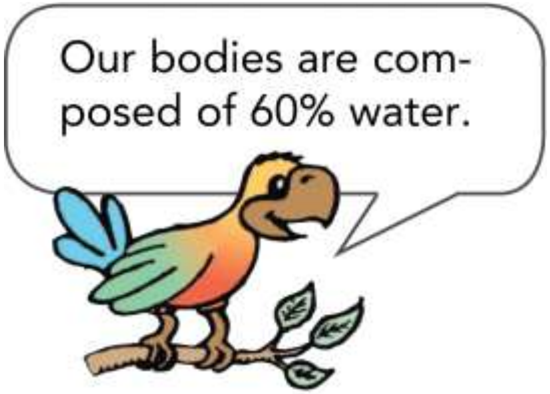
THE BIG IDEA

In the liquid phase, molecules can flow freely from position to position by sliding over one another. A liquid takes the shape of its container.

In the liquid phase, molecules can flow freely from position to position by sliding over one another. A liquid takes the shape of its container.



19.1 Liquid Pressure

The pressure of a liquid at rest depends only on gravity and the density and depth of the liquid.

19.1 Liquid Pressure

A liquid in a container exerts forces on the walls and bottom of the container.

Recall that *pressure* is defined as the force per unit area on which the force acts.

$$\text{pressure} = \frac{\text{force}}{\text{area}}$$

19.1 Liquid Pressure

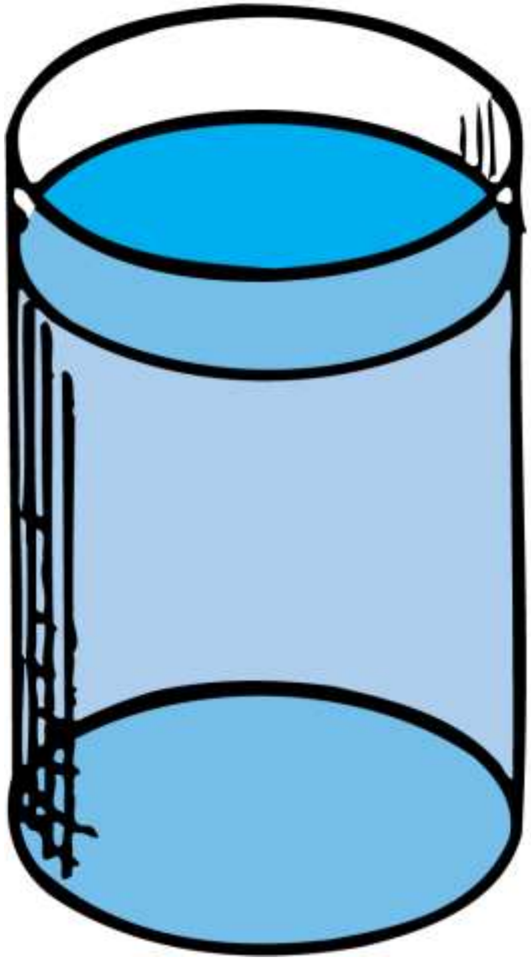
The pressure that a block exerts on a table is simply the weight of the block divided by its area of contact.

The pressure a liquid in a cylindrical container exerts against the bottom of the container is the weight of the liquid divided by the area of the container bottom.

(We'll ignore for now the additional atmospheric pressure.)

19.1 Liquid Pressure

The liquid exerts a pressure against the bottom of its container, just as the block exerts a pressure against the table.



19.1 Liquid Pressure

Density

How much a liquid weighs, and thus how much pressure it exerts, depends on its density.

- For the same depth, a denser liquid exerts more pressure.
- Mercury is 13.6 times as dense as water.
- For the same volume of liquid, the weight of mercury is 13.6 times the weight of water.
- The pressure of mercury on the bottom is 13.6 times the pressure of water.

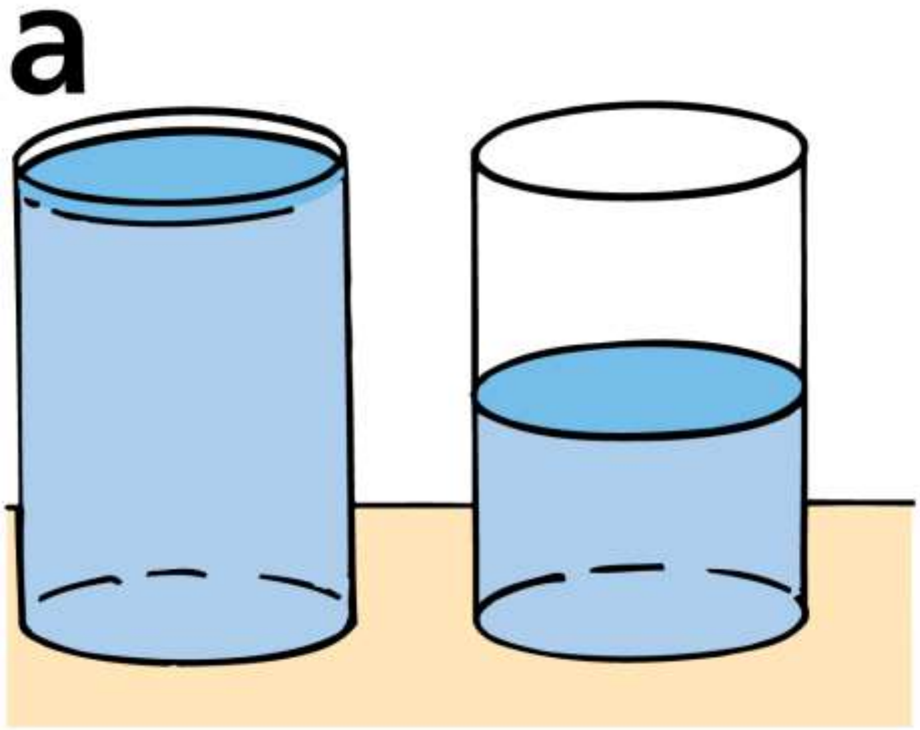
19.1 Liquid Pressure

Depth

For any given liquid, the pressure on the bottom of the container will be greater if the liquid is deeper.

19.1 Liquid Pressure

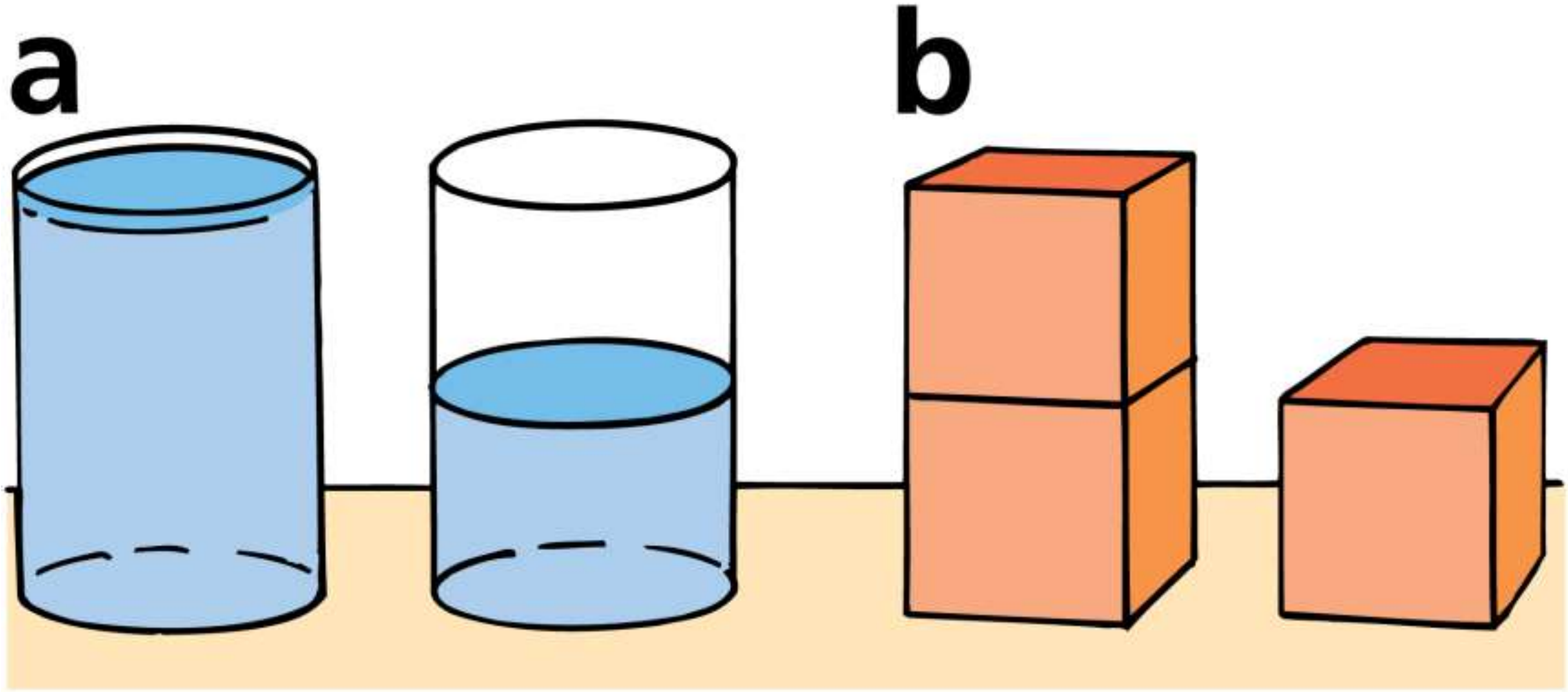
a. The liquid in the first container is twice as deep, so the pressure on the bottom is twice that in the second container.



19.1 Liquid Pressure

a. The liquid in the first container is twice as deep, so the pressure on the bottom is twice that in the second container.

b. Two blocks exert twice as much pressure on the table.



19.1 Liquid Pressure

The pressure of a liquid at rest does not depend on the shape of the container or the size of its bottom surface.

Liquids are practically incompressible, at a given temperature, so the density of a liquid is normally the same at all depths.

The pressure created by a liquid is:

$$\text{pressure due to liquid} = \text{density} \times g \times \text{depth}$$

19.1 Liquid Pressure

At a given depth, a liquid exerts the same pressure against *any* surface—the bottom or sides of its container, or even the surface of an object submerged in the liquid to that depth.

The pressure a liquid exerts depends on its density and depth.

19.1 Liquid Pressure

The total pressure of a liquid is density × *g* × depth *plus* the pressure of the atmosphere.

When this distinction is important we use the term *total pressure.*

Otherwise, our discussions of liquid pressure refer to pressure in addition to the normally ever-present atmospheric pressure.

19.1 Liquid Pressure

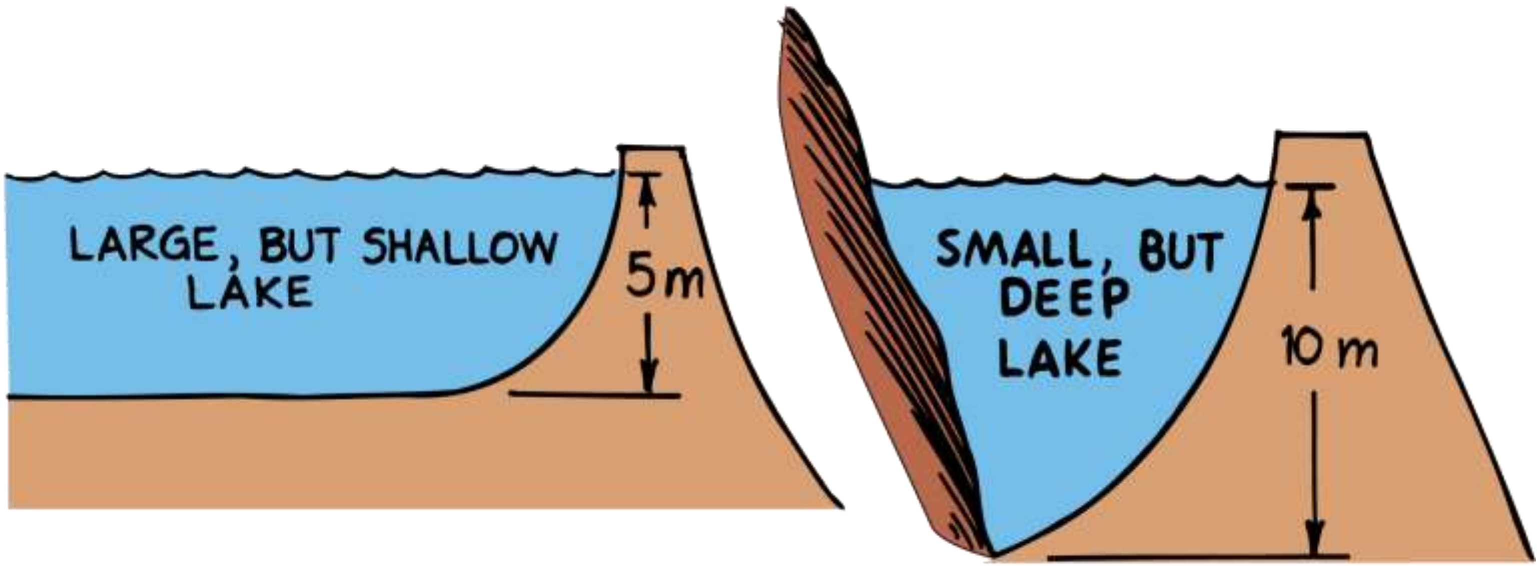
Volume

The pressure of a liquid does not depend on the amount of liquid.

Neither the volume nor even the total weight of liquid matters.

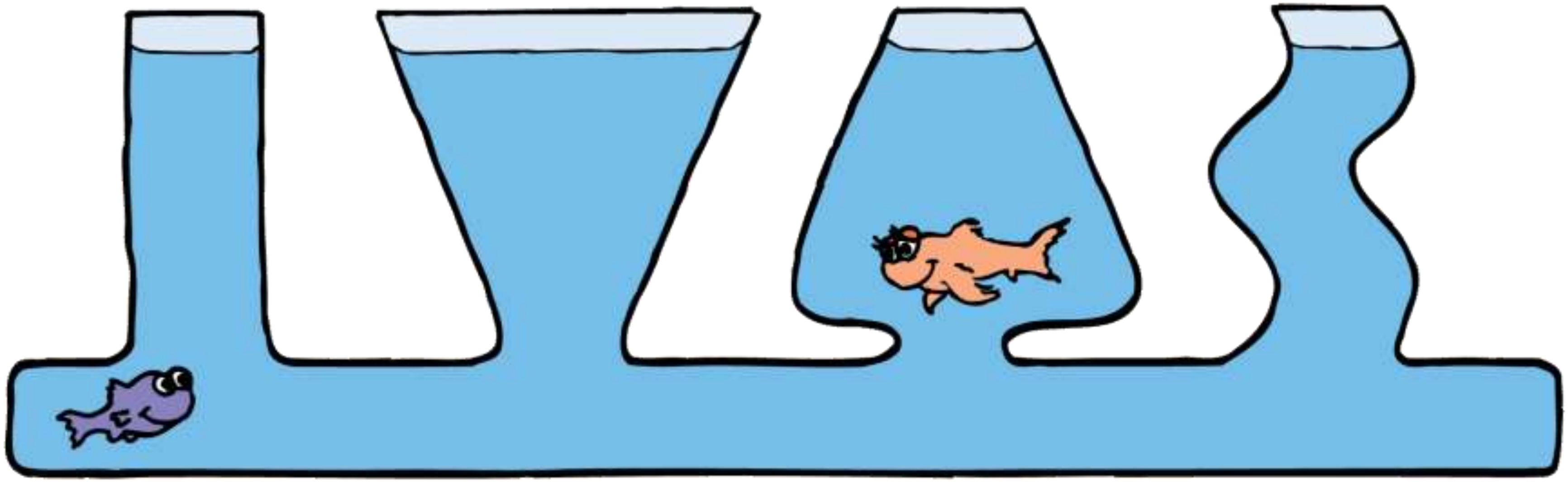
19.1 Liquid Pressure

The water pressure is greater at the bottom of the deeper lake. The dam holding back water twice as deep must withstand greater average water pressure, regardless of the total volume of water.



19.1 Liquid Pressure

The pressure of the liquid is the same at any given depth below the surface, regardless of the shape of the container.



19.1 Liquid Pressure

The “Pascal’s vases” illustrate that water pressure depends on depth and not on volume.

The water’s surface in each of the connected vases is at the same level. The pressures at equal depths are the same.

At the bottom of all four vases, for example, the pressures are equal.

19.1 Liquid Pressure

At any point within a liquid, the forces that produce pressure are exerted equally in all directions.

When you are swimming underwater, no matter which way you tilt your head, your ears feel the same amount of water pressure.

19.1 Liquid Pressure

When the liquid is pressing against a surface, there is a force from the liquid directed perpendicular to the surface.

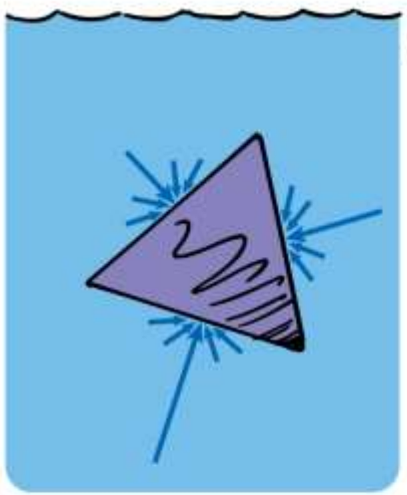
If there is a hole in the surface, the liquid initially will move perpendicular to the surface.

Gravity causes the path of the liquid to curve downward.

At greater depths, the net force is greater, and the velocity of the escaping liquid is greater.

19.1 Liquid Pressure

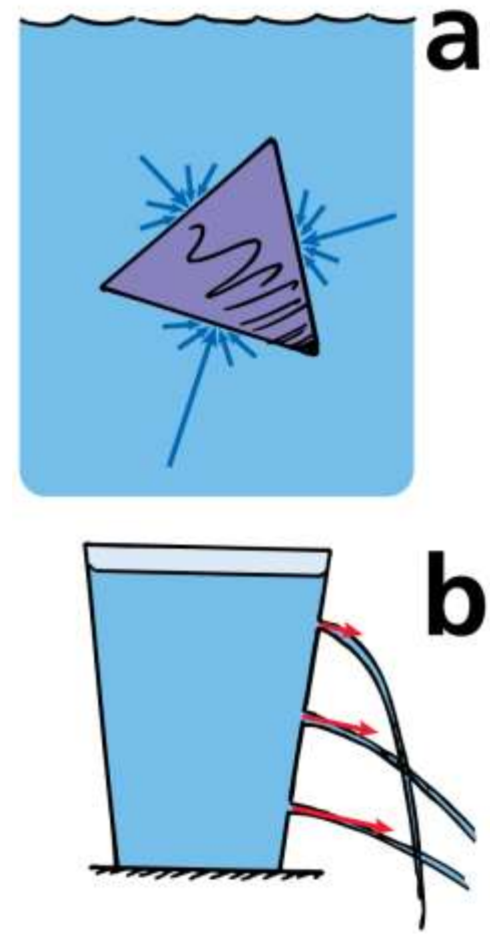
a. The forces against a surface add up to a net force that is perpendicular to the surface.



19.1 Liquid Pressure

a. The forces against a surface add up to a net force that is perpendicular to the surface.

b. Liquid escaping through a hole initially moves perpendicular to the surface.



19.1 Liquid Pressure

think!

A brick mason wishes to mark the back of a building at the exact height of bricks already laid at the front of the building. How can he measure the same height using only a garden hose and water?

19.1 Liquid Pressure

think!

A brick mason wishes to mark the back of a building at the exact height of bricks already laid at the front of the building. How can he measure the same height using only a garden hose and water?

Answer:

The brick mason can extend a garden hose that is open at both ends from the front to the back of the house, and fill it with water until the water level reaches the height of bricks in the front. Since water seeks its own level, the level of water in the other end of the hose will be the same!

19.1 Liquid Pressure

CONCEPT CHECK

What determines the pressure of a liquid?

19.2 Buoyancy

When the weight of a submerged object is greater than the buoyant force, the object will sink. When the weight is less than the buoyant force, the object will rise to the surface and float.

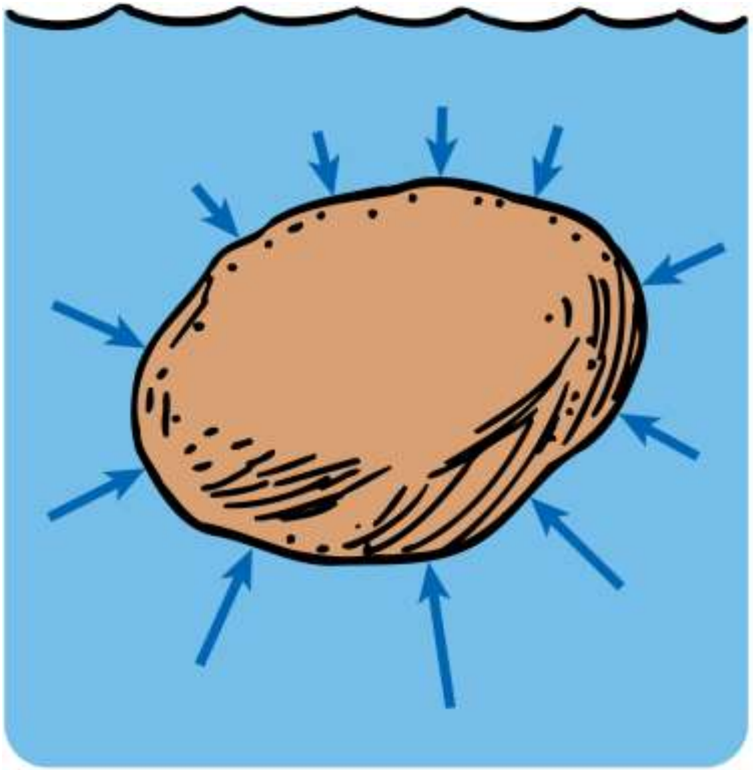
19.2 Buoyancy

Buoyancy is the apparent loss of weight of objects when submerged in a liquid.

- It is easier to lift a boulder submerged on the bottom of a riverbed than to lift it above the water's surface.
- When the boulder is submerged, the water exerts an upward force that is opposite in direction to gravity. This upward force is called the buoyant force.
- The **buoyant force** is the net upward force exerted by a fluid on a submerged or immersed object.

19.2 Buoyancy

The upward forces against the bottom of a submerged object are greater than the downward forces against the top. There is a net upward force, the buoyant force.



19.2 Buoyancy

Arrows represent the forces within the liquid that produce pressure against the submerged boulder.

- The forces are greater at greater depth.
- The forces acting horizontally against the sides cancel each other, so the boulder is not pushed sideways.
- Forces acting upward against the bottom are greater than those acting downward against the top.
- The difference in upward and downward forces is the buoyant force.

19.2 Buoyancy

When the weight is equal to the buoyant force, the submerged object will remain at any level, like a fish.

19.2 Buoyancy

If a stone is placed in a container of water, the water level will rise.

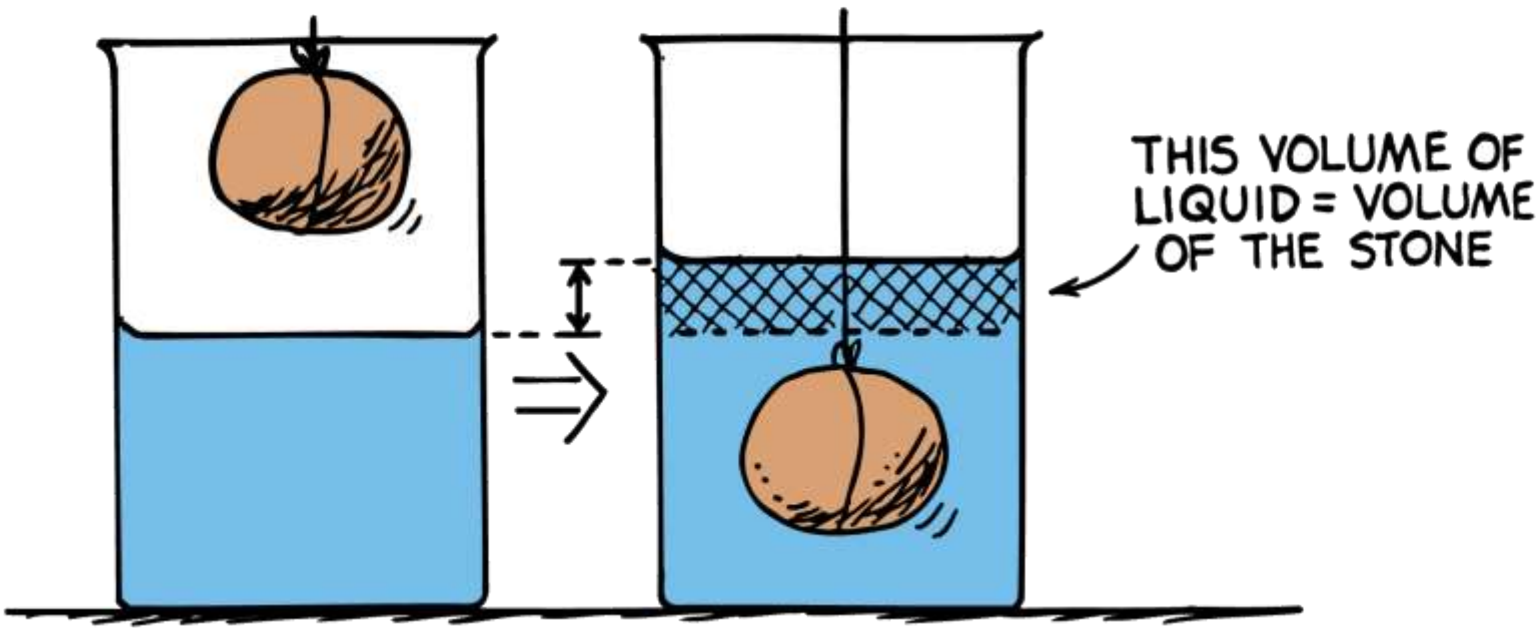
Water is said to be displaced, or pushed aside, by the stone.

The volume of water displaced is equal to the volume of the stone.

A completely submerged object always displaces a volume of liquid equal to its own volume.

19.2 Buoyancy

When an object is submerged, it displaces a volume of water equal to the volume of the object itself.



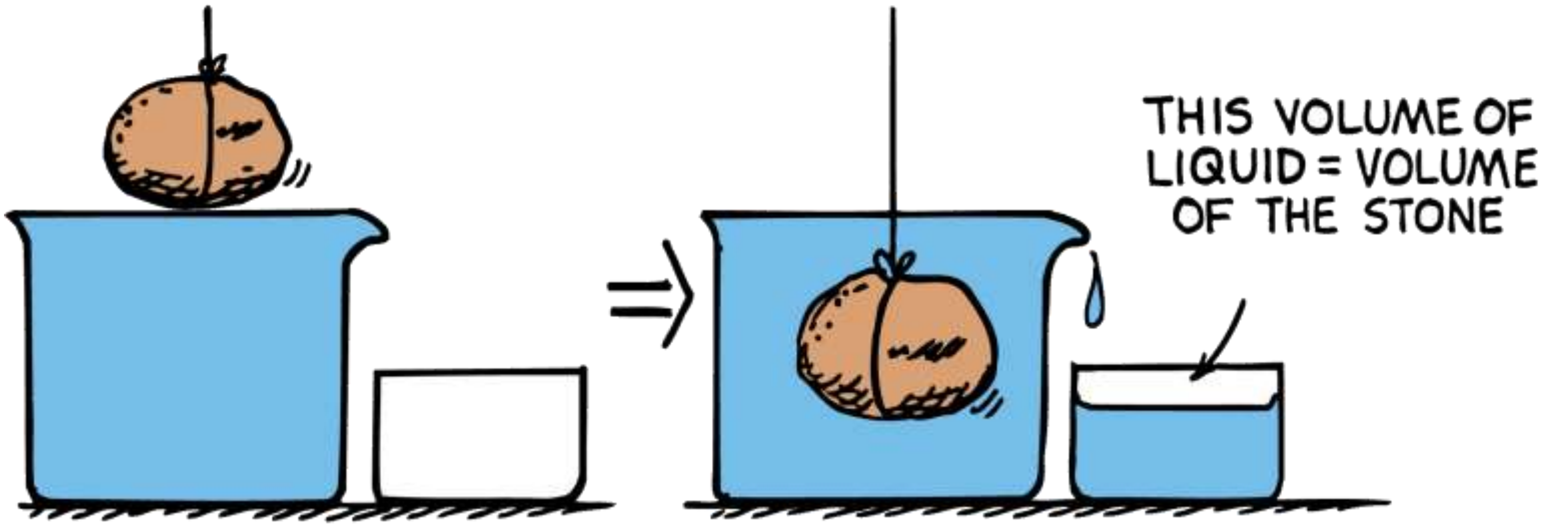
19.2 Buoyancy

To determine the volume of an irregularly shaped object, submerge it in water in a measuring cup. Note the apparent increase in volume of the water.

The increase is equal to the volume of the submerged object.

19.2 Buoyancy

When an object is submerged in a container that is initially full, the volume of water overflowing is equal to the volume of the object.



19.2 Buoyancy

CONCEPT CHECK

What determines if an object will sink or float?

19.3 Archimedes' Principle

Archimedes' principle states that the buoyant force on an immersed object is equal to the weight of the fluid it displaces.

19.3 Archimedes' Principle

Archimedes' principle describes the relationship between buoyancy and displaced liquid.

It was discovered in ancient times by the Greek philosopher Archimedes (third century B.C.).

Archimedes' principle is true for liquids and gases, which are both fluids.

19.3 Archimedes' Principle

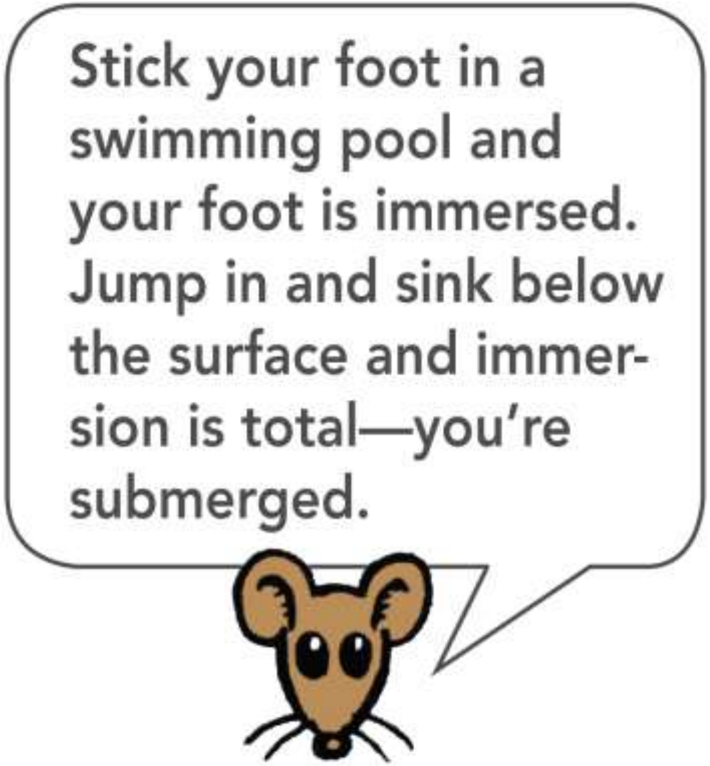
A liter of water occupies 1000 cubic centimeters, has a mass of 1 kilogram, and weighs 10 N. Any object with a volume of 1 liter will experience a buoyant force of 10 N when fully submerged in water.

19.3 Archimedes' Principle

Immersed means "either completely or partially submerged."

If we immerse a sealed 1-liter container halfway into water, it will displace half a liter of water and be buoyed up by the weight of half a liter of water.

If we immerse it all the way (submerge it), it will be buoyed up by the weight of a full liter of water (10 newtons).



19.3 Archimedes' Principle

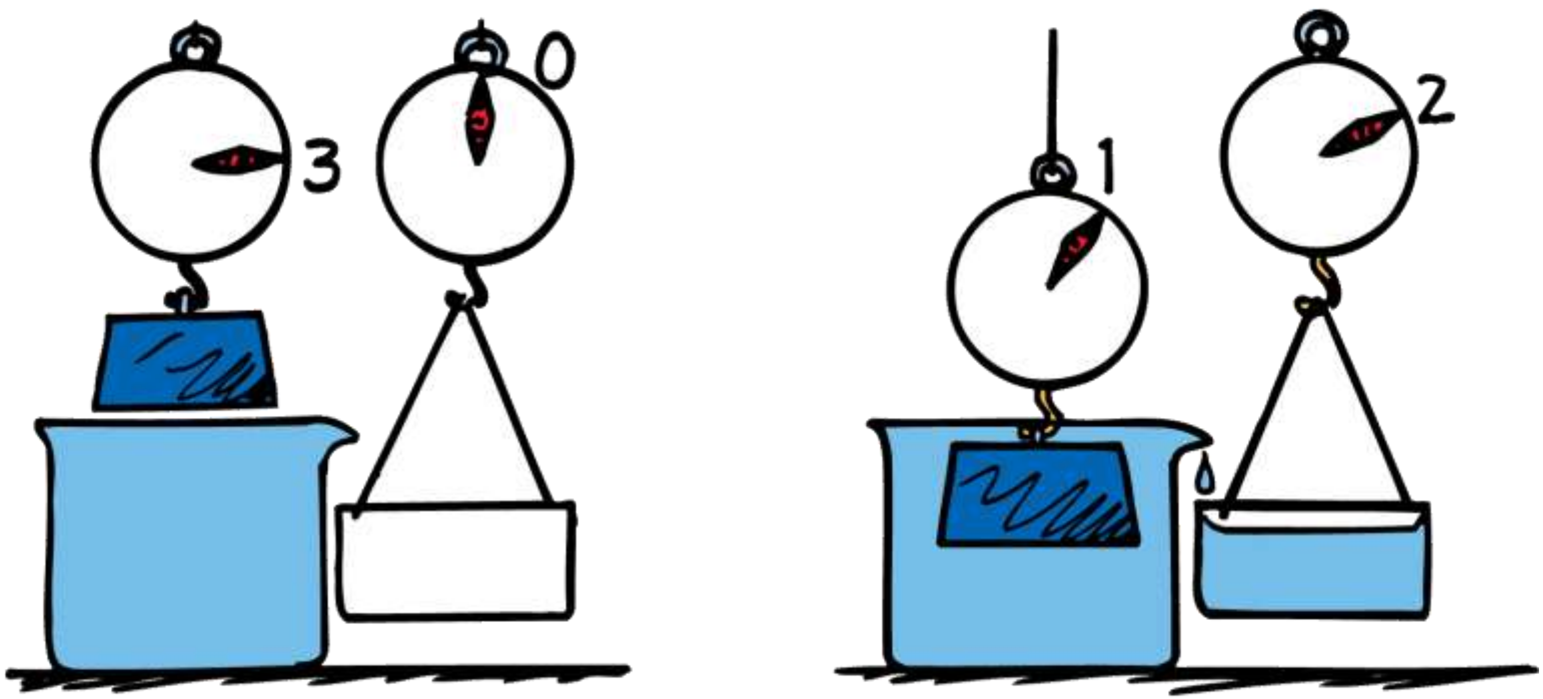
Unless the completely submerged container becomes compressed, the buoyant force will equal the weight of 1 liter of water at *any* depth.

The container will displace the same volume of water, and hence the same weight of water, at any depth.

The weight of this displaced water (not the weight of the submerged object!) is the buoyant force.

19.3 Archimedes' Principle

A brick weighs less in water than in air. The buoyant force on the submerged brick is equal to the weight of the water displaced.



19.3 Archimedes' Principle

A 300-gram brick weighs about 3 N in air.

If the brick displaces 2 N of water when it is submerged, the buoyant force on the submerged brick will also equal 2 N.

The brick will seem to weigh less under water than above water.

The apparent weight of a submerged object is its weight in air minus the buoyant force.

19.3 Archimedes' Principle

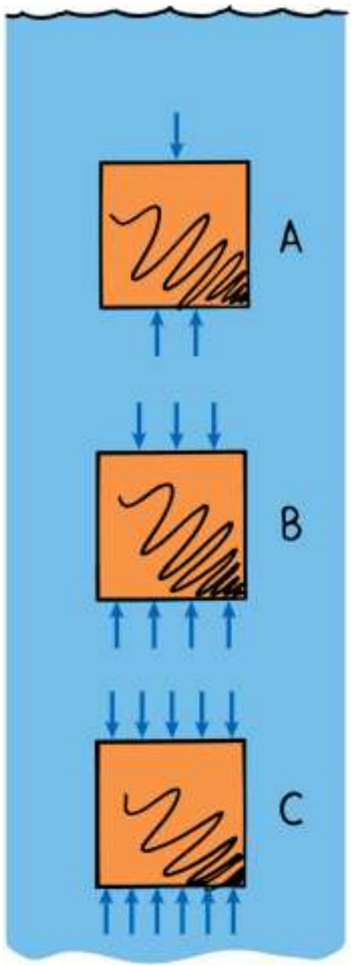
For any submerged block, the upward force due to water pressure on the bottom of the block, minus the downward force due to water pressure on the top, equals the weight of liquid displaced.

As long as the block is submerged, depth makes no difference.

There is more pressure at greater depths but the *difference* in pressures on the bottom and top of the block is the same at any depth.

19.3 Archimedes' Principle

The difference in the upward force and the downward force acting on the submerged block is the same at any depth.



19.3 Archimedes' Principle

think!

A 1-liter (L) container filled with mercury has a mass of 13.6 kg and weighs 136 N. When it is submerged in water, what is the buoyant force on it?

19.3 Archimedes' Principle

think!

A 1-liter (L) container filled with mercury has a mass of 13.6 kg and weighs 136 N. When it is submerged in water, what is the buoyant force on it?

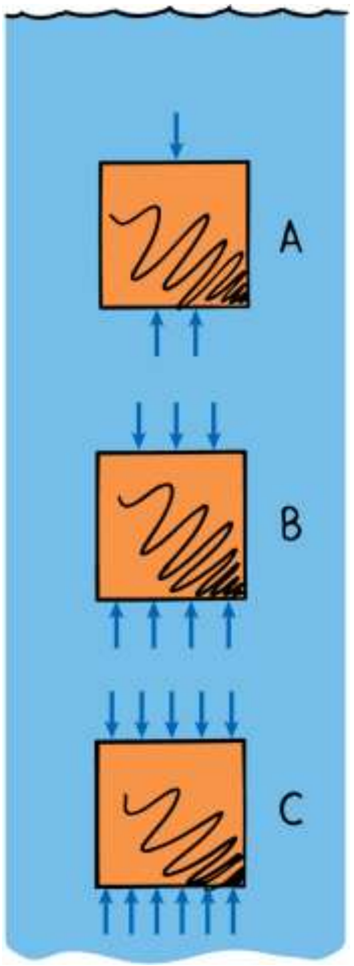
Answer:

The buoyant force equals the weight of 1 L of water (about 10 N) because the *volume* of displaced water is 1 L.

19.3 Archimedes' Principle

think!

A block is held suspended beneath the water in the three positions, A, B, and C. In which position is the buoyant force on it greatest?



19.3 Archimedes' Principle

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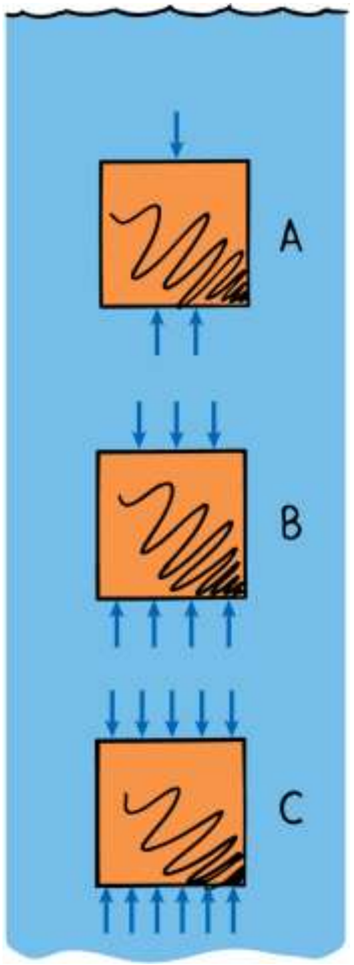


Answer:

The buoyant force is the same at all three positions, because the amount of water displaced is the same in A, B, and C.

19.3 Archimedes' Principle

think!

A stone is thrown into a deep lake. As it sinks deeper and deeper into the water, does the buoyant force on it increase, decrease, or remain unchanged?

19.3 Archimedes' Principle

think!

A stone is thrown into a deep lake. As it sinks deeper and deeper into the water, does the buoyant force on it increase, decrease, or remain unchanged?

Answer:

The volume of displaced water is the same at any depth. Water is practically incompressible, so its density is the same at any depth, and equal volumes of water weigh the same. The buoyant force on the stone remains unchanged as it sinks deeper and deeper.

19.3 Archimedes' Principle

CONCEPT CHECK

What does Archimedes' principle state?

19.4 Does It Sink, or Does It Float?

Sinking and floating can be summed up in three simple rules.

1. An object more dense than the fluid in which it is immersed sinks.
2. An object less dense than the fluid in which it is immersed floats.
3. An object with density equal to the density of the fluid in which it is immersed neither sinks nor floats.

19.4 Does It Sink, or Does It Float?

The buoyant force on a submerged object depends on its volume.

- A smaller object displaces less water, so a smaller buoyant force acts on it.
- A larger object displaces more water, so a larger buoyant force acts on it.
- The submerged object's *volume*—not its *weight*—determines buoyant force.

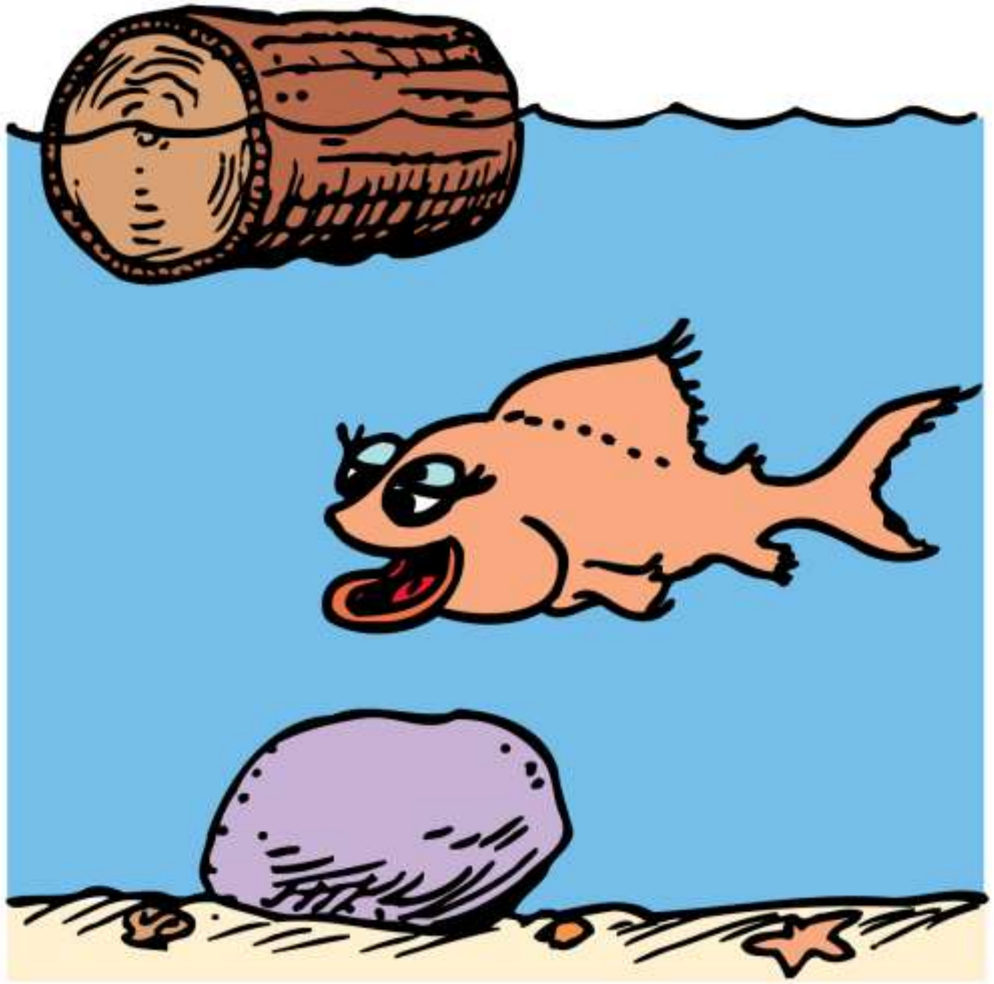
19.4 Does It Sink, or Does It Float?

Whether an object sinks or floats (or does neither) depends on both its buoyant force (up) and its weight (down).

- When the buoyant force exactly equals the weight of a completely submerged object, then the object's weight must equal the weight of displaced water.
- Since the volumes of the object and of the displaced water are the same, the density of the object must equal the density of water.

19.4 Does It Sink, or Does It Float?

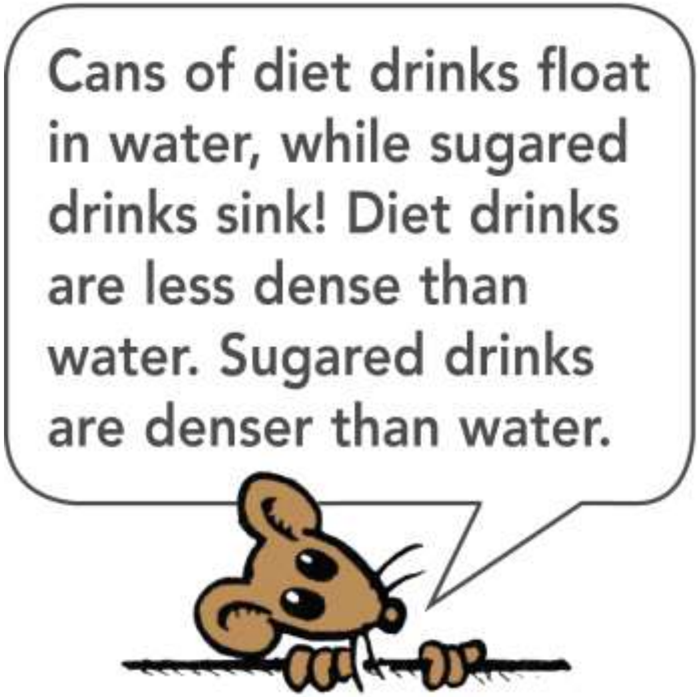
The wood floats because it is less dense than water. The rock sinks because it is denser than water. The fish neither rises nor sinks because it has the same density as water.



19.4 Does It Sink, or Does It Float?

The fish is "at one" with the water—it doesn't sink or float.

- The density of the fish equals the density of water.
- If the fish were somehow bloated up, it would be less dense than water, and would float to the top.
- If the fish swallowed a stone and became more dense than water, it would sink to the bottom.



19.4 Does It Sink, or Does It Float?

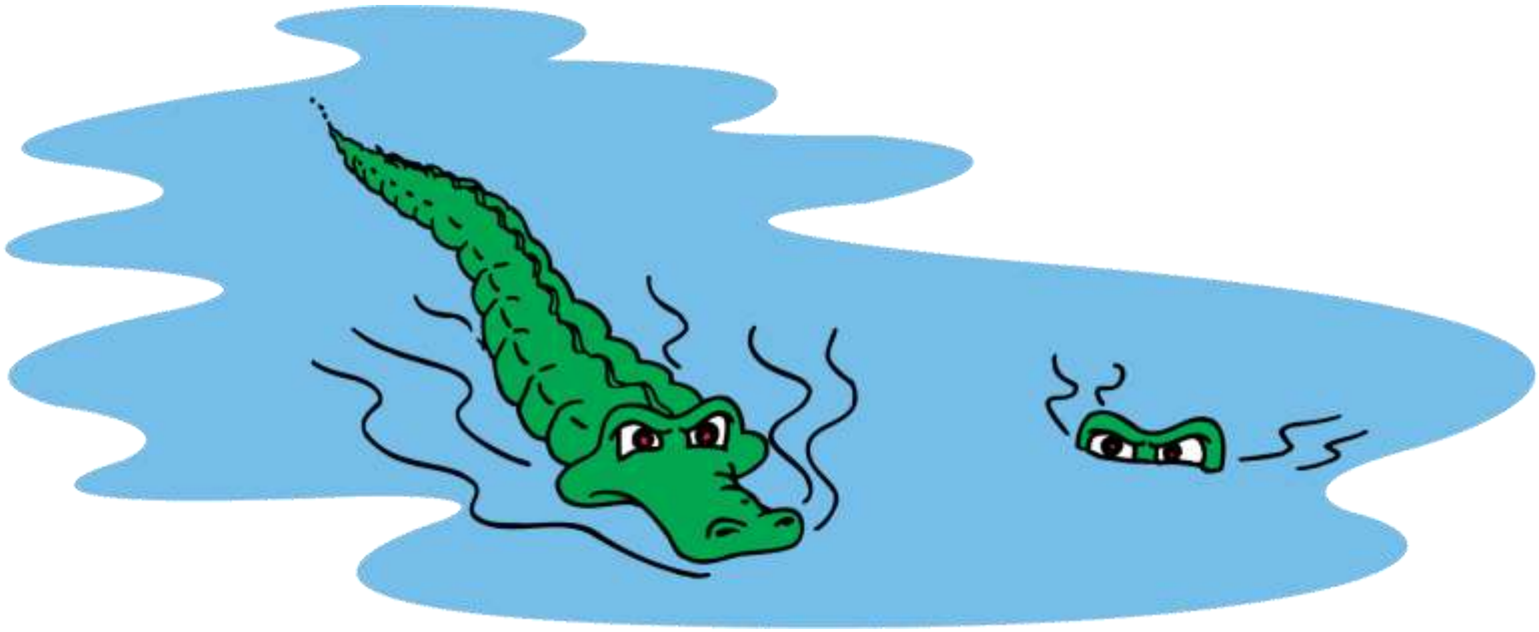
The density of a submarine is controlled by the flow of water into and out of its ballast tanks to achieve the desired average density.

A fish regulates its density by expanding or contracting an air sac that changes its volume. It moves upward by increasing its volume and downward by contracting its volume.

A crocodile increases its density when it swallows stones to swim lower in the water and expose less of itself to its prey.

19.4 Does It Sink, or Does It Float?

The crocodile on the left is less dense than the crocodile on the right because its belly is not full of stones.



19.4 Does It Sink, or Does It Float?

think!

If a fish makes itself more dense, it will sink; if it makes itself less dense, it will rise. In terms of buoyant force, why is this so?

19.4 Does It Sink, or Does It Float?

think!

If a fish makes itself more dense, it will sink; if it makes itself less dense, it will rise. In terms of buoyant force, why is this so?

Answer:

When the fish increases its density by decreasing its volume, it displaces less water, so the buoyant force decreases. When the fish decreases its density by expanding, it displaces more water, and the buoyant force increases.

19.4 Does It Sink, or Does It Float?

CONCEPT CHECK

What are the three rules of sinking and floating?

19.5 Flotation

The principle of flotation states that a floating object displaces a weight of fluid equal to its own weight.

19.5 Flotation

How does a ship made of iron float? This is an example of the principle of flotation.

Iron is nearly eight times as dense as water. When it is submerged, a solid 1-ton block of iron will displace only 1/8 ton of water.

The buoyant force will be far from enough to keep it from sinking.

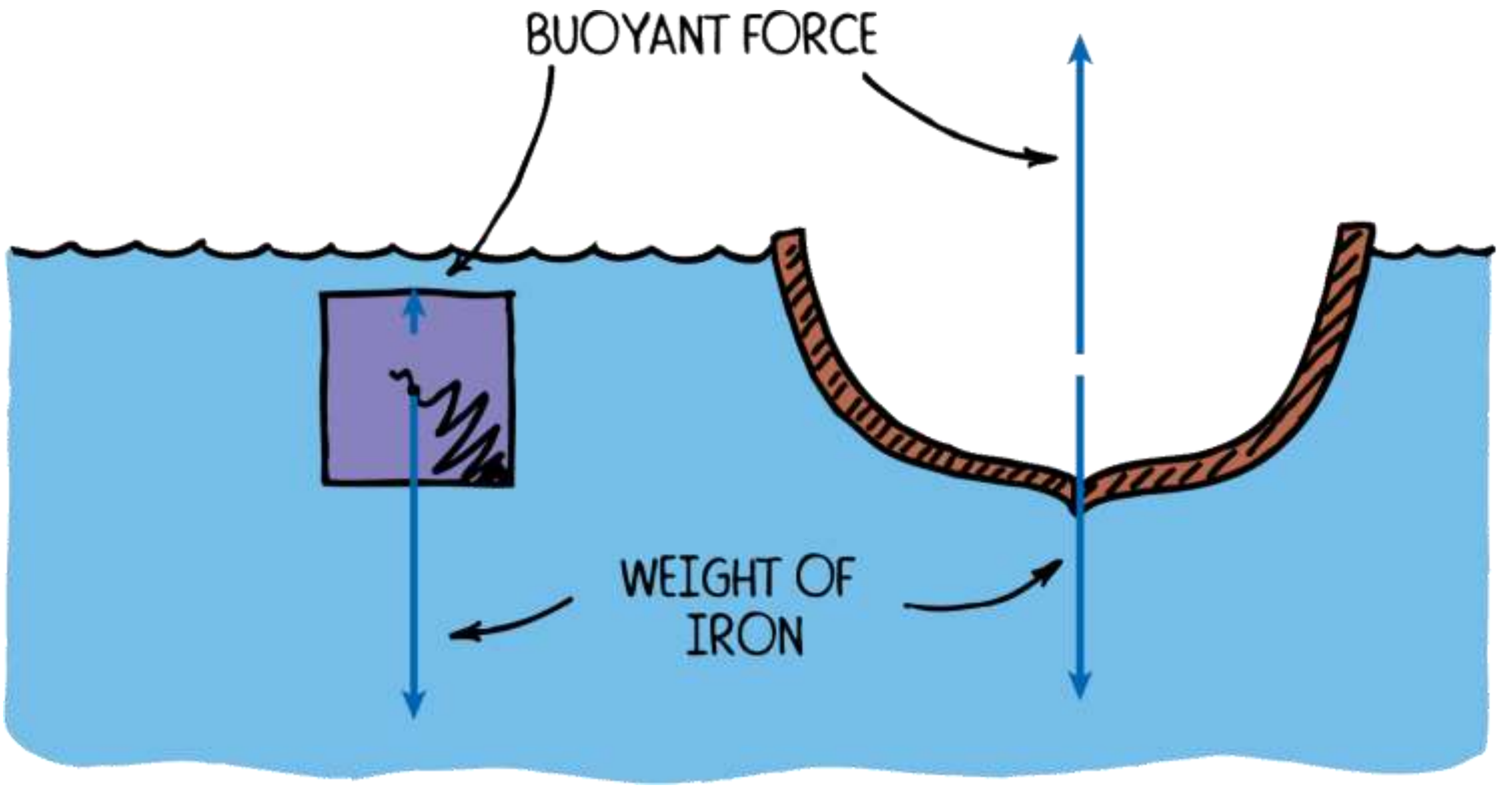
19.5 Flotation

Reshape the same iron block into a bowl shape.

- The iron bowl still weighs 1 ton but if you lower the bowl into a body of water, it displaces a greater volume of water.
- The deeper the bowl is immersed, the more water is displaced and the greater is the buoyant force exerted on the bowl.
- When the weight of the displaced water equals the weight of the bowl, it will sink no farther.
- The buoyant force now equals the weight of the bowl.

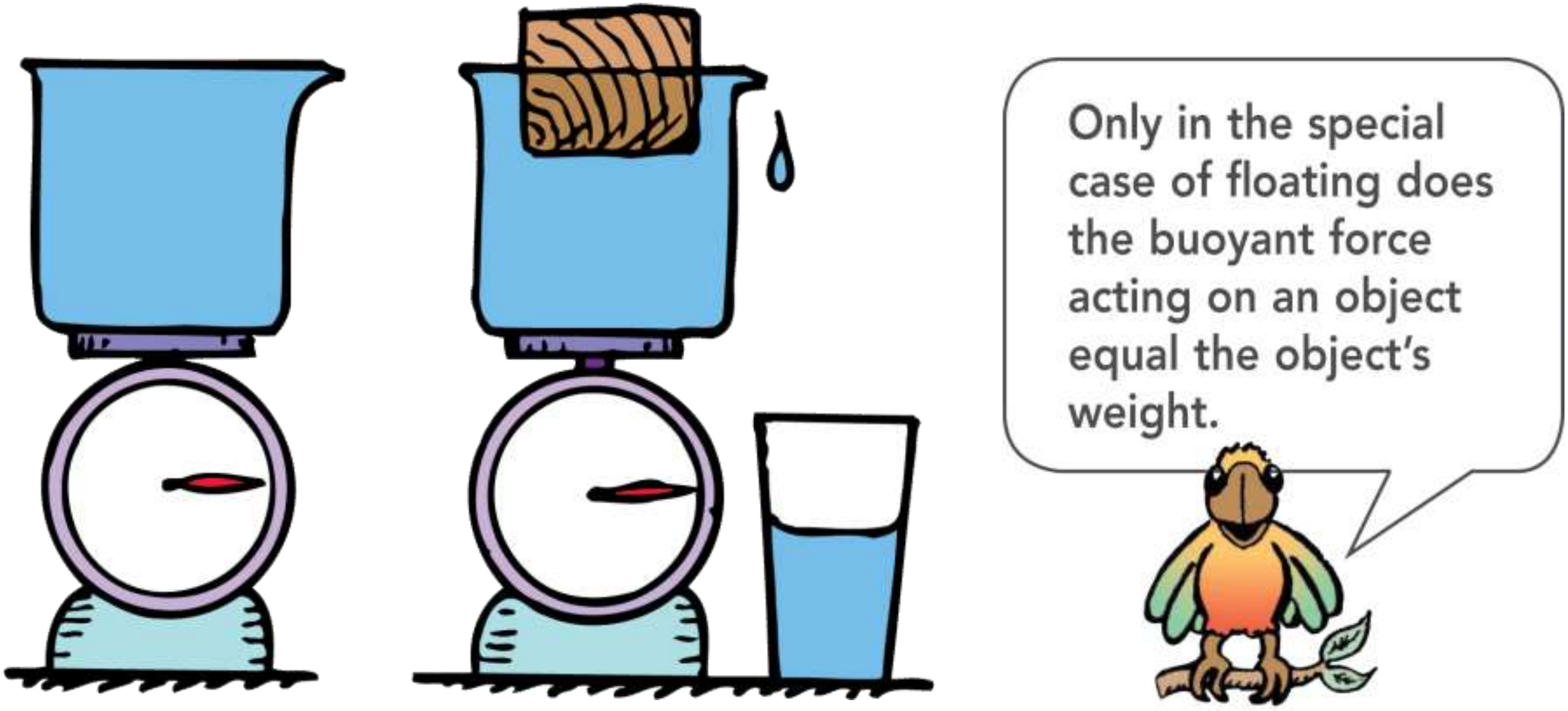
19.5 Flotation

A solid iron block sinks, while the same block shaped to occupy at least eight times as much volume floats.



19.5 Flotation

A floating object displaces a weight of liquid equal to its own weight.



19.5 Flotation

Every ship must be designed to displace a weight of water equal to its own weight.

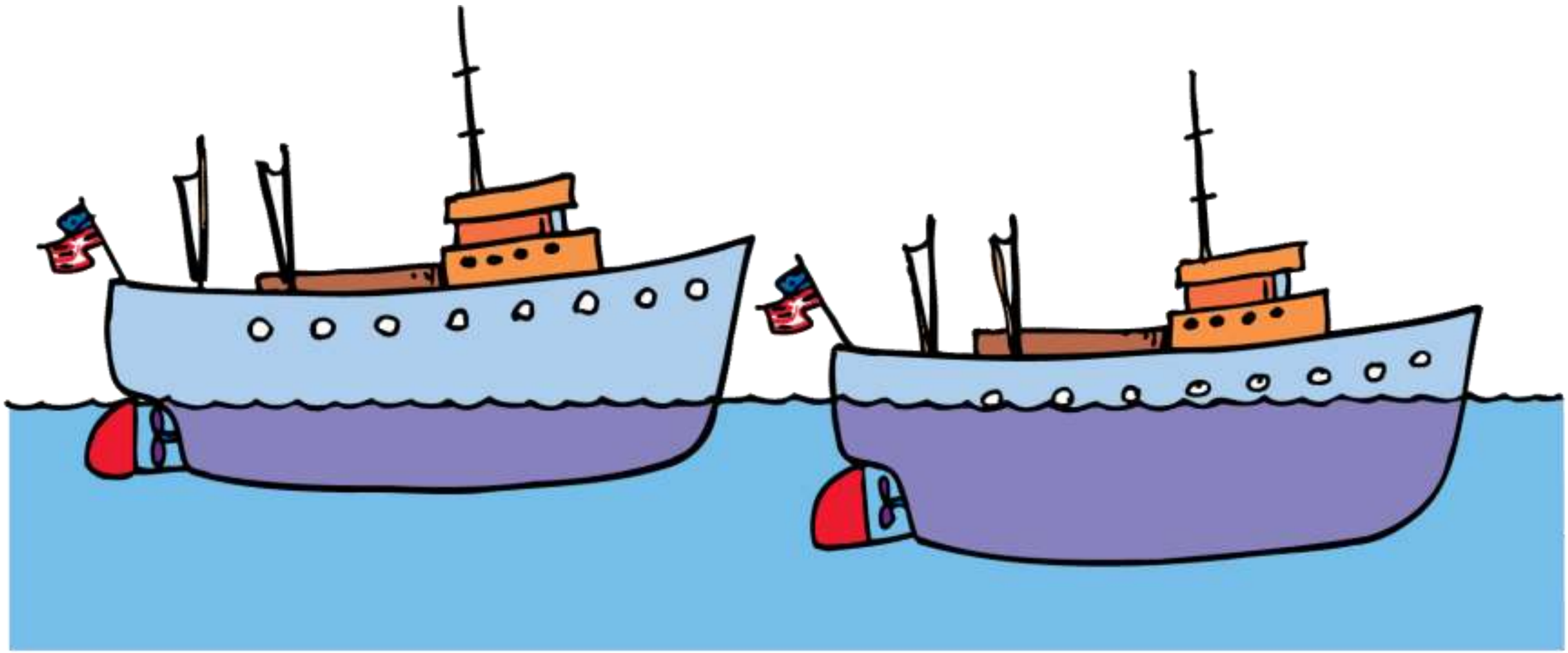
A 10,000-ton ship must be built wide enough to displace 10,000 tons of water before it sinks too deep below the surface.

19.5 Flotation

The weight of the floating canoe equals the weight of the water displaced by the submerged part of the canoe. It floats lower in the water when loaded.

19.5 Flotation

The same ship is shown empty and loaded. The weight of the ship's load equals the weight of extra water displaced.



19.5 Flotation

If a submarine beneath the surface displaces a weight of water greater than its own weight, it will rise.

If it displaces less, it will go down.

If it displaces exactly its weight, it will remain at constant depth.

Water has slightly different densities at different temperatures, so a submarine must make periodic adjustments.

19.5 Flotation

CONCEPT CHECK

What does the principle of flotation state?

19.6 Pascal's Principle

Pascal's principle states that changes in pressure at any point in an enclosed fluid at rest are transmitted undiminished to all points in the fluid and act in all directions.

19.6 Pascal's Principle

A change in the pressure in one part of a fluid is transmitted to other parts.

If the pressure of city water is increased at the pumping station by 10 units of pressure, the pressure everywhere in the pipes of the connected system will be increased by 10 units of pressure.

Pascal's principle describes how changes in a pressure are transmitted in a fluid.

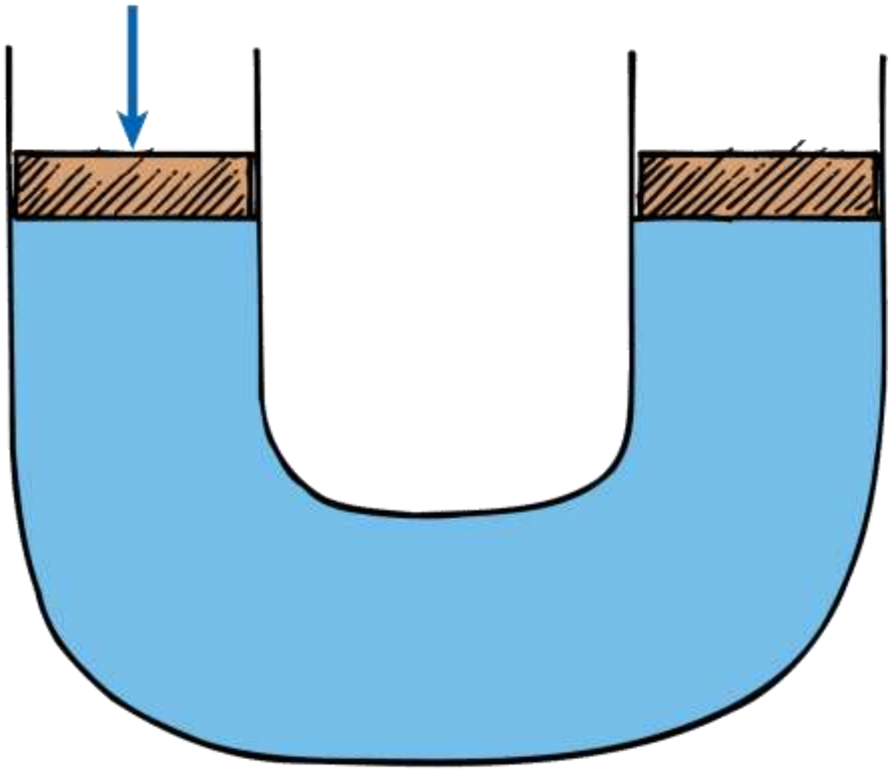
19.6 Pascal's Principle

Pascal's principle is employed in a hydraulic press.

- Fill a U-shaped tube with water and place pistons at each end.
- Pressure exerted against the left piston will be transmitted throughout the liquid and against the bottom of the right piston.
- The pressure the left piston exerts against the water will be exactly equal to the pressure the water exerts against the right piston if the levels are the same.

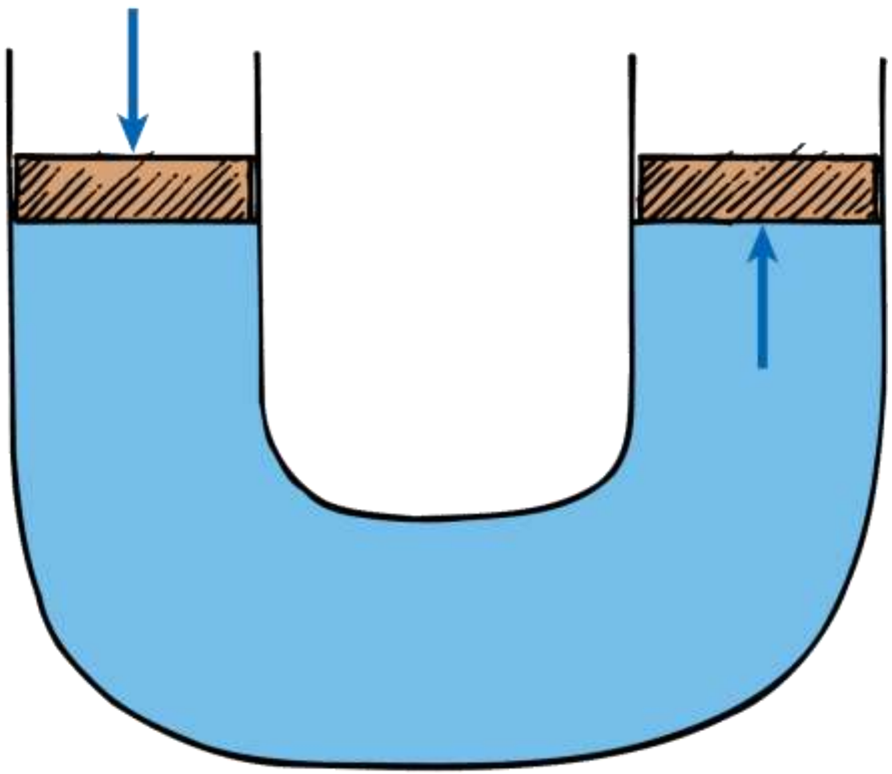
19.6 Pascal's Principle

The force exerted on the left piston increases the pressure in the liquid and is transmitted to the right piston.



19.6 Pascal's Principle

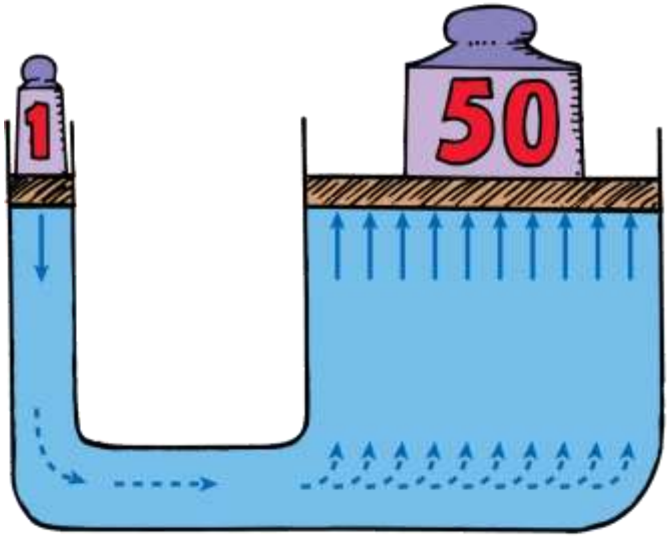
The force exerted on the left piston increases the pressure in the liquid and is transmitted to the right piston.



19.6 Pascal's Principle

A 1-N load on the left piston will support 50 N on the right piston.

$$\frac{F}{A} = p = \frac{F}{A}$$



19.6 Pascal's Principle

The piston on the left has an area of 1 cm^2, and the piston on the right has an area 50 times as great, 50 cm^2.

- A 1-newton load on the left piston causes an additional pressure of 1 newton per square centimeter (1 N/cm^2).
- The pressure is transmitted throughout the liquid and up against the larger piston.

19.6 Pascal's Principle

- The additional pressure of 1 N/cm^2 is exerted against *every* square centimeter of the larger piston.
- The total extra force exerted on the larger piston is 50 newtons.
- The larger piston will support a 50-newton load. This is 50 times the load on the smaller piston!

19.6 Pascal's Principle

We can multiply forces with such a device—1 newton input, 50 newtons output.

By further increasing the area of the larger piston, we can multiply forces to any amount.

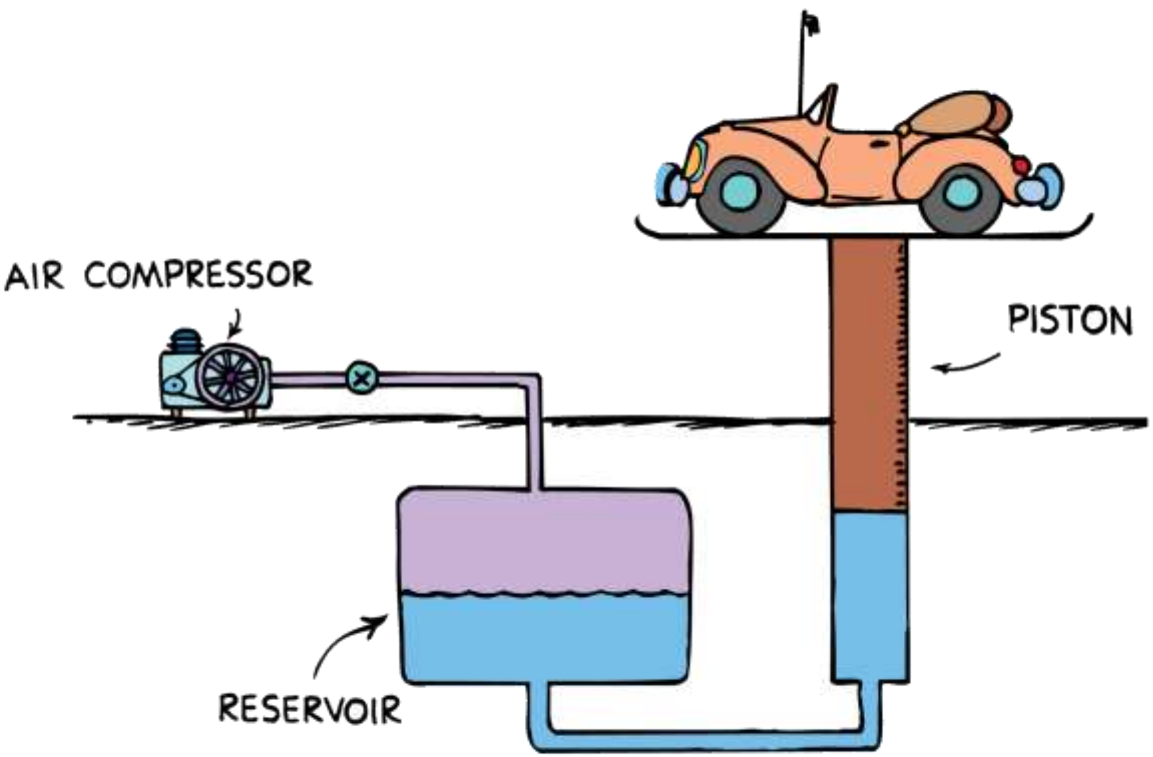
19.6 Pascal's Principle

The increase in force is compensated for by a decrease in distance.

- When the small piston is moved downward 10 cm, the large piston will be raised only one fiftieth of this, or 0.2 cm.
- The input force multiplied by the distance it moves is equal to the output force multiplied by the distance it moves.

19.6 Pascal’s Principle

The automobile lift in a service station is an application of Pascal’s principle. A low pressure exerted over a relatively large area produces a large force.



19.6 Pascal's Principle

Pascal's principle applies to all fluids (gases and liquids).

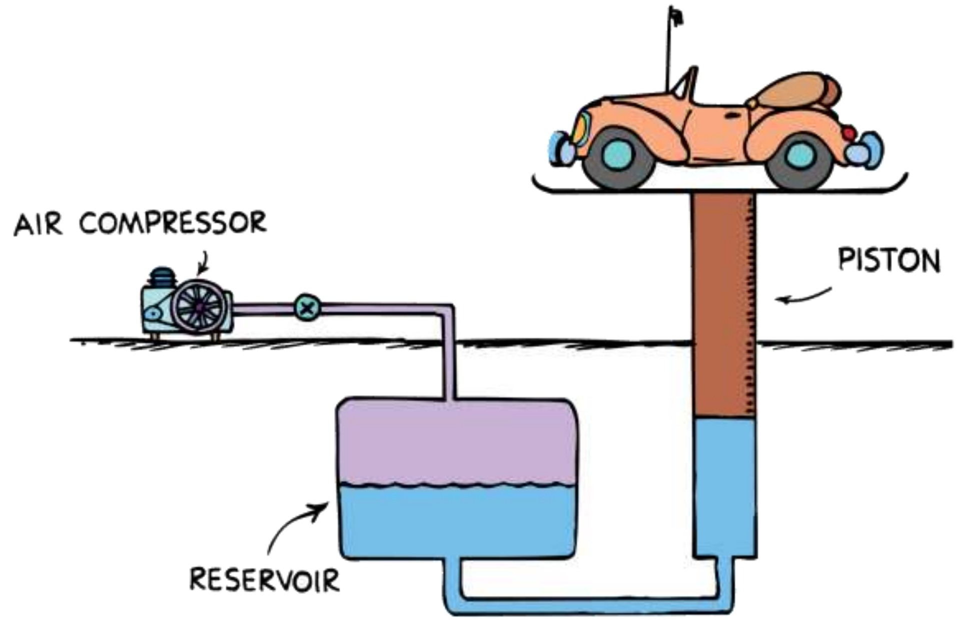
The automobile lift is in many service stations.

- Compressed air exerts pressure on the oil in an underground reservoir.
- The oil transmits the pressure to a cylinder, which lifts the automobile.
- Whatever air pressure the compressor supplies to the reservoir, is transmitted through the oil to the piston that raises the car.

19.6 Pascal's Principle

think!

As the automobile is being lifted, how does the change in oil level in the reservoir compare with the distance the automobile moves?



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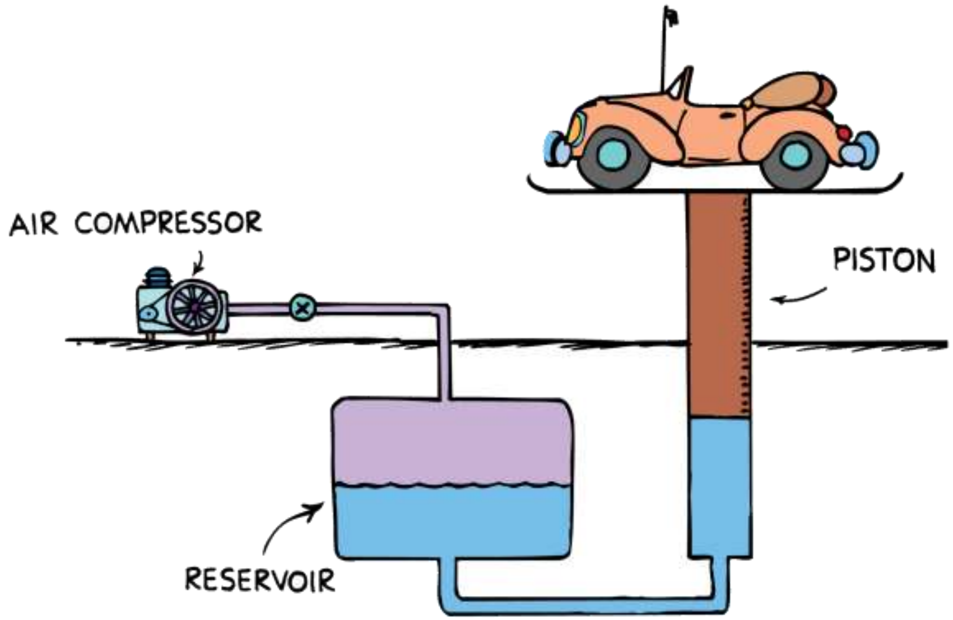

Answer:

The car moves up a greater distance than the oil level drops, since the area of the piston is smaller than the surface area of the oil in the reservoir. (Note: The surface area of the reservoir doesn't matter—it contains no piston.)

19.6 Pascal's Principle

CONCEPT CHECK

What does Pascal's principle state?

Assessment Questions

1. Water pressure at the bottom of a lake depends on the
   a. weight of water in the lake.
   b. surface area of the lake.
   c. depth of the lake.
   d. density of the water.

Assessment Questions

1. Water pressure at the bottom of a lake depends on the
   a. weight of water in the lake.
   b. surface area of the lake.
   c. depth of the lake.
   d. density of the water.

Answer: C

Assessment Questions

2. The buoyant force that acts on an object submerged in water is due to
   a. equal water pressures on all sides.
   b. greater water pressure on the bottom than on the top.
   c. the greater volume of the submerged object compared with the volume of an equal weight of water.
   d. whether or not the object is denser than water.

Assessment Questions

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   d. whether or not the object is denser than water.

Answer: B

Assessment Questions

3. If an object submerged in water displaces 20 kg of water, then the buoyant force that acts on the object is
   a. 20 kg.
   b. 20 N.
   c. 200 N.
   d. 400 N.

Assessment Questions

3. If an object submerged in water displaces 20 kg of water, then the buoyant force that acts on the object is
   a. 20 kg.
   b. 20 N.
   c. 200 N.
   d. 400 N.

Answer: C

Assessment Questions

4. The buoyant force that normally acts on a 1-kg fish is
   a. less than 10 N.
   b. 10 N.
   c. more than 10 N.
   d. dependent on whether it is in salt water or fresh water.

Assessment Questions

4. The buoyant force that normally acts on a 1-kg fish is
   a. less than 10 N.
   b. 10 N.
   c. more than 10 N.
   d. dependent on whether it is in salt water or fresh water.

Answer: B

Assessment Questions

5. The buoyant force that acts on a 20,000-N ship is
   a. somewhat less than 20,000 N.
   b. 20,000 N.
   c. more than 20,000 N.
   d. dependent on whether it is in fresh water or salt water.

Assessment Questions

5. The buoyant force that acts on a 20,000-N ship is
   a. somewhat less than 20,000 N.
   b. 20,000 N.
   c. more than 20,000 N.
   d. dependent on whether it is in fresh water or salt water.

Answer: B

Assessment Questions

6. Consider a U-shaped tube filled with water with pistons at each end. When pressure is increased at one end of the tube, pressure at the other side will
   a. increase by the same amount.
   b. increase more if the piston at the output end has a greater area.
   c. decrease if the piston at the output end has a smaller area.
   d. decrease in accord with the conservation of energy, regardless of piston area.

Assessment Questions

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   a. increase by the same amount.
   b. increase more if the piston at the output end has a greater area.
   c. decrease if the piston at the output end has a smaller area.
   d. decrease in accord with the conservation of energy, regardless of piston area.

Answer: A