Physics 2A
Chapter 9: Momentum

"The answers you receive depend upon the questions you ask." – Thomas Kuhn

"Life is a mirror and will reflect back to the thinker what he thinks into it." – Ernest Holmes

"What we see depends mainly on what we look for." – John Lubbock

"Your thoughts are the architects of your destiny." – David O. McKay

Reading: pages 260 – 274; 281

Outline:

⇒ impulse
⇒ momentum and impulse-momentum theorem
    everyday example of applications of the impulse-momentum theorem
    solving impulse and momentum problems
⇒ conservation of momentum
⇒ collisions in one dimension
    elastic and inelastic collisions

Problem Solving

Most calculations of impulse are rather straightforward. Remember that impulse is a vector quantity and you must, for example, use the *x* component of the force to find the *x* component of the impulse. You might also be given sufficient information to calculate the initial and final linear momentum of a particle. Then, use $\vec{F}_{avg}\Delta t = \vec{p}_f - \vec{p}_i = m\vec{v}_f - m\vec{v}_i$ to calculate the impulse.

Many problems of this chapter can be worked using the principle of conservation of linear momentum. If you suspect the principle can be used, first check for external forces: if there are none or if they add to zero, total linear momentum is conserved. Write the momentum at the beginning of some interval in terms of the velocities and masses of the particles involved. Do the same for the momentum at the end of the interval. Equate the two expressions and solve for the unknown quantities.

For collisions between two objects, the total linear momentum is always conserved. Nearly every problem solution begins by writing the equation for conservation of linear momentum. Always use symbols, not numbers, even for given quantities. Make a list of the quantities given in the problem statement and a list of the unknowns. If there is only one unknown, the linear momentum conservation equation can be solved immediately for it.

SUMMARY

The goals of Chapter 9 have been to introduce the ideas of impulse, momentum, and angular momentum and to learn a new problem-solving strategy based on conservation laws.

GENERAL PRINCIPLES

Law of Conservation of Momentum

The total momentum $\vec{P} = \vec{p}_1 + \vec{p}_2 + \cdots$ of an isolated system is a constant. Thus

$$\vec{P}_f = \vec{P}_i$$

Conservation of Angular Momentum

The angular momentum L of a rotating object subject to zero external torque does not change. Thus

$$L_f = L_i$$

This can be written in terms of the moment of inertia and angular velocity as

$$I_f \omega_f = I_i \omega_i$$

Solving Momentum Conservation Problems

PREPARE Choose an isolated system or a system that is isolated during at least part of the problem. Draw a visual overview of the system before and after the interaction.

SOLVE Write the law of conservation of momentum in terms of vector components:

$$(p_{1x})_f + (p_{2x})_f + \cdots = (p_{1x})_i + (p_{2x})_i + \cdots$$

$$(p_{1y})_f + (p_{2y})_f + \cdots = (p_{1y})_i + (p_{2y})_i + \cdots$$

In terms of masses and velocities, this is

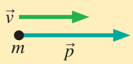
$$m_1(v_{1x})_f + m_2(v_{2x})_f + \cdots = m_1(v_{1x})_i + m_2(v_{2x})_i + \cdots$$

$$m_1(v_{1y})_f + m_2(v_{2y})_f + \cdots = m_1(v_{1y})_i + m_2(v_{2y})_i + \cdots$$

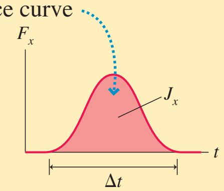
ASSESS Is the result reasonable?

IMPORTANT CONCEPTS

Momentum $\vec{p} = m\vec{v}$



Impulse J_x = area under force curve



Impulse and momentum are related by the **impulse-momentum theorem**

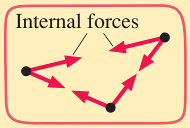
$$\Delta p_x = J_x$$

This is an alternative statement of Newton's second law.

Angular momentum $L = I\omega$ is the rotational analog of linear momentum $\vec{p} = m\vec{v}$.

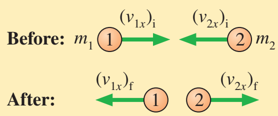
System A group of interacting particles.

Isolated system A system on which the net external force is zero.



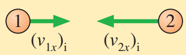
Before-and-after visual overview

- Define the system.
- Use two drawings to show the system *before* and *after* the interaction.
- List known information and identify what you are trying to find.

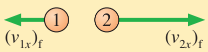


APPLICATIONS

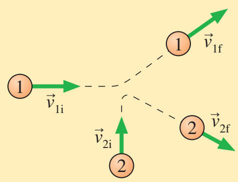
Collisions Two or more particles come together. In a perfectly inelastic collision, they stick together and move with a common final velocity.



Explosions Two or more particles move away from each other.



Two dimensions Both the x- and y-components of the total momentum P must be conserved, giving two simultaneous equations.



Questions and Example Problems from Chapter 9

Question 1
To win a prize at the county fair, you' re trying to knock down a heavy bowling pin by hitting it with a thrown object. Should you choose to throw a rubber ball or a beanbag of equal size and weight? Explain.

Question 2
Two ice skaters, Megan and Jason, push off from each other on frictionless ice. Jason's mass is twice that of Megan. (a) Which skater, if either, experiences the greater impulse during the push? Explain. (b) Which skater, if either, has the greater speed after the push off? Explain.

Question 3
An ice boat is coasting along a frozen lake. Friction between the ice and the boat is negligible, and so is air resistance. Nothing is propelling the boat. From a bridge, someone jumps straight down and lands in the boat, which continues to coast straight ahead. (a) Does the horizontal momentum of the boat change? (b) Does the speed of the boat increase, decrease, or remain the same? Explain your answers.

Question 4
Two particles collide, one of which was initially moving and the other initially at rest.
(a) Is it possible for *both* particles to be at rest after the collision? Give an example in which this happens, or explain why it can't happen. (b) Is it possible for *one* particle to be at rest after the collision? Give an example in which this happens, or explain why it can't happen.

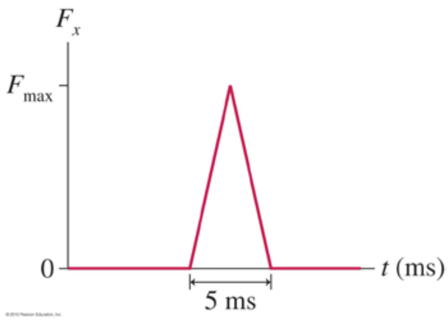
Problem 1

A sled and rider, gliding over horizontal, frictionless ice at 4.0 m/s, have a combined mass of 80.0 kg. The sled then slides over a rough spot in the ice, slowing down to 3.0 m/s. (a) What impulse was delivered to the sled by the friction force from the rough spot? (b) If the sled was in contact with the rough spot is 1.50 s, what was the average force exerted by friction?

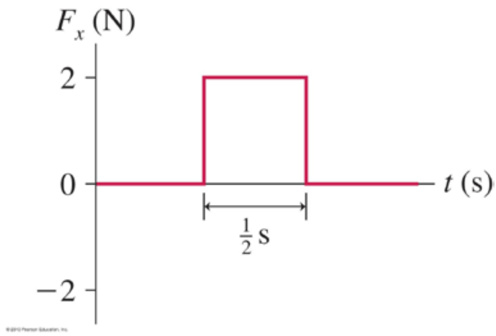
Problem 2

A truck of mass 10^4 kg is initially traveling at 35 m/s when it hits the brakes. If the brakes are applied for 2.0 s, what is the average force required to bring it to rest?

Problem 3
A 200.0 g ball is dropped from a height of 2.00 m, bounces on a hard floor, and rebounds to a height of 1.50 m. The figure below shows the impulse received from the floor. What maximum force does the floor exert on the ball?



Problem 4
A 2.0 kg object is moving to the right with a speed of 1.0 m/s when it experiences the force shown in the figure below. What are the object's speed and direction after the force ends?

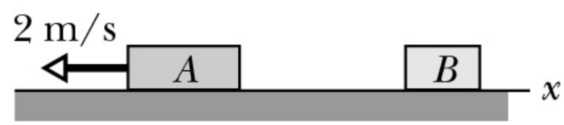


Problem 5

A 0.14 kg baseball moves horizontally with a speed of 35 m/s towards the bat. After striking the bat the ball moves vertically upward with half its initial speed. Find the direction and magnitude of the impulse delivered to the ball by the bat.

Problem 6

A 10 kg block is sliding with a velocity of 5.0 m/s to the right on a frictionless surface when it explodes into two pieces. After the explosion, piece A, with a mass of 7.0 kg, is traveling 2 m/s to the left as shown in the figure below. Find the velocity of piece B assuming that no mass is lost in the explosion.



Problem 7
A 0.150 kg projectile is fired with a velocity of +715 m/s at a 2.00 kg wooden block that rests on a frictionless table. The velocity of the block, immediately after the projectile passes through it, is +40.0 m/s. Find the velocity with which the projectile exits from the block.

Problem 8
A small, 100.0 g cart is moving at 1.20 m/s on an air track when it collides with a larger, 1.00 kg cart at rest. After the collision, the small cart recoils at 0.850 m/s. What is the speed of the large cart after the collision?

Problem 9
A 71 kg baseball player jumps straight up to catch a line drive. If the 140 g ball is moving horizontally at 28 m/s. and the catch is made when the ballplayer is at the highest point of his leap, what is his speed immediately after stopping the ball?

Problem 10
A completely inelastic collision occurs between two balls of wet putty that move directly toward each other along a vertical axis. Just before the collision, one ball, of mass 3.0 kg, is moving upward at 20 m/s and the other ball, of mass 2.0 kg, is moving downward at 12 m/s. How high do the combined two balls of putty rise above the collision point?