CHAPTER 4 Summary

BIG IDEA Newton's laws describe the predictable ways in which forces interact to change the motion of objects. Free-body diagrams help depict the multiple forces that are acting on an object.

SECTION 1 Changes in Motion

KEY TERM

force

- Force is a vector quantity that causes acceleration (when unbalanced).
- Force can act either through the physical contact of two objects (contact force) or at a distance (field force).
- A free-body diagram shows only the forces that act on one object. These forces are the only ones that affect the motion of that object.

SECTION 2 Newton's First Law

KEY TERMS

inertia
net force
equilibrium

- The tendency of an object not to accelerate is called *inertia*. Mass is the physical quantity used to measure inertia.
- The net force acting on an object is the vector sum of all external forces acting on the object. An object is in a state of equilibrium when the net force acting on the object is zero.

SECTION 3 Newton's Second and Third Laws

- The net force acting on an object is equal to the product of the object's mass and the object's acceleration.
- When two bodies exert force on each other, the forces are equal in magnitude and opposite in direction. These forces are called an action-reaction pair. Forces always exist in such pairs.

SECTION 4 Everyday Forces

KEY TERMS

weight
normal force
static friction
kinetic friction
coefficient of friction

- The weight of an object is the magnitude of the gravitational force on the object and is equal to the object's mass times the acceleration due to gravity.
- A normal force is a force that acts on an object in a direction perpendicular to the surface of contact.
- Friction is a resistive force that acts in a direction opposite to the direction of the relative motion of two contacting surfaces. The force of friction between two surfaces is proportional to the normal force.

VARIABLE SYMBOLS

Quantities	Units	Conversions
F (vector) force	N newtons	$= kg \bullet m/s^2$
F (scalar) force	N newtons	$= kg \bullet m/s^2$
μ coefficient of friction	(no units)	

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.**

Forces and Newton's First Law

REVIEWING MAIN IDEAS

1. Is it possible for an object to be in motion if no net force is acting on it? Explain.

2. If an object is at rest, can we conclude that no external forces are acting on it?

3. An object thrown into the air stops at the highest point in its path. Is it in equilibrium at this point? Explain.

4. What physical quantity is a measure of the amount of inertia an object has?

CONCEPTUAL QUESTIONS

5. A beach ball is left in the bed of a pickup truck. Describe what happens to the ball when the truck accelerates forward.

6. A large crate is placed on the bed of a truck but is not tied down.
   a. As the truck accelerates forward, the crate slides across the bed until it hits the tailgate. Explain what causes this.
   b. If the driver slammed on the brakes, what could happen to the crate?

PRACTICE PROBLEMS

For problems 7–9, see Sample Problem A.

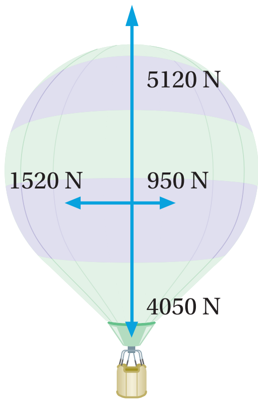
7. Earth exerts a downward gravitational force of 8.9 N on a cake that is resting on a plate. The plate exerts a force of 11.0 N upward on the cake, and a knife exerts a downward force of 2.1 N on the cake. Draw a free-body diagram of the cake.

8. A chair is pushed forward with a force of 185 N. The gravitational force of Earth on the chair is 155 N downward, and the floor exerts a force of 155 N upward on the chair. Draw a free-body diagram showing the forces acting on the chair.

9. Draw a free-body diagram representing each of the following objects:
   a. a ball falling in the presence of air resistance
   b. a helicopter lifting off a landing pad
   c. an athlete running along a horizontal track

For problems 10–12, see Sample Problem B.

10. Four forces act on a hot-air balloon, shown from the side in the figure below. Find the magnitude and direction of the resultant force on the balloon.



11. Two lifeguards pull on ropes attached to a raft. If they pull in the same direction, the raft experiences a net force of 334 N to the right. If they pull in opposite directions, the raft experiences a net force of 106 N to the left.
    a. Draw a free-body diagram representing the raft for each situation.
    b. Find the force exerted by each lifeguard on the raft for each situation. (Disregard any other forces acting on the raft.)

12. A dog pulls on a pillow with a force of 5 N at an angle of 37° above the horizontal. Find the x- and y-components of this force.

Newton's Second and Third Laws

REVIEWING MAIN IDEAS

13. The force that attracts Earth to an object is equal to and opposite the force that Earth exerts on the object. Explain why Earth's acceleration is not equal to and opposite the object's acceleration.

14. State Newton's second law ($\Sigma\mathbf{F} = m\mathbf{a}$) in your own words, and interpret the law to predict how the acceleration of an object changes if the net force on the object decreases by half.

15. An astronaut on the moon has a 110 kg crate and a 230 kg crate. How do the forces required to lift the crates straight up on the moon compare with the forces required to lift them on Earth? (Assume that the astronaut lifts with constant velocity in both cases.)

16. Draw a force diagram to identify all the action-reaction pairs that exist for a horse pulling a cart.

CONCEPTUAL QUESTIONS

17. A space explorer is moving through space far from any planet or star and notices a large rock, taken as a specimen from an alien planet, floating around the cabin of the ship. Should the explorer push it gently or kick it toward the storage compartment? Why?

18. Explain why a rope climber must pull downward on the rope in order to move upward. Discuss the force exerted by the climber's arms in relation to the weight of the climber during the various stages of each "step" up the rope.

19. An 1850 kg car is moving to the right at a constant speed of 1.44 m/s.
a. What is the net force on the car?
b. What would be the net force on the car if it were moving to the left?

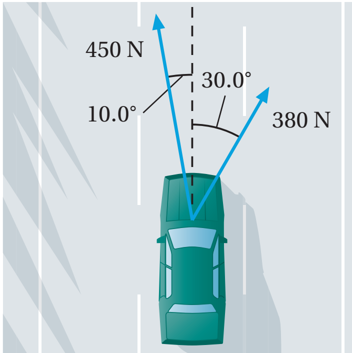
PRACTICE PROBLEMS

For problems 20–22, see Sample Problem C.

20. What acceleration will you give to a 24.3 kg box if you push it horizontally with a net force of 85.5 N?

21. What net force is required to give a 25 kg suitcase an acceleration of 2.2 m/s^2 to the right?

22. Two forces are applied to a car in an effort to accelerate it, as shown below.
a. What is the resultant of these two forces?
b. If the car has a mass of 3200 kg, what acceleration does it have? (Disregard friction.)



Weight, Friction, and Normal Force

REVIEWING MAIN IDEAS

23. Explain the relationship between mass and weight.

24. A 0.150 kg baseball is thrown upward with an initial speed of 20.0 m/s.
a. What is the force on the ball when it reaches half of its maximum height? (Disregard air resistance.)
b. What is the force on the ball when it reaches its peak?

25. Draw free-body diagrams showing the weight and normal forces on a laundry basket in each of the following situations:
a. at rest on a horizontal surface
b. at rest on a ramp inclined 12° above the horizontal
c. at rest on a ramp inclined 25° above the horizontal
d. at rest on a ramp inclined 45° above the horizontal

26. If the basket in item 25 has a mass of 5.5 kg, find the magnitude of the normal force for the situations described in (a) through (d).

27. A teapot is initially at rest on a horizontal tabletop, and then one end of the table is lifted slightly. Does the normal force increase or decrease? Does the force of static friction increase or decrease?

28. Which is usually greater, the maximum force of static friction or the force of kinetic friction?

29. A 5.4 kg bag of groceries is in equilibrium on an incline of angle $\theta = 15°$. Find the magnitude of the normal force on the bag.

CONCEPTUAL QUESTIONS

30. Imagine an astronaut in space at the midpoint between two stars of equal mass. If all other objects are infinitely far away, what is the weight of the astronaut? Explain your answer.

31. A ball is held in a person's hand.
- **a.** Identify all the external forces acting on the ball and the reaction force to each.
- **b.** If the ball is dropped, what force is exerted on it while it is falling? Identify the reaction force in this case. (Disregard air resistance.)

32. Explain why pushing downward on a book as you push it across a table increases the force of friction between the table and the book.

33. Analyze the motion of a rock dropped in water in terms of its speed and acceleration. Assume that a resistive force acting on the rock increases as the speed increases.

34. A skydiver falls through the air. As the speed of the skydiver increases, what happens to the skydiver's acceleration? What is the acceleration when the skydiver reaches terminal speed?

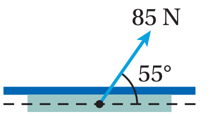
PRACTICE PROBLEMS

For problems 35–37, see Sample Problem D.

35. A 95 kg clock initially at rest on a horizontal floor requires a 650 N horizontal force to set it in motion. After the clock is in motion, a horizontal force of 560 N keeps it moving with a constant velocity. Find μ_s and μ_k between the clock and the floor.

36. A box slides down a 30.0° ramp with an acceleration of 1.20 m/s^2. Determine the coefficient of kinetic friction between the box and the ramp.

37. A 4.00 kg block is pushed along the ceiling with a constant applied force of 85.0 N that acts at an angle of 55.0° with the horizontal, as in the figure. The block accelerates to the right at 6.00 m/s^2. Determine the coefficient of kinetic friction between the block and the ceiling.



For problems 38–39, see Sample Problem E.

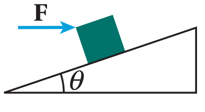
38. A clerk moves a box of cans down an aisle by pulling on a strap attached to the box. The clerk pulls with a force of 185.0 N at an angle of 25.0° with the horizontal. The box has a mass of 35.0 kg, and the coefficient of kinetic friction between box and floor is 0.450. Find the acceleration of the box.

39. A 925 N crate is being pulled across a level floor by a force **F** of 325 N at an angle of 25° above the horizontal. The coefficient of kinetic friction between the crate and floor is 0.25. Find the magnitude of the acceleration of the crate.

Mixed Review

REVIEWING MAIN IDEAS

40. A block with a mass of 6.0 kg is held in equilibrium on an incline of angle $\theta = 30.0°$ by a horizontal force, **F**, as shown in the figure. Find the magnitudes of the normal force on the block and of **F.** (Ignore friction.)



41. A 2.0 kg mass starts from rest and slides down an inclined plane 8.0×10^{-1} m long in 0.50 s. What net force is acting on the mass along the incline?

42. A 2.26 kg book is dropped from a height of 1.5 m.
- **a.** What is its acceleration?
- **b.** What is its weight in newtons?

43. A 5.0 kg bucket of water is raised from a well by a rope. If the upward acceleration of the bucket is $3.0\ m/s^2$, find the force exerted by the rope on the bucket of water.

44. A 3.46 kg briefcase is sitting at rest on a level floor.
a. What is the briefcases's acceleration?
b. What is its weight in newtons?

45. A boat moves through the water with two forces acting on it. One is a 2.10×10^3 N forward push by the motor, and the other is a 1.80×10^3 N resistive force due to the water.
a. What is the acceleration of the 1200 kg boat?
b. If it starts from rest, how far will it move in 12 s?
c. What will its speed be at the end of this time interval?

46. A girl on a sled coasts down a hill. Her speed is 7.0 m/s when she reaches level ground at the bottom. The coefficient of kinetic friction between the sled's runners and the hard, icy snow is 0.050, and the girl and sled together weigh 645 N. How far does the sled travel on the level ground before coming to rest?

47. A box of books weighing 319 N is shoved across the floor by a force of 485 N exerted downward at an angle of 35° below the horizontal.
a. If μ_k between the box and the floor is 0.57, how long does it take to move the box 4.00 m, starting from rest?
b. If μ_k between the box and the floor is 0.75, how long does it take to move the box 4.00 m, starting from rest?

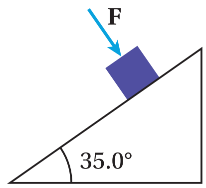
48. A 3.00 kg block starts from rest at the top of a 30.0° incline and accelerates uniformly down the incline, moving 2.00 m in 1.50 s.
a. Find the magnitude of the acceleration of the block.
b. Find the coefficient of kinetic friction between the block and the incline.
c. Find the magnitude of the frictional force acting on the block.
d. Find the speed of the block after it has slid a distance of 2.00 m.

49. A hockey puck is hit on a frozen lake and starts moving with a speed of 12.0 m/s. Exactly 5.0 s later, its speed is 6.0 m/s. What is the puck's average acceleration? What is the coefficient of kinetic friction between the puck and the ice?

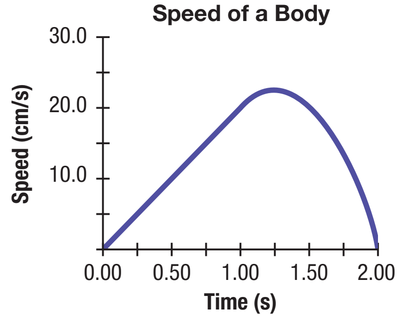
50. The parachute on a racecar that weighs 8820 N opens at the end of a quarter-mile run when the car is traveling 35 m/s. What net retarding force must be supplied by the parachute to stop the car in a distance of 1100 m?

51. A 1250 kg car is pulling a 325 kg trailer. Together, the car and trailer have an acceleration of $2.15\ m/s^2$ directly forward.
a. Determine the net force on the car.
b. Determine the net force on the trailer.

52. The coefficient of static friction between the 3.00 kg crate and the 35.0° incline shown here is 0.300. What is the magnitude of the minimum force, *F*, that must be applied to the crate perpendicularly to the incline to prevent the crate from sliding down the incline?



53. The graph below shows a plot of the speed of a person's body during a chin-up. All motion is vertical, and the mass of the person (excluding the arms) is 64.0 kg. Find the magnitude of the net force exerted on the body at 0.50 s intervals.



54. A machine in an ice factory is capable of exerting 3.00×10^2 N of force to pull a large block of ice up a slope. The block weighs 1.22×10^4 N. Assuming there is no friction, what is the maximum angle that the slope can make with the horizontal if the machine is to be able to complete the task?

ALTERNATIVE ASSESSMENT

1. Predict what will happen in the following test of the laws of motion. You and a partner face each other, each holding a bathroom scale. Place the scales back to back, and slowly begin pushing on them. Record the measurements of both scales at the same time. Perform the experiment. Which of Newton's laws have you verified?

2. Research how the work of scientists Antoine Lavoisier, Isaac Newton, and Albert Einstein related to the study of mass. Which of these scientists might have said the following?
   a. The mass of a body is a measure of the quantity of matter in the body.
   b. The mass of a body is the body's resistance to a change in motion.
   c. The mass of a body depends on the body's velocity.

   To what extent are these statements compatible or contradictory? Present your findings to the class for review and discussion.

3. Imagine an airplane with a series of special instruments anchored to its walls: a pendulum, a 100 kg mass on a spring balance, and a sealed half-full aquarium. What will happen to each instrument when the plane takes off, makes turns, slows down, lands, and so on? If possible, test your predictions by simulating airplane motion in elevators, car rides, and other situations. Use instruments similar to those described above, and also observe your body sensations. Write a report comparing your predictions with your experiences.

4. With a small group, determine which of the following statements is correct. Use a diagram to explain your answer.
   a. Rockets cannot travel in space because there is nothing for the gas exiting the rocket to push against.
   b. Rockets can travel because gas exerts an unbalanced force on the rocket.
   c. The action and reaction forces are equal and opposite. Therefore, they balance each other, and no movement is possible.

GRAPHING CALCULATOR PRACTICE

Static Friction

The force of static friction depends on two factors: the coefficient of static friction for the two surfaces in contact and the normal force between the two surfaces. The relationship can be represented on a graphing calculator by the following equation:

$$Y_1 = SX$$

Given a value for the coefficient of static friction (S), the graphing calculator can calculate and graph the force of static friction (Y_1) as a function of normal force (X).

In this activity, you will use a graphing calculator program to compare the force of static friction of wood boxes on a wood surface with that of steel boxes on a steel surface.

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