Lecture PowerPoints

Chapter 4

Physics: for Scientists & Engineers, with Modern Physics, 4th edition
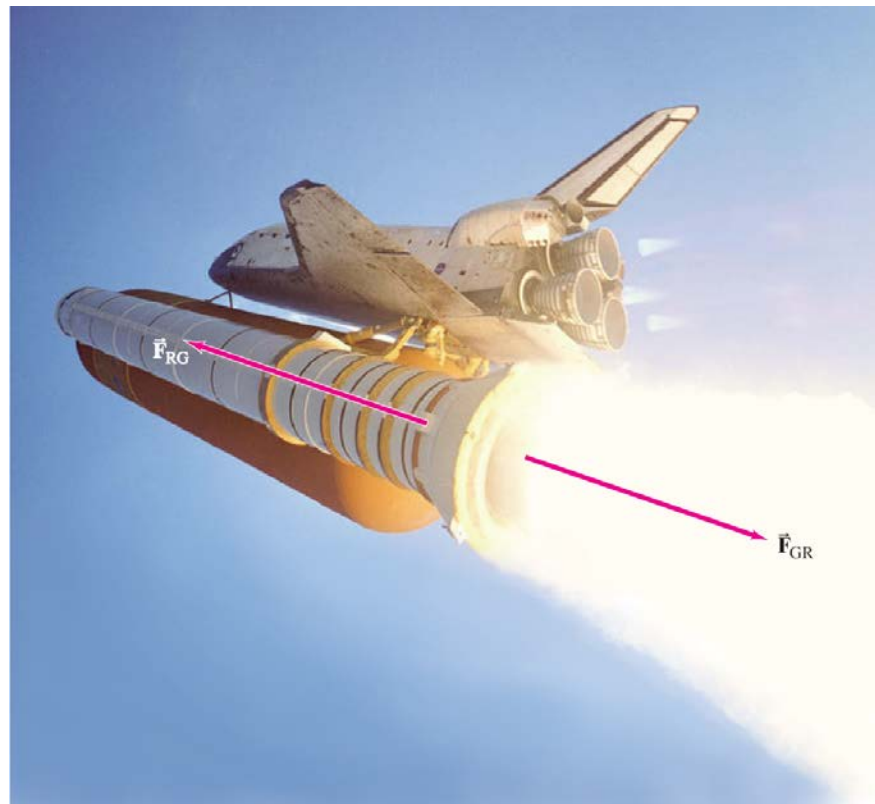
Giancoli

Chapter 4

Dynamics: Newton's Laws of Motion

Units of Chapter 4

- **Force**

- **Newton's First Law of Motion**

- **Mass**

- **Newton's Second Law of Motion**

- **Newton's Third Law of Motion**

- **Weight—the Force of Gravity; and the Normal Force**

- **Solving Problems with Newton's Laws: Free-Body Diagrams**

- **Problem Solving—A General Approach**

4-1 Force

A force is a push or pull. An object at rest needs a force to get it moving; a moving object needs a force to change its velocity.

4-1 Force
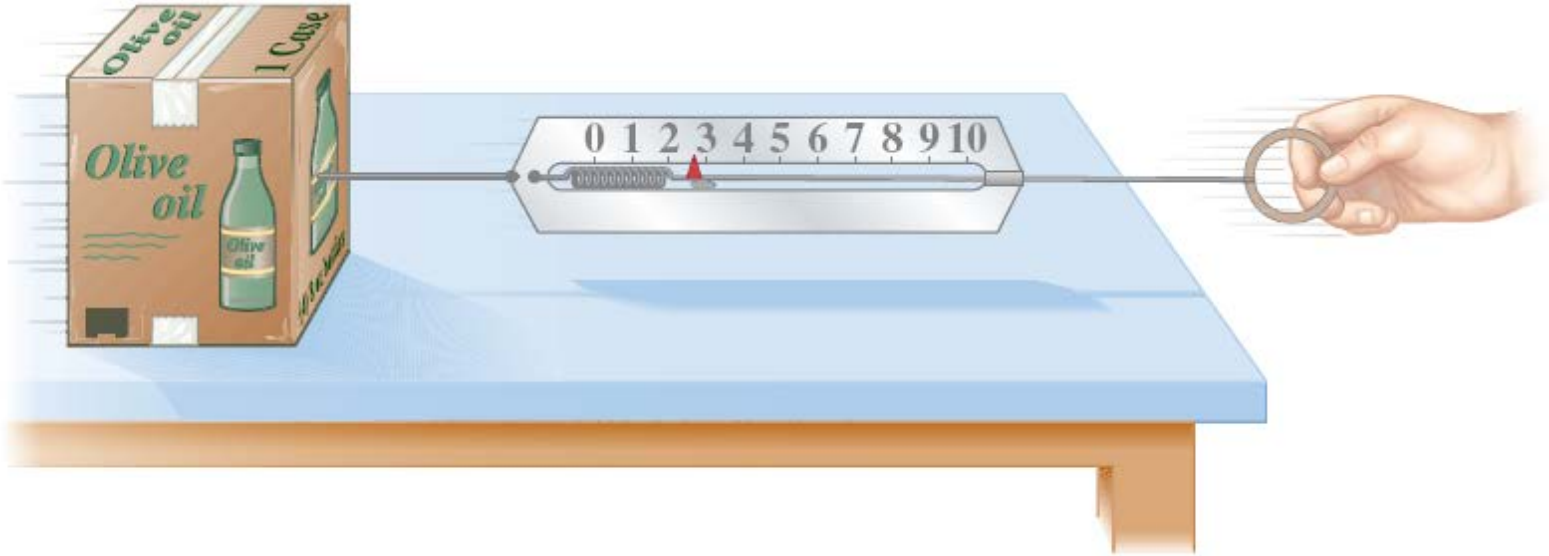
Force is a vector, having both magnitude and direction. The magnitude of a force can be measured using a spring scale.

4-2 Newton's First Law of Motion

It may seem as though it takes a force to keep an object moving. Push your book across a table—when you stop pushing, it stops moving.

But now, throw a ball across the room. The ball keeps moving after you let it go, even though you are not pushing it any more. Why?

It doesn't take a force to keep an object moving in a straight line—it takes a force to **change** its motion. Your book stops because the force of friction stops it.

4-2 Newton's First Law of Motion

This is Newton's first law, which is often called the law of inertia:

Every object continues in its state of rest, or of uniform velocity in a straight line, as long as no net force acts on it.

$$\vec{F}$$

$$\vec{F}_{fr}$$
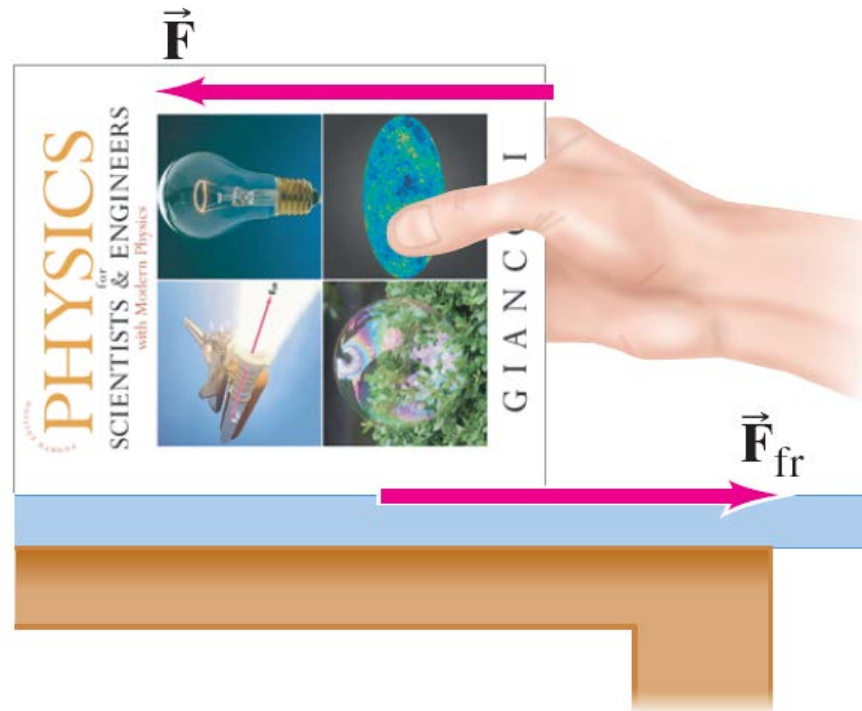
4-2 Newton's First Law of Motion

Conceptual Example 4-1: Newton's first law.

A school bus comes to a sudden stop, and all of the backpacks on the floor start to slide forward. What force causes them to do that?

4-2 Newton's First Law of Motion

Inertial reference frames:

Newton's first law does not hold in every reference frame, such as a reference frame that is accelerating or rotating.

An inertial reference frame is one in which Newton's first law is valid. This excludes rotating and accelerating frames.

How can we tell if we are in an inertial reference frame? By checking to see if Newton's first law holds!

4-3 Mass

Mass is the measure of inertia of an object, sometimes understood as the quantity of matter in the object. In the **SI** system, mass is measured in **kilograms**.

Mass is not **weight**.

Mass is a **property** of an object. Weight is the **force** exerted on that object by gravity.

If you go to the Moon, whose gravitational acceleration is about 1/6 g, you will weigh much less. Your mass, however, will be the same.

4-4 Newton's Second Law of Motion

Newton's **second law** is the relation between acceleration **and** force. Acceleration is proportional to force and **inversely** proportional to mass.

$$\Sigma \vec{F} = m\vec{a}$$

It takes a force to change either the direction or the speed of an object. More force means more acceleration; the same force exerted on a more massive object will yield less acceleration.

4-4 Newton's Second Law of Motion

Force is a **vector**, so $\Sigma \vec{F} = m\vec{a}$ is true along each coordinate axis.

TABLE 4–1
Units for Mass and Force

System	Mass	Force
SI	kilogram (kg)	newton (N) $(= \text{kg} \cdot \text{m/s}^2)$
cgs	gram (g)	dyne $(= \text{g} \cdot \text{cm/s}^2)$
British	slug	pound (lb)

Conversion factors: 1 dyne $= 10^{-5}$ N; 1 lb ≈ 4.45 N.

The unit of force in the SI system is the **newton (N)**.

Note that the **pound** is a unit of **force**, not of mass, and can therefore be equated to newtons but not to kilograms.
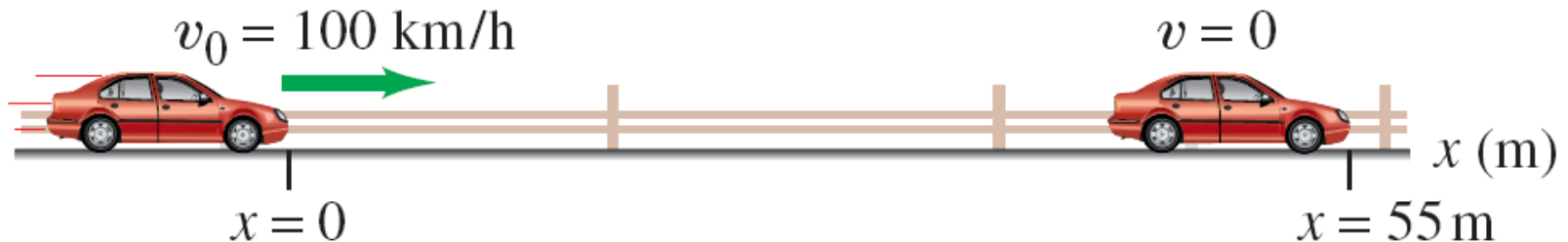
4-4 Newton's Second Law of Motion

Example 4-2: Force to accelerate a fast car.

Estimate the net force needed to accelerate (a) a 1000-kg car at ½ g; (b) a 200-g apple at the same rate.

Example 4-3: Force to stop a car.

What average net force is required to bring a 1500-kg car to rest from a speed of 100 km/h within a distance of 55 m?
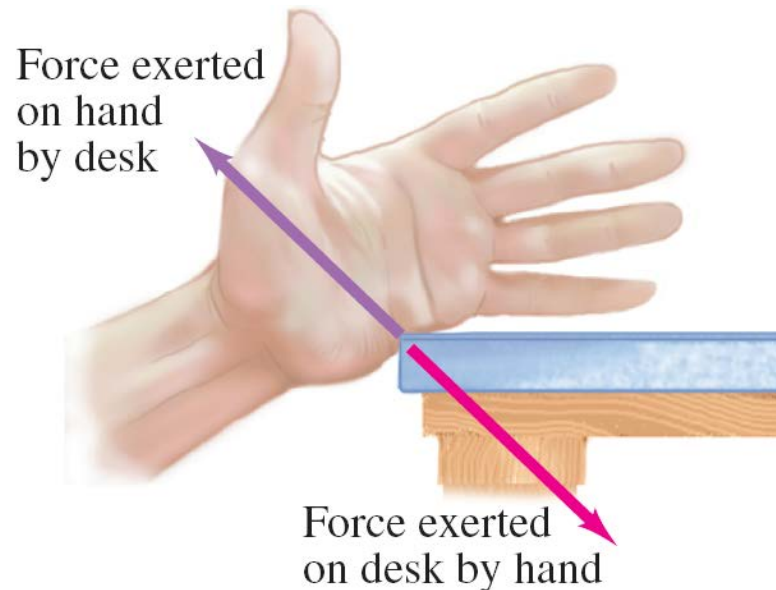

$v_0 = 100$ km/h $v = 0$

$x = 0$ x (m)

$x = 55$ m

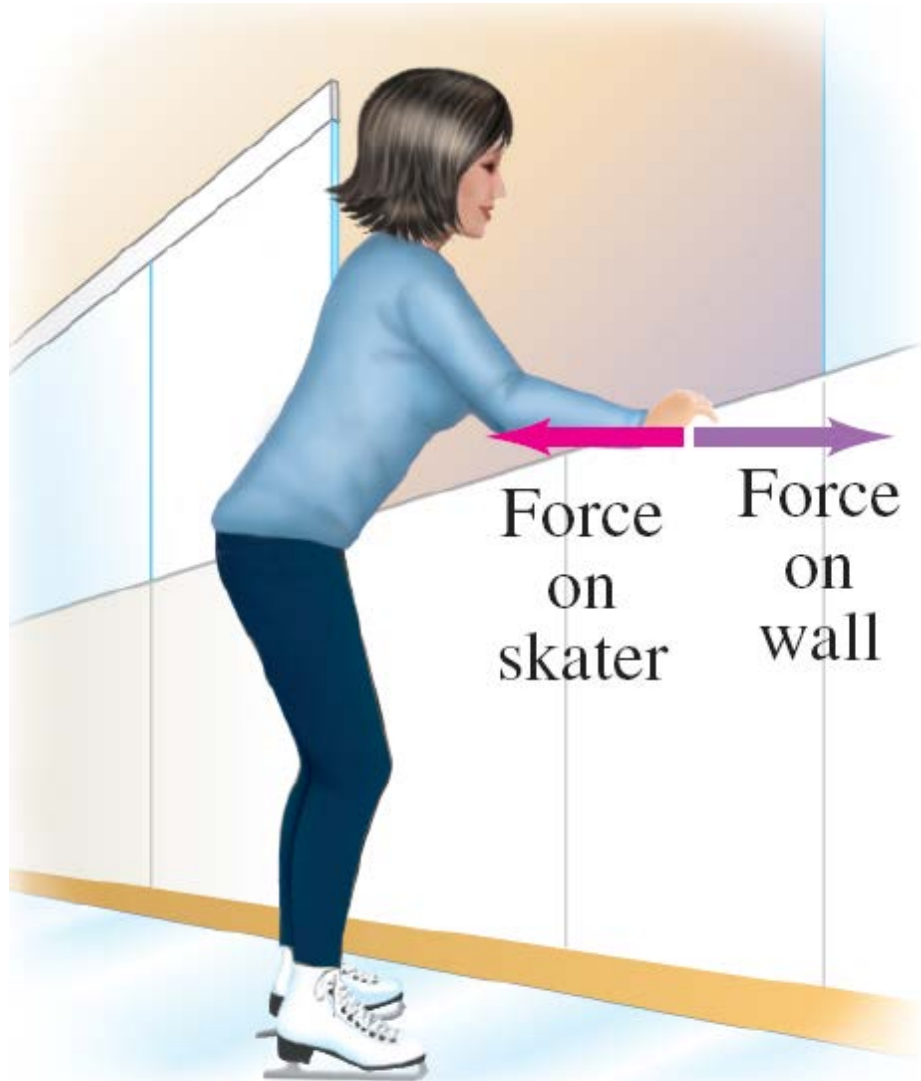# 4-5 Newton's Third Law of Motion

Any time a force is exerted on an object, that force is caused by another object.

Newton's third law:

Whenever one object exerts a force on a second object, the second exerts an equal force in the opposite direction on the first.

Force exerted on hand by desk

Force exerted on desk by hand

4-5 Newton's Third Law of Motion

Force on skater

Force on wall

A key to the correct application of the third law is that *the forces are exerted on different objects*. Make sure you don't use them as if they were acting on the *same* object.

4-5 Newton's Third Law of Motion

Rocket propulsion can also be explained using Newton's third law: hot gases from combustion spew out of the tail of the rocket at high speeds. The **reaction force** is what propels the rocket.

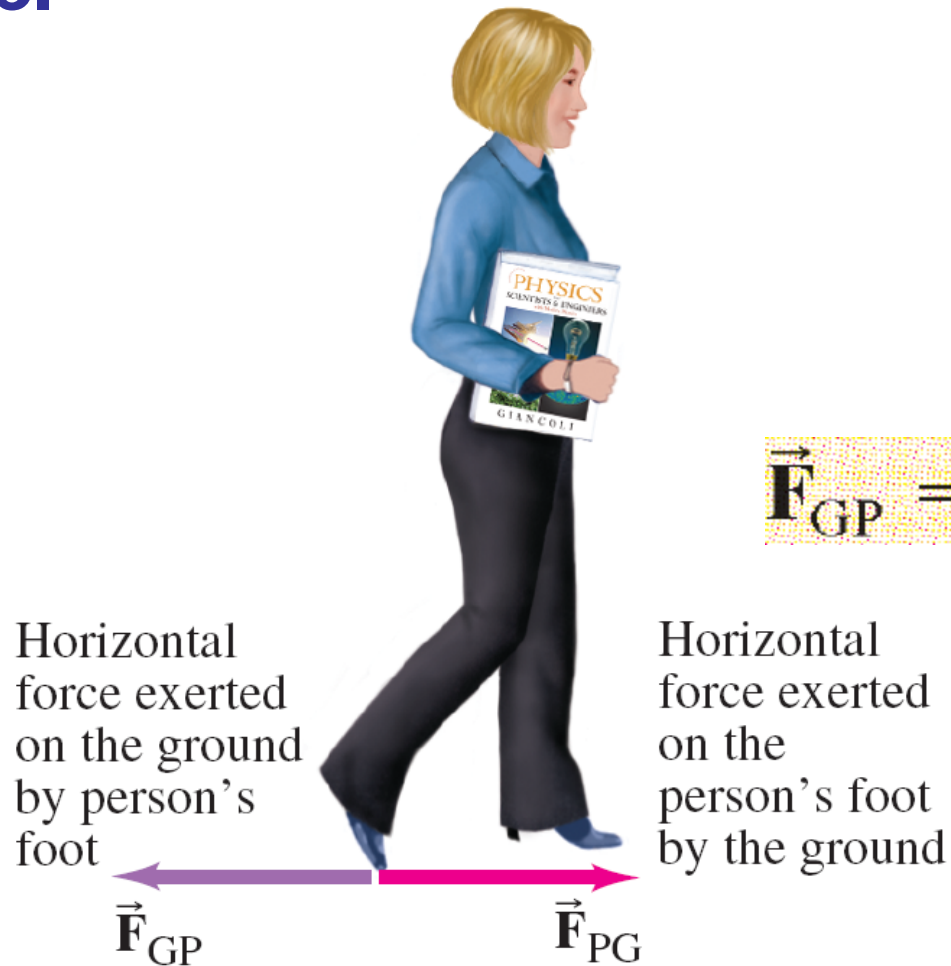Note that the rocket does not need anything to "push" against.

4-5 Newton's Third Law of Motion

Conceptual Example 4-4: What exerts the force to move a car?

Response: A common answer is that the engine makes the car move forward. But it is not so simple. The engine makes the wheels go around. But if the tires are on slick ice or deep mud, they just spin. Friction is needed. On firm ground, the tires push backward against the ground because of friction. By Newton's third law, the ground pushes on the tires in the opposite direction, accelerating the car forward.
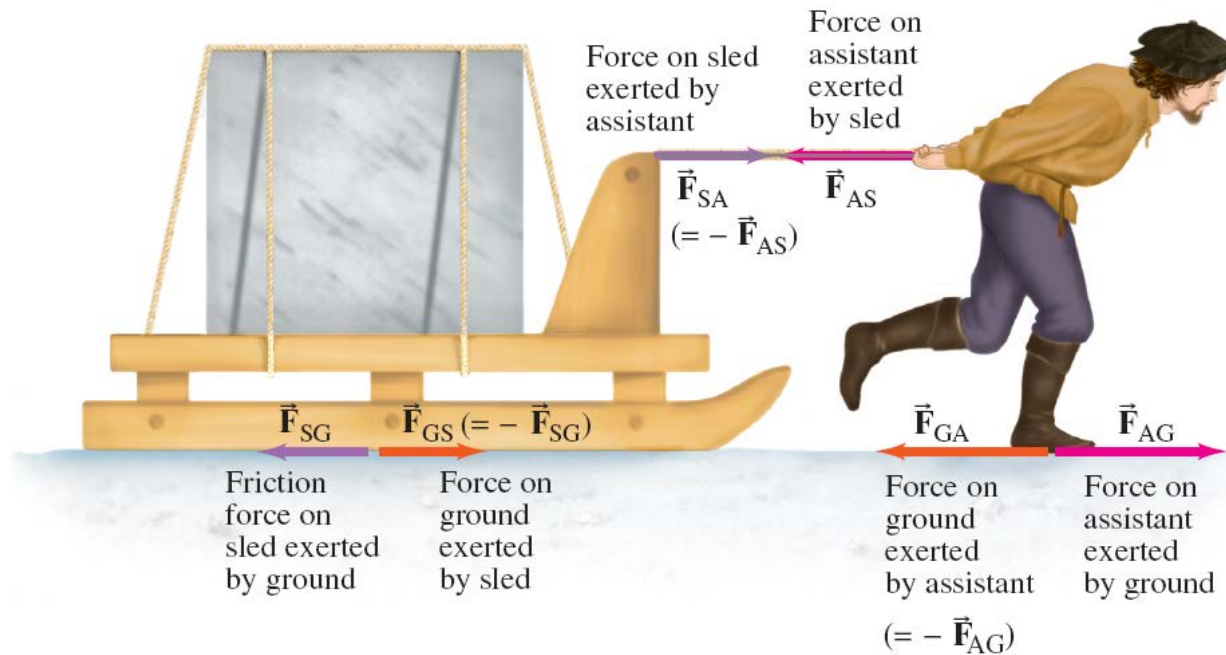
4-5 Newton's Third Law of Motion

Helpful notation: the first subscript is the object that the force is being exerted on; the second is the source.

$$\vec{F}_{GP} = -\vec{F}_{PG}$$

Horizontal force exerted on the ground by person's foot

Horizontal force exerted on the person's foot by the ground

$\vec{F}_{GP}$

$\vec{F}_{PG}$

4-5 Newton's Third Law of Motion

Force on sled exerted by assistant

$\vec{F}_{SA}$ $(= -\vec{F}_{AS})$

Force on assistant exerted by sled

$\vec{F}_{AS}$

Friction force on sled exerted by ground

$\vec{F}_{SG}$

Force on ground exerted by sled

$\vec{F}_{GS}(= -\vec{F}_{SG})$

Force on ground exerted by assistant

$\vec{F}_{GA}$

$(= -\vec{F}_{AG})$

Force on assistant exerted by ground

$\vec{F}_{AG}$

Conceptual Example 4-5: Third law clarification.

Michelangelo's assistant has been assigned the task of moving a block of marble using a sled. He says to his boss, "When I exert a forward force on the sled, the sled exerts an equal and opposite force backward. So how can I ever start it moving? No matter how hard I pull, the backward reaction force always equals my forward force, so the net force must be zero. I'll never be able to move this load." Is he correct?

4-6 Weight—the Force of Gravity; and the Normal Force

Weight is the force exerted on an object by gravity. Close to the surface of the Earth, where the gravitational force is nearly constant, the weight of an object of mass m is:

$$\vec{\mathbf{F}}_G = m\vec{\mathbf{g}},$$

where

$$g = 9.80 \text{ m/s}^2.$$

4-6 Weight—the Force of Gravity; and the Normal Force

An object at rest must have no **net force** on it. If it is sitting on a table, the force of gravity is still there; what other force is there?

The force exerted perpendicular to a surface is called the **normal force.** It is exactly as large as needed to balance the force from the object. (If the required force gets too big, something breaks!)
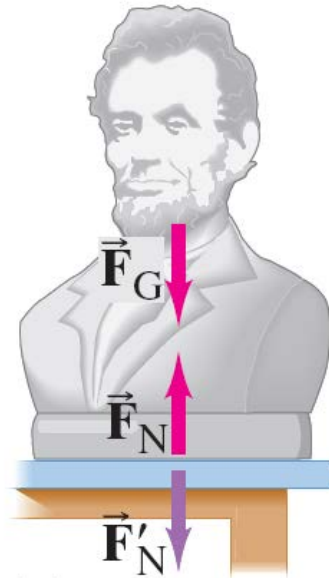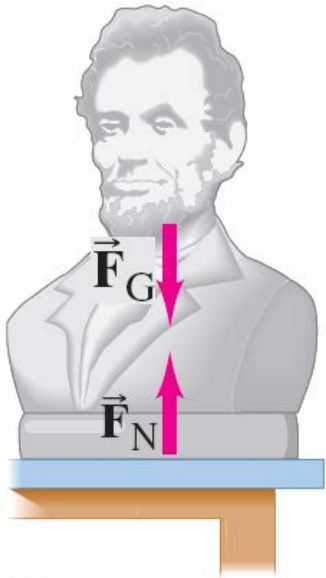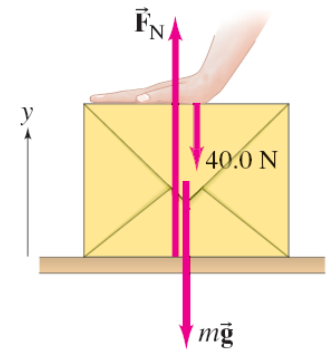
4-6 Weight—the Force of Gravity; and the Normal Force

Example 4-6: Weight, normal force, and a box.

A friend has given you a special gift, a box of mass 10.0 kg with a mystery surprise inside. The box is resting on the smooth (frictionless) horizontal surface of a table.
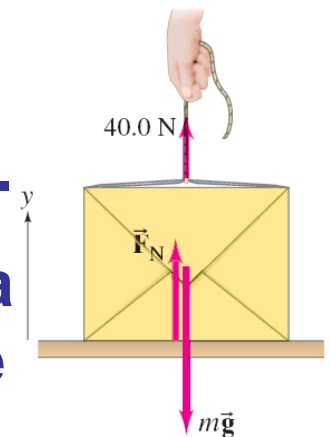
(a) Determine the weight of the box and the normal force exerted on it by the table.

(b) Now your friend pushes down on the box with a force of 40.0 N. Again determine the normal force exerted on the box by the table.

(c) If your friend pulls upward on the box with a force of 40.0 N, what now is the normal force exerted on the box by the table?
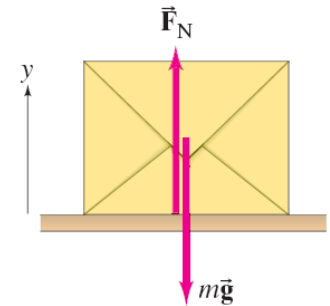
(a) $\Sigma F_y = F_N - mg = 0$

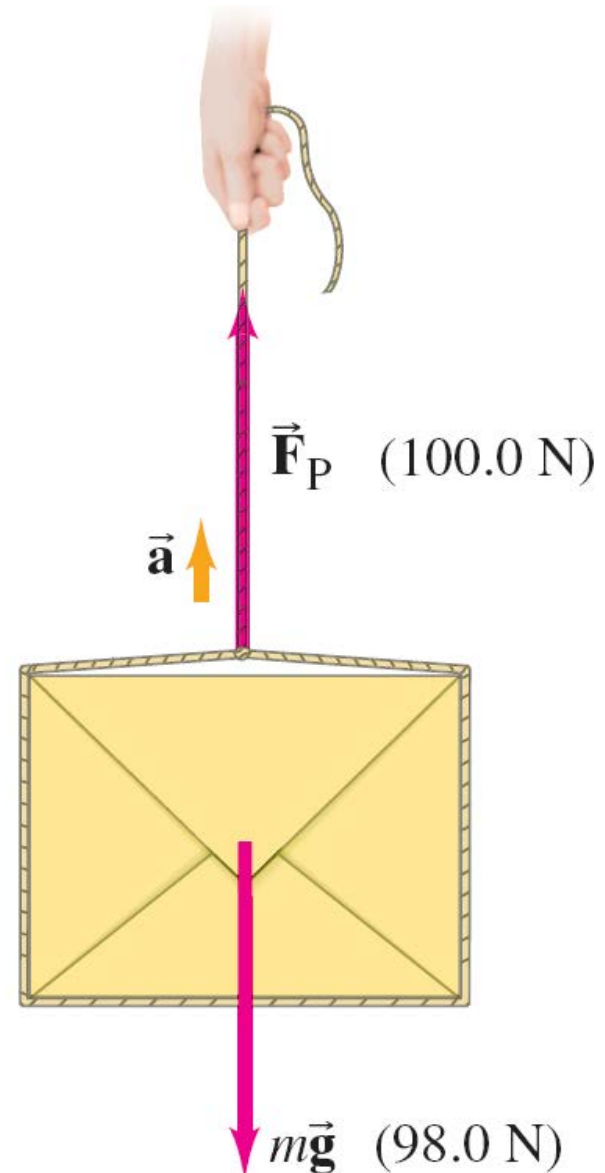(b) $\Sigma F_y = F_N - mg - 40.0 \, \text{N} = 0$

(c) $\Sigma F_y = F_N - mg + 40.0 \, \text{N} = 0$

4-6 Weight—the Force of Gravity; and the Normal Force

Example 4-7: Accelerating the box.

What happens when a person pulls upward on the box in the previous example with a force greater than the box's weight, say 100.0 N?
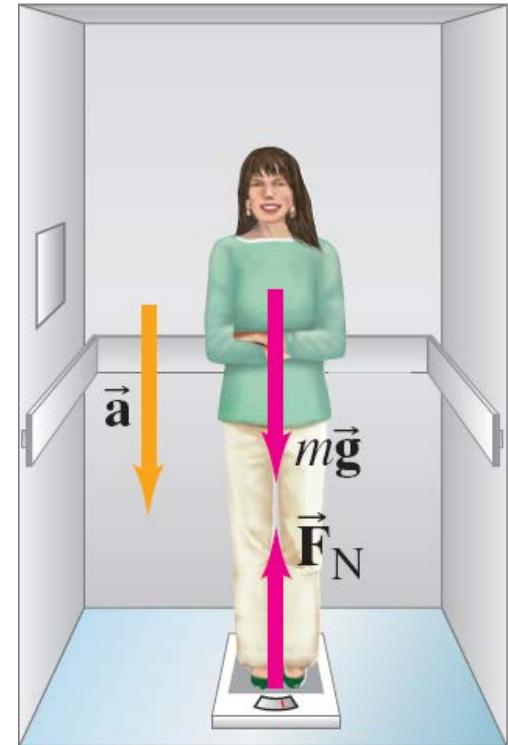
$\vec{\mathbf{F}}_P$ (100.0 N)

$\vec{\mathbf{a}}$

$m\vec{\mathbf{g}}$ (98.0 N)

4-6 Weight—the Force of Gravity; and the Normal Force

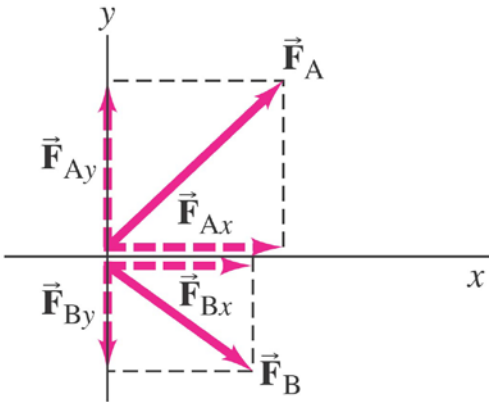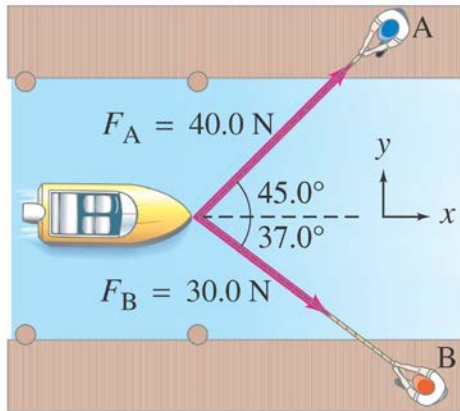**Example 4-8: Apparent weight loss.**

A 65-kg woman descends in an elevator that briefly accelerates at 0.20g downward. She stands on a scale that reads in kg.

(a) During this acceleration, what is her weight and what does the scale read?

(b) What does the scale read when the elevator descends at a constant speed of 2.0 m/s?

4-7 Solving Problems with Newton's Laws: Free-Body Diagrams

$F_A = 40.0$ N

$45.0°$

$37.0°$

$F_B = 30.0$ N

$\vec{F}_A$

$\vec{F}_{Ay}$

$\vec{F}_{Ax}$

$\vec{F}_{By}$

$\vec{F}_{Bx}$

$\vec{F}_B$

$\vec{F}_{Ry}$

$\vec{F}_R$

θ

$\vec{F}_{Rx}$
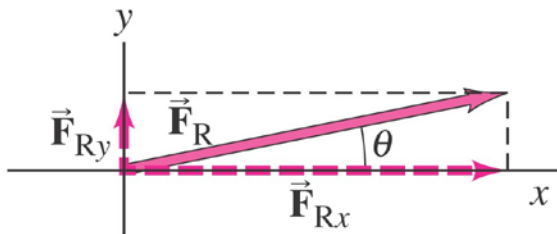
1. Draw a **sketch**.

2. For one object, draw a **free-body diagram**, showing all the forces acting *on* the object. Make the **magnitudes** and **directions** as accurate as you can. **Label** each force. If there are multiple objects, draw a separate diagram for each one.

3. **Resolve** vectors into components.

4. Apply Newton's **second law** to each component.

5. **Solve**.

4-7 Solving Problems with Newton's Laws: Free-Body Diagrams
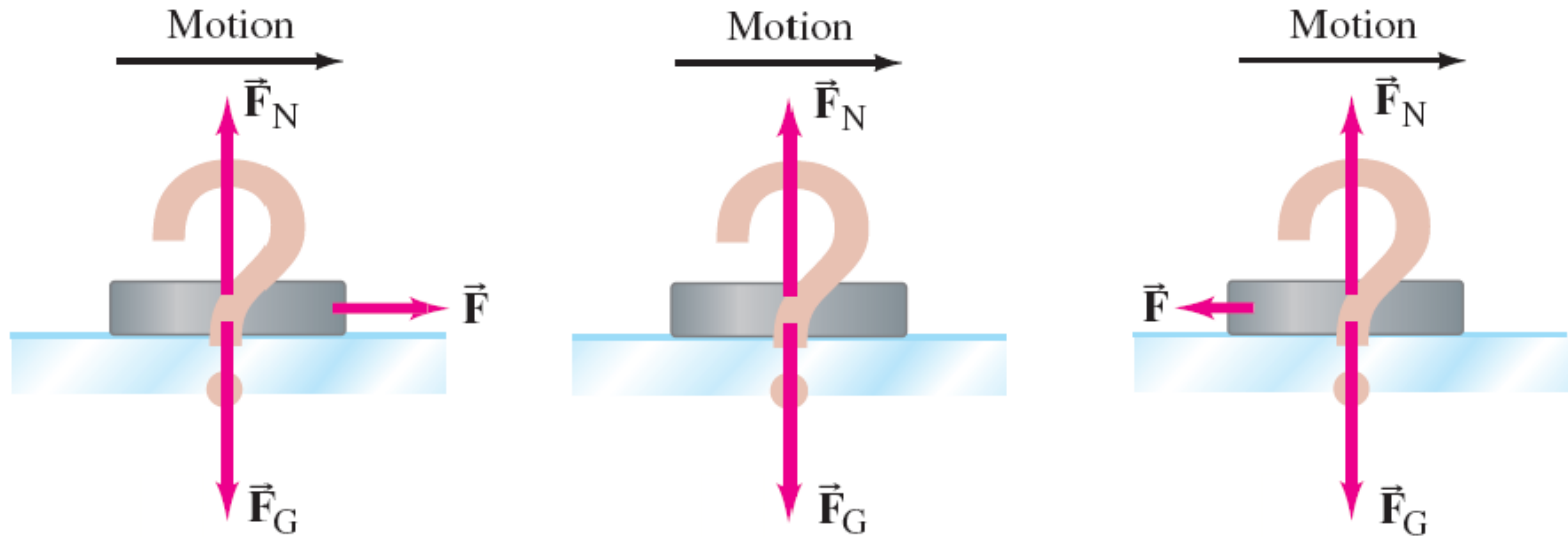
Conceptual Example 4-10: The hockey puck.

A hockey puck is sliding at constant velocity across a flat horizontal ice surface that is assumed to be frictionless. Which of these sketches is the correct free-body diagram for this puck? What would your answer be if the puck slowed down?

4-7 Solving Problems with Newton's Laws: Free-Body Diagrams

$F_P = 40.0$ N

$30.0°$

$\vec{F}_P$

$30.0°$

$\vec{F}_N$

$m\vec{g}$

$\vec{F}_N$

$\vec{F}_P$

$m\vec{g}$
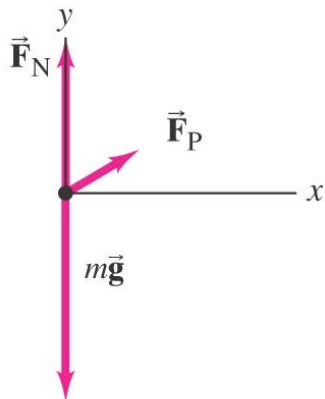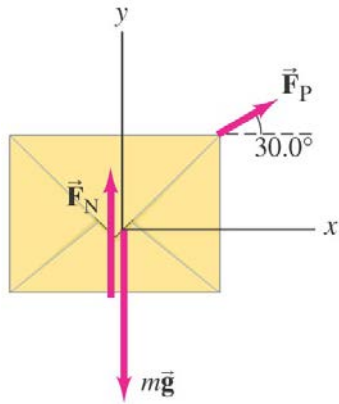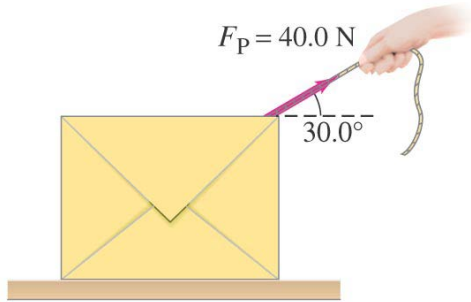
Example 4-11: Pulling the mystery box. Suppose a friend asks to examine the 10.0-kg box you were given previously, hoping to guess what is inside; and you respond, "Sure, pull the box over to you." She then pulls the box by the attached cord along the smooth surface of the table. The magnitude of the force exerted by the person is F_P = 40.0 N, and it is exerted at a 30.0° angle as shown. Calculate

(a) the acceleration of the box, and

(b) the magnitude of the upward force F_N exerted by the table on the box.

4-7 Solving Problems with Newton's Laws: Free-Body Diagrams
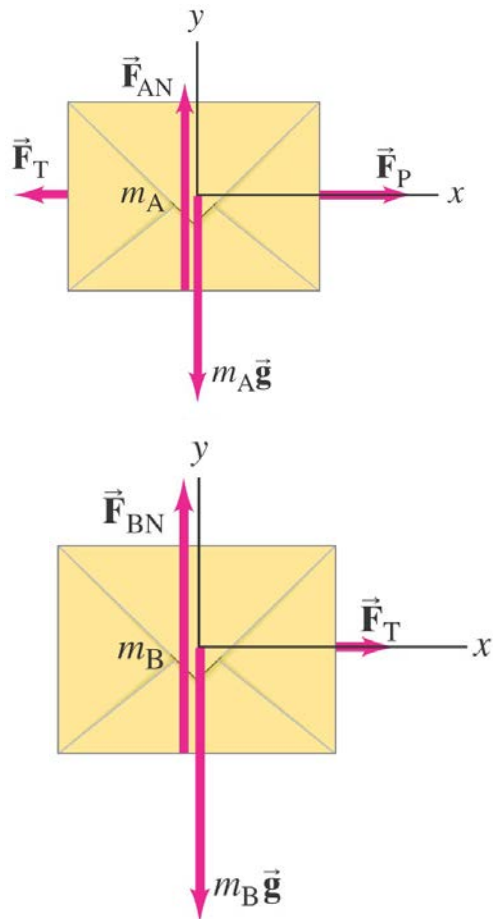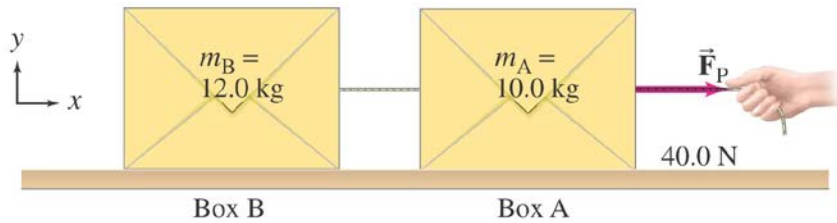
Example 4-12: Two boxes connected by a cord.

Two boxes, A and B, are connected by a lightweight cord and are resting on a smooth table. The boxes have masses of 12.0 kg and 10.0 kg. A horizontal force of 40.0 N is applied to the 10.0-kg box. Find (a) the acceleration of each box, and (b) the tension in the cord connecting the boxes.

4-7 Solving Problems with Newton's Laws: Free-Body Diagrams

Example 4-13: Elevator and counterweight (Atwood's machine).

**A system of two objects suspended over a pulley by a flexible cable is sometimes referred to as an Atwood's machine. Here, let the mass of the counterweight be 1000 kg. Assume the mass of the empty elevator is 850 kg, and its mass when carrying four passengers is 1150 kg. For the latter case calculate (a) the acceleration of the elevator and (b) the tension in the cable.**
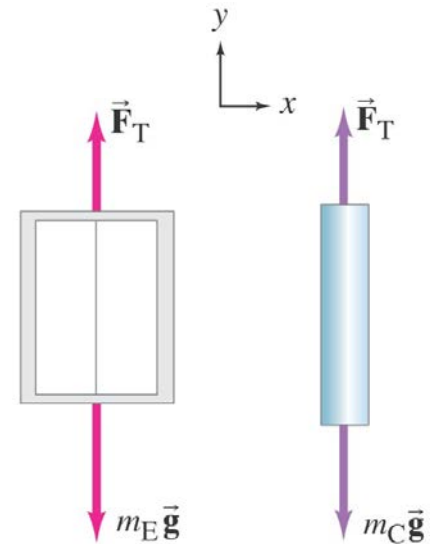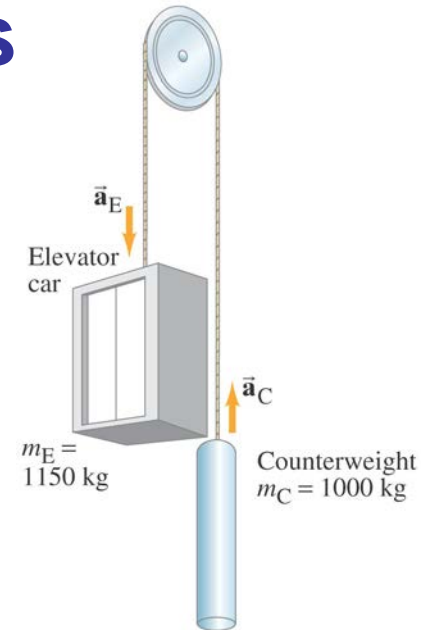
4-7 Solving Problems with Newton's Laws: Free-Body Diagrams

**Conceptual Example 4-14: The advantage of a pulley.**

A mover is trying to lift a piano (slowly) up to a second-story apartment. He is using a rope looped over two pulleys as shown. What force must he exert on the rope to slowly lift the piano's 2000-N weight?
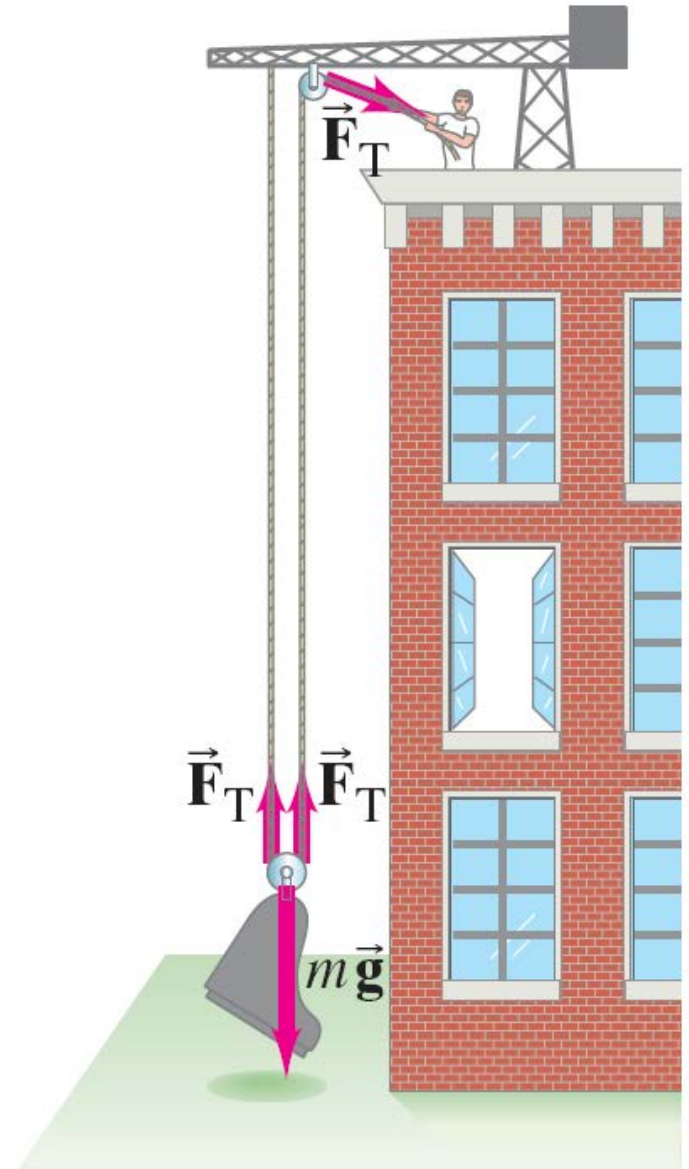
4-7 Solving Problems with Newton's Laws: Free-Body Diagrams

Example 4-15: Accelerometer.

A small mass m hangs from a thin string and can swing like a pendulum. You attach it above the window of your car as shown. What angle does the string make (a) when the car accelerates at a constant a = 1.20 m/s², and (b) when the car moves at constant velocity, v = 90 km/h?
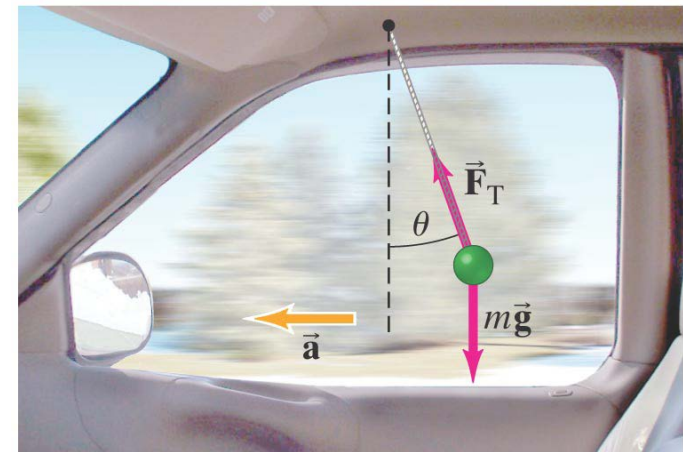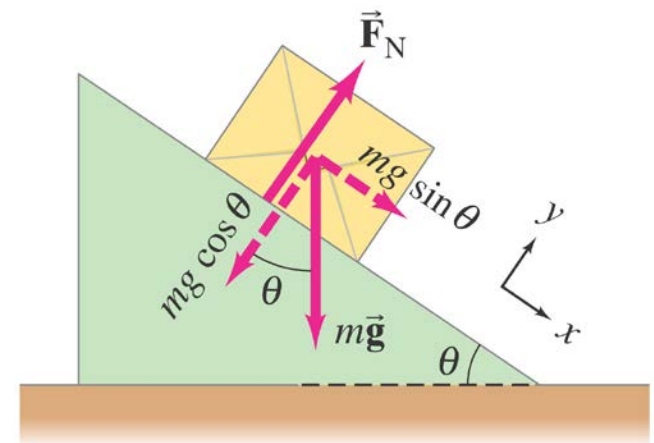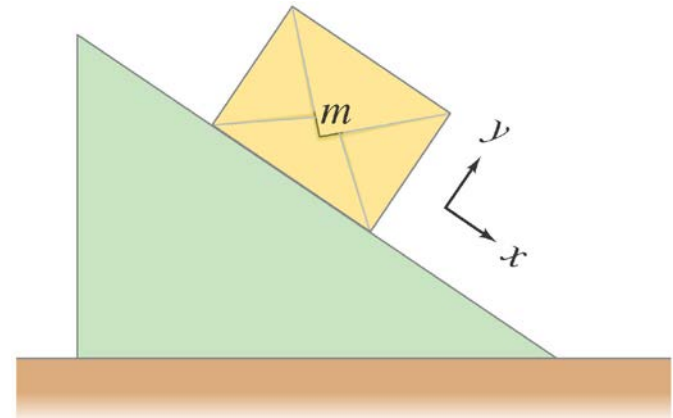
4-7 Solving Problems with Newton's Laws: Free-Body Diagrams

Example 4-16: Box slides down an incline.

A box of mass m is placed on a smooth incline that makes an angle θ with the horizontal. (a) Determine the normal force on the box. (b) Determine the box's acceleration. (c) Evaluate for a mass m = 10 kg and an incline of θ = 30°.

4-8 Problem Solving—A General Approach

1. **Read** the problem carefully; then read it again.

2. **Draw** a sketch, and then a free-body diagram.

3. Choose a convenient **coordinate system.**

4. List the **known** and **unknown** quantities; find relationships between the knowns and the unknowns.

5. **Estimate** the answer.

6. Solve the problem without putting in any numbers (**algebraically**); once you are satisfied, put the numbers in.

7. Keep track of **dimensions.**

8. Make sure your answer is **reasonable.**

Summary of Chapter 4

• **Newton's first law: If the net force on an object is zero, it will remain either at rest or moving in a straight line at constant speed.**

• **Newton's second law:** $\Sigma \vec{F} = m\vec{a}.$

• **Newton's third law:** $\vec{F}_{AB} = -\vec{F}_{BA}.$

• **Weight is the gravitational force on an object.**

• **Free-body diagrams are essential for problem-solving. Do one object at a time, make sure you have all the forces, pick a coordinate system and find the force components, and apply Newton's second law along each axis.**