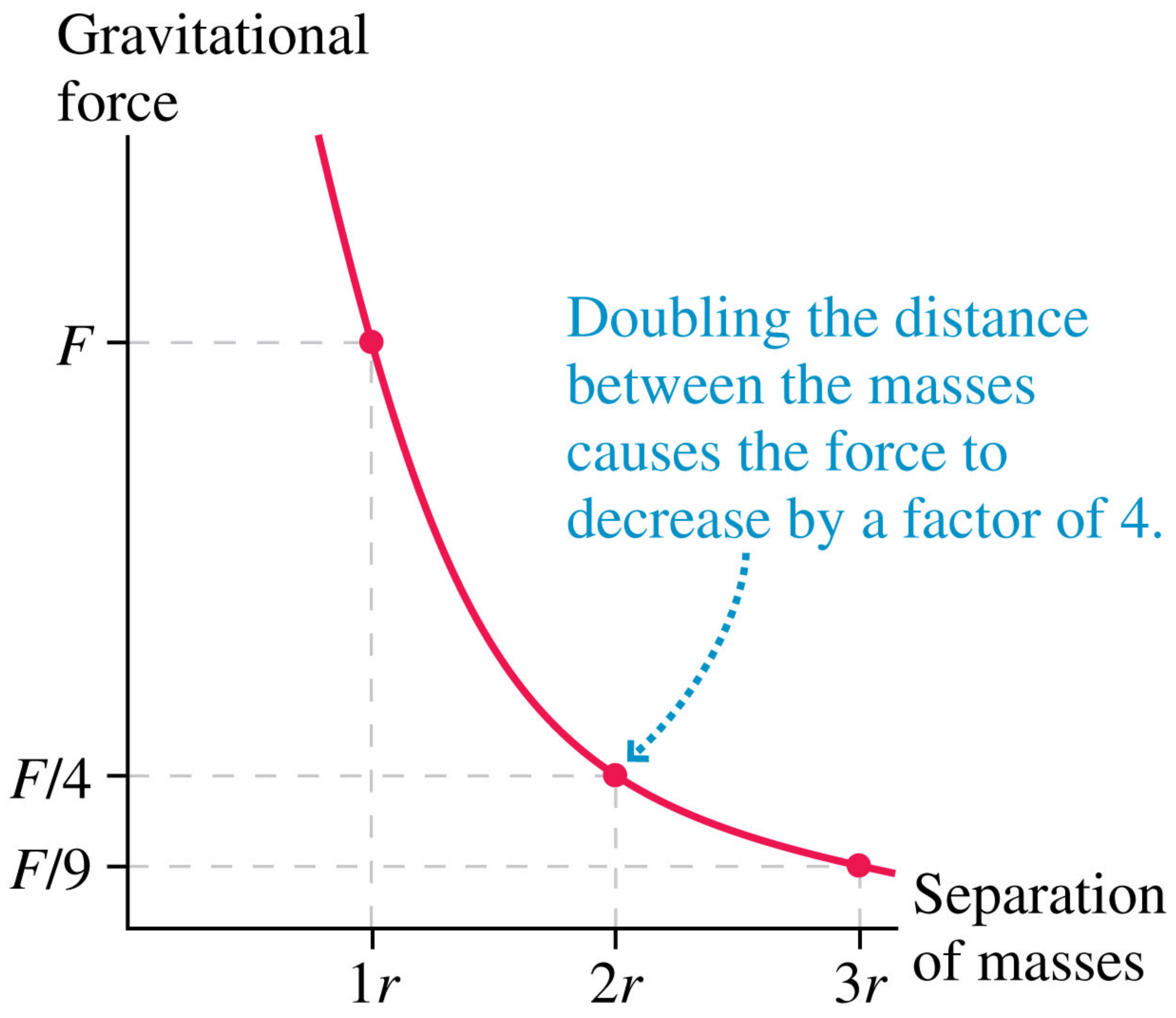
Physics 211

Lecture 39

David Newman

Newton's Law of Gravity

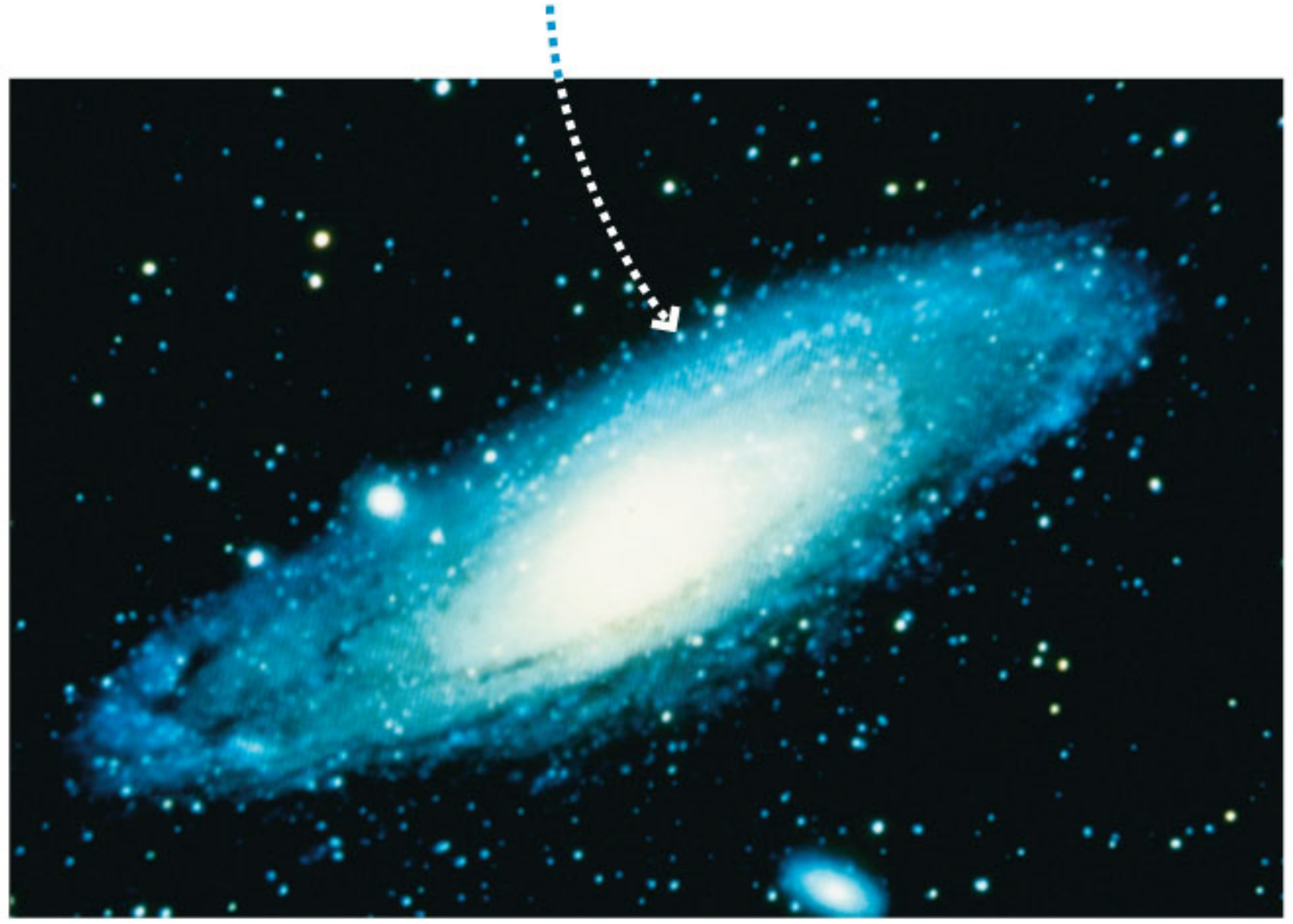
- The gravitational force is an inverse-square force.



Newton's Law of Gravity

- Since G is so small, it means that the attractive force between two $1.0\ \text{kg}$ masses, whose centers are $1.0\ \text{m}$ apart, is $6.7 \times 10^{-11}\ \text{N}$.
- This is 100 billion times weaker than the force of gravity from the earth on either of the masses!
- Although weak, gravity is a *long-range* force.
- Gravity keeps the earth orbiting the sun and the solar system orbiting the center of the Milky Way galaxy.

The dynamics of stellar motions, spanning many thousands of light years, are governed by Newton's law of gravity.



Decrease of g with Distance

TABLE 13.1 Variation of g with height above the ground

Height h	Example	g (m/s^2)
0 m	ground	9.83
4500 m	Mt. Whitney	9.82
10,000 m	jet airplane	9.80
300,000 m	space station	8.90
35,900,000 m	communications satellite	0.22

QuickCheck 13.5

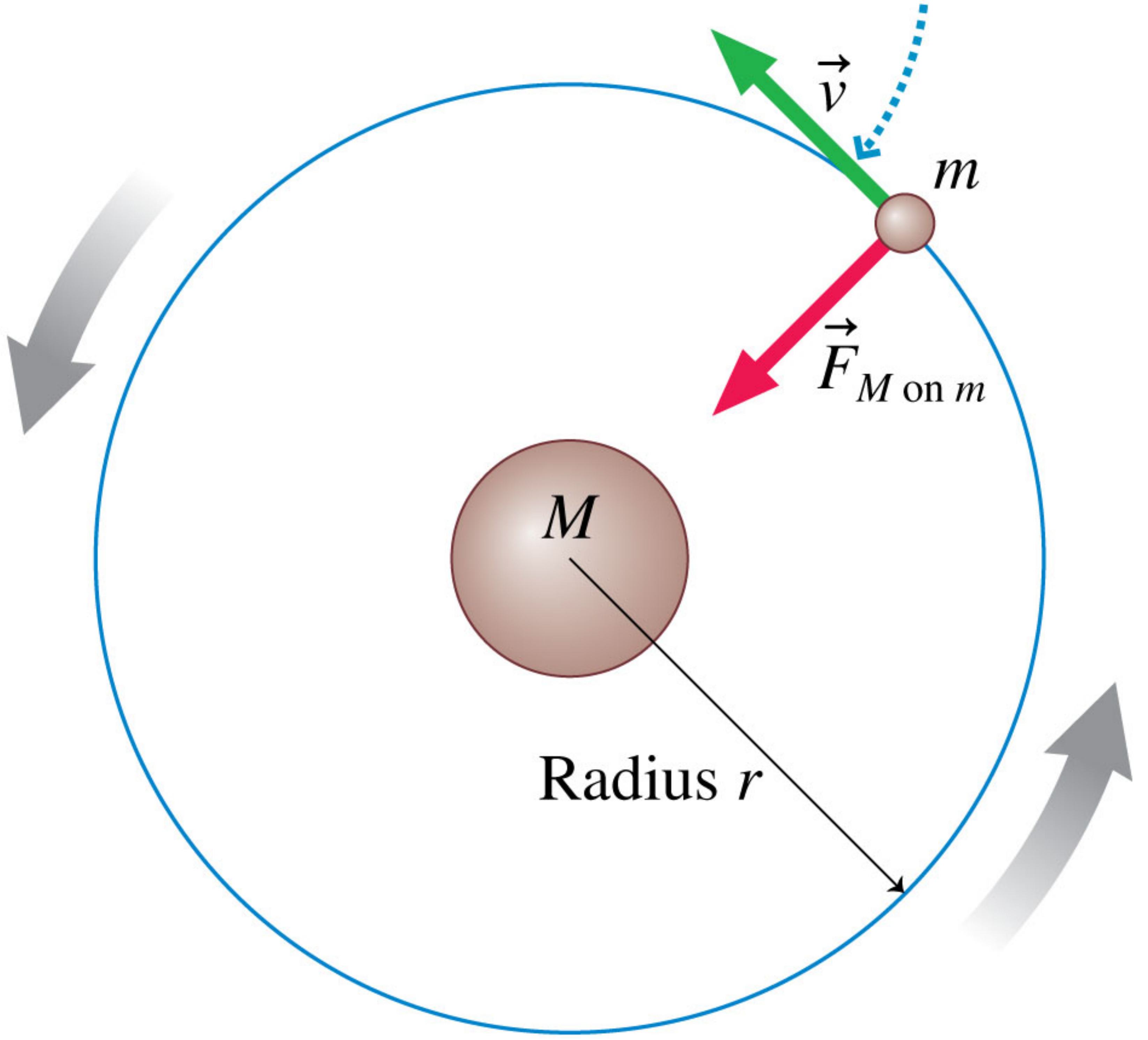
Astronauts on the International Space Station are weightless because

A. There's no gravity in outer space.
B. The net force on them is zero.
C. The centrifugal force balances the gravitational force.
D. g is very small, although not zero.
E. They are in free fall.

Satellite Orbits

- A circle is a special case of an ellipse.
- If a small mass m orbits a much larger mass M, the small mass is called a satellite.
- The speed of a satellite in a circular orbit is:

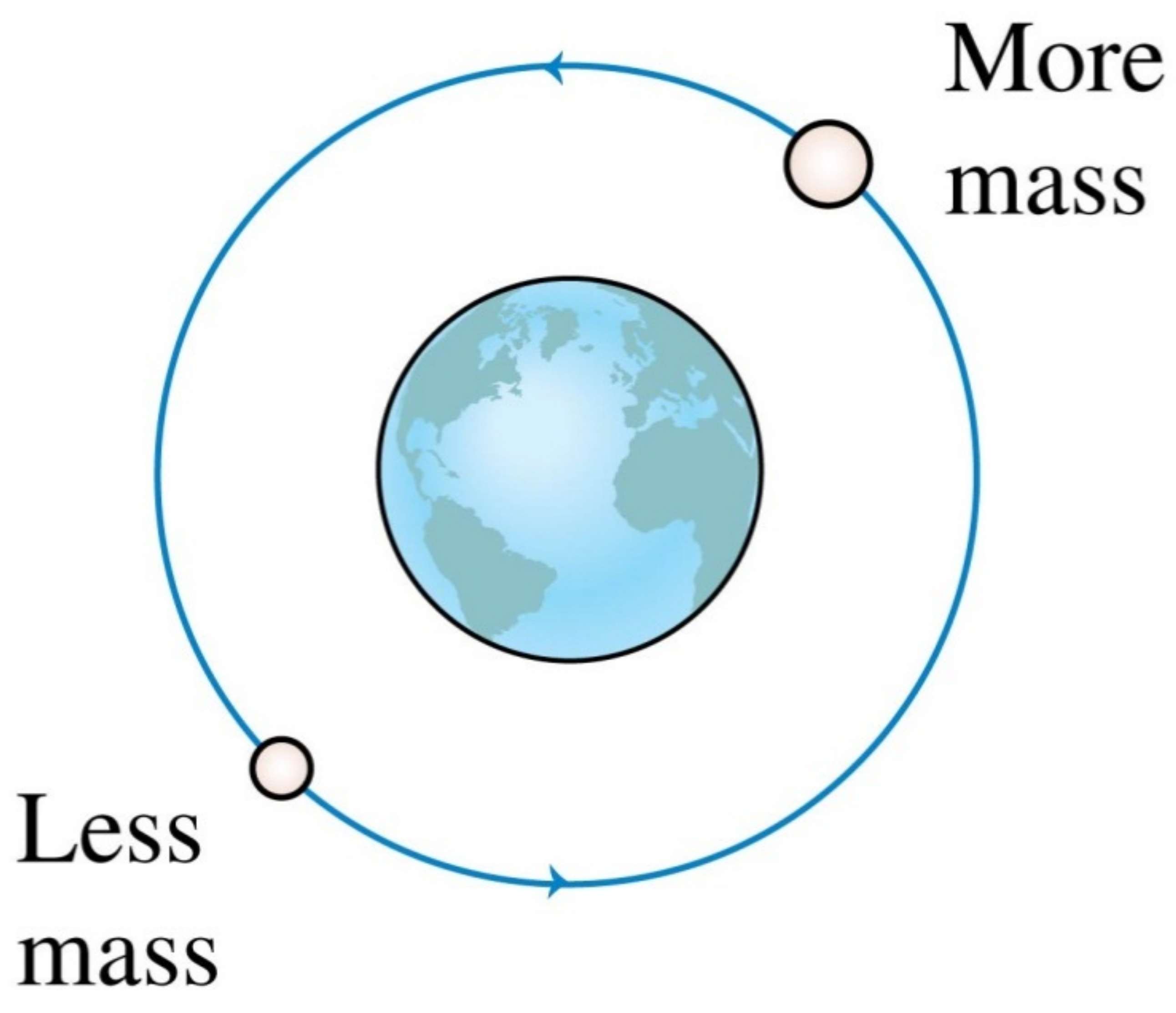
$$v = \sqrt{\frac{GM}{r}}$$



QuickCheck 13.7

Two satellites have circular orbits with the same radius. Which has a higher speed?

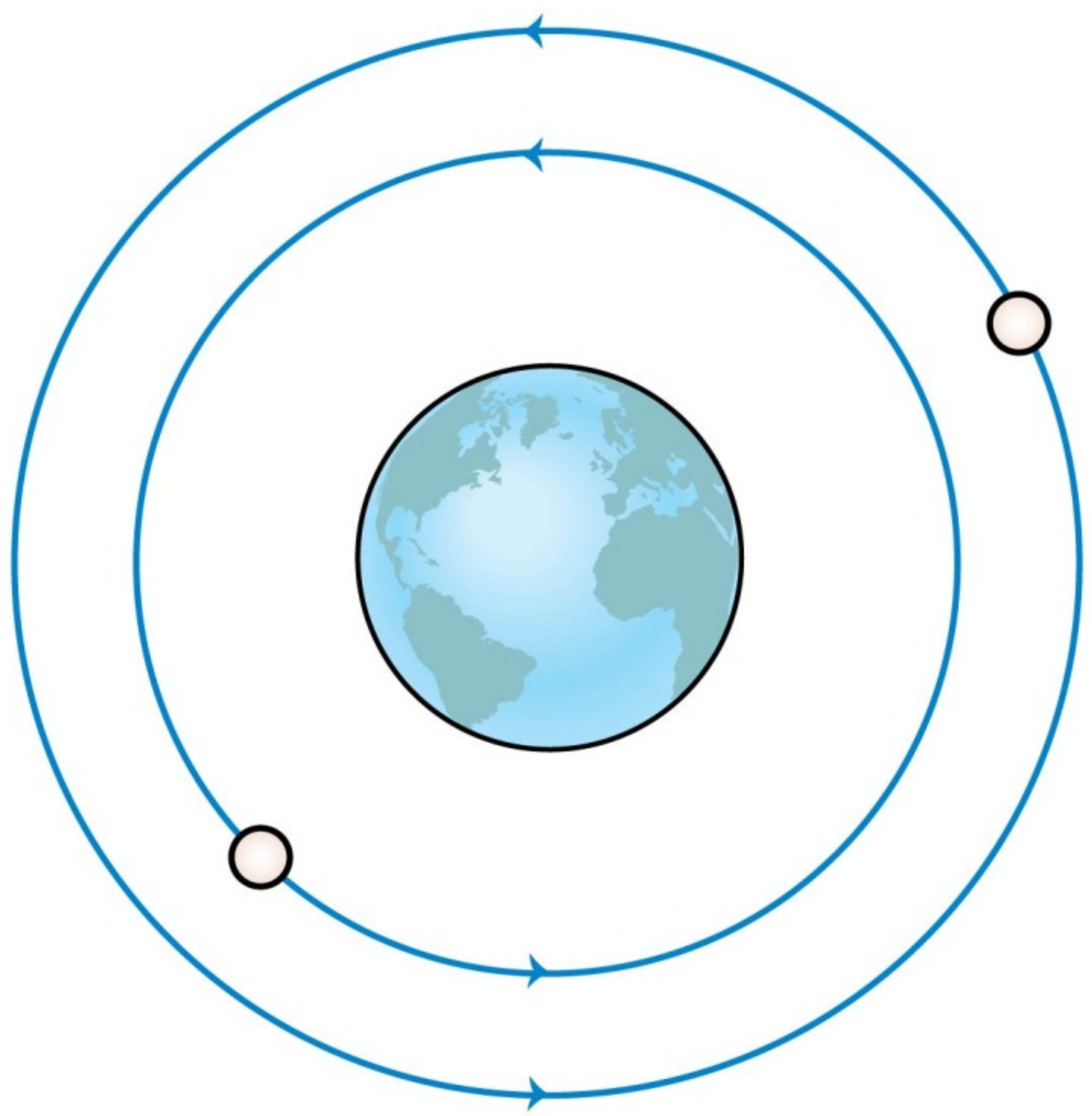
A. The one with more mass.
B. The one with less mass.
C. They have the same speed.



QuickCheck 13.8

Two identical satellites have different circular orbits. Which has a higher speed?

A. The one in the larger orbit.
B. The one in the smaller orbit.
C. They have the same speed.



Orbital Energetics

- We know that for a satellite in a circular orbit, its speed is related to the size of its orbit by $v^2 = GM/r$. The satellite's kinetic energy is thus

$$K = \frac{1}{2}mv^2 = \frac{GMm}{2r}$$

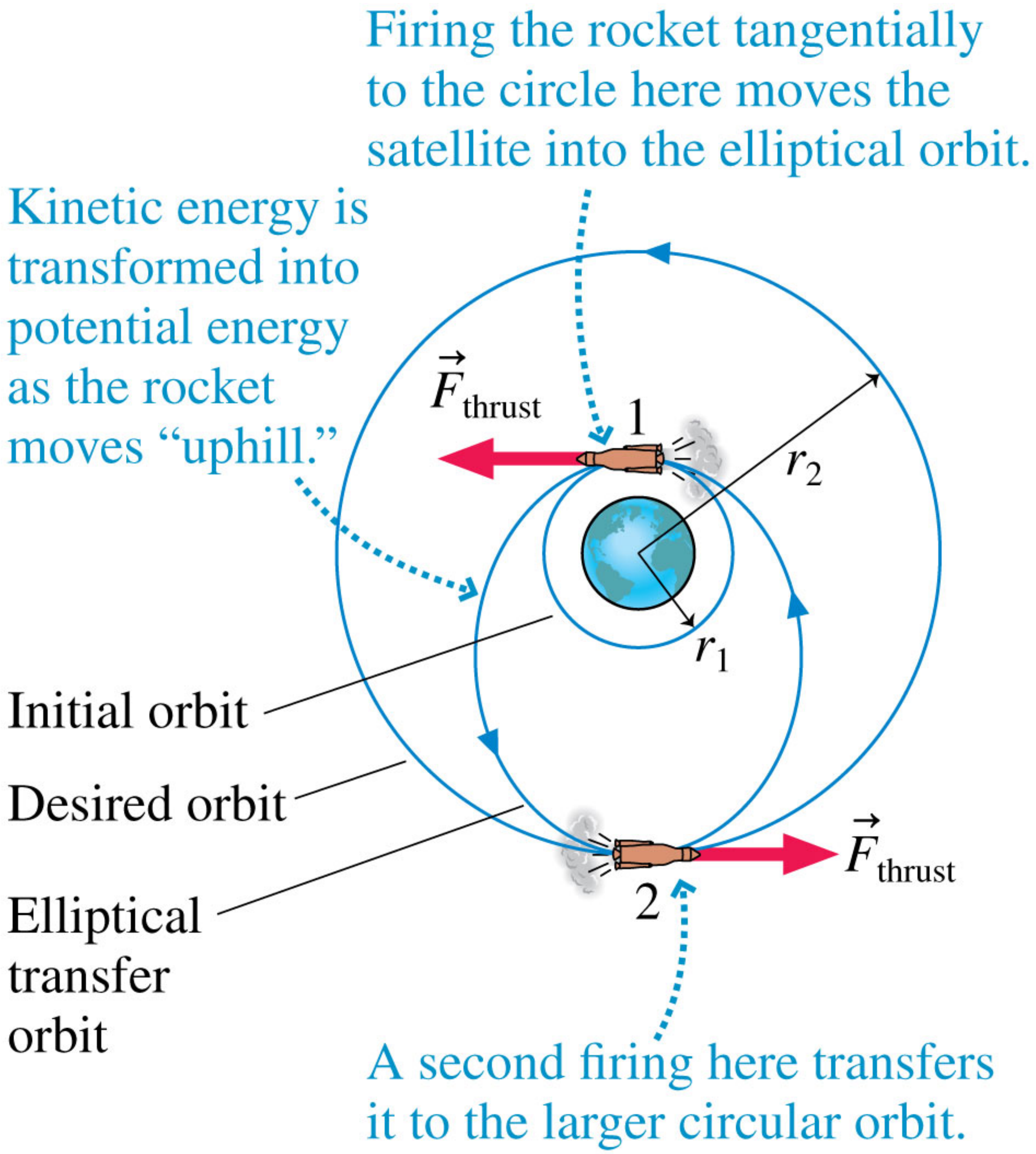
- But $-GMm/r$ is the potential energy, U_G, so

$$K = -\tfrac{1}{2}U_G$$

- If K and U do not have this relationship, then the trajectory will be elliptical rather than circular. So, the mechanical energy of a satellite in a circular orbit is always

$$E_{mech} = K + U_G = \tfrac{1}{2}U_G$$

Orbital Energetics

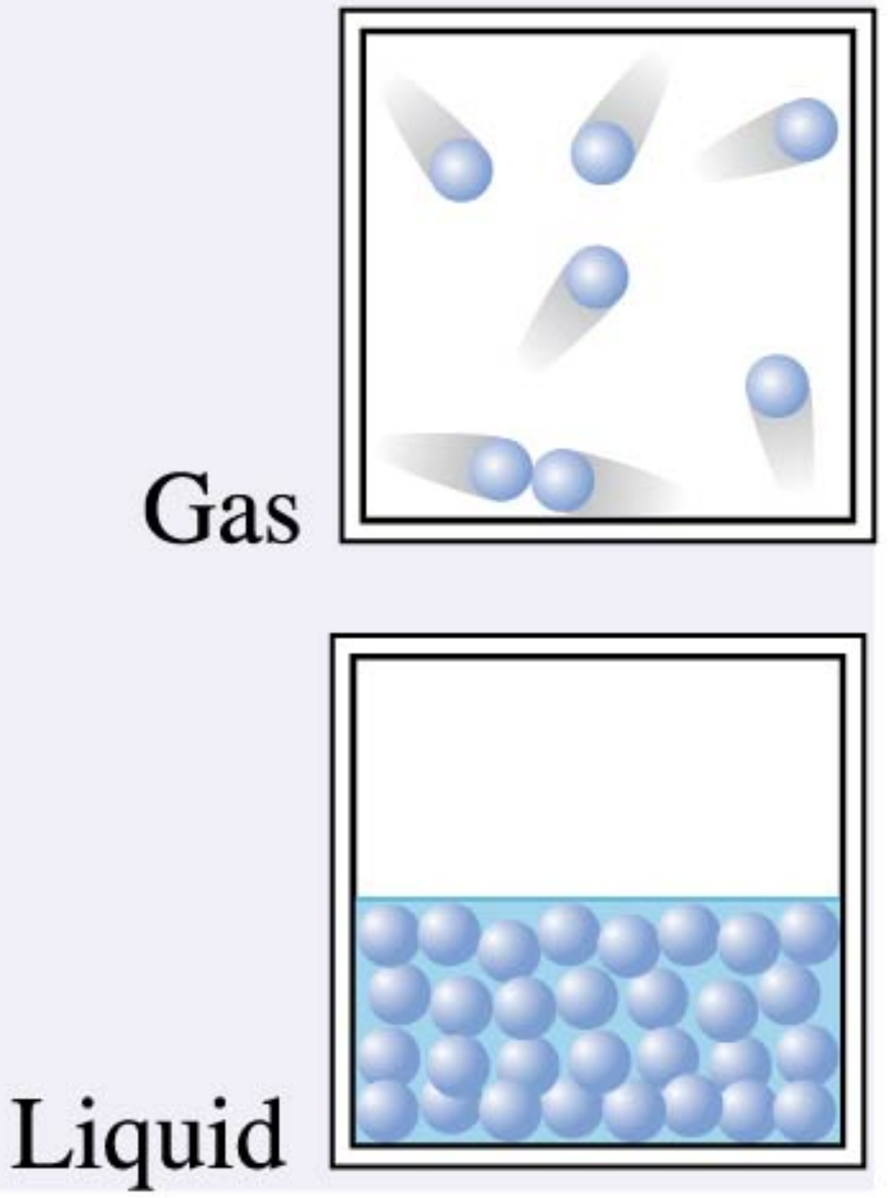


- The figure shows the steps involved to lift a satellite to a higher circular orbit.
- The first kick increases K without increasing U_G, so K is not $-\frac{1}{2}U_G$, and the orbit is elliptical.
- The satellite then slows down as r increases.
- The second kick increases K again so that $K = -\frac{1}{2}U_G$, and the orbit is circular.

What is a fluid?

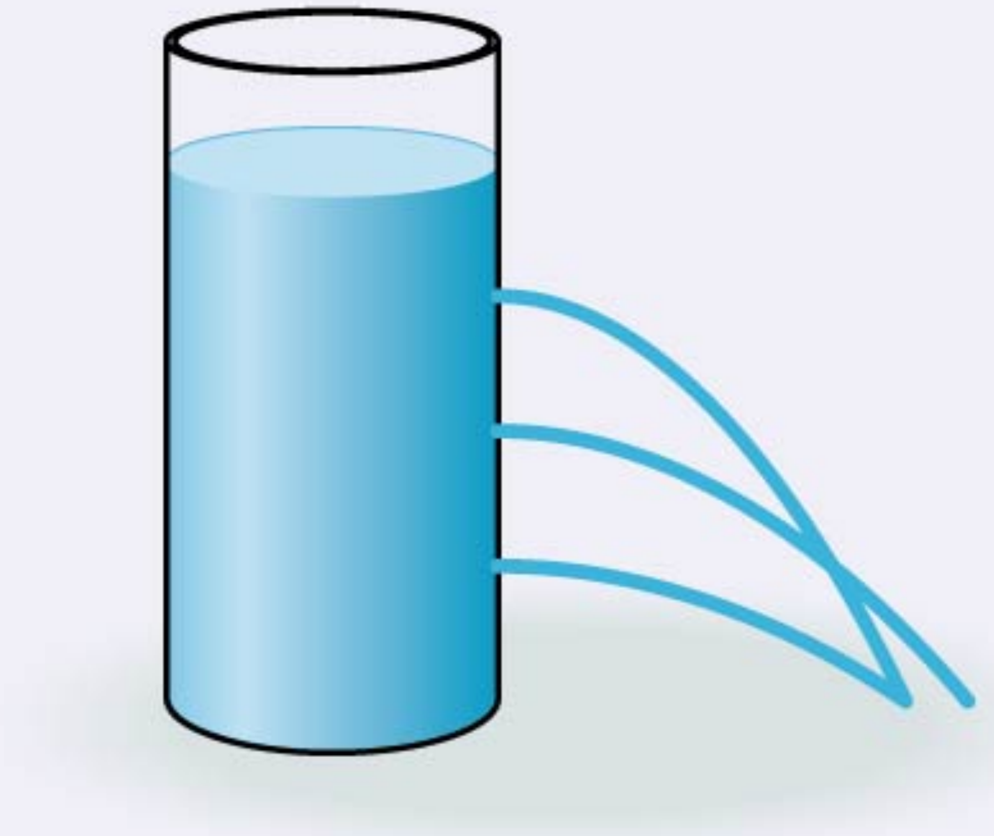
A fluid is a substance that flows. Both gases and liquids are fluids.

- A gas is compressible. The molecules move freely with few interactions.
- A liquid is incompressible. The molecules are weakly bound to one another.



What is pressure?

Fluids exert forces on the walls of their containers. Pressure is the force-to-area ratio F/A.

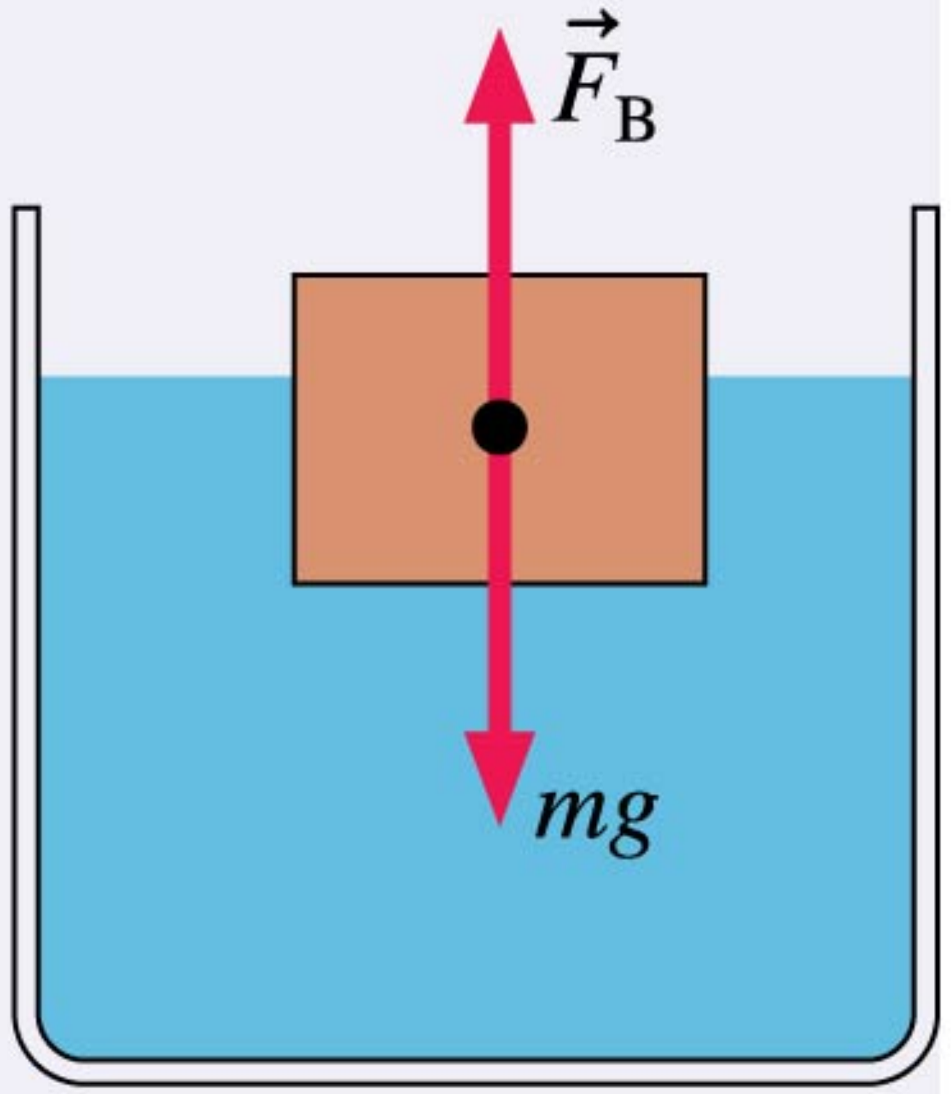


- Pressure in liquids, called hydrostatic pressure, is due to gravity. Pressure increases with depth.
- Pressure in gases is primarily thermal. Pressure is constant in a container.

What is buoyancy?

Buoyancy is the upward force a fluid exerts on an object.

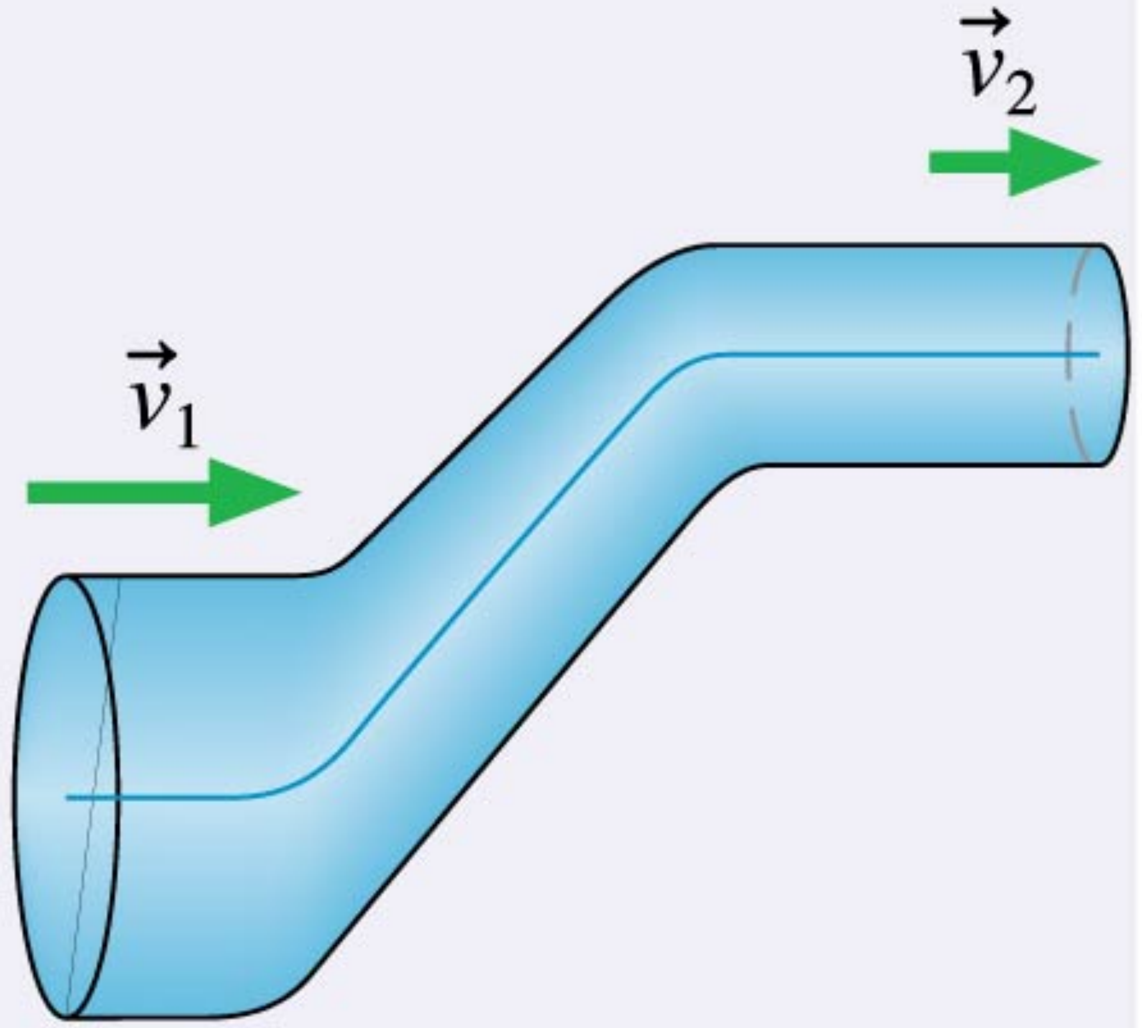
- Archimedes' principle says that the buoyant force equals the weight of the displaced fluid.
- An object floats if the buoyant force is sufficient to balance the object's weight.



« LOOKING BACK Section 6.1 Equilibrium

How does a fluid flow?

An ideal fluid—an incompressible, nonviscous fluid flowing smoothly—flows along streamlines. Bernoulli's equation, a statement of energy conservation, relates the pressures, speeds, and heights at two points on a streamline.

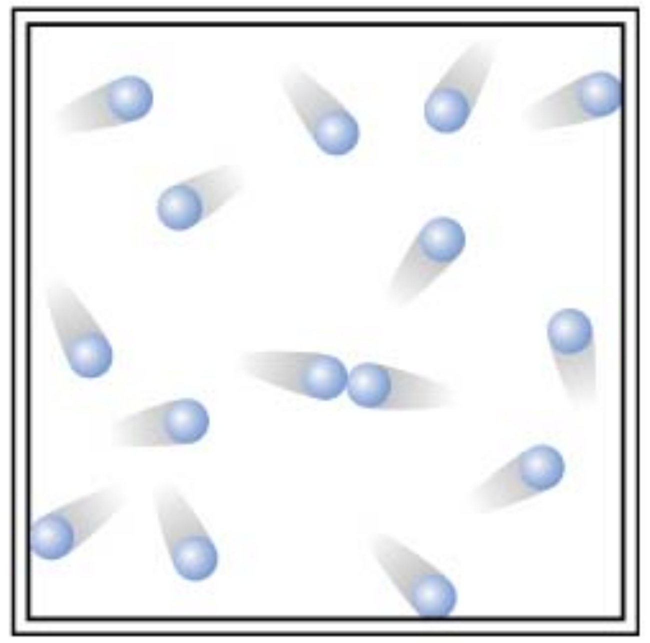


MODEL 14.1

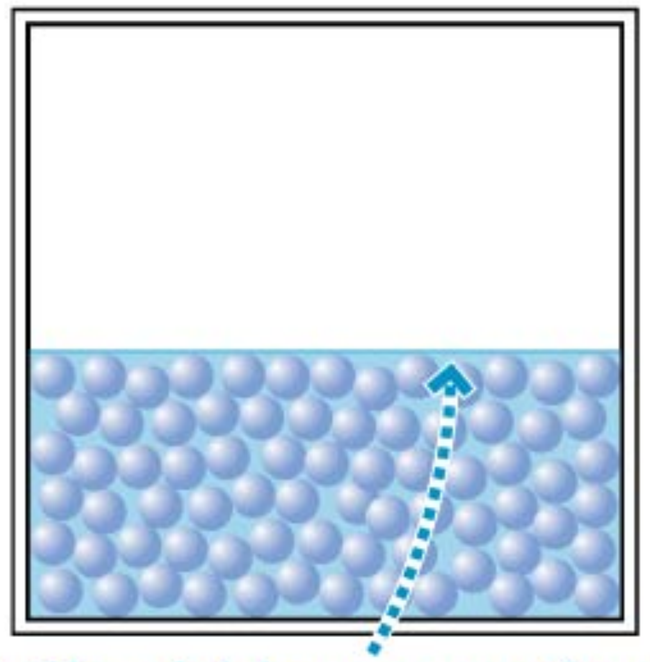
Molecular model of gases and liquids

Gases and liquids are fluids—they flow and exert pressure.

- **Gases**
  - Molecules move freely through space.
  - Molecules do not interact except for occasional collisions with each other or the walls.
  - Molecules are far apart, so a gas is *compressible*.
- **Liquids**
  - Molecules are weakly bound and stay close together.
  - A liquid is *incompressible* because the molecules can't get any closer.
  - Weak bonds allow the molecules to move around.



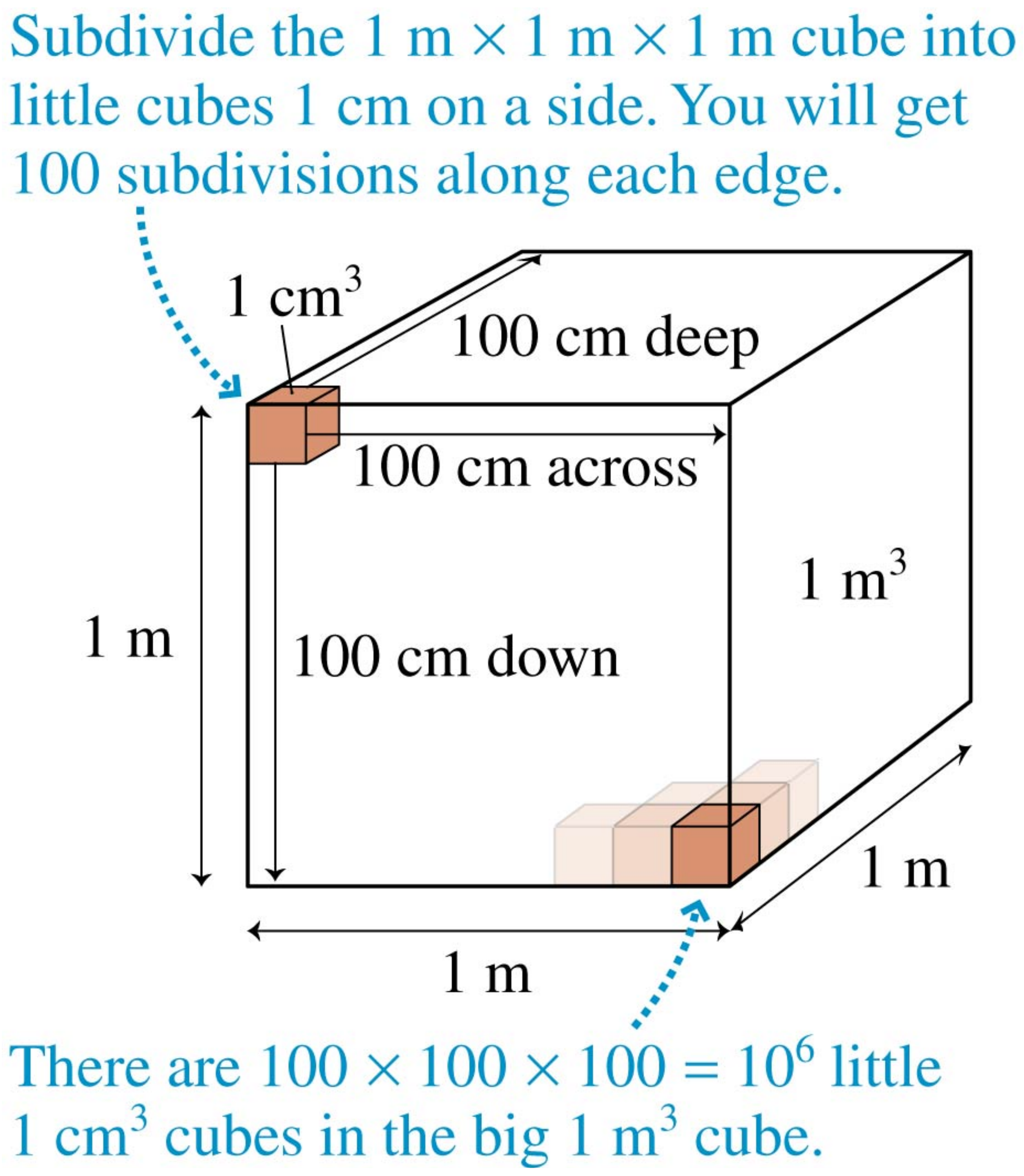
A gas fills the container.



A liquid has a surface.

- An important parameter of a macroscopic system is its volume V.
- The S.I. unit of volume is m^3.
- Some unit conversions:

$$1\ m^3 = 1000\ L$$
$$1\ L = 1000\ cm^3$$
$$1\ m^3 = 10^6\ cm^3$$



Density

- The ratio of an object's or material's mass to its volume is called the **mass density**, or sometimes simply "the density."

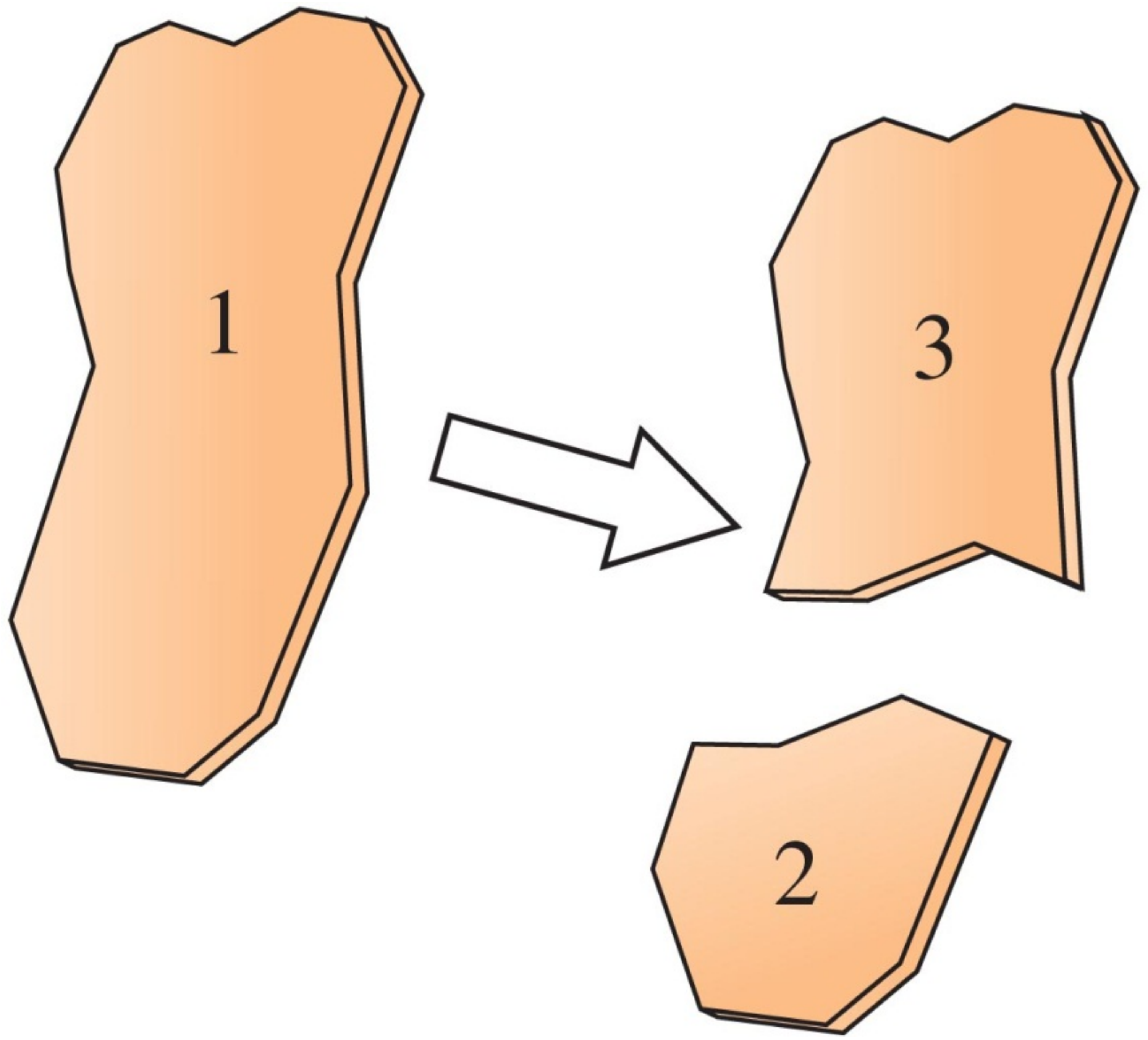
$$\rho = \frac{m}{V} \quad \text{(mass density)}$$

- The SI units of mass density are $\mathrm{kg/m^3}$.

QuickCheck 14.1

A piece of glass is broken into two pieces of different size. How do their densities compare?

A. $\rho_1 > \rho_3 > \rho_2$
B. $\rho_1 = \rho_3 = \rho_2$
C. $\rho_1 < \rho_3 < \rho_2$



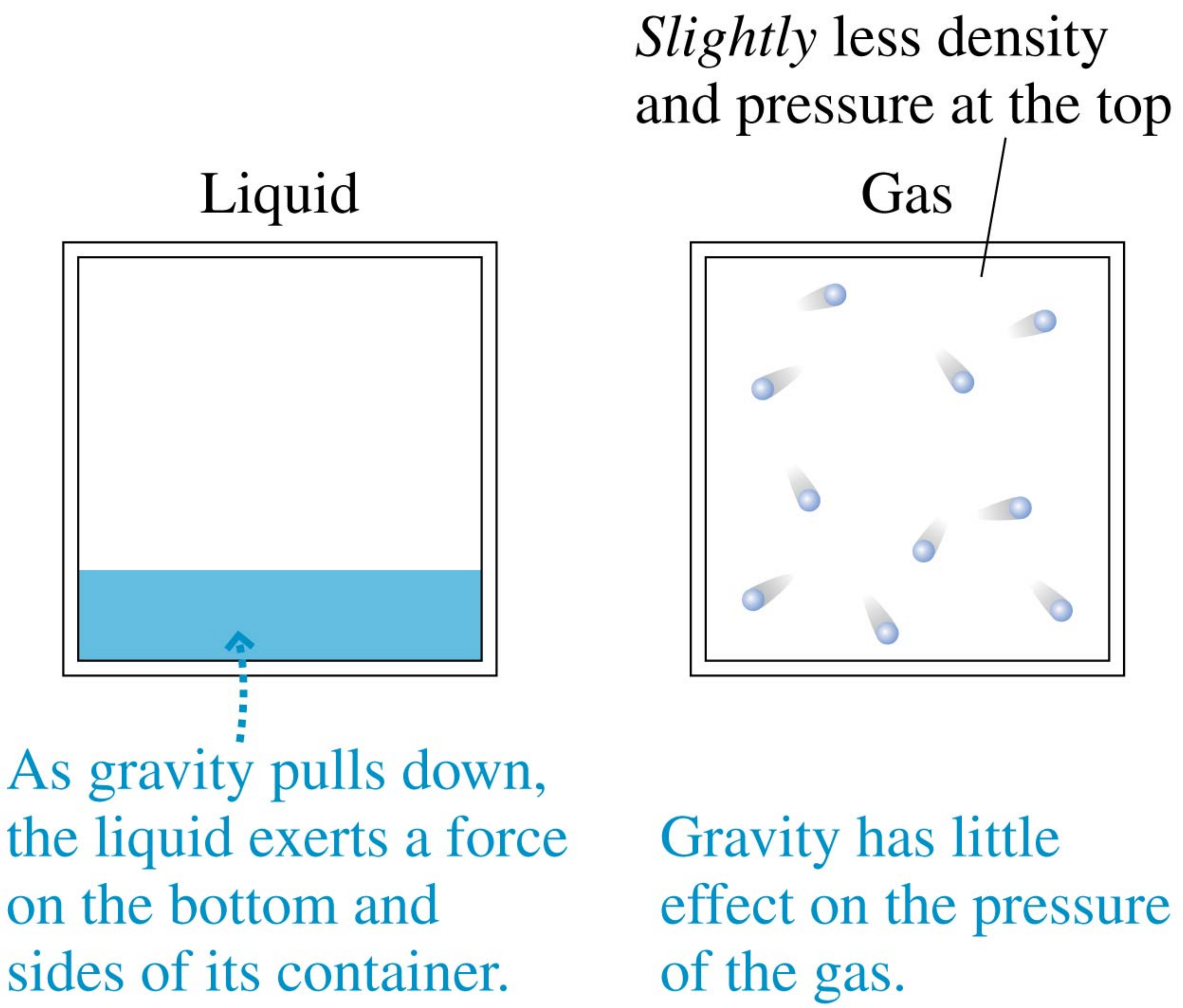
Densities of Various Fluids

TABLE 14.1 Densities of fluids at standard temperature (0°C) and pressure (1 atm)

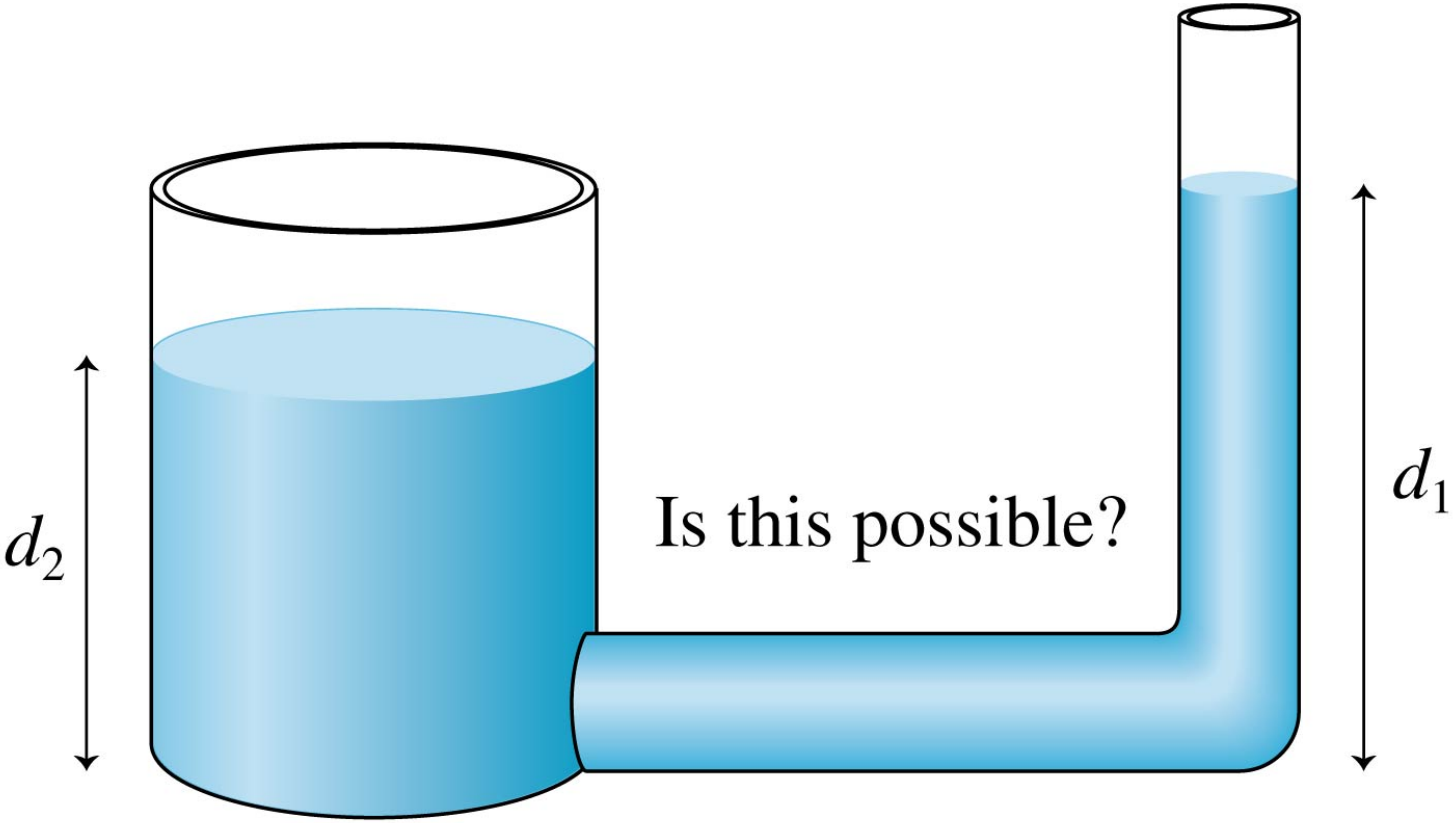
Substance	ρ (kg/m^3)
Helium gas	0.18
Air	1.29
Gasoline	680
Ethyl alcohol	790
Benzene	880
Oil (typical)	900
Water	1000
Seawater	1030
Glycerin	1260
Mercury	13,600

Pressure

- There are two contributions to the pressure in a container of fluid:
  1. A *gravitational contribution*, due to gravity pulling down on the liquid or gas.
  2. A *thermal contribution*, due to the collisions of freely moving gas molecules within the walls, which depends on gas temperature.



Liquids in Hydrostatic Equilibrium

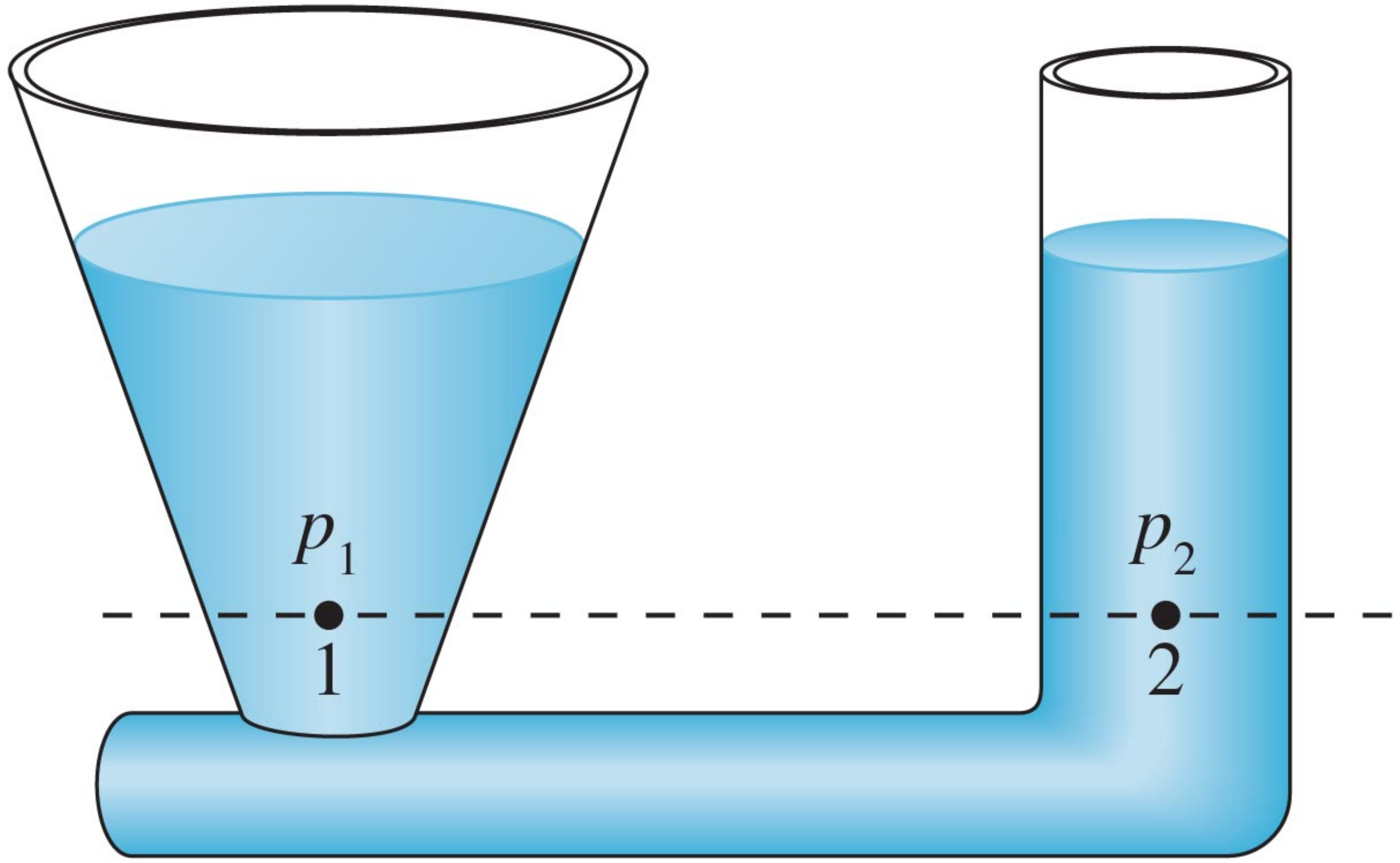


- No!
- A connected liquid in hydrostatic equilibrium rises to the same height in all open regions of the container.

QuickCheck 14.2

What can you say about the pressures at points 1 and 2?

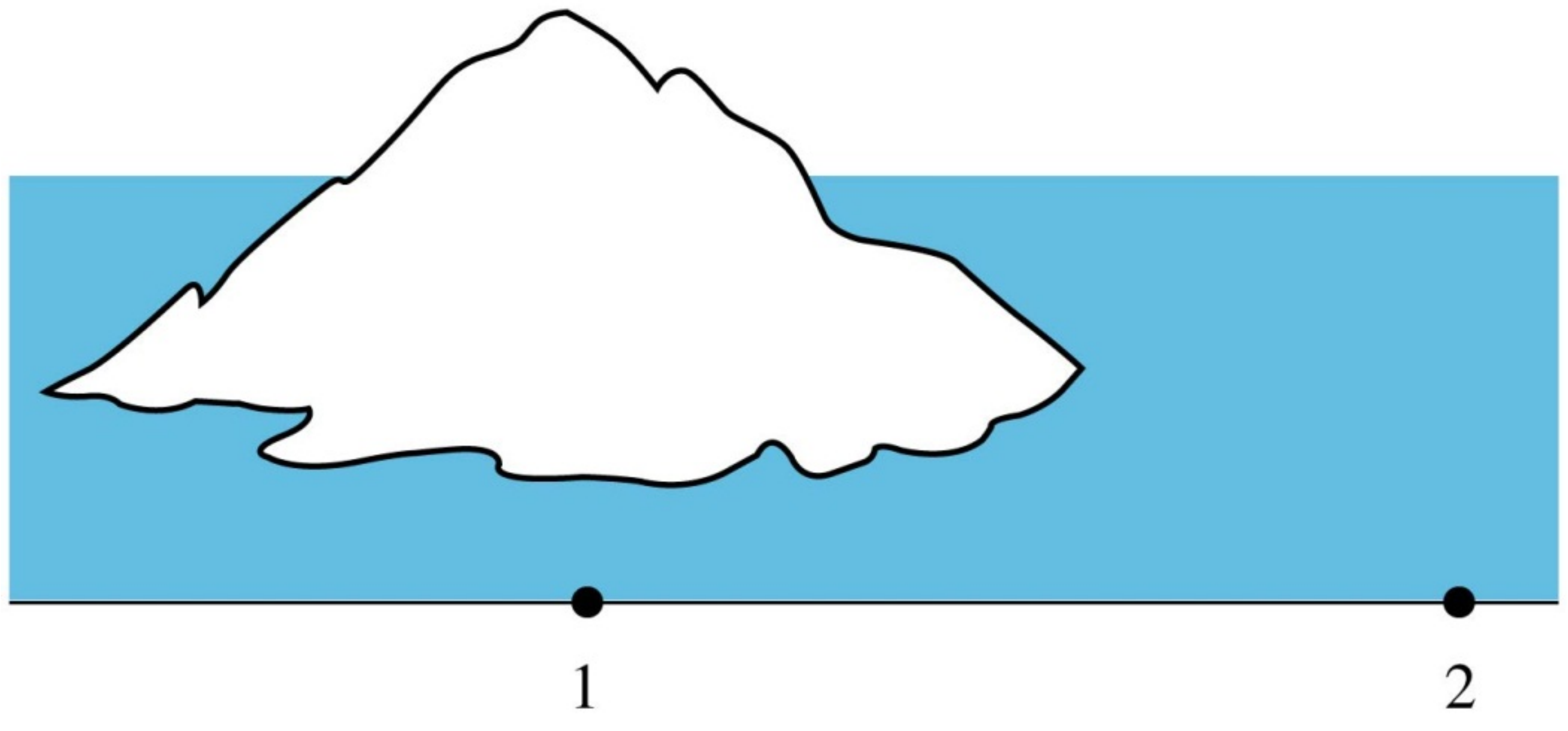
A. $p_1 > p_2$
B. $p_1 = p_2$
C. $p_1 < p_2$



QuickCheck 14.3

An iceberg floats in a shallow sea. What can you say about the pressures at points 1 and 2?

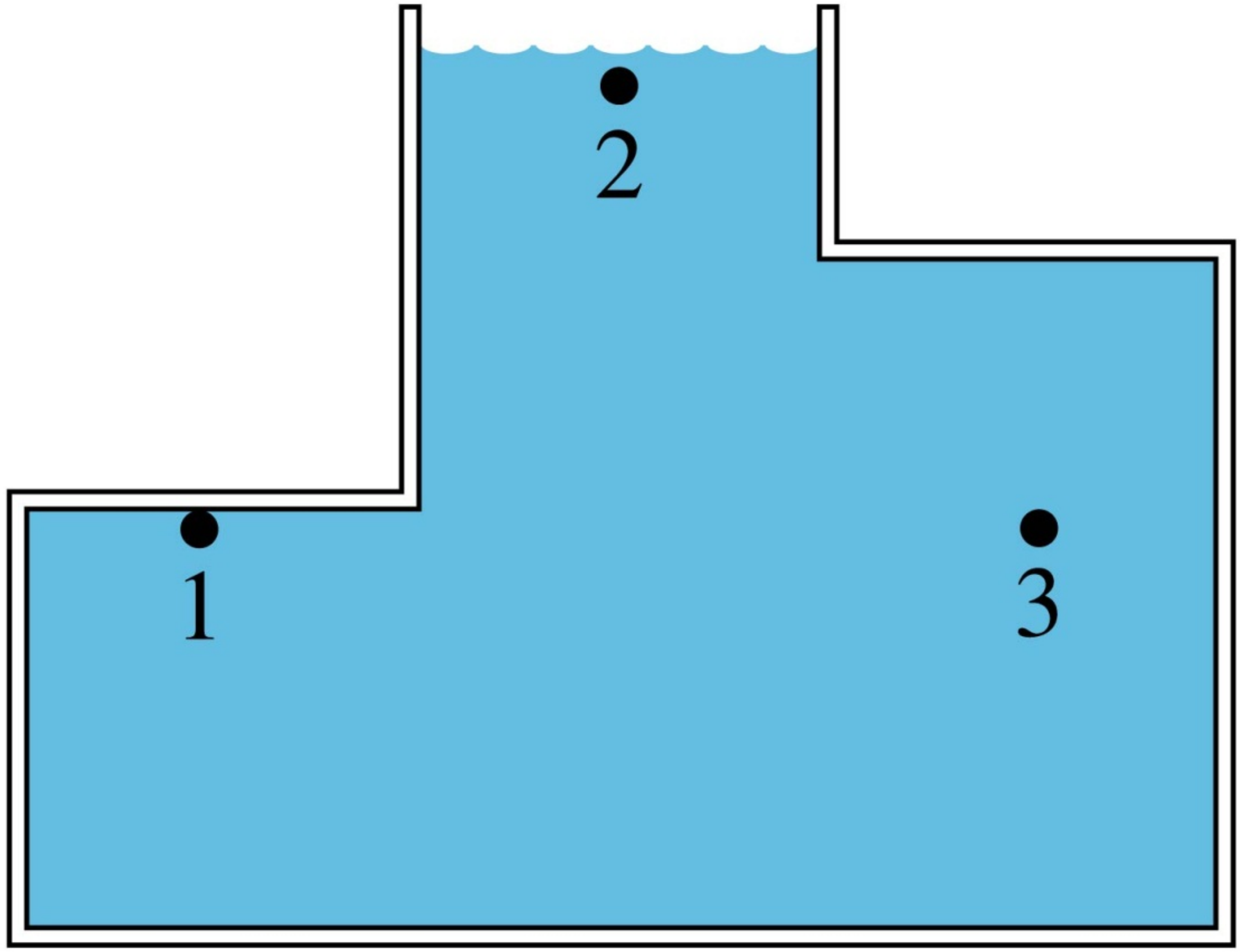
A. $p_1 > p_2$
B. $p_1 = p_2$
C. $p_1 < p_2$



QuickCheck 14.4

What can you say about the pressures at points 1, 2, and 3?

A. $p_1 = p_2 = p_3$
B. $p_1 = p_2 > p_3$
C. $p_3 > p_1 = p_2$
D. $p_3 > p_1 > p_2$
E. $p_1 = p_3 > p_2$

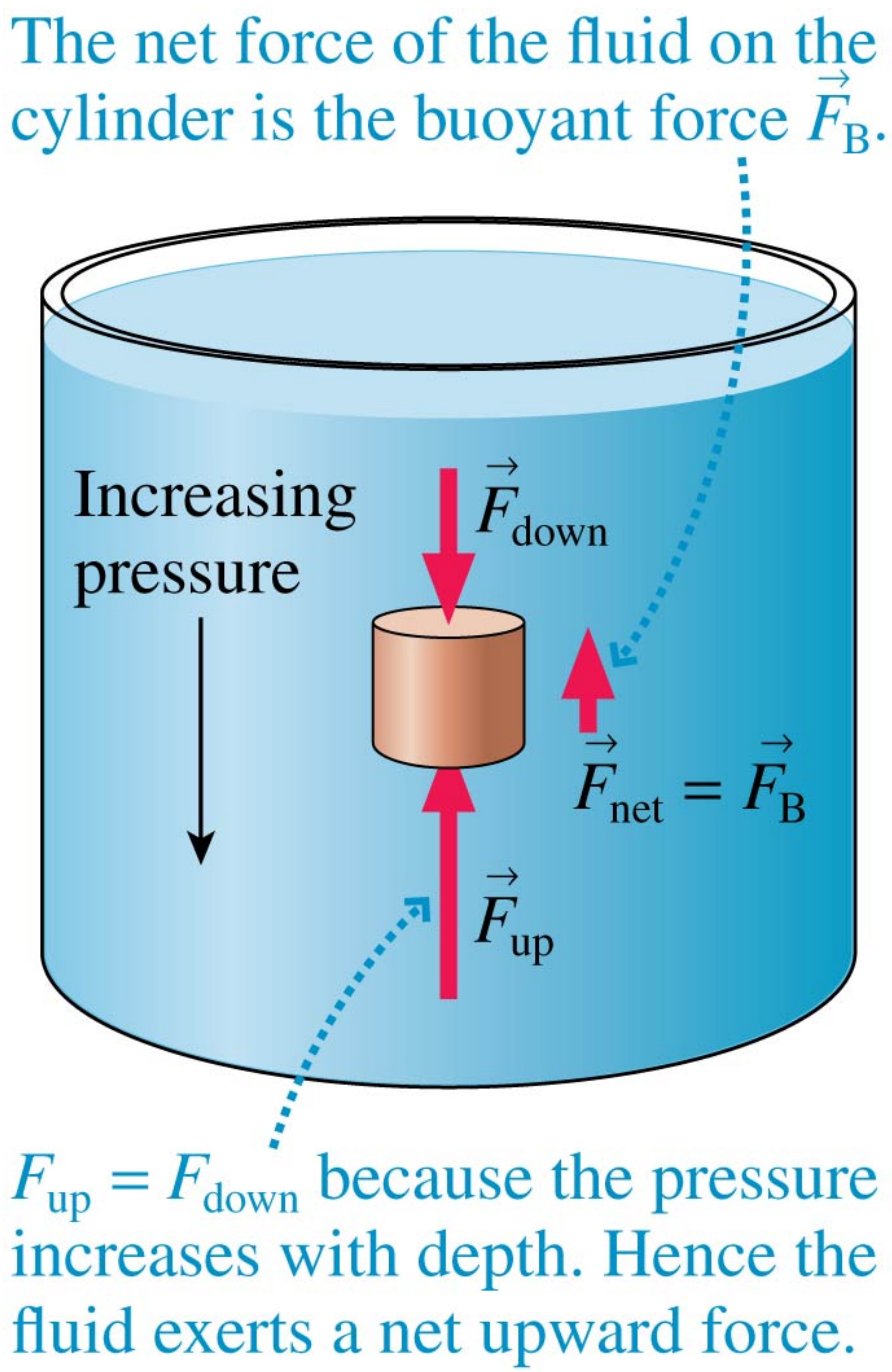


Buoyancy

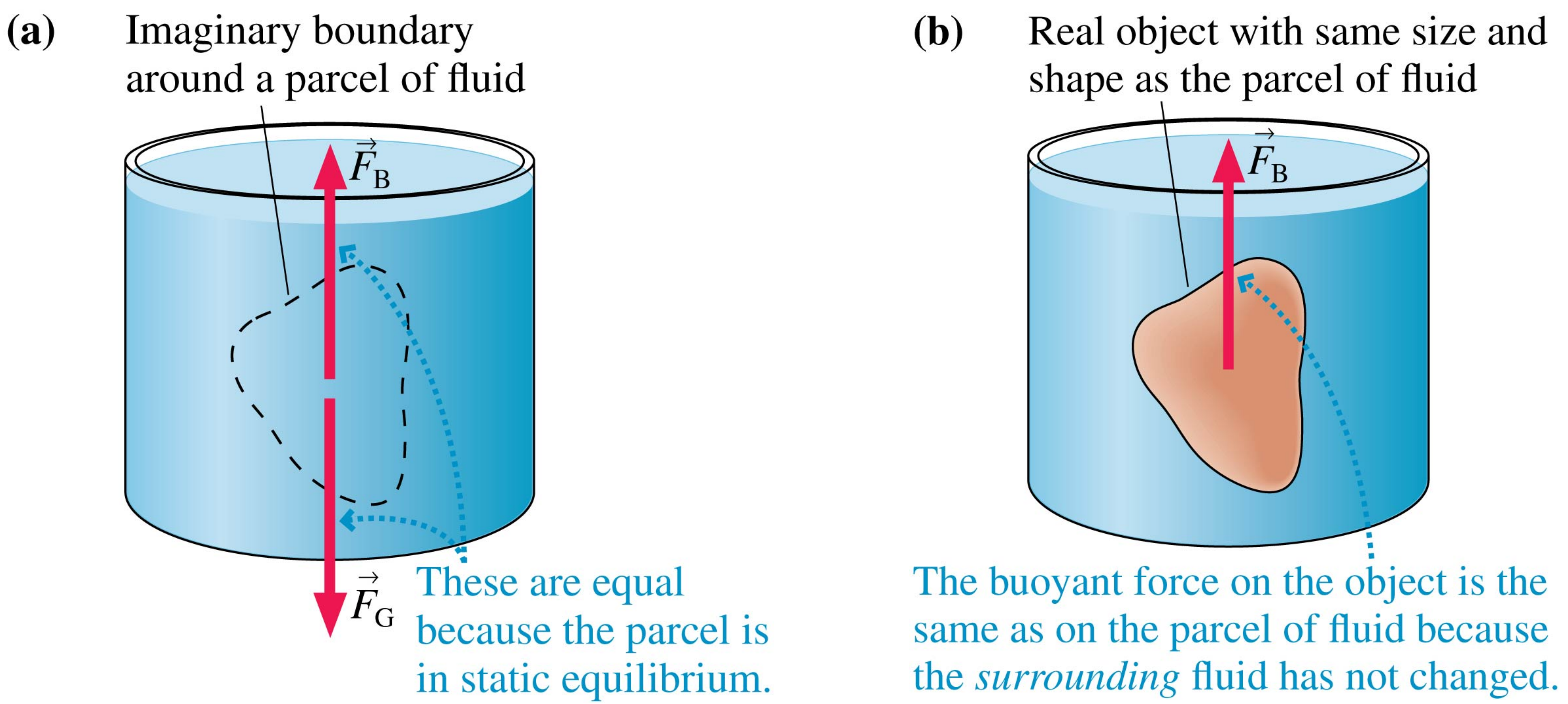
- Consider a cylinder submerged in a liquid.
- The pressure in the liquid increases with depth.
- Both cylinder ends have equal area, so $F_{up} > F_{down}$
- The pressure in the liquid exerts a *net upward force* on the cylinder:

$$F_{net} = F_{up} - F_{down}$$

- This is the buoyant force.



Buoyancy



- The buoyant force on an object is the same as the buoyant force on the fluid it displaces.

Buoyancy

- When an object (or portion of an object) is immersed in a fluid, it displaces fluid.
- The **displaced fluid's** volume equals the volume of the portion of the object that is immersed in the fluid.

> **Archimedes' principle** A fluid exerts an upward buoyant force $\vec{F}_B$ on an object immersed in or floating on the fluid. The magnitude of the buoyant force equals the weight of the fluid displaced by the object.

- Suppose the fluid has density ρ_f and the object displaces volume V_f of fluid.
- Archimedes' principle in equation form is

$$F_B = \rho_f V_f g$$

QuickCheck 14.5

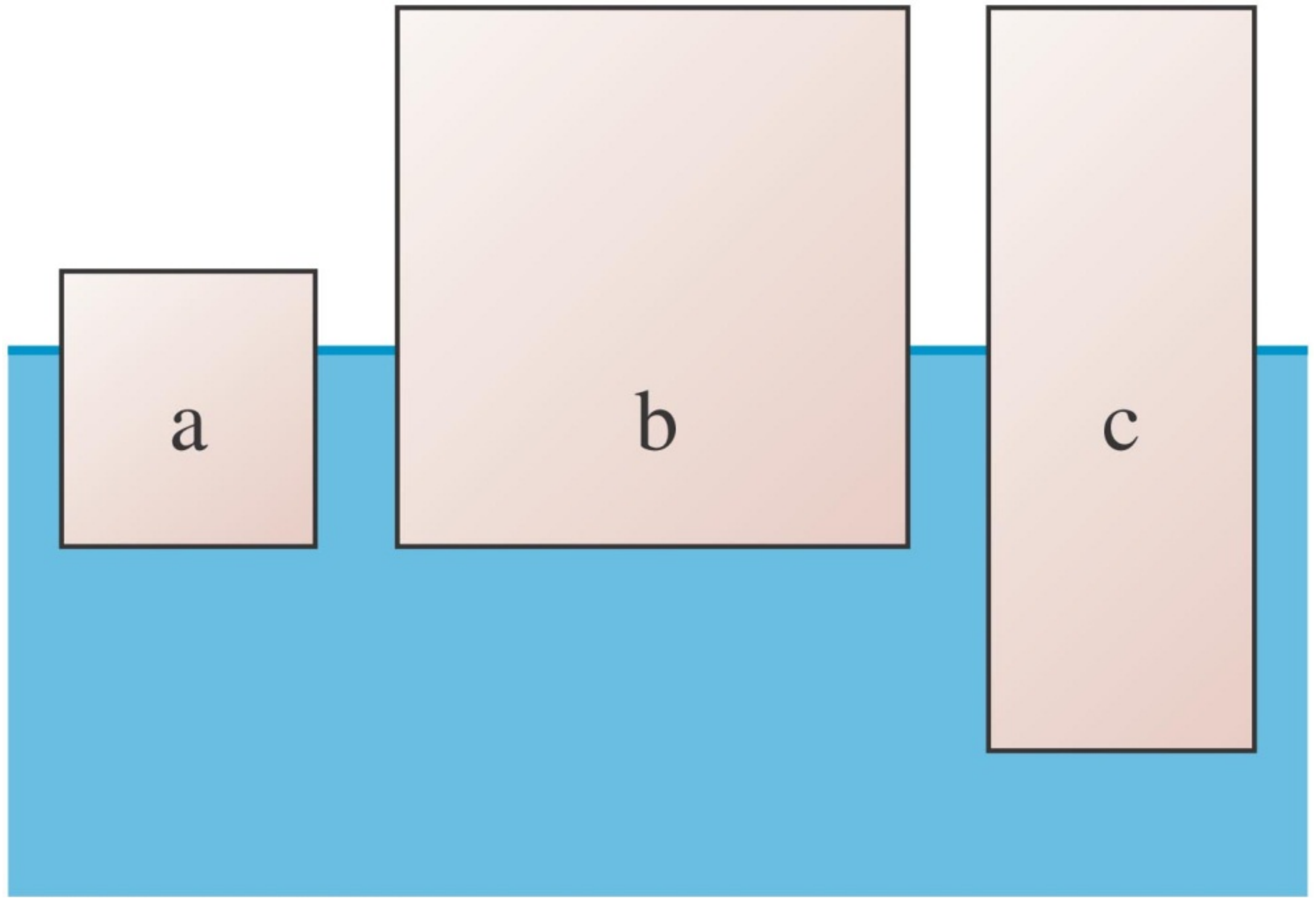
A heavy lead block and a light aluminum block of equal sizes are both submerged in water. Upon which is the buoyant force greater?

A. On the lead block
B. On the aluminum block
C. They both experience the same buoyant force.

QuickCheck 14.7

Which floating block is most dense?

A. Block a
B. Block b
C. Block c
D. Blocks a and b are tied.
E. Blocks b and c are tied.



QuickCheck 14.8

Blocks a, b, and c are all the same size. Which experiences the largest buoyant force?

A. Block a
B. Block b
C. Block c
D. All have the same buoyant force.
E. Blocks a and c have the same buoyant force, but the buoyant force on block b is different.