Newton’s law of motion

References

University Physics with Modern Physics

– Hugh D. Young, Roger A. Freedman

Newton's First Law

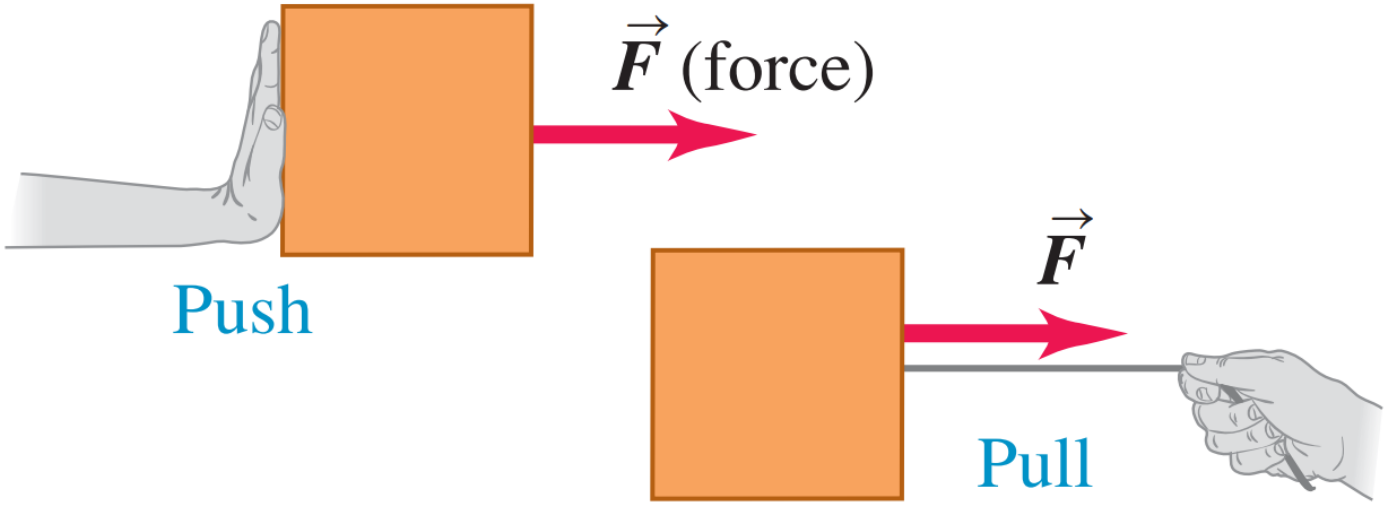
Newton's first law of motion: **A body acted on by no net force moves with constant velocity (which may be zero) and zero acceleration.**

$$\sum \vec{F} = 0 \qquad \text{(body in equilibrium)}$$

Zero net force means constant velocity

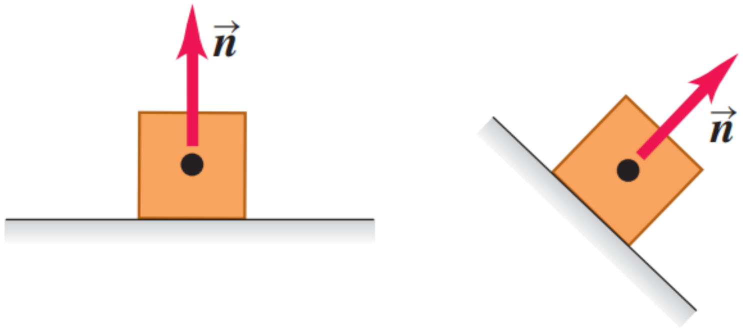
Some properties of forces

- 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.

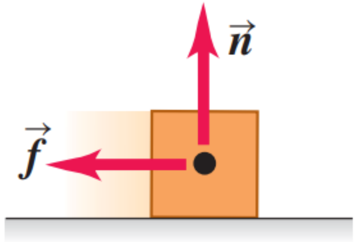


Four common types of forces

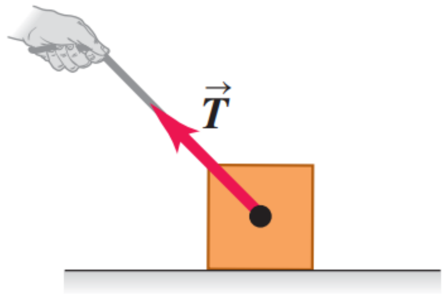
(a) **Normal force $\vec{n}$:** When an object rests or pushes on a surface, the surface exerts a push on it that is directed perpendicular to the surface.



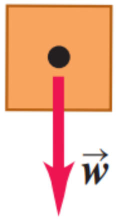
(b) **Friction force $\vec{f}$:** In addition to the normal force, a surface may exert a frictional force on an object, directed parallel to the surface.



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



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



Lets watch this video

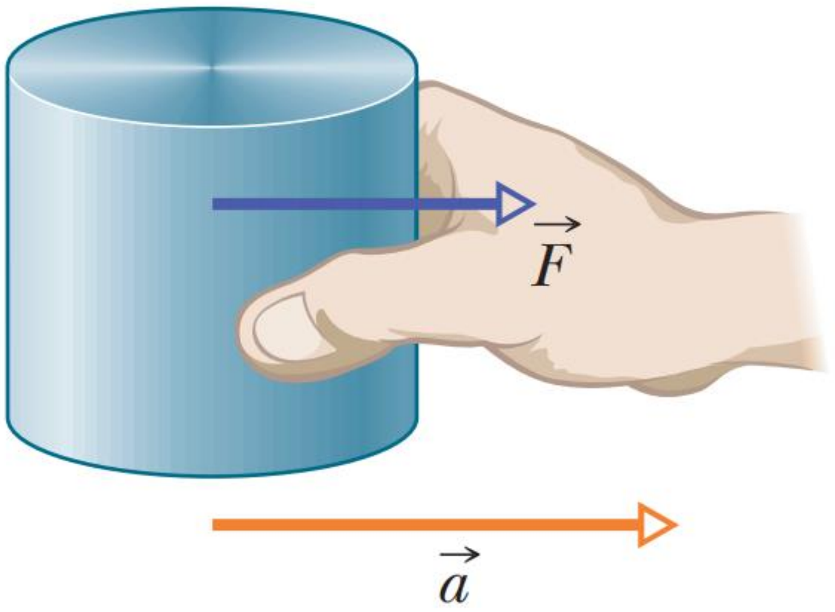
Newton's First Law of Motion - Class 9 Tutorial

https://www.youtube.com/watch?v=erghLWXDScI

Inertial Reference Frames

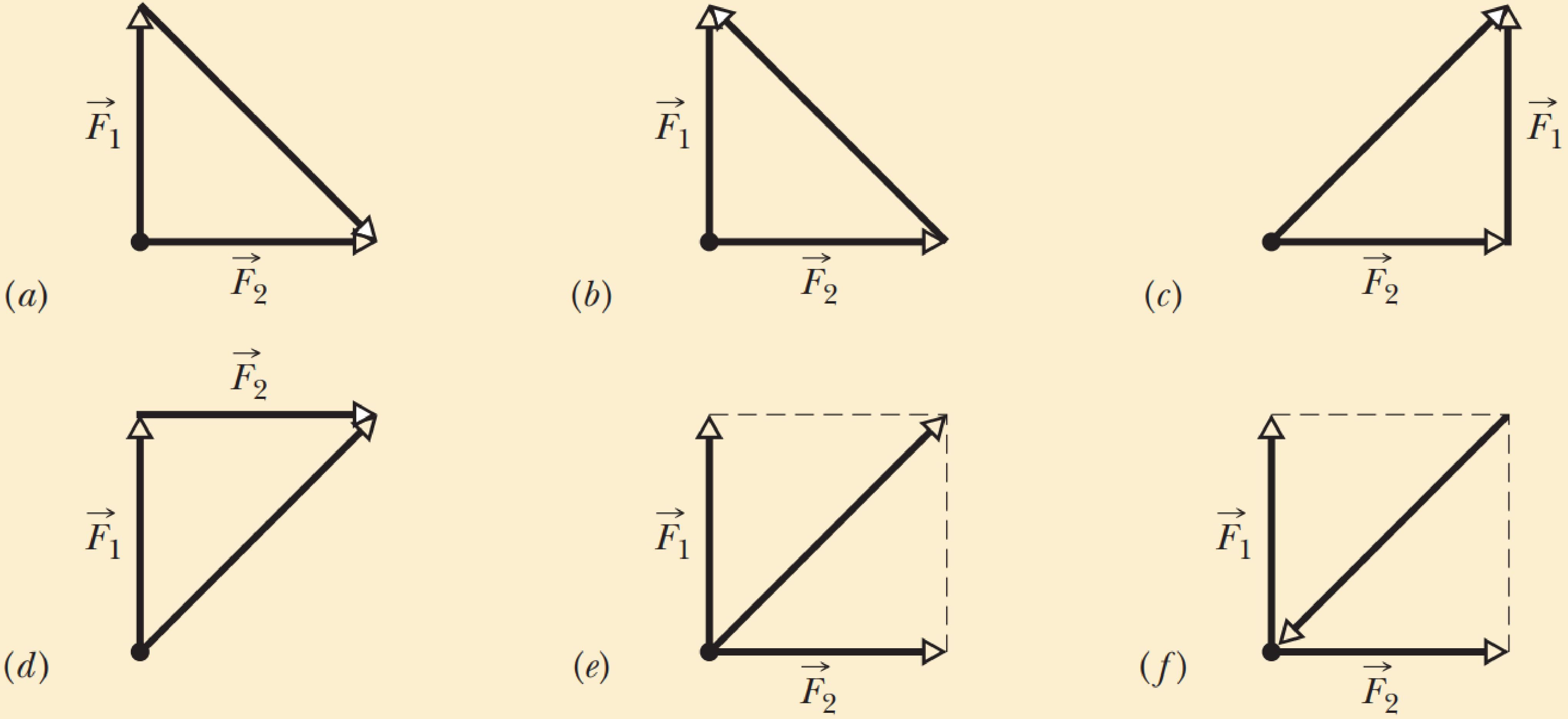
An inertial reference frame is one in which Newton's laws hold.

A force on the standard kilogram gives that body an acceleration.



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 $\vec{F}_{net}$?



Check yourself

In which of the following situations is there zero net force on the body?

(i) an airplane flying due north at a steady and at a constant altitude;
(ii) a car driving straight up a hill with a 3° slope at a constant 90 km/h;
(iii) a hawk circling at a constant at a 20 km/h constant height of 15 m above an open field;
(iv) a box with slick, frictionless surfaces in the back of a truck as the truck accelerates forward on a level road at 5 m/s^2.

Newton's Second Law

What happens when the net force is *not* zero?

A non-zero net force acting on a body causes the body to accelerate in the same direction as the net force.

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One newton is the amount of net force that gives an acceleration of 1 meter per second squared to a body with a mass of 1 kilogram.

Newton's Second Law

Newton's second law of motion: If a net external force acts on a body, the body accelerates. The direction of acceleration is the same as the direction of the net force. The mass of the body times the acceleration of the body equals the net force vector.

$$\sum \vec{F} = m\vec{a} \qquad \text{(Newton's second law of motion)}$$

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

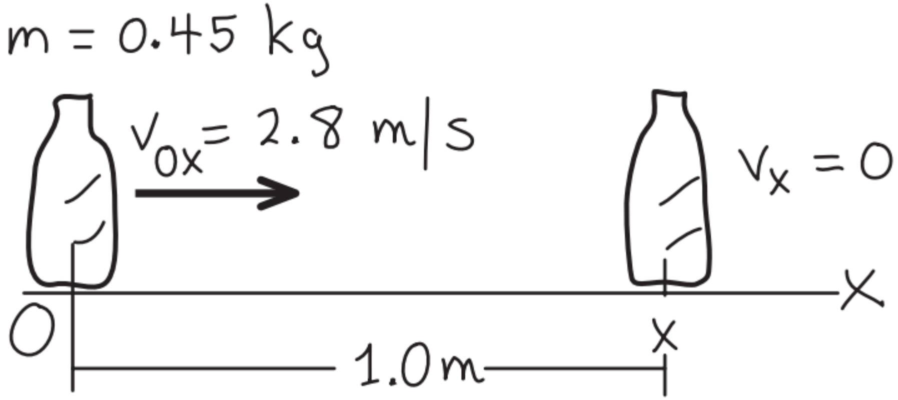
Using Newton's Second Law

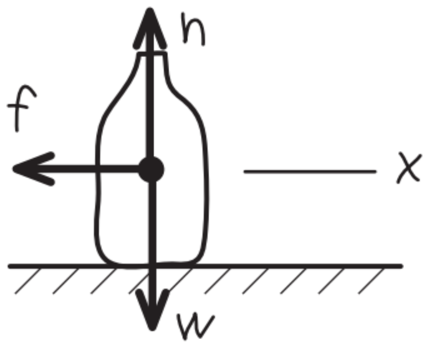
$$\sum F_x = ma_x \qquad \sum F_y = ma_y \qquad \sum F_z = ma_z$$ (Newton's second law of motion)

This car stopped because of Newton's second law: The tree exerted an external force on the car, giving the car an acceleration that changed its velocity to zero.

Determining force from acceleration

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





Determining force from acceleration

$$v_x^2 = v_{0x}^2 + 2a_x(x - x_0)$$

$$a_x = \frac{v_x^2 - v_{0x}^2}{2(x - x_0)} = \frac{(0\ \text{m/s})^2 - (2.8\ \text{m/s})^2}{2(1.0\ \text{m} - 0\ \text{m})} = -3.9\ \text{m/s}^2$$

$$\begin{aligned}\sum F_x &= -f = ma_x = (0.45\ \text{kg})(-3.9\ \text{m/s}^2)\\ &= -1.8\ \text{kg}\cdot\text{m/s}^2 = -1.8\ \text{N}\end{aligned}$$

The negative sign shows that the net force on the bottle is toward the left. The *magnitude* of the friction force is $f = 1.8\ \text{N}$.

Mass and Weight

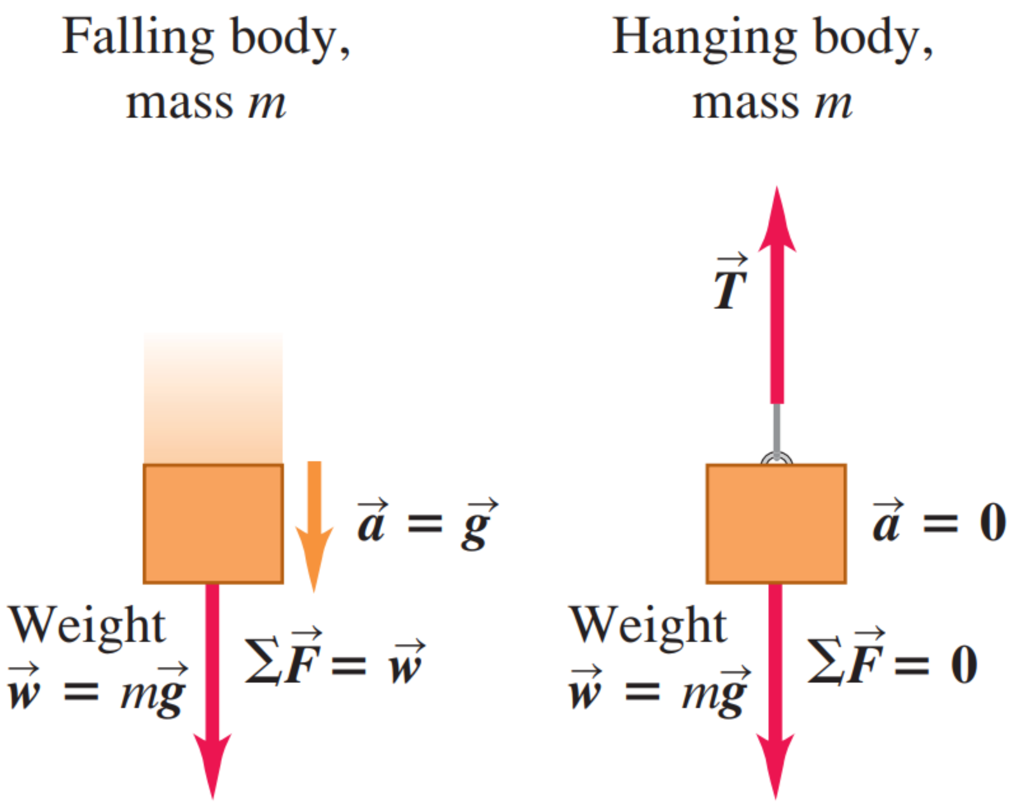
$$\text{Newton's second law, } \sum \vec{F} = m\vec{a}.$$

Mass characterizes the *inertial* properties of a body. The greater the mass, the greater the force needed to cause a given acceleration.

Weight, on the other hand, is a *force* exerted on a body by the pull of the earth. Mass and weight are related: Bodies having large mass also have large weight. A large stone is hard to throw because of its large *mass*, and hard to lift off the ground because of its large *weight*.

$$w = mg \qquad \text{(magnitude of the weight of a body of mass } m\text{)}$$

The relationship of mass and weight



- The relationship of mass to weight: $\vec{w} = m\vec{g}$.
- This relationship is the same whether a body is falling or stationary.

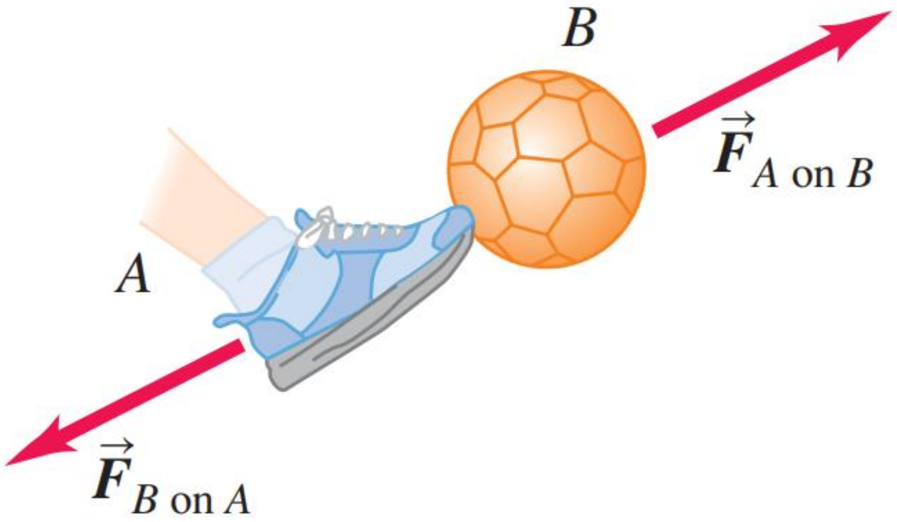
$$\boxed{\vec{w} = m\vec{g}}$$

A body's weight acts at all times.

Newton’s Third Law

Newton’s third law of motion: **If body A exerts a force on body B (an “action”), then body B exerts a force on body A (a “reaction”). These two forces have the same magnitude but are opposite in direction. These two forces act on *different* bodies.**

4.25 If body A exerts a force $\vec{F}_{A \text{ on } B}$ on body B, then body B exerts a force $\vec{F}_{B \text{ on } A}$ on body A that is equal in magnitude and opposite in direction: $\vec{F}_{A \text{ on } B} = -\vec{F}_{B \text{ on } A}$.



$$\vec{F}_{A \text{ on } B} = -\vec{F}_{B \text{ on } A} \qquad \text{(Newton's third law of motion)}$$

Action–reaction pair

CAUTION **The two forces in an action–reaction pair act on different bodies** We stress that the two forces described in Newton's third law act on *different* bodies. This is important in problems involving Newton's first or second law, which involve the forces that act on a single body. For instance, the net force on the soccer ball in Fig. 4.25 is the vector sum of the weight of the ball and the force $\vec{F}_{A \text{ on } B}$ exerted by the kicker. You wouldn't include the force $\vec{F}_{B \text{ on } A}$ because this force acts on the kicker, not on the ball.

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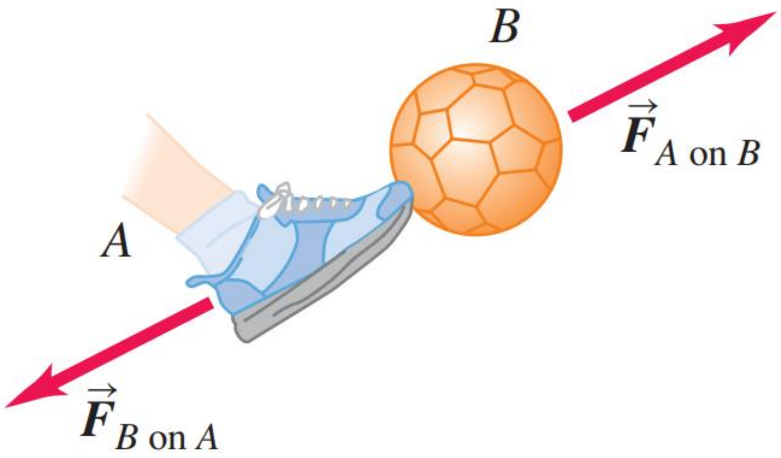
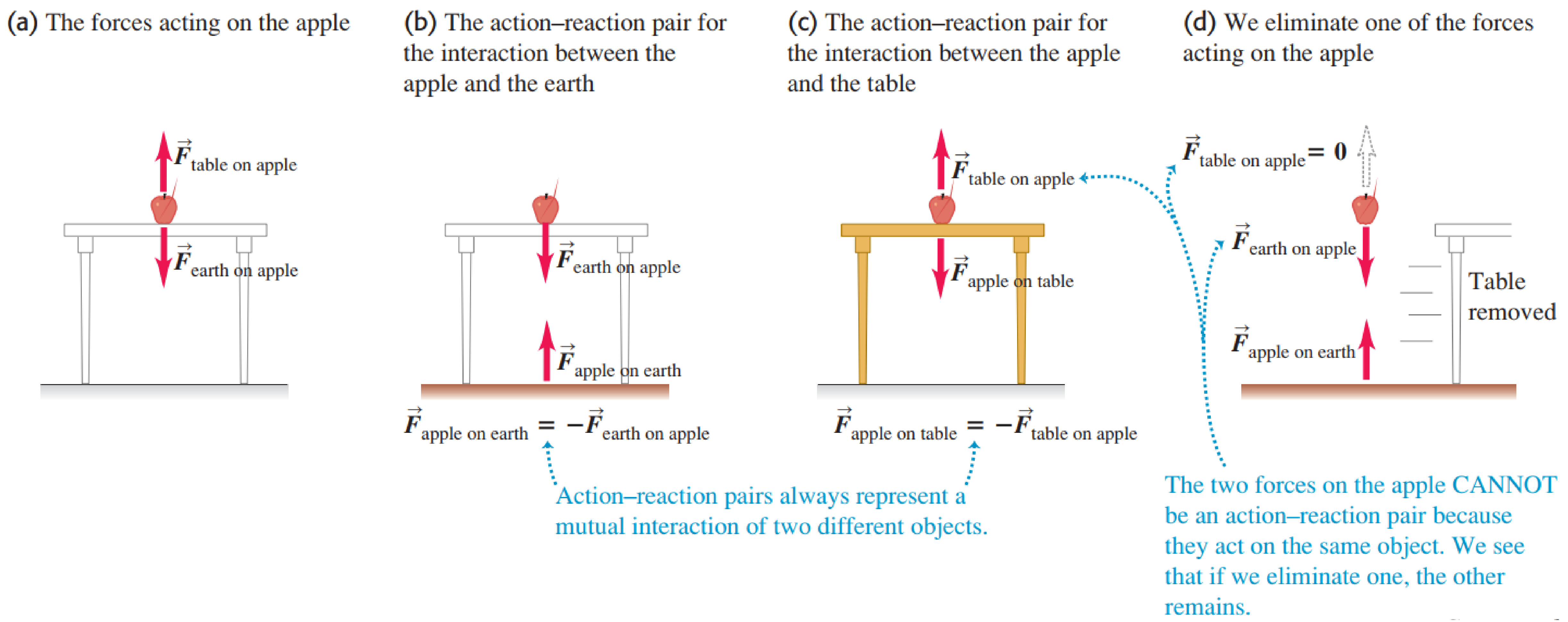


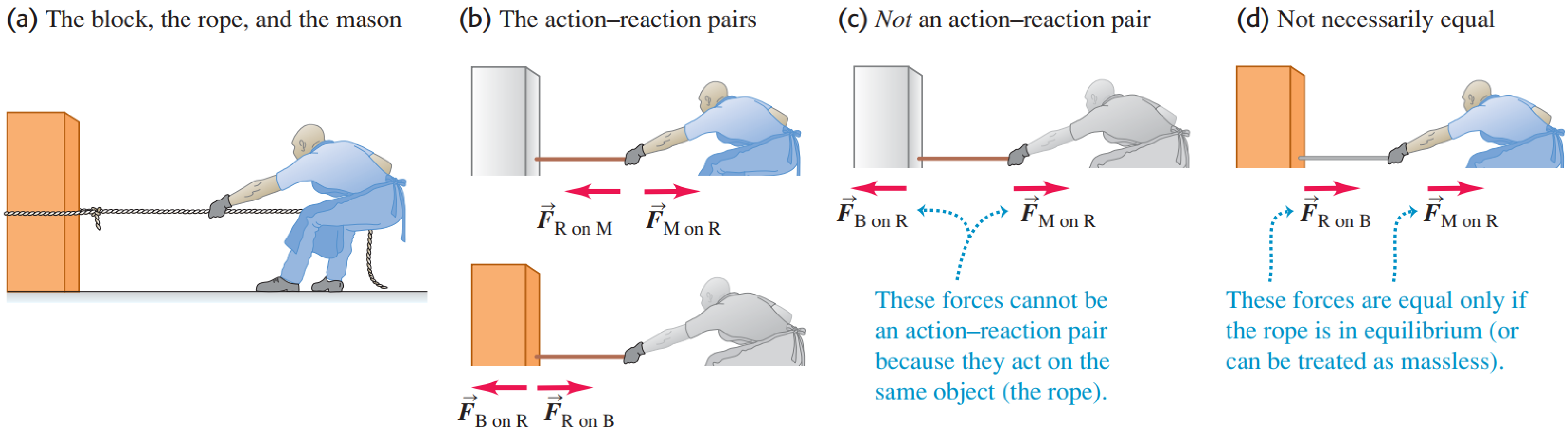
Applying Newton's third law: Objects at rest

4.26 The two forces in an action–reaction pair always act on different bodies.



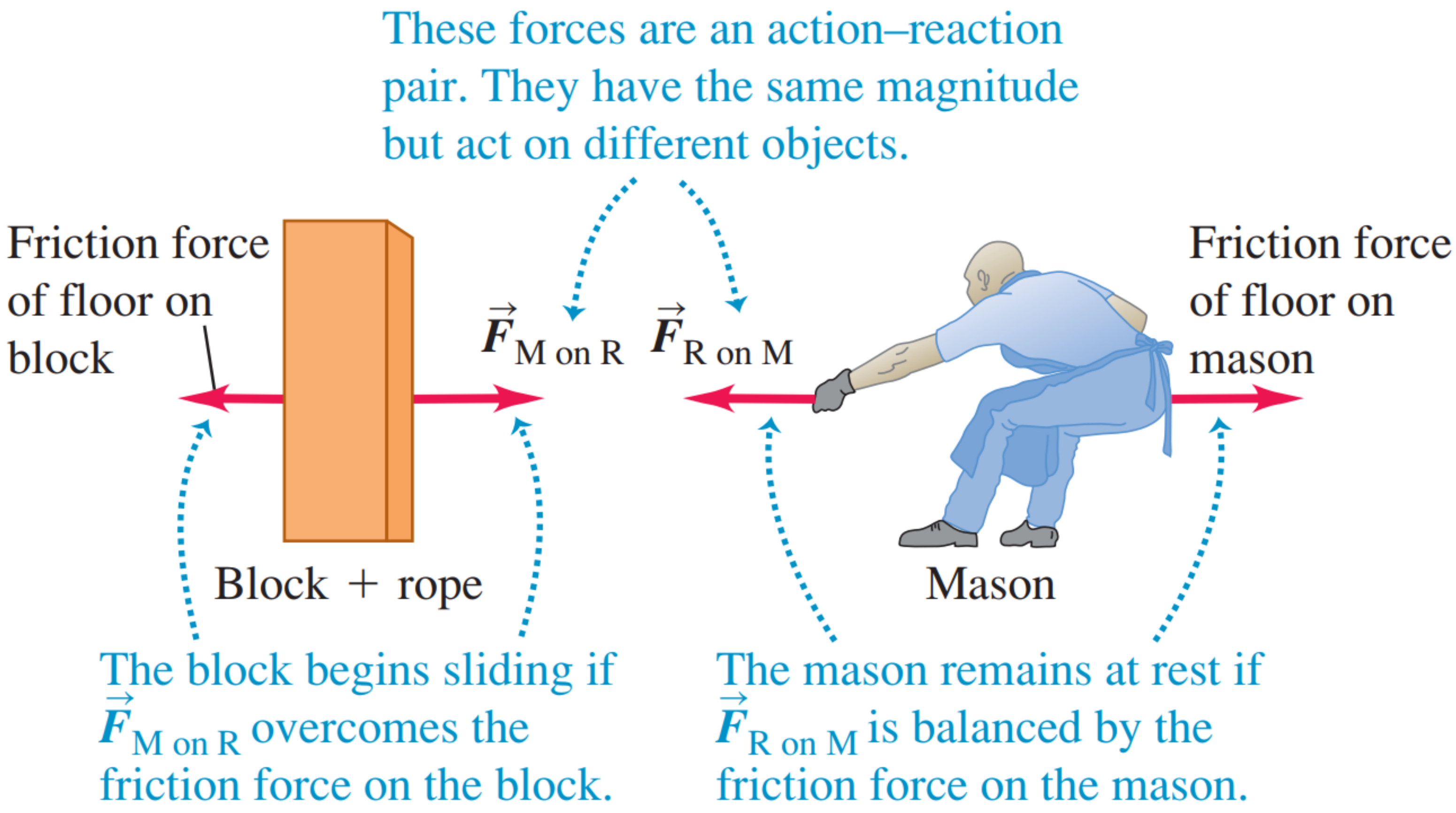
Applying Newton's third law: Objects in motion

4.27 Identifying the forces that act when a mason pulls on a rope attached to a block.



A Newton’s third law paradox?

4.28 The horizontal forces acting on the block–rope combination (left) and the mason (right). (The vertical forces are not shown.)



Readings

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Chapter 4: Newton's Law of Motion

Exercises: 4.7 – 4.25