

# NEWTON'S LAWS OF MOTION I

PHYS1112

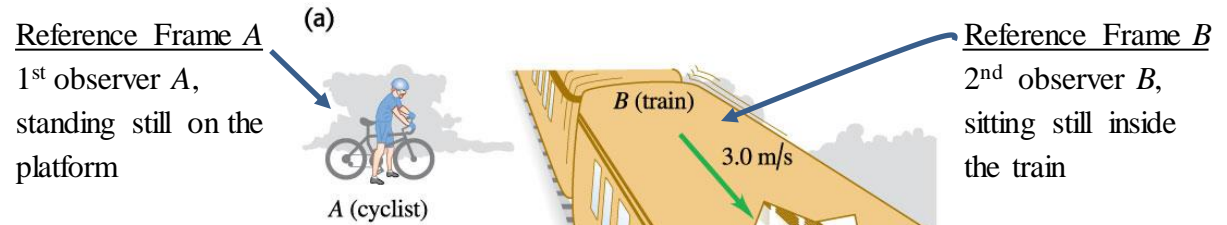
Lecture 2

# Intended Learning Outcomes

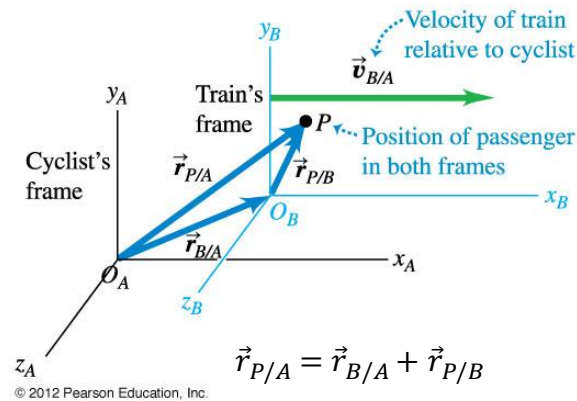
- After this lecture you will learn:
  1. the concept of frame of reference and relative velocity
  2. to use the Newton's three laws of motion to solve problems.
  3. the concept of inertial frame of reference.
  4. the meanings of apparent weight and weightlessness.

**Relative velocity –**  
concerning more than one  
observer

An observer making  
observation/measurement  
forms a reference frame  
e.g.



(b)



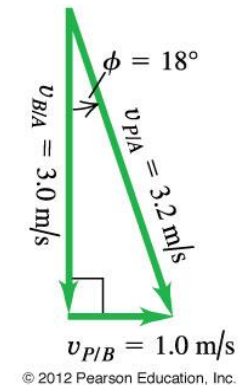
$\Rightarrow \vec{v}_{P/A} = \vec{v}_{B/A} + \vec{v}_{P/B}$

velocity of P  
measured in  
frame A

velocity of  
frame B  
measured in  
frame A

velocity of P  
measured in  
frame B

(c) Relative velocities  
(seen from above)





The pilot of a light airplane with an airspeed of 200 km/h wants to fly due west. There is a strong wind of 120 km/h blowing from the north.

If the pilot points the nose of the airplane north of west so that her ground track is due west, what will be her ground speed?

- A. 80 km/h
- B. 120 km/h
- C. 160 km/h
- D. 180 km/h
- E. It would impossible to fly due west in this situation.



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# Newton's first law of motion

A body acted on by no net force moves with constant velocity

$$\sum \vec{F} = 0$$

body in equilibrium



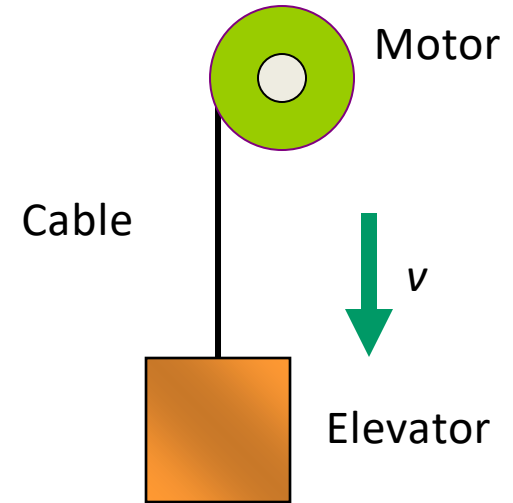
may be moving

#### Q4.6



An elevator is being lowered at constant speed by a steel cable attached to an electric motor. There is no air resistance, nor is there any friction between the elevator and the walls of the elevator shaft.

The upward force exerted on the elevator by the cable has the same magnitude as the force of gravity on the elevator, but points in the opposite direction. Why?

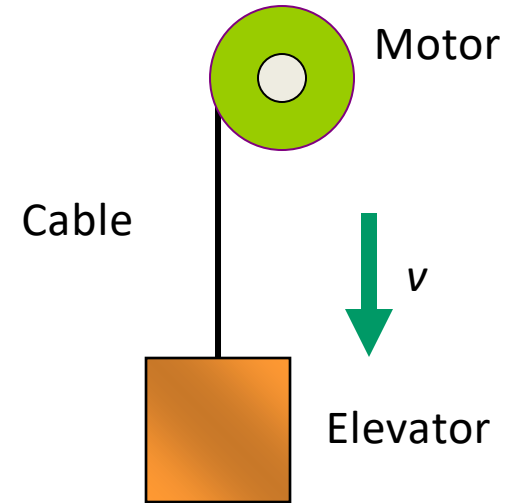


- A. Newton's first law
- B. Newton's second law
- C. Newton's third law

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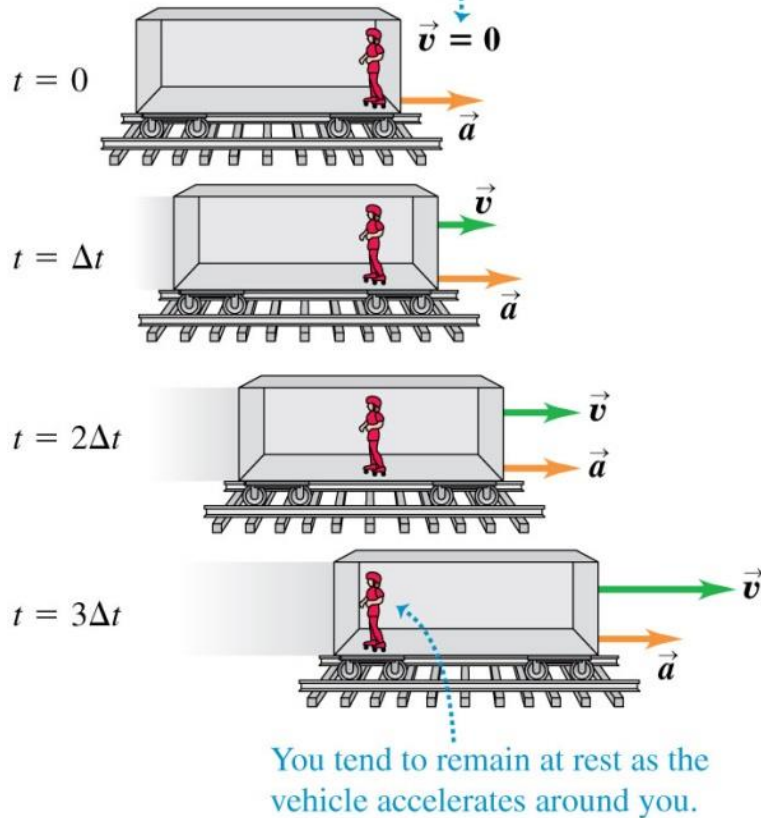


- A. Newton's first law
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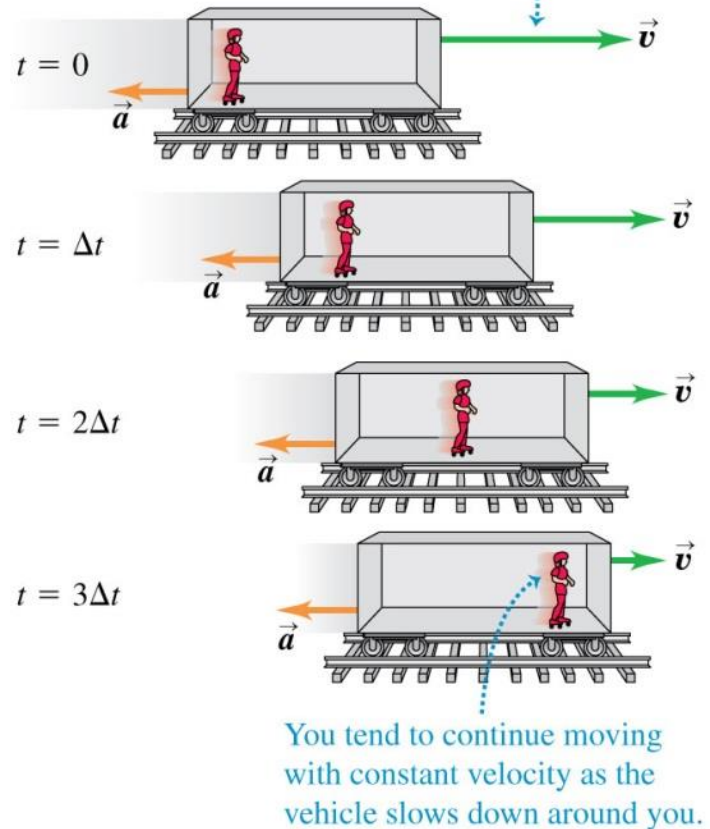
# Inertial Frame of Reference

(a) Initially, you and the vehicle are at rest.



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(b) Initially, you and the vehicle are in motion.



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Passenger (in roller skate) accelerates inside the train, but net force is zero.  
Violate Newton's first law??  
The train is not an inertial frame.

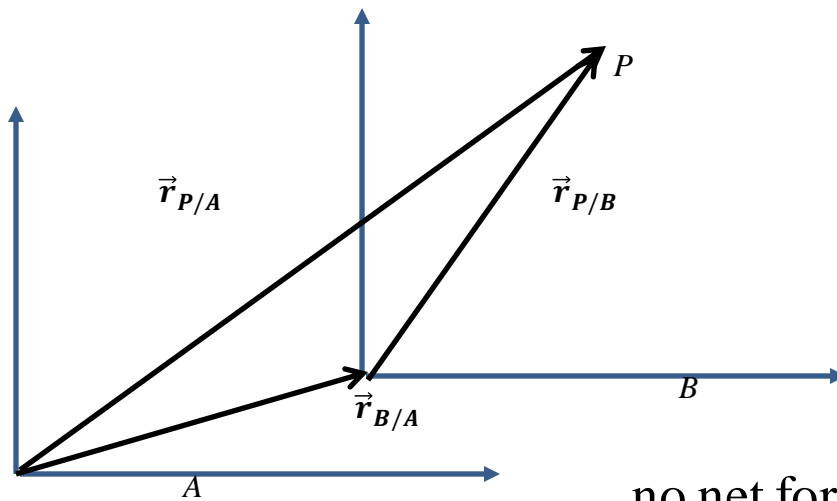
# Inertial Frame

Definition:

A frame of reference in which  
Newton's first law is valid is called  
an inertial frame

Note: 1. Is the earth an inertial frame?  
Only approximately

2. Given an inertial frame  $A$ ,



$$\vec{v}_{P/A} = \vec{v}_{P/B} + \vec{v}_{B/A}$$

no net force

$\Rightarrow \vec{v}_{P/A}$  constant

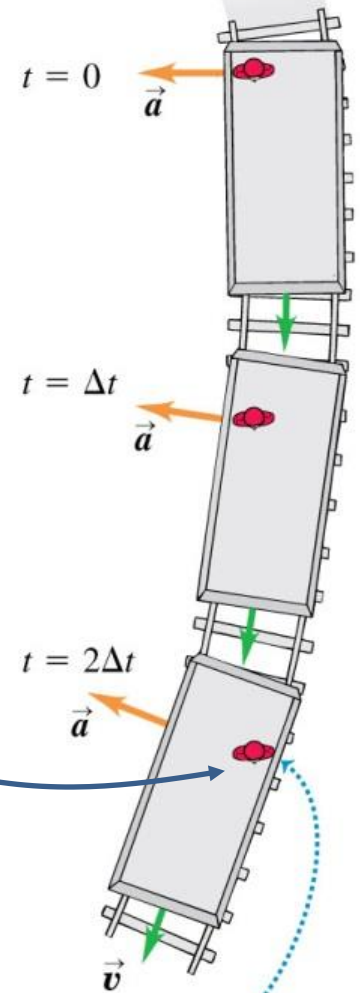
$\Rightarrow \vec{v}_{P/B}$  constant provided  $\vec{v}_{B/A}$  constant

Any frame  $B$  moving with constant  $\vec{v}_{B/A}$  (can be zero) is also an inertial frame

In a non-inertial frame of reference, may feel like being acted on by a (non-existing) force.

(c) The vehicle rounds a turn at constant speed.

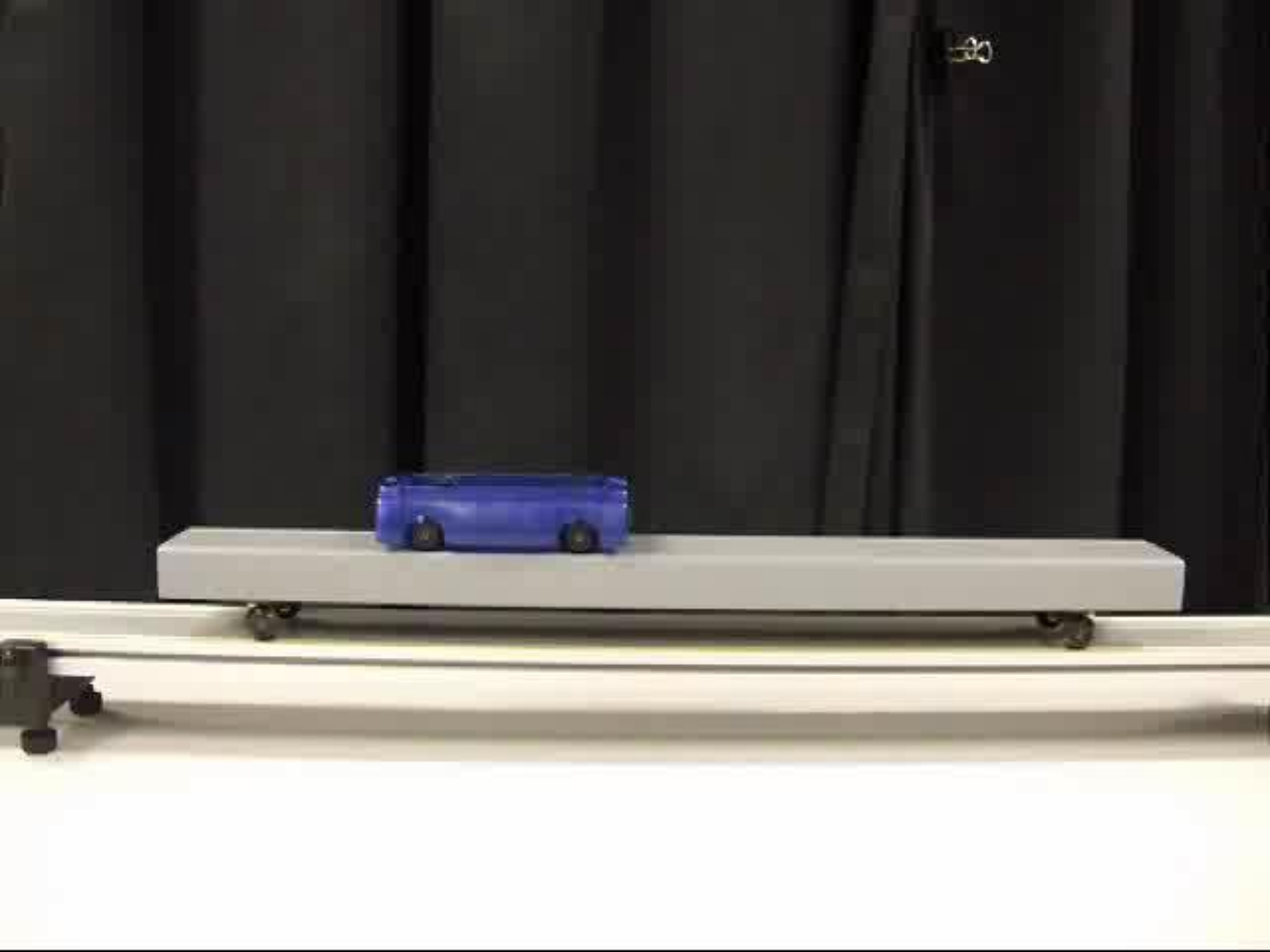
feel like a force pushing you aside



You tend to continue moving in a straight line as the vehicle turns.

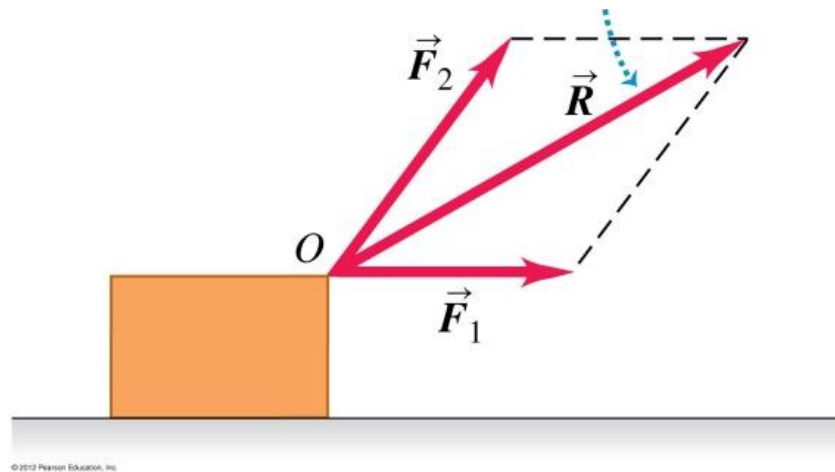
# Question

- In which of the following situations is there zero net force on the body?
  - a) an airplane flying due north at a steady speed and at a constant altitude, assuming that the earth is flat and is an inertial frame;
  - b) a car driving straight up a hill at constant speed;
  - c) a hawk circling at constant speed and constant height above an open field;
  - d) a box with slick, frictionless surfaces in the back of a truck as the truck accelerates forward on a level road at constant acceleration.



Forces are vectors and can be added up (superposition of forces)

$\vec{R}$  is called the net or resultant force



The SI unit of force is newton,  
 $1 \text{ N} = 1 \text{ kg m/s}^2$

# Newton's second law

If a *net* external force acts on a body, the body accelerates according to

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

inertial mass

– how reluctant the body is to change its velocity



Make sure  $\vec{F}$  is the net force, see Demonstration: fan car

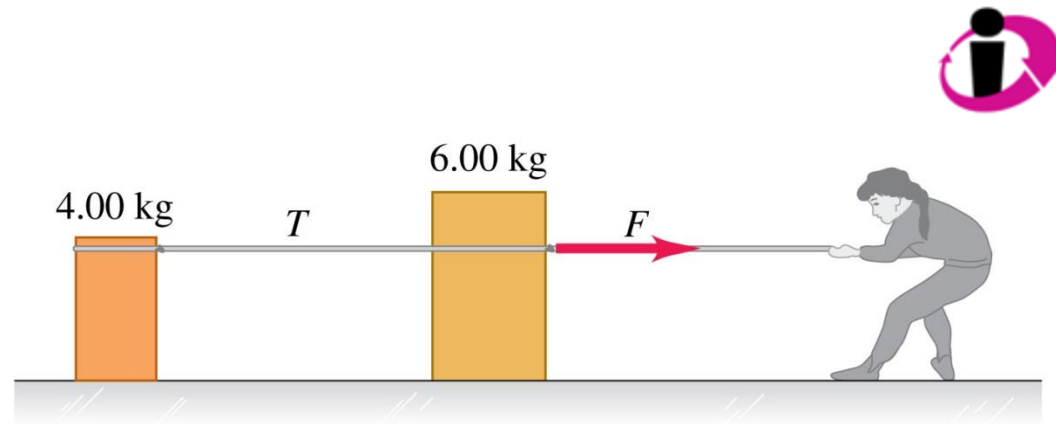


D



## Q4.12

A woman pulls on a 6.00-kg crate, which in turn is connected to a 4.00-kg crate by a light rope. It is given that both crates have non-zero accelerations and the light rope remains taut.

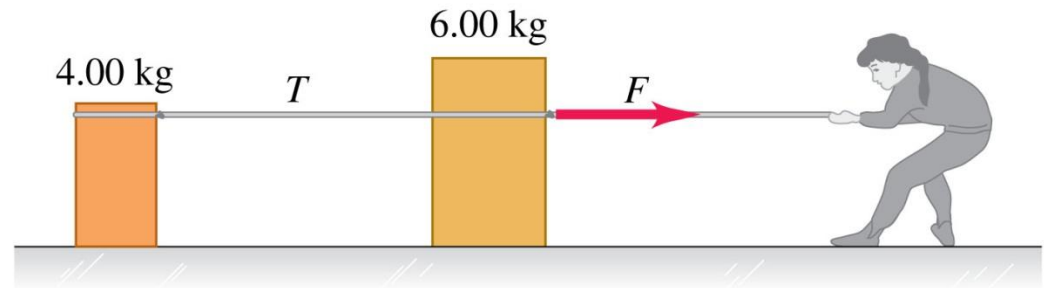


Compared to the 6.00-kg crate, the lighter 4.00-kg crate

- A. is subjected to the same net force and has the same acceleration.
- B. is subjected to a smaller net force and has the same acceleration.
- C. is subjected to the same net force and has a smaller acceleration.
- D. is subjected to a smaller net force and has a smaller acceleration.
- E. none of the above

## A4.12

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# Question

- Suppose an astronaut landed on a planet where  $g = 19.6 \text{ m/s}^2$ .
- Compared to earth,
  - it would be (easier / harder / just as easy) for her to walk around;
  - it would be (easier / harder / just as easy) for her to catch a ball that is moving horizontally at 12 m/s.  $\rightarrow 0$

$g$

$$\underline{F} = \underline{ma}$$

# Newton's third law of motion

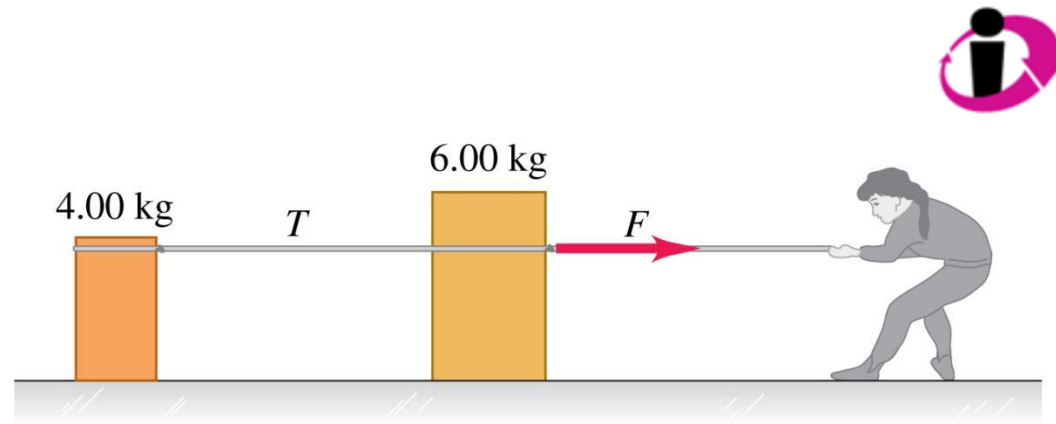
- If body A exerts a force on body B (an “action”), then body B exerts a force on body A (a “reaction”).
- These two forces have the same magnitude but are opposite in direction.
- These two forces act on different bodies.

# Question

- Since action and reaction are equal and opposite, should they cancel each other?

## Q4.14

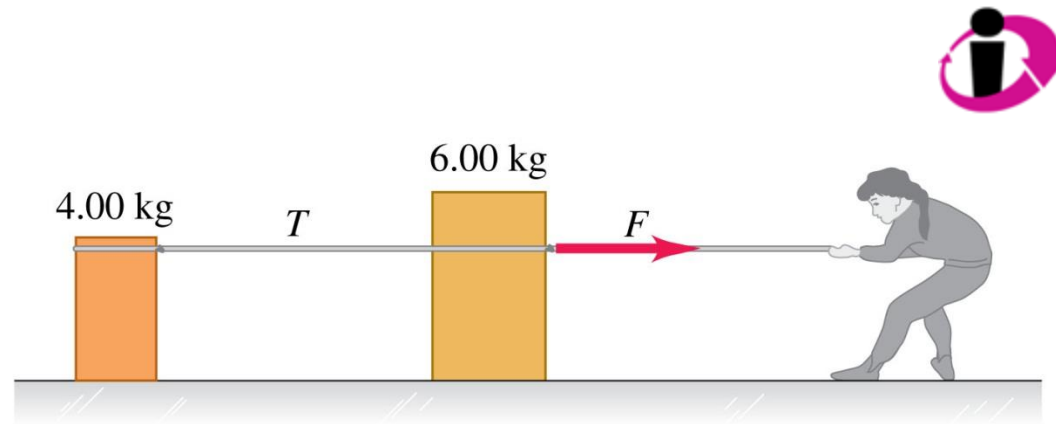
A woman pulls on a 6.00-kg crate, which in turn is connected to a 4.00-kg crate by a light rope. It is given that both crates have non-zero accelerations and the light rope remains taut.



- A. the 6.00-kg crate exerts more force on the 4.00-kg crate than the 4.00-kg crate exerts on the 6.00-kg crate.
- B. the 6.00-kg crate exerts less force on the 4.00-kg crate than the 4.00-kg crate exerts on the 6.00-kg crate.
- C. the 6.00-kg crate exerts as much force on the 4.00-kg crate as the 4.00-kg crate exerts on the 6.00-kg crate.

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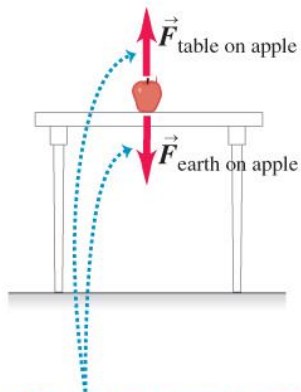
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# Example 4.9

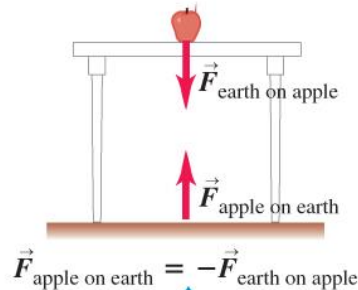
## Action and reaction forces acting on an apple sitting on a table

(a) The forces acting on the apple



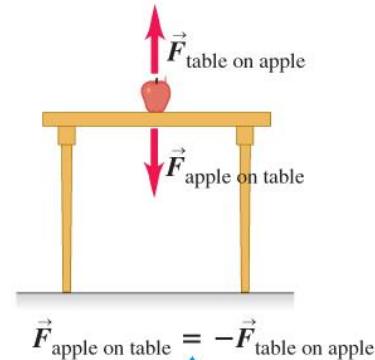
The two forces on the apple *cannot* be an action–reaction pair because they act on the same object.

(b) The action–reaction pair for the interaction between the apple and the earth

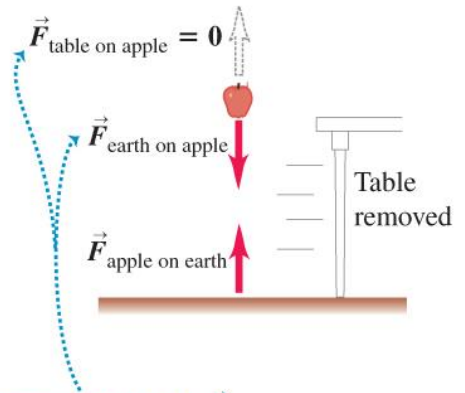


An action–reaction pair is a mutual interaction between two objects. The two forces act on two *different* objects.

(c) The action–reaction pair for the interaction between the apple and the table



(d) We eliminate the force of the table on the apple.



When we remove the table,  $\vec{F}_{\text{table on apple}}$  becomes zero but  $\vec{F}_{\text{earth on apple}}$  is unchanged. Hence these forces (which act on the same object) *cannot* be an action–reaction pair.

# Question

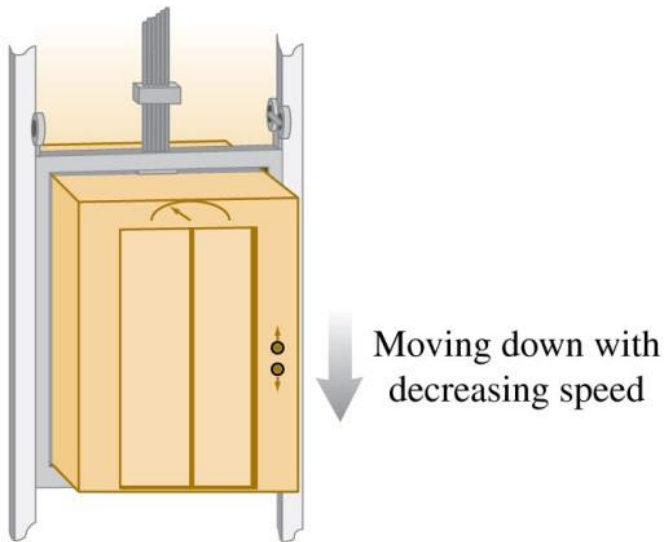
- The buoyance force experienced by a scuba diver is one half of an action-reaction pair.
- What force is the other half of this pair?
  - a) the weight of the diver;
  - b) the forward thrust force;
  - c) the backward drag force;
  - d) the downward force that the swimmer exerts on the water.

## Example: Tension in an elevator cable

An elevator, mass 800 kg, moving downwards at 10.0 m/s

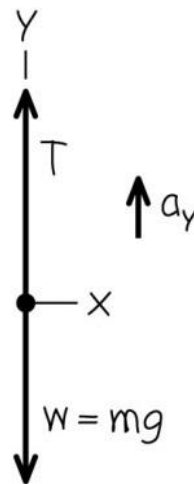
If it comes to a stop in a distance of 25.0 m

(a) Descending elevator



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(b) Free-body diagram for elevator



To find deceleration  $a_y$

$$v_y^2 = v_{0y}^2 + 2a_y(y - y_0)$$

0 m/s      -10.0 m/s      -25.0 m

$$\Rightarrow a_y = 2.00 \text{ m/s}^2$$

Tension in the cable

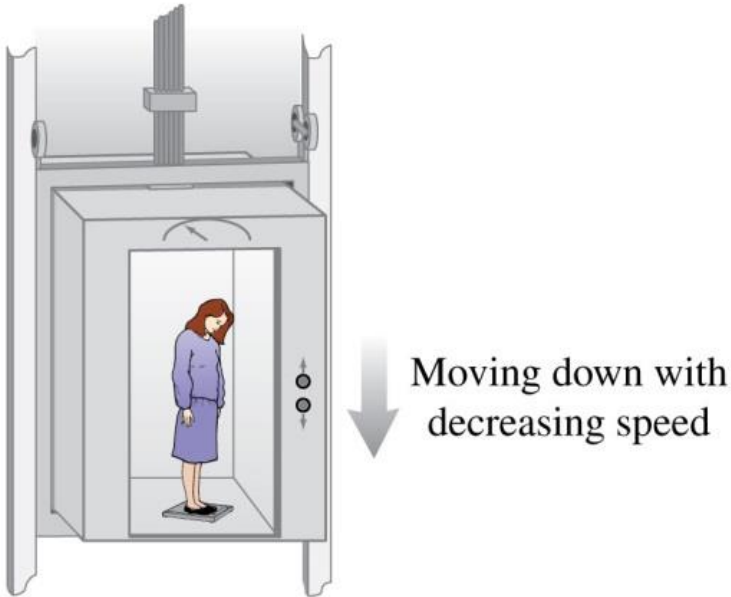
$$\sum F_y = T - w = ma_y$$

$$\Rightarrow T = m(g + a_y) = 9440 \text{ N}$$

## Apparent weight and weightlessness

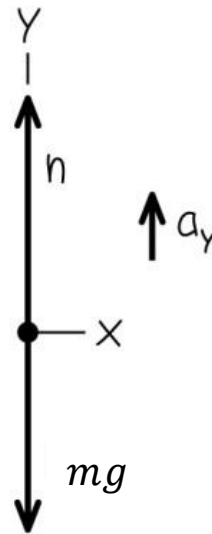
A person standing on a scale in an elevator, reading of the scale is  $n$

(a) Woman in a descending elevator



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(b) Free-body diagram for woman



$$\sum F_y = n - mg = ma_y$$
$$\Rightarrow n = m(g + a_y)$$

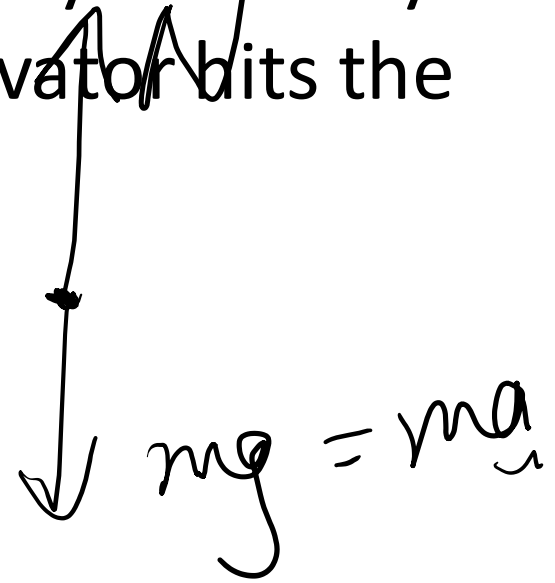
apparent weight of the person

What if free falling, i.e.,  
 $a_y = -g$ ,  $n = 0$   
apparent weightlessness

Her feet effectively lose contact with the floor

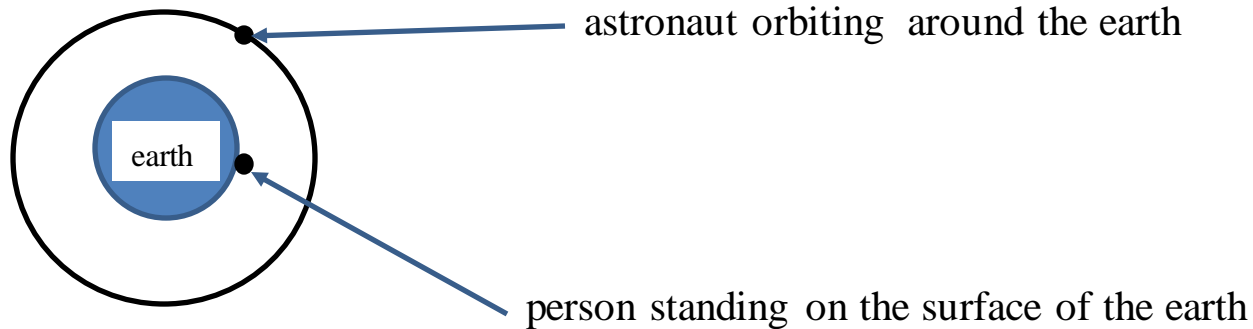
# Question

- One of your very clever classmates says, “If your elevator has a broken cable and is falling freely to the ground, you can save yourself by jumping up at the instant the elevator hits the ground.” Will this work?



A hand-drawn diagram illustrating a falling elevator. A vertical line with a downward-pointing arrow at the bottom represents the elevator's path. A small dot is placed on the line. To the right of the arrow, the equation  $mg = ma$  is written in a handwritten style.

# Question



Both are under the gravitational attraction of the earth.  
Why does the person has weight but the astronaut is weightless?