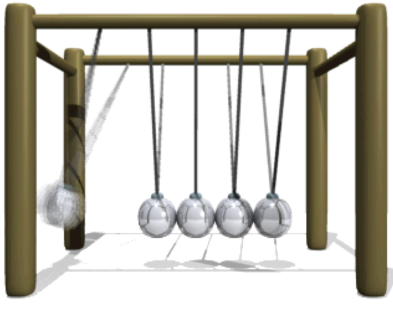
CHAPTER V

FORCE

MOTION I



Mechanics of Particle Motion

Newtonian Mechanics

- Sir Isaac Newton (1642-1727)
- Three laws relating force and motion
- Valid for a wide range of speed and scale of interacting bodies

Special Theory of relativity

- Albert Einstein (1879-1955)
- Holds for all speed including close to speed of light
- Replaces Newtonian Mechanics for very large speed

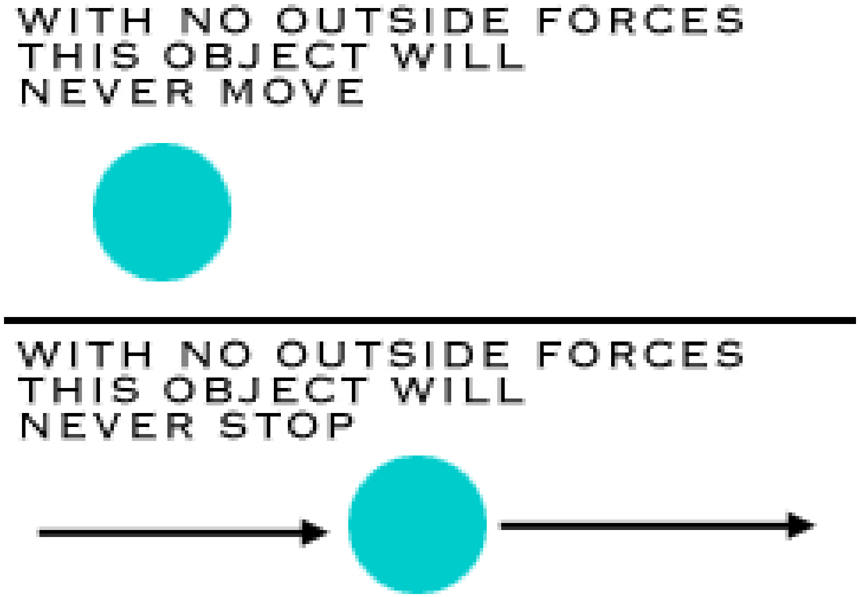
Quantum Mechanics

- Replaces Newtonian Mechanics for interacting bodies on the scale of atomic structure

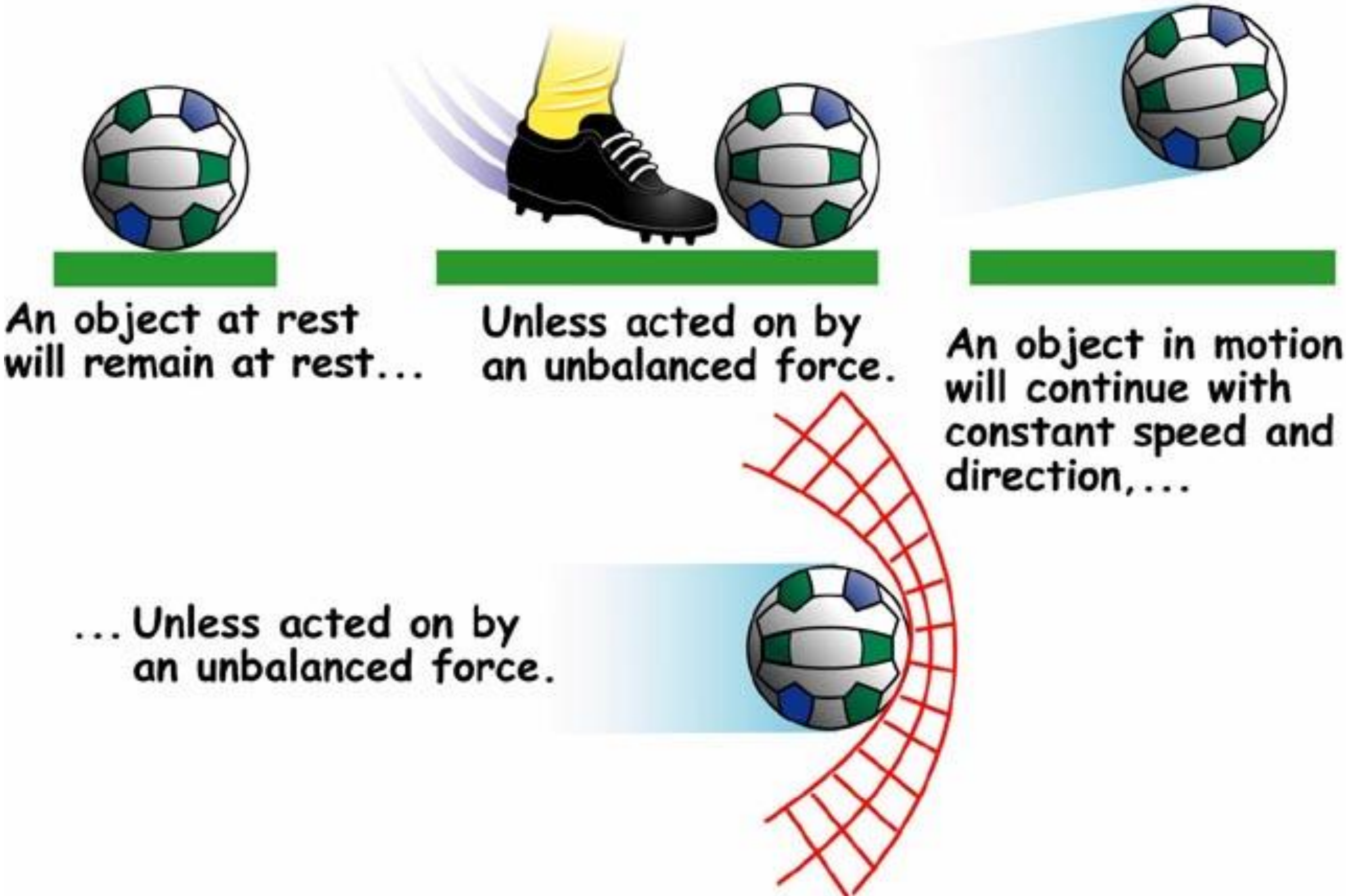
Newton’s First Law

✓ A body at rest tends to remain at rest & a body in motion at a constant velocity will tend to maintain the velocity.

If no force acts on a body, the body’s velocity cannot change; that is, the body cannot accelerate.



Newton's First Law of Motion

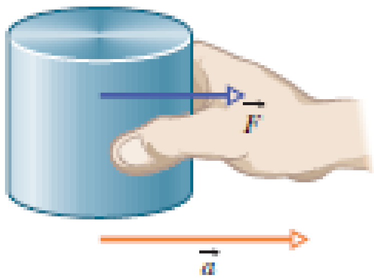


About Force...

- A force is measured by the acceleration it produces.
- Forces have both magnitudes and directions.
- Principle of superposition of forces.

$\vec{F}_{net}$: Sum of forces acting on a body (net force, resultant force)

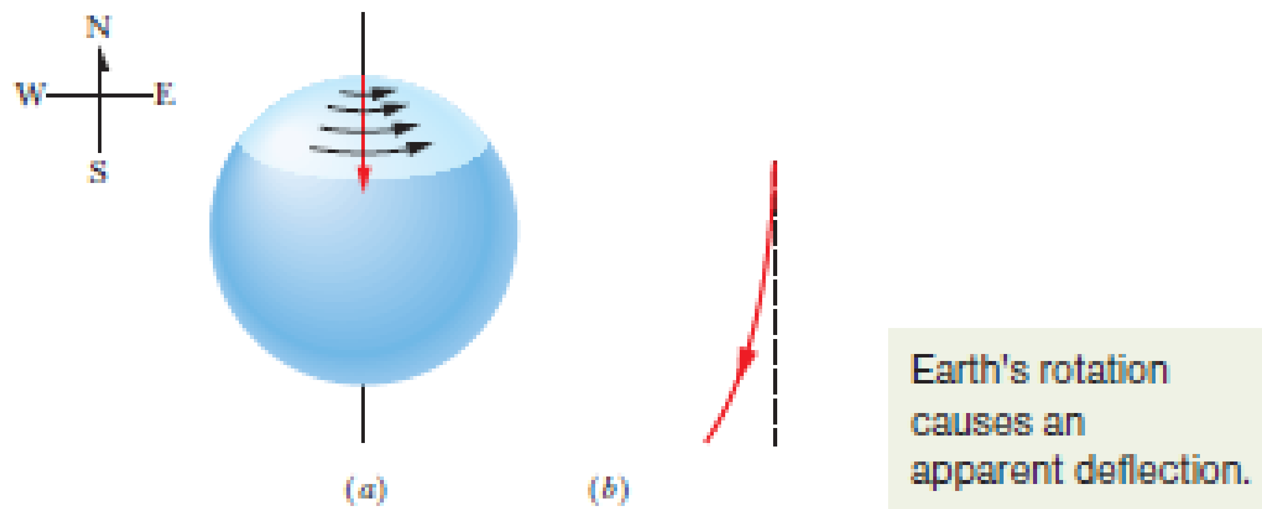
1 Newton = 1 kg.m/s² (SI)



Newton's First Law: If no *net* force acts on a body ($\vec{F}_{net} = 0$), the body's velocity cannot change; that is, the body cannot accelerate.

Inertial Reference Frames

An inertial reference frame is one in which Newton's laws hold.



(*a) The path of a puck sliding from the north pole as seen from a stationary* point in space. Earth rotates to the east. (*b) The path of the puck as seen from the ground.*

Inertial Reference Frames

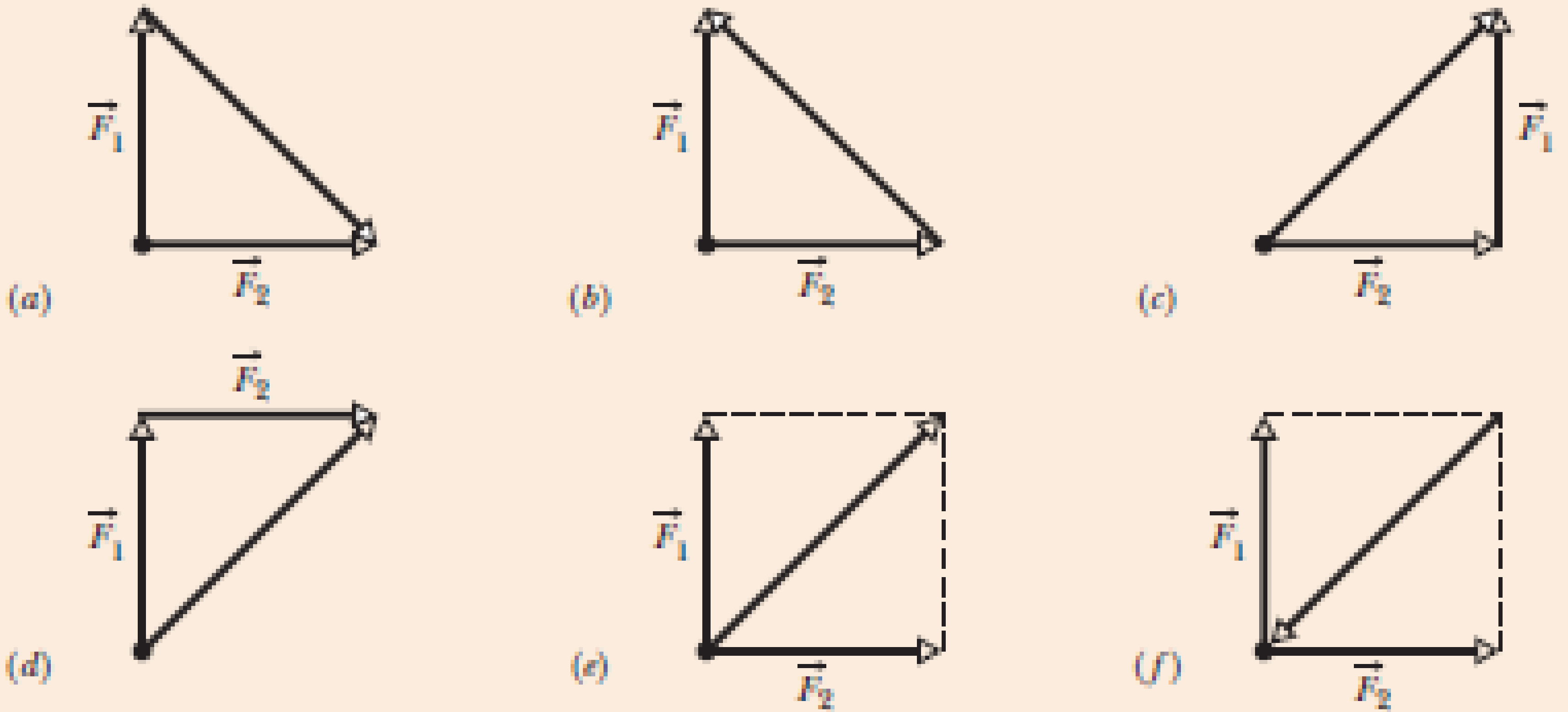
✓If a puck is sent sliding along a *short strip of* frictionless ice—the puck's motion obeys Newton's laws as observed from the Earth's surface.

✓ If the puck is sent sliding along a *long ice strip extending from* the north pole, and if it is viewed from a point on the Earth's surface, the puck's path is not a simple straight line.

✓ The apparent deflection is not caused by a force, but by the fact that we see the puck from a rotating frame. In this situation, the ground is a **noninertial frame.**

CHECKPOINT 1

Which of the figure's six arrangements correctly show the vector addition of forces $\vec{F}_1$ and $\vec{F}_2$ to yield the third vector, which is meant to represent their net force $\vec{F}_{net}$?



About Mass…

- Mass is the property of an object that measures how hard it is to change its motion.
- It is an *intrinsic characteristic* of a body.
- The mass of a body is the characteristic that relates a force on the body to the resulting acceleration.
- The ratio of the masses of two bodies is equal to the inverse of the ratio of their accelerations when the same force is applied to both.

$$\frac{m_X}{m_0} = \frac{a_0}{a_X}.$$

Newton's Second Law

✓ Change of motion is proportional to the moving force impressed and takes place in the direction of the straight line in which such force is impressed

$$\vec{F}_{net} = m\vec{a}$$

$$F_{net,x} = ma_x, \quad F_{net,y} = ma_y, \quad \text{and} \quad F_{net,z} = ma_z.$$

$$F = ma$$

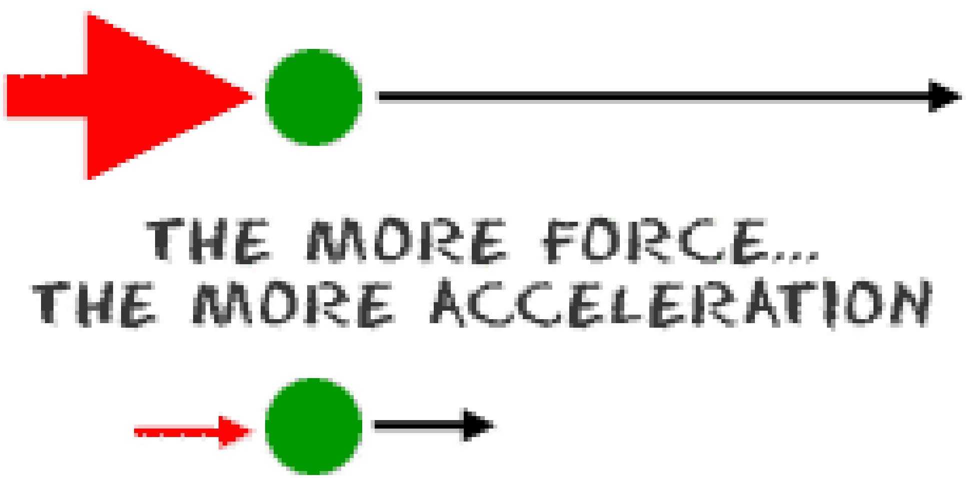


TABLE 5-1

Units in Newton's Second Law (Eqs. 5-1 and 5-2)

System	Force	Mass	Acceleration
SI	newton (N)	kilogram (kg)	m/s^2
CGS[a]	dyne	gram (g)	cm/s^2
British[b]	pound (lb)	slug	ft/s^2

[a] 1 dyne = $1\ g \cdot cm/s^2$.

[b] 1 lb = $1\ slug \cdot ft/s^2$.

1 Newton (N) =(1 kg).(1 m/s^2)=1kg•m/s^2

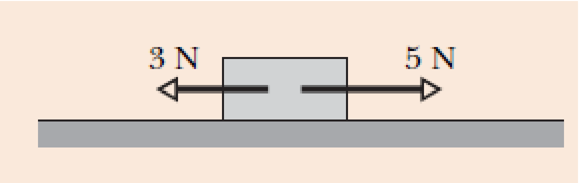
More on Newton's second law:

Drawing a <u>free-body diagram</u> (FBD)

✓In a free-body diagram, the only body shown is the one for which we are summing forces.

✓Each force on the body is drawn as a vector arrow with its tail on the body.

✓A coordinate system is usually included, and the acceleration of the body is sometimes shown with a vector arrow (labeled as an acceleration).



The figure here shows two horizontal forces acting on a block on a frictionless floor.

Example 1: Forces

Parts A, B, and C of Fig. 5-3 show three situations in which one or two forces act on a puck that moves over frictionless ice along an x axis, in one-dimensional motion. The puck's mass is $m = 0.20$ kg. Forces $\vec{F}_1$ and $\vec{F}_2$ are directed along the axis and have magnitudes $F_1 = 4.0$ N and $F_2 = 2.0$ N. Force $\vec{F}_3$ is directed at angle $\theta = 30°$ and has magnitude $F_3 = 1.0$ N. In each situation, what is the acceleration of the puck?

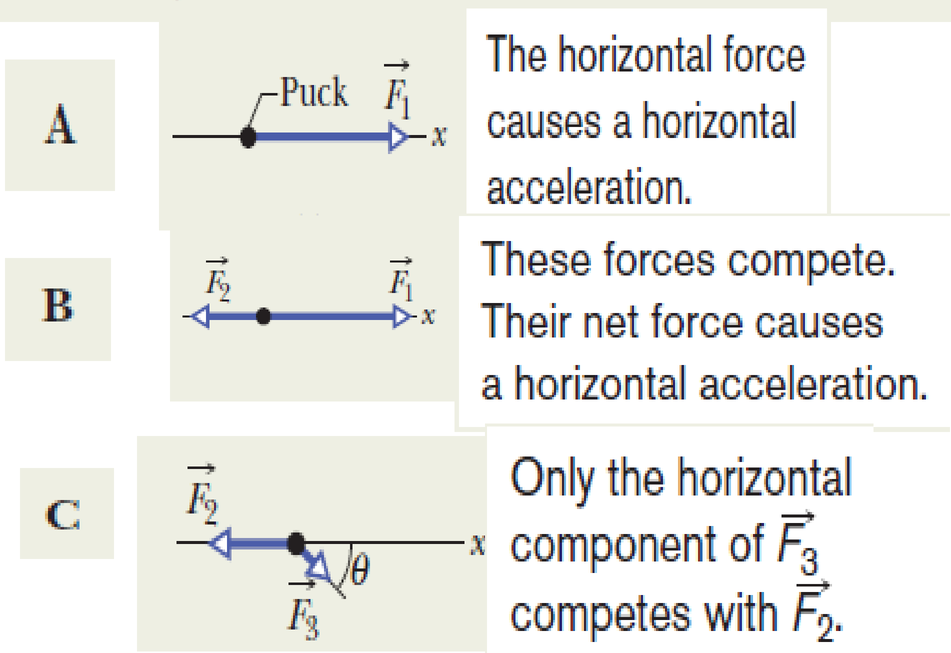
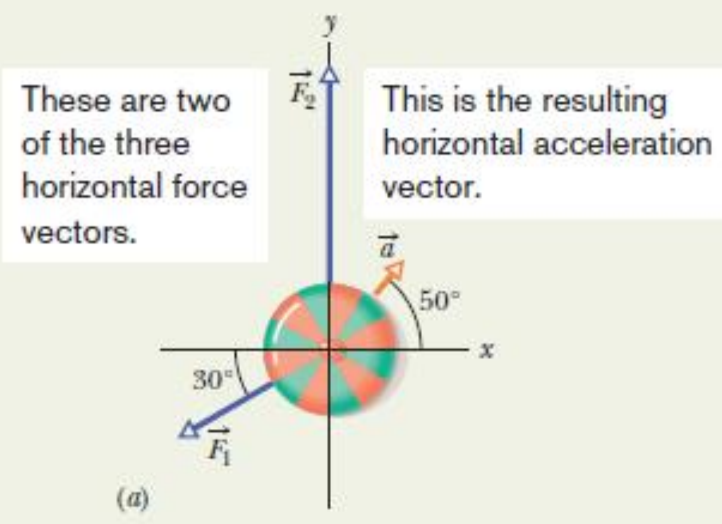
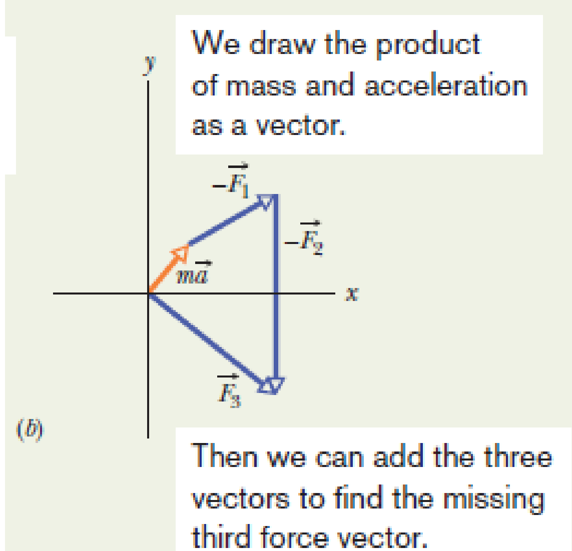


Fig. 5-3 In three situations, forces act on a puck that moves along an x axis.

Example 2: 2-D Forces:

In the overhead view of Fig. 5-4*a*, a 2.0 kg cookie tin is accelerated at 3.0 m/s^2 in the direction shown by $\vec{a}$, over a frictionless horizontal surface. The acceleration is caused by three horizontal forces, only two of which are shown: $\vec{F}_1$ of magnitude 10 N and $\vec{F}_2$ of magnitude 20 N. What is the third force $\vec{F}_3$ in unit-vector notation and in magnitude-angle notation?





Some Particular Forces

1) The Gravitational Force:

A gravitational force on a body is a certain type of pull that is directed toward a second body.

$-F_g = m(-g)$ or $F_g = mg.$

(In vector notation)

$$\vec{F}_g = -F_g\hat{j} = -mg\hat{j} = m\vec{g}.$$

2) Weight:

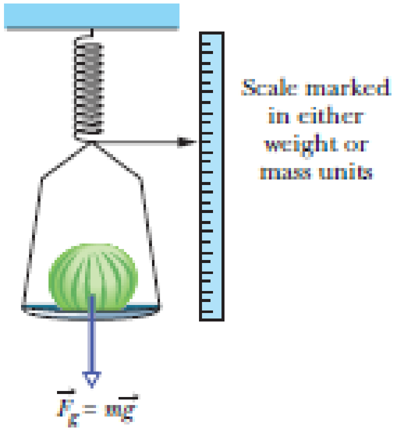
The weight, W, of a body is equal to the magnitude F_g of the gravitational force on the body.

$$F_{net,y} = ma_y.$$

$$W - F_g = m(0)$$

or

$$W = F_g \qquad \text{(weight, with ground as inertial frame).}$$



W = mg (weight),

CAUTION: A body's weight is not its mass!

3) Normal Force:

When a body presses against a surface, the surface (even a seemingly rigid one) deforms and pushes on the body with a normal force, F_N, that is perpendicular to the surface.

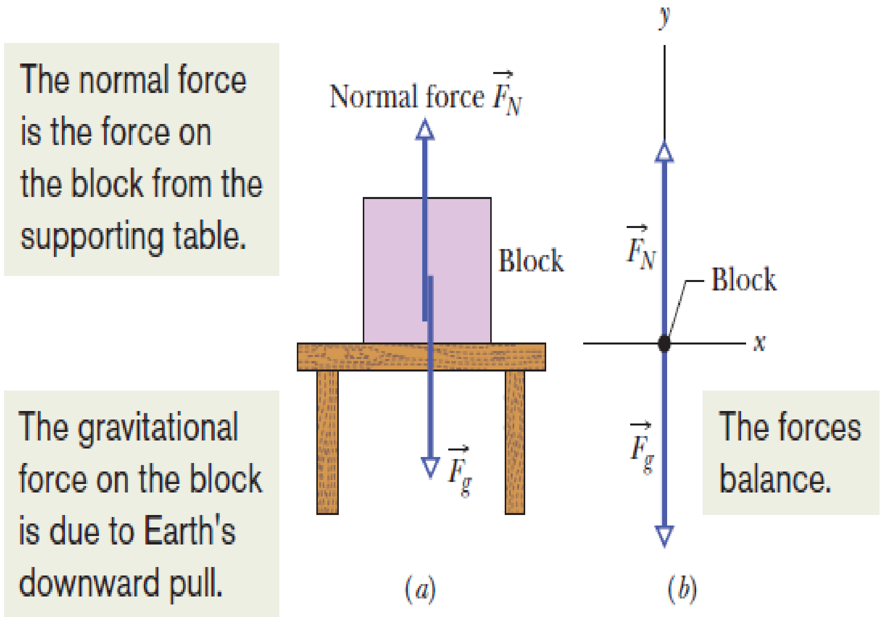


Fig. 5-7 (a) A block resting on a table experiences a normal force perpendicular to the tabletop. (b) The free-body diagram for the block.

<u>Newton's second law says for a positive-upward *y axis:*</u>

($F_{net,\,y} = ma_y$), as:

$$F_N - F_g = ma_y.$$

$$F_N - mg = ma_y.$$

$$F_N = mg + ma_y = m(g + a_y)$$

<u>**For any vertical acceleration *a_y* *of the table and block.***</u>

4) Friction:

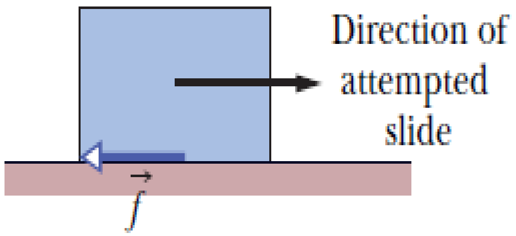


Fig. 5-8 A frictional force $\vec{f}$ opposes the attempted slide of a body over a surface.

- The force **f** is either called frictional force or simply friction.

Sometimes, to simplify a stiuation, friction is assumed to be negligible. (So the surface is frictionless.)

5) Tension

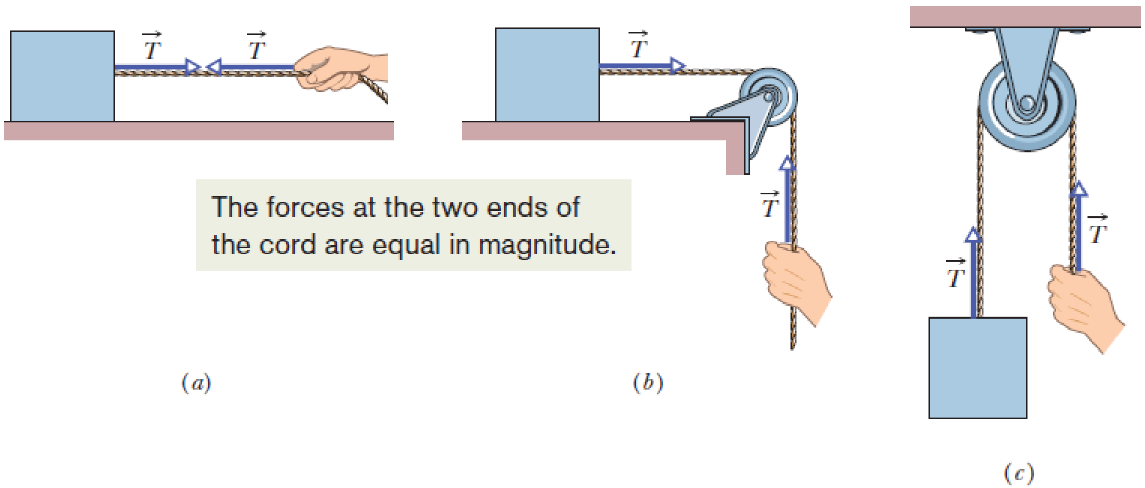


Fig. 5-9 (*a) The cord, pulled taut, is* under tension. If its mass is negligible, the cord pulls on the body and the hand with force **T**, even if the cord runs around a massless, frictionless pulley as in (*b) and (c).*

Newton's Third Law

➢ When two bodies interact, the forces on the bodies from each other are always equal in magnitude and opposite in direction and collinear.

For the book and crate, we can write this law as the scalar relation

$$F_{BC} = F_{CB} \qquad \text{(equal magnitudes)}$$

or as the vector relation

$$\vec{F}_{BC} = -\vec{F}_{CB} \qquad \text{(equal magnitudes and opposite directions),}$$

➢ The forces between two interacting bodies are called a **third-law force pair.**

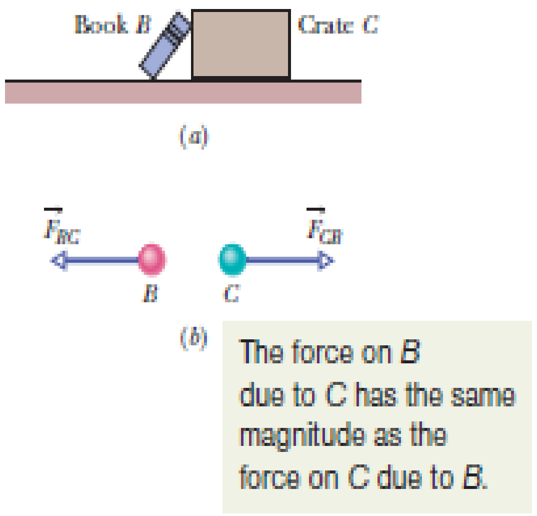
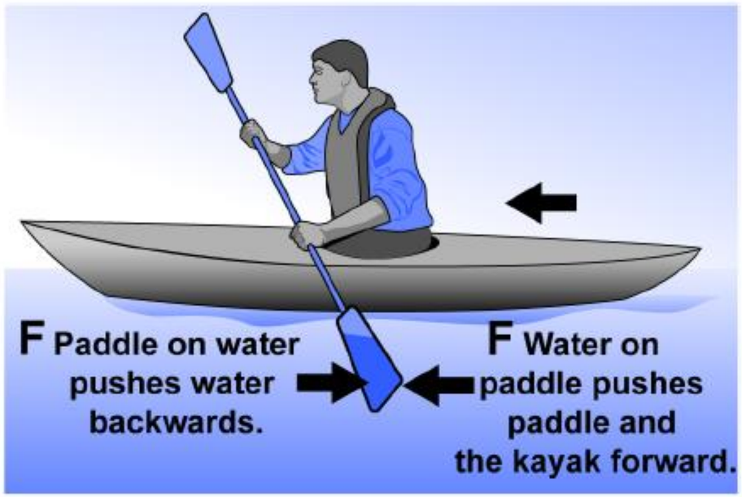
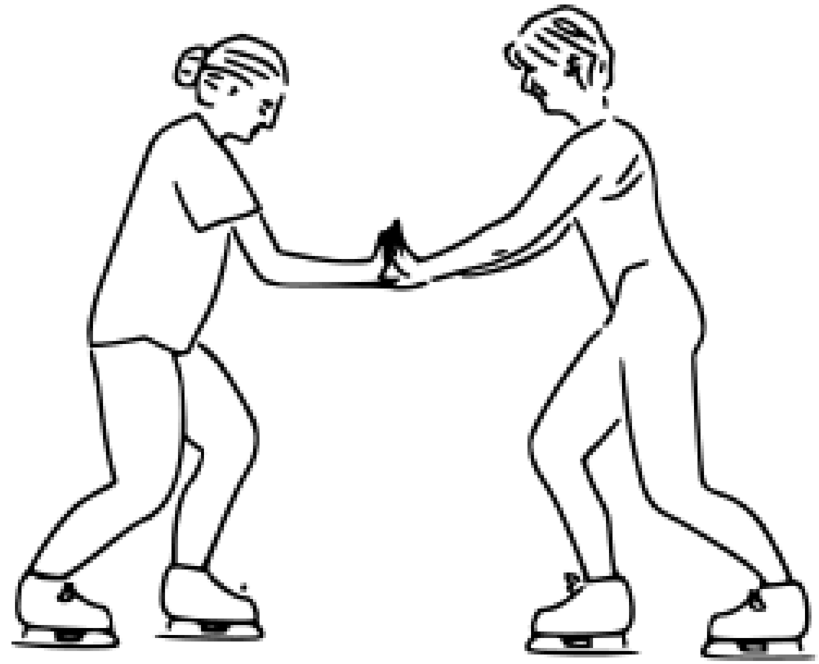
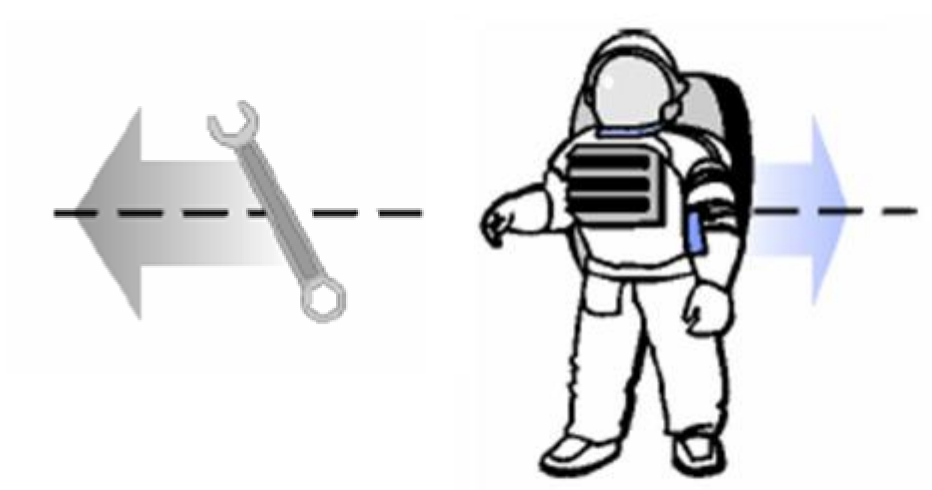


Fig. 5-10 (*a*) Book *B* leans against crate *C*. (*b*) Forces $\vec{F}_{BC}$ (the force on the book from the crate) and $\vec{F}_{CB}$ (the force on the crate from the book) have the same magnitude and are opposite in direction.

More on Newton's Third Law







CHECK YOUR UNDERSTANDING

1) Suppose you are an astronaut in outer space giving a brief push to a spacecraft whose mass is bigger than your own. Compare the magnitude of the force you exert on the spacecraft, F_S, to the magnitude of the force exerted by the spacecraft on you, F_A, while you are pushing:

1. $F_A = F_S$ ← correct   Third Law!
2. $F_A > F_S$
3. $F_A < F_S$

2) Compare the magnitudes of the acceleration you experience, a_A, to the magnitude of the acceleration of the spacecraft, a_S, while you are pushing:

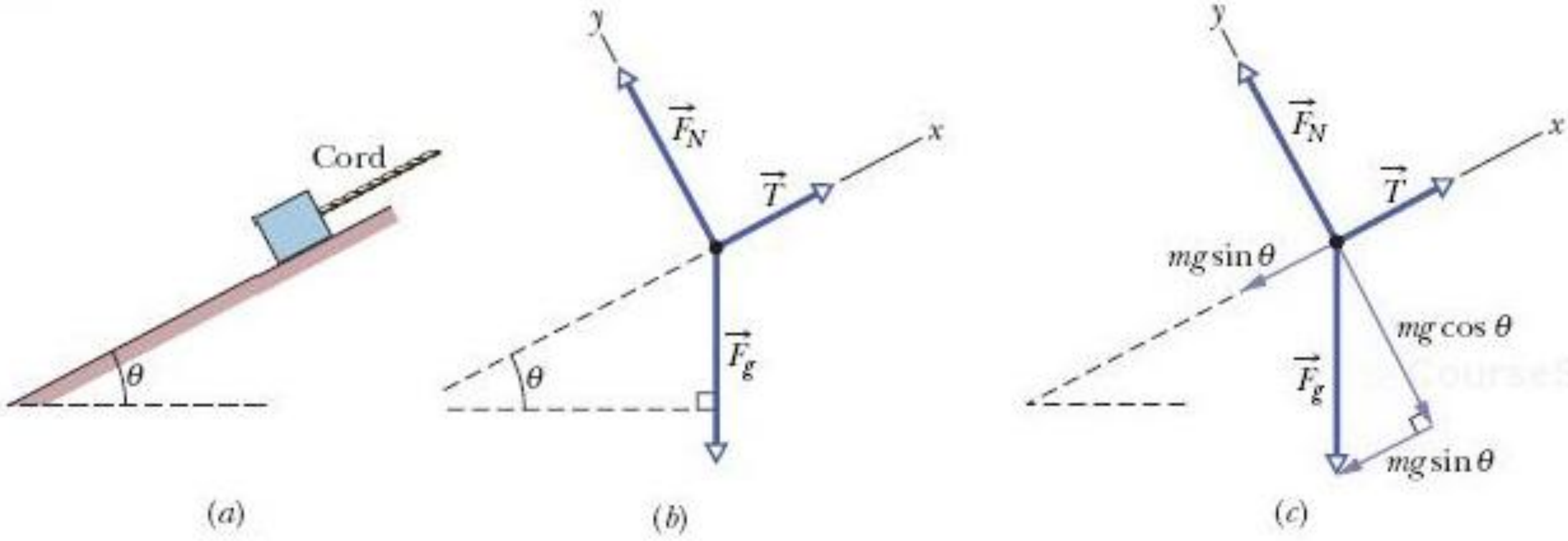
1. $a_A = a_S$
2. $a_A > a_S$ ← correct
3. $a_A < a_S$

a=F/m

<u>**(F same ⇒ lower mass gives larger a)**</u>

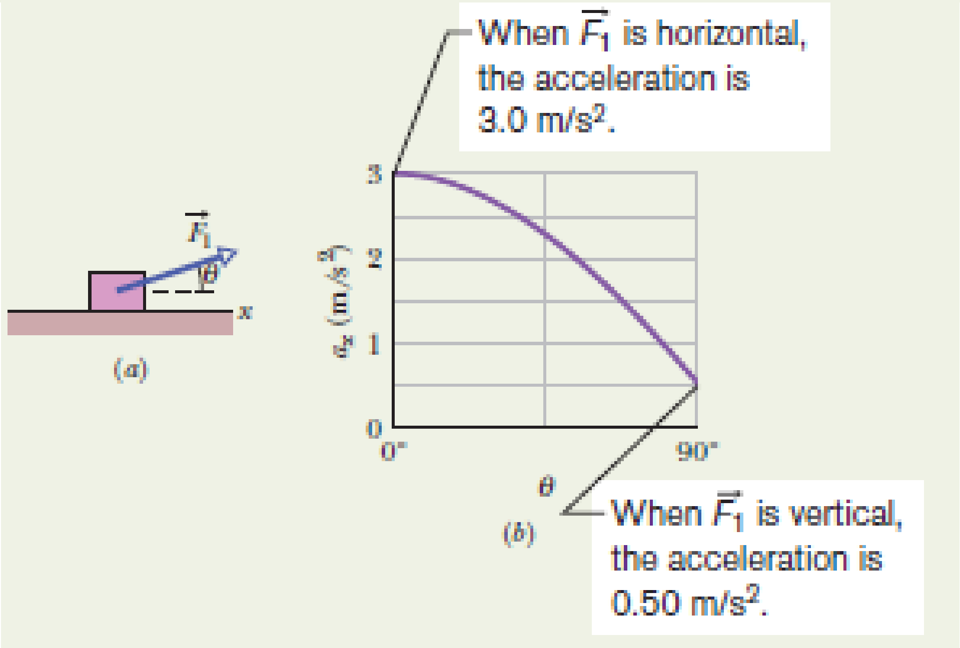
Example 3: Cord accelerates block up a ramp

In Fig. 5-15*a*, a cord pulls on a box of sea biscuits up along a frictionless plane inclined at $\theta = 30°$. The box has mass $m = 5.00$ kg, and the force from the cord has magnitude $T = 25.0$ N. What is the box's acceleration component a along the inclined plane?



Example 4: Reading a force graph

Figure 5-16*a* shows the general arrangement in which two forces are applied to a 4.00 kg block on a frictionless floor, but only force $\vec{F}_1$ is indicated. That force has a fixed magnitude but can be applied at an adjustable angle θ to the positive direction of the x axis. Force $\vec{F}_2$ is horizontal and fixed in both magnitude and angle. Figure 5-16*b* gives the horizontal acceleration a_x of the block for any given value of θ from 0° to 90°. What is the value of a_x for $\theta = 180°$?



Example 5: Forces within an elevator cab

In Fig. 5-17*a*, a passenger of mass $m = 72.2$ kg stands on a platform scale in an elevator cab. We are concerned with the scale readings when the cab is stationary and when it is moving up or down.

(a) Find a general solution for the scale reading, whatever the vertical motion of the cab.

(b) What does the scale read if the cab is stationary or moving upward at a constant 0.50 m/s?

(c) What does the scale read if the cab accelerates upward at 3.20 m/s^2 and downward at 3.20 m/s^2?

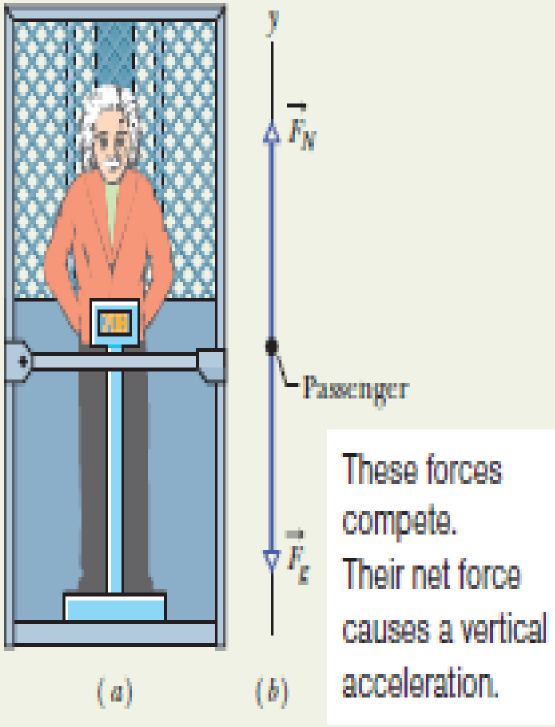


Fig. 5-17 (*a*) A passenger stands on a platform scale that indicates either his weight or his apparent weight. (*b*) The free-body diagram for the passenger, showing the normal force $\vec{F}_N$ on him from the scale and the gravitational force $\vec{F}_g$.

Example 6: Acceleration of block pushing on block

In Fig. 5-18*a*, a constant horizontal force $\vec{F}_{app}$ of magnitude 20 N is applied to block *A* of mass $m_A = 4.0$ kg, which pushes against block *B* of mass $m_B = 6.0$ kg. The blocks slide over a frictionless surface, along an *x* axis.

(a) What is the acceleration of the blocks?

(b) What is the (horizontal) force $\vec{F}_{BA}$ on block *B* from block *A* (Fig. 5-18*c*)?

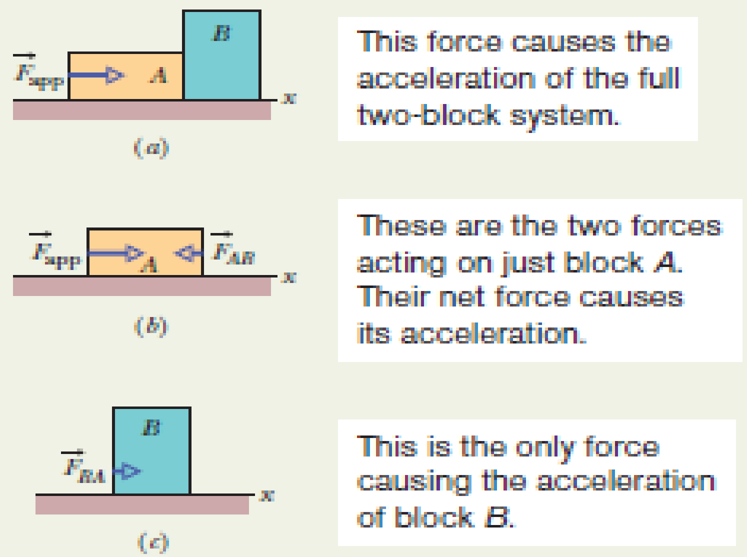


Fig. 5-18 (*a*) A constant horizontal force $\vec{F}_{app}$ is applied to block *A*, which pushes against block *B*. (*b*) Two horizontal forces act on block *A*. (*c*) Only one horizontal force acts on block *B*.

HOME EXERCISE

- Since $\boldsymbol{F}_{m,b} = -\boldsymbol{F}_{b,m}$ why isn't $\boldsymbol{F}_{net} = 0$, and $\boldsymbol{a} = 0$?