t} \\
\vec{a}_{\text{avg}} &= \frac{\Delta \vec{v}}{\Delta t}
\end{align*}
\]

4.A.2: The acceleration is equal to the rate of change of velocity with time, and velocity is equal to the rate of change of position with time. a. The acceleration of the center of mass of a system is directly proportional to the net force exerted on it by all objects interacting with the system and inversely proportional to the mass of the system. b. Force and acceleration are both vectors, with acceleration in the same direction as the net force. c. The acceleration of the center of mass of a system is equal to the rate of change of the center of mass velocity with time, and the center of mass velocity is equal to the rate of change of the position of the center of mass with time. d. The variables \(x, v, \) and \(a\) all refer to the center-of-mass quantities.
### References & Suggested Instructional Websites

![Image](image_url)

#### Vocabulary

<table>
<thead>
<tr>
<th>Acceleration</th>
<th>Initial velocity.</th>
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<tr>
<td>Constant acceleration.</td>
<td>Mean velocity</td>
</tr>
<tr>
<td>Constant velocity.</td>
<td>Uniform acceleration</td>
</tr>
<tr>
<td>Deceleration.</td>
<td>Velocity.</td>
</tr>
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</table>

\[
\begin{align*}
\vec{a} &= \frac{\sum \vec{F}}{m_{\text{system}}} \\
\vec{v}_{\text{avg}} &= \frac{\Delta \vec{x}}{\Delta t} \\
\vec{a}_{\text{avg}} &= \frac{\Delta \vec{v}}{\Delta t}
\end{align*}
\]
# References & Suggested Instructional Websites

**Textbook:**
Physics
Giancoli, D. C.
Pearson

**Websites:**
- https://www.edx.org/course/apr-physics-1-part-1-linear-motion-ricex-advphy1-1x
- http://www.physicsclassroom.com/class/1DKin/Lesson-6/Kinematic-Equations
- https://www.youtube.com/watch?v=8G1oc5Qq90U&disable_polymer=true

Essential Materials, Supplementary Materials, Links to Best Practices.

**Phet labs: Motion and Stability**
https://phet.colorado.edu/en/simulations/category/physics/motion

**Online:** AP Practice Problems (College Board).
### NJSLS: HS-PS2

**Big Idea 1:** Objects and systems have properties such as mass and charge. Systems may have internal structure.

**Big Idea 2:** Fields existing in space can be used to explain interactions.

**Big Idea 3:** The interactions of an object with other objects can be described by forces.

**Big Idea 4:** Interactions between systems can result in changes in those systems.

### Enduring Understanding:

- **1.A:** The internal structure of a system determines many properties of the system.
- **1.C:** Objects and systems have properties of inertial mass and gravitational mass that are experimentally verified to be the same and that satisfy conservation principles.
- **2.B:** A gravitational field is caused by an object with mass.
- **3.A:** All forces share certain common characteristics when considered by observers in inertial reference frames.
- **3.B:** Classically, the acceleration of an object interacting with other objects can be predicted by using
  \[ \text{\textbf{a}} = \sum \frac{\text{\textbf{F}}}{m}. \]
- **3.C:** At the macroscopic level, forces can be categorized as either long-range (action-at-a-distance) forces or contact forces.
- **4.A:** The acceleration of the center of mass of a system is related to the net force exerted on the system, where
  \[ \text{\textbf{a}} = \sum \frac{\text{\textbf{F}}}{m}. \]

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<tr>
<td>1.A.5.1: The student is able to model verbally or visually the properties of a system based on its substructure and to relate this to changes in the system properties over time as external variables are changed. [SP 1.1, 7.1]</td>
<td>Applying Newton’s Second Law Both force and acceleration are vector quantities. When more than one force is applied to an object, the net force is calculated. The net force is the vector sum of the forces applied to the object, and Newton’s second law can be expressed in the following way:</td>
<td>1.A.1: A system is an object or a collection of objects. Objects are treated as having no internal structure. a. A collection of particles in which internal interactions change little or not at all, or</td>
<td>Lab-Friction Students will determine Normal force, Friction force, and the coefficient of friction μ. Students will find</td>
</tr>
</tbody>
</table>
1.C.1.1: The student is able to design an experiment for collecting data to determine the relationship between the net force exerted on an object its inertial mass and its acceleration. [SP 4.2]

1.C.3.1: The student is able to design a plan for collecting data to measure gravitational mass and to measure inertial mass and to distinguish between the two experiments. [SP 4.2]

2.B.1.1: The student is able to calculate the gravitational force on an object with mass m in a gravitational field of strength g in the context of the effects of a net force on objects and systems. [SP 2.2, 7.2]

\[
\text{where } n \text{ represents the sum of all the forces acting on the object in the direction of the acceleration and } m \text{ represents the mass of object on which the forces are being exerted. The SI unit of force is the newton and a newton has the following relationship to the other fundamental units:}
\]

**Newton’s 2nd law:**

\[
F = ma
\]

\[
\Delta a = \Delta v/\Delta t
\]

**For falling bodies**

\[a = g\]

\[F = mg\]

**Weight is a force**

\[W = mg\]

Apply concept of vectors to draw free body diagrams

in which changes in these interactions are irrelevant to the question addressed, can be treated as an object. b. Some elementary particles are fundamental particles (e.g., electrons). Protons and neutrons are composed of fundamental particles (i.e., quarks) and might be treated as either systems or objects, depending on the question being addressed. c. The electric charges on neutrons and protons result from their quark compositions.

1.A.5: Systems have properties determined by the properties and interactions of their constituent atomic and molecular substructures. In AP Physics, when the properties of the constituent parts are not important in modeling the behavior of the macroscopic system, the system itself may be referred to as an object.

1.C.1: Inertial mass is the property of an object or a system that determines how experimentally the value for the coefficient of friction for a variety of surfaces.

- Inertial Mass
- Atwood’s Machine
- Weight Versus Mass
- The Friction Coefficient of your block
- Hooke’s Law
- Terminal Velocity
- Friction on a Ramp
- Giancoli textbook problems
- AP practice problems
- Interdisciplinary connection problems
- Diagnostic pre- and post-assessment, Class Discussions, Worksheets with teacher feedback, Drafts of lab reports with teacher feedback.
3.A.2.1: The student is able to represent forces in diagrams or mathematically using appropriately labeled vectors with magnitude, direction, and units during the analysis of a situation. [SP 1.1]

3.A.3.1: The student is able to analyze a scenario and make claims (develop arguments, justify assertions) about the forces exerted on an object by other objects for different types of forces or components of forces. [SP 6.4, 7.2]

Friction Frictional forces occur when two surfaces are interacting by contact. There are two types of frictional forces (kinetic friction and static friction) and the type depends on the type of interaction. Kinetic Friction

Kinetic friction exists when the two surfaces in contact are in relative motion to each other. An example of this would be a book sliding down the hallway: the frictional force would be acting on the book to bring the book to rest as it slides.

The kinetic frictional force is dependent on only two physical factors. The first factor is the contact force between the two surfaces (also called the normal force). The second factor is the quality of friction between the two surfaces, which is represented by the physical property called the coefficient of friction, which is a dimensionless physical constant represented by the symbol. The following is the relationship for its motion changes when it interacts with other objects or systems.

\[
\ddot{a} = \sum \frac{F}{m}
\]

1.C.3: Objects and systems have properties of inertial mass and gravitational mass that are experimentally verified to be the same and that satisfy conservation principles.

2.B.1: A gravitational field at the location of an object with mass \( m \) causes a gravitational force of magnitude \( mg \) to be exerted on the object in the direction of the field. a. On Earth, this gravitational force is called weight. b. The gravitational field at a point in space is measured by dividing the gravitational force exerted by the field on a test object at that point by the mass of the test object and has the same design and perform a crash-prevention and force-reduction investigation.
3.A.3.2: The student is able to challenge a claim that an object can exert a force on itself. [SP 6.1]

3.A.3.3: The student is able to describe a force as an interaction between two objects and identify both objects for any force. [SP 1.4]

3.A.4.1: The student is able to construct explanations of physical situations involving the interaction of bodies using Newton’s third law and the representation of action-reaction pairs of forces. [SP 1.4, 6.2]

3.A.4.2: The student is able to use Newton’s third law to make claims and predictions about the action-reaction pairs of forces when two objects interact. [SP 6.4, 7.2]

3.A.4.3: The student is able to analyze situations involving interactions among several objects by using free-body diagrams that include the application of Newton’s third law to identify forces. [SP 1.4]

3.B.1.1: The student is able to kinetic friction:
One important feature of working with friction is that the direction of the frictional force is determined independently. The direction of a kinetic frictional force is always in the opposite direction of the relative motion of the two surfaces.

Static Friction The force of static friction occurs when the two surfaces in contact are not in relative motion to each other. The force of static friction can be any value (necessary) up to some maximum value. This means that only the maximum static frictional force can be determined by a relationship and for all other values (less than maximum) the static frictional force can only be determined by applying Newton’s laws to the system

\[ F = \mu R.\]

Hooke’s Law/Force Exerted by a Spring
A spring exerts a linear restoring force opposite to the direction of the displacement of a mass attached to a spring. This relationship for this linear restoring force is also called Hooke’s law. \( F \) is the force exerted on a spring, \( k \) is the spring constant indicating the stiffness of the spring, and is the displacement as the spring is stretched or compressed from its equilibrium position. The negative sign represents the restoring part of the relationship. If a spring is pulled to the right by some external force and the spring is displaced to the right, then the spring responds to this stretching by exerting leftward force. It is a force direction as the force. c. If the gravitational force is the only force exerted on the object, the observed free-fall acceleration of the object (in meters per second squared) is numerically equal to the magnitude of the gravitational field (in Newtons/kilogram) at that location. Relevant Equation

\[ F = mg \]

3.A.2: Forces are described by vectors. a. Forces are detected by their influence on the motion of an object. b. Forces have magnitude and direction

3.A.3: A force exerted on an object is always due to the interaction of that object with another object. a. An object cannot exert a force on itself. b. Even though an object is at rest, there may be forces
predict the motion of an object subject to forces exerted by several objects using an application of Newton’s second law in a variety of physical situations with acceleration in one dimension. [SP 6.4, 7.2]

3.B.1.2: The student is able to design a plan to collect and analyze data for motion (static, constant, or accelerating) from force measurements and carry out an analysis to determine the relationship between the net force and the vector sum of the individual forces. [SP 4.2, 5.1]

3.B.1.3: The student is able to reexpress a free-body diagram representation into a mathematical representation and solve the mathematical representation for the acceleration of the object. [SP 1.5, 2.2]

3.B.1: If an object of interest interacts with several other objects, the net force is the vector sum of the individual forces. Projectile motion and circular motion are both included in AP Physics 1. Relevant Equation:

3.B.2.1: The student is able to that always tends to restore the spring system back towards the equilibrium position. $F = -k\Delta x$.

exerted on that object by other objects. c. The acceleration of an object, but not necessarily its velocity, is always in the direction of the net force exerted on the object by other objects.

3.A.4: If one object exerts a force on a second object, the second object always exerts a force of equal magnitude on the first object in the opposite direction.
create and use free-body diagrams to analyze physical situations to solve problems with motion qualitatively and quantitatively. [SP 1.1, 1.4, 2.2]

3.B.1: If an object of interest interacts with several other objects, the net force is the vector sum of the individual forces. Projectile motion and circular motion are both included in AP Physics 1.

\[
\vec{a} = \frac{\sum \vec{F}}{m} = \frac{\vec{F}_{net}}{m}
\]

3.C.4.1: The student is able to make claims about various contact forces between objects based on the microscopic cause of those forces. [SP 6.1]
3.C.4.2: The student is able to explain contact forces (tension, etc.)
friction, normal, buoyant, spring) as arising from interatomic electric forces and that they therefore have certain directions. [SP 6.2]

4.A.1.1 The student is able to use representations of the center of mass of an isolated two-object system to analyze the motion of the system qualitatively and semi-quantitatively. [SP 1.2, 1.4, 2.3, 6.4]

4.A.2.2: The student is able to evaluate using given data whether all the forces on a system or whether all the parts of a system have been identified. [SP 5.3]

4.A.3.1: The student is able to apply Newton’s second law to systems to calculate the change in the center-of-mass velocity when an external force is exerted on the system. [SP 2.2]

3.B.2: Free-body diagrams are useful tools for visualizing forces being exerted on a single object and writing the equations that represent a physical situation. a. An object can be drawn as if it was extracted from its environment and the interactions with the environment identified. b. A force exerted on an object can be represented as an arrow whose length represents the magnitude of the force and whose direction shows the direction of the force. c. A coordinate system with one axis parallel to the direction of the acceleration simplifies the translation from the free body diagram to the algebraic representation. d. Free-body diagrams are depicted where the forces exerted on an object are represented as
4.A.3.2: The student is able to use visual or mathematical representations of the forces between objects in a system to predict whether or not there will be a change in the center-of-mass velocity of that system. [SP 1.4]

3.C.4: Contact forces result from the interaction of one object touching another object and they arise from interatomic electric forces. These forces include tension, friction, normal, spring (Physics 1).

4.A.1: The linear motion of a system can be described by the displacement, velocity, and acceleration of its center of mass. The variables $x$, $v$, and $a$ all refer to the center-of-mass quantities:

$$x = x_0 + v_0 t + \frac{1}{2} a t^2$$

$$v = v_0 + a t$$

$$u = u_0 + a t$$

$$F = F_0 + a t$$

arrows pointing outward from a dot, and also diagrams that show at what point on the object each force is exerted.
4.A.2: The acceleration is equal to the rate of change of velocity with time, and velocity is equal to the rate of change of position with time. a. The acceleration of the center of mass of a system is directly proportional to the net force exerted on it by all objects interacting with the system and inversely proportional to the mass of the system.

\[ \ddot{a} = \frac{\sum \vec{F}}{m_{\text{system}}} \]

b. Force and acceleration are both vectors, with acceleration in the same direction as the net force.

\[ \ddot{v}_{\text{avg}} = \frac{\Delta \vec{x}}{\Delta t} \]
\[ \ddot{a}_{\text{avg}} = \frac{\Delta \ddot{v}}{\Delta t} \]

c. The acceleration of the center of mass of a system is equal to the rate of change of the center of mass velocity.
with time, and the center of mass velocity is equal to the rate of change of the position of the center of mass with time. d. The variables x, v, and a all refer to the center-of-mass quantities.

\[ \vec{a} = \frac{\sum F}{m} = \frac{\vec{F}_{net}}{m} \]

4.A.3: Forces that systems exert on each other are due to interactions between objects in the systems. If the interacting objects are parts of the same system, there will be no change in the center-of-mass velocity of that system.

\[ \vec{a} = \frac{\sum F}{m} = \frac{\vec{F}_{net}}{m} \]
## Vocabulary

<table>
<thead>
<tr>
<th>Acceleration</th>
<th>Friction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Applied Force</td>
<td>Hooke’s Law</td>
</tr>
<tr>
<td>Gravitational Force</td>
<td>Inertia</td>
</tr>
<tr>
<td>Free body diagram</td>
<td>Momentum System</td>
</tr>
<tr>
<td>Force</td>
<td></td>
</tr>
</tbody>
</table>

## References & Suggested Instructional Websites
# References & Suggested Instructional Websites

**Textbook:**
Physics  
Giancoli, D. C.  
Pearson  

**Lab:**
Friction; Timeline (120 minutes); In the unit folder  
Inertia; Timeline(120 minutes); in the unit folder  
*Forces in One Dimension:* Timeline (120 minutes); In the Unit Folder

**Websites:**
- [https://njctl.org/courses/downloads/attachments/by-md5/d/1/d1eb75f24a2ee32a97b4026bd96a593c/friction-lab-2015-06-20.docx](https://njctl.org/courses/downloads/attachments/by-md5/d/1/d1eb75f24a2ee32a97b4026bd96a593c/friction-lab-2015-06-20.docx)
- [http://www.physicstutorials.org/home/mechanics/dynamics](http://www.physicstutorials.org/home/mechanics/dynamics)

**Phet labs:**

**Test Prep:**
AP Practice Problems (College Board) [https://apstudent.collegeboard.org/apcourse/ap-physics-1/exam-practice](https://apstudent.collegeboard.org/apcourse/ap-physics-1/exam-practice)

| Grade: AP Physics I | Unit 3: Conservative Laws: | Topic: 3.i. Circular Motion and Gravitation  
Duration: 4 Weeks |
NJSLS: HS-PS2

Big Idea 1: Objects and systems have properties such as mass and charge. Systems may have internal structure.
Big Idea 2: Fields existing in space can be used to explain interactions.
Big Idea 3: The interactions of an object with other objects can be described by forces.
Big Idea 4: Interactions between systems can result in changes in those systems.

Enduring Understanding:

- 1.C: Objects and systems have properties of inertial mass and gravitational mass that are experimentally verified to be the same and that satisfy conservation principles.
- 2.A: A field associates a value of some physical quantity with every point in space. Field models are useful for describing interactions that occur at a distance (long-range forces) as well as a variety of other physical phenomena.
- 2.B: A gravitational field is caused by an object with mass
- 3.A: All forces share certain common characteristics when considered by observers in inertial reference frames.
- 3.B: Classically, the acceleration of an object interacting with other objects can be predicted by using $\ddot{a} = \sum \frac{\vec{F}}{m}$.
- 3.C: At the macroscopic level, forces can be categorized as either long-range (action-at-a distance) forces or contact forces.
- 4.A: The acceleration of the center of mass of a system is related to the net force exerted on the system, where $\ddot{\vec{a}} = \sum \frac{\vec{F}}{m}$.
- 4.C: Interactions with other objects or systems can change the total energy of a system.
The student is able to design a plan for collecting data to measure gravitational mass and to measure inertial mass and to distinguish between the two experiments. [SP 4.2]

Universal Law of Gravitation

The universal law of gravitation describes the interaction between (large) objects, such as a planet and a moon. The direction of the force is always attractive between the objects. The gravitational force depends on three physical factors: the mass of each object and the distance from the center of one object to the center of the other object.

$$|F| = G \frac{M_1 M_2}{r^2}$$

where $F$ is the magnitude of the gravitational force between two objects. $G$ is the universal gravitational constant.

$$G = 6.67 \times 10^{-11} \text{ N} \cdot \text{m}^2/\text{kg}^2.$$

Gravitational Field

One way to define it is to use the definition of a field. A gravitational field can be defined as the ratio of the gravitational force acting on a mass to the mass. It can be expressed as

$$\vec{g} = \frac{\vec{F}_g}{m}$$

1.C.2: Gravitational mass is the property of an object or a system that determines the strength of the gravitational interaction with other objects, systems, or gravitational fields. a. The gravitational mass of an object determines the amount of force exerted on the object by a gravitational field. b. Near the Earth’s surface, all objects fall (in a vacuum) with the same acceleration, regardless of their inertial mass.

1.C.3: Objects and systems have properties of inertial mass and gravitational mass that are experimentally verified to be the same and that satisfy conservation principles

2.A.1: A vector field gives, as a function of position (and perhaps time), the value of a physical quantity that is described by a

Giancoli textbook problems
AP practice problems
Interdisciplinary connection problems
Diagnostic pre- and post-assessment, Class Discussions, Worksheets with teacher feedback, Drafts of lab reports with teacher feedback

Lab-Centripetal Force (Discovery)

Students verify graphically that the centripetal force $F$ is proportional to $v^2$ and determine the mass.

Lab-Centripetal Force

Students will determine that centripetal force is proportional to $v^2$

Students will use Newton’s law to find the mass of the rotating object
2.B.1: The student is able to calculate the gravitational force on an object with mass \( m \) in a gravitational field of strength \( g \) in the context of the effects of a net force on objects and systems. [SP 2.2, 7.2]

Objects Moving in Uniform Circular Motion: An object that moves in a circular path of radius \( r \) at a constant speed \( v \) will have an acceleration associated with its constantly changing direction of motion. This acceleration is always directed radially towards the center of the circular path and is called the centripetal acceleration. The magnitude of the centripetal acceleration is defined by the following relationship:

\[
a_c = \frac{v^2}{r}
\]

2.B.1: A gravitational field at the location of an object with mass \( m \) causes a gravitational force of magnitude \( mg \) to be exerted on the object in the direction of the field. a. On Earth, this gravitational force is called weight. b. The gravitational field at a point in space is measured by dividing the gravitational force exerted by the field on a test object at that point by the mass of the test object and has the same direction as the force. c. If the gravitational force is the only force exerted on the object, the observed free-fall acceleration of the object (in meters per second squared) is numerically equal to the magnitude of the gravitational field (in Newtons/kilogram) at that location.

- Vector fields are represented by field vectors indicating direction and magnitude. b. When more than one source object with mass or electric charge is present, the field value can be determined by vector addition. c. Conversely, a known vector field can be used to make inferences about the number, relative size, and location of sources.
2.B.2.1: The student is able to calculate the gravitational field due to an object with mass M, where the field is a vector directed toward the center of the object of mass M. [SP 2.2]

2.B.2.2: The student is able to approximate a numerical value of the gravitational field (g) near the surface of an object from its radius and mass relative to those of the Earth or other reference objects. [SP 2.2]

3.A.1.1: The student is able to express the motion of an object using narrative, mathematical, and graphical representations. [SP 1.5, 2.1, 2.2]

3.A.1.2: The student is able to design an experimental investigation of the motion of an object. [SP 4.2]

<table>
<thead>
<tr>
<th>Application of F = mg</th>
<th>Location. Relevant Equation: ( \vec{g} = \frac{\vec{F}}{m} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>g = GM/r^2</td>
<td>2.B.2: The gravitational field caused by a spherically symmetric object with mass is radial and, outside the object, varies as the inverse square of the radial distance from the center of that object. a. The gravitational field caused by a spherically symmetric object is a vector whose magnitude outside the object is equal to ( G \frac{M}{r^2} ). b. Only spherically symmetric objects will be considered as sources of the gravitational field. Relevant Equation ( \vec{a} = \frac{\sum \vec{F}}{m} = \frac{\vec{F}_{ext}}{m} )</td>
</tr>
<tr>
<td>3.A.1: An observer in a particular reference frame can describe the motion of an object using such quantities as position, displacement, distance, velocity, speed, and acceleration. a. Displacement, velocity, and</td>
<td></td>
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</tbody>
</table>
3.A.1.3: The student is able to analyze experimental data describing the motion of an object and is able to express the results of the analysis using narrative, mathematical and graphical representatives. [SP 5.1]

<p>| | | |</p>
<table>
<thead>
<tr>
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</thead>
<tbody>
<tr>
<td>acceleration are all vector quantities.</td>
<td>b. Displacement is change in position. Velocity is the rate of change of position with time. Acceleration is the rate of change of velocity with time. Changes in each property are expressed by subtracting initial values from final values.</td>
<td></td>
</tr>
<tr>
<td>[ \vec{u}_{avg} = \frac{\Delta \vec{x}}{\Delta t} ]</td>
<td></td>
<td></td>
</tr>
<tr>
<td>[ \vec{a}_{avg} = \frac{\Delta \vec{u}}{\Delta t} ]</td>
<td></td>
<td></td>
</tr>
<tr>
<td>c. A choice of reference frame determines the direction and the magnitude of each of these quantities.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>d. We know of three fundamental interactions or forces in nature: the gravitational force, the electroweak force, and the strong force. The fundamental forces determine both the structure of objects and the motion of objects.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>e. In inertial reference frames, forces are detected by their influence on the motion (specifically the velocity) of an object. So force, like velocity, is a</td>
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</tbody>
</table>
vector quantity. A force vector has magnitude and direction. When multiple forces are exerted on an object, the vector sum of these forces, referred to as the net force, causes a change in the motion of the object. The acceleration of the object is proportional to the net force.

f. The three kinematic equations only apply to constant acceleration situations (this includes projectile motion). The three kinematic equations describing linear motion with constant acceleration in one and two dimensions are:

\[
\begin{align*}
v_x &= v_{x0} + a_x t \\
x &= x_0 + v_{x0} t + \frac{1}{2} a_x t^2 \\
v^2_x &= v^2_{x0} + 2a_x (x - x_0)
\end{align*}
\]

g. For rotational motion there are analogous quantities such as angular position, angular velocity, and angular acceleration. The kinematic equations describing angular motion with constant angular acceleration are:

\[
\begin{align*}
\omega &= \omega_0 + \alpha t \\
\theta &= \theta_0 + \omega_0 t + \frac{1}{2} \alpha t^2 \\
\omega^2 &= \omega^2_0 + 2\alpha \theta
\end{align*}
\]
3.A.2.1: The student is able to represent forces in diagrams or mathematically using appropriately labeled vectors with magnitude, direction, and units during the analysis of a situation. [SP 1.1]

3.A.3.1: The student is able to analyze a scenario and make claims (develop arguments, justify assertions) about the forces exerted on an object by other objects for different types of forces or components of forces. [SP 6.4, 7.2]

3.A.3.3: The student is able to describe a force as an interaction between two objects and identify both objects for any force. [SP 1.4]

3.A.4.1: The student is able to construct explanations of physical situations where there is both a radial and tangential acceleration for an object moving in a circular path. Relevant Equation:

\[ a = \frac{v^2}{r} \]

i. For uniform circular motion of radius \( r \), \( v \) is proportional to \( \omega \) (for a given \( r \)), and proportional to \( r \) (for a given \( \omega \)). Given a radius \( r \) and a period of rotation \( T \), students derive and apply \( v = \frac{(2\pi r)}{T} \).

3.A.2: Forces are described by vectors. a. Forces are detected by their influence on the motion of an object. b. Forces have magnitude and direction.

3.A.3: A force exerted on an object is always due to the interaction of that object with another object. a. An object cannot exert a force on itself. b. Even though an object is at rest, there may be forces exerted on that
situations involving the interaction of bodies using Newton’s third law and the representation of action-reaction pairs of forces. [SP 1.4, 6.2]

3.A.4.2: The student is able to use Newton’s third law to make claims and predictions about the action-reaction pairs of forces when two objects interact. [SP 6.4, 7.2]

3.A.4.3: The student is able to analyze situations involving interactions among several objects by using free-body diagrams that include the application of Newton’s third law to identify forces. [SP 1.4]

3.B.1.2: The student is able to design a plan to collect and analyze data for motion (static, constant, or accelerating) from force measurements and carry out an analysis to determine the relationship between the net force and the vector sum of the individual forces. [SP 4.2, 5.1]

3.B.1.3: The student is able to object by other objects. c. The acceleration of an object, but not necessarily its velocity, is always in the direction of the net force exerted on the object.

3.A.4: If one object exerts a force on a second object, the second object always exerts a force of equal magnitude on the first object in the opposite direction.

3.B.1: If an object of interest interacts with several other objects, the net force is the vector sum of the individual forces.

3.B.2: Free-body diagrams are useful tools for visualizing forces being exerted on a single object and writing the equations that represent a physical situation. a. An object can be drawn as if it was extracted from its environment and
<table>
<thead>
<tr>
<th>reexpress a free-body diagram representation into a mathematical representation and solve the mathematical representation for the acceleration of the object. [SP 1.5, 2.2]</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.B.2.1: The student is able to create and use free-body diagrams to analyze physical situations to solve problems with motion qualitatively and quantitatively. [SP 1.1, 1.4, 2.2]</td>
</tr>
<tr>
<td>3.C.1.1: The student is able to use Newton’s law of gravitation to calculate the gravitational force the two objects exert on each other and use that force in contexts other than orbital motion. [SP 2.2]</td>
</tr>
<tr>
<td>3.C.1.2: The student is able to use Newton’s law of gravitation to calculate the gravitational force between two objects and use that force in contexts involving orbital motion (for circular orbital motion only in Physics 1). [SP 2.2]</td>
</tr>
<tr>
<td>the interactions with the environment identified. b. A force exerted on an object can be represented as an arrow whose length represents the magnitude of the force and whose direction shows the direction of the force. c. A coordinate system with one axis parallel to the direction of the acceleration simplifies the translation from the free body diagram to the algebraic representation.</td>
</tr>
<tr>
<td>3.C.1: Gravitational force describes the interaction of one object with mass with another object with mass. a. The gravitational force is always attractive. b. The magnitude of force between two spherically symmetric objects of mass m1 and m2 where r is the center-to-center distance between the objects. c. In a narrow range of heights above the Earth’s surface, the local gravitational field, g, is approximately constant. Relevant Equations:</td>
</tr>
</tbody>
</table>
3.C.2.2: The student is able to connect the concepts of gravitational force and electric force to compare similarities and differences between the forces. [SP 7.2]

3.G.1.1: The student is able to articulate situations when the gravitational force is the dominant force and when the electromagnetic, weak, and strong forces can be ignored. [SP 7.1]

4.A.2.2: The student is able to evaluate using given data whether

\[ |\vec{F}_g| = \frac{G m_1 m_2}{r^2} \]

\[ \vec{g} = -\frac{\vec{F}_g}{m} \]

3.C.2: Electric force results from the interaction of one object that has an electric charge with another object that has an electric charge. a. Electric forces dominate the properties of the objects in our everyday experiences. However, the large number of particle interactions that occur make it more convenient to treat everyday forces in terms of nonfundamental forces called contact forces, such as normal force, friction, and tension. b. Electric forces may be attractive or repulsive, depending upon the charges on the objects involved. Relevant Equations:

\[ F_g = \frac{G m_1 m_2}{r^2} \]

\[ F_E = \frac{k q_1 q_2}{r^2} \]

3.G.1: Gravitational forces are exerted at all scales and dominate at the largest distance and mass scales

4.A.2: The acceleration is equal to
all the forces on a system or whether all the parts of a system have been identified. [SP 5.3]

<table>
<thead>
<tr>
<th>4.C.1.1: The student is able to calculate the total energy of a system and justify the mathematical routines used in the calculation of component types of energy within the system whose sum is the total energy. [SP 1.4, 2.1, 2.2]</th>
</tr>
</thead>
</table>
| the rate of change of velocity with time, and velocity is equal to the rate of change of position with time. a. The acceleration of the center of mass of a system is directly proportional to the net force exerted on it by all objects interacting with the system and inversely proportional to the mass of the system. b. Force and acceleration are both vectors, with acceleration in the same direction as the net force. Relevant Equation: 
\[
\dot{a} = \frac{\sum \vec{F}}{m} = \frac{\vec{F}_{\text{net}}}{m}
\] |
| 4.C.1: The energy of a system includes its kinetic energy, potential energy, and microscopic internal energy. Examples should include gravitational potential energy, elastic potential energy, and kinetic energy. a. A rotating, rigid body may be considered to be a system, and may have both translational and rotational kinetic energy. b. Although thermodynamics is not part of Physics 1, included is the idea that during an inelastic collision, some of the mechanical energy dissipates as (converts to) thermal...
energy. Boundary Statement: Thermodynamics is treated in Physics 2 only.

Relevant Equations:

\[ K = \frac{1}{2}mv^2 \]
\[ K = \frac{1}{2}I\omega^2 \]
\[ \Delta U_g = mg\Delta y \]
\[ U_g = -\frac{Gm_1m_2}{r} \]
\[ U_s = \frac{1}{2}kx^2 \]

**Vocabulary**

<table>
<thead>
<tr>
<th>Attractive force</th>
<th>Gravity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Centripetal Circular Motion</td>
<td>Gravitational Force</td>
</tr>
</tbody>
</table>
# References & Suggested Instructional Websites

**Textbook**  
Physics  
Giancoli, D. C.  
Pearson  

**Website:**  

**Lab:**  
Centripetal Force; timeline (120 minutes); (in the folder unit)

**Phet Lab:**  
https://phet.colorado.edu/en/simulation/gravity-and-orbits
Big Idea 3: The interactions of an object with other objects can be described by forces.

Big Idea 4: Interactions between systems can result in changes in those systems.

Big Idea 5: Changes that occur as a result of interactions are constrained by conservation laws.

**Student Learning Objective:**

**Enduring understanding**

3.E: A force exerted on an object can change the kinetic energy of the object.

4.C: Interactions with other objects or systems can change the total energy of a system.

5.A: Certain quantities are conserved, in the sense that the changes of those quantities in a given system are always equal to the transfer of that quantity to or from the system by all possible interactions with other systems.

5.B: The energy of a system is conserved.

5.D: The linear momentum of a system is conserved.

<table>
<thead>
<tr>
<th>NJDOE Student Learning Objective</th>
<th>Skills, Strategies &amp; Concepts</th>
<th>Essential Understandings/Questions</th>
<th>Tasks/Activities</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.E.1.1: The student is able to make predictions about the changes in kinetic energy of an object based on considerations of</td>
<td>Kinetic Energy Kinetic energy is the energy associated with moving objects. Kinetic energy is expressed as</td>
<td>3.E.1: The change in the kinetic energy of an object depends on the force exerted on the object and on the displacement of the object</td>
<td>Activity: Understanding Work – use a variety of everyday situations to develop an understanding of the concepts of</td>
</tr>
</tbody>
</table>
the direction of the net force on the object as the object moves. [SP 6.4, 7.2]

3.E.1.2: The student is able to use net force and velocity vectors to determine qualitatively whether kinetic energy of an object would increase, decrease, or remain unchanged. [SP 1.4]

3.E.1.3: The student is able to use force and velocity vectors to determine qualitatively or quantitatively the net force exerted on an object and qualitatively whether kinetic energy of that object would increase, decrease, or remain unchanged. [SP 1.4, 2.2]

3.E.1.4: The student is able to apply mathematical routines to determine the change in kinetic energy of an object given the forces on the object and the displacement of the object. [SP 2.2]

| K= \( \frac{1}{2}mv^2 \) where K represents the kinetic energy of an object due to its velocity. The SI unit for energy is the joule (kg m\(^2\)/s\(^2\)). | during the interval that the force is exerted. 
| Work and Energy Relationships | During the interval that the force is exerted, 

a. Only the component of the net force exerted on an object parallel or antiparallel to the displacement of the object will increase (parallel) or decrease (antiparallel) the kinetic energy of the object.

b. The magnitude of the change in the kinetic energy is the product of the magnitude of the displacement and of the magnitude of the component of force parallel or antiparallel to the displacement. Relevant Equation:

c. The component of the net force exerted on an object perpendicular to the direction of the displacement of the object can change the direction of the motion of the object without changing the kinetic energy of the object. This should include uniform circular motion and projectile motion.

d. The kinetic energy of a rigid system may be translational, rotational, or a combination of both. The change in the rotational kinetic energy of a rigid system is

Gravitational Potential Energy (Low Earth Altitude) Gravitational

work and energy

Activity: Angles and Work – utilize everyday situations to develop a method of determining work done at an angle

Activity: Types of Energy – develop terminology based on everyday situations to describe different types of energy

Activity: Representing Work/Energy – use a variety of methods to represent Work/Energy and the concept of conservation (verbal, pictorial, graphical, mathematical)

Class Activity: Conservation of Energy – provide examples of situation where energy is conserved but does not remain constant for the system

Lab: Determining Power – develop an understanding of what power represents by allowing students to develop a lab in which they determine the power of a system

Lab: Elastic and Inelastic Collisions Lab

Textbook: Giancoli Activity: Individual/Group Problem Solving (textbook, AP practice problems, problems involving interdisciplinary connections)
4.C.1.1: The student is able to calculate the total energy of a system and justify the mathematical routines used in the calculation of component types of energy within the system whose sum is the total energy. [SP 1.4, 2.1, 2.2]

4.C.1.2: The student is able to predict changes in the total energy of a system due to changes in position and speed of objects or frictional interactions within the system. [SP 6.4]

4.C.1: The energy of a system includes its kinetic energy, potential energy, and microscopic internal energy. Examples include gravitational potential energy, elastic potential energy, and kinetic energy. a. A rotating, rigid body may be considered to be a system, and may have both translational and rotational kinetic energy. b. during an inelastic collision, some of the mechanical energy dissipates as (converts to) thermal energy. Relevant Equations:

\[ KE = \frac{1}{2}mv^2 \]
\[ \Delta E = W = Fd = Fdcos\theta \]

Lab-Energy Skate Park
Students will explore the transformation of the potential energy into kinetic energy

Students will analyze the conservation of energy

Students will build 3D tracks and ramps for skating

Lab-Power
Apply concepts of conservation of energy, gravitational potential energy, work, and power.

Lab-Marble Launch
Students will identify the conservation of energy concept
body may be considered to be a system, and may have both translational and rotational kinetic energy. b. Although thermodynamics is not part of Physics 1, included is the idea that during an inelastic collision, some of the mechanical energy dissipates as (converts to) thermal energy. Relevant Equations:

4.C.2.1: The student is able to make predictions about the changes in the mechanical energy of a system when a component of an external force acts parallel or antiparallel to the direction of the displacement of the center of mass. [SP 6.4]

4.C.2.2: The student is able to apply the concepts of Conservation of Energy and the Work-Energy theorem to determine qualitatively and/or quantitatively that work done on a two-object system in linear motion will change the kinetic energy of the center of mass of the system, the potential energy of the systems, and/or the internal energy of the system. [SP 1.4, 2.2, 7.2]

Students will show relationship among the following energies: Kinetic Energy (KE), Gravitational Potential Energy (GPE), and Elastic Potential Energy (EPE).

4.C.2: Mechanical energy (the sum of kinetic and potential energy) is transferred into or out of a system when an external force is exerted on a system such that a component of the force is parallel to its displacement. The process through which the energy is transferred is called work. a. If the force is constant during a given displacement, then the work done is the product of the displacement and the component of the force parallel or antiparallel to the displacement. Relevant Equation: 
\[ W = F d \]
b. Work (change in energy) can be found from the area under a graph of the magnitude of the force component parallel to the displacement versus displacement. Relevant Equation:
\[ \Delta E = W = F \Delta x = F d \cos \theta \]

5.A.1: A system is an object or a
5.A.2.1: The student is able to define open and closed systems for everyday situations and apply conservation concepts for energy, charge, and linear momentum to those situations. [SP 6.4, 7.2]

5.B.1.1: The student is able to set up a representation or model showing that a single object can only have kinetic energy and use information about that object to reach the equilibrium position of the mass–spring system.

5.A.2: 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.

5.A.3: An interaction can be either a force exerted by objects outside the system or the transfer of some quantity with objects outside the system.

5.A.4: The placement of a boundary between a system and its environment is a decision made by the person considering the situation in order to simplify or otherwise assist in analysis.

5.B.1: Classically, an object can only have kinetic energy since potential energy requires an interaction between two or more objects.

Relevant Equation
<table>
<thead>
<tr>
<th>Calculate its kinetic energy. [SP 1.4, 2.2]</th>
<th>KE = ( \frac{1}{2}mv^2 ).</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.B.1.2: The student is able to translate between a representation of a single object, which can only have kinetic energy, and a system that includes the object, which may have both kinetic and potential energies. [SP 1.5]</td>
<td>5.B.2: A system with internal structure can have internal energy, and changes in a system’s internal structure can result in changes in internal energy. [Physics 1: includes mass-spring oscillators and simple pendulums.]</td>
</tr>
<tr>
<td>5.B.2.1: The student is able to calculate the expected behavior of a system using the object model (i.e., by ignoring changes in internal structure) to analyze a situation. Then, when the model fails, the student can justify the use of conservation of energy principles to calculate the change in internal energy due to changes in internal structure because the object is actually a system. [SP 1.4, 2.1]</td>
<td>5.B.3: A system with internal structure can have potential energy. Potential energy exists within a system if the objects within that system interact with conservative forces. a. The work done by a conservative force is independent of the path taken. The work description is used for forces external to the system. Potential</td>
</tr>
<tr>
<td>5.B.3.1: The student is able to describe and make qualitative and/or quantitative predictions about everyday examples of systems with internal potential energy. [SP 2.2, 6.4, 7.2]</td>
<td>5.B.3.2: The student is able to describe and make qualitative and/or quantitative predictions about everyday examples of systems with internal potential energy. [SP 2.2, 6.4, 7.2]</td>
</tr>
</tbody>
</table>
5.B.3.3: The student is able to apply mathematical reasoning to create a description of the internal potential energy of a system from a description or diagram of the objects and interactions in that system. [SP 1.4, 2.2]

5.B.4.1: The student is able to describe and make predictions about the internal energy of systems. [SP 6.4, 7.2]

5.B.4.2: The student is able to calculate changes in kinetic energy and potential energy of a system, using information from representations of that system. [SP 1.4, 2.1, 2.2]

5.B.5.1: The student is able to design an experiment and analyze data to examine how a force exerted on an object or system

energy is used when the forces are internal interactions between parts of the system. b. Changes in the internal structure can result in changes in potential energy. Examples include mass-spring oscillators, objects falling in a gravitational field. c. The change in electric potential in a circuit is the change in potential energy per unit charge. (Physics 1: only in the context of circuits.)

\[ \Delta U_g = mg \Delta y \]

\[ U_s = \frac{1}{2} kx^2 \]

5.B.4.1: The student is able to describe and make predictions about the internal energy of systems. [SP 6.4, 7.2]

5.B.4.2: The student is able to calculate changes in kinetic energy and potential energy of a system, using information from representations of that system. [SP 1.4, 2.1, 2.2]

5.B.5: Energy can be transferred by an external force exerted on an object or system that moves the object or system through a
does work on the object or system as it moves through a distance. [SP 4.2, 5.1]

5.B.5.2: The student is able to design an experiment and analyze graphical data in which interpretations of the area under a force-distance curve are needed to determine the work done on or by the object or system. [SP 4.2, 5.1]

5.B.5.3: The student is able to predict and calculate from graphical data the energy transfer to or work done on an object or system from information about a force exerted on the object or system through a distance. [SP 1.4, 2.2, 6.4]

5.B.5.4: The student is able to make claims about the interaction between a system and its environment in which the environment exerts a force on the system, thus doing work on the system and changing the energy of the system (kinetic energy plus potential energy). [SP 6.4, 7.2]

5.B.5.5: The student is able to predict and calculate the energy distance; this energy transfer is called work. Energy transfer in mechanical or electrical systems may occur at different rates. Power is defined as the rate of energy transfer into, out of, or within a system. [A piston filled with gas getting compressed or expanded is treated in Physics 2 as part of thermodynamics.]

Relevant Equations:

\[ \Delta E = W = Fd = Fd\cos\theta \]

\[ P = \frac{\Delta E}{\Delta t} \]
transfer to (i.e., the work done on) an object or system from information about a force exerted on the object or system through a distance. [SP 2.2, 6.4]

5.D.1.1: The student is able to make qualitative predictions about natural phenomena based on conservation of linear momentum and restoration of kinetic energy in elastic collisions. [SP 6.4, 7.2]

5.D.1.2: The student is able to apply the principles of conservation of momentum and restoration of kinetic energy to reconcile a situation that appears to be isolated and elastic, but in which data indicate that linear momentum and kinetic energy are not the same after the interaction, by refining a scientific question to identify interactions that have not been considered. Students will be expected to solve qualitatively and/or quantitatively for one dimensional situations and only qualitatively in two dimensional situations. [SP 2.2, 3.2, 5.1, 5.3]

5.D.1.3: The student is able to apply mathematical routines

5.D.1: In a collision between objects, linear momentum is conserved. In an elastic collision, kinetic energy is the same before and after. a. In a closed system, the linear momentum is constant throughout the collision. b. In a closed system, the kinetic energy after an elastic collision is the same as the kinetic energy before the collision. Relevant Equations:

\[ \dot{p} = m \dot{v} \]

\[ K = \frac{1}{2} mv^2 \]
appropriately to problems involving elastic collisions in one dimension and justify the selection of those mathematical routines based on conservation of momentum and restoration of kinetic energy. [SP 2.1, 2.2]

5.D.1.4: The student is able to design an experimental test of an application of the principle of the conservation of linear momentum, predict an outcome of the experiment using the principle, analyze data generated by that experiment whose uncertainties are expressed numerically, and evaluate the match between the prediction and the outcome. [SP 4.2, 5.1, 5.3, 6.4]

5.D.1.5: The student is able to classify a given collision situation as elastic or inelastic, justify the selection of conservation of linear momentum and restoration of kinetic energy as the appropriate principles for analyzing an elastic collision, solve for missing variables, and calculate their values. [SP 2.1, 2.2]

5.D.2.1: The student is able to
qualitatively predict, in terms of linear momentum and kinetic energy, how the outcome of a collision between two objects changes depending on whether the collision is elastic or inelastic. [SP 6.4, 7.2]

5.D.2.3: The student is able to apply the conservation of linear momentum to a closed system of objects involved in an inelastic collision to predict the change in kinetic energy. [SP 6.4, 7.2]

<table>
<thead>
<tr>
<th>5.D.2: In a collision between objects, linear momentum is conserved. In an inelastic collision, kinetic energy is not the same before and after the collision.</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. In a closed system, the linear momentum is constant throughout the collision. b. In a closed system, the kinetic energy after an inelastic collision is different from the kinetic energy before the collision.</td>
</tr>
<tr>
<td>$\vec{p} = m\vec{v}$</td>
</tr>
<tr>
<td>$K = \frac{1}{2}mv^2$</td>
</tr>
</tbody>
</table>
### Vocabulary

<table>
<thead>
<tr>
<th>Energy conservation</th>
<th>Thermal Energy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gravitational Potential Energy</td>
<td>Translational energy</td>
</tr>
<tr>
<td>Kinetic Energy</td>
<td>Power</td>
</tr>
<tr>
<td>Mechanical Energy</td>
<td>Work done</td>
</tr>
<tr>
<td>Spring Potential energy</td>
<td></td>
</tr>
</tbody>
</table>

### References & Suggested Instructional Websites
References & Suggested Instructional Websites

Textbook:
Physics
Giancoli, D. C.
Pearson

Website:
https://www.edx.org/course/apr-physics-1-part-1-linear-motion-ricex-advphy1-1x

Lab:
Energy Skate Park; Timeline (90 minutes); (in the folder unit)

Lab:
Energy Skate Park: Basics:

Lab:
Power; Timeline (60 minutes); (in the folder unit) https://njctl.org/courses/downloads/attachments/by-md5/8/0/8064126a32ca1ba8d20f1297da154cd0/power-lab_2016-03-09.docx
Marble Launcher; Timeline (90 minutes); (in the unit folder) https://njctl.org/courses/downloads/attachments/by-md5/8/5/85fa38745d4df551d76cde4ccb1ded10/marble-launcher-lab-2-2015-07-10.docx

Phet Lab:
https://phet.colorado.edu/en/simulation/energy-skate-park-basics

Other online resources:
https://www.khanacademy.org/science/physics/work-and-energy
https://www.energy.gov/science-innovation/science-technology/physics
https://www.youtube.com/watch?v=x-Is8oOr7yg
https://www.youtube.com/watch?v=AzXb63GEMss
Grade: AP Physics I  
Unit 3: Conservative Laws  
Topic: 3.iii. Momentum  
Duration: 3 Weeks

**NJSLS:** HS-PS2  
Big Idea 3: The interactions of an object with other objects can be described by forces.

Big Idea 4: Interactions between systems can result in changes in those systems.

Big Idea 5: Changes that occur as a result of interactions are constrained by conservation laws

**Enduring Understanding:**
- 3.D: A force exerted on an object can change the momentum of the object
- 5.A: Certain quantities are conserved, in the sense that the changes of those quantities in a given system are always equal to the transfer of that quantity to or from the system by all possible interactions with other systems.
- 5.D: The linear momentum of a system is conserved

<table>
<thead>
<tr>
<th>NJDOE Student Learning Objective</th>
<th>Skills, Strategies &amp; Concepts</th>
<th>Essential Understandings/Questions</th>
<th>Tasks/Activities</th>
</tr>
</thead>
</table>
| 3.D.1.1: The student is able to justify the selection of data needed to determine the relationship between the direction of the force acting on an object and the change in momentum caused by that force. [SP 4.1] | Momentum Linear momentum is a physical property of a moving object. The definition of momentum is: Momentum is a vector quantity that points in the same direction as the velocity vector of a moving object. The units of momentum are Kg m/s. Impulse The impulse is always directed in the same direction as the change in the momentum of the object. In AP Physics 1 the force acting on an object relating | 3.D.1: The change in momentum of an object is a vector in the direction of the net force exerted on the object. Relevant Equation: \( \Delta p = \vec{F} \Delta t \)  
3.D.2: The change in momentum of an object occurs over a time interval. a. The force that one object exerts on a second object changes the momentum of the second object (in the absence of other forces on | Impulse and Momentum  
Conservation of Momentum in Collisions  
Conservation of Momentum – Ballistic Pendulum  
Hooke's Law  
Giancoli textbook problems  
AP practice problems  
Interdisciplinary connection problems  
Diagnostic pre- and post- |
3.D.2.2: The student is able to predict the change in momentum of an object from the average force exerted on the object and the interval of time during which the force is exerted. [SP 6.4]

3.D.2.3: The student is able to analyze data to characterize the change in momentum of an object from the average force exerted on the object and the interval of time during which the force is exerted. [SP 5.1]

3.D.2.4: The student is able to design a plan for collecting data to investigate the relationship between changes in momentum and the average force exerted on an object over time. [SP 4.2]

4.B.1.1: The student is able to calculate the change in linear momentum of a two object system with constant mass in linear motion from a representation of the system (data, graphs, etc.). [SP 1.4, 2.2]

4.B.1.2: The student is able to analyze data to find the change in linear momentum for a constant mass system is the product of the mass of the system and the change in velocity of the center of mass. Relevant Equation: \( P = mv \)

4.B.1: The change in linear momentum for a constant-mass system is the product of the mass of the system and the change in velocity of the center of mass. Relevant Equation: \( \Delta \dot{p} = \vec{F} \Delta t \)

b. The change in momentum of that object depends on the impulse, which is the product of the average force and the time interval during which the interaction occurred. Relevant Equation: \( \Delta \dot{p} = \vec{F} \Delta t \)

| Lab-HT Momentum | Students will confirm the conservation of momentum through investigations and collecting data |
| Lab-Parachute and Terminal Velocity | Students will analyze how having two variables on a falling object influences the speed |
| | Students will show mathematically how changing the height and the mass of the object will influence the speed. |
mass system using the product of the mass and the change in velocity of the center of mass. [SP 5.1]

4.B.1: The change in linear momentum for a constant-mass system is the product of the mass of the system and the change in velocity of the center of mass. Relevant Equation:

4.B.2.1: The student is able to apply mathematical routines to calculate the change in momentum of a system by analyzing the average force exerted over a certain time on the system. [SP 2.2]

4.B.2.2: The student is able to perform analysis on data presented as a forcetime graph and predict the change in momentum of a system. [SP 5.1]

5.A.2.1: The student is able to define open and closed systems for everyday situations and apply conservation concepts for energy, linear momentum, and angular momentum. Relevant Equations:

4.B.2: The change in linear momentum of the system is given by the product of the average force on that system and the time interval during which the force is exerted.

a. The units for momentum are the same as the units of the area under the curve of a force versus time graph.

b. The change in linear momentum and force are both vectors in the same direction.

Relevant Equations:

\[ \dot{p} = m\ddot{v} \]

\[ \Delta p = F \Delta t \]

5.A.2: For all systems under all circumstances, energy, charge, linear momentum, and angular momentum are conserved. For an isolated or a closed system,
5.D.1: In a collision between objects, linear momentum is conserved. In an elastic collision, kinetic energy is the same before and after.

a. In a closed system, the linear momentum is constant throughout the collision.
b. In a closed system, the kinetic energy after an elastic collision is the same as the kinetic energy before the collision.

\[ \bar{p} = m\bar{v} \]

\[ K = \frac{1}{2}mv^2 \]
apply mathematical routines appropriately to problems involving elastic collisions in one dimension and justify the selection of those mathematical routines based on conservation of momentum and restoration of kinetic energy. [SP 2.1, 2.2]

5.D.1.4: The student is able to design an experimental test of an application of the principle of the conservation of linear momentum, predict an outcome of the experiment using the principle, analyze data generated by that experiment whose uncertainties are expressed numerically, and evaluate the match between the prediction and the outcome. [SP 4.2, 5.1, 5.3, 6.4]

5.D.1.5: The student is able to classify a given collision situation as elastic or inelastic, justify the selection of conservation of linear momentum and restoration of kinetic energy as the appropriate principles for analyzing an elastic collision, solve for missing variables, and calculate their values. [SP 2.1, 2.2]
<table>
<thead>
<tr>
<th>5.D.2.1: The student is able to qualitatively predict, in terms of linear momentum and kinetic energy, how the outcome of a collision between two objects changes depending on whether the collision is elastic or inelastic. [SP 6.4, 7.2]</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.D.2.2: The student is able to plan data collection strategies to test the law of conservation of momentum in a two-object collision that is elastic or inelastic and analyze the resulting data graphically. [SP 4.1, 4.2, 5.1]</td>
</tr>
<tr>
<td>5.D.2.3: The student is able to apply the conservation of linear momentum to a closed system of objects involved in an inelastic collision to predict the change in kinetic energy. [SP 6.4, 7.2]</td>
</tr>
<tr>
<td>5.D.2.4: The student is able to analyze data that verify conservation of momentum in collisions with and without an external friction force. [SP 4.1, 4.2, 4.4, 5.1, 5.3]</td>
</tr>
<tr>
<td>5.D.2.5: The student is able to classify a given collision situation</td>
</tr>
<tr>
<td>5.D.2: In a collision between objects, linear momentum is conserved. In an inelastic collision, kinetic energy is not the same before and after the collision.</td>
</tr>
<tr>
<td>a. In a closed system, the linear momentum is constant throughout the collision.</td>
</tr>
<tr>
<td>b. In a closed system, the kinetic energy after an inelastic collision is different from the kinetic energy before the collision.</td>
</tr>
<tr>
<td>Relevant Equations:</td>
</tr>
</tbody>
</table>
| \[
\begin{align*}
\hat{p} &= m\hat{\vec{v}} \\
K &= \frac{1}{2}mv^2
\end{align*}
\] |
as elastic or inelastic, justify the selection of conservation of linear momentum as the appropriate solution method for an inelastic collision, recognize that there is a common final velocity for the colliding objects in the totally inelastic case, solve for missing variables, and calculate their values. [SP 2.1, 2.2]

5.D.3.1: The student is able to predict the velocity of the center of mass of a system when there is no interaction outside of the system but there is an interaction within the system (i.e., the student simply recognizes that interactions within a system do not affect the center of mass motion of the system and is able to determine that there is no external force). [SP 6.4]

5.D.3: The velocity of the center of mass of the system cannot be changed by an interaction within the system. [Physics 1: includes no calculations of centers of mass. However, without doing calculations, Physics 1 students are expected to be able to locate the center of mass of highly symmetric mass distributions, such as a uniform rod or cube of uniform density, or two spheres of equal mass.]

a. The center of mass of a system depends upon the masses and positions of the objects in the system. In an isolated system (a system with no external forces) the velocity of the center of mass does not change.
b. When objects in a system collide, the velocity of the center of mass of the system will not change unless an external force is exerted on the system.

c. Included in Physics 1 is the idea that where there is both a heavier and lighter mass, the center of mass is closer to the heavier mass. Only a qualitative understanding of this concept is required.

### Vocabulary

<table>
<thead>
<tr>
<th>Force</th>
<th>Inertia</th>
</tr>
</thead>
<tbody>
<tr>
<td>Law of conservation of momentum</td>
<td>Applied force</td>
</tr>
<tr>
<td>Gravitation force</td>
<td>Free-body diagram</td>
</tr>
<tr>
<td>Friction</td>
<td>Impulse</td>
</tr>
</tbody>
</table>
### References & Suggested Instructional Websites

<table>
<thead>
<tr>
<th>Textbook</th>
<th>Website:</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Textbook</strong></td>
<td><strong>Website:</strong></td>
</tr>
<tr>
<td>Physics</td>
<td><a href="https://www.edx.org/course/apr-physics-1-part-1-linear-motion-ricex-advphy1-1x">https://www.edx.org/course/apr-physics-1-part-1-linear-motion-ricex-advphy1-1x</a></td>
</tr>
<tr>
<td></td>
<td><a href="https://www.youtube.com/watch?v=V54MeDvJNXo">https://www.youtube.com/watch?v=V54MeDvJNXo</a></td>
</tr>
</tbody>
</table>

| Lab:                   |                                                                 |
|                       | **Lab:**                                                             |
|                       | HT Momentum; Timeline( 120 minute); In the Unit Folder               |
|                       | [https://njctl.org/courses/downloads/attachments/by-md5/a/3/a30198b5d50bb43b480c146a0a70fc3/momentum-lab-ht-2013-07-25.docx](https://njctl.org/courses/downloads/attachments/by-md5/a/3/a30198b5d50bb43b480c146a0a70fc3/momentum-lab-ht-2013-07-25.docx) |

| Phet Lab:              |                                                                 |
|                       | **Phet Lab:**                                                        |

<table>
<thead>
<tr>
<th>Grade: AP Physics I</th>
<th>Unit 3: Conservative Laws</th>
<th>Topic:  3.iv. Simple Harmonic Motion</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><strong>Unit 3: Conservative Laws</strong></td>
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<td>Duration: 4 Weeks</td>
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</table>

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NJSLS: HS-PS2

Big Idea 3: The interactions of an object with other objects can be described by forces.

Big Idea 5: Changes that occur as a result of interactions are constrained by conservation laws.

Enduring Understanding:

- 3.B: Classically, the acceleration of an object interacting with other objects can be predicted by using
  \[ a = \frac{\sum F}{m} \]
- 5.B: The energy of a system is conserved.

<table>
<thead>
<tr>
<th>NJDOE Student Learning Objective</th>
<th>Skills, Strategies &amp; Concepts</th>
<th>Essential Understandings/Questions</th>
<th>Tasks/Activities</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.B.3.1: The student is able to predict which properties determine the motion of a simple harmonic oscillator and what the dependence of the motion is on those properties. [SP 6.4, 7.2]</td>
<td>The concept of a force being directed towards the center at all times. When an object is at max acceleration, its velocity is zero. Conversely, when an object is at rest, its acceleration is maximum. Mass-spring Oscillating System Simple Pendulum d. Oscillation and Energy Transformation Simple harmonic motion (SHM) occurs when an object is subjected to a linear restoring force (such as</td>
<td>3.B.3: Restoring forces can result in oscillatory motion. When a linear restoring force is exerted on an object displaced from an equilibrium position, the object will undergo a special type of motion called simple harmonic motion. Examples include gravitational force exerted by the Earth on a simple pendulum and mass-spring oscillator. a. For a spring that exerts a linear restoring force, the period of a mass-spring oscillator increases with mass and decreases with spring stiffness. b. For a simple pendulum, the period increases with the length of the</td>
<td>Activity: Simple Harmonic Oscillator Activity: use the pendulum to determine g. Activity: Individual/Group Problem Solving (textbook, AP practice problems, problems involving interdisciplinary connections) Calculation of g using the pendulum</td>
</tr>
<tr>
<td>3.B.3.2: The student is able to design a plan and collect data in order to ascertain the characteristics of the motion of a system undergoing oscillatory motion caused by a restoring force. [SP 4.2]</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3.B.3.3: The student can analyze data to identify qualitative or</td>
<td></td>
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</tbody>
</table>

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quantitative relationships between given values and variables (i.e., force, displacement, acceleration, velocity, period of motion, frequency, spring constant, string length, mass) associated with objects in oscillatory motion to use that data to determine the value of an unknown. [SP 2.2, 5.1]

3.B.3.4: The student is able to construct a qualitative and/or a quantitative explanation of oscillatory behavior given evidence of a restoring force. [SP 2.2, 6.2]

5.B.2.1: The student is able to calculate the expected behavior of a system using the object model (i.e., by ignoring changes in internal structure) to analyze a situation. Then, when the model fails, the student can justify the use of conservation of energy principles to calculate the change in internal energy due to changes in internal structure because the object is actually a system. [SP 1.4, 2.1]

5.B.3.1: The student is able to describe and make qualitative a force exerted by a spring on an object. The object will oscillate back and forth over the same path, with each oscillation taking the same amount of time. The equation that expresses the position versus time for SHM is where is the position, is the amplitude (the greatest distance from the equilibrium point), is the frequency of oscillation measured in Hz, and t is the variable of time.

\[ x(t) = A \cos(2\pi ft) \]

Period of SHM Oscillations occur when a system has a restoring force and is disturbed from a position of equilibrium. When the object oscillates back and forth, each vibration takes the same amount of time. The time for one oscillation is called the period (T). The SI unit of period is the second. Another way to characterize an object in SHM is to use the measurement of frequency. Frequency (f) is defined as the number of oscillations per unit time and the SI unit for frequency is Hz (Hz = sec⁻¹). Period and frequency are related in the following way:

\[ T_s = 2\pi \sqrt{\frac{1}{g}} \]
\[ T_p = 2\pi \sqrt{\frac{m}{k}} \]

5.B.2: A system with internal structure can have internal energy, and changes in a system’s internal structure can result in changes in internal energy. [Physics 1: includes mass-spring oscillators and simple pendulums. Physics 2: includes charged object in electric fields and examining changes in internal energy with changes in configuration.]

5.B.3: A system with internal structure can have potential
and/or quantitative predictions about everyday examples of systems with internal potential energy. [SP 2.2, 6.4, 7.2]

5.B.3.2: The student is able to make quantitative calculations of the internal potential energy of a system from a description or diagram of that system. [SP 1.4, 2.2]

5.B.3.3: The student is able to apply mathematical reasoning to create a description of the internal potential energy of a system from a description or diagram of the objects and interactions in that system. [SP 1.4, 2.2]

5.B.4.1: The student is able to describe and make predictions about the internal energy of systems. [SP 6.4, 7.2]

5.B.4.2: The student is able to calculate changes in kinetic energy and potential energy of a system, using information from representations of that system. [SP 1.4, 2.1, 2.2]

<table>
<thead>
<tr>
<th>T = 1/ f</th>
</tr>
</thead>
<tbody>
<tr>
<td>The period is also related to another measurement: angular frequency (ω). Angular frequency is measured in rad/s and is related to the period in the following way:</td>
</tr>
<tr>
<td>Ω = 2π / T</td>
</tr>
</tbody>
</table>

Concept of Resonance

the period of pendulum depends on mass and spring constant.

the relationships between the period and length of the pendulum.

Period of Mass–Spring System in SHM The period of oscillation of a mass oscillating in SHM attached to a linear spring is completely dependent on the characteristics of the spring and the mass. The period does not depend on the amplitude of the oscillation. The equation for period is

\[ T_s = 2\pi \sqrt{\frac{m}{k}} \]

A simple pendulum consists of a small object of mass, with mass energy. Potential energy exists within a system if the objects within that system interact with conservative forces. a. The work done by a conservative force is independent of the path taken. The work description is used for forces external to the system. Potential energy is used when the forces are internal interactions between parts of the system. b. Changes in the internal structure can result in changes in potential energy. Examples include mass-spring oscillators and objects falling in a gravitational field. c. The change in electric potential in a circuit is the change in potential energy per unit charge. [Physics 1: only in the context of circuits.] Relevant Equations:

\[ T_p = 2\pi \sqrt{\frac{m}{g}} \]

\[ U_g = \frac{1}{2} kx^2 \]

\[ \Delta U_s = mg \Delta y \]

5.B.4.1: The student is able to
suspended from the end of a lightweight (massless) string of length displaced a relatively small angle from the vertical (or equilibrium) position. The motion of the pendulum bob is approximately simple harmonic motion and can be described mathematically in the same way as a mass oscillating on a spring. This implies that the pendulum is periodic and its period depends on the physical characteristic of the pendulum system — but not on the mass of the pendulum bob! The period of a pendulum is represented by the following relationship:

\[ T_p = 2\pi \sqrt{\frac{l}{g}} \]

describe and make predictions about the internal energy of systems. [SP 6.4, 7.2] 5.B.4.2: The student is able to calculate changes in kinetic energy and potential energy of a system, using information from representations of that system. [SP 1.4, 2.1, 2.2]

5.B.4: The internal energy of a system includes the kinetic energy of the objects that make up the system and the potential energy of the configuration of the objects that make up the system. a. Since energy is constant in a closed system, changes in a system’s potential energy can result in changes to the system’s kinetic energy. b. The changes in potential and kinetic energies in a system may be further constrained by the construction of the system.
## Vocabulary

<table>
<thead>
<tr>
<th>Oscillation</th>
<th>Rest position</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency</td>
<td>Period time</td>
</tr>
<tr>
<td>Amplitude</td>
<td></td>
</tr>
</tbody>
</table>

## References & Suggested Instructional Websites

**Textbook**
Physics
Giancoli, D. C.
Pearson

**Website:**
- [https://www.youtube.com/watch?v=jxstE6A_CYQ](https://www.youtube.com/watch?v=jxstE6A_CYQ)

**Phet labs:**
- [https://phet.colorado.edu/en/simulation/pendulum-lab](https://phet.colorado.edu/en/simulation/pendulum-lab)

**Test Prep:**
AP Practice Problems (College Board) [https://apstudent.collegeboard.org/apcourse/ap-physics-1/exam-practice](https://apstudent.collegeboard.org/apcourse/ap-physics-1/exam-practice)
### Grade: AP Physics I

<table>
<thead>
<tr>
<th>Unit 3: Conservative Laws</th>
<th>Topic: 3.v. Torque and Rotational Motion. Duration: 3 Weeks</th>
</tr>
</thead>
</table>

**NJSLS: HS-PS2**

Big Idea 3: The interactions of an object with other objects can be described by forces.

Big Idea 4: Interactions between systems can result in changes in those systems.

Big Idea 5: Changes that occur as a result of interactions are constrained by conservation laws.

**Enduring Understanding:**
- 3.A: All forces share certain common characteristics when considered by observers in inertial reference frames
- 3.F: A force exerted on an object can cause a torque on that object
- 4.D: A net torque exerted on a system by other objects or systems will change the angular momentum of the system
- 5.E: The angular momentum of a system is conserved

<table>
<thead>
<tr>
<th>NJDOE Student Learning Objective</th>
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</tr>
</thead>
</table>
| 3.A.1.1: The student is able to express the motion of an object using narrative, mathematical, and graphical representations. [SP 1.5, 2.1, 2.2] | Linear Motion | Rotational Motion | Angular Position and Angular Displacement Angular position can be measured in various ways: a degree measurement, a fraction of a circle, etc. However, in physics, the SI unit for angular measurement is the radian. The \[ F = ma \]
|                               | Force (N)                   | Torque \( \tau \) (N\cdot m)   | Angular velocity \( \omega \) |
|                               | Velocity (m/s)              | Angular acceleration            | Rotational inertia |
|                               | Acceleration                | \( \tau = I \omega \)           |                         |
|                               | Mass                        |                                  |                           |
|                               | F = ma                      |                                  |                           |

3.A.1: An observer in a particular reference frame can describe the motion of an object using such quantities as position, displacement, distance, velocity, speed, and acceleration. a. For rotational motion, there are analogous quantities such as angular position, angular velocity, and angular acceleration. The kinematic equations describing angular motion with constant angular acceleration are:

| Activity: Understanding Equilibrium and Torque – utilize our understanding of linear dynamics and apply it to rotational situations
| Activity: Angular Kinematics – utilize our understanding of linear kinematics and apply it to rotational situations
| Activity: Angular Momentum – utilize our understanding of momentum and apply it to rotational situations

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<table>
<thead>
<tr>
<th>3.F.1.1: The student is able to use representations of the relationship between force and torque. [SP 1.4]</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.F.1.2: The student is able to compare the torques on an object caused by various forces. [SP 1.4]</td>
</tr>
<tr>
<td>3.F.1.3: The student is able to estimate the torque on an object caused by various forces in comparison to other situations. [SP 2.3]</td>
</tr>
<tr>
<td>3.F.1.4: The student is able to design an experiment and radian is easy to work with since it is based on the unit circle: radians is equivalent to 360 degrees. In order to execute mathematical and physical manipulations in rotational motion, all measurements need to be made in radians. Uniform Angular Acceleration The kinematic relationships that govern the relationships of an object translating with a uniform acceleration are also true in the rotational version of uniformly accelerated angular motion. The general definitions of average velocity and average acceleration are as follows: Angular displacement $= \Delta \theta$ Angular velocity $\omega = \Delta \theta / t$ Angular acceleration $a = \Delta \omega / t$ $\theta = \theta_0 + \omega_0 t + \frac{1}{2}at^2$ or $\Delta \theta = \omega_0 t + \frac{1}{2}at^2$ $\omega = \omega_0 + at$ Newton’s Second Law for Rotating Objects Angular acceleration is the rate at which the angular velocity changes as a result of an applied torque. The relationship between angular acceleration, torque, and rotational inertia is the rotational equivalent of Newton’s second law. This law is analogous to Newton’s second law for a linearly moving object and is represented in the following way: $\omega = \omega_0 + at$ $\theta = \theta_0 + \omega_0 t + \frac{1}{2}at^2$ $\omega^2 = \omega_0^2 + 2at\theta$</td>
</tr>
<tr>
<td>b. For uniform circular motion of radius $r$, $v$ is proportional to $\omega$ (for a given $r$), and proportional to $r$ (for a given $\omega$). Given a radius $r$ and a period of rotation $T$, students derive and apply $v = (2\pi r)/T$.</td>
</tr>
<tr>
<td>3.F.1: Only the force component perpendicular to the line connecting the axis of rotation and the point of application of the force results in a torque about that axis. a. The lever arm is the perpendicular distance from the axis of rotation or revolution to the line of application of the force. b. The magnitude of the torque is the product of the magnitude of the lever arm and the magnitude of the force. c. The net torque on a balanced system is zero. Relevant Equation: $\tau = rF \sin \theta$</td>
</tr>
<tr>
<td>Activity: Rotational Energy – utilize our understanding of work/energy and apply it to rotational situations</td>
</tr>
<tr>
<td>Class Activity: Conservation of Angular Momentum – utilize rotating objects such as a bicycle wheel to demonstrate the importance of understanding angular momentum</td>
</tr>
<tr>
<td>Lab: Design Lab</td>
</tr>
<tr>
<td>Lab: Rotating Arm/Platform</td>
</tr>
<tr>
<td>Lab: Ballistic Pendulum</td>
</tr>
<tr>
<td>Textbook: Giancoli Chapter 8 and Chapter 9</td>
</tr>
<tr>
<td>Activity: Individual/Group Problem Solving (textbook, AP practice problems, problems involving interdisciplinary connections)</td>
</tr>
</tbody>
</table>
analyze data testing a question about torques in a balanced rigid system. [SP 4.1, 4.2, 5.1]

3.F.1.5: The student is able to calculate torques on a two-dimensional system in static equilibrium, by examining a representation or model (such as a diagram or physical construction). [SP 1.4, 2.2]

3.F.2.1: The student is able to make predictions about the change in the angular velocity about an axis for an object when forces exerted on the object cause a torque about that axis. [SP 6.4]

3.F.2.2: The student is able to plan data collection and analysis strategies designed to test the relationship between a torque exerted on an object and the change in angular velocity of that object about an axis. [SP 4.1, 4.2, 5.1]

| $\alpha = \frac{\sum \tau}{I}$ |

Where $\alpha$ is the angular acceleration of an object or system of objects and $\sum \tau$ is the sum of the applied torques on the system. $I$ is defined as the rotational inertia of the system.

Torque An object or rigid system that can revolve or rotate about a fixed axis will change its rotational motion when an external force exerts a torque on the object. The torque depends on the magnitude and direction of the force and where the force is applied. The product of this force and perpendicular distance between the point of rotation and point of application is defined as torque:

$$\tau = r \times F = |r| |F| \sin \theta$$

Where $\tau$ is the torque applied to an object, $r$ is the perpendicular distance from where the force is applied to the point of rotation, $F$ is the magnitude of the position vector, $|r|$ is the magnitude of the force applied to the object, and $\theta$ is the angle between the position and force vectors when the two vectors are not collinear.

3.F.2: The presence of a net torque along any axis will cause a rigid system to change its rotational motion or an object to change its rotational motion about that axis. 

a. Rotational motion can be described in terms of angular displacement, angular velocity, and angular acceleration about a fixed axis.

b. Rotational motion of a point can be related to linear motion of the point using the distance of the point from the axis of rotation.

c. The angular acceleration of an object or rigid system can be calculated from the net torque and the rotational inertia of the object or rigid system.
3.F.3.1: The student is able to predict the behavior of rotational collision situations by the same processes that are used to analyze linear collision situations using an analogy between impulse and change of linear momentum and angular impulse and change of angular momentum. [SP 6.4, 7.2]

drawn from a common origin. Torque is a vector and is either clockwise (CW) or counterclockwise (CCW), and it is measured in the SI unit.

Angular Momentum Angular momentum is the rotational analog to linear momentum. An object or extended body that has an angular velocity will also have angular momentum. A rotating object or extended body having a rotational inertia will also have angular momentum. This momentum is expressed with the following relationship:

\[ L = I\omega \]

The SI unit of angular momentum is \( \text{kg} \cdot \text{m}^2/\text{s} \). Angular momentum is a vector and can have either a clockwise (CW) or counterclockwise (CCW) direction or sense, which is the same sense of rotation as the rotating object.

Change in Angular Momentum The change in angular momentum of an object can be described by the angular impulse acting on the object. This is the rotational equivalent to the impulse–momentum relationship:

\[ \Delta L = \tau \Delta t \]

Relevant Equations:

\[ \tau = rF = rF\sin\theta \]
\[ \alpha = \sum \frac{\tau}{I} \]
\[ \theta = \theta_0 + \omega_0 t + \frac{1}{2} \alpha t^2 \]
\[ \omega = \omega_0 + \alpha t \]
\[ \omega^2 = \omega_0^2 + 2\alpha(\theta - \theta_0) \]

3.F.3: A torque exerted on an object can change the angular momentum of an object.

a. Angular momentum is a vector quantity, with its direction determined by a right-hand rule.

b. The magnitude of angular momentum of a point object about an axis can be calculated by multiplying the perpendicular distance from the axis of rotation to the line of motion by the magnitude of linear momentum.

c. The magnitude of angular momentum of an extended object can also be found by multiplying the rotational inertia by the angular velocity. Students do not need to know the equation for an object’s rotational inertia, as it will be provided at the exam. They should have a qualitative sense of
3.F.3.2: In an unfamiliar context or using representations beyond equations, the student is able to justify the selection of a mathematical routine to solve for the change in angular momentum of an object caused by torques exerted on the object. [SP 2.1]

3.F.3.3: The student is able to plan data collection and analysis strategies designed to test the relationship between torques exerted on an object and the change in angular momentum of that object. [SP 4.1, 4.2, 5.1, 5.3]

| 4.D.1.1: The student is able to describe a representation and | Rotational Kinetic Energy Rotational kinetic energy is the energy of an object or extended body rotating about an axis. The equation for rotational kinetic energy is analogous to the translational KE: \( K_r = \frac{1}{2} I \omega^2 \) | what factors affect rotational inertia, for example why a hoop has more rotational inertia than a puck of the same mass and radius. d. The change in angular momentum of an object is given by the product of the average torque and the time the torque is exerted. Relevant Equations

\[
L = I\omega \\
\Delta L = t\Delta t \\
L = mvr
\]

4.D.1: Torque, angular velocity, angular acceleration, and angular momentum are vectors and can be characterized as positive or negative depending upon whether they give rise to or correspond to counterclockwise or clockwise rotation with respect to an axis. Relevant Equations:
use it to analyze a situation in which several forces exerted on a rotating system of rigidly connected objects change the angular velocity and angular momentum of the system. [SP 1.2, 1.4]

4.D.1.2: The student is able to plan data collection strategies designed to establish that torque, angular velocity, angular acceleration, and angular momentum can be predicted accurately when the variables are treated as being clockwise or counterclockwise with respect to a well-defined axis of rotation, and refine the research question based on the examination of data. [SP 3.2, 4.1, 4.2, 5.1, 5.3]
rotational system and use that model to analyze a situation in which angular momentum changes due to interaction with other objects or systems. [SP 1.2, 1.4]

4.D.2.2: The student is able to plan a data collection and analysis strategy to determine the change in angular momentum of a system and relate it to interactions with other objects and systems. [SP 4.2]

angular velocity. Students do not need to know the equation for an object’s rotational inertia, as it will be provided at the exam. They should have a qualitative sense that rotational inertia is larger when the mass is farther from the axis of rotation.

Relevant Equations:

\[ L = I \omega \]
\[ \Delta L = \tau \Delta t \]
\[ \tau = rF = r F \sin \theta \]

4.D.3: The change in angular momentum is given by the product of the average torque and the time interval during which the torque is exerted.

Relevant Equations:

\[ L = I \omega \]
\[ \Delta L = \tau \Delta t \]
\[ \tau = rF = r F \sin \theta \]
4.D.3.1: The student is able to use appropriate mathematical routines to calculate values for initial or final angular momentum, or change in angular momentum of a system, or average torque or time during which the torque is exerted in analyzing a situation involving torque and angular momentum. [SP 2.2]

4.D.3.2: The student is able to plan a data collection strategy designed to test the relationship between the change in angular momentum of a system and the product of the average torque applied to the system and the time interval during which the torque is exerted. [SP 4.1, 4.2]

5.E.1: If the net external torque exerted on the system is zero, the angular momentum of the system does not change. Relevant Equations:

\[ L = I\omega \]
\[ \Delta L = \tau \Delta t \]
\[ \tau = r_i F = rF \sin \theta \]

5.E.2: The angular momentum of a system is determined by the locations and velocities of the objects that make up the system. The rotational inertia of an object or system depends upon the distribution of mass within the object or system. Changes in the radius of a system or in the distribution of mass within the system result in changes in the system’s rotational inertia, and hence in its angular velocity and linear speed for a given angular momentum. Examples include elliptical orbits in an Earth-satellite system. Mathematical
| 5.E.1.2: The student is able to make calculations of quantities related to the angular momentum of a system when the net external torque on the system is zero. [SP 2.1, 2.2] |
| 5.E.2.1: The student is able to describe or calculate the angular momentum and rotational inertia of a system in terms of the locations and velocities of objects that make up the system. Students are expected to do qualitative reasoning with compound objects. Students are expected to do calculations with a fixed set of extended objects and point masses. [SP 2.2] |
| Expressions for the moments of inertia will be provided where needed. Students will not be expected to know the parallel axis theorem. Students do not need to know the equation for an object’s rotational inertia, as it will be provided at the exam. They should have a qualitative sense that rotational inertia is larger when the mass is farther from the axis of rotation. Relevant Equation: \[ I = mr^2 \] |
### Vocabulary

<table>
<thead>
<tr>
<th>Torque</th>
<th>Angular velocity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pivot</td>
<td>Inertia</td>
</tr>
<tr>
<td>Static equilibrium</td>
<td>Angular acceleration</td>
</tr>
<tr>
<td>Dynamic equilibrium</td>
<td></td>
</tr>
</tbody>
</table>

### References & Suggested Instructional Websites

**Textbook:**
Physics  
Giancoli, D. C.  
Pearson  

**Website:**

**Phet labs**
- [https://phet.colorado.edu/en/simulation/legacy/torque](https://phet.colorado.edu/en/simulation/legacy/torque)

**Test Prep:**
### NJDOE Student Learning Objective

| 1.B.1.1: The student is able to make claims about natural phenomena based on conservation of electric charge. [SP 6.4] |
| 1.B.1.2: The student is able to make predictions, using the conservation of electric charge, about the sign and relative quantity of net charge of objects or systems after various charging processes, including conservation of charge in simple circuits. [SP 6.4, 7.2] |

#### Skills, Strategies & Concepts

- Types of electric charges; Positive and negative. The inverse square law applies to electric charges as well and is very similar to gravitational force, \( F = \frac{kQQ}{r^2} \)
- Application of law to determine the force between charges.

#### Essential Understandings/Questions

- 1.B.1: Electric charge is conserved. The net charge of a system is equal to the sum of the charges of all the objects in the system.
  - a. An electrical current is a movement of charge through a conductor.
  - b. A circuit is a closed loop of electrical current.
- Relevant Equation: \( I = \frac{\Delta q}{\Delta t} \)

#### Tasks/Activities

- Activity: Coulomb's Law
- Lab: Determining Resistance
- Textbook: Giancoli
- Activity: Individual/Group Problem Solving (textbook, AP Practice problems.)
- Lab: Electric Charge
  - Students will observe how static electricity is generated
  - Students will determine the...
1.B.2.1: The student is able to construct an explanation of the two-charge model of electric charge based on evidence produced through scientific practices. [SP 6.2]

1.B.3.1: The student is able to challenge the claim that an electric charge smaller than the elementary charge has been isolated. [SP 1.5, 6.1, 7.2]

3.C.2.1: The student is able to use Coulomb’s law qualitatively and quantitatively to make predictions about the interaction between two electric point charges (interactions

---

1.B.2: There are only two kinds of electric charge. Neutral objects or systems contain equal quantities of positive and negative charge, with the exception of some fundamental particles that have no electric charge. a. Like-charged objects and systems repel, and unlike-charged objects and systems attract.

Relevant Equation

\[
|F_e| = \frac{kq_1q_2}{r^2}
\]

1.B.3: The smallest observed unit of charge that can be isolated is the electron charge, also known as the elementary charge.

a. The magnitude of the elementary charge is equal to 1.6 x 10^-19 coulombs.

b. Electrons have a negative elementary charge; protons have a positive elementary charge of equal magnitude, although the mass of a proton is much larger than the mass of an electron.

3.C.2: Electric force results from the interaction of one object that has an electric charge with another

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Lab-Electric Tape
Students will observe how static electricity is generated
Students will determine the properties of electric charge and electric force

Lab-Electric Tape Discovery
Students will analyze the properties of electric charges and electric fields

Lab-Faraday’s Law
Students will investigate how the change in the magnetic flux can produce an electric flow.

Lab-Charges and Fields
Students will determine the variables that affect how charged bodies interact.

Students will describe the strength and direction of the electric field around a charged body.

Students will use free-body diagrams and vector addition to help explain the interactions.
between collections of electric point charges are not covered in Physics 1 and instead are restricted to Physics 2). [SP 2.2, 6.4]

3.C.2.2: The student is able to connect the concepts of gravitational force and electric force to compare similarities and differences between the forces. [See SP 7.2]

5.A.2.1: The student is able to define open and closed systems for everyday situations and apply conservation concepts for energy, charge and linear momentum to those situations. [SP 6.4, 7.2]

<table>
<thead>
<tr>
<th>Analyze and Explain the Concept Related to</th>
</tr>
</thead>
<tbody>
<tr>
<td>A student touches an electroscope with his hand at the same time he brings a positively charged rod close to the electroscope without touching. When he removes his hand first and then moves the rod away from the electroscope the leaves move apart. Why? What type of charge is on the leaves?</td>
</tr>
</tbody>
</table>

Object that has an electric charge.

a. Electric forces dominate the properties of the objects in our everyday experiences. However, the large number of particle interactions that occur make it more convenient to treat everyday forces in terms of nonfundamental forces called contact forces, such as normal force, friction, and tension. b. Electric forces may be attractive or repulsive, depending upon the charges on the objects involved.

Relevant Equations

\[ |F_\text{e}| = k \frac{|q_1 q_2|}{r^2} \]

\[ |F_\text{g}| = \frac{m_1 m_2}{r^2} \]

5.A.2: 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.
Vocabulary

<table>
<thead>
<tr>
<th>Faraday’s laws</th>
<th>Electric force</th>
</tr>
</thead>
<tbody>
<tr>
<td>Static electricity</td>
<td>Charge particle</td>
</tr>
<tr>
<td>Electricity</td>
<td>Positive charge</td>
</tr>
<tr>
<td>Electrons</td>
<td>Negative charge</td>
</tr>
<tr>
<td>Electric field</td>
<td></td>
</tr>
</tbody>
</table>

References & Suggested Instructional Websites
# References & Suggested Instructional Websites

**Textbook:**  
Physics  
Giancoli, D. C.  
Pearson  

**Websites:**  
https://www.youtube.com/watch?v=_0hQw5gFgSo  
https://www.varsitytutors.com/ap_physics_1-help/fundamentals-of-electric-charge  
https://www.beaverdam.k12.wi.us/faculty/letkewiczt/ELECTRIC%20FIELD%20PRACTICE.pdf

**Phet Lab:**  

**Labs:**  
Electric Charge; Timeline (90 minutes); In the unit folder  
Electric Tape; Timeline (120 minutes); in the Unit Folder  
https://njctl.org/courses/downloads/attachments/by-md5/4/e/4eba8dd9aba9b00c8aea432efa2dc3ec/electric-tape-lab-2013-08-19.docx  
Lab-Electric Tape Discovery; Timeline (120 minutes); In the Unit Folder  
**Faraday’s Law:** Investigate Faraday's law and how a changing magnetic flux can produce a flow of electricity!; Timeline (120 minutes); in the Unit Folder.  
**Charges and Fields:** Move point charges around on the playing field and then view the electric field, voltages, equipotential lines, and more.

| Grade: AP Physics I | Unit 3: Conservative Laws | Topic: 3.vii. DC Circuits  
|---------------------|--------------------------|-----------------------------  
|                     |                          | Duration: 2 Weeks           |
**NJSLS: HS-PS2**

Big Idea 1: Objects and systems have properties such as mass and charge. Systems may have internal structure.

Big Idea 5: Changes that occur as a result of interactions are constrained by conservation laws.

**Enduring Understanding:**
- 1.B: Electric charge is a property of an object or system that affects its interactions with other objects or systems containing charge.
- 1.E: Materials have many macroscopic properties that result from the arrangement and interactions of the atoms and molecules that make up the material.
- 5.B: The energy of a system is conserved.
- 5.C: The electric charge of a system is conserved.

<table>
<thead>
<tr>
<th>NJDOE Student Learning Objective</th>
<th>Skills, Strategies &amp; Concepts</th>
<th>Essential Understandings/Questions</th>
<th>Tasks/Activities</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.B.1.1: The student is able to make claims about natural phenomena based on conservation of electric charge. [SP 6.4]</td>
<td>Current is the flow of electrons. The direction of flow is the direction of “positive charges”. Current only flows in a closed loop. Ohm’s Law: ( V = IR ). Application of ohm’s law to series and parallel circuits. For series circuits: ( R = \sum R ). For parallel circuits:</td>
<td>1.B.1: Electric charge is conserved. The net charge of a system is equal to the sum of the charges of all the objects in the system. a. An electrical current is a movement of charge through a conductor. b. A circuit is a closed loop of electrical current. Relevant Equation: ( I = \frac{\Delta q}{\Delta t} )</td>
<td>Lab-Series Circuit Students will measure and calculate voltage drops across any part of a series circuit. Students will Measure and calculate the current through any part of a series circuit. Students will determine the equivalent resistance for a series circuit.</td>
</tr>
<tr>
<td>1.B.1.2: The student is able to make predictions, using the conservation of electric charge, about the sign and relative quantity of net charge of objects or systems after various charging processes, including conservation of charge in simple circuits. [SP 6.4, 7.2]</td>
<td></td>
<td></td>
<td>Lab–Parallel Circuit Students will measure and calculate voltage drops across any part of a parallel circuit. Students will measure and calculate the current through any part of a parallel circuit. Students will determine the equivalent resistance for a parallel circuit.</td>
</tr>
<tr>
<td>1.E.2.1: The student is able to choose and justify the selection of</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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**101 | Page**
data needed to determine resistivity for a given material. [SP 4.1]

5.B.9.1: The student is able to construct or interpret a graph of the energy changes within an electrical circuit with only a single battery and resistors in series and/or in, at most, one parallel branch as an application of the conservation of energy (Kirchhoff’s loop rule). [SP 1.1, 1.4]

5.B.9.2: The student is able to apply conservation of energy concepts to the design of an experiment that will demonstrate the validity of Kirchhoff’s loop rule (∑ΔV=0) in a circuit with only a battery and resistors either in series or in, at most, one pair of parallel branches. [SP 4.2, 6.4, 7.2]

5.B.9.3: The student is able to apply conservation of energy (Kirchhoff’s loop rule) in calculations involving the total material depends on its molecular and atomic structure. b. The resistivity depends on the temperature of the material. Resistivity changes with temperature. Relevant Equation:

\[
\frac{1}{R} = \sum \frac{1}{R_i}
\]

Understand the power rating of an appliance

Power = VI
I = P/V
That is, the larger the voltage the smaller the Current. Hence the reason for 240V being cheaper as electricity is consumed by Current usage.

5.B.9: Kirchhoff’s loop rule describes conservation of energy in electrical circuits. The potential difference across an ideal battery is also referred to as the emf of the battery, represented as ε. [Non-ideal batteries are not covered in Physics 1.]
a. Energy changes in simple electrical circuits are conveniently represented in terms of energy change per charge moving through a battery and a resistor.
b. Since electric potential difference times charge is energy, and energy is conserved, the sum of the potential differences about any closed loop must add to zero.
c. The electric potential difference across a resistor is given by the product of the current and the resistance.
d. The rate at which energy is transferred from a resistor is equal to the power consumed by the resistor.
<table>
<thead>
<tr>
<th>Electric potential difference for complete circuit loops with only a single battery and resistors in series and/or in, at most, one parallel branch. [SP 2.2, 6.4, 7.2]</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>5.C.3.1:</strong> The student is able to apply conservation of electric charge (Kirchhoff’s junction rule) to the comparison of electric current in various segments of an electrical circuit with a single battery and resistors in series and in, at most, one parallel branch and predict how those values would change if configurations of the circuit are changed. [SP 6.4, 7.2]</td>
</tr>
<tr>
<td><strong>5.C.3.2:</strong> The student is able to design an investigation of an electrical circuit with one or more resistors in which evidence of conservation of electric charge can be collected and analyzed. [SP 4.1, 4.2, 5.1]</td>
</tr>
<tr>
<td><strong>5.C.3.3:</strong> The student is able to use a description or schematic diagram of an electrical circuit to calculate unknown values of current in various segments or branches of the circuit. Relevant Equations:</td>
</tr>
<tr>
<td>[ I = \frac{\Delta V}{R} ]</td>
</tr>
<tr>
<td>[ P = I \Delta V ]</td>
</tr>
<tr>
<td><strong>5.C.3:</strong> Kirchhoff’s junction rule describes the conservation of electric charge in electrical circuits. Since charge is conserved, current must be conserved at each junction in the circuit. Examples include circuits that combine resistors in series and parallel. [Physics 1: covers circuits with resistors in series, with at most one parallel branch, one battery only. Physics 2: includes capacitors in steady-state situations. For circuits with capacitors, situations should be limited to open circuit, just after circuit is closed, and a long time after the circuit is closed.] Relevant Equations:</td>
</tr>
</tbody>
</table>
the circuit. [SP 1.4, 2.2]

\[
I = \frac{\Delta q}{\Delta t}
\]

\[
I = \frac{\Delta V}{R}
\]

\[
P = I \Delta V
\]

\[
R_s = \sum R_i
\]

\[
\frac{1}{R_p} = \sum \frac{1}{R_i}
\]

**Vocabulary**

- Ohm’s law
- Current I
- Voltage V
- Resistance R
- Series circuit

- Parallel circuit
- Combined circuit
- Kirchoff’s Law
- Resistivity

**References & Suggested Instructional Websites**
References & Suggested Instructional Websites

Textbook:
Physics
Giancoli, D. C.
Pearson

Website:

Phet labs:
https://phet.colorado.edu/en/simulation/legacy/circuit-construction-kit-ac-virtual-lab

Labs: Series Circuit ; Timeline (90 minutes); In the Unit Folder
Parallel Circuit; Timeline (90 minute); In the Unit Folder

Test Prep:
AP Practice Problems (College Board) https://apstudent.collegeboard.org/apcourse/ap-physics-I/exam-practice
**Grade: AP Physics I**

**Unit 4: Mechanical Waves and Sound**

**Topic: Mechanical Waves and Sound**

**Duration: 2 Weeks.**

**NJSLS:** HS-PS4-1, HS-PS3

Big Idea 6: Waves can transfer energy and momentum from one location to another without the permanent transfer of mass and serve as a mathematical model for the description of other phenomena

**Enduring Understanding:**

- 6.A: A wave is a traveling disturbance that transfers energy and momentum
- 6.B: A periodic wave is one that repeats as a function of both time and position and can be described by its amplitude, frequency, wavelength, speed, and energy.
- 6.D: Interference and superposition lead to standing waves and beats.

<table>
<thead>
<tr>
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</thead>
<tbody>
<tr>
<td>6.A.1.1: The student is able to use a visual representation to construct an explanation of the distinction between transverse and longitudinal waves by focusing on the vibration that generates the wave. [SP 6.2]</td>
<td>In a transverse wave, the particles are displaced perpendicular to the direction the wave travels. Examples of transverse waves include vibrations on a string and ripples on the surface of water. We can make a horizontal transverse wave by moving the slinky vertically up and down.</td>
<td>6.A.1: Waves can propagate via different oscillation modes such as transverse and longitudinal. a. Mechanical waves can be either transverse or longitudinal. Examples include waves on a stretched string and sound waves. b. This includes, as part of the mechanism of “propagation,” the idea that the speed of a wave depends only on properties of the medium. c. The propagation of sound waves included in this EK includes the idea that the traveling disturbance</td>
<td>Activity: interdisciplinary connections) Lab: Design Lab Lab: Rotating Arm/Platform Lab: Ballistic Pendulum Textbook: Giancoli Chapter 8 and Chapter 9 Activity: Individual/Group Problem Solving (textbook, AP practice problems, problems involving interdisciplinary connections)</td>
</tr>
<tr>
<td>6.A.1.2: The student is able to describe representations of transverse and longitudinal waves. [SP 1.2]</td>
<td>In a longitudinal wave the particles are displaced parallel to the direction the wave travels. An example of longitudinal waves is compressions moving along a</td>
<td></td>
<td>Lab- Wave on a String</td>
</tr>
</tbody>
</table>
6.A.2.1: The student is able to describe sound in terms of transfer of energy and momentum in a medium and relate the concepts to everyday examples. [SP 6.4, 7.2].

6.A.3.1: The student is able to use graphical representation of a periodic mechanical wave to determine the amplitude of the wave. [SP 1.4]

| Application of Wavelength ($\lambda$) – |
| Frequency | Period wave | Crest | Trough | Expansion | Compression |
| $\lambda = \frac{f}{v}$ |
| $\lambda$ - wavelength |
| v- speed of wave |
| f -frequency of wave |

Waves carry energy through a medium. Any displacement of the wave is resisted by a directly proportional restoring force. The work to produce a big wave amplitude requires both large forces and displacements, which results in more wave energy. Therefore, energy transported by a wave increases with the wave.

| consists of pressure variations coupled to displacement variations. |
| d. This applies to both periodic waves and to wave pulses. |

6.A.2: For propagation, mechanical waves require a medium, while electromagnetic waves do not require a physical medium. Examples include light traveling through a vacuum and sound not traveling through a vacuum.

6.A.3: The amplitude is the maximum displacement of a wave from its equilibrium value.

a. The amplitude is the maximum displacement from equilibrium of the wave. A sound wave may be represented by either the pressure or the displacement of atoms or molecules. This covers both periodic waves and wave pulses.

b. The pressure amplitude of a sound wave is the maximum difference between local pressure and atmospheric pressure.

6.A.4.1: The student is able to explain and/or predict qualitatively how the energy carried by a sound

<p>| Students will observe waves on a string and adjust the amplitude, frequency, damping and tension. Students will demonstrate the wave properties. |
| Lab- Slinky |
| Students will observe patterns of waves and determine what happened when they interact |
| Lab- Ripple Tank |
| Students will determine wave properties such as medium, reflection, diffraction and interference |
| Lab- Resonance Tube |
| Students will use resonance to calculate the velocity of the waves |
| Students will determine what are the causes of resonance |
| Lab- Sound Waves |
| Students will adjust the frequency to both see and hear how the wave changes to explain how different sounds are modeled, described, and produced. |
| Lab- Doppler Effect |
| Students will explore the detection of sound waves from a moving... |</p>
<table>
<thead>
<tr>
<th><strong>6.A.4.1:</strong> The student is able to explain and/or predict qualitatively how the energy carried by a sound wave relates to the amplitude of the wave, and/or apply this concept to a real-world example. [SP 6.4]</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>6.B.1.1:</strong> The student is able to use a graphical representation of a periodic mechanical wave (position versus time) to determine the period and frequency of the wave and describe how a change in the frequency would modify features of the representation. [SP 1.4, 2.2]</td>
</tr>
<tr>
<td><strong>6.B.2.1:</strong> The student is able to use a visual representation of a periodic mechanical wave to determine wavelength of the wave.</td>
</tr>
<tr>
<td><strong>amplitude.</strong></td>
</tr>
<tr>
<td>Reflection and superposition of waves:</td>
</tr>
<tr>
<td>Interference:</td>
</tr>
<tr>
<td>Constructive waves</td>
</tr>
<tr>
<td>Destructive waves</td>
</tr>
<tr>
<td><strong>wave relates to the amplitude of the wave, and/or apply this concept to a real-world example. [SP 6.4]</strong></td>
</tr>
<tr>
<td><strong>6.A.4:</strong> Classically, the energy carried by a wave depends upon and increases with amplitude. Examples include sound waves. a. Higher amplitude refers to both greater pressure variations and greater displacement variations. b. Examples include both periodic waves and wave pulses.</td>
</tr>
<tr>
<td><strong>6.B.1:</strong> For a periodic wave, the period is the repeat time of the wave. The frequency is the number of repetitions of the wave per unit time. a. In a periodic sound wave, pressure variations and displacement variations are both present and with the same frequency. Relevant Equation:</td>
</tr>
<tr>
<td>$T = \frac{1}{f}$</td>
</tr>
<tr>
<td><strong>6.B.2:</strong> For a periodic wave, the wavelength is the repeat distance of the wave.</td>
</tr>
<tr>
<td>source and the change in frequency of the detected wave via the Doppler effect.</td>
</tr>
<tr>
<td>Lab-Refraction through Glass Students will trace the course of different rays of light through a rectangular glass slab at different angles of incidence, measure the angle of incidence, refraction, measure the lateral displacement to verify Snell’s law.</td>
</tr>
<tr>
<td>6.B.4.1: The student is able to design an experiment to determine the relationship between periodic wave speed, wavelength, and frequency and relate these concepts to everyday examples. [SP 4.2, 5.1, 7.2]</td>
</tr>
<tr>
<td>6.B.5.1: The student is able to create or use a wave front diagram to demonstrate or interpret qualitatively the observed frequency of a wave, dependent upon relative motions of source and observer. [SP 1.4]</td>
</tr>
<tr>
<td>6.D.1.1: The student is able to use representations of individual pulses and construct representations to model the interaction of two wave pulses to analyze the superposition of two pulses. [SP 1.1, 1.4]</td>
</tr>
<tr>
<td>6.D.1.2: The student is able to design a suitable experiment and analyze data illustrating the superposition of mechanical waves (only for wave pulses or standing waves). [SP 4.2, 5.1]</td>
</tr>
</tbody>
</table>

| 6.B.4: For a periodic wave, wavelength is the ratio of speed over frequency. Relevant Equation: |
| \[ \lambda = \frac{v}{f} \] |

| 6.B.5: The observed frequency of a wave depends on the relative motion of source and observer. This is a qualitative treatment only. |
| 6.D.1: Two or more wave pulses can interact in such a way as to produce amplitude variations in the resultant wave. When two pulses cross, they travel through each other; they do not bounce off each other. Where the pulses overlap, the resulting displacement can be determined by adding the displacements of the two pulses. This is called superposition |
6.D.1.3: The student is able to design a plan for collecting data to quantify the amplitude variations when two or more traveling waves or wave pulses interact in a given medium. [SP 4.2]

6.D.2.1: The student is able to analyze data or observations or evaluate evidence of the interaction of two or more traveling waves in one or two dimensions (i.e., circular wave fronts) to evaluate the variations in resultant amplitudes. [SP 5.1]

6.D.3.1: The student is able to refine a scientific question related to standing waves and design a detailed plan for the experiment that can be conducted to examine the phenomenon qualitatively or quantitatively. [SP 2.1, 3.2, 4.2]

6.D.3.2: The student is able to predict properties of standing waves that result from the addition of incident and reflected waves that are confined to a region and have nodes and antinodes. Examples include waves on a fixed length of string and sound waves in both closed and open tubes.

a. Reflection of waves and wave pulses, even if a standing wave is not created, is covered in Physics 1.

b. For standing sound waves, pressure nodes correspond to displacement antinodes, and vice versa. For example, the open end of a tube is a pressure node because the pressure equalizes.
relationship under test, perform data analysis, evaluate evidence compared to the prediction, explain any discrepancy and, if necessary, revise the relationship among variables responsible for establishing standing waves on a string or in a column of air. [SP 3.2, 4.1, 5.1, 5.2, 5.3]

6.D.3.4: The student is able to describe representations and models of situations in which standing waves result from the addition of incident and reflected waves confined to a region. [SP 1.2]

6.D.4.1: The student is able to challenge with evidence the claim that the wavelengths of standing waves are determined by the frequency of the source regardless of the size of the region. [SP 1.5, 6.1]

6.D.4.2: The student is able to calculate wavelengths and frequencies (if given wave speed) of standing waves based on boundary conditions and length of region within which the wave is confined, and calculate numerical with the surrounding air pressure and therefore does not oscillate. The closed end of a tube is a displacement node because the air adjacent to the closed end is blocked from oscillating.

6.D.4: The possible wavelengths of a standing wave are determined by the size of the region to which it is confined.  
   a. A standing wave with zero amplitude at both ends can only have certain wavelengths. Examples include fundamental frequencies and harmonics. 
   b. Other boundary conditions or other region sizes will result in different sets of possible wavelengths. 
   c. The term first harmonic refers to the standing waves corresponding to the fundamental frequency, i.
values of wavelengths and frequencies. Examples include musical instruments. [SP 2.2]

6.D.5.1: The student is able to use a visual representation to explain how waves of slightly different frequency give rise to the phenomenon of beats. [SP 1.2]

e., the lowest frequency corresponding to a standing wave. The second harmonic is the standing wave corresponding to the second lowest frequency that generates a standing wave in the given scenario.

d. Resonance is another term for standing sound wave. Relevant Equations:

$$\lambda = \frac{v}{f}$$

$$T = \frac{1}{f}$$

6.D.5: Beats arise from the addition of waves of slightly different frequency.

a. Because of the different frequencies, the two waves are sometimes in phase and sometimes out of phase. The resulting regularly spaced amplitude changes are called beats. Examples include the tuning of an instrument.

b. The beat frequency is the difference in frequency between the two waves. c.

In Physics 1, only qualitative understanding of EK 6.D.5 is necessary.
### Vocabulary

<table>
<thead>
<tr>
<th>Wave</th>
<th>Propagation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amplitude</td>
<td>Resonance</td>
</tr>
<tr>
<td>Frequency</td>
<td>Interference</td>
</tr>
<tr>
<td>Reflection</td>
<td>Constructive interference</td>
</tr>
<tr>
<td>Refraction</td>
<td>Destructive interference</td>
</tr>
<tr>
<td>Wavelength</td>
<td></td>
</tr>
</tbody>
</table>

### References & Suggested Instructional Websites
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Textbook:
Physics
Giancoli, D. C.
Pearson

Website:

Phet labs:
https://phet.colorado.edu/en/simulations/category/physics/sound-and-waves

Test Prep:
AP Practice Problems (College Board) https://apstudent.collegeboard.org/apcourse/ap-physics-1/exam-practice

Field Trip Ideas
Unit 1

Six Flags Great Adventure [https://www.sixflags.com/greatadven](https://www.sixflags.com/greatadven), Rochester Institute of Technology, New York Hall of Science, American Museum Of Natural History, Liberty Science Center

Unit 2

Newton Virtual Field Trip, others mentioned above

Unit 3

Passaic River [Passaic River/Newark (New Jersey) | Urban Waters …](https://www.epa.gov), NJ Department of Environmental Protection, [Field Trips to the Rock-it Science Lab](https://www.real-world-physics-problems.com/physics-project-ideas.html), others mentioned above

Unit Project (Suggested)

AP Projects:


[https://www.gamedev.net/forums/topic/124749-ideas-for-ap-physics-project/](https://www.gamedev.net/forums/topic/124749-ideas-for-ap-physics-project/)

[https://www.reddit.com/r/Physics/comments/69enac/ap_physics_project_ideas/](https://www.reddit.com/r/Physics/comments/69enac/ap_physics_project_ideas/)
