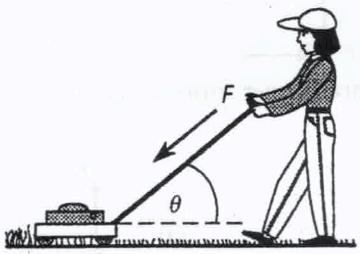
**48.** Three forces with magnitudes of 10. newtons, 8 newtons, and 6 newtons acting concurrently on an object produce equilibrium. The resultant of the 6-newton and 8-newton forces has a magnitude of

(1) 0.0 N
(2) between 0.0 N and 10. N
(3) 10. N
(4) more than 10. N

**49.** What is the total number of components into which a single force can be resolved?

(1) an unlimited number
(2) two components
(3) three components
(4) four components at right angles to each other

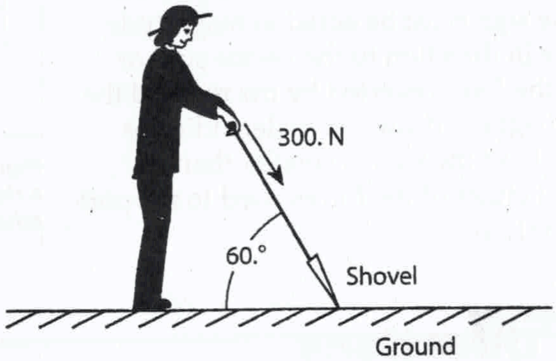
**50.** A lawnmower is pushed with a constant force *F*, as shown in the following diagram.




As angle $\theta$ between the lawnmower handle and the horizontal increases, what happens to the horizontal and vertical components of *F*?

(1) The horizontal component decreases and the vertical component decreases.
(2) The horizontal component decreases and the vertical component increases.
(3) The horizontal component increases and the vertical component decreases.
(4) The horizontal component increases and the vertical component increases.

**51.** The following diagram shows a person exerting a 300.-newton force on the handle of a shovel that makes an angle of 60.° with the horizontal ground.




Calculate the magnitude of the component of the force perpendicular to the ground.

**52.** A vector makes an angle $\theta$ with the horizontal. The horizontal and vertical components of the vector will be equal in magnitude if angle $\theta$ is

(1) 30.° (2) 45° (3) 60.° (4) 90.°

**53.** Which terms represent a vector quantity and the scalar quantity of the vector's magnitude, respectively?

(1) acceleration and velocity
(2) mass and force
(3) speed and time
(4) displacement and distance

**54.** The fundamental units for a force of one newton are

(1) meters / second$^2$
(2) kilograms
(3) meters / second$^2$ / kilogram
(4) kilogram • meters / second$^2$

## Dynamics

The branch of mechanics that deals with how the forces acting on an object affect its motion is called dynamics. The physical laws that govern dynamics were formulated by Isaac Newton.

### Newton's Three Laws of Motion

Recall that when the net force acting on an object is zero, it is said to be in equilibrium. An object in static equilibrium is at rest. An object in dynamic equilibrium moves with a constant velocity, that is, at constant speed in a straight line.

**Newton's First Law** According to Newton's first law, an object maintains a state of equilibrium, remaining at rest or moving with constant velocity, unless acted upon by an unbalanced force. An **unbalanced force** is a nonzero net force acting on an object. According to the first law, an unbalanced force always produces a change in an object's velocity, a vector quantity. This change in velocity produces an acceleration because the object's speed, or direction of motion, or both speed and direction are changing. The inertia of an object is independent of its speed or velocity.

The law of inertia is another name for the first law. **Inertia** is the resistance of an object to a change in its motion. The inertia of an object is directly proportional to its mass. The fundamental SI unit of mass is the **kilogram,** kg. Mass is a scalar quantity.

Inertia can have a devastating effect on a person not wearing a seat belt in a car traveling at high speed. If the car runs off the road and collides with a tree, the force of the collision causes the car to rapidly decelerate. However, the force does not act on the passengers in the car. They continue to move with the same velocity as before the collision, until they are decelerated by colliding with the dashboard or front window. When seat belts are used, the passengers are fastened to the car and decelerate upon impact at the same rate as the car.

**Newton's Second Law** According to Newton's second law, when an unbalanced force acts on an object, the object is accelerated in the same direction as the force. The acceleration is directly proportional to the magnitude of the unbalanced force and inversely proportional to the mass of the object, as shown in this formula.

$$a = \frac{F_{net}}{m}$$

Mass $m$ is in kilograms, acceleration $a$ is in meters per second$^2$, and the net force $F_{net}$ is in newtons. One **newton** is equal to the force that imparts an acceleration of one meter per second$^2$ to a one-kilogram mass. The newton, N, is the derived SI unit of force. One newton equals one kilogram • meter per second$^2$, kg • m/s$^2$.

Simple laboratory experiments can be performed to verify Newton's second law. In one experiment, the net force on a cart originally at rest on a horizontal surface is varied and the resulting acceleration calculated by timing the motion of the cart for some distance. The data is plotted with force as the independent variable on the horizontal axis and acceleration as the dependent variable on the vertical axis. Figure 2-11 shows such a graph.

The slope of the line of best fit is $\frac{\Delta a}{\Delta F}$ and is equal to $\frac{1}{m}$. Therefore, the reciprocal of the slope of the line of best fit is the mass of the object being accelerated. Sometimes the axes are reversed so that the mass of the object can be determined directly from the slope.

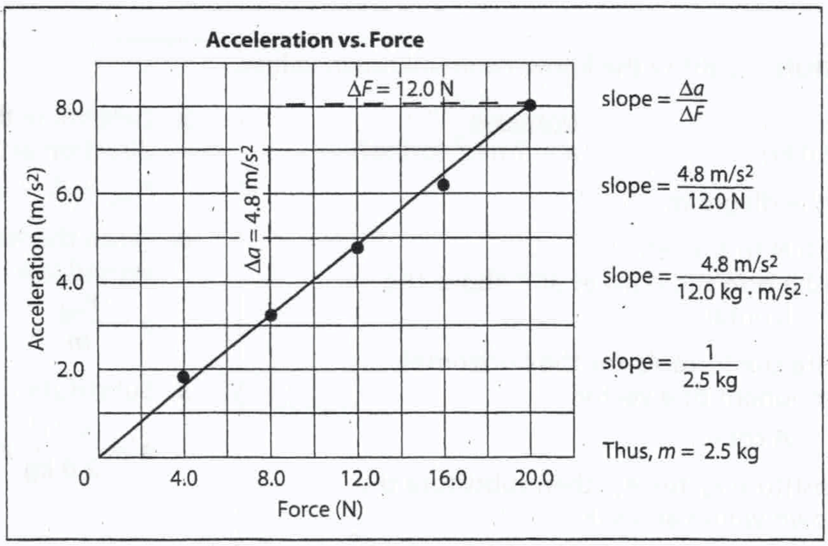



**Figure 2-11. The slope of the line on an acceleration-force graph gives the reciprocal of the mass of the object being accelerated. Note in the calculation that the newton, N, is equivalent to a kilogram · meter per second$^2$.**

**Newton's Third Law** According to Newton's third law, when one object exerts a force on a second object, the second object exerts a force on the first that is equal in magnitude and opposite in direction. The two equal and opposing forces constitute an action/reaction pair. The third law indicates that for every action force there is an equal and opposite reaction force. This means that a single force cannot be generated in nature. When one force is generated, another force of equal magnitude and opposite direction must also be generated.

## SAMPLE PROBLEM

A 10.-newton force gives a mass $m_1$ an acceleration $a$. A 20.-newton force gives another mass $m_2$ the same acceleration $a$. What is the ratio of $m_1$ to $m_2$?

**SOLUTION:** Identify the known and unknown values.

*Known*

$F_1 = 10.\text{ N}$

$F_2 = 20.\text{ N}$

*Unknown*

$\frac{m_1}{m_2} = ?$

**1.** Write the formula that defines acceleration.

$a = \frac{F_{net}}{m}$

**2.** Solve the equation for $m$.

$m = \frac{F_{net}}{a}$

**3.** Substitute the known values for each mass.

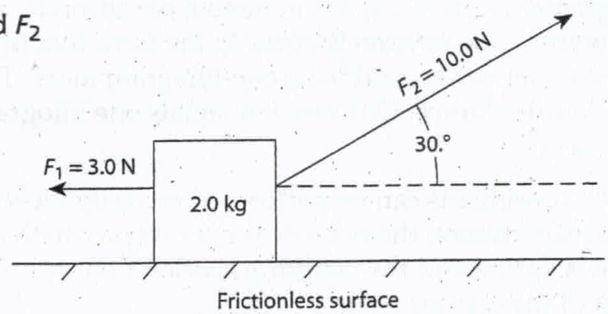
$m_1 = \frac{10.\text{ N}}{a}$ and $m_2 = \frac{20.\text{ N}}{a}$

**4.** Divide the first equation by the second.

$\frac{m_1}{m_2} = \frac{10.\text{ N}/a}{20.\text{ N}/a} = \frac{1}{2}$

## SAMPLE PROBLEM

The diagram at the right shows two forces $F_1$ and $F_2$ applied to a 2.0-kilogram box originally at rest on a horizontal frictionless surface. Calculate the magnitude and direction of the acceleration of the box.




**SOLUTION:** Identify the known and unknown values.

*Known*

$m = 2.0\text{ kg}$

*Unknown*

$a = ?\text{ m/s}^2$ to the?

From the diagram:

$F_1 = 3.0\text{ N}$ to the left

$F_2 = 10.0\text{ N}$ to the right at 30.° above the horizontal

**1.** Write the formula for the horizontal component of a vector.

$A_x = A\cos\theta$

**2.** Substitute $F_{2_x}$ for $A_x$, then substitute the known values and solve.

$F_{2_x} = F_2\cos\theta = (10.0\text{ N})(\cos 30.°) = 8.7\text{ N}$

**3.** Determine the net force in the horizontal direction acting on the box.

$F_{net_x} = F_{1_x} + F_{2_x} = -3.0\text{ N} + 8.7\text{ N} = 5.7\text{ N}$

**4.** Write the formula that defines Newton's second law.

$a = \frac{F_{net}}{m}$

**5.** Substitute the known values and solve.

$a = \frac{5.7\text{ N}}{2.0\text{ kg}} = 2.9\text{ m/s}^2$ to the right

A baseball bat striking a ball is an example of an action-reaction pair. If the bat exerts a 50.-newton force on the baseball, the ball exerts a 50.-newton force on the bat in the opposite direction. Each member of the action/reaction pair of forces acts on a different object; one force acts on the ball and the other on the bat. If no other forces are present, the objects are accelerated in opposite directions as long as the forces are applied.

## Review Questions

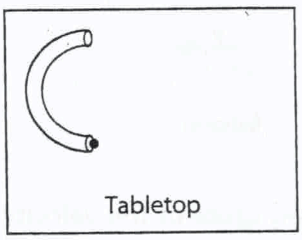
**55.** As the mass of an object on Earth's surface decreases, what happens to the inertia and weight of the object?

(1) Inertia decreases, and weight decreases.
(2) Inertia decreases, and weight remains the same.
(3) Inertia increases, and weight decreases.
(4) Inertia remains the same, and weight remains the same.

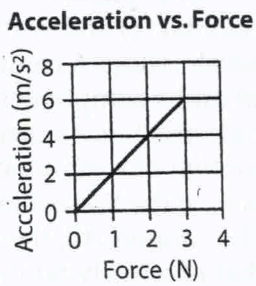
**56.** Compared to the inertia of a 0.10-kilogram steel ball, the inertia of a 0.20-kilogram Styrofoam ball is

(1) one-half as great (3) the same
(2) twice as great (4) four times as great

**57.** A ball rolls through a hollow semicircular tube lying flat on a horizontal tabletop. On the following diagram, draw a line with an arrowhead to represent the path of the ball after emerging from the tube, as viewed from above.




**58.** The following graph shows the relationship between the acceleration of an object and the net force on the object.




What is the mass of the object?

(1) 1 kg (2) 2 kg (3) 0.5 kg (4) 0.2 kg

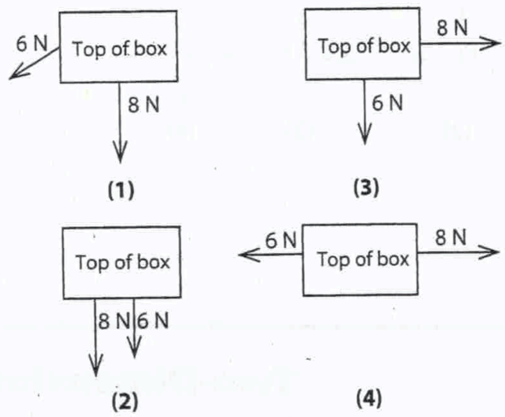
**59.** A cart is uniformly accelerating from rest. The net force acting on the cart is

(1) decreasing (3) constant but not zero
(2) zero (4) increasing

**60.** An 8.0-kilogram block and a 2.0-kilogram block rest on a horizontal frictionless surface. When horizontal force $F$ is applied to the 8.0-kilogram block, it accelerates at 5.0 meters per second$^2$ east. If the same force was applied to the 2.0-kilogram block, the magnitude of the block's acceleration would be

(1) 1.3 m/s$^2$ (3) 10. m/s$^2$
(2) 2.5 m/s$^2$ (4) 20. m/s$^2$

**61.** A 6-newton force and an 8-newton force act concurrently on a box located on a frictionless horizontal surface. Which top-view diagram shows the forces producing the smallest magnitude of acceleration of the box?




**62.** As the vector sum of all the forces acting on a moving object increases, the magnitude of the acceleration of the object

(1) decreases (3) remains the same
(2) increases

**63.** An unbalanced force of 10.0 newtons north acts on a 20.0-kilogram mass for 5.0 seconds. Calculate the acceleration of the mass.

In Figure 2-17 the gravitational field lines are directed radially toward the center of Earth, that is, normal to Earth's surface. The concentration of the field lines increases as Earth's surface is approached. This indicates that gravitational field strength, a vector quantity, increases as the distance from Earth decreases. At any point in a gravitational field, **gravitational field strength,** $g$, equals the force per unit mass at that point. The relationship is expressed by this formula.

$$g = \frac{F_g}{m} \quad \text{(R)}$$

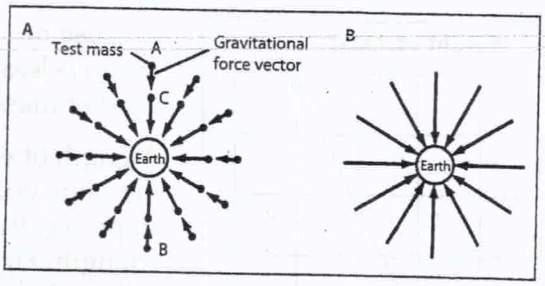



**Figure 2-17. The gravitational field around Earth:** (A) When the test mass is at points *A* or *B*, the magnitude of the gravitational force is the same because both points are the same distance from the center of Earth. At point *C* the gravitational force is greater than at points *A* and *B* because *C* is closer to the center of Earth. (B) The force vectors have been joined to form lines of gravitational force.

On a mass $m$ in kilograms the gravitational force $F_g$ is in newtons, and the gravitational field strength $g$ is in newtons per kilogram, N/kg. Gravitational field strength has the same direction as the gravitational force acting on the mass.

The unit for gravitational field strength is the same as the unit for acceleration. Because 1 newton = 1 kilogram · meter / second², then

$$1\,\frac{\text{newton}}{\text{kilogram}} = 1\,\frac{\cancel{\text{kilogram}} \cdot \text{meter / second}^2}{\cancel{\text{kilogram}}}$$
$$= 1\ \text{meter / second}^2$$

Recall that the acceleration of an object equals the ratio $\frac{F_{net}}{m}$ from the equation $a = \frac{F_{net}}{m}$. Consequently $g$ is the acceleration produced on a mass $m$ by the gravitational force $F_g$. Therefore, the gravitational field strength $g$ is the same as the acceleration due to gravity. For short distances near the surface of Earth, the gravitational field is considered to be uniform and $g$ is the same for all masses:

$$g \text{ (gravitational field strength)} = 9.81\ \text{N/kg}$$
$$g \text{ (acceleration due to gravity)} = 9.81\ \text{m/s}^2$$

Do not confuse $g$ the acceleration due to gravity (9.81 m/s²) with $G$ the universal gravitational constant ($6.67 \times 10^{-11}\ \text{N} \cdot \text{m}^2/\text{kg}^2$).

## Weight

The gravitational force with which a planet attracts a mass is called **weight.** If $M$ is the mass of Earth, $m$ is the mass of an object on Earth's surface, and $r$ is the distance from the center of Earth, it can be seen from Newton's universal law of gravitation that the weight $F_g$ of an object on Earth's surface is directly proportional to its mass $m$ because all the other quantities in the equation are constant. Weight is a vector quantity (force) directed toward the center of a planet that is measured in newtons, whereas mass is a scalar quantity measured in kilograms. The weight of an object decreases with increasing distance from the center of a planet because the gravitational field strength decreases. But the mass of an object is constant because it is independent of its location in any gravitational field.

The weight of an object can be determined by solving the gravitational field strength equation for $F_g$ ($F_g = mg$) and substituting values for the mass and the acceleration due to gravity. The result shows that the weight $F_g$ of a 1.00-kilogram object on Earth's surface is 9.81 newtons. The weight

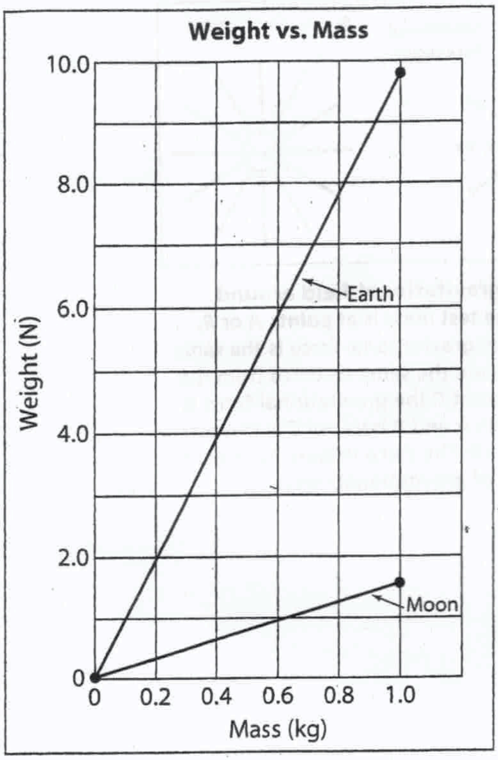



**Figure 2-18. On a weight-mass graph the slope of the line equals the acceleration due to gravity or gravitational field strength.**

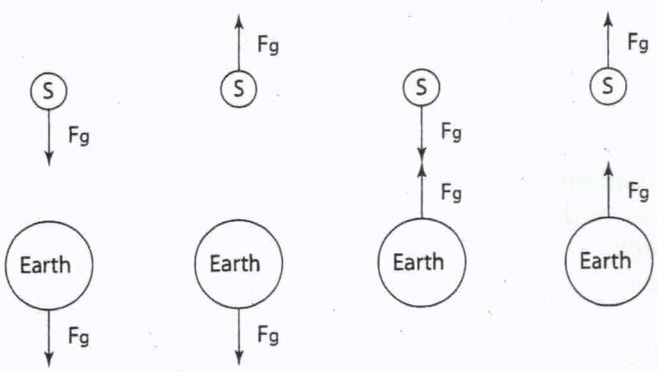
of a 1.00-kilogram object on the Moon is less than 9.81 newtons because the gravitational field strength on the surface of the Moon is less than on Earth. The difference results from the smaller mass of the Moon.

A graph of weight versus mass for a series of objects located at the same point in a gravitational field is a straight line whose slope is $g$, the acceleration due to gravity or gravitational field strength. Figure 2-18 shows the lines produced from data collected on the surface of Earth and the surface of the Moon. The slope of the line for Earth is six times as great as the slope of the line for the Moon.

If a person stands on a scale in an elevator at rest, the scale registers the downward force of the person's weight. The elevator floor exerts an upward force to balance this weight. However, when the elevator starts to rise, it must exert an additional upward force to accelerate the person's mass. By the law of action-reaction, the person's body must exert an equal force downward in addition to its weight. Thus, the scale on an elevator accelerating upward registers an increased total force or weight for a person. When the elevator stops accelerating and rises at constant speed, there is no additional force and the scale reading returns to the person's weight alone. If the elevator were to accelerate downward, the scale would register a force less than the weight of the person at rest.

## Review Questions

**104.** Which diagram best represents the gravitational forces, $F_g$, between a satellite, $S$, and Earth?



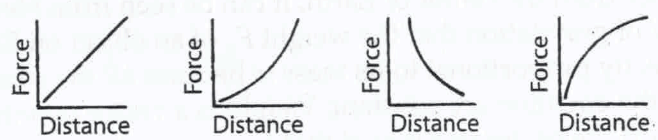

(1) (2) (3) (4)

**105.** When a satellite is a distance $d$ from the center of Earth, the magnitude of the gravitational force that the satellite exerts on Earth is $F$. What is the magnitude of the gravitational force that the satellite exerts on Earth when the satellite's distance from the center of Earth is $3d$?

**106.** The magnitude of the gravitational force that object $A$ exerts on object $B$ is 20. newtons. If the mass of each object is doubled, the magnitude of the gravitational force that $A$ exerts on $B$ is

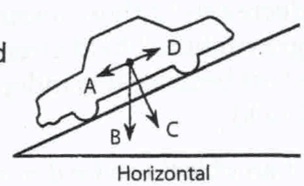
(1) 5.0 N (2) 10. N (3) 20. N (4) 80. N

**107.** Which graph best represents the relationship between the magnitude of the gravitational force that one point mass exerts on another point mass and the distance between them?




(1) (2) (3) (4)

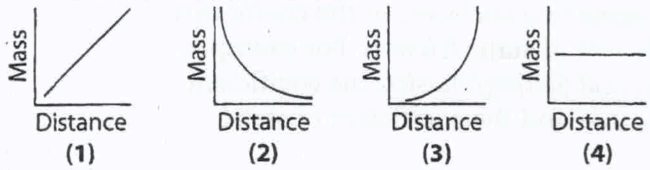
**108.** The following diagram represents a car stopped on a hill.



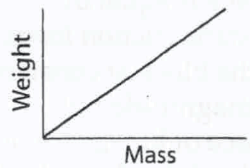

Which vector best represents the weight of the car?

**109.** Calculate the weight of a 5.00-kilogram object at the surface of Earth.

**110.** Which graph best represents the relationship between the mass of an object and its distance from the center of Earth?



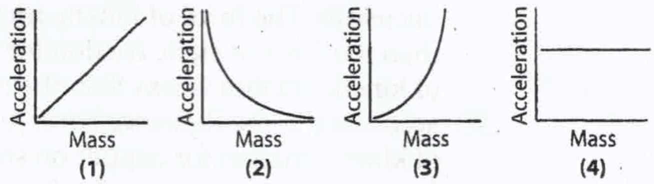

**111.** The following graph shows the relationship between weight and mass for a series of objects.




What is represented by the slope of the graph?

**112.** A 60.-kilogram astronaut weighs 96 newtons on the surface of the Moon. Calculate the acceleration due to gravity on the Moon.

**113.** Which graph best represents the relationship between acceleration due to gravity for objects near the surface of Earth and the mass of the objects? [Neglect friction.]




**114.** As an astronaut travels from the surface of Earth to a position that is four times as far away from the center of Earth, the astronaut's

(1) mass decreases
(2) mass remains the same
(3) weight increases
(4) weight remains the same

**115.** An 800-newton person is standing in an elevator. If the upward force of the elevator on the person is 600 newtons, the person is

(1) at rest
(2) accelerating upward
(3) accelerating downward
(4) moving downward at constant speed

## Friction

The force that opposes the relative motion of two objects in contact is called **friction.** A vector quantity, friction is always parallel to the two surfaces in contact and acts in the direction that opposes the slipping motion. The force of friction, $F_f$, is directly proportional to the magnitude of the normal force, $F_N$. The **normal force** is the force pressing the two contacting surfaces together. On a horizontal surface, the normal force is equal in magnitude and opposite in direction to the weight, $F_g$ or $mg$, of the object resting on the surface. For an object on a surface inclined at an angle $\theta$ to the horizontal, the normal force is equal in magnitude and opposite in direction to the component of the object's weight perpendicular to the inclined surface. That is, on an incline, the magnitude of the normal force $F_N$ is equal to $F_g \cos \theta$ or $mg \cos \theta$. The force of friction, which depends upon the nature of the two surfaces in contact, is given by this formula.

$$F_f = \mu F_N$$

The constant, $\mu$, is the **coefficient of friction,** which is the ratio of the frictional force to the normal force, and thus has no unit.

The formula implies that the frictional force is independent of the area in contact and the speed of motion. For example, a rectangular block of wood, smooth on all sides, has dimensions 4.0 cm × 6.0 cm × 10. cm, and thus, has three different surfaces with areas 24 cm$^2$, 40. cm$^2$, and 60. cm$^2$. If the block slides along a horizontal surface, it makes no difference which face of the block is in contact with the surface because the normal force (the weight of the block) is the same in each case. The magnitude of the frictional force depends only on the weight of the block.

## Static and Kinetic Friction

There are several kinds of friction. **Static friction** is the force that opposes the start of motion, whereas **kinetic friction** is the friction between objects in contact when they are in motion. Once motion starts, kinetic friction decreases. The force of kinetic friction for two surfaces in contact is less than the force of static friction for the same two surfaces, so the coefficient of kinetic friction is less than the coefficient of static friction. For example, according to the *Reference Tables for Physical Setting/Physics*, the coefficient of kinetic friction for copper on steel is 0.36 and the coefficient of static friction for copper on steel is 0.53.

Figure 2-19 shows forces acting concurrently on a 10.0-newton wooden block in equilibrium on a wooden horizontal surface. In each case, the normal force is equal in magnitude and opposite in direction to the weight of the block. In Figure 2-19A, the applied horizontal force is equal in magnitude but opposite in direction to the maximum static friction force. In Figure 2-19B, the horizontal force applied to move the block at constant speed to the right is equal in magnitude but opposite in direction to the force of kinetic friction. When the block is moved to the right at constant speed, the net force acting on the block in the horizontal direction is zero, and the block is in equilibrium.

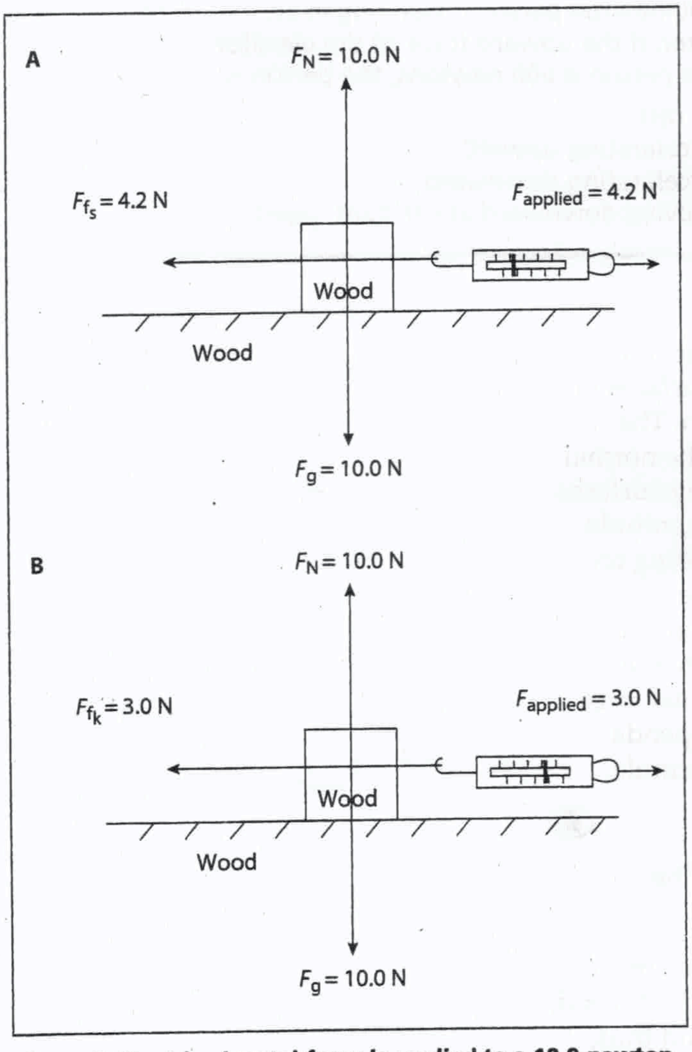



**Figure 2-19. A horizontal force is applied to a 10.0-newton wooden block on a horizontal wooden surface: (A) A maximum static friction force keeps the box from moving. (B) The box moves at constant speed to the right when the applied force equals the force of kinetic friction. Note: The vectors are *not* drawn to scale.**

Using the information in Figure 2-19, the coefficients of static and kinetic friction are

$$\mu_s = \frac{F_{f_s}}{F_N} = \frac{4.2\text{ N}}{10.0\text{ N}} = 0.42$$

and

$$\mu_k = \frac{F_{f_k}}{F_N} = \frac{3.0\text{ N}}{10.0\text{ N}} = 0.30$$

The values agree with those found in the *Reference Tables for Physical Setting/Physics*.

**Determining the Coefficient of Friction** A graph of frictional force versus normal force (weight) for a wooden block in contact with a wooden horizontal surface is a straight line for both static friction and kinetic friction. (Experimentally, the weight of the block can be varied by resting masses on top of it, thus keeping the nature of the two surfaces in contact the same at all times.) The slopes of the lines are the coefficient of static friction and the coefficient of kinetic friction, respectively. Figure 2-20 shows the lines that would result for data collected for a wooden block on a wooden table. The slope of the static friction line is 0.42 and the slope of the kinetic friction line is 0.30.

**Friction on an Inclined Surface** If an object is on a surface inclined at angle $\theta$ to the horizontal, the object's weight can be resolved into two components, one perpendicular to the inclined surface and the other parallel to the surface. The perpendicular component of the object's weight, $F_g \cos\theta$ or $mg \cos\theta$, is equal in magnitude and opposite in direction to the normal force and has no effect on the motion of the object. The object cannot move in the direction of either force. Only the component of the object's weight parallel to the inclined surface $F_g \sin\theta$ or $mg \sin\theta$ tends to accelerate the object down the incline. As the angle that the incline makes with the horizontal increases, the component of the object's weight parallel to the incline increases, and the acceleration of the object down the incline increases. This acceleration is opposed by the friction between the object and the incline. The magnitude of the force of friction is directly proportional the normal force, which is equal in magnitude but opposite in direction to the perpendicular component of the object's weight. Thus, as the angle of inclination increases, the component of the objects's weight perpendicular to the incline decreases, and the magnitude of the frictional force decreases. The steeper the slope of the incline, the greater the acceleration of the object down the incline.

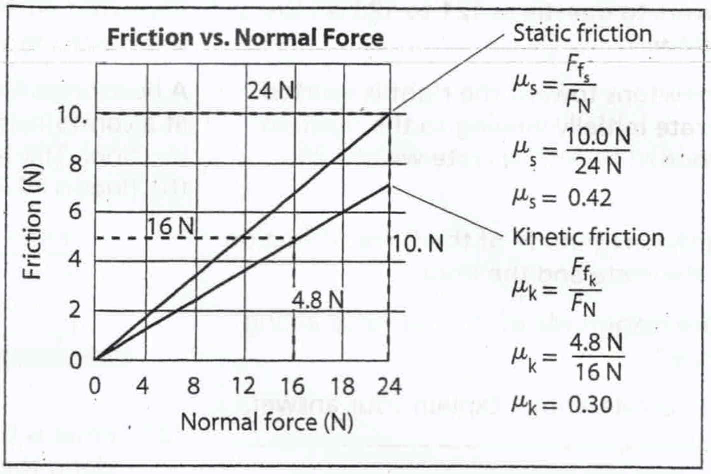



**Figure 2-20. Finding the coefficients of static and kinetic friction by determining the slopes of the lines on a friction-normal force graph**

**Fluid Friction** Fluid friction, which results from an object moving through a fluid such as air depends upon the surface area and the speed of the object moving through the fluid.

## Review Questions

**116.** An empty wooden crate slides across a warehouse floor. If the crate was filled, the coefficient of kinetic friction between the crate and the floor would

(1) decrease (2) increase (3) remain the same

**117.** An empty wooden crate slides across a warehouse floor. If the crate was filled, the magnitude of the force of kinetic friction between the crate and the floor would

(1) decrease (2) increase (3) remain the same

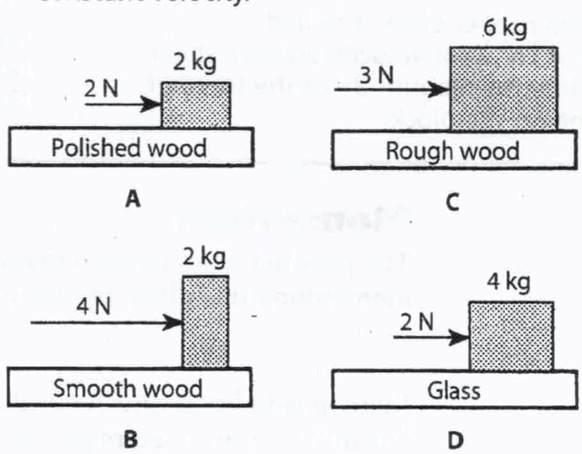
**118.** As an object initially at rest on a horizontal surface is set in motion, the magnitude of the force of friction between the object and the surface

(1) decreases (2) increases (3) remains the same

**119.** As a thrown baseball is acted on by air friction, the thermal energy of the ball

(1) decreases (2) increases (3) remains the same

**120.** Each of the following diagrams shows a different block being pushed to the right by a horizontal force across a horizontal surface at constant velocity.




In which two diagrams is the force of friction the same?