Chapter 4

Newton's Laws of Motion

PowerPoint® Lectures for
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Goals for Chapter 4

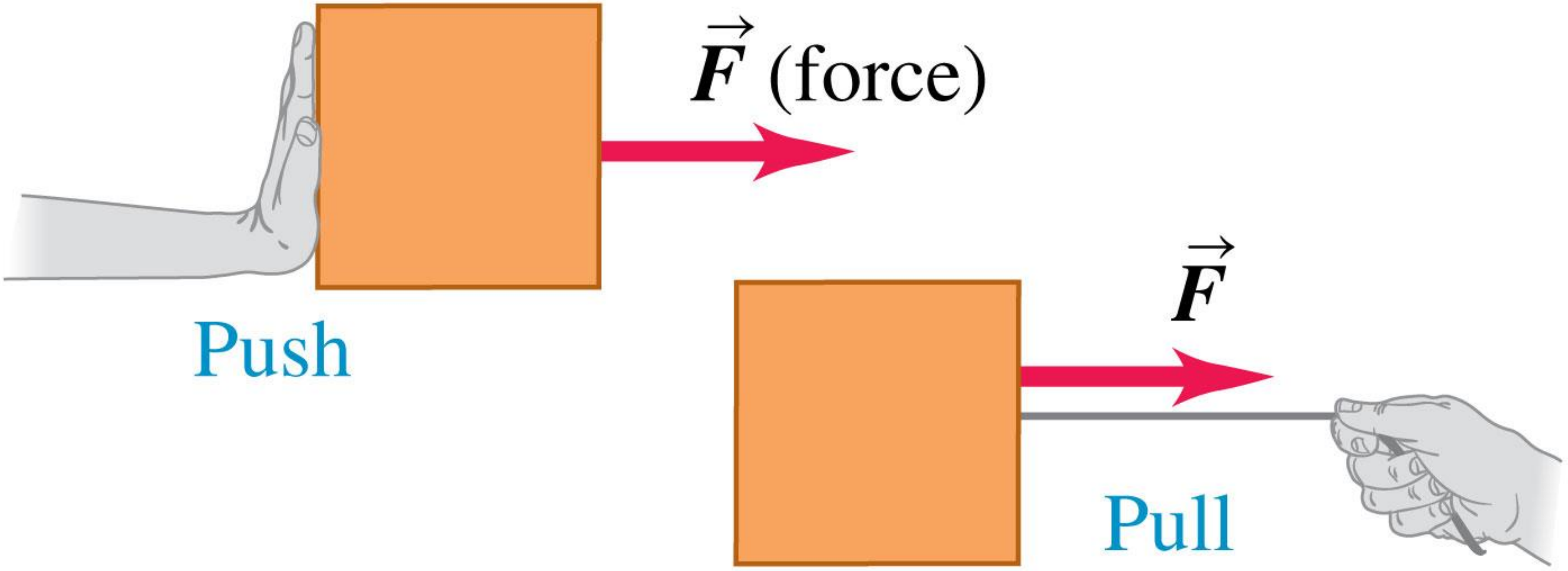
- To understand the meaning of force in physics
- To view force as a vector and learn how to combine forces
- To understand the behavior of a body on which the forces balance: Newton's First Law of Motion
- To learn the relationship between mass, acceleration, and force: Newton's Second Law of Motion
- To relate mass and weight
- To see the effect of action-reaction pairs: Newton's Third Law of Motion
- To learn to make free-body diagrams

Introduction

- We’ve studied motion in one, two, and three dimensions… but what *causes* motion?
- This causality was first understood in the late 1600s by Sir Isaac Newton.
- Newton formulated three laws governing moving objects, which we call *Newton’s laws of motion*.
- Newton’s laws were deduced from huge amounts of *experimental evidence*.
- The laws are simple to state but intricate in their application.

What are some properties of a force?

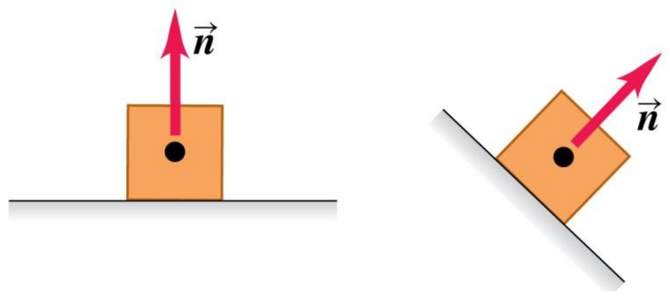
- A force is a push or a pull.
- A force is an interaction between two objects or between an object and its environment.
- A force is a vector quantity, with magnitude and direction.



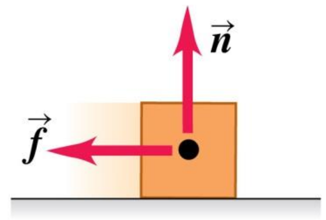
There are four common types of forces

- The *normal force*: When an object pushes on a surface, the surface pushes back on the object perpendicular to the surface. This is a contact force.
- *Friction force*: This force occurs when a surface resists sliding of an object and is parallel to the surface. Friction is a contact force.

(a) **Normal force $\vec{n}$:** When an object rests or pushes on a surface, the surface exerts a push on it that is directed perpendicular to the surface.



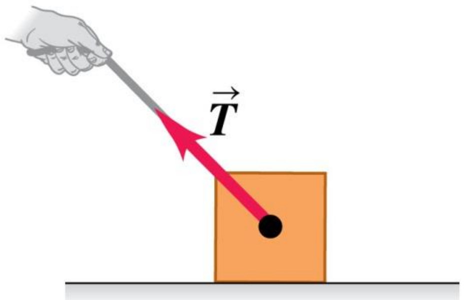
(b) **Friction force $\vec{f}$:** In addition to the normal force, a surface may exert a frictional force on an object, directed parallel to the surface.



There are four common types of forces II

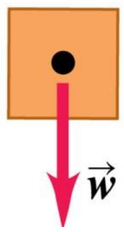
- *Tension force*: A pulling force exerted on an object by a rope or cord. This is a contact force.

(c) Tension force $\vec{T}$: A pulling force exerted on an object by a rope, cord, etc.



- *Weight*: The pull of gravity on an object. This is a long-range force.

(d) Weight $\vec{w}$: The pull of gravity on an object is a long-range force (a force that acts over a distance).



What are the magnitudes of common forces?

Table 4.1 Typical Force Magnitudes

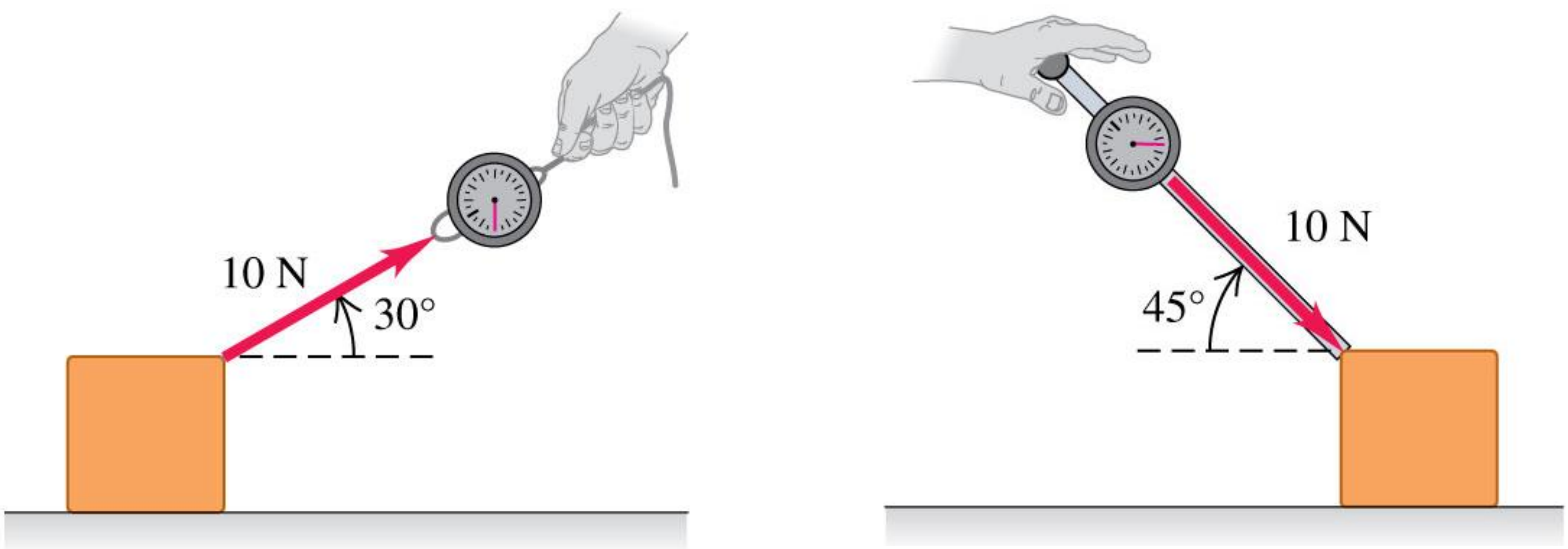
Sun's gravitational force on the earth	3.5×10^{22} N
Thrust of a space shuttle during launch	3.1×10^{7} N
Weight of a large blue whale	1.9×10^{6} N
Maximum pulling force of a locomotive	8.9×10^{5} N
Weight of a 250-lb linebacker	1.1×10^{3} N
Weight of a medium apple	1 N
Weight of smallest insect eggs	2×10^{-6} N
Electric attraction between the proton and the electron in a hydrogen atom	8.2×10^{-8} N
Weight of a very small bacterium	1×10^{-18} N
Weight of a hydrogen atom	1.6×10^{-26} N
Weight of an electron	8.9×10^{-30} N
Gravitational attraction between the proton and the electron in a hydrogen atom	3.6×10^{-47} N

Drawing force vectors—Figure 4.3

- Use a vector arrow to indicate the magnitude and direction of the force.

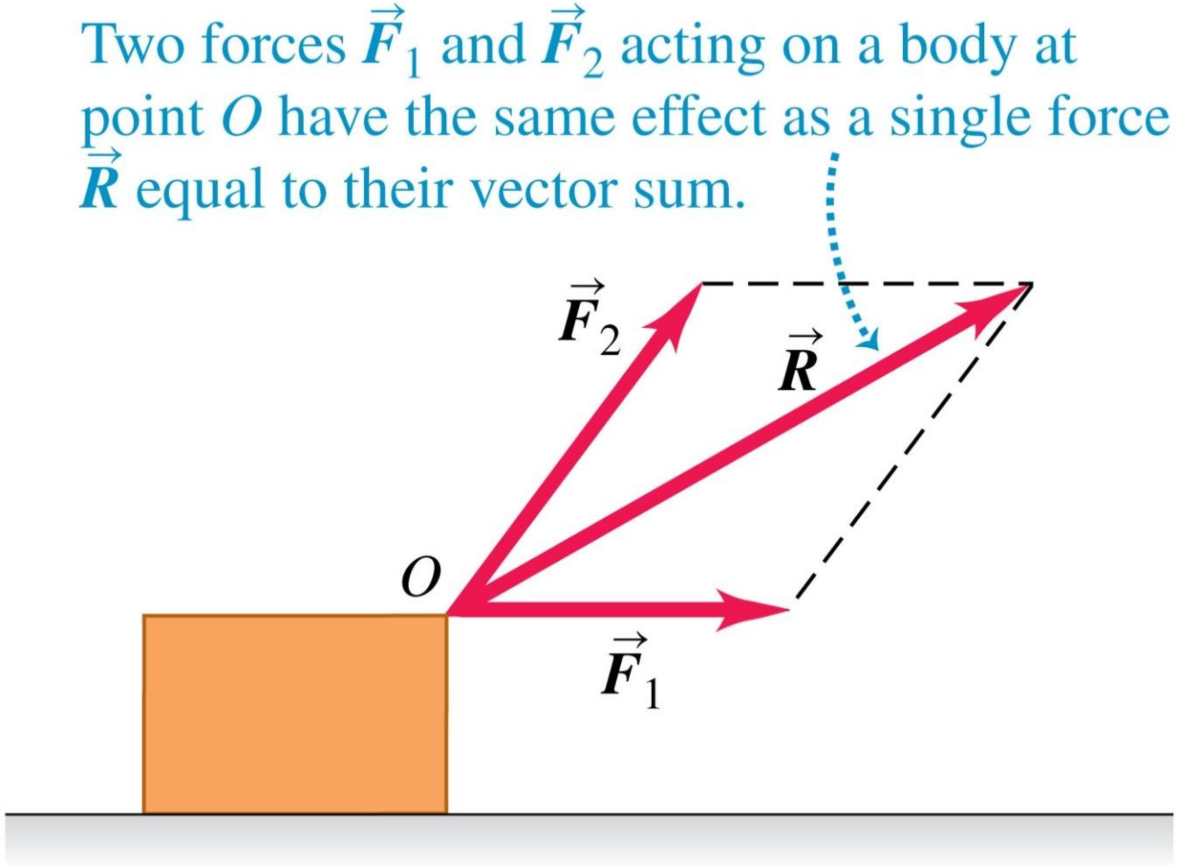
(a) A 10-N pull directed 30° above the horizontal

(b) A 10-N push directed 45° below the horizontal



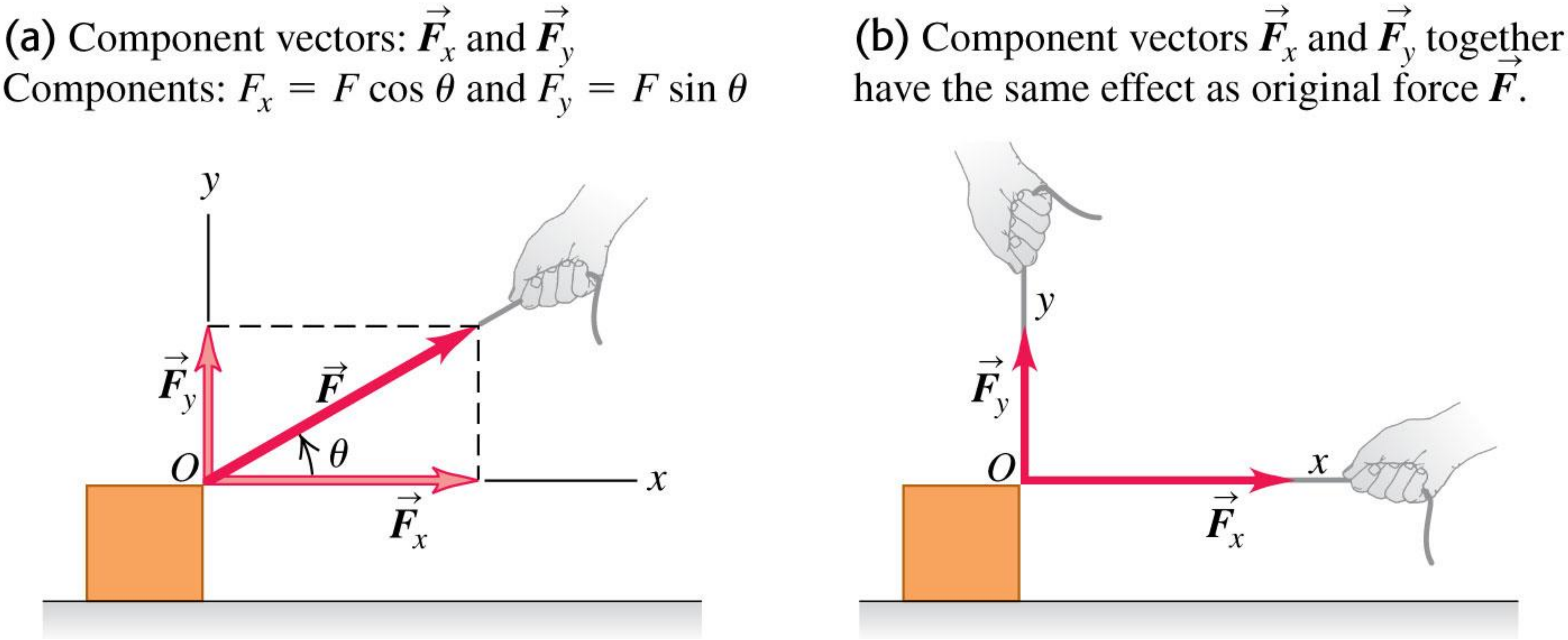
Superposition of forces—Figure 4.4

- Several forces acting at a point on an object have the same effect as their vector sum acting at the same point.



Decomposing a force into its component vectors

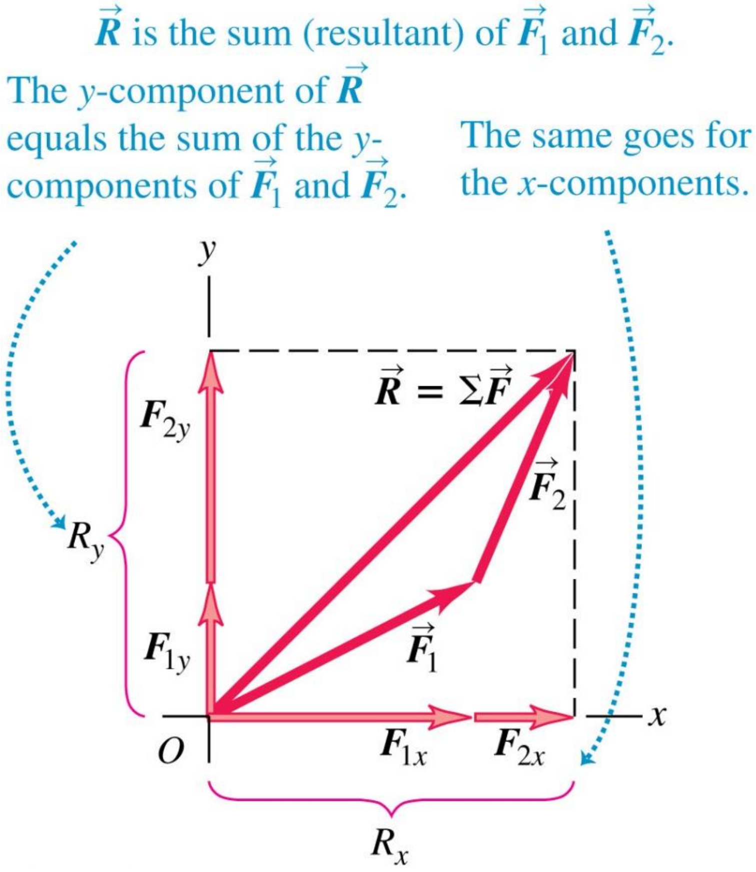
- Choose perpendicular x and y axes.
- F_x and F_y are the components of a force along these axes.
- Use trigonometry to find these force components.



Notation for the vector sum

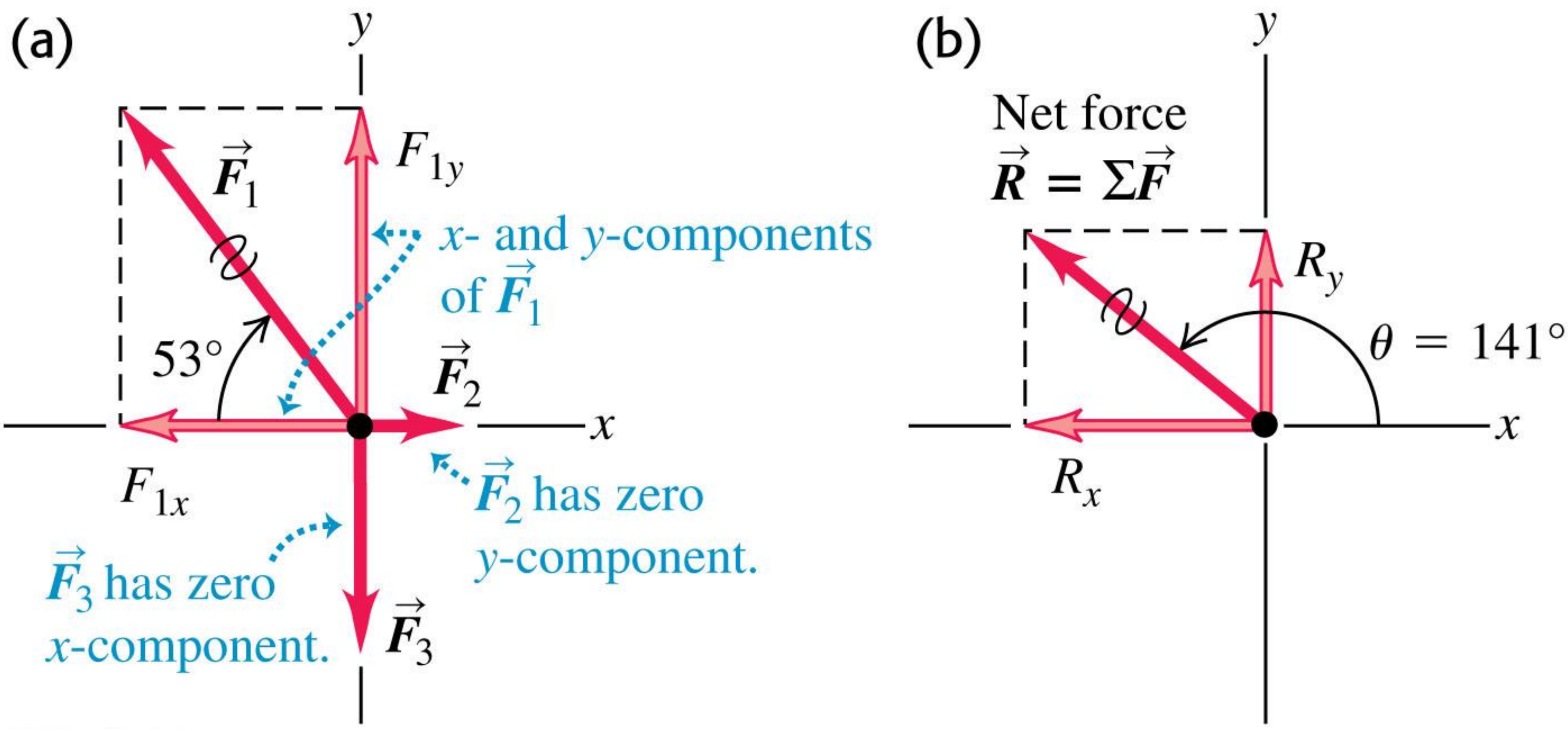
- The vector sum of all the forces on an object is called the *resultant* of the forces or the *net forces*.

$$\vec{R} = \vec{F}_1 + \vec{F}_2 + \vec{F}_3 + \cdots = \sum \vec{F}$$



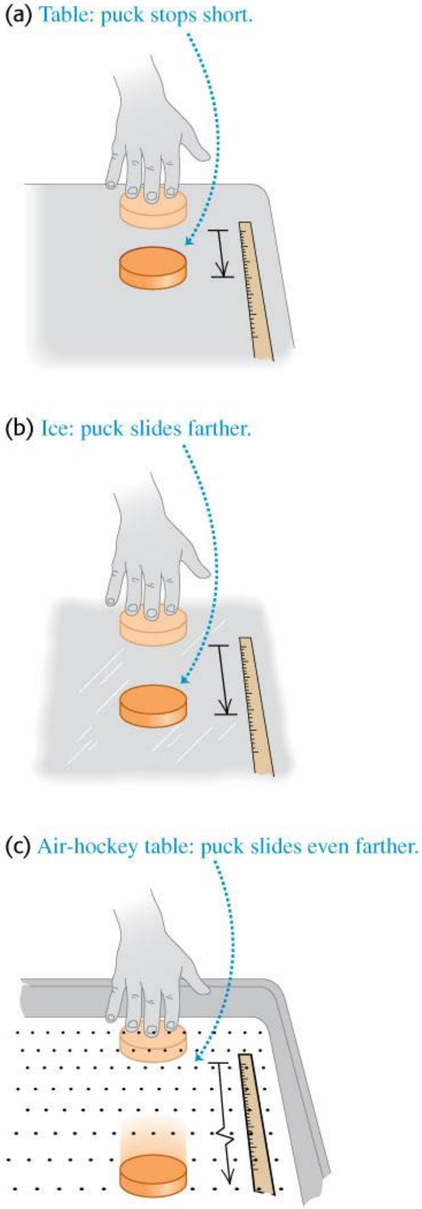
Superposition of forces—Example 4.1

- Force vectors are most easily added using components: $R_x = F_{1x} + F_{2x} + F_{3x} + \ldots$, $R_y = F_{1y} + F_{2y} + F_{3y} + \ldots$. See Example 4.1 (which has three forces).



Newton's First Law

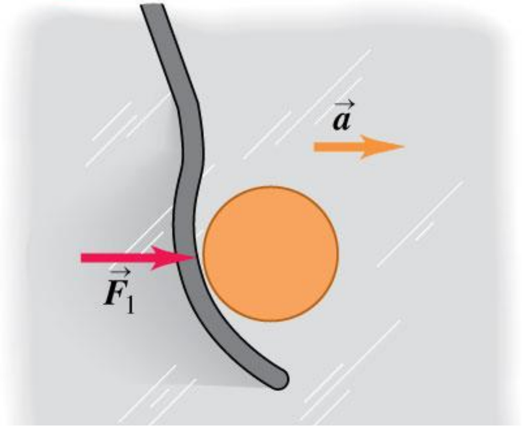
- Simply stated — "An object at rest tends to stay at rest, an object in motion tends to stay in uniform motion."
- More properly, "A body acted on by zero net force moves with constant velocity and zero acceleration."



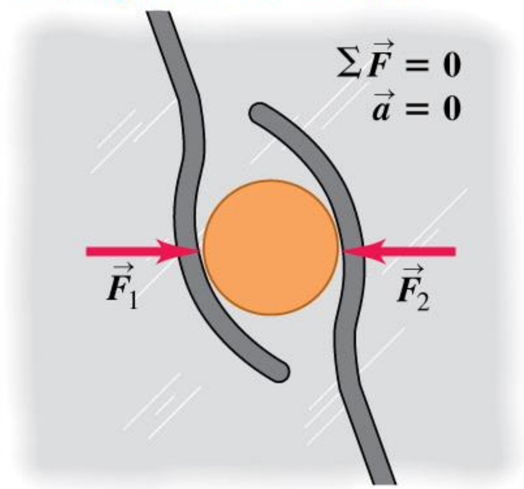
Newton's First Law II—Figure 4.10

- In part (a) of Figure 4.10 a net force acts, causing acceleration.
- In part (b) the net force is zero, resulting in no acceleration.

(a) A puck on a frictionless surface accelerates when acted on by a single horizontal force.



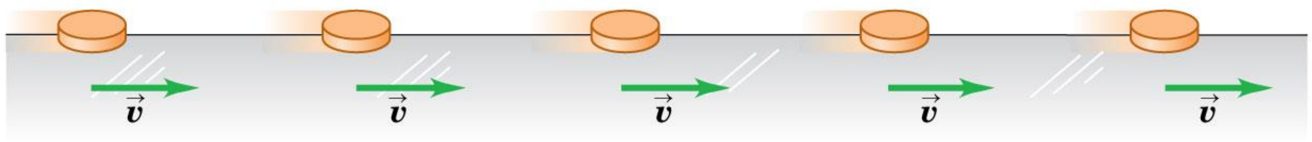
(b) An object acted on by forces whose vector sum is zero behaves as though no forces act on it.



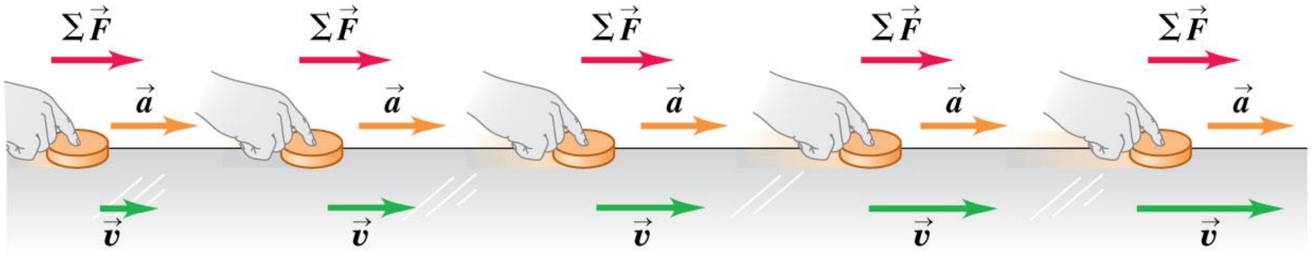
Newton's Second Law

- If the net force on an object is not zero, it causes the object to accelerate.

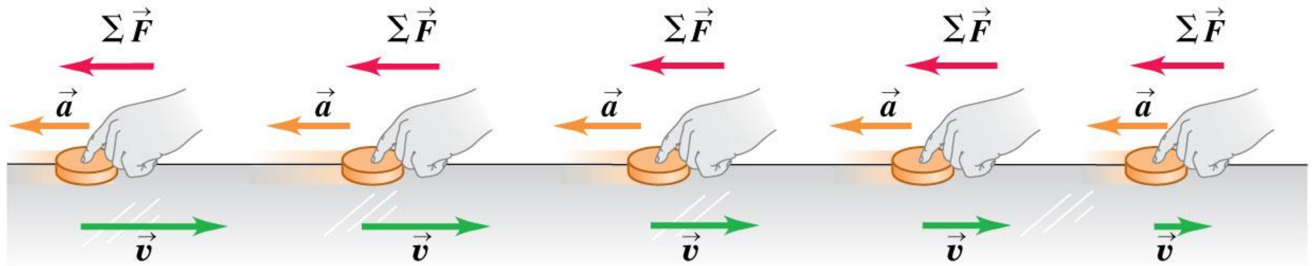
(a) A puck moving with constant velocity (in equilibrium): $\sum\vec{F} = \mathbf{0}$, $\vec{a} = \mathbf{0}$



(b) A constant net force in the direction of motion causes a constant acceleration in the same direction as the net force.

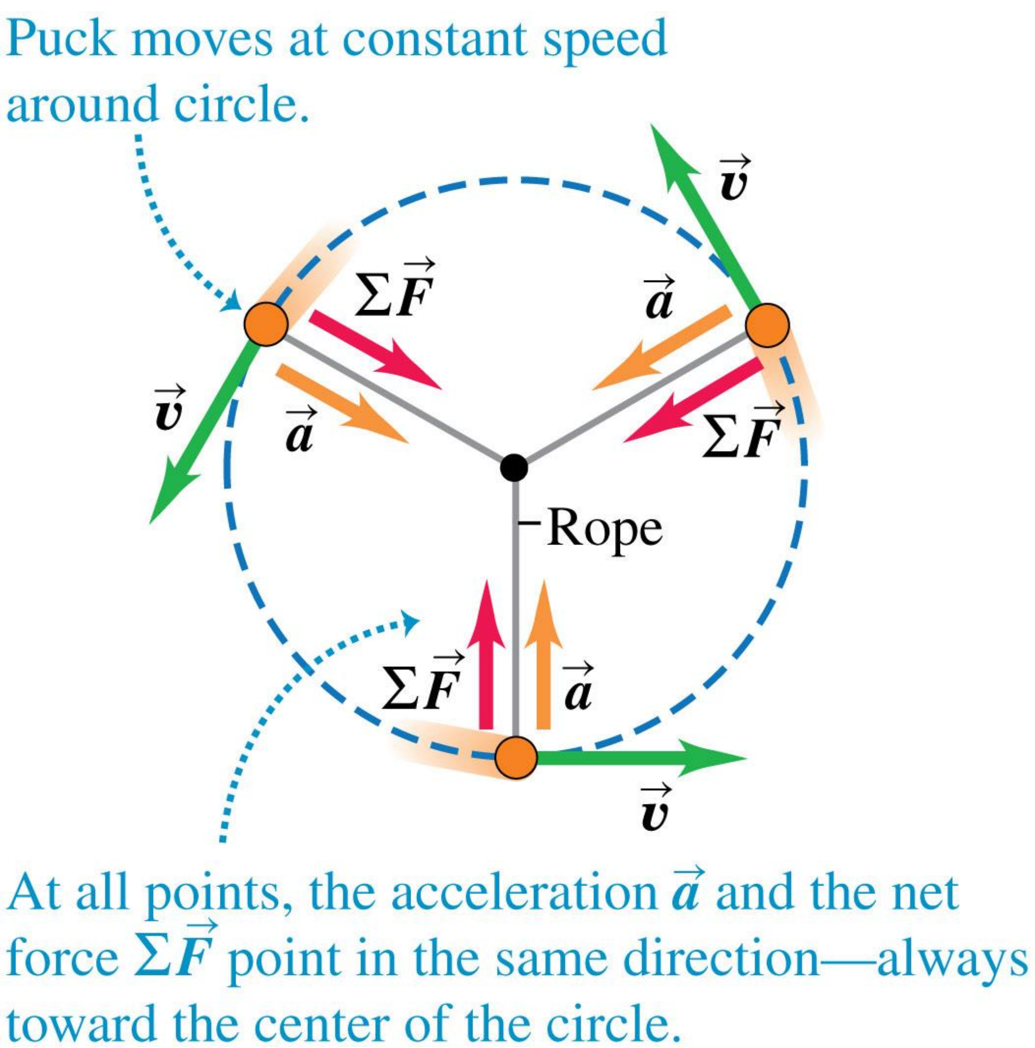


(c) A constant net force opposite the direction of motion causes a constant acceleration in the same direction as the net force.



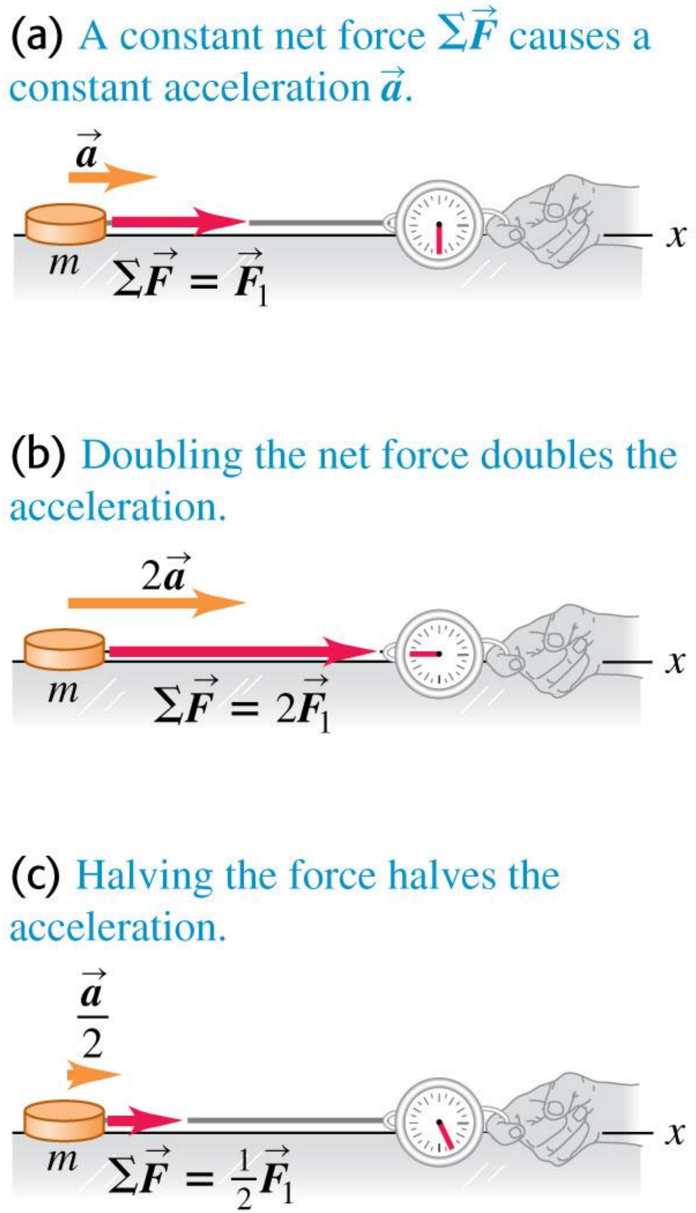
An object undergoing uniform circular motion

- As we have already seen, an object in uniform circular motion is accelerated toward the center of the circle. So the net force on the object must point toward the center of the circle. (Refer to Figure 4.14.)



Force and acceleration

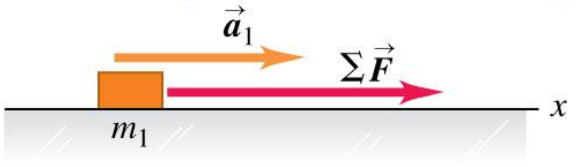
- The acceleration $\vec{a}$ of an object is directly proportional to the net force $\Sigma\vec{F}$ on the object.



Mass and acceleration

- The acceleration of an object is inversely proportional to the object's mass if the net force remains fixed.

(a) A known force $\sum\vec{F}$ causes an object with mass m_1 to have an acceleration $\vec{a}_1$.



(b) Applying the same force $\sum\vec{F}$ to a second object and noting the acceleration allow us to measure the mass.

(c) When the two objects are fastened together, the same method shows that their composite mass is the sum of their individual masses.

Newton's second law of motion

- The acceleration of an object is directly proportional to the net force acting on it, and inversely proportional to the mass of the object.

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

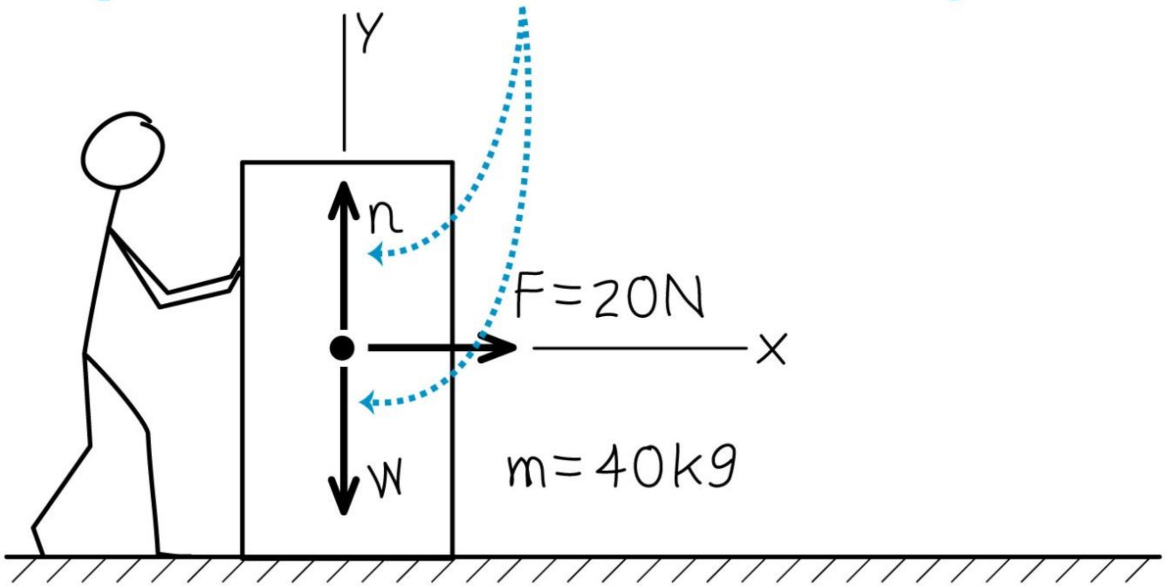
- The SI unit for force is the newton (N).

$$1\ \text{N} = 1\ \text{kg}\cdot\text{m/s}^2$$

Using Newton's Second Law—Example 4.4

A worker applies a constant horizontal force with magnitude 20 N to a box with mass 40 kg resting on a level floor with negligible friction. What is the acceleration of the box.

The box has no vertical acceleration, so the vertical components of the net force sum to zero. Nevertheless, for completeness, we show the vertical forces acting on the box.

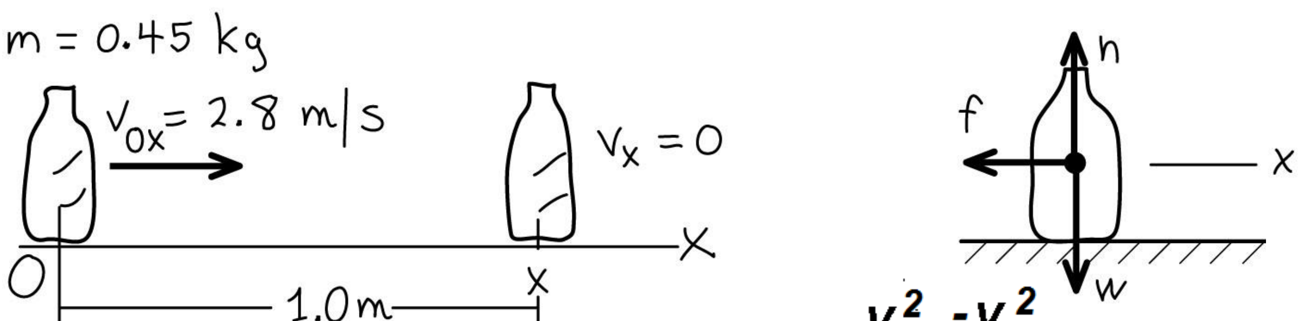


$\Sigma F = F = 20\ \mathrm{N} = ma \qquad a = \frac{F}{a} = \frac{20\ N}{40\ kg} = 0.5\ m/s^2$

Using Newton's Second Law II—Example 4.5

A waitress shoves a bottle with mass 0.45 kg to her right along smooth, level counter. The bottle leaves her hand moving at 2.8 m/s, then slows down as it slides because of a constant friction force exerted on it the countertop. It slides 1.0 m before coming to rest What are the magnitude and direction of the friction force?

We draw one diagram for the bottle's motion and one showing the forces on the bottle.



First find acceleration from equation $x = \frac{v_{xf}^2 - v_{xi}^2}{2a}$, obtain $a = \frac{v_{xf}^2 - v_{xi}^2}{2x}$

$a = \frac{0-\left(\frac{2.8m}{s}\right)^2}{2*1m} = -3.9m/s^2$ $F_{net} = f = ma = 0.45\text{ kg}*(-3.9\text{m/s}^2) = -1.8\text{N}$

Systems of units (Table 4.2)

- We will use the SI system.
- In the British system, force is measured in *pounds*, distance in feet, and mass in *slugs*.
- In the cgs system, mass is in grams, distance in centimeters, and force in *dynes*.

Table 4.2 Units of Force, Mass, and Acceleration

System of Units	Force	Mass	Acceleration
SI	newton (N)	kilogram (kg)	m/s^2
cgs	dyne (dyn)	gram (g)	cm/s^2
British	pound (lb)	slug	ft/s^2

Mass and weight

- The *weight* of an object (on the earth) is the gravitational force that the earth exerts on it.
- The weight W of an object of mass m is

$$W = mg$$

- The value of g depends on altitude.
- On other planets, g will have an entirely different value than on the earth.

Example

A high diver of mass 70 kg jumps off a board 10 m above the water, If her downward motion is stopped 2 s after she enters the water what average upward force did the water exert on her?

(1) Find v just before the diver hits the water from equation $y = \frac{v_f^2 - v_i^2}{-2g}$

V_i=0 **$v_f = (2yg)^{1/2} = 14$ m/s donward**

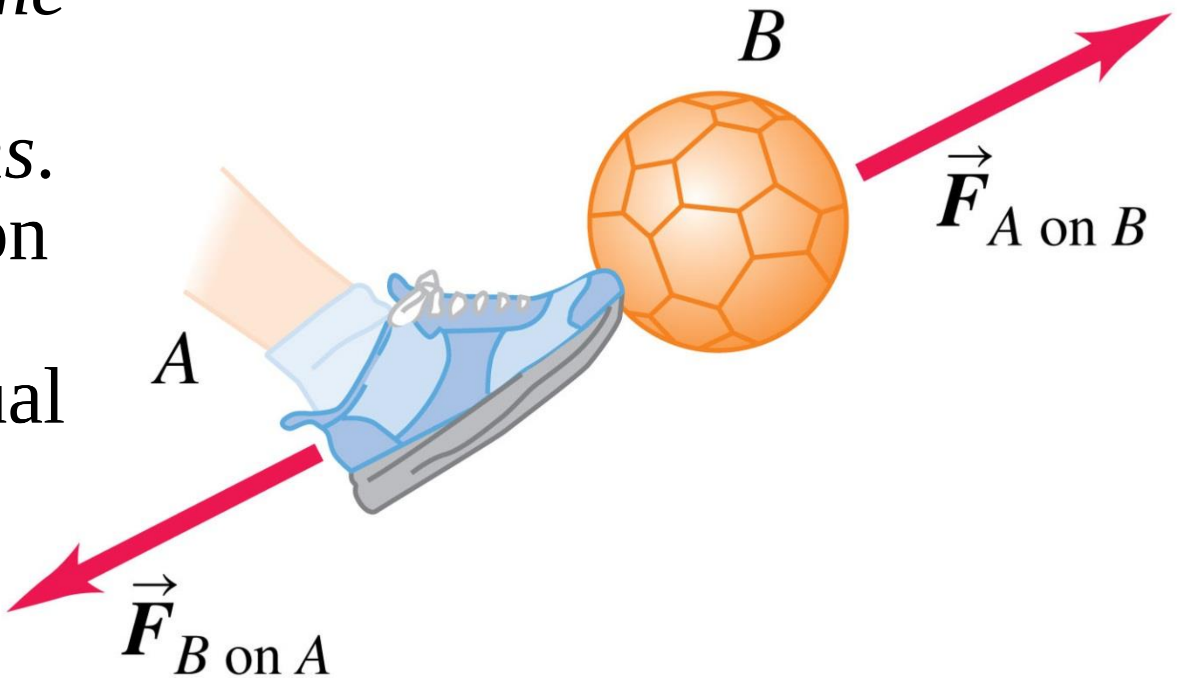
(2) Find deceleration in the water: $v = v_i - at$ **a=14 m/s/2s =7m/s^2 upward**

(3) Find the force from $F_{net} = ma$ F-mg=ma F = m(g+a) =

70kg(9.8+7.0) = 1176 N

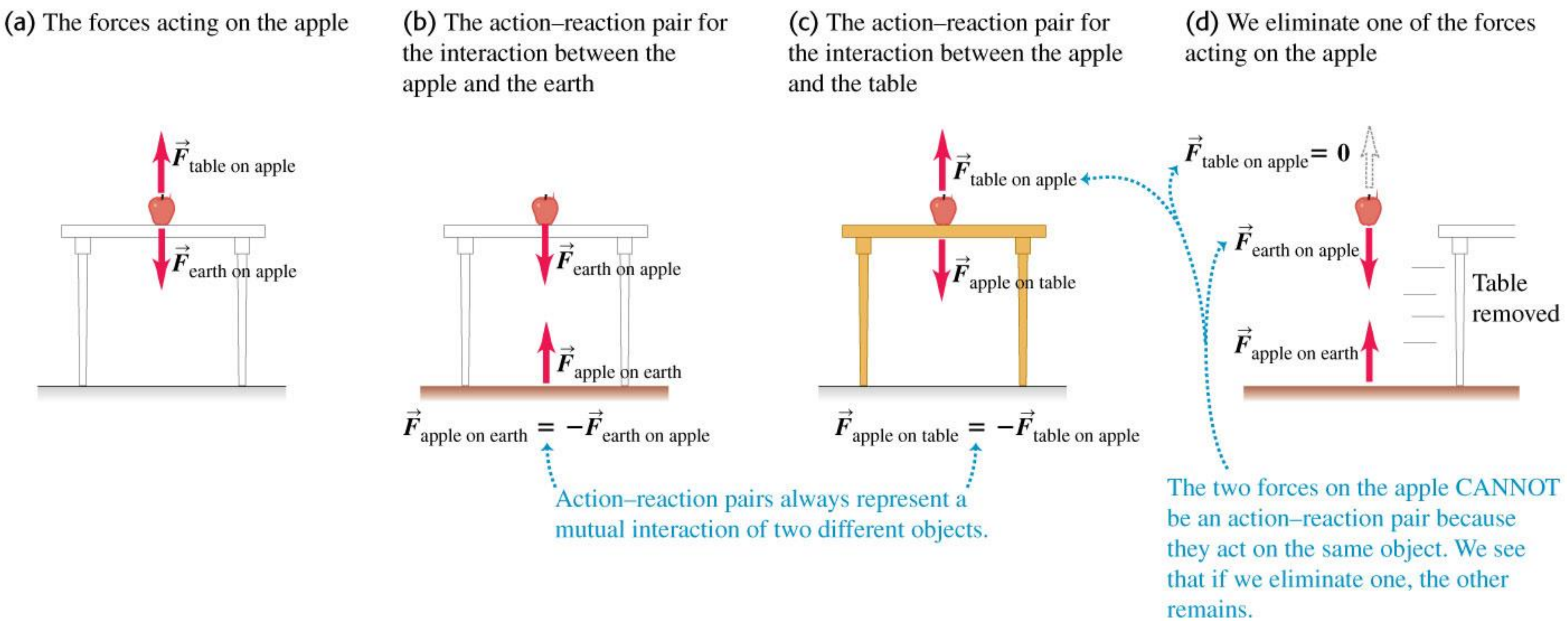
Newton's Third Law

- If you exert a force on a body, the body always exerts a force (the "reaction") back upon you.
- Figure 4.25 shows "an action-reaction pair."
- A force and its reaction force have the *same magnitude but opposite directions*. These forces act on *different bodies*. [Follow Conceptual Example 4.8]



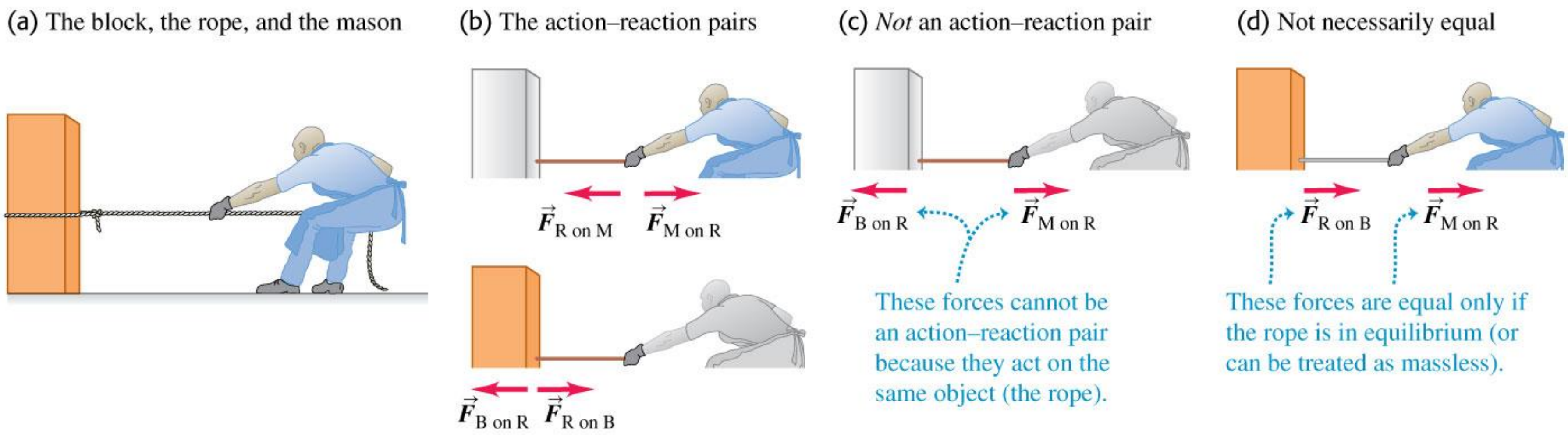
Applying Newton's Third Law: Objects at rest

- An apple rests on a table. Identify the forces that act on it and the action-reaction pairs. [Follow Conceptual Example 4.9]



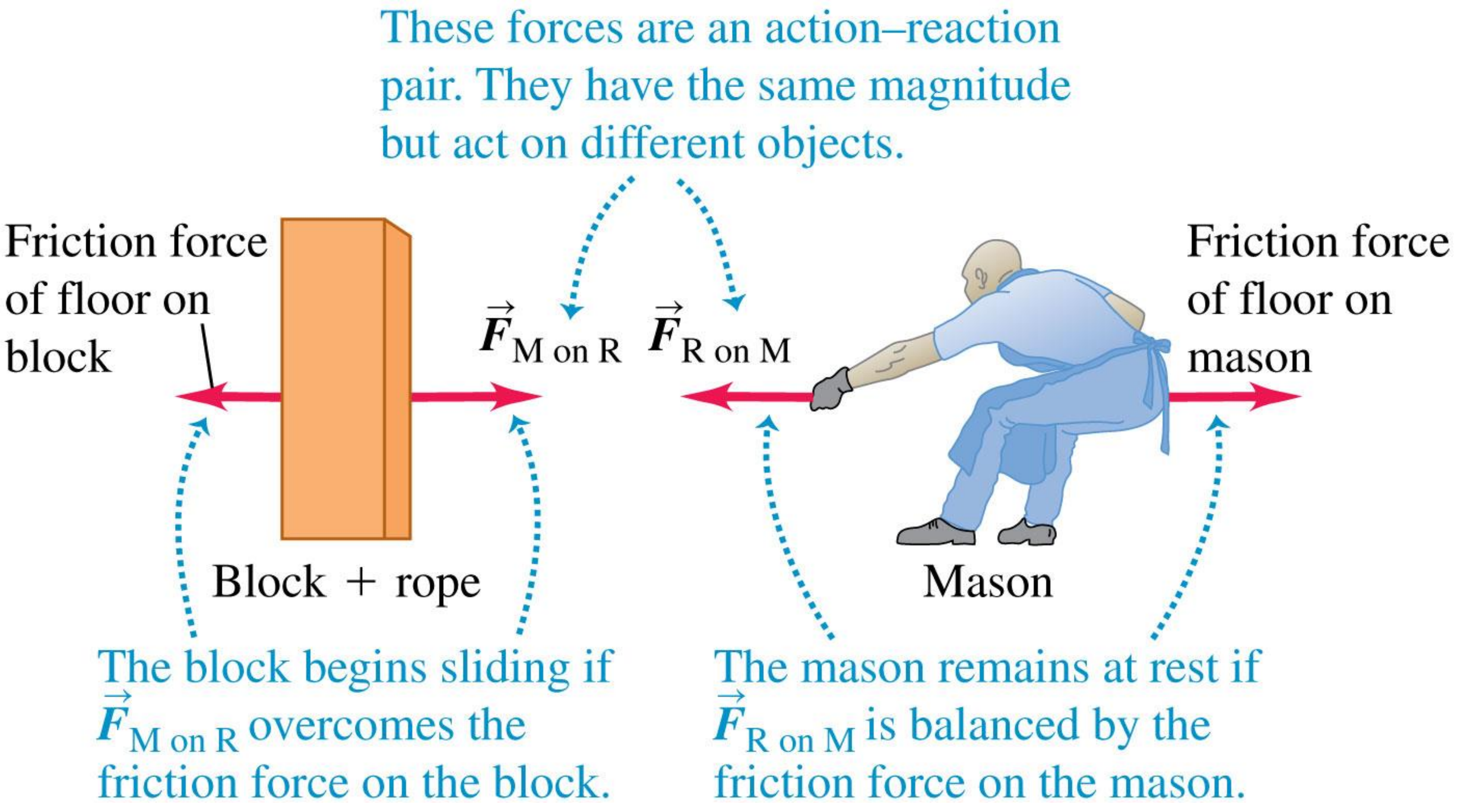
Applying Newton's Third Law: Objects in motion

- A person pulls on a block across the floor. Identify the action-reaction pairs.



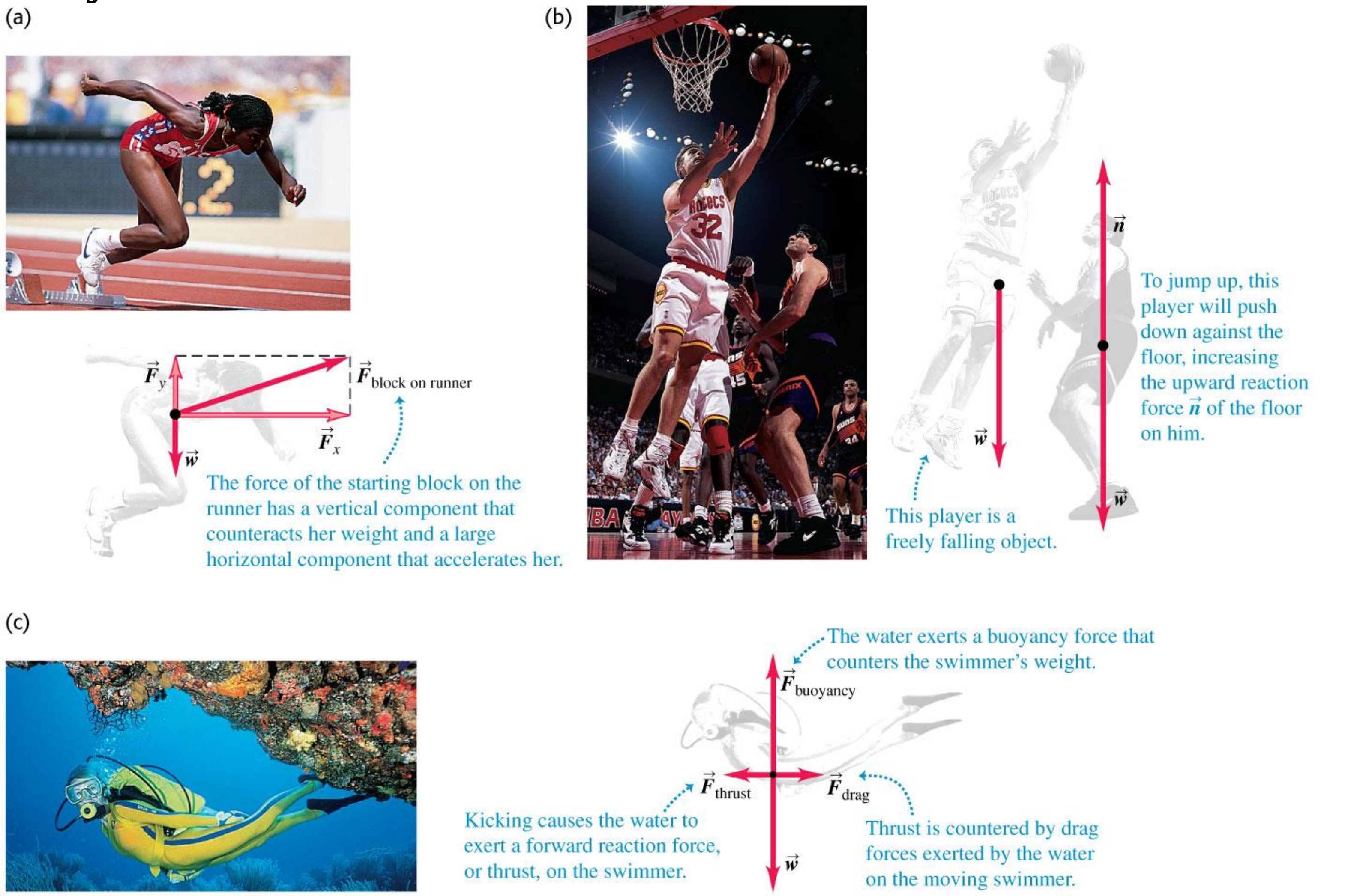
A paradox?

- If an object pulls back on you just as hard as you pull on it, how can it ever accelerate?

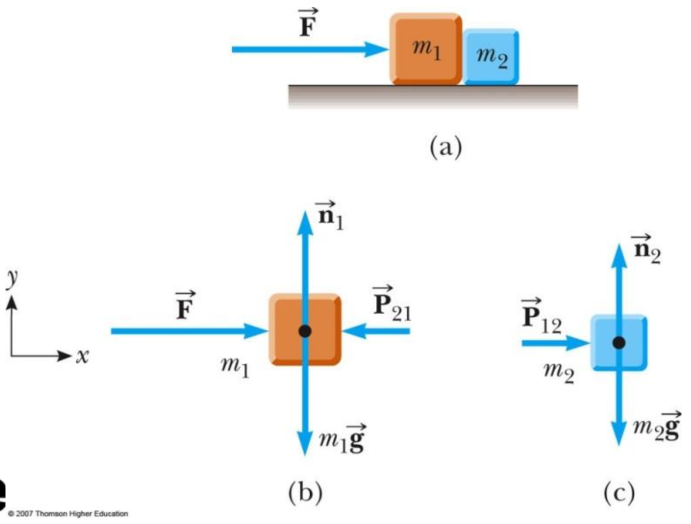


Free-body diagrams—Figure 4.30

- A *free-body diagram* is a sketch showing all the forces acting on an object.



Multiple Objects, Example



Two blocks of masses m_1=10kg and m_2 =7 kg are placed in contact with each other on a frictionless surface. A constant horizontal force F =12 N is applied to m_1. a) Find the acceleration of the system. b) Find the magnitude of the contact force between the two blocks.

(a) $P = m_2 a \quad F - P = m_1 a \quad F - m_2 a = m_1 a$

$$a = \frac{F}{m_1 + m_2} = 0.7 m/s^2$$

(a) $P = m_2 a \quad P = 7\ kg * 0.7\ m/s^2 = 4.94\ N$