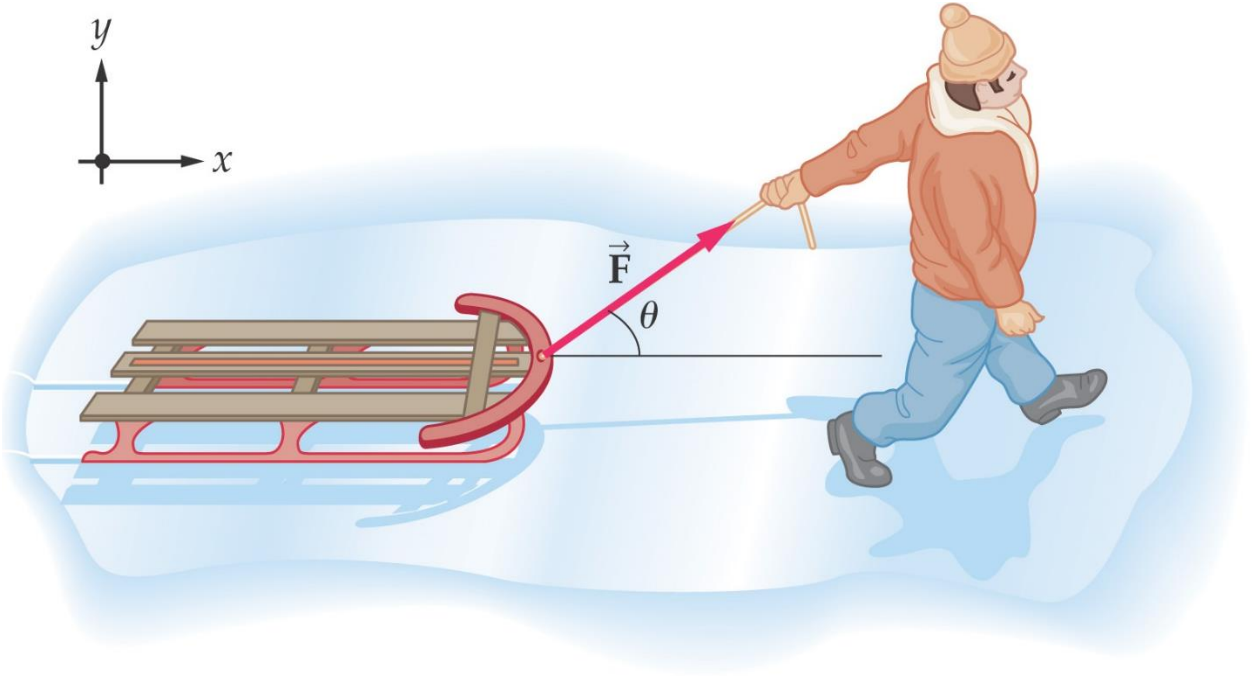
The Laws of motion

5.1 The Concept of Force

Force: push or pull

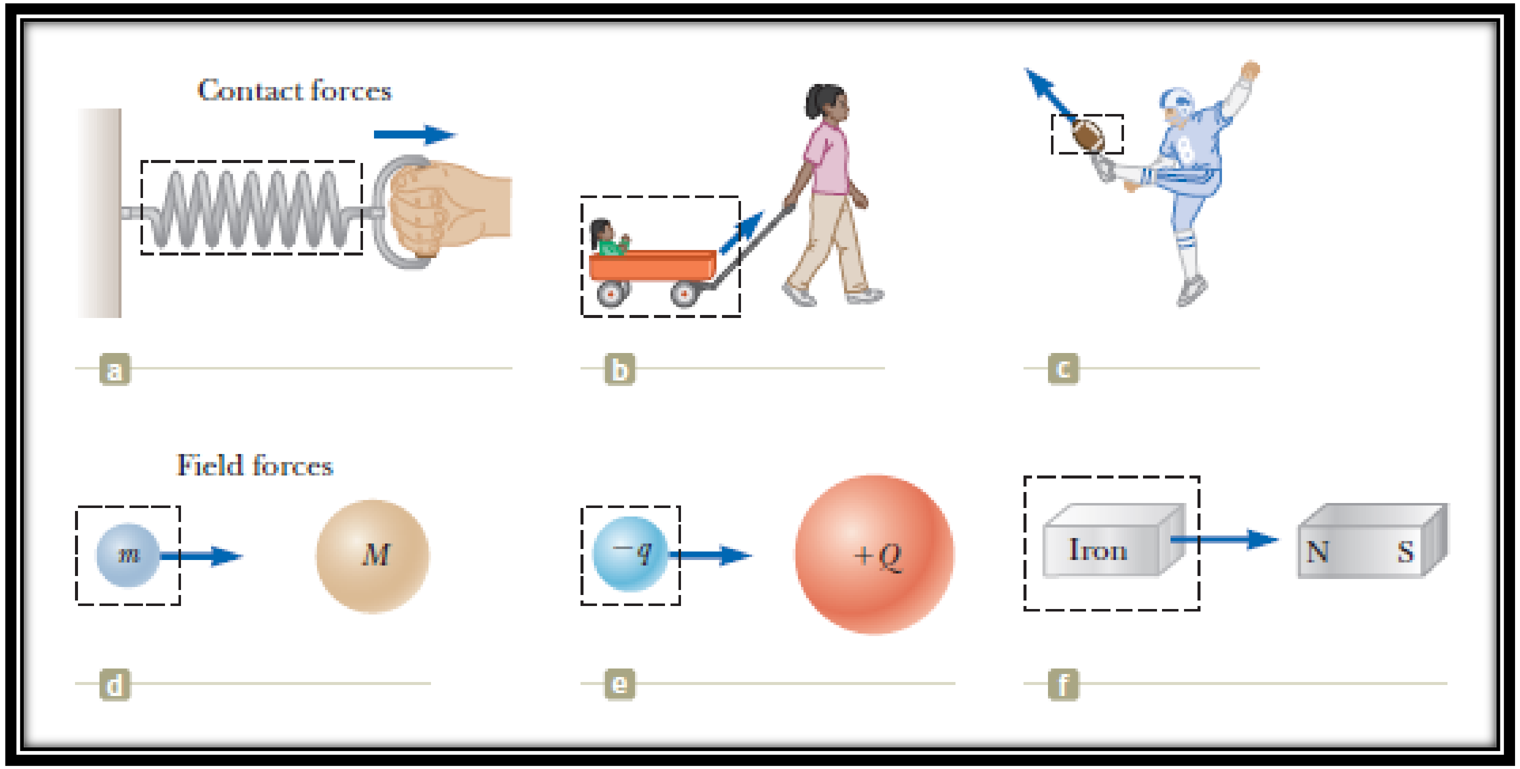
Force is a vector – it has magnitude and direction



5.1 The Concept of Force

**Contact forces* involve physical contact between two objects.

* *field forces,* does not involve physical contact between two objects.



5.1 The Concept of Force

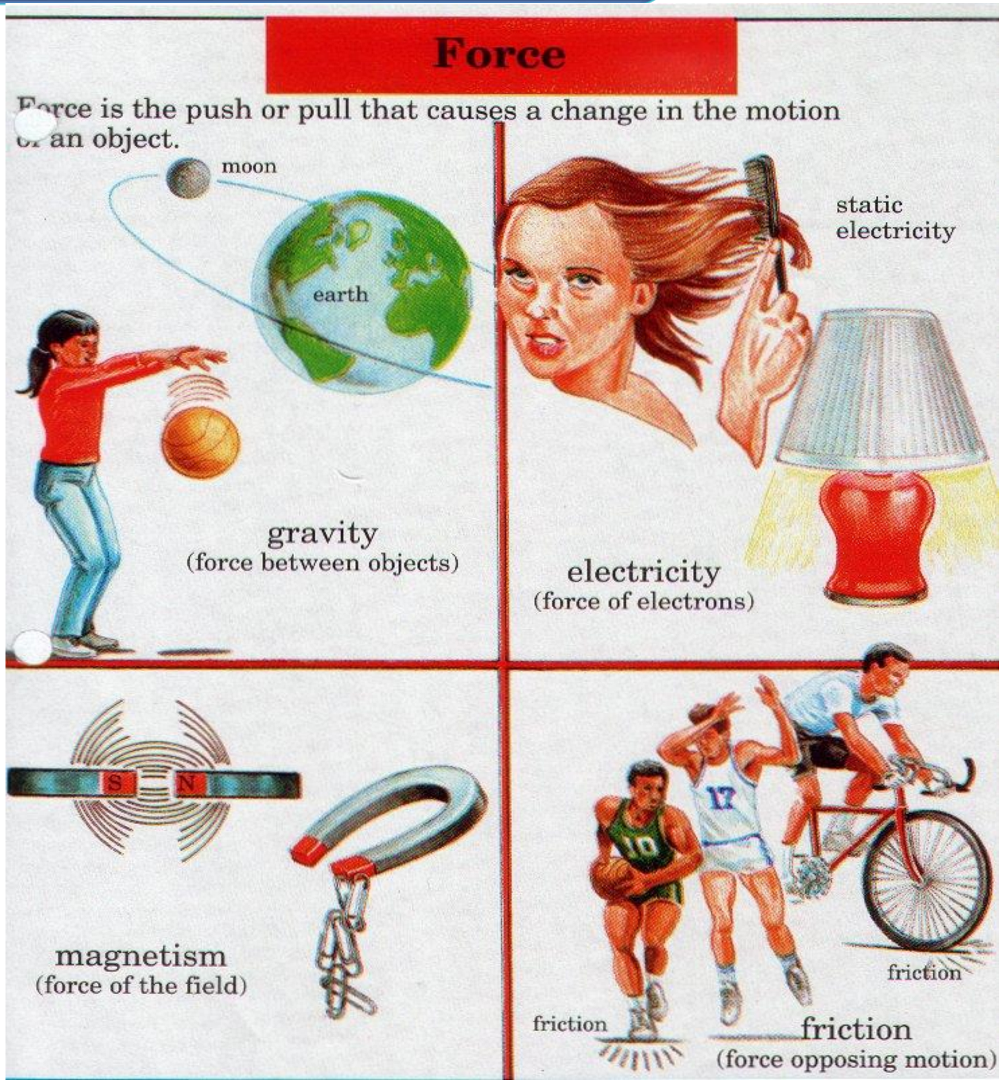
The only known *fundamental* forces in nature are all field forces:

(1) *gravitational forces* between objects

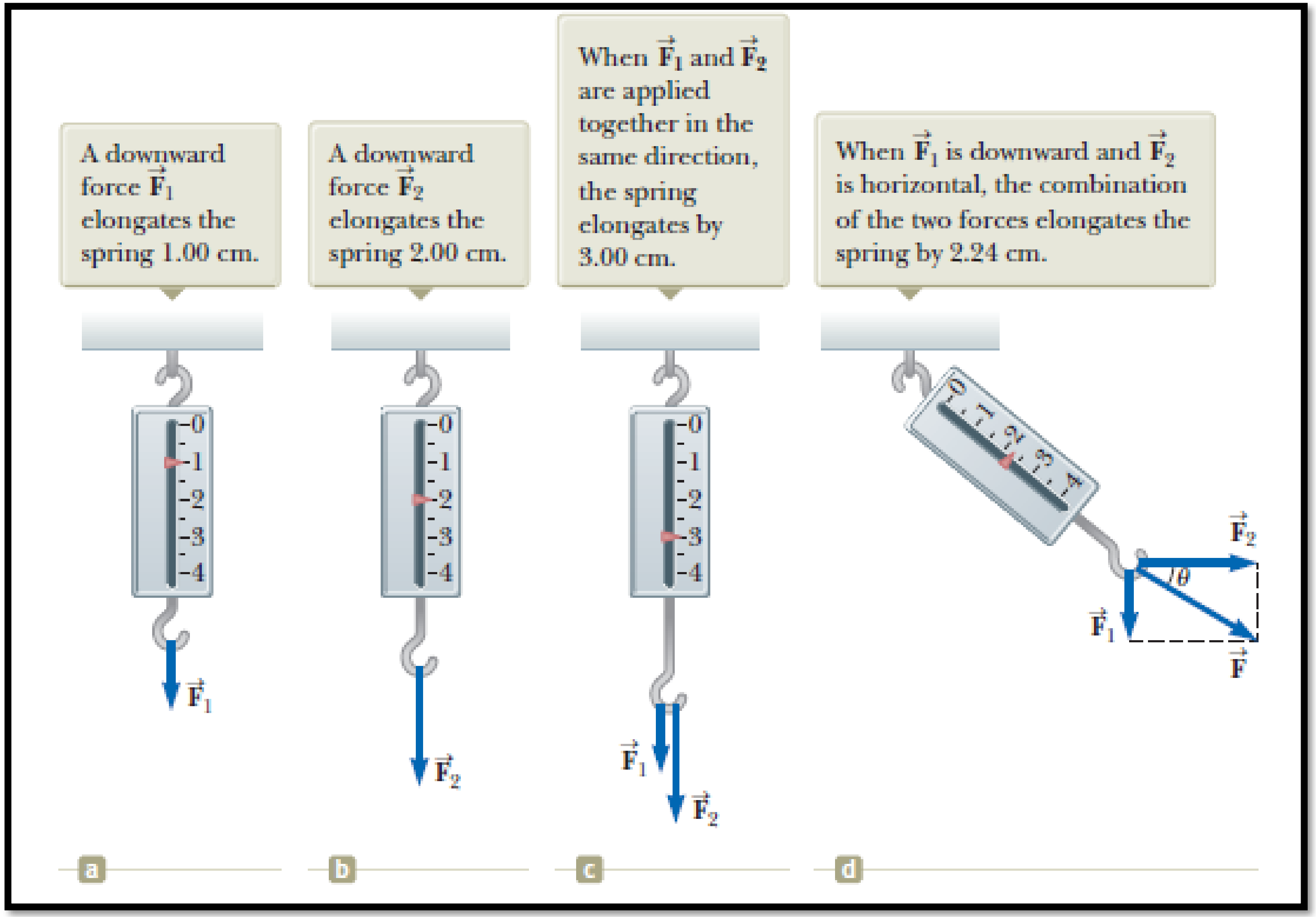
(2) *electromagnetic forces* between electric charges

(3) *strong forces* between subatomic particles

(4) *weak forces* that arise in certain radioactive decay processes.



5.1 The Concept of Force



5.2 Newton’s First Law and Inertial Frames:

Newton’s first law of motion, sometimes called the(*law of inertia) is*

If an object does not interact with other objects, it is possible to identify a reference frame in which the object has zero acceleration.

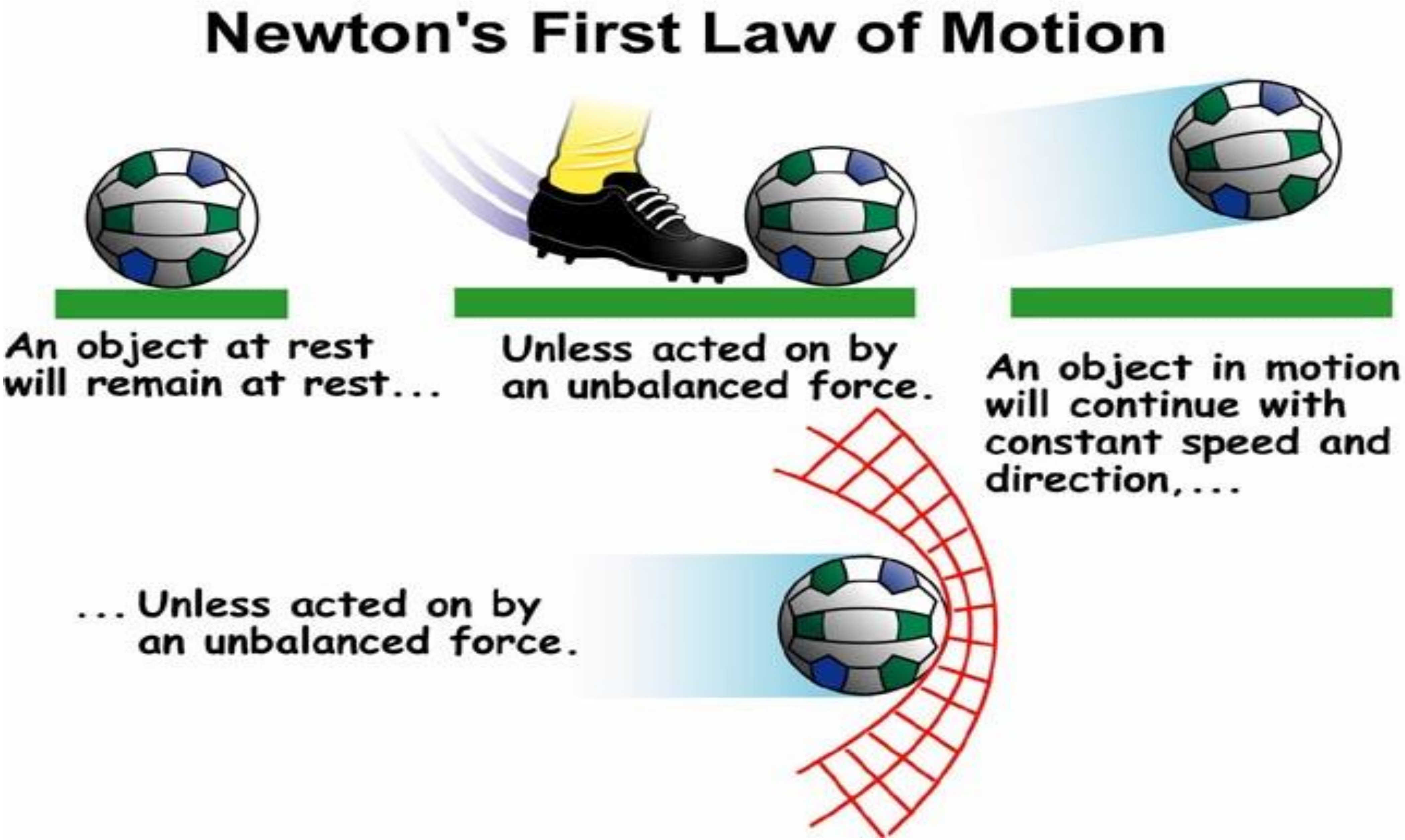
Such a reference frame is called an **inertial frame of reference.**

Another statement of Newton’s first law:

In the absence of external forces and when viewed from an inertial reference frame, an object at rest remains at rest and an object in motion continues in motion with a constant velocity (that is, with a constant speed in a straight line).

In other words, **when no force acts on an object, the acceleration of the object is zero.**

*****In turn, from the first law, we can define **force** as **that which causes a change in motion of an object.**


Newton's First Law of Motion
An object at rest will remain at rest...
Unless acted on by an unbalanced force.
An object in motion will continue with constant speed and direction,...
...Unless acted on by an unbalanced force.

5.3 Mass:

Mass is that property of an object that specifies how much resistance an object exhibits to changes in its velocity,

* The SI unit of mass is the kilogram.

Suppose a force acting on an object of mass m_1 produces a change in motion of the object that we can quantify with the object's acceleration $\vec{a}_1$, and the *same force* acting on an object of mass m_2 produces an acceleration $\vec{a}_2$. The ratio of the two masses is defined as the *inverse* ratio of the magnitudes of the accelerations produced by the force:

$$\frac{m_1}{m_2} \equiv \frac{a_2}{a_1} \qquad (1)$$

*We conclude that the magnitude of the acceleration of an object is inversely proportional to its mass when acted on by a given force.

*mass is a scalar quantity.

*Mass and weight are two different quantities.

The weight of an object is equal to the magnitude of the gravitational force exerted on the object and varies with location.

5.4 Newton's Second Law:

When viewed from an inertial reference frame, the acceleration of an object is directly proportional to the net force acting on it and inversely proportional to its mass:

$$\vec{a} \propto \frac{\Sigma\vec{F}}{m}$$

If we choose a proportionality constant of 1, we can relate mass, acceleration, and force through the following mathematical statement of Newton's second law:

$$\Sigma\vec{F} = m\vec{a} \qquad (2)$$

*The acceleration is due to the *net force* $\Sigma\overrightarrow{F}$ acting on an object.

*The **net force** on an object is the vector sum of all forces acting on the object.

*Many forces may be acting on an object, but there is only one acceleration.

*Equation (2) is a vector expression and hence is equivalent to three component equations:

$$\Sigma F_x = ma_x \quad \Sigma F_y = ma_y \quad \Sigma F_z = ma_z \quad (3)$$

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

*A force of $1\ N$ is the force that, when acting on an object of mass $1\ kg$, produces an acceleration of $1\ m/s^2$.

5.4 Newton's Second Law:

Example 5.1 An Accelerating Hockey Puck

A hockey puck having a mass of 0.30 kg slides on the frictionless, horizontal surface of an ice rink. Two hockey sticks strike the puck simultaneously, exerting the forces on the puck shown in Figure 5.4. The force $\vec{F}_1$ has a magnitude of 5.0 N, and the force $\vec{F}_2$ has a magnitude of 8.0 N. Determine both the magnitude and the direction of the puck's acceleration.

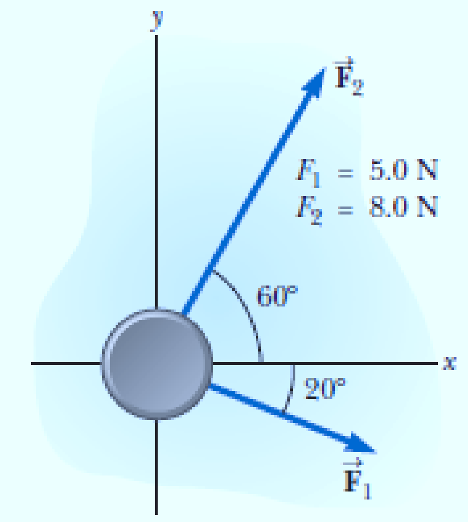
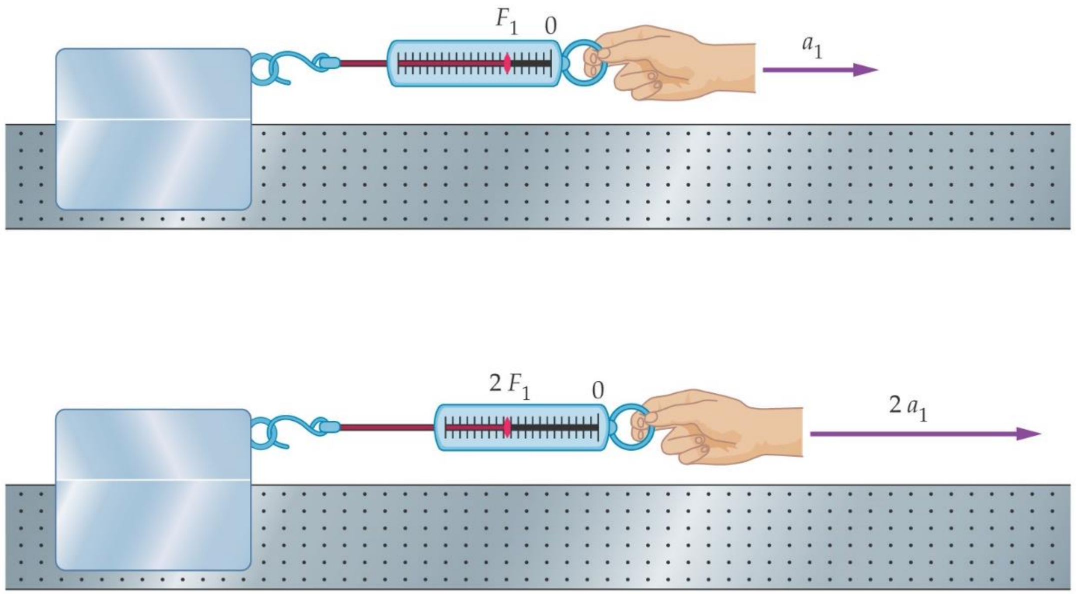
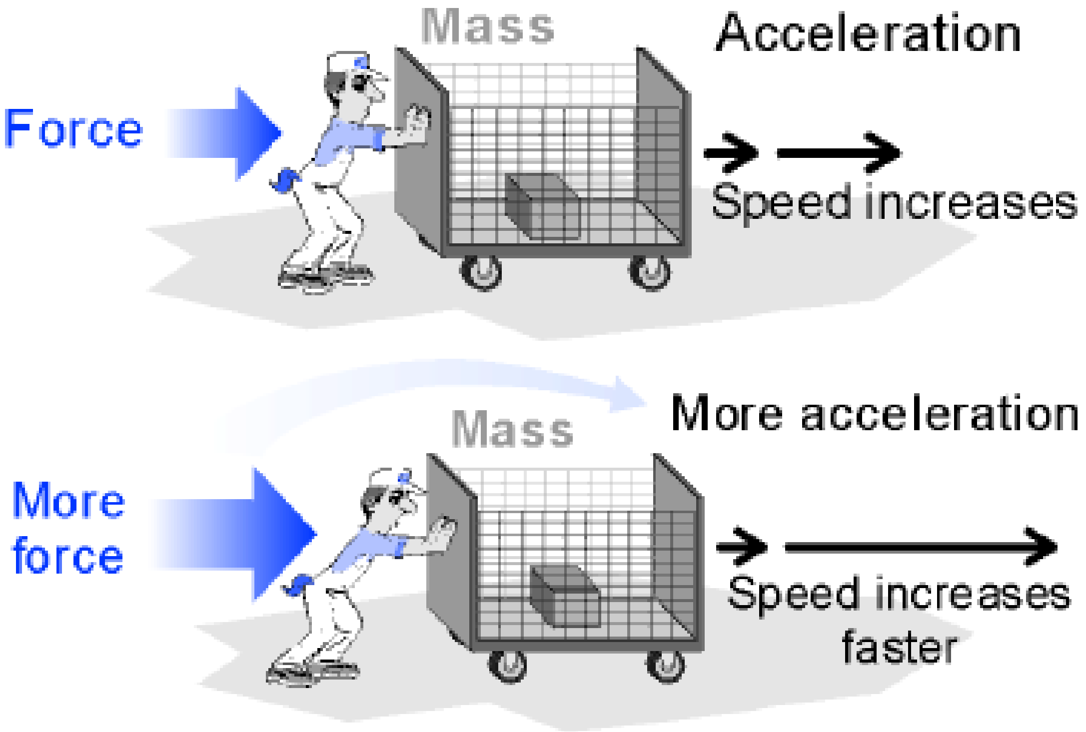


Figure 5.4 (Example 5.1) A hockey puck moving on a frictionless surface is subject to two forces $\vec{F}_1$ and $\vec{F}_2$.

5.4 Newton’s Second Law:

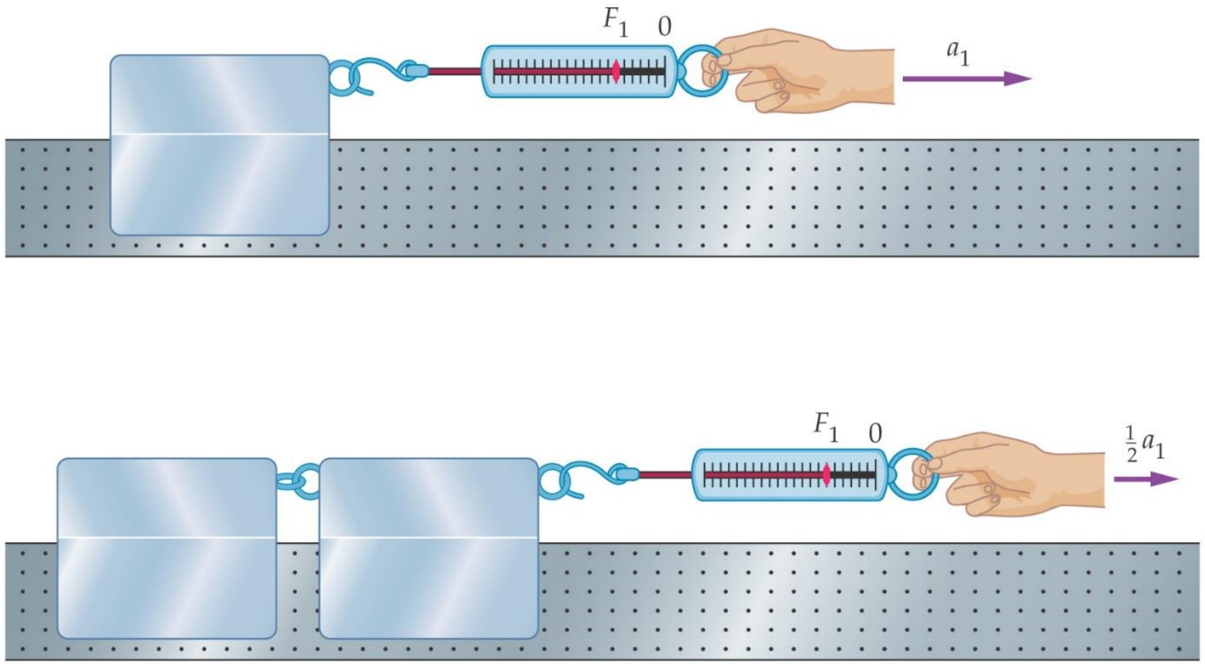
If you apply more force to an object, it accelerates at a higher rate.

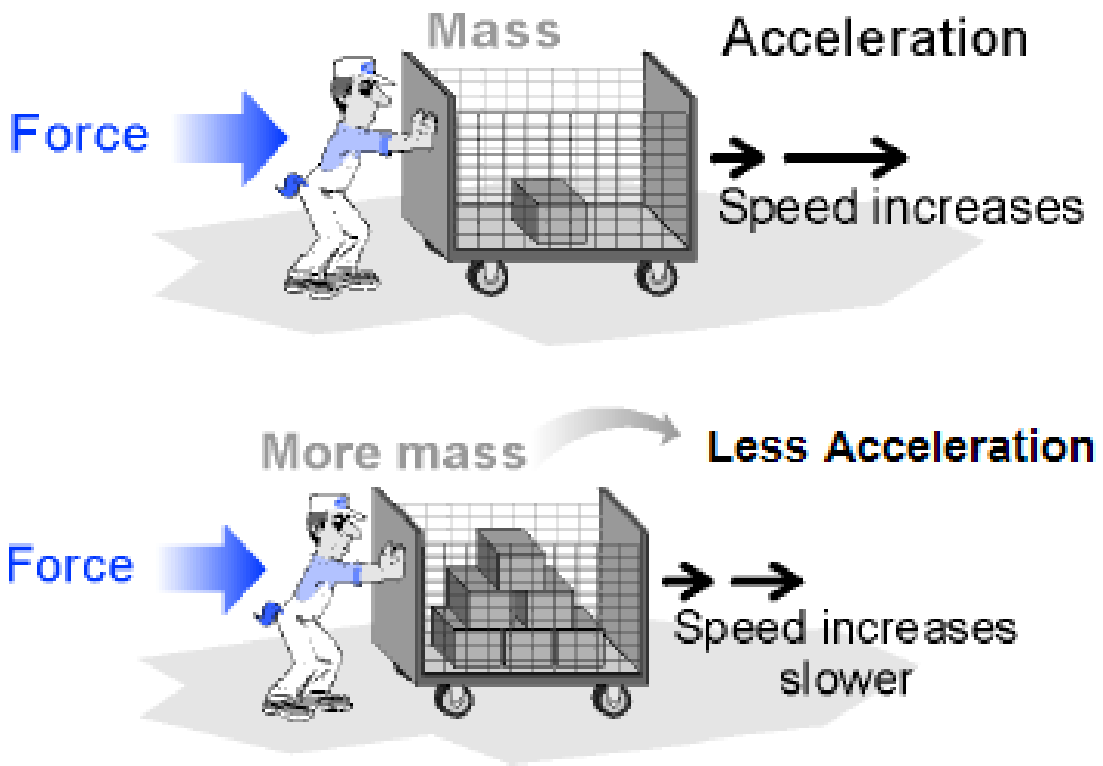




5.4 Newton's Second Law:

If an object has <u>more</u> mass it accelerates at a lower rate





5.6 Newton's Third Law:

The attractive force exerted by the Earth on an object is called the **gravitational force** $\vec{F}_g$.

Applying Newton's second law(Equation(2)) to a freely falling object of mass m, with $\vec{a} = \vec{g}$ and $\Sigma\vec{F} = \vec{F}_g$, gives:

$$\vec{F}_g = m\vec{g}$$

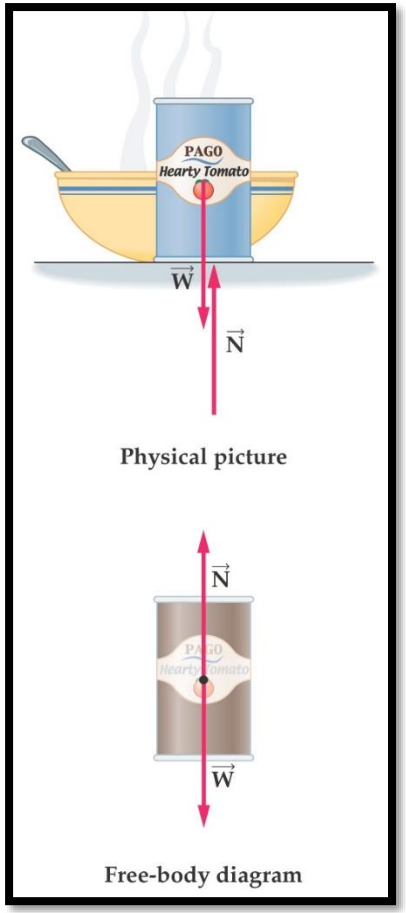
Therefore, the weight of an object, being defined as the magnitude of $\vec{F}_g$, is equal to mg:

$$F_g = mg \qquad (4)$$

The mass m in Equation (4) determines the strength of the gravitational attraction between the object and the Earth. We call m in Equation (4) the **gravitational mass.**

*Mass in Equation (2) is called **inertial mass.**

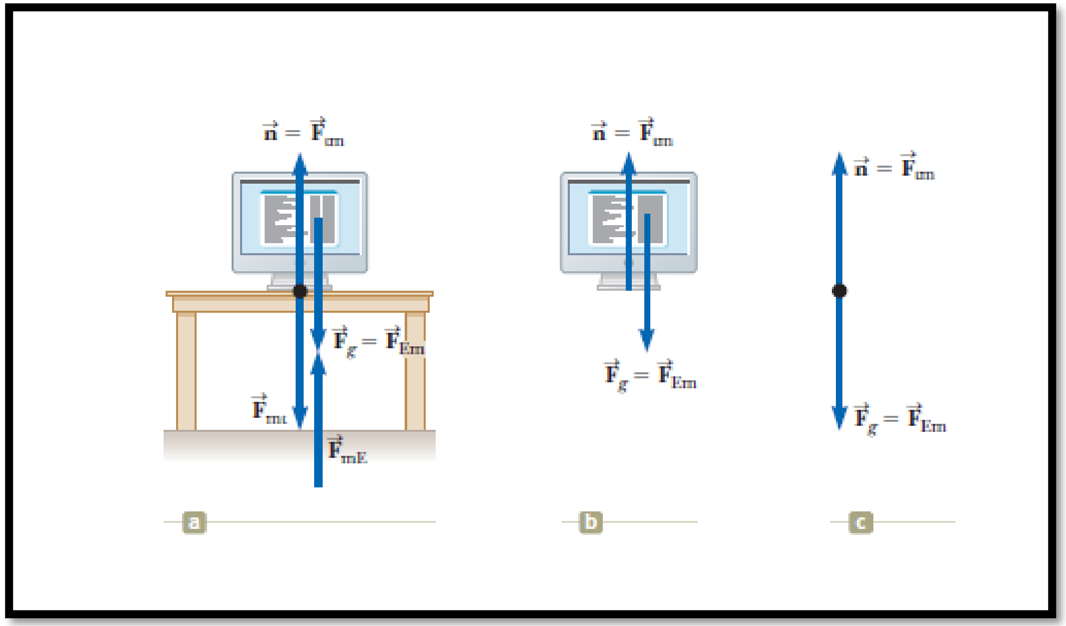
5.6 Newton's Third Law:



If two objects interact, the force $\vec{F}_{12}$ exerted by object 1 on object 2 is equal in magnitude and opposite in direction to the force $\vec{F}_{21}$ exerted by object 2 on object 1:

$$\vec{F}_{12} = -\vec{F}_{21} \qquad (5)$$

* The normal force is the force exerted by a surface on an object.

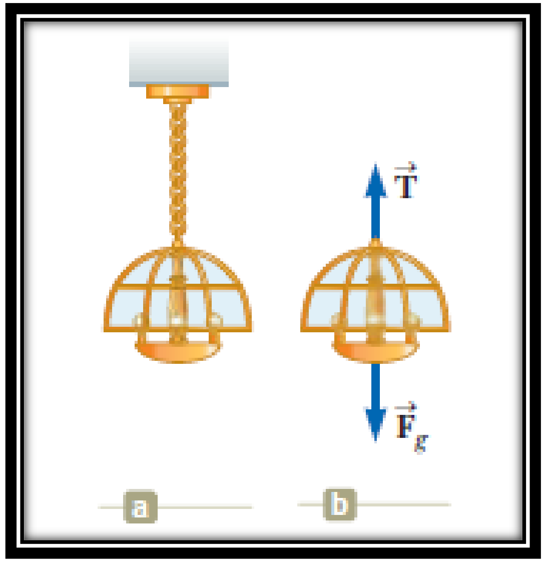


5.7 Analysis Models Using Newton's Second Law:

Analysis Model: The Particle in Equilibrium:

If the acceleration of an object modeled as a particle **is zero**, the object is treated with the **particle in equilibrium** model. In this model, the net force on the object is zero:

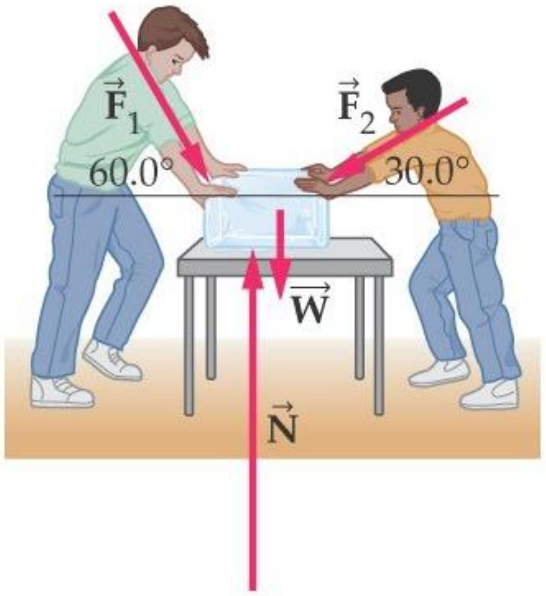
$$\sum \vec{F} = 0 \qquad (7)$$



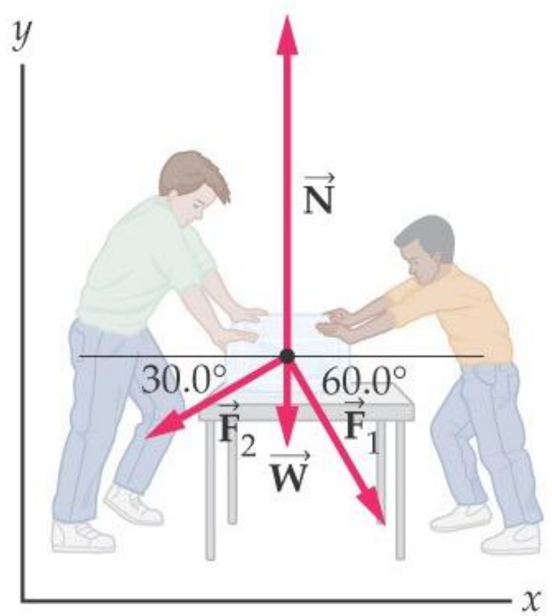
5.7 Analysis Models Using Newton's Second Law:

Analysis Model: The Particle Under a Net Force:

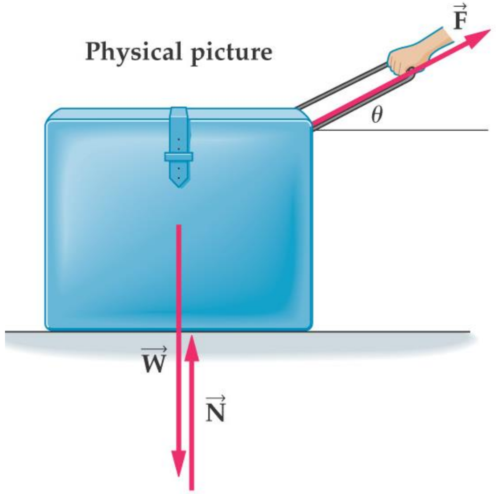
If an object experiences an acceleration, its motion can be analyzed with the **particle under a net force** model. The appropriate equation for this model is Newton's second law, Equation (2): $\sum \vec{F} = m\vec{a}$ (8)

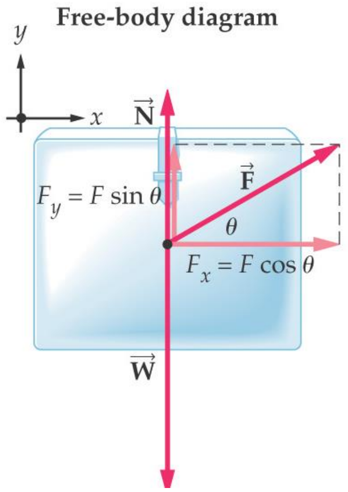


Physical picture



Free-body diagram





Example 5.4 A Traffic Light at Rest

A traffic light weighing 122 N hangs from a cable tied to two other cables fastened to a support as in Figure 5.10a. The upper cables make angles of 37.0° and 53.0° with the horizontal. These upper cables are not as strong as the vertical cable and will break if the tension in them exceeds 100 N. Does the traffic light remain hanging in this situation, or will one of the cables break?

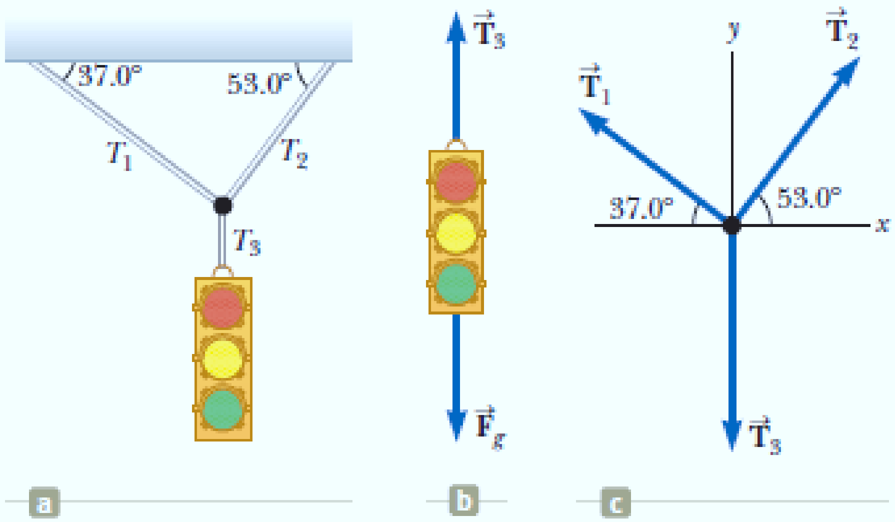


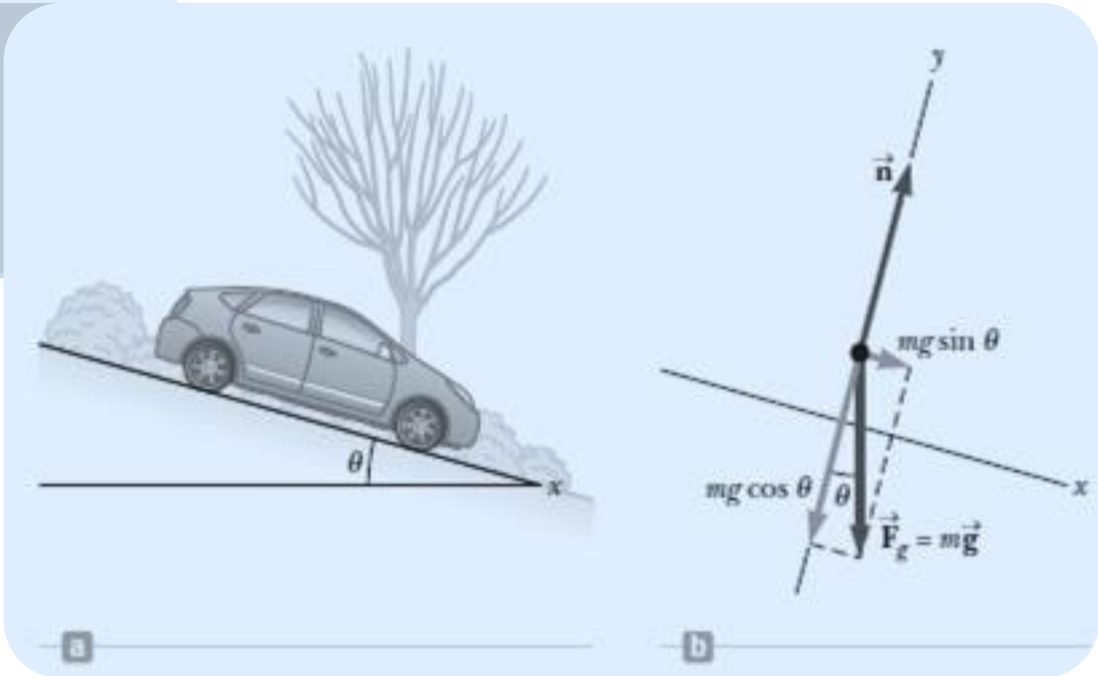
Figure 5.10 (Example 5.4) (a) A traffic light suspended by cables. (b) The forces acting on the traffic light. (c) The free-body diagram for the knot where the three cables are joined.

5.7 Analysis Models Using Newton's Second Law:

Example 5.6 **The Runaway Car**

A car of mass m is on an icy driveway inclined at an angle θ as in Figure 5.11a.

(A) Find the acceleration of the car, assuming the driveway is frictionless.



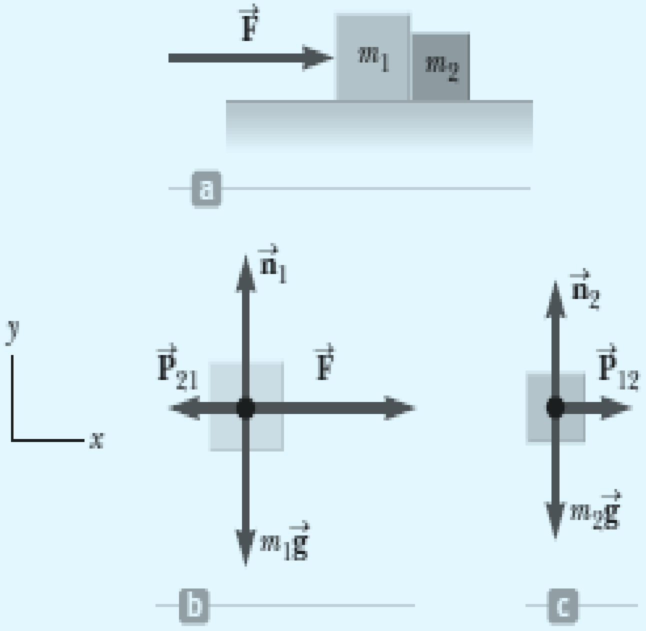
(B) Suppose the car is released from rest at the top of the incline and the distance from the car's front bumper to the bottom of the incline is d. How long does it take the front bumper to reach the bottom of the hill, and what is the car's speed as it arrives there?

5.7 Analysis Models Using Newton's Second Law:

Example 5.7 One Block Pushes Another

Two blocks of masses m_1 and m_2, with $m_1 > m_2$, are placed in contact with each other on a frictionless, horizontal surface as in Active Figure 5.12a. A constant horizontal force $\vec{F}$ is applied to m_1 as shown.

(A) Find the magnitude of the acceleration of the system.



ACTIVE FIGURE 5.12

(Example 5.7) (a) A force is applied to a block of mass m_1, which pushes on a second block of mass m_2. (b) The forces acting on m_1. (c) The forces acting on m_2.

(B) Determine the magnitude of the contact force between the two blocks.

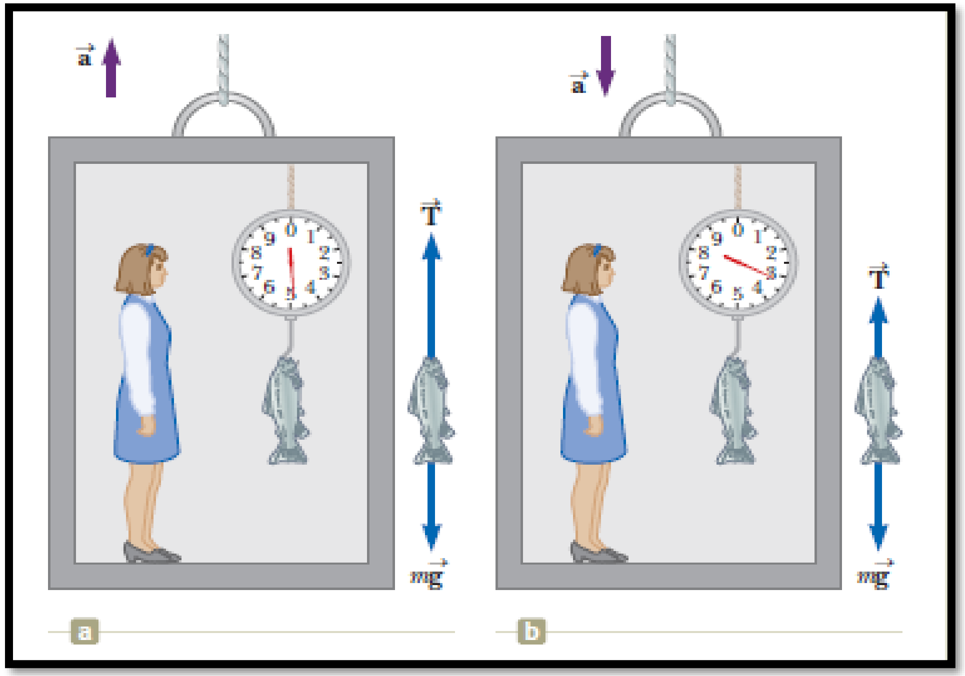
5.7 Analysis Models Using Newton's Second Law:

Example 5.8 Weighing a Fish in an Elevator

A person weighs a fish of mass m on a spring scale attached to the ceiling of an elevator as illustrated in Figure 5.13.

(A) Show that if the elevator accelerates either upward or downward, the spring scale gives a reading that is different from the weight of the fish.

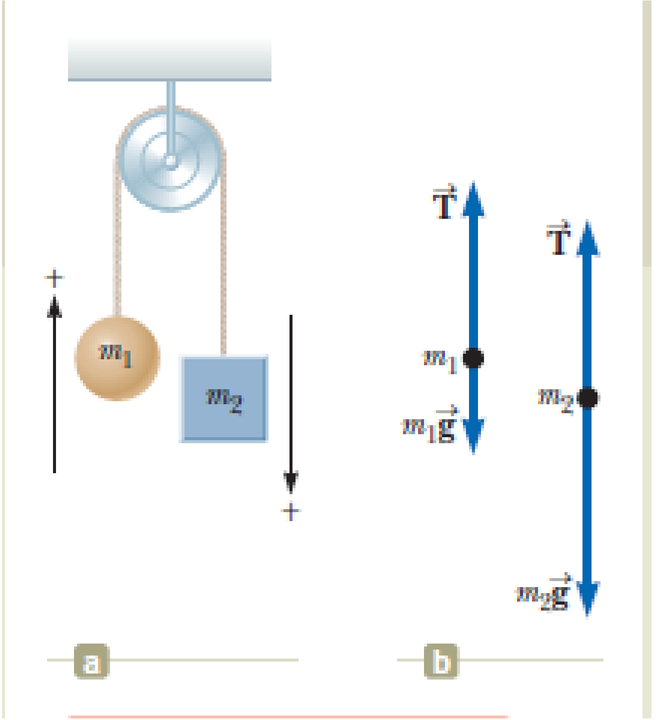
(B) Evaluate the scale readings for a 40.0-N fish if the elevator moves with an acceleration $a_y = \pm 2.00 \text{ m/s}^2$.



5.7 Analysis Models Using Newton's Second Law:

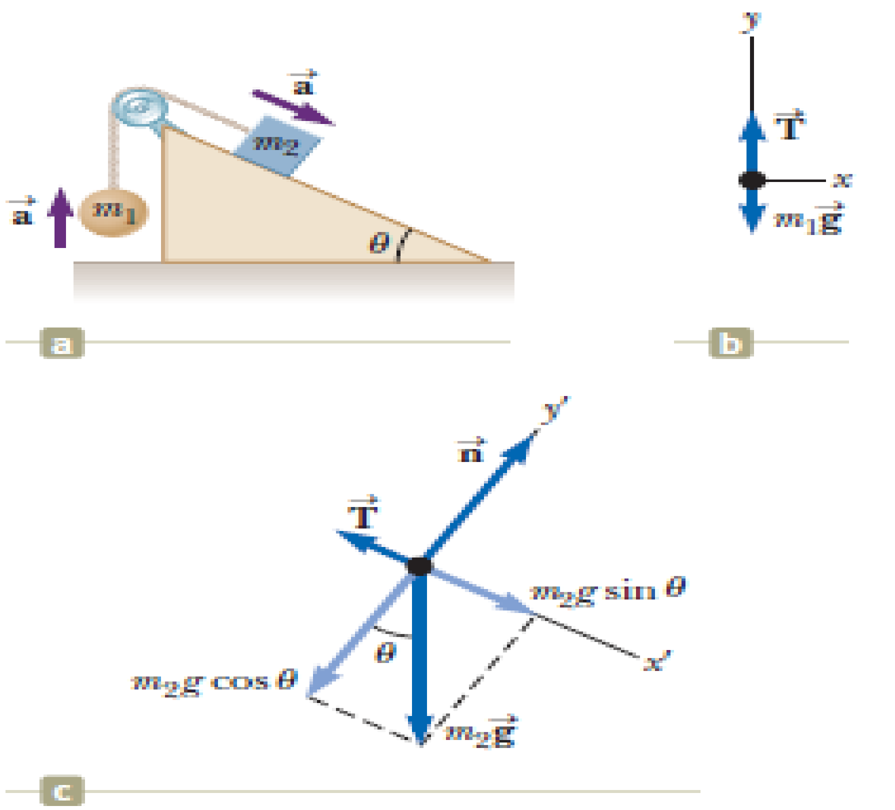
Example 5.9 The Atwood Machine

When two objects of unequal mass are hung vertically over a frictionless pulley of negligible mass as in Active Figure 5.14a, the arrangement is called an *Atwood machine*. The device is sometimes used in the laboratory to determine the value of *g*. Determine the magnitude of the acceleration of the two objects and the tension in the lightweight cord.



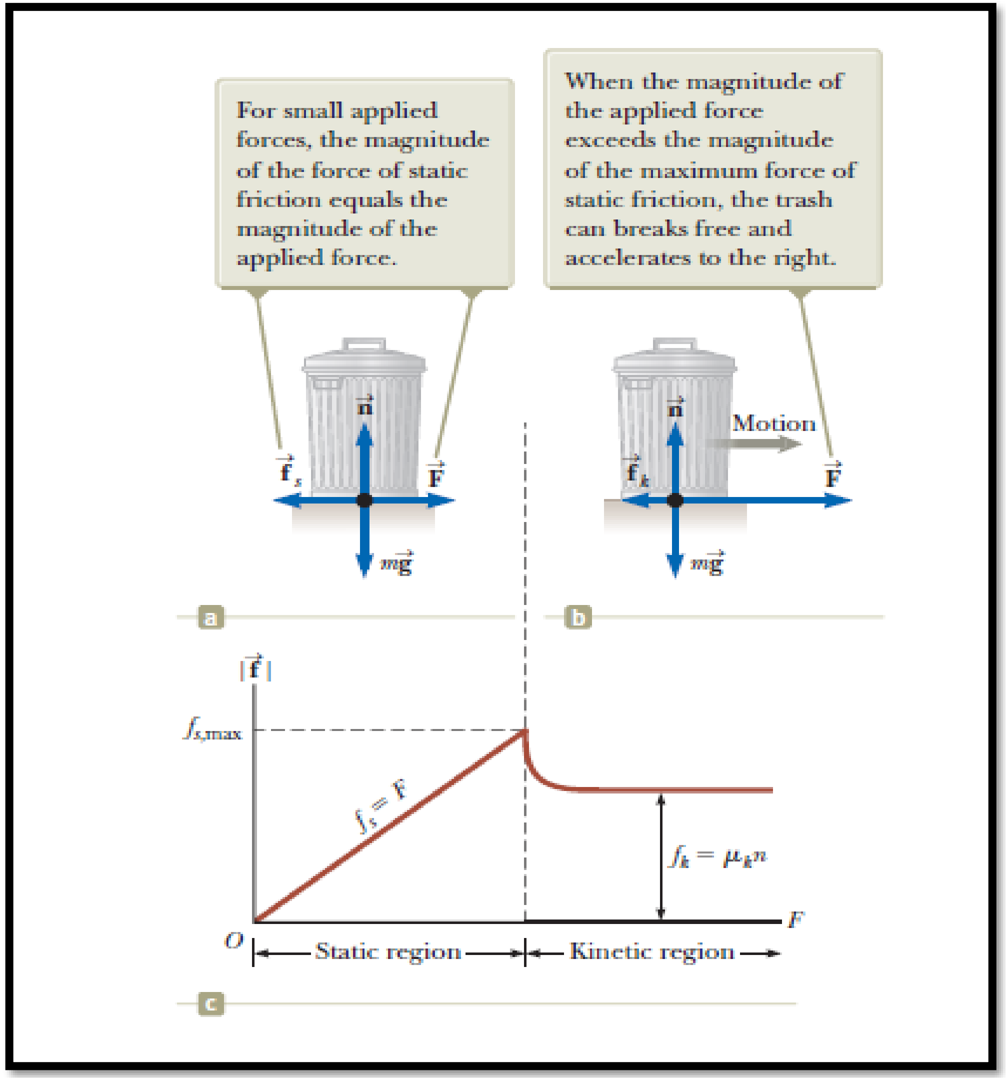
Example 5.10 Acceleration of Two Objects Connected by a Cord

A ball of mass m_1 and a block of mass m_2 are attached by a lightweight cord that passes over a frictionless pulley of negligible mass as in Figure 5.15a. The block lies on a frictionless incline of angle θ. Find the magnitude of the acceleration of the two objects and the tension in the cord.



5.8 Forces of Friction:

When an object is in motion either on a surface or in a viscous medium such as air or water, there is resistance to the motion because the object interacts with its surroundings. We call such resistance a **force of friction.**



5.8 Forces of Friction:

The following descriptions of the force of friction are based on experimental observations and serve as the model we shall use for forces of friction in problem solving:

The magnitude of the force of static friction between any two surfaces in contact can have the values:

$$f_s \le \mu_s n \qquad (9)$$

where the dimensionless constant μ_s is called the **coefficient of static friction** and *n* is the magnitude of the normal force exerted by one surface on the other.

The equality in Equation (9) holds when the surfaces are on the verge of slipping, that is, when $f_s = f_{s,max} = \mu_s n$. This situation is called *impending motion.* The inequality holds when the surfaces are not on the verge of slipping.

5.8 Forces of Friction:

The magnitude of the force of kinetic friction acting between two surfaces is

$$f_k = \mu_k n \qquad (10)$$

where μ_k is the **coefficient of kinetic friction.**

- The values of μ_k and μ_s depend on the nature of the surfaces, but μ_k is generally less than μ_s.
- The values range from around 0.03 to 1.0.(see the Table in next slide)

The direction of the friction force on an object is parallel to the surface with which the object is in contact and opposite to the actual motion (kinetic friction) or the impending motion (static friction) of the object relative to the surface.

5.8 Forces of Friction:

The coefficients of friction are nearly independent of the area of contact between the surfaces.

TABLE 5.1 *Coefficients of Friction*

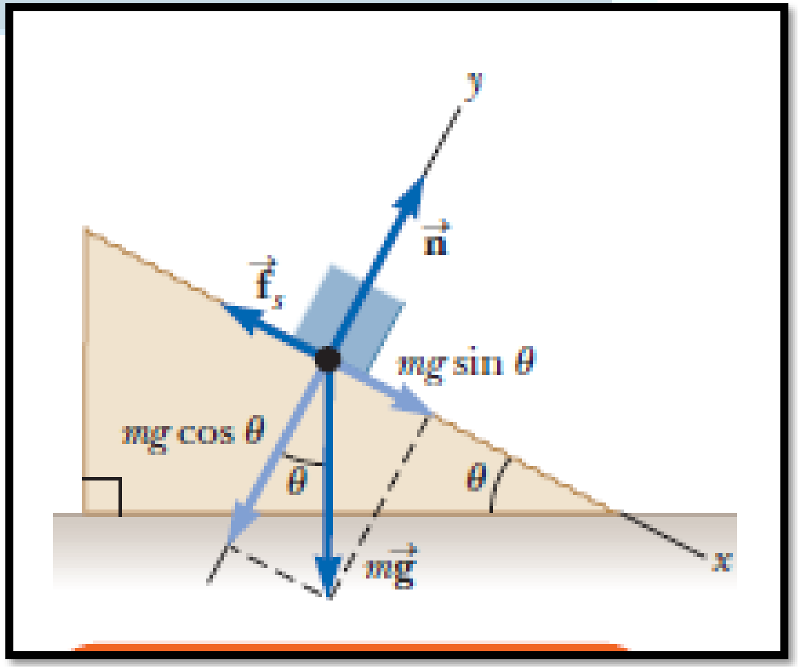
	μ_s	μ_k
Rubber on concrete	1.0	0.8
Steel on steel	0.74	0.57
Aluminum on steel	0.61	0.47
Glass on glass	0.94	0.4
Copper on steel	0.53	0.36
Wood on wood	0.25–0.5	0.2
Waxed wood on wet snow	0.14	0.1
Waxed wood on dry snow	—	0.04
Metal on metal (lubricated)	0.15	0.06
Teflon on Teflon	0.04	0.04
Ice on ice	0.1	0.03
Synovial joints in humans	0.01	0.003

Note: All values are approximate. In some cases, the coefficient of friction can exceed 1.0.

5.8 Forces of Friction:

Example 5.11 **Experimental Determination of μ_s and μ_k**

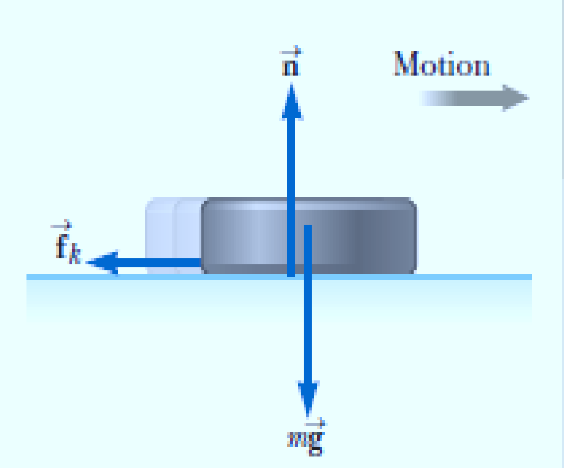
The following is a simple method of measuring coefficients of friction. Suppose a block is placed on a rough surface inclined relative to the horizontal as shown in Active Figure 5.18. The incline angle is increased until the block starts to move. Show that you can obtain μ_s by measuring the critical angle θ_c at which this slipping just occurs.



5.8 Forces of Friction:

Example 5.12 **The Sliding Hockey Puck**

A hockey puck on a frozen pond is given an initial speed of 20.0 m/s. If the puck always remains on the ice and slides 115 m before coming to rest, determine the coefficient of kinetic friction between the puck and ice.



5.8 Forces of Friction:

Example 5.13 Acceleration of Two Connected Objects When Friction Is Present

A block of mass m_2 on a rough, horizontal surface is connected to a ball of mass m_1 by a lightweight cord over a lightweight, frictionless pulley as shown in Figure 5.20a. A force of magnitude F at an angle θ with the horizontal is applied to the block as shown, and the block slides to the right. The coefficient of kinetic friction between the block and surface is μ_k. Determine the magnitude of the acceleration of the two objects.