AP® Physics C: Mechanics

COURSE FRAMEWORK AND EXAM OVERVIEW

Effective Fall 2024
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Effective Fall 2024

AP COURSE AND EXAM DESCRIPTIONS ARE UPDATED PERIODICALLY
Please visit AP Central (apcentral.collegeboard.org) to determine whether a more recent course and exam description is available.
What AP® Stands For

Thousands of Advanced Placement teachers have contributed to the principles articulated here. These principles are not new; they are, rather, a reminder of how AP already works in classrooms nationwide. The following principles are designed to ensure that teachers' expertise is respected, required course content is understood, and that students are academically challenged and free to make up their own minds.

1. AP stands for clarity and transparency. Teachers and students deserve clear expectations. The Advanced Placement Program makes public its course frameworks and sample assessments. Confusion about what is permitted in the classroom disrupts teachers and students as they navigate demanding work.

2. AP is an unflinching encounter with evidence. AP courses enable students to develop as independent thinkers and to draw their own conclusions. Evidence and the scientific method are the starting place for conversations in AP courses.

3. AP opposes censorship. AP is animated by a deep respect for the intellectual freedom of teachers and students alike. If a school bans required topics from their AP courses, the AP Program removes the AP designation from that course and its inclusion in the AP Course Ledger provided to colleges and universities. For example, the concepts of evolution are at the heart of college biology, and a course that neglects such concepts does not pass muster as AP Biology.

4. AP opposes indoctrination. AP students are expected to analyze different perspectives from their own, and no points on an AP Exam are awarded for agreement with any specific viewpoint. AP students are not required to feel certain ways about themselves or the course content. AP courses instead develop students' abilities to assess the credibility of sources, draw conclusions, and make up their own minds.

As the AP English Literature course description states: “AP students are not expected or asked to subscribe to any one specific set of cultural or political values, but are expected to have the maturity to analyze perspectives different from their own and to question the meaning, purpose, or effect of such content within the literary work as a whole.”

5. AP courses foster an open-minded approach to the histories and cultures of different peoples. The study of different nationalities, cultures, religions, races, and ethnicities is essential within a variety of academic disciplines. AP courses ground such studies in primary sources so that students can evaluate experiences and evidence for themselves.

6. Every AP student who engages with evidence is listened to and respected. Students are encouraged to evaluate arguments but not one another. AP classrooms respect diversity in backgrounds, experiences, and viewpoints. The perspectives and contributions of the full range of AP students are sought and considered. Respectful debate of ideas is cultivated and protected; personal attacks have no place in AP.

7. AP is a choice for parents and students. Parents and students freely choose to enroll in AP courses. Course descriptions are available online for parents and students to inform their choice. Parents do not define which college-level topics are suitable within AP courses; AP course and exam materials are crafted by committees of professors and other expert educators in each field. AP courses and exams are then further validated by the American Council on Education and studies that confirm the use of AP scores for college credits by thousands of colleges and universities nationwide.

The AP Program encourages educators to review these principles with parents and students so they know what to expect in an AP course. Advanced Placement is always a choice, and it should be an informed one. AP teachers should be given the confidence and clarity that once parents have enrolled their child in an AP course, they have agreed to a classroom experience that embodies these principles.
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Acknowledgments

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About AP

The Advanced Placement® Program (AP®) enables willing and academically prepared students to pursue college-level studies—with the opportunity to earn college credit, advanced placement, or both—while still in high school. Through AP courses in 39 subjects, each culminating in a challenging exam, students learn to think critically, construct solid arguments, and see many sides of an issue—skills that prepare them for college and beyond. Taking AP courses demonstrates to college admission officers that students have sought the most challenging curriculum available to them, and research indicates that students who score a 3 or higher on an AP Exam typically experience greater academic success in college and are more likely to earn a college degree than non-AP students. Each AP teacher’s syllabus is evaluated and approved by faculty from some of the nation’s leading colleges and universities, and AP Exams are developed and scored by college faculty and experienced AP teachers. Most four-year colleges and universities in the United States grant credit, advanced placement, or both on the basis of successful AP Exam scores—more than 3,300 institutions worldwide annually receive AP scores.

AP Course Development

In an ongoing effort to maintain alignment with best practices in college-level learning, AP courses and exams emphasize challenging, research-based curricula aligned with higher education expectations.

Individual teachers are responsible for designing their own curriculum for AP courses, selecting appropriate college-level readings, assignments, and resources. This course and exam description presents the content and skills that are the focus of the corresponding college course and that appear on the AP Exam. It also organizes the content and skills into a series of units that represent a sequence found in widely adopted college textbooks and that many AP teachers have told us they follow in order to focus their instruction. The intention of this publication is to respect teachers’ time and expertise by providing a roadmap that they can modify and adapt to their local priorities and preferences. Moreover, by organizing the AP course content and skills into units, the AP Program is able to provide teachers and students with free formative assessments—Progress Checks—that teachers can assign throughout the year to measure student progress as they acquire content knowledge and develop skills.

Enrolling Students: Equity and Access

The AP Program 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 AP Program also believes that all students should have access to academically challenging coursework 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.

Offering AP Courses: The AP Course Audit

The AP Program unequivocally supports the principle that each school implements its own curriculum that will enable students to develop the content understandings and skills described in the course framework.

While the unit sequence represented in this publication is optional, the AP Program does have a short list of curricular and resource requirements that must be fulfilled before a school can label a course “Advanced Placement” or “AP.” Schools wishing to offer AP courses must participate in the AP Course Audit, a process through which AP teachers’ course materials 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’ courses meet or exceed the curricular and resource expectations that college and secondary school faculty have established for college-level courses.
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. A syllabus or course outline, detailing how course requirements are met, is submitted by the AP teacher for review by college faculty.

Please visit collegeboard.org/apcourseaudit for more information to support the preparation and submission of materials for the AP Course Audit.

How the AP Program Is Developed

The scope of content for an AP course and exam is derived from an analysis of hundreds of syllabi and course offerings of colleges and universities. Using this research and data, a committee of college faculty and expert AP teachers work within the scope of the corresponding college course to articulate what students should know and be able to do upon the completion of the AP course. The resulting course framework is the heart of this course and exam description and serves as a blueprint of the content and skills that can appear on an AP Exam.

The AP Test Development Committees are responsible for developing each AP Exam, ensuring the exam questions are aligned to the course framework. The AP Exam development process is a multiyear endeavor; all AP Exams undergo extensive review, revision, piloting, and analysis to ensure that questions are accurate, fair, and valid, and that there is an appropriate spread of difficulty across the questions.

Committee members are selected to represent a variety of perspectives and institutions (public and private, small and large schools and colleges), and a range of gender, racial/ethnic, and regional groups. A list of each subject’s current AP Test Development Committee members is available on apcentral.collegeboard.org.

Throughout AP course and exam development, 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 or college credit.

How AP Exams Are Scored

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 freeresponse questions and through-course performance assessments, as applicable, are scored by thousands of college faculty and expert AP teachers. Most are scored at the annual AP Reading, while a small portion is scored online. All AP 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 serves as Chief Faculty Consultant and, with the help of AP Readers in leadership positions, maintains the accuracy of the scoring standards. Scores on the free-response questions and performance assessments are weighted and combined with the results of the computer-scored multiple-choice questions, and this raw score is converted into a composite AP score on a 1–5 scale.

AP Exams are not norm-referenced or graded on a curve. Instead, they are criterion-referenced, which means that every student who meets the criteria for an AP score of 2, 3, 4, or 5 will receive that score, no matter how many students that is. The criteria for the number of points students must earn on the AP Exam to receive scores of 3, 4, or 5—the scores that research consistently validates for credit and placement purposes—include:

- The number of points successful college students earn when their professors administer AP Exam questions to them.
- The number of points researchers have found to be predictive that an AP student will succeed when placed into a subsequent higher-level college course.
- Achievement-level descriptions formulated by college faculty who review each AP Exam question.

Using and Interpreting AP Scores

The extensive work done by college faculty and AP teachers in the development of the course and exam and throughout the scoring process ensures that AP Exam scores accurately represent students’ achievement in the equivalent college course. Frequent and regular research studies establish the validity of AP scores as follows:

<table>
<thead>
<tr>
<th>AP Score</th>
<th>Credit Recommendation</th>
<th>College Grade Equivalent</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>Extremely well qualified</td>
<td>A</td>
</tr>
<tr>
<td>4</td>
<td>Well qualified</td>
<td>A-, B+, B</td>
</tr>
<tr>
<td>3</td>
<td>Qualified</td>
<td>B-, C+, C</td>
</tr>
<tr>
<td>2</td>
<td>Possibly qualified</td>
<td>n/a</td>
</tr>
<tr>
<td>1</td>
<td>No recommendation</td>
<td>n/a</td>
</tr>
</tbody>
</table>
While colleges and universities are responsible for setting their own credit and placement policies, most private colleges and universities award credit and/or advanced placement for AP scores of 3 or higher. Additionally, most states in the U.S. have adopted statewide credit policies that ensure college credit for scores of 3 or higher at public colleges and universities. To confirm a specific college’s AP credit/placement policy, a search engine is available at collegeboard.org/creditandplacement/searchcredit-policies.

BECOMING AN AP READER
Each June, thousands of AP teachers and college faculty members from around the world gather for seven days in multiple locations to evaluate and score the free-response sections of the AP Exams. Ninetyeight percent of surveyed educators who took part in the AP Reading say it was a positive experience.

There are many reasons to consider becoming an AP Reader, including opportunities to:

- **Bring positive changes to the classroom:** Surveys show that the vast majority of returning AP Readers—both high school and college educators—make improvements to the way they teach or score because of their experience at the AP Reading.

- **Gain in-depth understanding of AP Exam and AP scoring standards:** AP Readers gain exposure to the quality and depth of the responses from the entire pool of AP Exam takers, and thus are better able to assess their students’ work in the classroom.

- **Receive compensation:** AP Readers are compensated for their work during the Reading. Expenses, lodging, and meals are covered for Readers who travel.

- **Score from home:** AP Readers have online distributed scoring opportunities for certain subjects. Check collegeboard.org/apreading for details.

- **Earn Continuing Education Units (CEUs):** AP Readers earn professional development hours and CEUs that can be applied to PD requirements by states, districts, and schools.

**How to Apply**
Visit collegeboard.org/apreading for eligibility requirements and to start the application process.
About the AP Physics C: Mechanics Course

AP Physics C: Mechanics is a calculus-based introductory college-level physics course. Students cultivate their understanding of physics by developing models of physical phenomena through inquiry-based investigations.

Students build their understanding of physical models as they explore and solve problems in these topics:

- Kinematics
- Forces and Translational Dynamics
- Work, Energy, and Power
- Linear Momentum
- Torque and Rotational Dynamics
- Energy and Momentum of Rotating Systems
- Oscillations

College Course Equivalent
AP Physics C: Mechanics is equivalent to the first course in an introductory college course sequence in calculus-based physics.

Timing and Pacing
If AP Physics C: Mechanics is taught as a full-year course, approximately 45 minutes per day plus an additional 45-minute lab period per week (approximately equivalent to 270 minutes per week) is necessary to devote sufficient time to study the material at an appropriate depth and to allow time for laboratory investigations. In a school that uses a form of block scheduling that provides double the amount of instructional time in a single semester, one of the Calculus-Based AP Physics courses, but not both, can be taught in a single semester.

In some schools, AP Physics C: Mechanics has been taught successfully as the first part of a two-semester physics curriculum in conjunction with Calculus-Based AP Physics C: Electricity & Magnetism. Because of the intense pace of taking both of these courses in a single academic year, it is strongly recommended that students take a standard high-school physics course prior to taking both of the Calculus-Based AP Physics courses in a subsequent year.

Whichever approach is taken, the nature of the AP Physics C: Mechanics course requires teachers to spend time on the extra preparation needed for both class and laboratory. AP teachers should have a teaching load that is adjusted accordingly.

Prerequisites
Students should have taken or be concurrently taking calculus.
**Laboratory Requirement**

This course requires that 25 percent of 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 the science practices.

Inquiry-based laboratory experiences support the AP Physics C: Mechanics course and AP Course Audit curricular requirements by providing opportunities for students to engage in the science practices as they design plans for experiments, make predictions, collect and analyze data, apply mathematical routines, develop explanations, and communicate about their work.

Colleges may require students to present their laboratory materials from AP science courses before granting college credit for laboratory work, so students should be encouraged to retain their laboratory notebooks, reports, and other materials.
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AP PHYSICS C: MECHANICS

Course Framework
Introduction

The AP Physics C: Mechanics course outlined in this framework reflects a commitment to what physics teachers, professors, and researchers have agreed is the main goal of a college-level physics course: to help students develop a deep understanding of the foundational principles that shape classical mechanics. By confronting complex physical situations or scenarios, the course is designed to enable students to develop the ability to reason about physical phenomena using important science practices, such as creating and analyzing representations of physical scenarios, designing experiments, analyzing data, and using mathematics to model and to solve problems.

To foster this deeper level of learning, the AP Physics C: Mechanics course defines concepts, skills, and understandings required by representative colleges and universities for granting college credit and placement. Students will practice reasoning skills used by physicists by discussing and debating, with peers, the physical phenomena investigated in class, as well as by designing and conducting inquiry-based laboratory investigations to solve problems through first-hand observations, data collection, analysis, and interpretation.

This document is not a complete curriculum. Teachers create their own local curriculum by selecting, for each concept, content that enables students to explore the course learning objectives and meets state or local requirements. This result is a course that prepares students for college credit and placement.
Course Framework Components

Overview
This course framework provides 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 to qualify for college credit or placement.

The course framework includes two essential components:

1. SCIENCE PRACTICES
   The science practices are central to the study and practice of physics. Students should develop and apply the described practices on a regular basis over the span of the course.

2. COURSE CONTENT
   The course content is organized into commonly taught units of study that provide a suggested sequence for the course and detail required content and conceptual understandings that colleges and universities typically expect students to master to qualify for college credit and/or placement.
The table that follows presents the science practices that students should develop during the AP Physics C: Mechanics course. These practices form the basis of many tasks on the AP Physics C: Mechanics exam.

More detailed information about teaching the science practices will be provided in the Course and Exam Description publication scheduled for release in spring 2024.
# Science Practices

## Practice 1

### Creating Representations 1
Create representations that depict physical phenomena situations, excluding graphs.

**SKILLS**

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

## Practice 2

### Mathematical Routines 2
Conduct analyses to derive, calculate, estimate, or predict.

**SKILLS**

2. **A** Derive a symbolic expression from known quantities by selecting and following a logical mathematical pathway.
2. **B** Calculate or estimate an unknown quantity with units from known quantities, by selecting and following a logical computational pathway.
2. **C** Compare physical quantities between two or more scenarios or at different times and locations in a single scenario.
2. **D** Predict new values or factors of change of physical quantities using functional dependence between variables.

## Practice 3

### Scientific Questioning and Argumentation 3
Describe experimental procedures, analyze data, and support claims.

**SKILLS**

3. **A** Create experimental procedures that are appropriate for a given scientific question.
3. **B** Apply an appropriate law, definition, theoretical relationship, or model to make a claim.
3. **C** Justify or support a claim using evidence from experimental data, physical representations, or physical principles or laws.
Course Content

This course framework provides a clear and detailed description of the course requirements for student success. The framework specifies what students must know, be able to do, and understand with a focus on ideas that encompass core principles, theories, and processes of physics. This framework also encourages instruction that prepares students to make connections across domains through a broader way of thinking about the physical world.

UNITS

The course content is organized into commonly taught units. The units have been arranged in a logical sequence frequently found in many college courses and textbooks.

The seven units in AP Physics C: Mechanics and their relevant weightings on the multiple-choice section of the AP Exam are listed below.

Pacing recommendations on the Course at a Glance page provide suggestions for how teachers can cover both the required course content and the Progress Checks. The suggested class periods are based on a schedule in which the class meets five days a week for 45 minutes each day. While these recommendations have been made to aid in planning, teachers are free to adjust the pacing based on the needs of their students, alternate schedules (e.g., block scheduling), or their school’s academic calendar.
Exam Weighting for the Multiple-Choice Section of the AP Physics C: Mechanics Exam.

<table>
<thead>
<tr>
<th>Units of Instruction</th>
<th>Exam Weighting</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Unit 1: Kinematics</strong></td>
<td>10–14%</td>
</tr>
<tr>
<td><strong>Unit 2: Force and Translational Dynamics</strong></td>
<td>20–24%</td>
</tr>
<tr>
<td><strong>Unit 3: Work, Energy, and Power</strong></td>
<td>18–22%</td>
</tr>
<tr>
<td><strong>Unit 4: Linear Momentum</strong></td>
<td>14–18%</td>
</tr>
<tr>
<td><strong>Unit 5: Torque and Rotational Dynamics</strong></td>
<td>10–14%</td>
</tr>
<tr>
<td><strong>Unit 6: Energy and Momentum of Rotating Systems</strong></td>
<td>10–14%</td>
</tr>
<tr>
<td><strong>Unit 7: Oscillations</strong></td>
<td>10–14%</td>
</tr>
</tbody>
</table>

TOPICS
Each unit is divided into teachable segments called topics. Visit the topic pages (starting on page 31) to see all the required content for each topic.

Learning Objectives and Science Practices
In the AP Physics C: Mechanics courses and exams, every assessment of student proficiency will be aligned to a Learning Objective and a Skill. The Learning Objectives represent the content domain, while the Skill represents the Science Practice required to successfully complete the assessment. The three categories of science practices are described as discrete practices; but they are in fact interrelated. For example, scientific questions and predictions are associated with the underlying mathematical relationships, and those relationships are used to create diagrams and graphs. The ordering of the science practices is not meant to describe any hierarchy of importance or difficulty.

The three science practices, and their associated skills, will be applied to all learning objectives in the Course Framework. The task verb “describe,” which is used in nearly all learning objectives, encompasses the range of possible graphical, mathematical, or verbal skill applications. Within these multiple representations, students should be able to “describe” a physical concept graphically, mathematically, and in prose.

For example, for a given Learning Objective, teachers are encouraged to ask the following questions about a physical phenomenon:

- How would students create or interpret graphs or other visual representations?
- What quantitative problems could students solve?
- What experiment could a student design, or what data would students analyze?
- How could the concepts be characterized using prose?
- How could the material be used as evidence to justify or support a claim about the behavior of a system, physical phenomena, or outcome of an experiment?

Required Equations
Not all equations in this curriculum framework appear on the equation sheet provided to students while taking the AP Physics C: Mechanics Exam. Many of the equations in this document are provided for reference and guidance, or to demonstrate the final results of derivations expected of students on the exam. These equations are denoted as “Derived Equations.” Additionally, variables used within this curriculum framework follow the definitions given on the equation sheet. For a complete list of the equations available to students on the AP Physics C: Mechanics Exam, please see the AP Physics C: Mechanics reference sheet in the Appendix.
## Course at a Glance

### Plan

The Course at a Glance provides a useful visual organization for the AP Physics Mechanics course components, including:

- Sequence of units, along with approximate weighting and suggested pacing. Please note, pacing is based on 50-minute class periods, meeting five days each week for a full academic year.
- Progression of topics within each unit.
- Spiraling of the science practices across units.

### Teach

**SCIENCE PRACTICES**

Practices: Science Practices Spiral throughout the course

- Creating Representations
- Mathematical Routines
- Scientific Questioning and Argumentation

### Assess

Assign the Progress Checks—either as homework or in class—for each unit. Each Progress Check contains formative multiple-choice and free-response questions. The feedback from these checks shows students the areas where they need to focus.

### Progress Check 1

- **Multiple-choice:** ~18 questions
- **Free-response:** 4 question
  - Math Routines Question
  - Qualitative/Quantitative Translation
  - Experimental Design
  - Translation Between Representation

### Progress Check 2

- **Multiple-choice:** ~30 questions
- **Free-response:** 4 question
  - Math Routines Question
  - Qualitative/Quantitative Translation
  - Experimental Design
  - Translation Between Representation
**Progress Check 6**

Multiple-choice: ~18 questions
Free-response: 2 question
- Math Routines Question
- Qualitative/Quantitative Translation
- Experimental Design
- Translation Between Representation

**Progress Check 7**

Multiple-choice: ~18 question
Free-response: 4 question
- Math Routines Question
- Qualitative/Quantitative Translation
- Experimental Design
- Translation Between Representation

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<table>
<thead>
<tr>
<th>UNIT 6</th>
<th>Energy and Momentum of Rotating Systems</th>
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<tbody>
<tr>
<td>~13-19 Class Periods</td>
<td>10-14% AP Exam Weighting</td>
</tr>
<tr>
<td>1 2 3</td>
<td>6.1 Rotational Kinetic Energy</td>
</tr>
<tr>
<td>1 2 3</td>
<td>6.2 Torque and Work</td>
</tr>
<tr>
<td>1 2 3</td>
<td>6.3 Angular Momentum and Angular Impulse</td>
</tr>
<tr>
<td>1 2 3</td>
<td>6.4 Conservation of Angular Momentum</td>
</tr>
<tr>
<td>1 2 3</td>
<td>6.5 Rolling</td>
</tr>
<tr>
<td>1 2 3</td>
<td>6.6 Motion of Orbiting Satellites</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>UNIT 7</th>
<th>Oscillations</th>
</tr>
</thead>
<tbody>
<tr>
<td>~12-17 Class Periods</td>
<td>10-14% AP Exam Weighting</td>
</tr>
<tr>
<td>1 2 3</td>
<td>7.1 Defining Simple Harmonic Motion (SHM)</td>
</tr>
<tr>
<td>1 2 3</td>
<td>7.2 Frequency and Period of SHM</td>
</tr>
<tr>
<td>1 2 3</td>
<td>7.3 Representing and Analyzing SHM</td>
</tr>
<tr>
<td>1 2 3</td>
<td>7.4 Energy of Simple Harmonic Oscillators</td>
</tr>
<tr>
<td>1 2 3</td>
<td>7.5 Simple and Physical Pendulums</td>
</tr>
</tbody>
</table>
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UNIT 1
Kinematics

10–14% AP EXAM WEIGHTING

~14/~19 CLASS PERIODS
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### Required Course Content

#### LEARNING OBJECTIVE

**1.1.A**
Describe a scalar or vector quantity using magnitude and direction, as appropriate.

#### ESSENTIAL KNOWLEDGE

**1.1.A.1**
Scalars are quantities described by magnitude only; vectors are quantities described by both magnitude and direction.

**1.1.A.2**
Vectors can be visually modeled as arrows with appropriate direction and lengths proportional to their magnitude.

**1.1.A.3**
Distance and speed are examples of scalar quantities, while position, displacement, velocity, and acceleration are examples of vector quantities.

**1.1.A.4**
Vectors can be expressed in unit vector notation or as a magnitude and a direction.

1. Unit vector notation can be used to represent vectors as the sum of their constituent components in the x-, y-, and z-directions, denoted by \( \vec{i} \), \( \vec{j} \), and \( \vec{k} \), respectively.

   *Relevant equation:*
   \[
   \vec{r} = (A\vec{i} + B\vec{j} + C\vec{k})
   \]

2. The position vector of a point is given by \( \vec{r} \), and the unit vector in the direction of the position vector is denoted \( \vec{r} \).

3. A resultant vector is the vector sum of the addend vectors’ components.

   *Relevant equation:*
   \[
   \vec{C} = \vec{A} + \vec{B}
   \]
   \[
   \vec{C} = (A_x + B_x)\vec{i} + (A_y + B_y)\vec{j}
   \]

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*continued on next page*
<table>
<thead>
<tr>
<th>LEARNING OBJECTIVE</th>
<th>ESSENTIAL KNOWLEDGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1.A</td>
<td>1.1.A.5</td>
</tr>
<tr>
<td>Describe a scalar or vector quantity using magnitude and direction, as appropriate.</td>
<td>In a given one-dimensional coordinate system, opposite directions are denoted by opposite signs.</td>
</tr>
</tbody>
</table>
LEARNING OBJECTIVE

1.2.A
Describe a change in an object’s position.

1.2.B
Describe the average velocity and acceleration of an object.

ESSENTIAL KNOWLEDGE

1.2.A.1
When using the object model, the size, shape, and internal configuration are ignored. The object may be treated as a single point with extensive properties such as mass and charge.

1.2.A.2
Displacement is the change in an object’s position.

*Relevant equation:*

\[ \Delta x = x_f - x_i \]

1.2.B.1
Averages of velocity and acceleration are calculated considering the initial and final states of an object over an interval of time.

1.2.B.2
Average velocity is the displacement of an object divided by the interval of time in which that displacement occurs.

\[ \bar{v}_{avg} = \frac{\Delta \vec{x}}{\Delta t} \]

1.2.B.3
Average acceleration is the change in velocity divided by the interval of time in which that change in velocity occurs.

\[ \bar{a}_{avg} = \frac{\Delta \vec{v}}{\Delta t} \]

1.2.B.4
An object is accelerating if either the magnitude and/or direction of the object’s velocity are changing.

*continued on next page*
LEARNING OBJECTIVE

1.2.B
Describe the average velocity and acceleration of an object.

1.2.C
Describe the instantaneous position, velocity, and acceleration of an object as a function of time.

ESSENTIAL KNOWLEDGE

1.2.B.5
Calculating average velocity or average acceleration over a very small time interval yields a value that is very close to the instantaneous velocity or instantaneous acceleration.

1.2.C.1
As the time interval used to calculate the average value of a quantity approaches zero, the average value of that quantity approaches the value of the quantity at that instant, called the instantaneous value.

i. Instantaneous velocity is the rate of change of the object’s position, which is equal to the derivative of position with respect to time.

Relevant equations:
\[ \vec{v} = \frac{d\vec{r}}{dt} \]
\[ v_x = \frac{dx}{dt} \]

ii. Instantaneous acceleration is the rate of change of the object’s velocity, which is equal to the derivative of velocity with respect to time.

Relevant equations:
\[ \vec{a} = \frac{d\vec{v}}{dt} \]
\[ a_x = \frac{dv_x}{dt} \]

1.2.C.2
Time-dependent functions and instantaneous values of position, velocity, and acceleration can be determined using differentiation and integration.
LEARNING OBJECTIVE

1.3.A
Describe the position, velocity, and acceleration of an object using representations of that object's motion.

ESSENTIAL KNOWLEDGE

1.3.A.1
Motion can be represented by motion diagrams, figures, graphs, equations, and narrative descriptions.

1.3.A.2
For constant acceleration, three kinematic equations can be used to describe instantaneous linear motion in one dimension:

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

Note: The equations above are written to indicate motion in the x-direction, but these equations can be used in any single dimension as appropriate.

1.3.A.3
Near the surface of Earth, the vertical acceleration caused by the force of gravity is downward, constant, and has a measured value approximately equal to

\[
a_x = g = 10 \text{ m/s}^2.
\]

1.3.A.4
Graphs of position, velocity, and acceleration as functions of time can be used to find the relationships between those quantities.

continued on next page
LEARNING OBJECTIVE
1.3.A
Describe the position, velocity, and acceleration of an object using representations of that object’s motion.

ESSENTIAL KNOWLEDGE
i. An object’s instantaneous velocity is the rate of change of the object’s position, which is equal to the slope of a line tangent to a point on a graph of the object’s position as a function of time.

Relevant equation:
\[ v_x = \frac{dx}{dt} \]

ii. An object’s instantaneous acceleration is the rate of change of the object’s velocity, which is equal to the slope of a line tangent to a point on a graph of the object’s velocity as a function of time.

Relevant equation:
\[ a_x = \frac{dv_x}{dt} \]

iii. The displacement of an object during a time interval is equal to the area under the curve of a graph of the object’s velocity as a function of time (i.e., the area bounded by the function and the horizontal axis for the appropriate interval).

Relevant equation:
\[ \Delta x = \int_{t_1}^{t_2} v_x(t) \, dt \]

iv. The change in velocity of an object during a time interval is equal to the area under the curve of a graph of the acceleration of the object as a function of time.

Relevant equation:
\[ \Delta v_x = \int_{t_1}^{t_2} a_x(t) \, dt \]

BOUNDARY STATEMENT
AP Physics C: Mechanics and AP Physics C: Electricity & Magnetism expects that for all situations in which a numerical quantity is required for g, the value \( g = 10 \text{ m/s}^2 \) will be used. However, students will not be penalized for correctly using the more precise commonly accepted values of \( g = 9.81 \text{ m/s}^2 \) or \( g = 9.8 \text{ m/s}^2 \).
TOPIC 1.4
Reference Frames & Relative Motion

Required Course Content

LEARNING OBJECTIVE
1.4.A
Describe the reference frame of a given observer.

1.4.B
Describe the motion of objects as measured by observers in different inertial reference frames.

ESSENTIAL KNOWLEDGE
1.4.A.1
The choice of reference frame will determine the direction and magnitude of quantities measured by an observer in that reference frame.

1.4.B.1
Measurements from a given reference frame may be converted to measurements from another reference frame.

1.4.B.2
The observed velocity of an object results from the combination of the object’s velocity and the velocity of the observer’s reference frame.
   i. Combining the motion of an object and the motion of an observer in a given reference frame involves the addition or subtraction of vectors.
   ii. The acceleration of any object is the same as measured from all inertial reference frames.

BOUNDARY STATEMENT:
Unless otherwise stated, the frame of reference of any problem may be assumed to be inertial.

SUGGESTED SCIENCE PRACTICES
1.A
Create diagrams, tables, charts, or schematics to represent physical situations.

2.B
Calculate or estimate an unknown quantity with units from known quantities, by selecting and following a logical computational pathway.

3.C
Compare physical quantities between two or more scenarios or at different times and/or locations within a single scenario.

3.B
Apply an appropriate law, definition, theoretical relationship, or model to make a claim.
TOPIC 1.5
Motion in Two or Three Dimensions

Required Course Content

LEARNING OBJECTIVE
1.5.A Describe the motion of an object moving in two or three dimensions.

ESSENTIAL KNOWLEDGE
1.5.A.1 Motion in two or three dimensions can be analyzed using one-dimensional kinematic relationships if the motion is separated into components.

1.5.A.2 Velocity and acceleration may be different in each dimension and may be nonuniform.

1.5.A.3 Motion in one dimension may be changed without causing a change in a perpendicular dimension.

1.5.A.4 Projectile motion is a special case of two-dimensional motion that has zero acceleration in one dimension and constant, nonzero acceleration in the second dimension.

BOUNDARY STATEMENT
AP Physics C: Mechanics only expects students to quantitatively analyze the motion of an object in two dimensions. AP Physics C: Electricity & Magnetism expects students to also qualitatively describe the motion of a particle in three dimensions.
UNIT 2

Force and Translational Dynamics

AP Exam Weighting: 20–24%

Class Periods: ~15/~25
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Required Course Content

**LEARNING OBJECTIVE**

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

**ESSENTIAL KNOWLEDGE**

2.1.A.1
System properties are determined by the interactions between objects within the system.

2.1.A.2
If the properties or interactions of the constituent objects within a system are not important in modeling the behavior of the macroscopic system, the system can itself be treated as a single object.

2.1.A.3
Systems may allow interactions between constituent parts of the system and the environment, which may result in the transfer of energy or mass.

2.1.A.4
Individual objects within a chosen system may behave differently from each other as well as from the system as a whole.

2.1.A.5
The internal structure of a system affects the analysis of that system.

2.1.A.6
As variables external to a system are changed, the system's substructure may change.

*continued on next page*
LEARNING OBJECTIVE

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

ESSENTIAL KNOWLEDGE

2.1.B.1
For objects or systems with symmetrical mass distributions, the center of mass is located on lines of symmetry.

2.1.B.2
The location of a system’s center of mass along a given axis can be calculated using the equation

\[
\bar{x}_{cm} = \frac{\sum m_i x_i}{\sum m_i}.
\]

2.1.B.3
For a nonuniform solid that can be considered as a collection of differential masses, \( dm \), the solid’s center of mass can be calculated using the equation

\[
\bar{r}_{cm} = \frac{\int \bar{r} \, dm}{\int dm}.
\]

i. The linear mass density of a rod or other linear rigid body is the derivative of the rod’s mass with respect to the position of the differential mass element on the rigid body.

\[ \lambda = \frac{d}{d\ell} m(\ell) \]

ii. If a function of mass density is given for a solid, the total mass can be determined by integrating the mass density over the length (one dimension), area (two dimensions), or volume (three dimensions) of the solid. For example:

\[ M_{\text{total}} = \int \rho(r) \, dV \]

2.1.B.4
A system can be modeled as a singular object that is located at the system’s center of mass.
TOPIC 2.2
Forces and Free-Body Diagrams

Required Course Content

LEARNING OBJECTIVE

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

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

ESSENTIAL KNOWLEDGE

2.2.A.1
Forces are vector quantities that describe the interactions between objects or systems.

i. A force exerted on an object or system is always due to the interaction of that object or system with another object or system.

ii. An object or system cannot exert a net force on itself.

2.2.A.2
Contact forces describe the interaction of an object or system touching another object or system and are macroscopic effects of interatomic electric forces.

2.2.B.1
Free-body diagrams are useful tools for visualizing forces being exerted on a single object or system and for determining the equations that represent a physical situation.

2.2.B.2
The free-body diagram of an object or system shows each of the forces exerted on the object or system by the environment.

2.2.B.3
Forces exerted on an object or system are represented as vectors originating from the representation of the center of mass, such as a dot. A system is treated as though all of its mass is located at the center of mass.

continued on next page
### Learning Objective

<table>
<thead>
<tr>
<th>LEARNING OBJECTIVE</th>
<th>ESSENTIAL KNOWLEDGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.2.B</td>
<td>A coordinate system with one axis parallel to the direction of acceleration of the object or system simplifies the translation from free-body diagram to algebraic representation. For example, in a free-body diagram of an object on an inclined plane, it is useful to set one axis parallel to the surface of the incline.</td>
</tr>
</tbody>
</table>

#### Boundary Statement:

*AP Physics C: Mechanics and AP Physics C: Electricity & Magnetism only expects students to depict the forces exerted on objects, not the force components on free-body diagrams. On the AP Physics exams, individual forces represented on a free-body diagram must be drawn as individual straight arrows, originating on the dot and pointing in the direction of the force. Individual forces that are in the same direction must be drawn side by side, not overlapping.*
Required Course Content

**ESSENTIAL KNOWLEDGE**

2.3.A.1 Newton's third law describes the interaction of two objects or systems in terms of the paired forces that each exerts on the other.

2.3.A.2 Interactions between objects within a system (internal forces) do not influence the motion of a system's center of mass.

2.3.A.3 Tension is the macroscopic net result of forces that infinitesimal segments of a string, cable, chain, or similar system exert on each other in response to an external force.

i. An ideal string has negligible mass and does not stretch when under tension.

ii. The tension in an ideal string is the same at all points within the string.

iii. In a string with nonnegligible mass, tension may not be the same at all points within the string.

iv. An ideal pulley is a pulley that has negligible mass and rotates about an axle through its center of mass with negligible friction.
## TOPIC 2.4

### Newton’s First Law

#### Required Course Content

<table>
<thead>
<tr>
<th>LEARNING OBJECTIVE</th>
<th>ESSENTIAL KNOWLEDGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.4.A</td>
<td>Describe the conditions under which a system’s velocity remains constant.</td>
</tr>
<tr>
<td>2.4.A.2</td>
<td>Translational equilibrium is the configuration of forces such that the net force exerted on a system is zero. Derived equation: ( \sum F_i = 0 )</td>
</tr>
<tr>
<td>2.4.A.4</td>
<td>Forces may be balanced in one dimension but unbalanced in another. The system’s velocity will change only in the direction of the unbalanced force.</td>
</tr>
</tbody>
</table>

SUGGESTED SCIENCE PRACTICES

1.C
Create qualitative sketches of graphs that represent features of a model or the behavior of the physical system.

2.B
Calculate or estimate an unknown quantity with units from known quantities, by selecting and following a logical computational pathway.

3.C
Compare physical quantities between two or more scenarios or at different times and/or locations within a single scenario.

3.C
Justify or support a claim using evidence from experimental data, physical representations, or physical principles or laws.
TOPIC 2.5
Newton’s Second Law

Required Course Content

LEARNING OBJECTIVE

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

ESSENTIAL KNOWLEDGE

2.5.A.1
Unbalanced forces are a configuration of forces such that the net force exerted on a system is not equal to zero.

2.5.A.2
Newton’s second law of motion states that the acceleration of a system’s center of mass has a magnitude proportional to the magnitude of the net force exerted on the system and is in the same direction as that net force.

Relevant equation:

\[ \vec{a}_{sys} = \frac{\vec{F}_{net}}{m_{sys}} \]

2.5.A.3
The velocity of a system’s center of mass will only change if a nonzero net external force is exerted on that system.
# TOPIC 2.6

**Gravitational Force**

## Required Course Content

### LEARNING OBJECTIVE

**2.6.A**

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

### ESSENTIAL KNOWLEDGE

**2.6.A.1**

Newton’s law of universal gravitation describes the gravitational force between two objects or systems as directly proportional to each of their masses and inversely proportional to the square of the distance between the systems’ centers of mass.

Relevant equation:

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

- The gravitational force is attractive.
- The gravitational force is always exerted along the line connecting the center of mass of the two interacting systems.
- The gravitational force on a system can be considered to be exerted on the system’s center of mass.

**2.6.A.2**

A field models the effects of a noncontact force exerted on an object at various positions in space.

- The magnitude of the gravitational field created by a system of mass \( M \) at a point in space is equal to the ratio of the gravitational force exerted by the system on a test object of mass \( m \) to the mass of the test object.

Derived equation:

\[ g = \frac{F}{m} = \frac{G M}{r^2} \]

*continued on next page*
LEARNING OBJECTIVE

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

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

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

ESSENTIAL KNOWLEDGE

ii. If the gravitational force is the only force exerted on an object, the observed acceleration of the object (in m/s²) is numerically equal to the magnitude of the gravitational field strength (in N/kg) at that location.

2.6.A.3
The gravitational force exerted by an astronomical body on a relatively small nearby object is called weight.
Derived equation:
Weight = F_g = mg

2.6.B.1
If the gravitational force between two systems’ centers of mass has a negligible change as the relative position of the two systems changes, the gravitational force can be considered constant at all points between the initial and final positions of the systems.

2.6.B.2
Near the surface of Earth, the strength of the gravitational field is
\[ g = 10 \text{ N/kg}. \]

2.6.C.1
The magnitude of the apparent weight of a system is the magnitude of the normal force exerted on the system.

2.6.C.2
If the system is accelerating, the apparent weight of the system is not equal to the magnitude of the gravitational force exerted on the system.

2.6.C.3
A system appears weightless when there are no forces exerted on the system or when the force of gravity is the only force exerted on the system.

2.6.C.4
The equivalence principle states that an observer in a noninertial reference frame is unable to distinguish between an object’s apparent weight and the gravitational force exerted on the object by a gravitational field.

continued on next page
**LEARNING OBJECTIVE**

2.6.D
Describe inertial and gravitational mass.

2.6.E
Describe the gravitational force exerted on an object by a uniform spherical distribution of mass.

**ESSENTIAL KNOWLEDGE**

2.6.D.1
Objects have inertial mass, or inertia, a property that determines how much an object’s motion resists changes when interacting with another object.

2.6.D.2
Gravitational mass is related to the force of attraction between two systems with mass.

2.6.D.3
Inertial mass and gravitational mass have been experimentally verified to be equivalent.

2.6.E.1
The net gravitational force exerted on an object by a uniform spherical distribution of mass is the sum of the individual forces from small differential masses that comprise the distribution.

2.6.E.2
Newton’s shell theorem describes the net gravitational force exerted on an object by a uniform spherical shell of mass.

   i. The net gravitational force exerted on an object inside a thin spherical shell is zero.
   
   ii. The net gravitational force exerted on an object outside a thin spherical shell can be determined by treating the shell as a single massive object located at the center of the shell.
   
   iii. An object inside a sphere of uniform density experiences a net gravitational force from only a partial mass of the sphere.
   
   iv. The partial mass of a sphere that contributes to the net gravitational force exerted on an object within that sphere is the portion of the sphere’s mass located a distance less than or equal to the object’s distance from the center of the sphere and can be calculated using the density of the sphere.

   Derived equation:

   \[ m_{\text{partial}} = \frac{4}{3} \pi \rho r_{\text{partial}}^3 \]

   continued on next page
LEARNING OBJECTIVE

2.6.E
Describe the gravitational force exerted on an object by a uniform spherical distribution of mass.

ESSENTIAL KNOWLEDGE

2.6.E.3
The gravitational force exerted on an object within a uniform sphere can be shown to be proportional to the object’s distance from the sphere’s center.

Derived equation:

\[ F_{\text{g, partial}} = -kr_{\text{partial}} \]

BOUNDARY STATEMENT:

*AP Physics C: Mechanics does not expect students to mathematically prove or derive Newton’s shell theorem.*
TOPIC 2.7
Kinetic and Static Friction

Required Course Content

<table>
<thead>
<tr>
<th>LEARNING OBJECTIVE</th>
<th>ESSENTIAL KNOWLEDGE</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>2.7.A</strong></td>
<td>Describe kinetic friction between two surfaces.</td>
</tr>
<tr>
<td><strong>2.7.A.1</strong></td>
<td>Kinetic friction occurs when two surfaces in contact move relative to each other.</td>
</tr>
<tr>
<td>i. The kinetic friction force is exerted in a direction opposite the motion of each surface relative to the other surface.</td>
<td></td>
</tr>
<tr>
<td>ii. The force of friction between two surfaces does not depend on the size of the surface area of contact.</td>
<td></td>
</tr>
<tr>
<td><strong>2.7.A.2</strong></td>
<td>The magnitude of the kinetic friction force exerted on an object is the product of the normal force the surface exerts on the object and the coefficient of kinetic friction.</td>
</tr>
<tr>
<td>Relevant equation:</td>
<td></td>
</tr>
<tr>
<td>[ \vec{F}_k = \mu_k \vec{F}_N ]</td>
<td></td>
</tr>
<tr>
<td>i. The coefficient of kinetic friction depends on the material properties of the surfaces that are in contact.</td>
<td></td>
</tr>
<tr>
<td>ii. Normal force is the perpendicular component of the force exerted on an object by the surface with which it is in contact; it is directed away from the surface.</td>
<td></td>
</tr>
<tr>
<td><strong>2.7.B</strong></td>
<td>Describe static friction between two surfaces.</td>
</tr>
<tr>
<td><strong>2.7.B.1</strong></td>
<td>Static friction may occur between the contacting surfaces of two objects that are not moving relative to each other.</td>
</tr>
</tbody>
</table>

continued on next page
LEARNING OBJECTIVE

2.7.B
Describe static friction between two surfaces.

ESSENTIAL KNOWLEDGE

2.7.B.2
Static friction adopts the value and direction required to prevent an object from slipping or sliding on a surface.

Relevant equation:

\[ |\vec{F}_{s}| \leq \mu_{s}\vec{F}_{N} \]

i. Slipping and sliding refer to situations in which two surfaces are moving relative to each other.

ii. There exists a maximum value for which static friction will prevent an object from slipping on a given surface.

Derived equation:

\[ F_{s,max} = \mu_{s}\vec{F}_{N} \]

2.7.B.3
The coefficient of static friction is typically greater than the coefficient of kinetic friction for a given pair of surfaces.
TOPIC 2.8
Spring Forces

Required Course Content

**LEARNING OBJECTIVE**

2.8.A
Describe the force exerted on an object by an ideal spring.

2.8.B
Describe the equivalent spring constant of a combination of springs exerting forces on an object.

**ESSENTIAL KNOWLEDGE**

2.8.A.1
An ideal spring has negligible mass and exerts a force that is proportional to the change in its length as measured from its relaxed length. A nonideal spring either has nonnegligible mass or exerts a force that is not proportional to the change in its length as measured from its relaxed length.

2.8.A.2
The magnitude of the force exerted by an ideal spring on an object is given by Hooke’s law:

\[ F = -k \Delta x \]

2.8.A.3
The force exerted on an object by a spring is always directed towards the equilibrium position of the object–spring system.

2.8.B.1
A collection of springs that exert forces on an object may behave as though they were a single spring with an equivalent spring constant \( k_{eq} \).

i. The inverse of the equivalent spring constant of a set of springs in series is equal to the sum of the inverses of the individual spring constants.

Derived equation:

\[
\frac{1}{k_{eq, \text{series}}} = \sum \frac{1}{k_i} = \frac{1}{k_1} + \frac{1}{k_2} + \ldots
\]

continued on next page
LEARNING OBJECTIVE

2.8.B
Describe the equivalent spring constant of a combination of springs exerting forces on an object.

ESSENTIAL KNOWLEDGE

ii. The equivalent spring constant of a set of springs arranged in series is smaller than the smallest constituent spring constant.

iii. The equivalent spring constant of a set of springs arranged in parallel is the sum of the individual spring constants.

Derived equation:

\[ k_{\text{eq, parallel}} = \sum_{i} k_i = k_1 + k_2 + \ldots \]

BOUNDARY STATEMENT:

AP Physics C: Mechanics only expects students to find the effective spring constant of systems of springs that are arranged either in series or in parallel and does not expect students to find the effective spring constant of a system in which springs are arranged in both series and parallel.
LEARNING OBJECTIVE

2.9.A
Describe the motion of an object subject to a resistive force.

ESSENTIAL KNOWLEDGE

2.9.A.1
A resistive force is defined as a velocity-dependent force in the opposite direction of an object’s velocity, for example:

\[ \vec{F}_r = -k\vec{v} \]

2.9.A.2
Applying Newton’s second law to an object upon which a resistive force is exerted results in a differential equation for velocity.

i. Using the method of separation of variables, the velocity can be determined by integrating over the proper limits of integration.

ii. The acceleration or position of a moving object that is subject to a velocity-dependent force may be determined using initial conditions of the object and methods of calculus, once a function for velocity is determined.

iii. The position, velocity, and acceleration as functions of time of an object under the influence of a resistive force of the form \( \vec{F}_r = -k\vec{v} \) are exponential and have asymptotes that are determined by the initial conditions of the object and the forces exerted on the object.

2.9.A.3
Terminal velocity is defined as the maximum speed achieved by an object moving under the influence of a constant force and a resistive force that are exerted on the object in opposite directions. The terminal condition is reached when the net force exerted on the object is zero.
TOPIC 2.10

Circular Motion

Required Course Content

LEARNING OBJECTIVE

2.10.A
Describe the motion of an object traveling in a circular path.

ESSENTIAL KNOWLEDGE

2.10.A.1
Centripetal acceleration is the component of an object’s acceleration directed toward the center of the object’s circular path.

i. The magnitude of centripetal acceleration for an object moving in a circular path is the ratio of the object’s tangential speed squared to the radius of the circular path.

Relevant equation:

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

ii. Centripetal acceleration is directed toward the center of an object’s circular path.

2.10.A.2
Centripetal acceleration can result from a single force, more than one force, or components of forces that are exerted on an object in circular motion.

i. At the top of a vertical, circular loop, an object requires a minimum speed to maintain circular motion. At this point, and with this minimum velocity, the gravitational force is the only force that causes the centripetal acceleration.

Derived equation:

\[ v = \sqrt{gr} \]

ii. Components of the static friction force and the normal force can contribute to the net force producing centripetal acceleration of an object traveling in a circle on a banked surface.

iii. A component of tension contributes to the net force producing centripetal acceleration experienced by a conical pendulum.

continued on next page
### LEARNING OBJECTIVE

**2.10.A**
Describe the motion of an object traveling in a circular path.

### ESSENTIAL KNOWLEDGE

**2.10.A.3**
Tangential acceleration is the rate at which an object’s speed changes and is directed tangent to the object’s circular path.

**2.10.A.4**
The net acceleration of an object moving in a circle is the vector sum of the centripetal acceleration and tangential acceleration.

**2.10.A.5**
The revolution of an object traveling in a circular path at a constant speed (uniform circular motion) can be described using period and frequency.

i. The time to complete one full circular path is defined as period, $T$.

ii. The rate at which an object is completing revolutions is defined as frequency, $f$.

*Relevant equation:*

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

iii. For an object traveling at a constant speed in a circular path, the period is given by the derived equation

$$T = \frac{2\pi r}{v}$$

**2.10.B**
Describe circular orbits using Kepler’s third law.

**2.10.B.1**
For a satellite in circular orbit around a central body, the satellite’s centripetal acceleration is caused only by gravitational attraction. The period and radius of the circular orbit are related to the mass of the central body.

*Derived equation:*

$$T^2 = \frac{4\pi^2 R^3}{GM}$$

### BOUNDARY STATEMENT:

*AP Physics C: Mechanics does not expect students to know Kepler’s first or second laws of planetary motion.*
UNIT 3

Work, Energy, and Power

AP EXAM WEIGHTING

18–22%

CLASS PERIODS

~12/~17
TOPIC 3.1
Translational Kinetic Energy

Required Course Content

LEARNING OBJECTIVE

3.1.A
Describe the translational kinetic energy of an object in terms of the object's mass and velocity.

ESSENTIAL KNOWLEDGE

3.1.A.1
An object’s translational kinetic energy is given by the equation
\[ K = \frac{1}{2}mv^2. \]

3.1.A.2
Translational kinetic energy is a scalar quantity.

3.1.A.3
Different observers may measure different values of the translational kinetic energy of an object, depending on the observer's frame of reference.
TOPIC 3.2

Work

Required Course Content

LEARNING OBJECTIVE

3.2.A
Describe the work done on an object or system by a given force or collection of forces.

ESSENTIAL KNOWLEDGE

3.2.A.1
Work is the amount of energy transferred into or out of a system by a force exerted on that system over a distance.

i. The work done by a conservative force exerted on a system is path-independent and only depends on the initial and final configurations of that system.

ii. The work done by a conservative force on a system—or the change in the potential energy of the system—will be zero if the system returns to its initial configuration.

iii. Potential energies are associated only with conservative forces.

iv. The work done by a nonconservative force is path-dependent.

v. The most common nonconservative forces are friction and air resistance.

3.2.A.2
Work is a scalar quantity that may be positive, negative, or zero.

3.2.A.3
The work done on an object by a variable force is calculated using

\[ W = \int_a^b \vec{F}(r) \cdot d\vec{r} , \]

where the integral is taken over the path from point a to point b.

i. The dot product between two vectors, \( \vec{A} \) and \( \vec{B} \), results in a scalar quantity of magnitude

\[ \vec{A} \cdot \vec{B} = AB\cos\theta . \]
**LEARNING OBJECTIVE**

3.2.A

Describe the work done on an object or system by a given force or collection of forces.

**ESSENTIAL KNOWLEDGE**

ii. Only the component of the force exerted on a system that is parallel to the displacement of the point of application of the force will change the system's total energy.

iii. If the component of the force exerted on a system that is parallel to the displacement is constant, the work done on the system by the force is given by the derived equation

\[ W = W_{\parallel} = Fd \cos \theta. \]

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

3.2.A.4

The work–energy theorem states that the change in an object's kinetic energy is equal to the sum of the work (net work) being done by all forces exerted on the object.

*Relevant equation:*

\[ \Delta K = \sum W_i = \sum F_{\parallel} d_i \]

i. An external force may change the configuration of a system. The component of the external force parallel to the displacement times the displacement of the point of application of the force gives the change in kinetic energy of the system.

ii. If the system's center of mass and the point of application of the force move the same distance when a force is exerted on a system, then the system may be modeled as an object, and only the system's kinetic energy can change.

iii. The energy dissipated by friction is typically equated to the force of friction times the length of the path over which the force is exerted.

\[ \Delta E_{\text{mech}} = F_i d \cos \theta \]

3.2.A.5

Work is equal to the area under the curve of a graph of \( F_{\parallel} \) as a function of displacement.

**BOUNDARY STATEMENT:**

*AP Physics C: Mechanics only expects students to analyze the transfer of mechanical energy, although students should be aware that mechanical energy may be dissipated in the form of thermal energy or sound.*
TOPIC 3.3
Potential Energy

Required Course Content

LEARNING OBJECTIVE
3.3.A
Describe the potential energy of a system.

ESSENTIAL KNOWLEDGE
3.3.A.1
A system composed of two or more objects has potential energy if the objects within that system only interact with each other through conservative forces.

3.3.A.2
Potential energy is a scalar quantity associated with the position of objects within a system.

3.3.A.3
The definition of zero potential energy for a given system is a decision made by the observer considering the situation to simplify or otherwise assist in analysis.

3.3.A.4
The relationship between conservative forces exerted on a system and the system’s potential energy is

$$\Delta U = -\int_{a}^{b} F_y(r) \cdot dr$$

3.3.A.5
The conservative forces exerted on a system in a single dimension can be determined using the slope of the system’s potential energy with respect to position in that dimension; these forces point in the direction of decreasing potential energy.

Relevant equation:

$$F_x = -\frac{dU(x)}{dx}$$

3.3.A.6
Graphs of a system’s potential energy as a function of its position can be useful in determining physical properties of that system.
**LEARNING OBJECTIVE**

3.3.A

Describe the potential energy of a system.

---

**ESSENTIAL KNOWLEDGE**

i. Stable equilibrium is a location at which a small displacement in an object’s position results in a force exerted on the object opposite to the direction of the small displacement, accelerating the object back toward the equilibrium position.

ii. Unstable equilibrium is a location at which a small displacement in an object’s position results in a force exerted on the object in the same direction as the small displacement, accelerating the object away from the equilibrium position.

iii. In a given dimension, stable equilibrium positions exist at locations where the potential energy as a function of position in that dimension has a local minimum.

iv. In a given dimension, unstable equilibrium positions occur at locations where the potential energy as a function of position in that dimension has a local maximum.

---

3.3.A.7

The potential energy of common physical systems can be described using the physical properties of that system.

i. The elastic potential energy of an ideal spring is given by the following equation, where $\Delta x$ is the distance the spring has been stretched or compressed from its equilibrium length.

   Relevant equation:
   
   $$U_e = \frac{1}{2} k (\Delta x)^2$$

ii. The general form for the gravitational potential energy of a system consisting of two approximately spherical distributions of mass (e.g., moons, planets, or stars) is given by the equation

   $$U_g = -G \frac{m_1 m_2}{r}$$

iii. Because the gravitational field near the surface of a planet is nearly constant, the change in gravitational potential energy in a system consisting of an object with mass $m$ and a planet with gravitational field of magnitude $g$ when the object is near the surface of the planet may be approximated by the equation

   $$\Delta U_g = mg \Delta y.$$
LEARNING OBJECTIVE

3.3.A
Describe the potential energy of a system.

ESSENTIAL KNOWLEDGE

3.3.A.8
The total potential energy of a system containing more than two objects is the sum of the potential energy of each pair of objects within the system.
TOPIC 3.4
Conservation of Energy

Required Course Content

**LEARNING OBJECTIVE**

3.4.A
Describe the energies present in a system.

3.4.B
Describe the behavior of a system using conservation of mechanical energy principles.

**ESSENTIAL KNOWLEDGE**

3.4.A.1
A system composed of only a single object can only have kinetic energy.

3.4.A.2
A system that contains objects that interact via conservative forces or that can change its shape reversibly may have both kinetic and potential energies.

3.4.B.1
Mechanical energy is the sum of a system's kinetic and potential energies.

3.4.B.2
Any change to a type of energy within a system must be balanced by an equivalent change of other types of energies within the system or by a transfer of energy between the system and its surroundings.

3.4.B.3
A system may be selected so that the total energy of that system is constant.

3.4.B.4
If the total energy of a system changes, that change will be equivalent to the energy transferred into or out of the system.

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LEARNING OBJECTIVE

3.4.C
Describe how the selection of a system determines whether the energy of that system changes.

ESSENTIAL KNOWLEDGE

3.4.C.1
Energy is conserved in all interactions.

3.4.C.2
If the work done on a selected system is zero and there are no nonconservative interactions within the system, the total mechanical energy of the system is constant.

3.4.C.3
If the work done on a selected system is nonzero, energy is transferred between the system and the environment.

BOUNDARY STATEMENT:

AP Physics C: Mechanics expects students to know that mechanical energy can be dissipated as thermal energy or sound by nonconservative forces.
TOPIC 3.5
Power

Required Course Content

**LEARNING OBJECTIVE**

3.5.A
Describe the transfer of energy into, out of, or within a system in terms of power.

**ESSENTIAL KNOWLEDGE**

3.5.A.1
Power is the rate at which energy changes with respect to time, either by transfer into or out of a system or by conversion from one type to another within a system.

3.5.A.2
Average power is the amount of energy being transferred or converted, divided by the time it took for that transfer or conversion to occur. 
*Relevant equation:*

\[ P_{\text{avg}} = \frac{\Delta E}{\Delta t} \]

3.5.A.3
Because work is the change in energy of an object or system due to a force, average power is the total work done, divided by the time during which that work was done. 
*Relevant equation:*

\[ P_{\text{avg}} = \frac{W}{\Delta t} \]

3.5.A.4
The instantaneous power delivered to an object by a force is given by the equation

\[ P_{\text{inst}} = \frac{dW}{dt} \]

3.5.A.5
The instantaneous power delivered to an object by the component of a constant force parallel to the object’s velocity can be described with the derived equation

\[ P_{\text{inst}} = F_{||}v = Fv\cos\theta. \]
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UNIT 4
Linear Momentum

AP EXAM WEIGHTING
14–18%

CLASS PERIODS
~11/~15
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TOPIC 4.1
Linear Momentum

Required Course Content

LEARNING OBJECTIVE

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

ESSENTIAL KNOWLEDGE

4.1.A.1
Linear momentum is defined by the equation \( \vec{p} = m \vec{v} \).

4.1.A.2
Momentum is a vector quantity and has the same direction as the velocity.

4.1.A.3
Momentum can be used to analyze collisions and explosions.
   i. A collision is a model for an interaction where the forces exerted between the involved objects in the system are much larger than the net external force exerted on those objects during the interaction.
   ii. As only the initial and final states of a collision are analyzed, the object model may be used to analyze collisions.
   iii. An explosion is a model for an interaction in which forces internal to the system move objects within that system apart.

SUGGESTED SCIENCE PRACTICES

1.C
Create qualitative sketches of graphs that represent features of a model or the behavior of the physical system.

2.B
Calculate or estimate an unknown quantity with units from known quantities, by selecting and following a logical computational pathway.

3.B
Predict new values or factors of change of physical quantities using functional dependence between variables.

3.D
Apply an appropriate law, definition, theoretical relationship, or model to make a claim.
TOPIC 4.2
Change in Momentum and Impulse

Required Course Content

LEARNING OBJECTIVE

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

ESSENTIAL KNOWLEDGE

4.2.A.1
The rate of change of a system's momentum is equal to the net external force exerted on that system.

Relevant equation:

$$F_{net} = \frac{dp}{dt}$$

4.2.A.2
Impulse is defined as the integral of a force exerted on an object or system over a time interval.

Relevant equation:

$$J = \int_{t_1}^{t_2} F_{net}(t)\,dt$$

4.2.A.3
Impulse is a vector quantity and has the same direction as the net force exerted on the system.

4.2.A.4
The impulse delivered to a system by a net external force is equal to the area under the curve of a graph of the net external force exerted on the system as a function of time.

4.2.A.5
The net external force exerted on a system is equal to the slope of a graph of the momentum of the system as a function of time.

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LEARNING OBJECTIVE

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

ESSENTIAL KNOWLEDGE

4.2.B.1
Change in momentum is the difference between a system’s final momentum and its initial momentum.

Relevant equation:

\[ \Delta \vec{p} = \vec{p} - \vec{p}_0 \]

4.2.B.2
The impulse–momentum theorem relates the impulse delivered to an object and the object’s change in momentum.

i. The impulse exerted on an object is equal to the object’s change in momentum.

Relevant equation:

\[ \bar{J} = \int_{t_1}^{t_2} \bar{F}_{\text{net}}(t) \, dt = \Delta \vec{p} \]

ii. Newton’s second law of motion is a direct result of the impulse–momentum theorem applied to systems with constant mass.

\[ \bar{F}_{\text{net}} = \frac{d\vec{p}}{dt} = m \frac{d\vec{v}}{dt} = m\bar{a} \]

iii. The impulse–momentum theorem also describes the behavior of a system in which the velocity is constant but the mass changes with respect to time.

\[ \bar{F}_{\text{net}} = \frac{d\vec{p}}{dt} = \frac{dm}{dt} \vec{v} \]
TOPIC 4.3

Conservation of Linear Momentum

Required Course Content

LEARNING OBJECTIVE

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

ESSENTIAL KNOWLEDGE

4.3.A.1 A collection of objects with individual momenta can be described as one system with one center-of-mass velocity.
   i. For a collection of objects, the velocity of a system’s center of mass can be calculated using the equation
   \[ \vec{v}_{cm} = \frac{\sum p_i}{\sum m_i} = \sum \left( \frac{m_i \vec{v}_i}{m_i} \right). \]
   ii. The velocity of a system’s center of mass is constant in the absence of a net external force.

4.3.A.2 The total momentum of a system is the sum of the momenta of the system’s constituent parts.

4.3.A.3 In the absence of net external forces, any change to the momentum of an object within a system must be balanced by an equivalent and opposite change of momentum elsewhere within the system. Any change to the momentum of a system is due to a transfer of momentum between the system and its surroundings.
   i. The impulse exerted by one object on a second object is equal and opposite to the impulse exerted by the second object on the first. This is a direct result of Newton’s third law.
   ii. A system may be selected so that the total momentum of that system is constant.

continued on next page
Learning Objective 4.3.A
Describe the behavior of a system using conservation of linear momentum.

Essential Knowledge

iii. If the total momentum of a system changes, that change will be equivalent to the impulse exerted on the system.

Relevant equation:
\[ \vec{j} = \Delta \vec{p} \]

4.3.A.4
Correct application of conservation of momentum can be used to determine the velocity of a system immediately before and immediately after collisions or explosions.

Boundary Statement:
AP Physics C: Mechanics only expects students to quantitatively analyze collisions and interactions in one or two dimensions. Three-dimensional collisions may be analyzed qualitatively.

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

4.3.B.1
Momentum is conserved in all interactions.

4.3.B.2
If the net external force on the selected system is zero, the total momentum of the system is constant.

4.3.B.3
If the net external force on the selected system is nonzero, momentum is transferred between the system and the environment.
TOPIC 4.4

Elastic and Inelastic Collisions

Required Course Content

**LEARNING OBJECTIVE**

4.4.A

Describe whether an interaction between objects is elastic or inelastic.

**ESSENTIAL KNOWLEDGE**

4.4.A.1

An elastic collision between objects is one in which the initial kinetic energy of the system is equal to the final kinetic energy of the system.

4.4.A.2

In an elastic collision, the final kinetic energies of each of the objects within the system may be different from their initial kinetic energies.

4.4.A.3

An inelastic collision between objects is one in which the total kinetic energy of the system decreases.

4.4.A.4

In an inelastic collision, some of the initial kinetic energy is not restored to kinetic energy but is transformed by nonconservative forces into other forms of energy.

4.4.A.5

In a perfectly inelastic collision, the objects stick together and move with the same velocity after the collision.
UNIT 5

Torque and Rotational Dynamics

10–14% AP EXAM WEIGHTING

~14/~20 CLASS PERIODS
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LEARNING OBJECTIVE

5.1.A Describe the rotation of a system with respect to time using angular displacement, angular velocity, and angular acceleration.

ESSENTIAL KNOWLEDGE

5.1.A.1 Angular displacement is the measurement of the angle, in radians, through which a point on a rigid system rotates about a specified axis.

Relevant equation:

\[ \Delta \theta = \theta - \theta_0 \]

i. A rigid system is one that holds its shape but in which different points on the system move in different directions during rotation. A rigid system cannot be modeled as an object.

ii. One direction of angular displacement about an axis of rotation — clockwise or counterclockwise — is typically indicated as mathematically positive, with the other direction becoming mathematically negative.

iii. If the rotation of a system about an axis may be well described using the motion of the system’s center of mass, the system may be treated as a single object. For example, the rotation of Earth about its axis may be considered negligible when considering the revolution of Earth about the center of mass of the Earth-Sun system.

5.1.A.2 Angular velocity is the rate at which angular position changes with respect to time.

Relevant equation:

\[ \omega = \frac{d\theta}{dt} \]
LEARNING OBJECTIVE

5.1.A
Describe the rotation of a system with respect to time using angular displacement, angular velocity, and angular acceleration

ESSENTIAL KNOWLEDGE

5.1.A.3
Angular acceleration is the rate at which angular velocity changes with respect to time.

Relevant equation:
\[ \alpha = \frac{d\omega}{dt} \]

5.1.A.4
Angular displacement, angular velocity, and angular acceleration around one axis are analogous to linear displacement, velocity, and acceleration in one dimension and demonstrate the same mathematical relationships.

i. For constant angular acceleration, the mathematical relationships between angular displacement, angular velocity, and angular acceleration can be described with the following equations:
\[ \omega = \omega_0 + \alpha t \]
\[ \theta = \theta_0 + \omega_0 t + \frac{1}{2} \alpha t^2 \]
\[ \omega^2 = \omega_0^2 + 2\alpha(\theta - \theta_0) \]

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

BOUNDARY STATEMENT:

AP Physics C: Mechanics expects students to be able to mathematically manipulate the magnitudes of angular displacement, angular velocity, and angular acceleration using vector conventions. However, the directions of said vectors will not be assessed on the exam.

Descriptions of the directions of rotational kinematics quantities for a point or object are limited to clockwise and counterclockwise with respect to a given axis of rotation.
TOPIC 5.2
Connecting Linear and Rotational Motion

Required Course Content

LEARNING OBJECTIVE

5.2.A
Describe the linear motion of a point on a rotating rigid system that corresponds to the rotational motion of that point, and vice versa.

ESSENTIAL KNOWLEDGE

5.2.A.1
For a point at a distance \( r \) from a fixed axis of rotation, the linear distance \( s \) traveled by the point as the system rotates through an angle \( \Delta \theta \) is given by the equation \( s = r \Delta \theta \).

5.2.A.2
Derived relationships of linear velocity and of the tangential component of acceleration to their respective angular quantities are given by the following equations:

\[
\begin{align*}
  s &= r \theta \\
  v &= r \omega \\
  a_T &= r \alpha
\end{align*}
\]

5.2.A.3
For a rigid system, all points within that system have the same angular velocity and angular acceleration.

BOUNDARY STATEMENT:

*AP Physics C: Mechanics* expects students to be able to mathematically manipulate the magnitudes of angular displacement, angular velocity, and angular acceleration using vector conventions. However, the directions of the vectors will not be assessed on the exam.

*Descriptions of the directions of rotational kinematics quantities for a point or rigid body are limited to clockwise and counterclockwise with respect to a given axis of rotation.*
## TOPIC 5.3

### Torque

**LEARNING OBJECTIVE**

- **5.3.A** Identify the torques exerted on a rigid system.
- **5.3.B** Describe the torques exerted on a rigid system.

**ESSENTIAL KNOWLEDGE**

- **5.3.A.1** Torque results only from the force component perpendicular to the position vector from the axis of rotation to the point of application of the force.

- **5.3.A.2** The lever arm is the perpendicular distance from the axis of rotation to the line of action of the exerted force.

- **5.3.B.1** Torques can be described using force diagrams.
  
  i. Force diagrams are similar to free-body diagrams and are used to analyze the torques exerted on a rigid system.
  
  ii. Similar to free-body diagrams, force diagrams represent the relative magnitude and direction of the forces exerted on a rigid system. Force diagrams also depict the location at which those forces are exerted relative to the axis of rotation.

- **5.3.B.2** The torque exerted on a rigid system about a chosen pivot point by a given force is described by

  \[
  \vec{\tau} = \vec{r} \times \vec{F}.
  \]

  i. The cross-product between two vectors, \( \vec{A} \) and \( \vec{B} \), results in a vector quantity of magnitude

  \[
  \vec{A} \times \vec{B} = AB \sin \theta.
  \]
LEARNING OBJECTIVE

5.3.B
Describe the torques exerted on a rigid system.

ESSENTIAL KNOWLEDGE

ii. The direction of the vector resulting from the cross-product of vectors $\vec{A}$ and $\vec{B}$ is perpendicular to both vectors $\vec{A}$ and $\vec{B}$ and therefore is normal to the plane defined by vectors $\vec{A}$ and $\vec{B}$.

iii. The direction of the vector resulting from the cross-product of vectors $\vec{A}$ and $\vec{B}$ can be qualitatively determined by applying the appropriate right-hand rule.
Torque and Rotational Dynamics

TOPIC 5.4
Rotational Inertia

Required Course Content

LEARNING OBJECTIVE

5.4.A.1
Describe the rotational inertia of a rigid system relative to a given axis of rotation.

ESSENTIAL KNOWLEDGE

5.4.A.1
Rotational inertia measures a rigid system’s resistance to changes in rotation and is related to the mass of the system and the distribution of that mass relative to the axis of rotation.

5.4.A.2
The rotational inertia of an object rotating a perpendicular distance $r$ from an axis is described by the equation $I = mr^2$.

5.4.A.3
The total rotational inertia of a collection of objects about an axis is the sum of the rotational inertias of each object about that axis.

$$I_{tot} = \sum_i I_i = \sum_i m_ir_i^2$$

5.4.A.4
For a solid that can be considered as a collection of differential masses, $dm$, the solid’s rotational inertia can be calculated using the equation

$$I = \int r^2 \, dm,$$

where $r$ is the perpendicular distance from $dm$ to the axis of rotation.

5.4.B
Describe the rotational inertia of a rigid system rotating about an axis that does not pass through the system’s center of mass.

5.4.B.1
A rigid system’s rotational inertia in a given plane is at a minimum when the rotational axis passes through the system’s center of mass.
LEARNING OBJECTIVE

5.4.B
Describe the rotational inertia of a rigid system rotating about an axis that does not pass through the system's center of mass.

ESSENTIAL KNOWLEDGE

5.4.B.2
The parallel axis theorem uses the following equation to relate the rotational inertia of a rigid system about any axis that is parallel to an axis through its center of mass:

\[ I' = I_{cm} + Md^2 \]

BOUNDARY STATEMENT:

AP Physics C: Mechanics only expects students to use calculus in the derivations of the rotational inertia of thin rods of uniform or nonuniform density about an arbitrary axis perpendicular to the rod, as well as derivations of the rotational inertia of a thin cylindrical shell, disk, or rigid bodies that can be considered to be made up of coaxial rings or shells about an axis that passes through their centers (e.g., annular rings).

Students should have a qualitative understanding of the factors that affect rotational inertia; for example, how rotational inertia is greater when mass is farther from the axis of rotation, which is why a hoop has more rotational inertia than a solid puck of the same mass and radius.
### Topic 5.5

Rotational Equilibrium and Newton’s First Law in Rotational Form

#### Required Course Content

**Learning Objective**  
5.5.A  
Describe the conditions under which a system’s angular velocity remains constant.

**Essential Knowledge**  
5.5.A.1  
A system may exhibit rotational equilibrium (constant angular velocity) without being in translational equilibrium, and vice versa.

i. Free-body and force diagrams describe the nature of the forces and torques exerted on an object or rigid system.

ii. Rotational equilibrium is a configuration of torques such that the net torque exerted on the system is zero.  
   
   Relevant equation:  
   
   \[ \sum \tau_i = 0 \]

iii. The rotational analog of Newton’s first law is that a system will have a constant angular velocity only if the net torque exerted on the system is zero.

**Boundary Statement:**  
*AP Physics C: Mechanics does not expect students to simultaneously analyze rotation in multiple planes.*
TOPIC 5.6
Newton’s Second Law in Rotational Form

Required Course Content

LEARNING OBJECTIVE
5.6.A Describe the conditions under which a system's angular velocity changes.

ESSENTIAL KNOWLEDGE
5.6.A.1 Angular velocity changes when the net torque exerted on the object or system is not equal to zero.

5.6.A.2 The rate at which the angular velocity of a rigid system changes is directly proportional to the net torque exerted on the rigid system and is in the same direction. The angular acceleration of the rigid system is inversely proportional to the rotational inertia of the rigid system.

Relevant equation:
$$\alpha = \frac{\tau}{I_{\text{sys}}}$$

5.6.A.3 To fully describe a rotating rigid system, linear and rotational analyses may need to be performed independently.
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UNIT 6

Energy and Momentum of Rotating Systems

AP EXAM WEIGHTING

10–14%

CLASS PERIODS

~13/~19
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LEARNING OBJECTIVE

6.1.A  Describe the rotational kinetic energy of a rigid system in terms of the rotational inertia and angular velocity of that rigid system.

ESSENTIAL KNOWLEDGE

6.1.A.1  The rotational kinetic energy of an object or rigid system is related to the rotational inertia and angular velocity of the rigid system and is given by the equation

\[ K_{\text{rot}} = \frac{1}{2} I \omega^2. \]

i. The rotational inertia of an object about a fixed axis can be used to show that the rotational kinetic energy of that object is equivalent to its translational kinetic energy, which is its total kinetic energy.

ii. The total kinetic energy of a rigid system is the sum of its rotational kinetic energy due to its rotation about its center of mass and the translational kinetic energy due to the linear motion of its center of mass.

6.1.A.2  A rigid system can have rotational kinetic energy while its center of mass is at rest due to the individual points within the rigid system having linear speed and, therefore, kinetic energy.

6.1.A.3  Rotational kinetic energy is a scalar quantity.
TOPIC 6.2
Torque and Work

Required Course Content

LEARNING OBJECTIVE
6.2.A
Describe the work done on a rigid system by a given torque or collection of torques.

ESSENTIAL KNOWLEDGE
6.2.A.1
A torque can transfer energy into or out of an object or rigid system if the torque is exerted over an angular displacement.

6.2.A.2
The amount of work done on a rigid system by a torque is related to the magnitude of that torque and the angular displacement through which the rigid system rotates during the interval in which that torque is exerted.

Relevant equation:
\[ W = \int_{\theta_1}^{\theta_2} \tau \, d\theta \]

6.2.A.3
Work done on a rigid system by a given torque can be found from the area under the curve of a graph of the torque as a function of angular position.
LEARNING OBJECTIVE

6.3.A
Describe the angular momentum of an object or rigid system.

ESSENTIAL KNOWLEDGE

6.3.A.1
The magnitude of the angular momentum of a rigid system about a specific axis can be described with the equation
\[ L = I\omega. \]

6.3.A.2
The angular momentum of an object about a given point is
\[ \vec{L} = \vec{r} \times \vec{p}. \]

i. The selection of the axis about which an object is considered to rotate influences the determination of the angular momentum of that object.

ii. The measured angular momentum of an object traveling in a straight line depends on the distance between the reference point and the object, the mass of the object, the speed of the object, and the angle between the radial distance and the velocity of the object.

6.3.B
Describe the angular impulse delivered to an object or rigid system by a torque.

6.3.B.1
Angular impulse is defined as the product of the torque exerted on an object or rigid system and the time interval during which the torque is exerted.

\[ \text{Relevant equation:} \]  
\[ \text{angular impulse} = \int \tau \, dt \]

6.3.B.2
Angular impulse has the same direction as the torque imparting it.

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**Energy and Momentum of Rotating Systems**

**LEARNING OBJECTIVE**

6.3.B
Describe the angular impulse delivered to an object or rigid system by a torque.

6.3.C
Relate the change in angular momentum of an object or rigid system to the angular impulse given to that object or rigid system.

**ESSENTIAL KNOWLEDGE**

6.3.B.3
The angular impulse delivered to an object or rigid system by a torque can be found from the area under the curve of a graph of the torque as a function of time.

6.3.C.1
The magnitude of the change in angular momentum can be described by comparing the magnitudes of the final and initial momenta of the object or rigid system.

\[ \Delta L = L_f - L_i \]

6.3.C.2
A rotational form of the impulse–momentum theorem relates the angular impulse delivered to an object or rigid system and the change in angular momentum of that object or rigid system.

i. The angular impulse exerted on an object or rigid system is equal to the change in angular momentum of that object or rigid system.

*Relevant equation:*

\[ \Delta L = \int_{t_i}^{t_f} \tau \, dt \]

ii. The rotational form of the impulse–momentum theorem is a direct result of Newton’s second law of motion for cases in which rotational inertia is constant.

\[ \tau_{\text{net}} = \frac{dL}{dt} = \frac{d\omega}{dt} = I\alpha \]

6.3.C.3
The net torque exerted on an object or rigid system is equal to the slope of the graph of the angular momentum of an object as a function of time.

6.3.C.4
The angular impulse delivered to an object or rigid system is equal to the area under the curve of a graph of the net external torque exerted on an object as a function of time.
TOPIC 6.4
Conservation of Angular Momentum

Required Course Content

LEARNING OBJECTIVE
6.4.A
Describe the behavior of a system using conservation of angular momentum.

ESSENTIAL KNOWLEDGE
6.4.A.1
The total angular momentum of a system about a rotational axis is the sum of the angular momenta of the system’s constituent parts about that rotational axis.

6.4.A.2
Any change to a system’s angular momentum must be due to an interaction between the system and its surroundings.

i. The angular impulse exerted by one object or system on a second object or system is equal and opposite to the angular impulse exerted by the second object or system on the first. This is a direct result of Newton’s third law.

ii. A system may be selected so that the total angular momentum of that system is constant.

iii. The angular speed of a nonrigid, system may change without the angular momentum of the system changing if the system changes shape by moving mass closer to or farther from the rotational axis.

iv. If the total angular momentum of a system changes, that change will be equivalent to the angular impulse exerted on the system.

continued on next page
<table>
<thead>
<tr>
<th>LEARNING OBJECTIVE</th>
<th>ESSENTIAL KNOWLEDGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.4.B</td>
<td>Describe how the selection of a system determines whether the angular momentum of that system changes.</td>
</tr>
<tr>
<td><strong>6.4.B.1</strong></td>
<td>Angular momentum is conserved in all interactions.</td>
</tr>
<tr>
<td><strong>6.4.B.2</strong></td>
<td>If the net external torque exerted on a selected object or rigid system is zero, the total angular momentum of that system is constant.</td>
</tr>
<tr>
<td><strong>6.4.B.3</strong></td>
<td>If the net external torque exerted on a selected object or rigid system is nonzero, angular momentum is transferred between the system and the environment.</td>
</tr>
</tbody>
</table>
Required Course Content

**LEARNING OBJECTIVE**

6.5.A
Describe the kinetic energy of a system that has translational and rotational motion.

6.5.B
Describe the motion of a system that is rolling without slipping.

6.5.C
Describe the motion of a system that is rolling while slipping.

**ESSENTIAL KNOWLEDGE**

6.5.A.1
The total kinetic energy of a system is the sum of the system’s translational and rotational kinetic energies.

Relevant equation:

\[ K_{\text{tot}} = K_{\text{trans}} + K_{\text{rot}} \]

6.5.B.1
While rolling without slipping, the translational motion of a system’s center of mass is related to the rotational motion of the system itself with the following equations:

\[ \Delta x_{\text{cm}} = r \Delta \theta \]
\[ v_{\text{cm}} = rv \]
\[ a_{\text{cm}} = r\alpha \]

6.5.B.2
For ideal cases, rolling without slipping implies that the frictional force does not dissipate any energy from the rolling system.

6.5.C.1
When slipping, the motion of a system’s center of mass and the system’s rotational motion cannot be directly related.

6.5.C.2
When a rotating system is slipping relative to another surface, the point of application of the force of kinetic friction exerted on the system moves with respect to the surface, so the force of kinetic friction will dissipate energy from the system.

**BOUNDARY STATEMENT:**

Rolling friction is beyond the scope of AP Physics C: Mechanics.
SUGGESTED SCIENCE PRACTICES

1.C
Create qualitative sketches of graphs that represent features of a model or the behavior of the physical system.

2.A
Derive a symbolic expression from known quantities by selecting and following a logical mathematical pathway.

3.C
Justify or support a claim using evidence from experimental data, physical representations, or physical principles or laws.

UNIT 6
Energy and Momentum of Rotating Systems

TOPIC 6.6
Motion of Orbiting Satellites

Required Course Content

LEARNING OBJECTIVE

6.6.A
Describe the motions of a system consisting of two objects or systems interacting only via gravitational forces.

ESSENTIAL KNOWLEDGE

6.6.A.1
In a system consisting only of a massive central object and an orbiting satellite with mass that is negligible in comparison to the central object’s mass, the motion of the central object itself is negligible.

6.6.A.2
The motion of satellites in orbits is constrained by conservation laws.

i. In circular orbits, the system’s total mechanical energy, the system’s gravitational potential energy, and the satellite’s angular momentum and kinetic energy are constant.

ii. In elliptical orbits, the system’s total mechanical energy and the satellite’s angular momentum are constant, but the system’s gravitational potential energy and the satellite’s kinetic energy can each change.

iii. The gravitational potential energy of a system consisting of a satellite and a massive central object is defined to be zero when the satellite is an infinite distance from the central object.

Relevant equation:

\[ U_s = -G \frac{m_1 m_2}{r} \]

continued on next page
LEARNING OBJECTIVE

6.6.A

Describe the motions of a system consisting of two objects interacting only via gravitational forces.

ESSENTIAL KNOWLEDGE

6.6.A.3

The total energy of a system consisting of a satellite orbiting a central object in a circular path can be written in terms of the gravitational potential energy of that system or the kinetic energy of the satellite.

Derived equations:

\[ K = -\frac{1}{2}U \]

\[ E_{\text{total}} = \frac{1}{2}U = -\frac{GMm}{2r} \]

6.6.A.4

The escape velocity of a satellite is the satellite’s velocity such that the mechanical energy of the satellite–central-object system is equal to zero.

i. When the only force exerted on a satellite is gravity from a central object, a satellite that reaches escape velocity will move away from the central body until its speed reaches zero at an infinite distance from the central body.

ii. The escape velocity of a satellite from a central body of mass \( M \) can be derived using conservation of energy laws.

Derived equation:

\[ v_{\text{esc}} = \sqrt{\frac{2GM}{r}} \]
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AP PHYSICS C: MECHANICS

UNIT 7

Oscillations

10–14% AP EXAM WEIGHTING

~12/~17 CLASS PERIODS
TOPIC 7.1
Defining Simple Harmonic Motion (SHM)

 Required Course Content

<table>
<thead>
<tr>
<th>LEARNING OBJECTIVE</th>
<th>ESSENTIAL KNOWLEDGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>7.1.A</td>
<td>7.1.A.1</td>
</tr>
<tr>
<td>Describe simple harmonic motion.</td>
<td>Simple harmonic motion is a special case of periodic motion.</td>
</tr>
<tr>
<td></td>
<td>7.1.A.2</td>
</tr>
<tr>
<td></td>
<td>SHM results when the magnitude of the restoring force exerted on an object is proportional to that object’s displacement from its equilibrium position.</td>
</tr>
<tr>
<td></td>
<td>Derived equation:</td>
</tr>
<tr>
<td></td>
<td>[ ma = -k \Delta x ]</td>
</tr>
<tr>
<td></td>
<td>i. A restoring force is a force that is exerted in a direction opposite to the object’s displacement from an equilibrium position.</td>
</tr>
<tr>
<td></td>
<td>ii. An equilibrium position is a location at which the net force exerted on an object or system is zero.</td>
</tr>
</tbody>
</table>

SUGGESTED SCIENCE PRACTICES
1.A Create diagrams, tables, charts, or schematics to represent physical situations.
2.C Compare physical quantities between two or more scenarios or at different times and/or locations within a single scenario.
3.B Apply an appropriate law, definition, theoretical relationship, or model to make a claim.
3.C Justify or support a claim using evidence from experimental data, physical representations, or physical principles or laws.
TOPIC 7.2

Frequency and Period of SHM

Required Course Content

LEARNING OBJECTIVE

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

ESSENTIAL KNOWLEDGE

7.2.A.1
The period of SHM is related to the angular frequency, ω, of the object’s motion by the following equation:

\[ T = \frac{2\pi}{\omega} = \frac{1}{f} \]

i. The period of an object—ideal spring oscillator is given by the equation

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

ii. The period of a simple pendulum displaced by a small angle is given by the equation

\[ T_p = 2\pi \sqrt{\frac{l}{g}}. \]
TOPIC 7.3
Representing and Analyzing SHM

Required Course Content

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

ESSENTIAL KNOWLEDGE
7.3.A.1
For an object exhibiting SHM, the displacement of that object measured from its equilibrium position can be represented by the equations

\[ x = A \cos(2\pi ft) \] or \[ x = A \sin(2\pi ft) \].

i. Minima, maxima, and zeros of displacement, velocity, and acceleration are features of harmonic motion.

ii. Recognizing the positions or times at which the displacement, velocity, and acceleration for SHM have extrema or zeros can help in qualitatively describing the behavior of the motion.

7.3.A.2
The position as a function of time for an object exhibiting SHM is a solution of the second-order differential equation derived from the application of Newton’s second law.

Derived equation:

\[ \frac{d^2x}{dt^2} = -\omega^2 x \]

7.3.A.3
Characteristics of SHM, such as velocity and acceleration, can be determined by or derived from the equation

\[ x = A \cos(\omega t + \phi) \].

i. The acceleration of an object exhibiting SHM is related to the object’s angular frequency and position.

Derived equation:

\[ a = -\omega^2 x \]

continued on next page
LEARNING OBJECTIVE

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

ESSENTIAL KNOWLEDGE

ii. It can be shown that the maximum velocity and acceleration of an object exhibiting SHM are related to the angular frequency of the object’s motion.

Derived equations:

\[ v_{\text{max}} = A\omega \]
\[ a_{\text{max}} = A\omega^2 \]

7.3.A.4
In the presence of a sinusoidal external force, a system may exhibit resonance.

i. Resonance occurs when an external force is exerted at the natural frequency of an oscillating system.

ii. Resonance increases the amplitude of oscillating motion.

iii. The natural frequency of a system is the frequency at which the system will oscillate when it is displaced from its equilibrium position.

7.3.A.5
Changing the amplitude of a system exhibiting SHM will not change its period.

7.3.A.6
Properties of SHM can be determined and analyzed using graphical representations.

BOUNDARY STATEMENT:

AP Physics C: Mechanics only expects students to know the solution to the second-order differential equation that describes SHM, as well as be able to identify SHM. AP Physics C: Mechanics does not expect students to mathematically prove that the solution is correct.
TOPIC 7.4
Energy of Simple Harmonic Oscillators

Required Course Content

LEARNING OBJECTIVE

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

ESSENTIAL KNOWLEDGE

7.4.A.1
The total energy of a system exhibiting SHM is the sum of the system’s kinetic and potential energies.

Relevant equation:

\[ E_{\text{total}} = U + K \]

7.4.A.2
Conservation of energy indicates that the total energy of a system exhibiting SHM is constant.

7.4.A.3
The kinetic energy of a system exhibiting SHM is at a maximum when the system's potential energy is at a minimum.

7.4.A.4
The potential energy of a system exhibiting SHM is at a maximum when the system's kinetic energy is at a minimum.

i. The minimum kinetic energy of a system exhibiting SHM is zero.

ii. Changing the amplitude of a system exhibiting SHM will change the maximum potential energy of the system and, therefore, the total energy of the system.

Relevant equation for a spring–object system:

\[ E_{\text{total}} = \frac{1}{2} kA^2 \]
TOPIC 7.5
Simple and Physical Pendulums

Required Course Content

**LEARNING OBJECTIVE**

7.5.A
Describe the properties of a physical pendulum.

**ESSENTIAL KNOWLEDGE**

7.5.A.1
A physical pendulum is a rigid body that undergoes oscillation about a fixed axis.

7.5.A.2
For small amplitudes of motion, the period of a physical pendulum is derived from the application of Newton's second law in rotational form.

*Relevant equation:*

\[ T_{phys} = 2\pi \sqrt{\frac{I}{mgd}} \]

i. When displaced from equilibrium, the gravitational force exerted on a physical pendulum's center of mass provides a restoring torque.

*Derived equation:*

\[ \tau = -mgd \sin \theta \]

ii. For small amplitudes of motion, the small-angle approximation can be applied to the restoring torque.

*Derived equation:*

\[ \sin \theta = \theta \]

\[ \tau = -mgd\theta = l\alpha \]

iii. The small-angle approximation and Newton's second law in rotational form yield a second-order differential equation that describes SHM:

\[ \frac{d^2\theta}{dt^2} = -\omega^2 \theta \]

continued on next page
LEARNING OBJECTIVE

7.5.A
Describe the properties of a physical pendulum.

ESSENTIAL KNOWLEDGE

7.5.A.3
A simple pendulum is a special case of physical pendulums in which the hanging object can be modeled as a point mass at a distance, $l$, from the pivot point. 

Relevant equation:

$$T_p = 2\pi \sqrt{\frac{l}{g}}$$

7.5.A.4
A torsion pendulum is a case of SHM where the restoring torque is proportional to the angular displacement of a rotating system. For example, a horizontal disk that is suspended from a wire attached to its center of mass may undergo rotational oscillations about the wire in the horizontal plane.

Derived equation:

$$I\alpha = -k\Delta\theta$$
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The AP Physics C: Mechanics exam assesses student application of the science practices and understanding of the learning objectives outlined in the course framework. The exam is 1 hour and 30 minutes long and includes 45–50 multiple-choice questions and 4 free-response questions. A four-function scientific or graphing calculator is allowed on both sections of the exam. The details of the exam, including exam weighting and timing, can be found below:

<table>
<thead>
<tr>
<th>Section</th>
<th>Type of Questions</th>
<th>Weighting</th>
<th>Timing</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>Multiple-Choice Questions</td>
<td>50%</td>
<td>90 minutes</td>
</tr>
<tr>
<td>II</td>
<td>Free-response questions</td>
<td>50%</td>
<td>90 minutes</td>
</tr>
</tbody>
</table>

Question 1: Mathematical Routines
Question 2: Translation Between Representations
Question 3: Experimental Design
Question 4: Qualitative/Quantitative Translation

The exam also assesses each of the seven units of instruction with the following exam weightings on the multiple-choice section of the AP exam:
### Exam Weighting for the Multiple-Choice Section of the AP Exam

<table>
<thead>
<tr>
<th>Unit of Instruction</th>
<th>Weighting</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Unit 1:</strong> Kinematics</td>
<td>10–14%</td>
</tr>
<tr>
<td><strong>Unit 2:</strong> Force and Translational Dynamics</td>
<td>20–24%</td>
</tr>
<tr>
<td><strong>Unit 3:</strong> Work, Energy and Power</td>
<td>18–22%</td>
</tr>
<tr>
<td><strong>Unit 4:</strong> Linear Momentum</td>
<td>14–18%</td>
</tr>
<tr>
<td><strong>Unit 5:</strong> Torque and Rotational Dynamics</td>
<td>10–14%</td>
</tr>
<tr>
<td><strong>Unit 6:</strong> Energy and Momentum of Rotating Systems</td>
<td>10–14%</td>
</tr>
<tr>
<td><strong>Unit 7:</strong> Gravitation</td>
<td>10–14%</td>
</tr>
</tbody>
</table>
# How Student Learning is Assessed on the AP Exam

## Exam Weighting by Science Practice

Science Practices 2 and 3 are assessed in the multiple-choice section with the following weighting (Science Practice 1 will not be assessed in the multiple-choice section). Science Practices 1, 2 and 3 are all assessed in the free-response section with the following weighting.

Please note: Required course content (Learning Objectives and Essential Knowledge) can be assessed with any skill.

<table>
<thead>
<tr>
<th>Science Practice</th>
<th>Approximate MCQ Exam Weighting</th>
<th>Approximate FR Exam Weighting</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1.A</strong></td>
<td>Create diagrams, tables, charts, or schematics to represent physical situations.</td>
<td>N/A</td>
</tr>
<tr>
<td><strong>1.B</strong></td>
<td>Create quantitative graphs with appropriate scales and units, including plotting data.</td>
<td>N/A</td>
</tr>
<tr>
<td><strong>1.C</strong></td>
<td>Create qualitative sketches of graphs that represent features of a model or the behavior of a physical system.</td>
<td>N/A</td>
</tr>
<tr>
<td><strong>2.A</strong></td>
<td>Derive a symbolic expression from known quantities by selecting and following a logical mathematical pathway.</td>
<td>N/A</td>
</tr>
<tr>
<td><strong>2.B</strong></td>
<td>Calculate or estimate an unknown quantity with units from known quantities, by selecting and following a logical computational pathway.</td>
<td>N/A</td>
</tr>
<tr>
<td><strong>2.C</strong></td>
<td>Compare physical quantities between two or more scenarios or at different times and locations in a single scenario.</td>
<td>70–80%</td>
</tr>
<tr>
<td><strong>2.D</strong></td>
<td>Predict new values or factors of change of physical quantities using functional dependence between variables.</td>
<td>70–80%</td>
</tr>
</tbody>
</table>
Free-Response Questions

The free-response section of the Physics C: Mechanics Exam consists of four question types listed below in the order they will appear on the exam.

### Mathematical Routines (MR)


The Mathematical Routines (MR) question assesses students' ability to use mathematics to analyze a scenario and make predictions about that scenario. Students will be expected to symbolically derive relationships between variables, as well as calculate numerical values. Students will be expected to create and use representations that describe the scenario, either to help guide the mathematical analysis (such as drawing a free-body diagram) or that are applicable to the scenario (such as sketching velocity as a function of time).

For AP Physics 1 and AP Physics 2, the MR question will ask students to make a claim or prediction about the scenario and use appropriate physics concepts and principles to support and justify that claim. The justification is expected to be a logical and sequential application of physics concepts that demonstrates a student’s ability to connect multiple concepts to each other.

### Translating Between Representations (TBR)


The Translating Between Representations (TBR) question assesses students’ ability to connect different representations of a scenario. Students will be expected to create a visual representation that describes a given scenario. Students will derive equations that are mathematically relevant to the scenario. Students will draw graphs that relate quantities within the scenario. Finally, students will be asked to do any one of the following:

- Justify why their answers to any two of the previous parts do/don’t agree with each other.
- Use their representations, mathematical analysis, or graph to make a prediction about another situation and justify their prediction using that reasoning or analysis.
- Use their representations, mathematical analysis, or graph to make a prediction about how those representations would change if properties of the scenario were altered and justify that claim using consistent reasoning or analysis.
Experimental Design and Analysis (LAB)

Science Practices: 1B 2B 2D 3A 3B 3C

The Experimental Design and Analysis (LAB) question assesses students’ ability to create scientific procedures that can be used with appropriate data analysis techniques to determine the answer to given questions. The LAB question can roughly be divided into two sections: Design and Analysis. In the Design portion of the LAB question, students will be asked to develop a method by which a question about a given physical scenario could be answered. The experimental procedure is expected to be scientifically sound: vary a single parameter, and measure how that change affects a single characteristic. Methods must be able to be performed in a typical high school laboratory. Measurements must be made with realistically obtainable equipment or sensors. Students will be expected to describe a method by which the collected data could be analyzed in order to answer the posed question, by either graphical or comparative analyses.

Students will then be given experimental data collected in order to answer a similar, but not identical, question to what was asked in the Design portion of the question. Students will be asked to use the data provided to create and plot a graph that can be analyzed to determine the answer to the given question. For instance, the slope or intercepts of the line may be used to determine a physical quantity or perhaps the nature of the slope would answer the posed question.

Finally, students will be asked an extension or reflection question about the experiment. For instance, identifying possible sources of experimental error and how that source may have affected the results. Students may be asked what the likely outcome would be if the experiment was modified and to use physics concepts to justify their predictions.

Qualitative/Quantitative Translation (QQT)

Science Practices: 2A 2D 3B 3C

The Qualitative/Quantitative Translation (QQT) question assesses students’ ability to connect the nature of the scenario, the physical laws that govern the scenario, and mathematical representations of that scenario to each other. Students will be asked to make and justify a claim about a given scenario, as well as derive an equation related to that scenario. Finally, students will be asked to do any one of the following:

- Justify why their answers to any of the previous parts do/do not agree with each other.
- Use their representations or mathematical analysis to make a prediction about another situation and justify their prediction using that reasoning or analysis.
- Use their representations and mathematical analysis to make a prediction about how those representations would change if properties of the scenario were altered and justify that claim using consistent reasoning or analysis.

While students may not be directly assessed on their ability to create diagrams or other representations of the system to answer the QQT, those skills may still help students to answer the QQT. For instance, some students may find that drawing a free-body diagram is useful when determining the acceleration of a system. However, the student will earn points for the explanation and conclusions that diagram indicates (or perhaps the derivation that results from the diagram), rather than for creating the diagram itself.
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