CHAPTER 6 Summary

BIG IDEA Momentum is proportional to the mass and velocity of an object. In a closed system, momentum is conserved.

SECTION 1 Momentum and Impulse

- Momentum is a vector quantity defined as the product of an object's mass and velocity.
- A net external force applied constantly to an object for a certain time interval will cause a change in the object's momentum equal to the product of the force and the time interval during which the force acts.
- The product of the constant applied force and the time interval during which the force is applied is called the impulse of the force for the time interval.

KEY TERMS

momentum
impulse

SECTION 2 Conservation of Momentum

- In all interactions between isolated objects, momentum is conserved.
- In every interaction between two isolated objects, the change in momentum of the first object is equal to and opposite the change in momentum of the second object.

SECTION 3 Elastic and Inelastic Collisions

- In a perfectly inelastic collision, two objects stick together and move as one mass after the collision.
- In a perfectly inelastic collision, momentum is conserved, but kinetic energy is not conserved.
- In an inelastic collision, kinetic energy is converted to internal elastic potential energy when the objects deform. Some kinetic energy is also converted to sound energy and internal energy.
- In an elastic collision, two objects return to their original shapes and move away from the collision separately.
- Both momentum and kinetic energy are conserved in an elastic collision.
- Few collisions are elastic or perfectly inelastic.

KEY TERMS

perfectly inelastic collision
elastic collision

VARIABLE SYMBOLS

Quantities		Units
$\mathbf{p}$	momentum	kg•m/s kilogram-meters per second
$\mathbf{F}\Delta t$	impulse	N•s Newton-seconds = kilogram-meters per second

Problem Solving

See **Appendix D: Equations** for a summary of the equations introduced in this chapter. If you need more problem-solving practice, see **Appendix I: Additional Problems.**

CHAPTER 6 Review

Momentum and Impulse

REVIEWING MAIN IDEAS

1. If an object is not moving, what is its momentum?

2. If two particles have equal kinetic energies, must they have the same momentum? Explain.

3. Show that $\mathbf{F} = m\mathbf{a}$ and $\mathbf{F} = \frac{\Delta \mathbf{p}}{\Delta t}$ are equivalent.

CONCEPTUAL QUESTIONS

4. A truck loaded with sand is moving down the highway in a straight path.
   a. What happens to the momentum of the truck if the truck's velocity is increasing?
   b. What happens to the momentum of the truck if sand leaks at a constant rate through a hole in the truck bed while the truck maintains a constant velocity?

5. Gymnasts always perform on padded mats. Use the impulse-momentum theorem to discuss how these mats protect the athletes.

6. When a car collision occurs, an air bag is inflated, protecting the passenger from serious injury. How does the air bag soften the blow? Discuss the physics involved in terms of momentum and impulse.

7. If you jump from a table onto the floor, are you more likely to be hurt if your knees are bent or if your legs are stiff and your knees are locked? Explain.

8. Consider a field of insects, all of which have essentially the same mass.
   a. If the total momentum of the insects is zero, what does this imply about their motion?
   b. If the total kinetic energy of the insects is zero, what does this imply about their motion?

9. Two students hold an open bed sheet loosely by its corners to form a "catching net." The instructor asks a third student to throw an egg into the middle of the sheet as hard as possible. Why doesn't the egg's shell break?

10. How do car bumpers that collapse on impact help protect a driver?

PRACTICE PROBLEMS

For problem 11, see Sample Problem A.

11. Calculate the linear momentum for each of the following cases:
    a. a proton with mass 1.67×10^{-27} kg moving with a velocity of 5.00×10^{6} m/s straight up
    b. a 15.0 g bullet moving with a velocity of 325 m/s to the right
    c. a 75.0 kg sprinter running with a velocity of 10.0 m/s southwest
    d. Earth ($m = 5.98 \times 10^{24}$ kg) moving in its orbit with a velocity equal to 2.98×10^{4} m/s forward

For problems 12–13, see Sample Problem B.

12. A 2.5 kg ball strikes a wall with a velocity of 8.5 m/s to the left. The ball bounces off with a velocity of 7.5 m/s to the right. If the ball is in contact with the wall for 0.25 s, what is the constant force exerted on the ball by the wall? What impulse was delivered to the ball?

13. A football punter accelerates a 0.55 kg football from rest to a speed of 8.0 m/s in 0.25 s. What constant force does the punter exert on the ball? What impulse was delivered to the ball?

For problem 14, see Sample Problem C.

14. A 0.15 kg baseball moving at +26 m/s is slowed to a stop by a catcher who exerts a constant force of −390 N. How long does it take this force to stop the ball? How far does the ball travel before stopping?

Conservation of Momentum

REVIEWING MAIN IDEAS

15. Two skaters initially at rest push against each other so that they move in opposite directions. What is the total momentum of the two skaters when they begin moving? Explain.

16. In a collision between two soccer balls, momentum is conserved. Is momentum conserved for each soccer ball? Explain.

17. Explain how momentum is conserved when a ball bounces against a floor.

CONCEPTUAL QUESTIONS

18. As a ball falls toward Earth, the momentum of the ball increases. How would you reconcile this observation with the law of conservation of momentum?

19. In the early 1900s, Robert Goddard proposed sending a rocket to the moon. Critics took the position that in a vacuum such as exists between Earth and the moon, the gases emitted by the rocket would have nothing to push against to propel the rocket. To settle the debate, Goddard placed a gun in a vacuum and fired a blank cartridge from it. (A blank cartridge fires only the hot gases of the burning gunpowder.) What happened when the gun was fired? Explain your answer.

20. An astronaut carrying a camera in space finds herself drifting away from a space shuttle after her tether becomes unfastened. If she has no propulsion device, what should she do to move back to the shuttle?

21. When a bullet is fired from a gun, what happens to the gun? Explain your answer using the principles of momentum discussed in this chapter.

PRACTICE PROBLEMS

For problems 22–23, see Sample Problem D.

22. A 65.0 kg ice skater moving to the right with a velocity of 2.50 m/s throws a 0.150 kg snowball to the right with a velocity of 32.0 m/s relative to the ground.

  a. What is the velocity of the ice skater after throwing the snowball? Disregard the friction between the skates and the ice.

  b. A second skater initially at rest with a mass of 60.0 kg catches the snowball. What is the velocity of the second skater after catching the snowball in a perfectly inelastic collision?

23. A tennis player places a 55 kg ball machine on a frictionless surface, as shown below. The machine fires a 0.057 kg tennis ball horizontally with a velocity of 36 m/s toward the north. What is the final velocity of the machine?

Elastic and Inelastic Collisions

REVIEWING MAIN IDEAS

24. Consider a perfectly inelastic head-on collision between a small car and a large truck traveling at the same speed. Which vehicle has a greater change in kinetic energy as a result of the collision?

25. Given the masses of two objects and their velocities before and after a head-on collision, how could you determine whether the collision was elastic, inelastic, or perfectly inelastic? Explain.

26. In an elastic collision between two objects, do both objects have the same kinetic energy after the collision as before? Explain.

27. If two objects collide and one is initially at rest, is it possible for both to be at rest after the collision? Is it possible for one to be at rest after the collision? Explain.

PRACTICE PROBLEMS

For problems 28–29, see Sample Problem E.

28. Two carts with masses of 4.0 kg and 3.0 kg move toward each other on a frictionless track with speeds of 5.0 m/s and 4.0 m/s, respectively. The carts stick together after colliding head-on. Find the final speed.

29. A 1.20 kg skateboard is coasting along the pavement at a speed of 5.00 m/s when a 0.800 kg cat drops from a tree vertically downward onto the skateboard. What is the speed of the skateboard-cat combination?

For problems 30–31, see Sample Problem F.

30. A railroad car with a mass of 2.00×10^4 kg moving at 3.00 m/s collides and joins with two railroad cars already joined together, each with the same mass as the single car and initially moving in the same direction at 1.20 m/s.
   a. What is the speed of the three joined cars after the collision?
   b. What is the decrease in kinetic energy during the collision?

31. An 88 kg fullback moving east with a speed of 5.0 m/s is tackled by a 97 kg opponent running west at 3.0 m/s, and the collision is perfectly inelastic. Calculate the following:
   a. the velocity of the players just after the tackle
   b. the decrease in kinetic energy during the collision

For problems 32–34, see Sample Problem G.

32. A 5.0 g coin sliding to the right at 25.0 cm/s makes an elastic head-on collision with a 15.0 g coin that is initially at rest. After the collision, the 5.0 g coin moves to the left at 12.5 cm/s.
   a. Find the final velocity of the other coin.
   b. Find the amount of kinetic energy transferred to the 15.0 g coin.

33. A billiard ball traveling at 4.0 m/s has an elastic head-on collision with a billiard ball of equal mass that is initially at rest. The first ball is at rest after the collision. What is the speed of the second ball after the collision?

34. A 25.0 g marble sliding to the right at 20.0 cm/s overtakes and collides elastically with a 10.0 g marble moving in the same direction at 15.0 cm/s. After the collision, the 10.0 g marble moves to the right at 22.1 cm/s. Find the velocity of the 25.0 g marble after the collision.

Mixed Review

REVIEWING MAIN IDEAS

35. If a 0.147 kg baseball has a momentum of $\mathbf{p} = 6.17$ kg•m/s as it is thrown from home to second base, what is its velocity?

36. A moving object has a kinetic energy of 150 J and a momentum with a magnitude of 30.0 kg•m/s. Determine the mass and speed of the object.

37. A 0.10 kg ball of dough is thrown straight up into the air with an initial speed of 15 m/s.
   a. Find the momentum of the ball of dough at its maximum height.
   b. Find the momentum of the ball of dough halfway to its maximum height on the way up.

38. A 3.00 kg mud ball has a perfectly inelastic collision with a second mud ball that is initially at rest. The composite system moves with a speed equal to one-third the original speed of the 3.00 kg mud ball. What is the mass of the second mud ball?

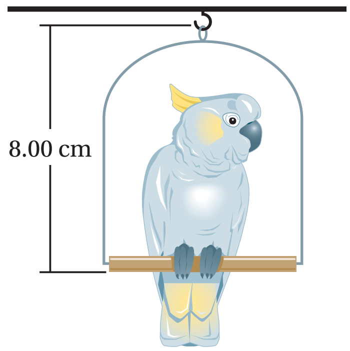
39. A 5.5 g dart is fired into a block of wood with a mass of 22.6 g. The wood block is initially at rest on a 1.5 m tall post. After the collision, the wood block and dart land 2.5 m from the base of the post. Find the initial speed of the dart.

40. A 730 N student stands in the middle of a frozen pond having a radius of 5.0 m. He is unable to get to the other side because of a lack of friction between his shoes and the ice. To overcome this difficulty, he throws his 2.6 kg physics textbook horizontally toward the north shore at a speed of 5.0 m/s. How long does it take him to reach the south shore?

41. A 0.025 kg golf ball moving at 18.0 m/s crashes through the window of a house in 5.0×10^{-4} s. After the crash, the ball continues in the same direction with a speed of 10.0 m/s. Assuming the force exerted on the ball by the window was constant, what was the magnitude of this force? What impulse was delivered to the ball?

42. A 1550 kg car moving south at 10.0 m/s collides with a 2550 kg car moving north. The cars stick together and move as a unit after the collision at a velocity of 5.22 m/s to the north. Find the velocity of the 2550 kg car before the collision.

43. The bird perched on the swing shown in the diagram has a mass of 52.0 g, and the base of the swing has a mass of 153 g. The swing and bird are originally at rest, and then the bird takes off horizontally at 2.00 m/s. How high will the base of the swing rise above its original level? Disregard friction.



44. An 85.0 kg astronaut is working on the engines of a spaceship that is drifting through space with a constant velocity. The astronaut turns away to look at Earth and several seconds later is 30.0 m behind the ship, at rest relative to the spaceship. The only way to return to the ship without a thruster is to throw a wrench directly away from the ship. If the wrench has a mass of 0.500 kg, and the astronaut throws the wrench with a speed of 20.0 m/s, how long does it take the astronaut to reach the ship?

45. A 2250 kg car traveling at 10.0 m/s collides with a 2750 kg car that is initially at rest at a stoplight. The cars stick together and move 2.50 m before friction causes them to stop. Determine the coefficient of kinetic friction between the cars and the road, assuming that the negative acceleration is constant and that all wheels on both cars lock at the time of impact.

46. A constant force of 2.5 N to the right acts on a 1.5 kg mass for 0.50 s.

a. Find the final velocity of the mass if it is initially at rest.

b. Find the final velocity of the mass if it is initially moving along the *x*-axis with a velocity of 2.0 m/s to the left.

47. Two billiard balls with identical masses and sliding in opposite directions have an elastic head-on collision. Before the collision, each ball has a speed of 22 cm/s. Find the speed of each billiard ball immediately after the collision. (See **Appendix A** for hints on solving simultaneous equations.)

GRAPHING CALCULATOR PRACTICE

Momentum

As you learned earlier in this chapter, the linear momentum, **p**, of an object of mass *m* moving with a velocity **v** is defined as the product of the mass and the velocity. A change in momentum requires force and time. This fundamental relationship between force, momentum, and time is shown in Newton's second law of motion.

$$\mathbf{F} = \frac{\Delta \mathbf{p}}{\Delta t}, \text{ where } \Delta \mathbf{p} = m\mathbf{v}_f - m\mathbf{v}_i$$

In this graphing calculator activity, you will determine the force that must be exerted to change the momentum of an object in various time intervals. This activity will help you better understand

- the relationship between time and force
- the consequences of the signs of the force and the velocity

Go online to HMHScience.com to find the skillsheet and program for this graphing calculator activity.

48. A 7.50 kg laundry bag is dropped from rest at an initial height of 3.00 m.

a. What is the speed of Earth toward the bag just before the bag hits the ground? Use the value 5.98×10^{24} kg as the mass of Earth.

b. Use your answer to part **(a)** to justify disregarding the motion of Earth when dealing with the motion of objects on Earth.

49. A 55 kg pole-vaulter falls from rest from a height of 5.0 m onto a foam-rubber pad. The pole-vaulter comes to rest 0.30 s after landing on the pad.

a. Calculate the athlete's velocity just before reaching the pad.

b. Calculate the constant force exerted on the pole-vaulter due to the collision.

50. An unstable nucleus with a mass of 17.0×10^{-27} kg initially at rest disintegrates into three particles. One of the particles, of mass 5.0×10^{-27} kg, moves along the positive *y*-axis with a speed of 6.0×10^{6} m/s. Another particle, of mass 8.4×10^{-27} kg, moves along the positive *x*-axis with a speed of 4.0×10^{6} m/s. Determine the third particle's speed and direction of motion. (Assume that mass is conserved.)

ALTERNATIVE ASSESSMENT

1. Design an experiment to test the conservation of momentum. You may use dynamics carts, toy cars, coins, or any other suitable objects. Explore different types of collisions, including perfectly inelastic collisions and elastic collisions. If your teacher approves your plan, perform the experiment. Write a report describing your results.

2. Design an experiment that uses a dynamics cart with other easily found equipment to test whether it is safer to crash into a steel railing or into a container filled with sand. How can you measure the forces applied to the cart as it crashes into the barrier? If your teacher approves your plan, perform the experiment.

3. Obtain a videotape of one of your school's sports teams in action. Create a play-by-play description of a short segment of the videotape, explaining how momentum and kinetic energy change during impacts that take place in the segment.

4. Use your knowledge of impulse and momentum to construct a container that will protect an egg dropped from a two-story building. The container should prevent the egg from breaking when it hits the ground. Do not use a device that reduces air resistance, such as a parachute. Also avoid using any packing materials. Test your container. If the egg breaks, modify your design and then try again.

5. An inventor has asked an Olympic biathlon team to test his new rifles during the target-shooting segment of the event. The new 0.75 kg guns shoot 25.0 g bullets at 615 m/s. The team's coach has hired you to advise him about how these guns could affect the biathletes' accuracy. Prepare figures to justify your answer. Be ready to defend your position.