Unit 5 Momentum

Content Area:	**Science**
Course(s):	**AP Physics 1**
Time Period:	**December**
Length:	**8 Blocks**
Status:	**Published**

Enduring Understandings

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

Essential Questions

- How does pushing an object change its momentum?
- How do interactions with other objects or systems change the linear momentum of a system?
- How is the physics definition of momentum different from how momentum is used to describe things in everyday life?
- How does the law of the conservation of momentum govern interactions between objects or systems?
- How can momentum be used to determine fault in car crashes?

- How does a force exerted on an object change the object's momentum?
- How are Newton's second and third laws related to momentum?
- What does it mean for momentum to be conserved?
- How can the outcome of a collision be used to characterize a collision as elastic or inelastic?
- What factors affect the collision of two objects, and how can you determine whether the collision is elastic or inelastic?
- How can changes in momentum be utilized to determine the forces applied to an object?

Content

5.1 Momentum and Impulse

3.D.1: The change in momentum of an object is a vector in the direction of the net force exerted on the object.

Relevant Equation:

$\boldsymbol{p} = m\boldsymbol{v}$

3.D.2: The change in momentum of an object occurs over a time interval.

- a. The force that one object exerts on a second object changes the momentum of the second object (in the absence of other forces on the second object).

- b. The change in momentum of that object depends on the impulse, which is the product of the average force and the time interval during which the interaction occurred.

Relevant Equation:

$\boldsymbol{p} = m\boldsymbol{v}$

5.2 Representations of Changes in Momentum

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

Relevant Equation:

$\boldsymbol{p} = m\boldsymbol{v}$

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

- a. The units for momentum are the same as the units of the area under the curve of a force versus time graph.
- b. The change in linear momentum and force are both vectors in the same direction.

Relevant Equations:

$\boldsymbol{p} = m\boldsymbol{v}$

$\Delta\boldsymbol{p} = \boldsymbol{F}\Delta t$

5.3 Open and Closed Systems: Momentum

5.A.2: For all systems under all circumstances, energy, charge, linear momentum, and angular momentum are conserved. For an isolated or a closed system, conserved quantities are constant. An open system is one that exchanges any conserved quantity with its surroundings.

5.4 Conservation of Linear Momentum

5.D.1: In a collision between objects, linear momentum is conserved. In an elastic collision, kinetic energy is the same before and after.

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

Relevant Equations:

$\boldsymbol{p} = m\boldsymbol{v}$

$K = (1/2)mv^2$

5.D.2: In a collision between objects, linear momentum is conserved. In an inelastic collision, kinetic energy is not the same before and after the collision.

- a. In a closed system, the linear momentum is constant throughout the collision.
- b. In a closed system, the kinetic energy after an inelastic collision is different from the kinetic energy before the collision.

  Relevant Equations:

  $\boldsymbol{p} = m\boldsymbol{v}$

  $K = (1/2)mv^2$

5.D.3: The velocity of the center of mass of the system cannot be changed by an interaction within the system. [Physics 1 includes no calculations of centers of mass; the equation is not provided until Physics 2. However, without doing calculations, Physics 1 students are expected to be able to locate the center of mass of highly symmetric mass distributions, such as a uniform rod or cube of uniform density, or two spheres of equal mass.]

- a. The center of mass of a system depends on the masses and positions of the objects in the system. In an isolated system (a system with no external forces), the velocity of the center of mass does not change.
- b. When objects in a system collide, the velocity of the center of mass of the system will not change unless an external force is exerted on the system.
- c. Included in Physics 1 is the idea that, where there is both a heavier and lighter mass, the center of mass is closer to the heavier mass. Only a qualitative understanding of this concept is required.

Vocabulary

- Impulse
- Momentum
- Open System
- Closed System
- Environment
- External Force
- Internal Force
- Law of Conservation of Momentum
- Elastic Collision
- Inelastic Collision
- Perfectly Inelastic Collision
- Angular Momentum

Skills

Enduring Understanding	Topic	Science Practices
3.D	5.1 Momentum and Impulse	• 2.1 The student can justify the selection • 4.1 The student can justify the selection • 4.2 The student can design a plan for col • 5.1 The student can analyze data to iden

		• 6.4 The student can make claims and pre
4.B	5.2 Representations of Changes in Momentum	• 1.4 The student can use representations a • 2.2 The student can apply mathematical • 5.1 The student can analyze data to iden
5.A	5.3 Open and Closed Systems: Momentum	• 6.4 The student can make claims and pre • 7.2 The student can connect concepts in
5.D	5.4 Conservation of Linear Momentum	• 2.1 The student can justify the selection • 2.2 The student can apply mathematical • 3.2 The student can refine scientific ques • 4.1 The student can justify the selection • 4.2 The student can design a plan for col • 4.4 The student can evaluate sources of • 5.1 The student can analyze data to iden • 5.3 The student can evaluate the evidenc • 6.4 The student can make claims and pre • 7.2 The student can connect concepts in

- Learning Objective (3.A.2.1): The student is able to represent forces in diagrams or mathematically using appropriately labeled vectors with magnitude, direction, and units during the analysis of a situation.
- Learning Objective (3.D.1.1): The student is able to justify the selection of data needed to determine the relationship between the direction of the force acting on an object and the change in momentum caused by that force.
- Learning Objective (3.D.2.1): The student is able to justify the selection of routines for the calculation of the relationships between changes in momentum of an object, average force, impulse, and time of interaction.
- Learning Objective (3.D.2.2): The student is able to predict the change in momentum of an object from the average force exerted on the object and the interval of time during which the force is exerted.
- Learning Objective (3.D.2.3): The student is able to analyze data to characterize the change in momentum of an object from the average force exerted on the object and the interval of time during which the force is exerted.
- Learning Objective (3.D.2.4): The student is able to design a plan for collecting data to investigate the relationship between changes in momentum and the average force exerted on an object over time.
- Learning Objective (4.B.1.1): The student is able to calculate the change in linear momentum of a two-object system with constant mass in linear motion from a representation of the system (data, graphs, etc.).
- Learning Objective (4.B.1.2): The student is able to analyze data to find the change in linear momentum for a constant-mass system using the product of the mass and the change in velocity of the center of mass.
- Learning Objective (4.B.2.1): The student is able to apply mathematical routines to calculate the change in momentum of a system by analyzing the average force exerted over a certain time on the system.
- Learning Objective (4.B.2.2): The student is able to perform analysis on data presented as a force-time graph and predict the change in momentum of a system.

- Learning Objective (5.A.2.1): The student is able to define open and closed systems for everyday situations and apply conservation concepts for energy, charge, and linear momentum to those situations.
- Learning Objective (5.D.1.1): The student is able to make qualitative predictions about natural phenomena based on conservation of linear momentum and restoration of kinetic energy in elastic collisions.
- Learning Objective (5.D.1.2): The student is able to apply the principles of conservation of momentum and restoration of kinetic energy to reconcile a situation that appears to be isolated and elastic, but in which data indicate that linear momentum and kinetic energy are not the same after the interaction, by refining a scientific question to identify interactions that have not been considered. Students will be expected to solve qualitatively and/or quantitatively for one-dimensional situations and only qualitatively in two-dimensional situations.
- Learning Objective (5.D.1.3): The student is able to apply mathematical routines appropriately to problems involving elastic collisions in one dimension and justify the selection of those mathematical routines based on conservation of momentum and restoration of kinetic energy.
- Learning Objective (5.D.1.4): The student is able to design an experimental test of an application of the principle of the conservation of linear momentum, predict an outcome of the experiment using the principle, analyze data generated by that experiment whose uncertainties are expressed numerically, and evaluate the match between the prediction and the outcome.
- Learning Objective (5.D.1.5): The student is able to classify a given collision situation as elastic or inelastic, justify the selection of conservation of linear momentum and restoration of kinetic energy as the appropriate principles for analyzing an elastic collision, solve for missing variables, and calculate their values.
- Learning Objective (5.D.2.1): The student is able to qualitatively predict, in terms of linear momentum and kinetic energy, how the outcome of a collision between two objects changes depending on whether the collision is elastic or inelastic.
- Learning Objective (5.D.2.2): The student is able to plan data collection strategies to test the law of conservation of momentum in a two-object collision that is elastic or inelastic and analyze the resulting data graphically.
- Learning Objective (5.D.2.3): The student is able to apply the conservation of linear momentum to a closed system of objects involved in an inelastic collision to predict the change in kinetic energy.
- Learning Objective (5.D.2.4): The student is able to analyze data that verify conservation of momentum in collisions with and without an external friction force.
- Learning Objective (5.D.2.5): The student is able to classify a given collision situation as elastic or inelastic, justify the selection of conservation of linear momentum as the appropriate solution method for an inelastic collision, recognize that there is a common final velocity for the colliding objects in the totally inelastic case, solve for missing variables, and calculate their values.
- Learning Objective (5.D.3.1): The student is able to predict the velocity of the center of mass of a system when there is no interaction outside of the system but there is an interaction within the system (i.e., the student simply recognizes that interactions within a system do not affect the center of mass motion of the system and is able to determine that there is no external force).

Standards

AP: Physics 1 (2021 -2022)

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

- Enduring Understanding 3.D: A force exerted on an object can change the momentum of the object.
  - Learning Objective (3.D.1.1): The student is able to justify the selection of data needed to determine the relationship between the direction of the force acting on an object and the change in momentum caused by that force. [See Science Practice 4.1]
  - Learning Objective (3.D.2.1): The student is able to justify the selection of routines for the calculation of the relationships between changes in momentum of an object, average force, impulse, and time of interaction. [See Science Practice 2.1]
  - Learning Objective (3.D.2.2): The student is able to predict the change in momentum of an object from the average force exerted on the object and the interval of time during which the force is exerted. [See Science Practice 6.4]
  - Learning Objective (3.D.2.3): The student is able to analyze data to characterize the change in momentum of an object from the average force exerted on the object and the interval of time during which the force is exerted. [See Science Practice 5.1]
  - Learning Objective (3.D.2.4): The student is able to design a plan for collecting data to investigate the relationship between changes in momentum and the average force exerted on an object over time. [See Science Practice 4.2]

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

- Enduring Understanding 4.B: Interactions with other objects or systems can change the total linear momentum of a system.
  - Learning Objective (4.B.1.1): The student is able to calculate the change in linear momentum of a two-object system with constant mass in linear motion from a representation of the system (data, graphs, etc.). [See Science Practices 1.4 and 2.2]
  - Learning Objective (4.B.1.2): The student is able to analyze data to find the change in linear momentum for a constant-mass system using the product of the mass and the change in velocity of the center of mass. [See Science Practice 5.1]
  - Learning Objective (4.B.2.1): The student is able to apply mathematical routines to calculate the change in momentum of a system by analyzing the average force exerted over a certain time on the system. [See Science Practice 2.2]
  - Learning Objective (4.B.2.2): The student is able to perform analysis on data presented as a force-time graph and predict the change in momentum of a system. [See Science Practice 5.1]

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

- Enduring Understanding 5.A: Certain quantities are conserved, in the sense that the changes of those quantities in a given system are always equal to the transfer of that quantity to or from the system by all possible interactions with other systems.
  - Learning Objective (5.A.2.1): The student is able to define open and closed systems for everyday situations and apply conservation concepts for energy, charge, and linear momentum to those situations. [See Science Practices 6.4 and 7.2]

- Enduring Understanding 5.D: The linear momentum of a system is conserved.
  - Learning Objective (5.D.1.1): The student is able to make qualitative predictions about natural phenomena based on conservation of linear momentum and restoration of kinetic energy in elastic collisions. [See Science Practices 6.4 and 7.2]
  - Learning Objective (5.D.1.2): The student is able to apply the principles of conservation of momentum and restoration of kinetic energy to reconcile a situation that appears to be isolated and elastic, but in which data indicate that linear momentum and kinetic energy are not the same after the interaction, by refining a scientific question to identify interactions that have not been considered. Students will be expected to solve qualitatively and/or quantitatively for one-dimensional situations and only qualitatively in two-dimensional situations. [See Science Practices 2.2, 3.2, 5.1, and 5.3]
  - Learning Objective (5.D.1.3): The student is able to apply mathematical routines appropriately to problems involving elastic collisions in one dimension and justify the selection of those mathematical routines based on conservation of momentum and restoration of kinetic energy. [See Science Practices 2.1 and 2.2]
  - Learning Objective (5.D.1.4): The student is able to design an experimental test of an application of the principle of the conservation of linear momentum, predict an outcome of the experiment using the principle, analyze data generated by that experiment whose uncertainties are expressed numerically, and evaluate the match between the prediction and the outcome. [See Science Practices 4.2, 5.1, 5.3, and 6.4]

- Learning Objective (5.D.1.5): The student is able to classify a given collision situation as elastic or inelastic, justify the selection of conservation of linear momentum and restoration of kinetic energy as the appropriate principles for analyzing an elastic collision, solve for missing variables, and calculate their values. [See Science Practices 2.1 and 2.2]
- Learning Objective (5.D.2.1): The student is able to qualitatively predict, in terms of linear momentum and kinetic energy, how the outcome of a collision between two objects changes depending on whether the collision is elastic or inelastic. [See Science Practices 6.4 and 7.2]
- Learning Objective (5.D.2.2): The student is able to plan data collection strategies to test the law of conservation of momentum in a two-object collision that is elastic or inelastic and analyze the resulting data graphically. [See Science Practices 4.1, 4.2, and 5.1]
- Learning Objective (5.D.2.3): The student is able to apply the conservation of linear momentum to a closed system of objects involved in an inelastic collision to predict the change in kinetic energy. [See Science Practices 6.4 and 7.2]
- Learning Objective (5.D.2.4): The student is able to analyze data that verify conservation of momentum in collisions with and without an external friction force. [See Science Practices 4.1, 4.2, 4.4, 5.1, and 5.3]
- Learning Objective (5.D.2.5): The student is able to classify a given collision situation as elastic or inelastic, justify the selection of conservation of linear momentum as the appropriate solution method for an inelastic collision, recognize that there is a common final velocity for the colliding objects in the totally inelastic case, solve for missing variables, and calculate their values. [See Science Practices 2.1 and 2.2]
- Learning Objective (5.D.3.1): The student is able to predict the velocity of the center of mass of a system when there is no interaction outside of the system but there is an interaction within the system (i.e., the student simply recognizes that interactions within a system do not affect the center-of-mass motion of the system and is able to determine that there is no external force). [See Science Practice 6.4]

The Standards above were taken from the 2014-2015 curriculum. The left over ones are not in the College Board for Unit 5.

AP: Physics 1 (2014 -15)
AP: AP
Big Idea 3: The interactions of an object with other objects can be described by forces
Enduring Understanding 3.A: All forces share certain common characteristics when considered by observers in inertial reference frames.
Learning Objective (3.A.2.1): The student is able to represent forces in diagrams or mathematically using appropriately labeled vectors with magnitude, direction, and units during the analysis of a situation. [See Science Practice 1.1]

Resources