Introduction: Momentum

Unit: Momentum

Topics covered in this chapter:

This chapter deals with the ability of a moving object (or potential for an object to move) to affect other objects.

- *Linear Momentum* describes a way to represent the movement of an object and what happens when objects collide, and the equations that relate to it.
- *Impulse* describes changes in momentum.
- *Conservation of Linear Momentum* explains and gives examples of the law that total momentum before a collision must equal total momentum after a collision.
- *Angular Momentum* describes momentum and conservation of momentum in rotating systems, and the transfer between linear and angular momentum.

New challenges in this chapter involve keeping track of the same quantity applied to the same object, but at different times.

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This unit is part of *Unit 4: Linear Momentum* and *Unit 6: Energy and Momentum of Rotating Systems* from the 2024 AP® Physics 1 Course and Exam Description.

Standards addressed in this chapter:

NGSS Standards/MA Curriculum Frameworks (2016):

HS-PS2-2. Use mathematical representations to support the claim that the total momentum of a system of objects is conserved when there is no net force on the system.

HS-PS2-3. Apply scientific principles of motion and momentum to design, evaluate, and refine a device that minimizes the force on a macroscopic object during a collision.

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AP® Physics 1 Learning Objectives/Essential Knowledge (2024):

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

4.1.A.1: Linear momentum is defined by the equation $\vec{\boldsymbol{p}} = m\vec{\boldsymbol{v}}$.

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

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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.

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

4.2.A.1: The rate of change of momentum is equal to the net external force exerted on an object or system.

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.

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.

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.

4.2.B.2: The impulse-momentum theorem relates the impulse exerted on a system and the system's change in momentum.

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.

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

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 $\vec{\boldsymbol{v}}_{cm} = \dfrac{\Sigma\,\vec{\boldsymbol{p}}_i}{\Sigma\,m_i} = \dfrac{\Sigma\,m_i\vec{\boldsymbol{v}}_i}{\Sigma\,m_i}$.

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 vector sum of the momenta of the system's constituent parts.

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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.

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.

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.

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.

4.4.A: Describe whether an interaction between objects is elastic or inelastic.

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" (remain) together and move with the same velocity after the collision.

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

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.1.i: The magnitude of the angular momentum of an object about a given point is $\vec{\boldsymbol{L}} = \vec{\boldsymbol{r}} \times \vec{\boldsymbol{p}} = rmv\sin\theta$.

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6.3.A.1.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.

6.3.B.2: Angular impulse has the same direction as the torque exerted on the object or system.

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

6.3.C.1: The magnitude of the change in angular momentum can be described by comparing the magnitudes of the final and initial angular momenta of the object or rigid system: $\Delta L = L - L_o$.

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.

6.3.C.2.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.

6.3.C.2.ii: The rotational form of the impulse-momentum theorem is a direct result of the rotational form of Newton's second law of motion for cases in which rotational inertia is constant: $\tau_{net} = \frac{\Delta L}{\Delta t} = I\frac{\Delta\omega}{\Delta t} = I\alpha$.

6.3.C.3: The net torque exerted on an object 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 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.

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

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 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.

6.4.A.2.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.

6.4.A.2.ii: A system may be selected so that the total angular momentum of that system is constant.

6.4.A.2.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 further from the rotational axis.

6.4.A.2.iv: If the total angular momentum of a system changes, that change will be equivalent to the angular impulse exerted on the system.

6.4.B: Describe how the selection of a system determines whether the angular momentum of that system changes.

6.4.B.1: Angular momentum is conserved in all interactions.

6.4.B.2: If the net external torque exerted on a selected object or rigid system is zero, the total angular momentum of that system is constant.

6.4.B.3: 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.

Skills learned & applied in this chapter:

- Working with more than one instance of the same quantity in a problem.
- Conservation laws (before/after problems).