# **04 Linear Momentum**

Content Area:	Science
Course(s):	AP Physics 1
Time Period:	Semester 1
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### Standards

	Patterns
SCI.HS-PS2-1	Analyze data to support the claim that Newton's second law of motion describes the mathematical relationship among the net force on a macroscopic object, its mass, and its acceleration.
SCI.HS.PS2.A	Forces and Motion
SCI.HS-PS2-3	Apply scientific and engineering ideas to design, evaluate, and refine a device that minimizes the force on a macroscopic object during a collision.
SCI.HS.PS2.A	Forces and Motion
SCI.HS.ETS1.C	Optimizing the Design Solution
	Cause and Effect
	Systems and System Models
	Scale, Proportion, and Quantity
	Using Mathematics and Computational Thinking
	Analyzing and Interpreting Data

## Enduring Understandings

A force exerted on an object can change the momentum of the object.

Interactions with other objects or systems can change the total linear momentum of a system.

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.

The linear momentum of a system is conserved.

#### **Essential Questions**

1. How is the physics definition of momentum different from how momentum is used to describe things in everyday life?

- 2. Can a person on an elevator that breaks loose and falls to the ground avoid harm by jumping at the last second?
- 3. Why will a water balloon break when thrown on the pavement, but not break if caught carefully?
- 4. Why is it important that cars are designed to include crumple zones?

## **Knowledge and Skills**

#### 4.1 Linear Momentum

#### Knowledge

- Linear momentum is defined by the equation  $\vec{p} = m\vec{v}$ .
- Momentum is a vector quantity and has the same direction as the velocity.
- Momentum can be used to analyze collisions and explosions.
  - 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.
  - $\circ\,$  As only the initial and final states of a collision are analyzed, the object model may be used to analyze collisions.
  - An explosion is a model for an interaction in which forces internal to the system move objects within that system apart.

#### Skills

- Create qualitative sketches of graphs that represent features of a model or the behavior of a physical system.
- Calculate or estimate an unknown quantity with units from known quantities, by selecting and following a logical computational pathway
- Apply an appropriate law, definition, theoretical relationship, or model to make a claim.
- Compare physical quantities between two or more scenarios or at different times and locations in a single scenario

#### 4.2 Change in Momentum and Impulse

#### Knowledge

- The rate of change of momentum is equal to the net external force exerted on an object or system.
- 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.
- Impulse is a vector quantity and has the same direction as the net force exerted on the system.
- 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.

- 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.
- Change in momentum is the difference between a system's final momentum and its initial momentum.
- The impulse-momentum theorem relates the impulse exerted on a system and the system's change in momentum
- Newton's second law of motion is a direct result of the impulse-momentum theorem applied to systems with constant mass.

Skills

- Create quantitative graphs with appropriate scales and units, including plotting data.
- Derive a symbolic expression from known quantities by selecting and following a logical mathematical pathway.
- Predict new values or factors of change of physical quantities using functional dependence between variables
- Create experimental procedures that are appropriate for a given scientific question.
- Justify or support a claim using evidence from experimental data, physical representations, or physical principles or laws

## 4.3 Conservation of Linear Momentum

## Knowledge

- A collection of objects with individual momenta can be described as one system with one center-ofmass velocity.
  - $\circ\,$  For a collection of objects, the velocity of a system's center of mass can be calculated using the equation

$$\vec{v}_{cm} = \frac{\sum_{i} \vec{p}_{i}}{\sum m_{i}} = \frac{\sum_{i} (m_{i} \vec{v}_{i})}{\sum m_{i}}$$

- $\circ$  The velocity of a system's center of mass is constant in the absence of a net external force.
- The total momentum of a system is the sum of the momenta of the system's constituent parts.
- 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.
  - 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.
  - $\circ$  A system may be selected so that the total momentum of that system is constant.
  - If the total momentum of a system changes, that change will be equivalent to the impulse exerted on the system.
- Correct application of conservation of momentum can be used to determine the velocity of a system immediately before and immediately after collisions or explosions.
- Momentum is conserved in all interactions.

- If the net external force on the selected system is zero, the total momentum of the system is constant.
- If the net external force on the selected system is nonzero, momentum is transferred between the system and the environment.

Skills

- Create diagrams, tables, charts, or schematics to represent physical situations.
- Derive a symbolic expression from known quantities by selecting and following a logical mathematical pathway.
- Predict new values or factors of change of physical quantities using functional dependence between variables.
- Justify or support a claim using evidence from experimental data, physical representations, or physical principles or laws.

#### 4.4 Elastic and Inelastic Collisions

Knowledge

- 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.
- In an elastic collision, the final kinetic energies of each of the objects within the system may be different from their initial kinetic energies.
- An inelastic collision between objects is one in which the total kinetic energy of the system decreases.
- 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.
- In a perfectly inelastic collision, the objects stick together and move with the same velocity after the collision.

Skills

- Create quantitative graphs with appropriate scales and units, including plotting data.
- Derive a symbolic expression from known quantities by selecting and following a logical mathematical pathway.
- Compare physical quantities between two or more scenarios or at different times and locations in a single scenario.
- Create experimental procedures that are appropriate for a given scientific question
- Apply an appropriate law, definition, theoretical relationship, or model to make a claim.

#### **Transfer Goals**

**Patterns**: Observed patterns in nature guide organization and classification and prompt questions about relationships and causes underlying them.

Cause and Effect: Events have causes, sometimes simple, sometimes multifaceted. Deciphering causal

relationships, and the mechanisms by which they are mediated, is a major activity of science and engineering.

**Scale, Proportion, and Quantity:** In considering phenomena, it is critical to recognize what is relevant at different size, time, and energy scales, and to recognize proportional relationships between different quantities as scales change.

**Systems and System Models**: A system is an organized group of related objects or components; models can be used for understanding and predicting the behavior of systems.

**Energy and Matter**: Tracking energy and matter flows, into, out of, and within systems helps one understand their system's behavior.

**Structure and Function:** The way an object is shaped or structured determines many of its properties and functions.

**Stability and Change**: For both designed and natural systems, conditions that affect stability and factors that control rates of change are critical elements to consider and understand.

#### Assessments

https://docs.google.com/document/d/1wR7bQF-8AQoRrt0g4C3hKja0yjwDjC9\_BiAmONWbTcl/edit?usp=sharing

#### **Modifications**

https://docs.google.com/document/d/1ODqaPP69YkcFiyG72fIT8XsUIe3K1VSG7nxuc4CpCec/edit?usp=shar ing