AP PHYSICS 1

UNIT 4

Linear Momentum

10–15%
AP EXAM WEIGHTING

~10–15
CLASS PERIODS

Remember to go to **AP Classroom** to assign students the online **Progress Check** for this unit.

Whether assigned as homework or completed in class, the **Progress Check** provides each student with immediate feedback related to this unit's topics and science practices

Progress Check 4

Multiple-choice: ~18 questions
Free-response: 4 questions

- Mathematical Routines
- Translation Between Representations
- Experimental Design and Analysis
- Qualitative/Quantitative Translation

UNIT 4

10–15% AP EXAM WEIGHTING

~10–15 CLASS PERIODS

Linear Momentum

ESSENTIAL QUESTIONS

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

Developing Understanding

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

Building the Science Practices

1.B 2.B 2.D 3.A

Inquiry learning and critical thinking and problem-solving skills are best developed when scientific inquiry experiences are designed and implemented with increasing student involvement. In Unit 4, students can be asked to practice collecting data and determining appropriate experimental procedures to answer scientific questions (**3.A**). For example, students can be asked to analyze a familiar experiment by providing a written explanation of how they would make observations or collect data in the given scenario.

Once students have designed a procedure and have collected data, they can practice analyzing that data (**1.B**, **2.B**, **2.D**) by plotting linearized graphs and using the best fit line to the plotted data to make claims about the physical scenario.

Preparing for the AP Exam

The third free-response question on the AP Physics 1 Exam is the Experimental Design and Analysis (LAB) question. In this question, students will need to justify their selection of the kind of data needed and then design a plan to collect these data. Because students often struggle with knowing where to start when designing an experiment, they will benefit from scaffolded opportunities to determine the data needed to answer a scientific question. In the Experimental Design and Analysis question on the exam, students will also be asked to linearize and analyze data. Practicing designing experiments, performing data analysis, and discussing sources of error throughout the course can help students prepare for and be successful on the Experimental Design and Analysis (LAB) question.

UNIT AT A GLANCE

Topic	Suggested Skills
4.1 Linear Momentum	**1.C** Create qualitative sketches of graphs that represent features of a model or the behavior of a physical system. **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. **3.B** Apply an appropriate law, definition, theoretical relationship, or model to make a claim.
4.2 Change in Momentum and Impulse	**1.B** Create quantitative graphs with appropriate scales and units, including plotting data. **2.A** Derive a symbolic expression from known quantities by selecting and following a logical mathematical pathway. **2.D** Predict new values or factors of change of physical quantities using functional dependence between variables. **3.A** Create experimental procedures that are appropriate for a given scientific question. **3.C** Justify or support a claim using evidence from experimental data, physical representations, or physical principles or laws.
4.3 Conservation of Linear Momentum	**1.A** Create diagrams, tables, charts, or schematics to represent physical situations. **2.A** Derive a symbolic expression from known quantities by selecting and following a logical mathematical pathway. **2.D** Predict new values or factors of change of physical quantities using functional dependence between variables. **3.C** Justify or support a claim using evidence from experimental data, physical representations, or physical principles or laws.
4.4 Elastic and Inelastic Collisions	**1.B** Create quantitative graphs with appropriate scales and units, including plotting data. **2.A** Derive a symbolic expression from known quantities by selecting and following a logical mathematical pathway. **2.C** Compare physical quantities between two or more scenarios or at different times and locations in a single scenario. **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.

Go to **AP Classroom** to assign the **Progress Check** for Unit 4.
Review the results in class to identify and address any student misunderstandings.

SAMPLE INSTRUCTIONAL ACTIVITIES

The sample activities on this page are optional and are offered to provide possible ways to incorporate various instructional approaches in the classroom. Teachers do not need to use these activities or instructional approaches and are free to alter or edit them. The examples below were developed in partnership with teachers from the AP community to share ways that they approach teaching some of the topics in this unit. Please refer to the Instructional Approaches section beginning on p. 153 for more examples of activities and strategies.

Activity	Topic	Sample Activity
1	4.2	**Conflicting Contentions** Ask students to imagine a pitcher throwing a baseball and a catcher catching it and have them debate who exerted more force on the ball (no way to know), who applied greater impulse (same for both), and who did a greater magnitude of net work on the ball (same). Repeat this process for a pitcher throwing the baseball and a batter hitting it back at the same speed.
2	4.2	**Desktop Experiment Task** Connect a spring-loaded lanyard between a cart and a force sensor, with a motion sensor on the other side of the cart. Have students take force and motion versus time data as the lanyard contracts and pulls, accelerating the cart. Show students that impulse applied to the cart equals the cart's change in momentum.
3	4.4	**Construct an Argument** Have students use momentum bar charts to explain why a dart bouncing off a cart makes the cart move faster than the dart sticking to the cart, passing through the cart, or stopping and dropping after colliding with the cart.
4	4.4	**Predict and Explain/Concept-Oriented Demonstration** Have a cart crash into a force sensor set to its highest setting in three different ways: cart sticks to sensor, cart bounces off the sensor on its hard side, and cart bounces off the sensor with its spring side. Have students predict in which case more force is registered and explain why.
5	4.4	**Desktop Experiment Task** Have two carts with different masses collide in a nonstick collision. Record the carts with a phone camera from above, with a meterstick next to the track. Have students use a frame-by-frame review app to determine the cart's initial and final speeds, whether momentum was conserved, and whether the collision was elastic.

SUGGESTED SKILLS

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

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.

3.B
Apply an appropriate law, definition, theoretical relationship, or model to make a claim.

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.

4.1.A.3.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.

4.1.A.3.ii
As only the initial and final states of a collision are analyzed, the object model may be used to analyze collisions.

4.1.A.3.iii
An explosion is a model for an interaction in which forces internal to the system move objects within that system apart.

BOUNDARY STATEMENT
Unless otherwise stated, the general term "momentum" will refer specifically to linear momentum.

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 momentum is equal to the net external force exerted on an object or system.

Relevant equation:

$$\vec{F}_{net} = \frac{\Delta\vec{p}}{\Delta t}$$

4.2.A.2

Impulse is defined as the product of the average force exerted on a system and the time interval during which that force is exerted on the system.

Relevant equation:

$$\vec{J} = \vec{F}_{avg}\Delta t$$

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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SUGGESTED SKILLS

1.B Create quantitative graphs with appropriate scales and units, including plotting data.

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

2.D Predict new values or factors of change of physical quantities using functional dependence between variables.

3.A Create experimental procedures that are appropriate for a given scientific question.

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

LEARNING OBJECTIVE	ESSENTIAL KNOWLEDGE
4.2.B Describe the relationship between the impulse exerted on an object or a system and the change in momentum of the object or system.	**4.2.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 exerted on a system and the system's change in momentum. *Relevant equation:* $\vec{J} = \vec{F}_{avg}\Delta t = \Delta\vec{p}$
	4.2.B.3 Newton's second law of motion is a direct result of the impulse–momentum theorem applied to systems with constant mass. *Relevant equation* $\vec{F}_{net} = \frac{\Delta\vec{p}}{\Delta t} = m\frac{\Delta\vec{v}}{\Delta t} = m\vec{a}$

BOUNDARY STATEMENT

AP Physics 1 does not require students to quantitatively analyze systems in which the mass of the system changes with respect to time.

TOPIC 4.3
Conservation of Linear Momentum

SUGGESTED SKILLS

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

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

2.D
Predict new values or factors of change of physical quantities using functional dependence between variables.

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

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.

4.3.A.1.i
For a collection of objects, the velocity of a system's center of mass can be calculated using the equation

$$\vec{v}_{\text{cm}} = \frac{\sum \vec{p}_i}{\sum m_i} = \frac{\sum m_i \vec{v}_i}{\sum m_i}.$$

4.3.A.1.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.

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LEARNING OBJECTIVE	ESSENTIAL KNOWLEDGE
4.3.A Describe the behavior of a system using conservation of linear momentum.	**4.3.A.3.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. **4.3.A.3.ii** A system may be selected so that the total momentum of that system is constant. **4.3.A.3.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 1 includes a quantitative and qualitative treatment of conservation of momentum in one dimension and a semiquantitative treatment of conservation of momentum in two dimensions. Exam questions involving solution of simultaneous equations are not included in AP Physics 1, but the AP Physics 1 Exam may include questions that assess whether students can set up the equations properly and reason about how changing a given mass, speed, or angle would affect other quantities. AP Physics 2 includes a full treatment of conservation of momentum in two dimensions for problems that include one unknown final velocity.

LEARNING OBJECTIVE	ESSENTIAL KNOWLEDGE
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.

SUGGESTED SKILLS

1.B

Create quantitative graphs with appropriate scales and units, including plotting data.

2.A

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

2.C

Compare physical quantities between two or more scenarios or at different times and locations in a single scenario.

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.