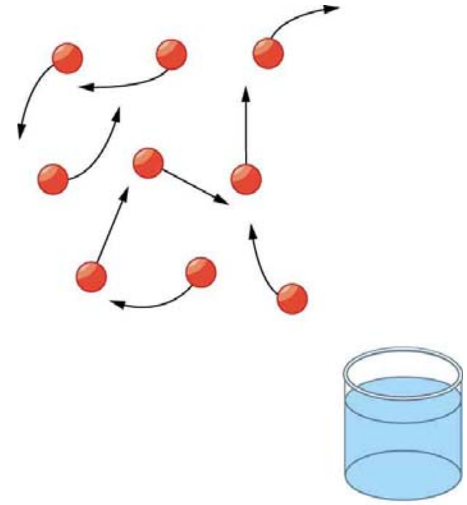
Chapter 7: Fluids

Fluids: Liquids & Gases

•Fluids are substances that are free to flow.
•Atoms and molecules are free to move.
•They take the shape of their containers.
•Cannot withstand or exert shearing forces.



(b)

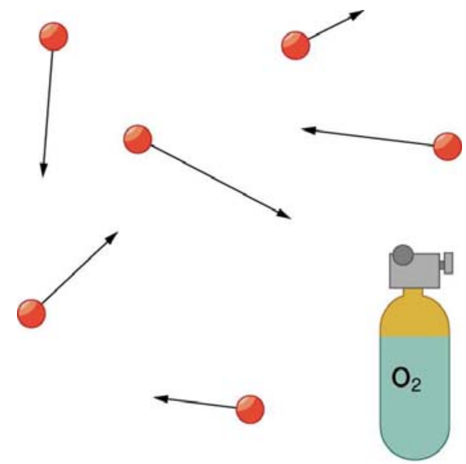
Liquids: Incompressible (density constant)
Gases: Compressible (density depends on pressure)

Parameters to describe Fluids:

Density: ρ = mass/volume

Pressure: P = Force/Area

[P] = N/m^2 = 1 Pascal (Pa)



 (c)

Density

$$\rho = \frac{m}{V} \qquad m = \rho V$$

- Density of water @4°C:

$$\rho_{water} = 1\text{g/cm}^3 = 1000\ \text{kg/m}^3 = 1\text{kg/liter}$$

- Density of air @ 0°C:

$$\rho_{Air} = 1.29\text{x}10^{-3}\ \text{g/cm}^3 = 1.29\ \text{kg/m}^3$$

Density depends on temperature!

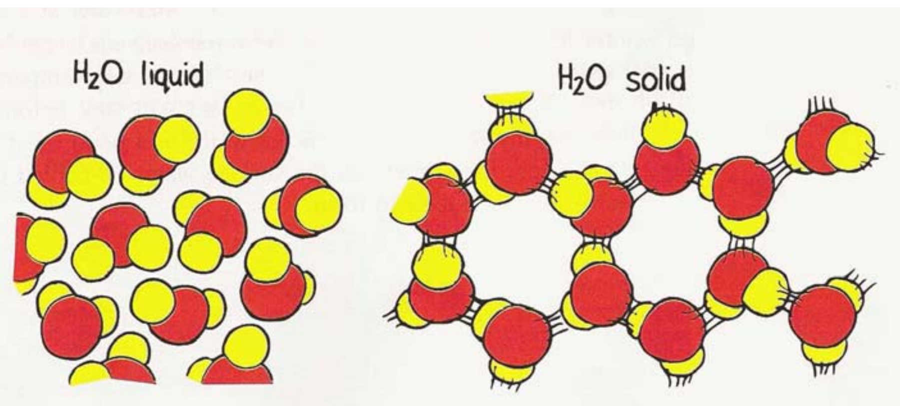
Most substances EXPAND upon heating.

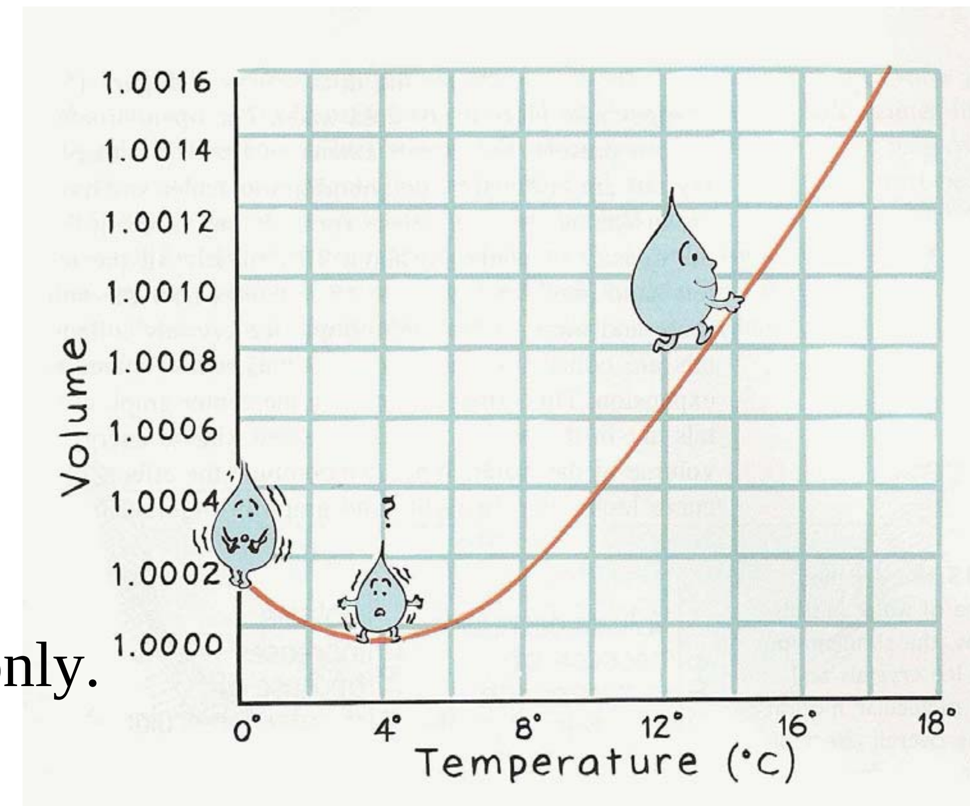
How does that change their densities?

$\rho = \frac{m}{V}$ ➡ REDUCES DENSITY!

Water: *The Exception*

- Water @4°C: ρ_{water} =1000 kg/m^3
- Ice @ 0°C: ρ_{ice} = 917 kg/m^3





Note: The graph is for ice water only.
Ice is not on the graph!

Liquid Units

There are 1000 liters in 1 cubic meter!

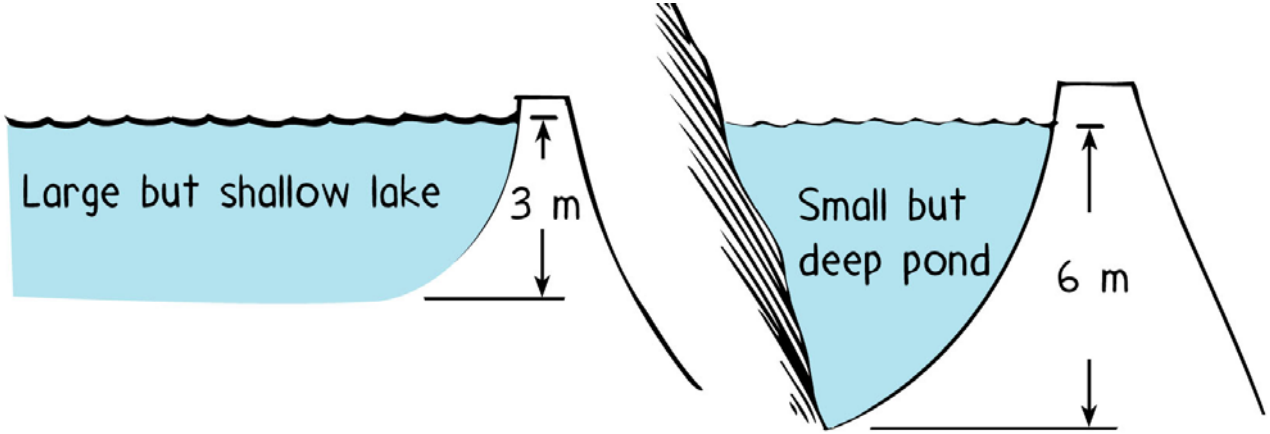
1 liter = 10^{-3} m^3 = 10^3 cm^3

1 liter of water has a mass of 1 kg and a weight of 9.8N.

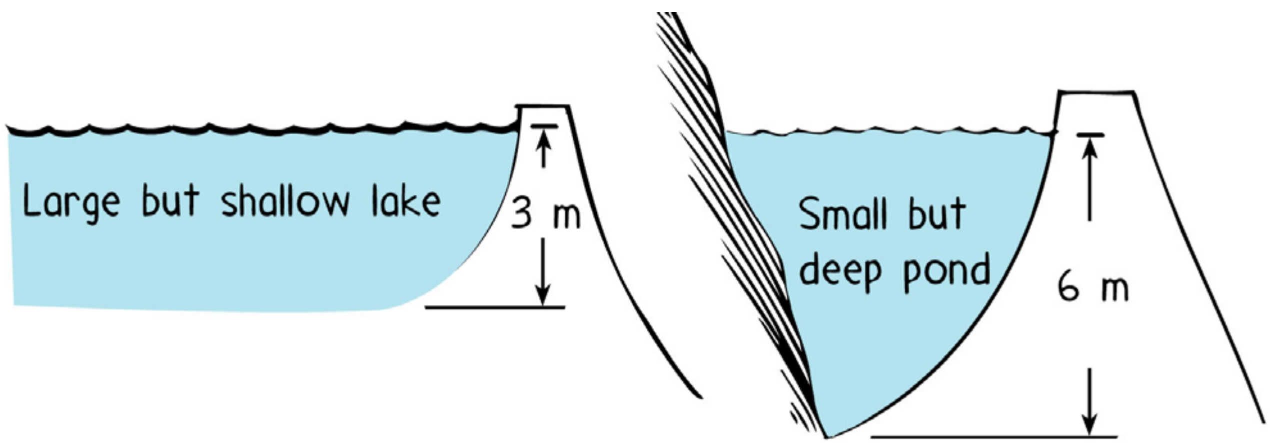
$$\rho_{H_2 0} = \frac{1kg}{liter} = \frac{1000kg}{m^3}$$

In which is the pressure greatest at the bottom?

a) Large but shallow lake
b) Small but deep pond
c) Same same



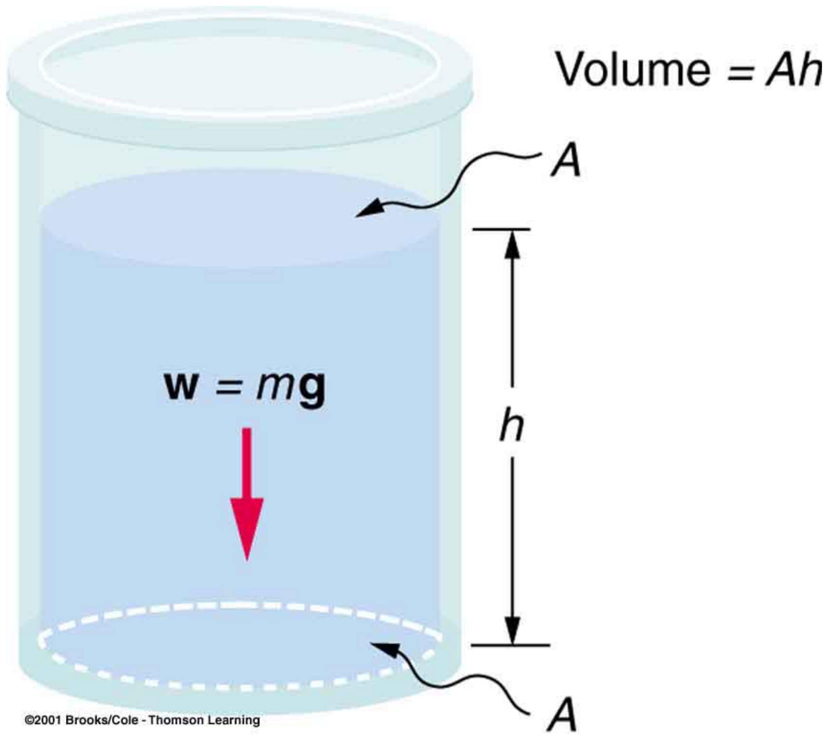
The average water pressure acting against the dam depends on the average depth of the water and not on the volume of the water held back!



Pressure in a fluid is due to the weight of a fluid.

$$P = \frac{Force}{Area}$$

$$= \frac{mg}{A} = \frac{mg}{V/h}$$



$$\boxed{P = (W/V)h}$$

$$\boxed{P = \text{weight density x height}}$$

Pressure depends on Depth!

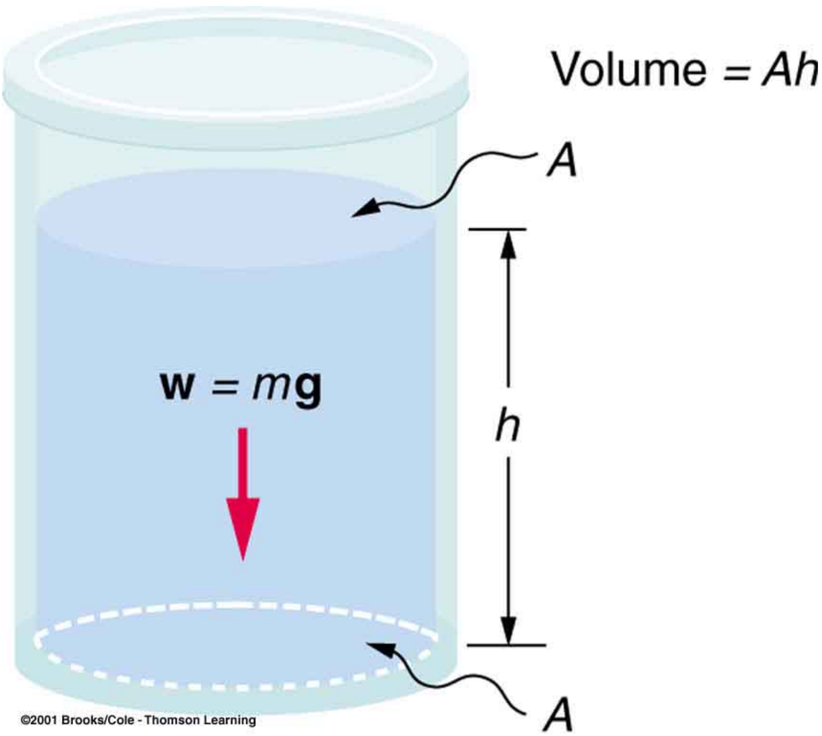
Pressure in a fluid is due to the weight of a fluid.

$$P = \frac{Force}{Area}$$

$$= \frac{mg}{A} = \frac{(\rho V)g}{A}$$

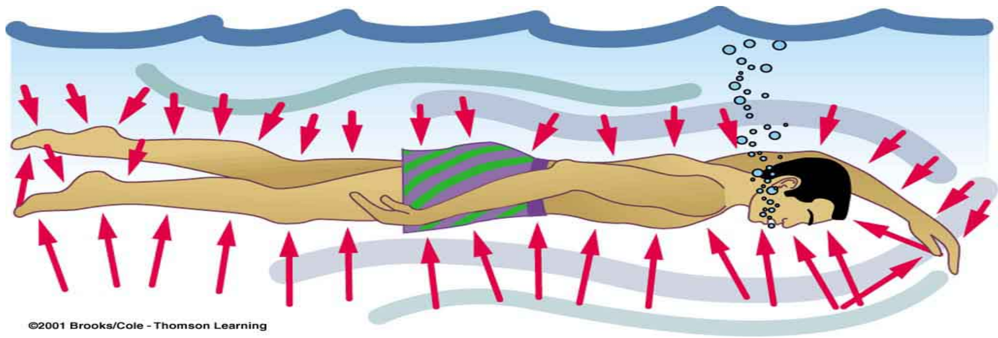
$$= \frac{(\rho A h)g}{A}$$

$$\boxed{P = \rho g h}$$

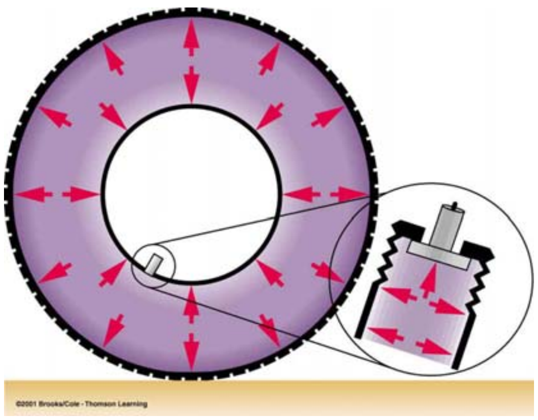


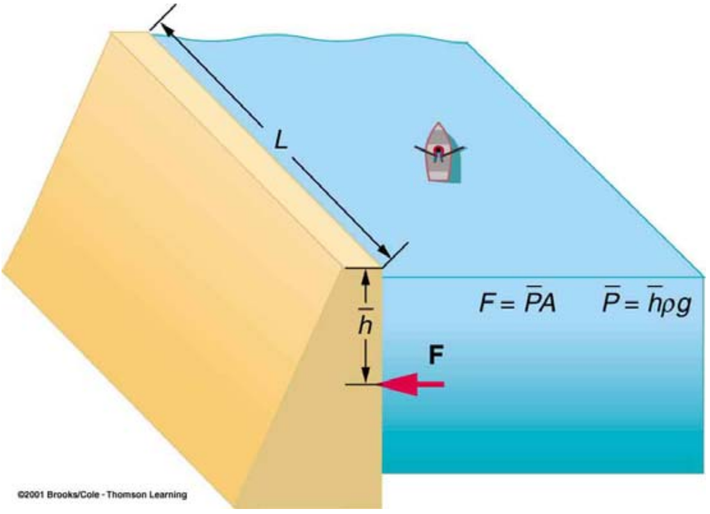
Pressure depends on Depth!

Pressure Acts ONLY Perpendicularly to the Surface

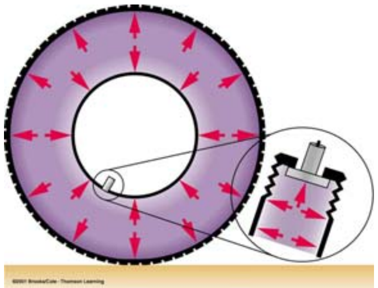


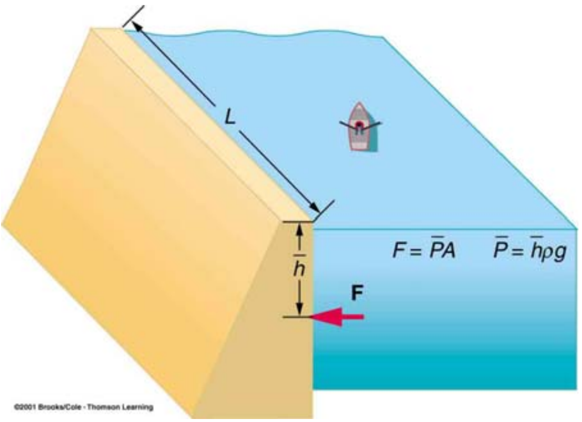
Pressure depends on depth.



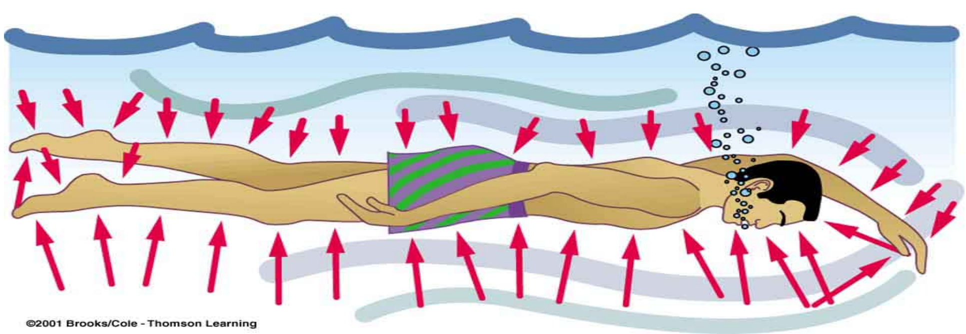


Pressure IN a Fluid





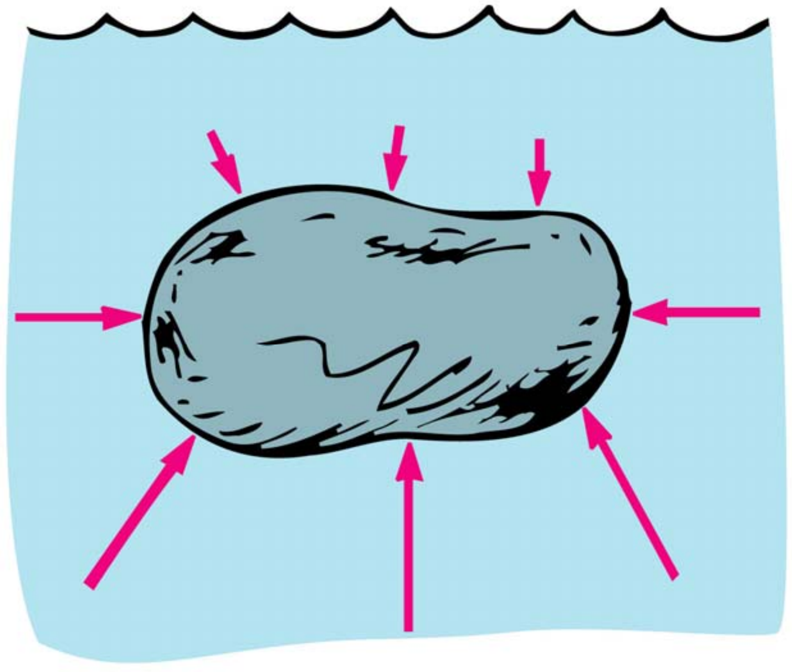
- Is due to the weight of the fluid above you
- Depends on Depth and Density Only
- Does NOT depend on how much water is present
- Acts perpendicular to surfaces (no shearing)
- Pressure’s add
- At a particular depth, pressure is exerted equally in ALL directions including sideways (empirical fact)

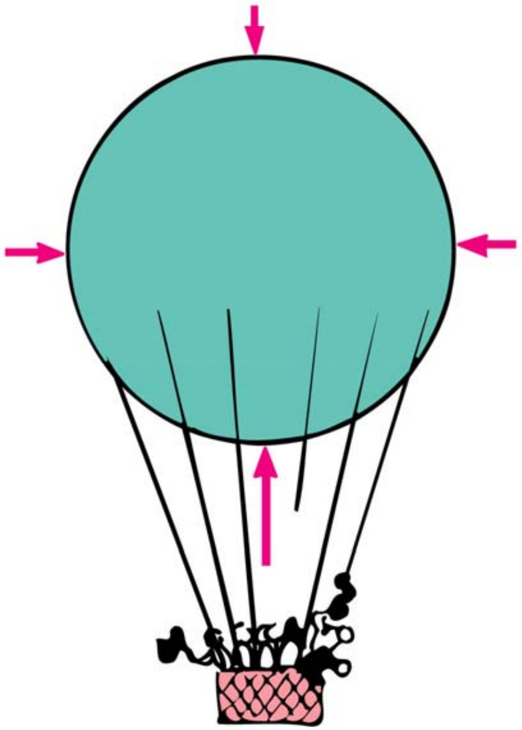


Buoyant Force

The difference in pressures at different depths or elevation produces a net upward or

Buoyant Force:



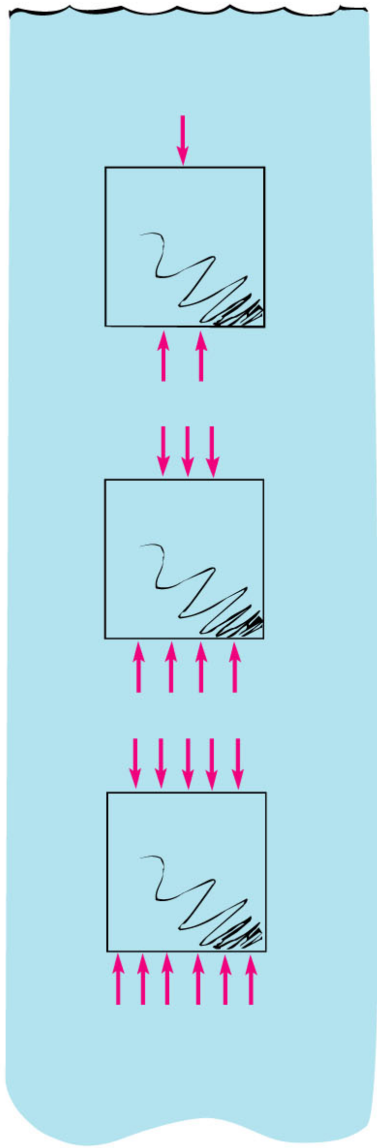


Deep Question

The net buoyant force increases with increasing depth.

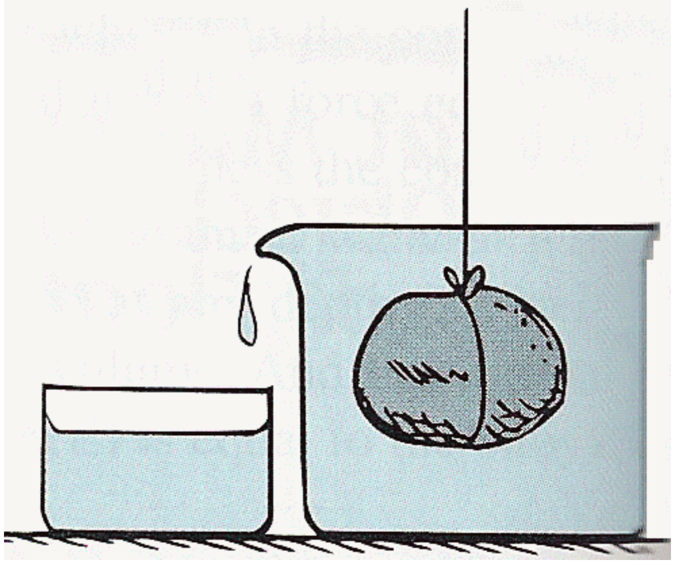
a) TRUE
b) FALSE

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

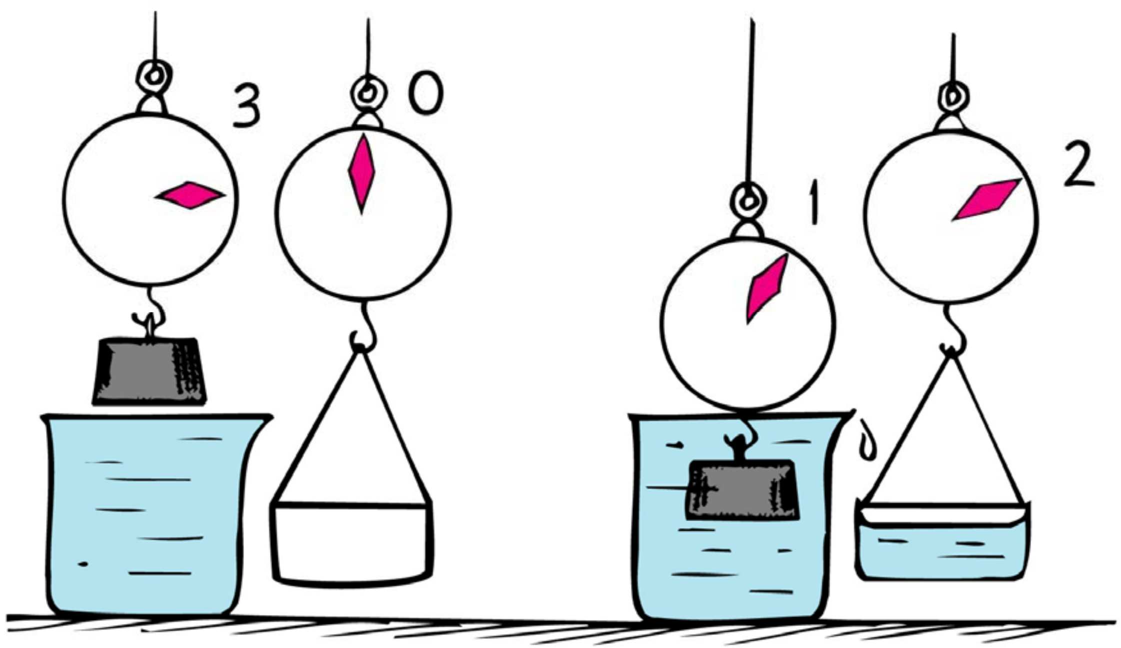


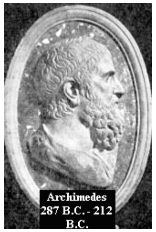
Submerged Volume

A submerged object displaces a volume of fluid equal to its own volume.



Objects weigh more in air than in water. The missing weight is equal to the weight of the water displaced.





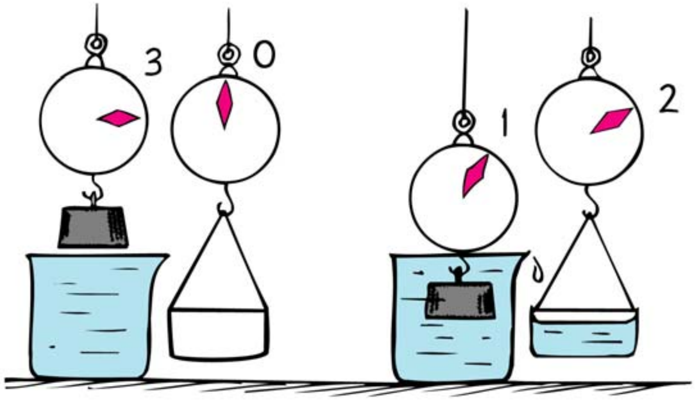
Archimedes Principle

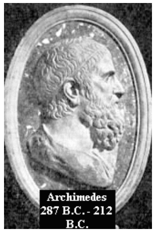
The buoyant force on an object equals the weight of the fluid it displaces.

$$BF = W_{fluid}$$

Note:

For the same volume of displaced fluid denser fluids exert a greater buoyant force. This is why ships float higher in salt water than fresh water.

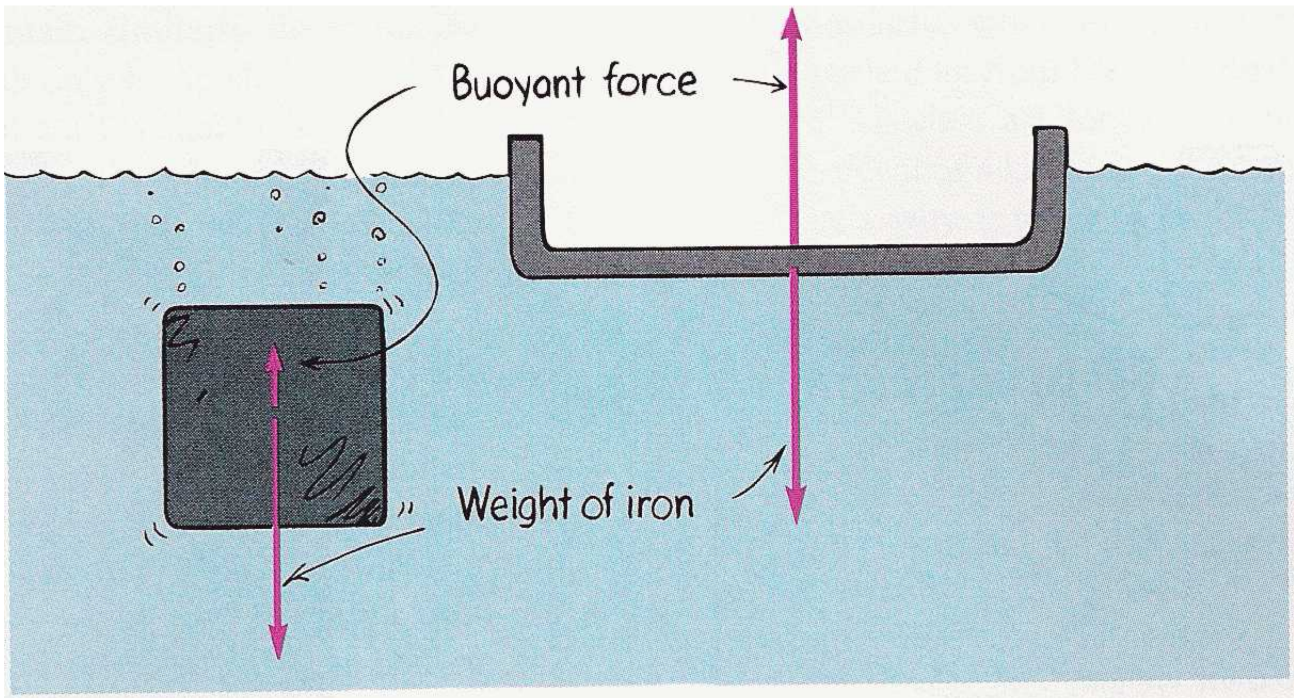




Archimedes Principle

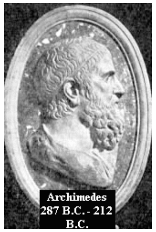
Floating

Buoyant force also depends on SHAPE which determines the VOLUME of displaced fluid.



This is how Iron Ships can float!!

They have a shape that displaces enough water to produce a Buoyant Force to balance the weight!



Archimedes Principle

Floating

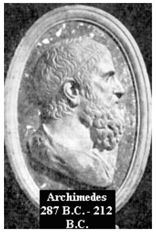
The buoyant force on an object equals the weight of the fluid it displaces.

$$BF = W_{fluid}$$

$W_{object} < BF$ Object will Float

$W_{object} > BF$ Object will Sink

$W_{object} = BF$ Object will Be Neutral



Archimedes Principle

Floating

Whether an object will float or sink depends on its density:

$$\rho_{object} < \rho_{fluid}$$ Float

$$\rho_{object} > \rho_{fluid}$$ Sink

$$\rho_{object} = \rho_{fluid}$$ Neutral

Buoyant Force Question

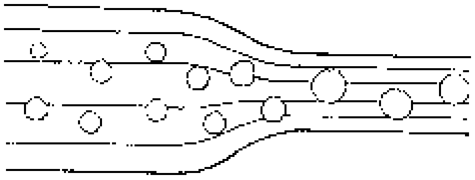
A boulder is thrown into a deep lake. As it sinks deeper and deeper into the water, does the buoyant force on it increase?

NO! The buoyant force does not change as the boulder sinks because the boulder displaces the same amount of fluid no matter how deep it is in the water!

Bernoulli’s Bubbles

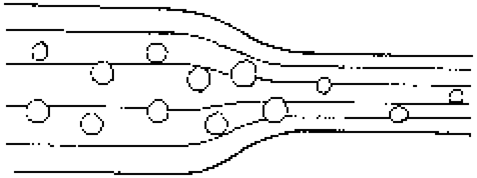
Water with air bubbles flows through a pipe that gets narrower. In the narrow region the water gains speed and the bubbles are

a) larger WHY?

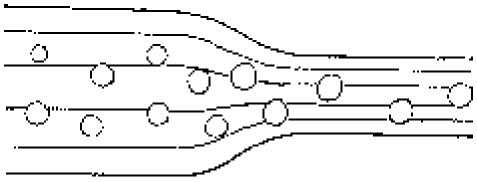


Lower pressure!!

b) smaller

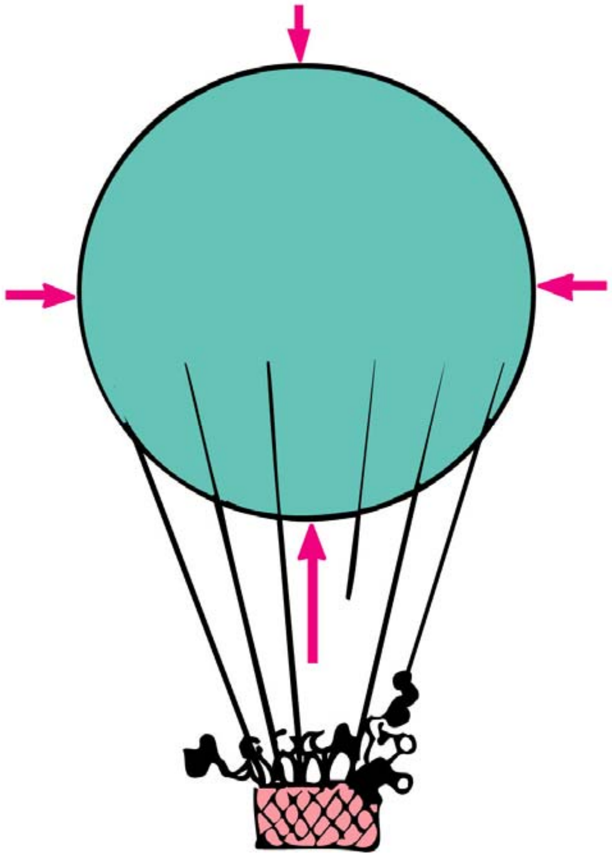


c) the same size



Buoyancy of Air

All bodies are buoyed up by a force equal to the weight of the air they displace.

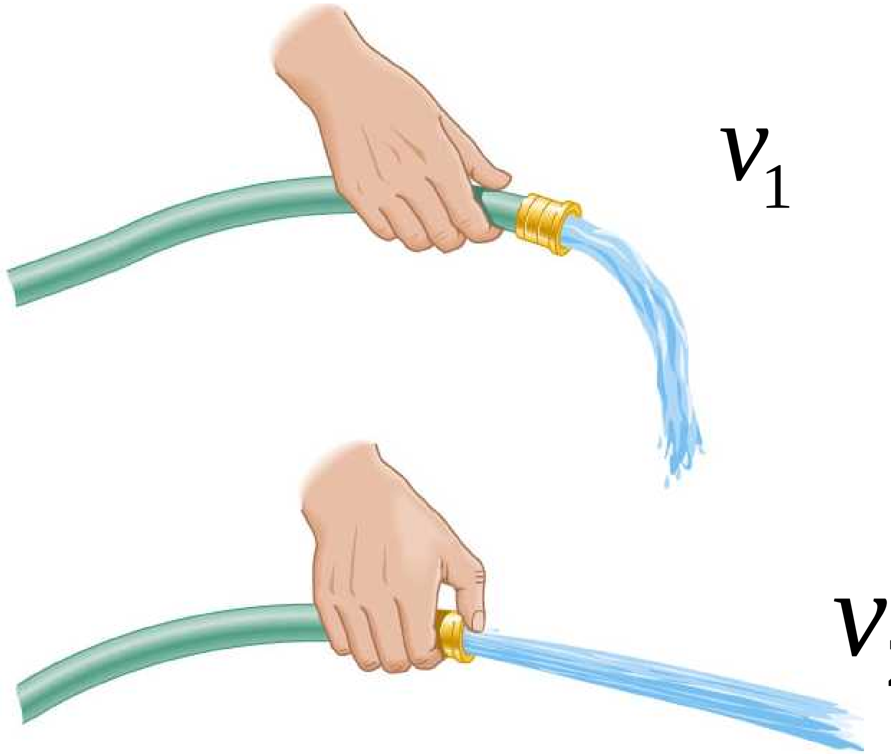


3. A one-ton blimp hovers in the air. The buoyant force acting on it is

a) zero b) one ton c) less than one ton d) more than ton.

Continuity of Fluid Flow

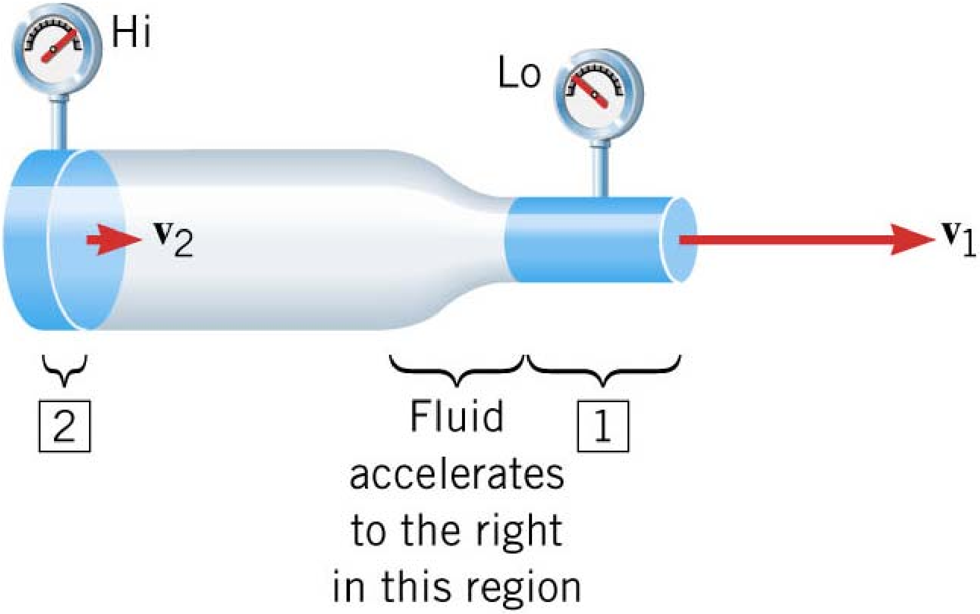
If the area decreases, the speed increases.



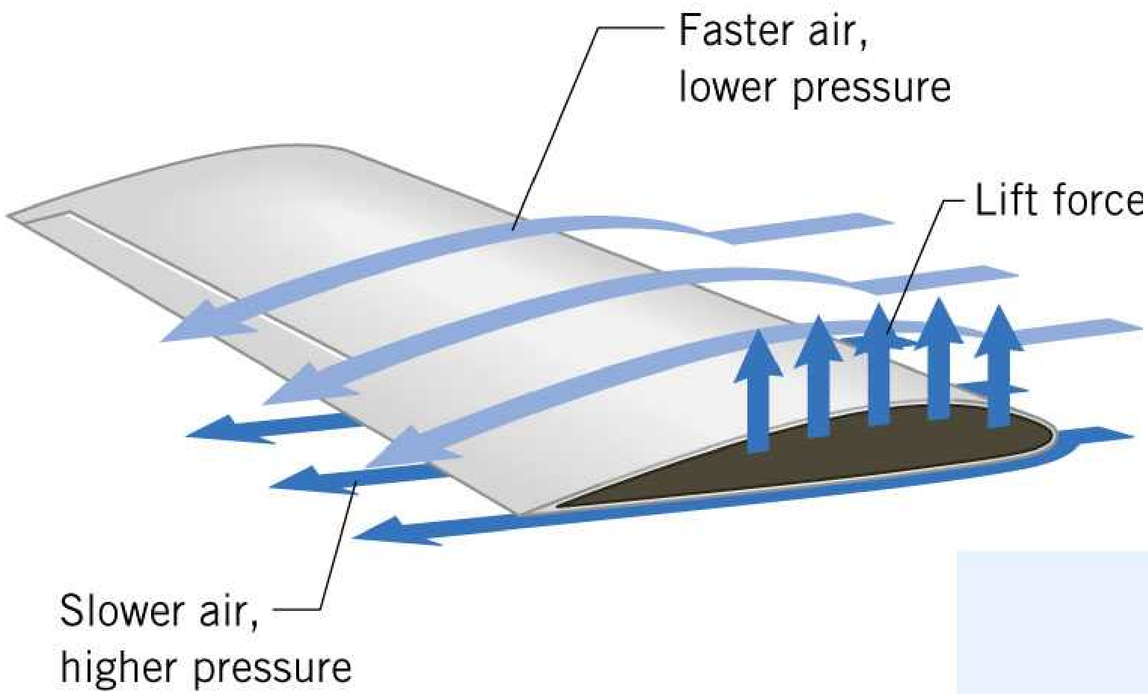
$$v_1 < v_2$$

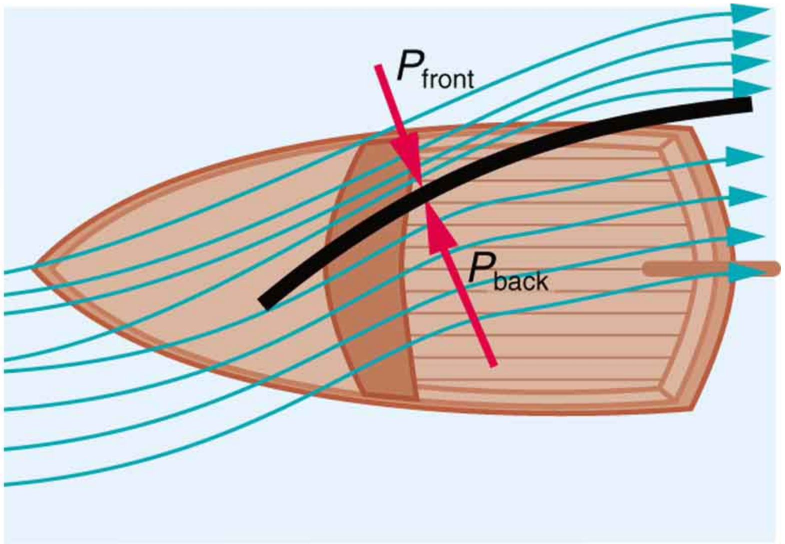
Bernoulli's Principle

Where the speed of a fluid increases, internal pressure in the fluid decreases.

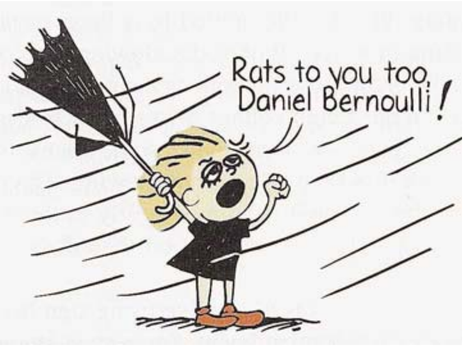


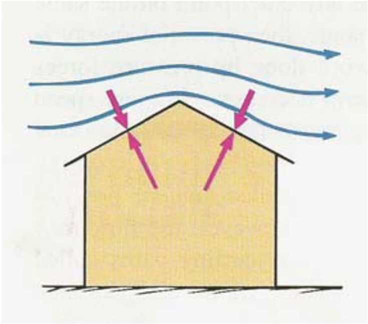
Bernoulli’s Principle: LIFT

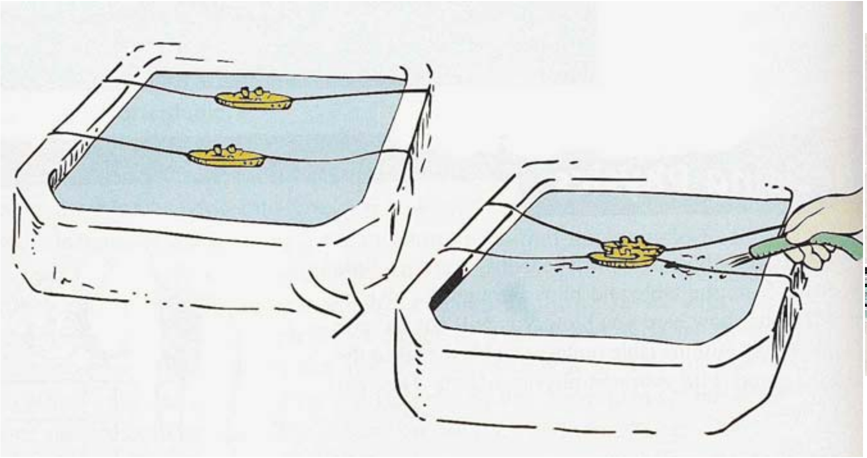


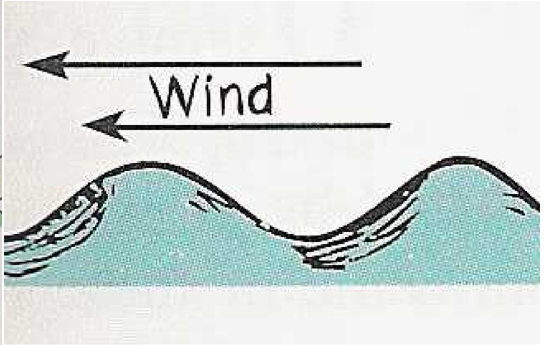


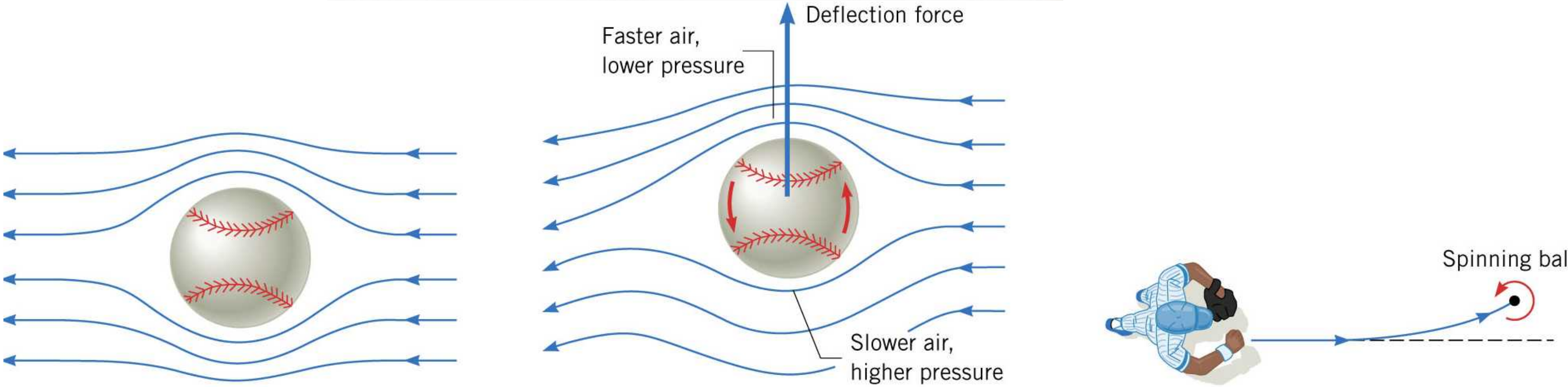
Bernoulli's Principle







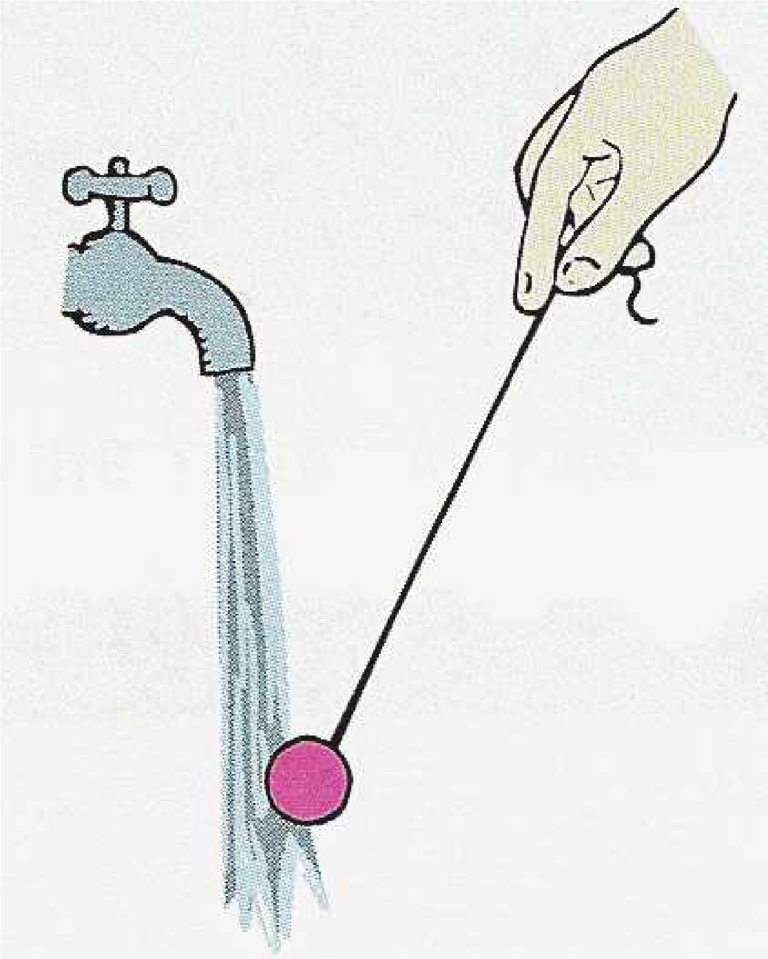




(*a*) Without spin (*b*) With spin (*c*)

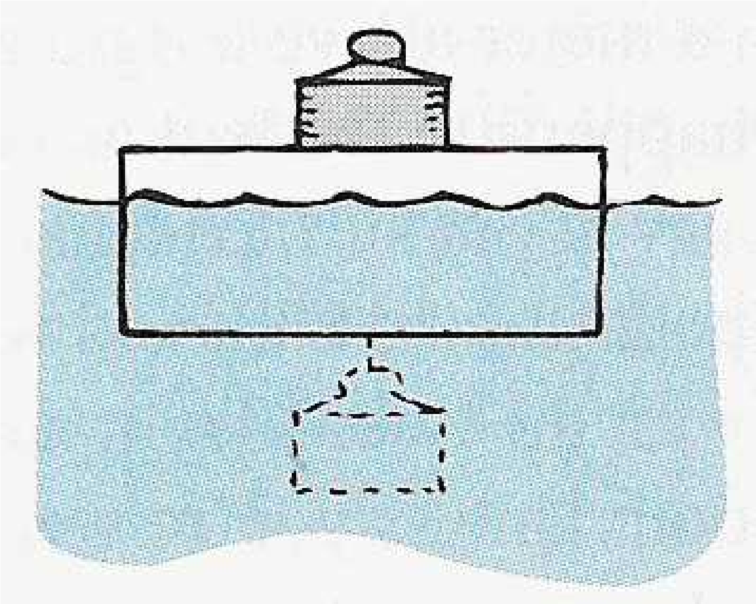
Bernoulli's Ball

Why does this happen?



Question

A piece of iron placed on a block of wood makes it float lower in the water. If the iron were instead suspended beneath the wood, would it float as low, lower or higher?



Question

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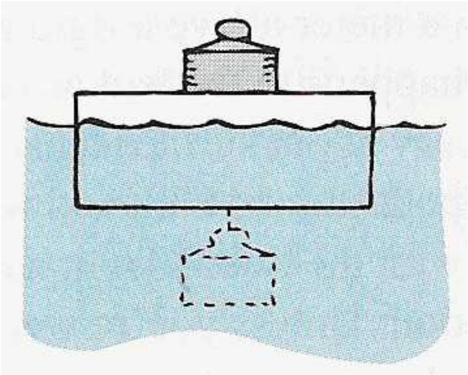
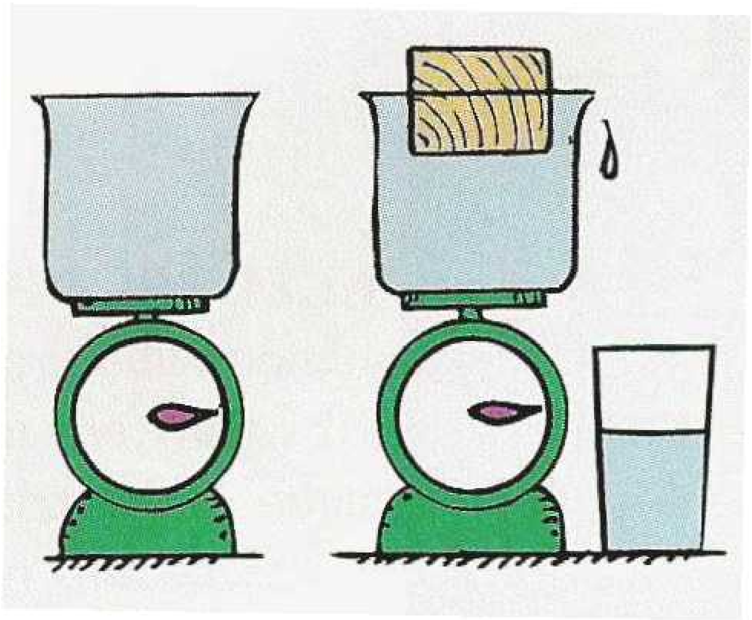


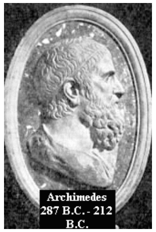
Answer

Higher. When the iron is on top, its whole weight pushes the wood into the water. But when the iron is submerged, buoyancy on it reduces its effective weight and less of the block is pulled beneath the water line.

Floating Volume

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

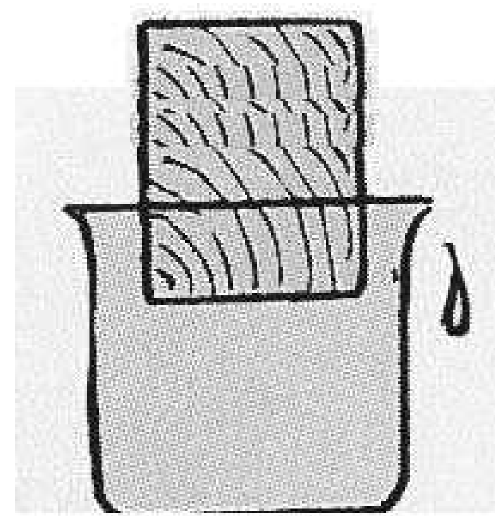




Archimedes Principle

Fraction of Object Floating

$$\frac{V_{submerged}}{V_{object}} = \frac{\rho_{object}}{\rho_{fluid}}$$



What is the density of the object?

What fraction is submerged? ~1/3

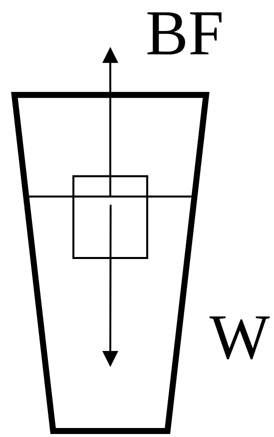
Density is 1/3 that of water.

Question

The glass is full to the brim with ice water and ice cubes. When the ice melts, will the water level decrease? Overflow? Remain the same? WHY?

Question

Here is a glass of ice water with an ice cube floating in it. When the ice cube melts, will the water level rise, drop or remain the same? Assume constant temperature.



same!

Answer

Since the cube floats, the BF equals its weight. $BF = W_{ice}$

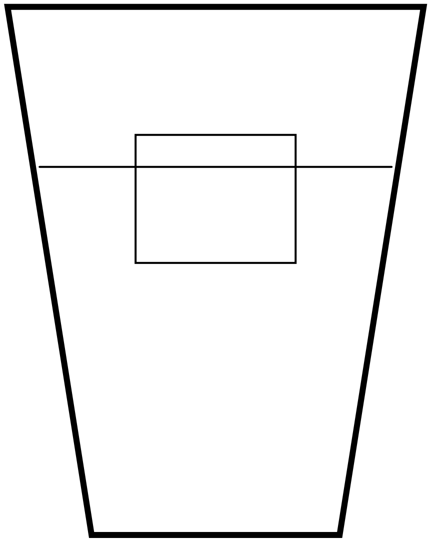
Weight of the water displaced equals the weight of the ice cube.

$$m_{water}g = m_{ice}g$$

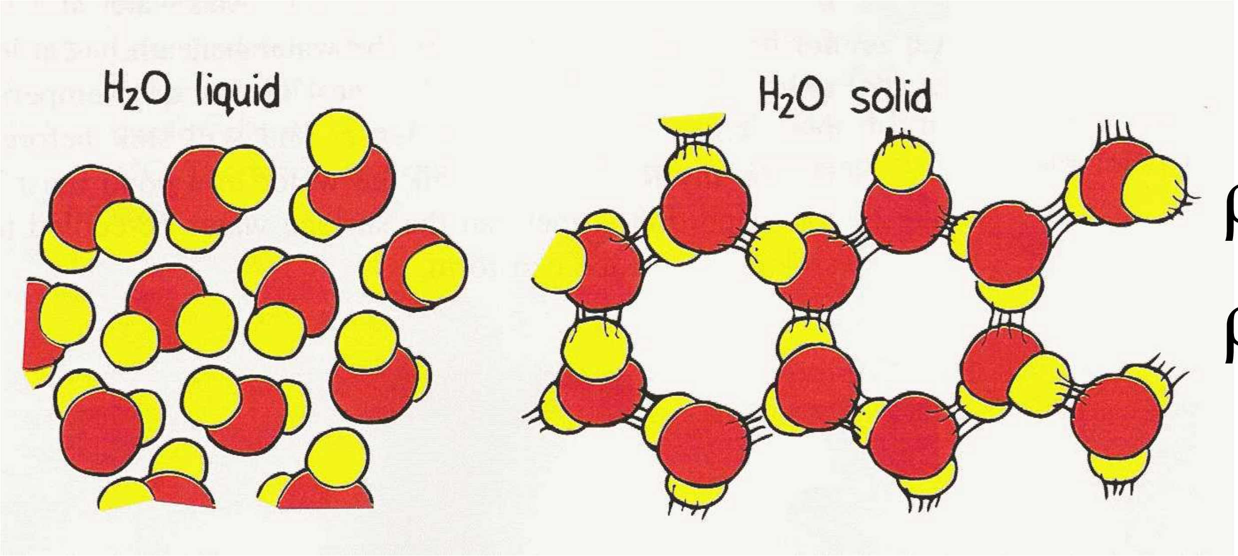
Mass of the water displaced equals the mass of the ice cube.

When the ice melts, it is water and since it has the same mass and density as the displaced water, it has the same volume, filling up the space where of the displaced water. The level remains unchanged.

Volume above and below



How does the volume of the billions of hexagonal open spaces in the structures of ice crystals in a piece of ice compare to the portion of ice that floats above the water line?



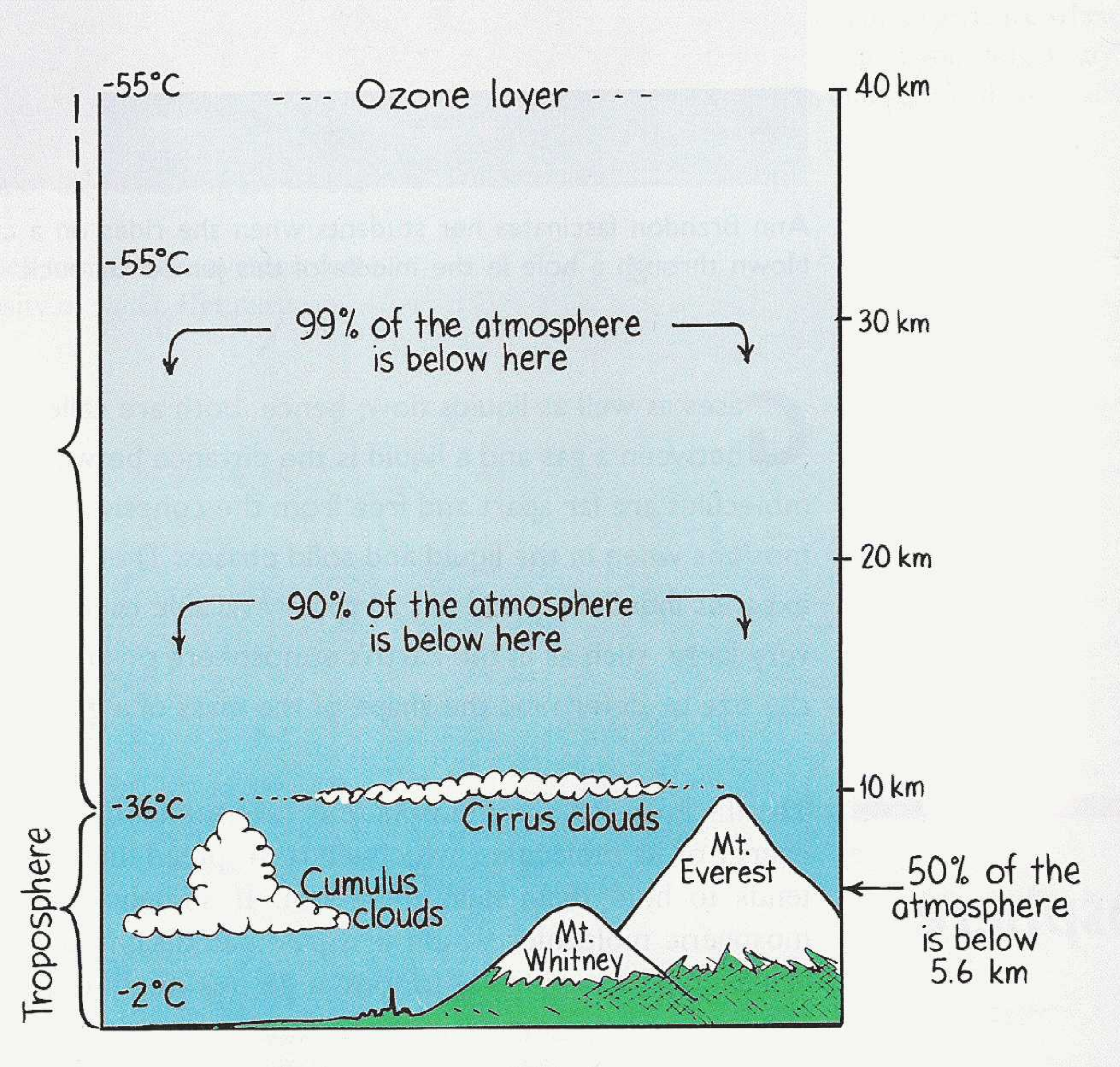
ρ_{water} =1000 kg/m^3

ρ_{ice} = 917 kg/m^3

Answer: The volume is the same! When the ice melts, the open spaces are filled in by the amount of ice that extends above the water level. This is also why the water level doesn't rise when ice melts.

The Atmosphere

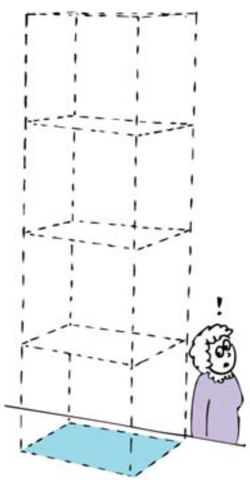
At sea level, the atmosphere has a density of about 1.29 kg/m^3. The average density up to 120 km is about 8.59×10^{-2} kg/m^3.

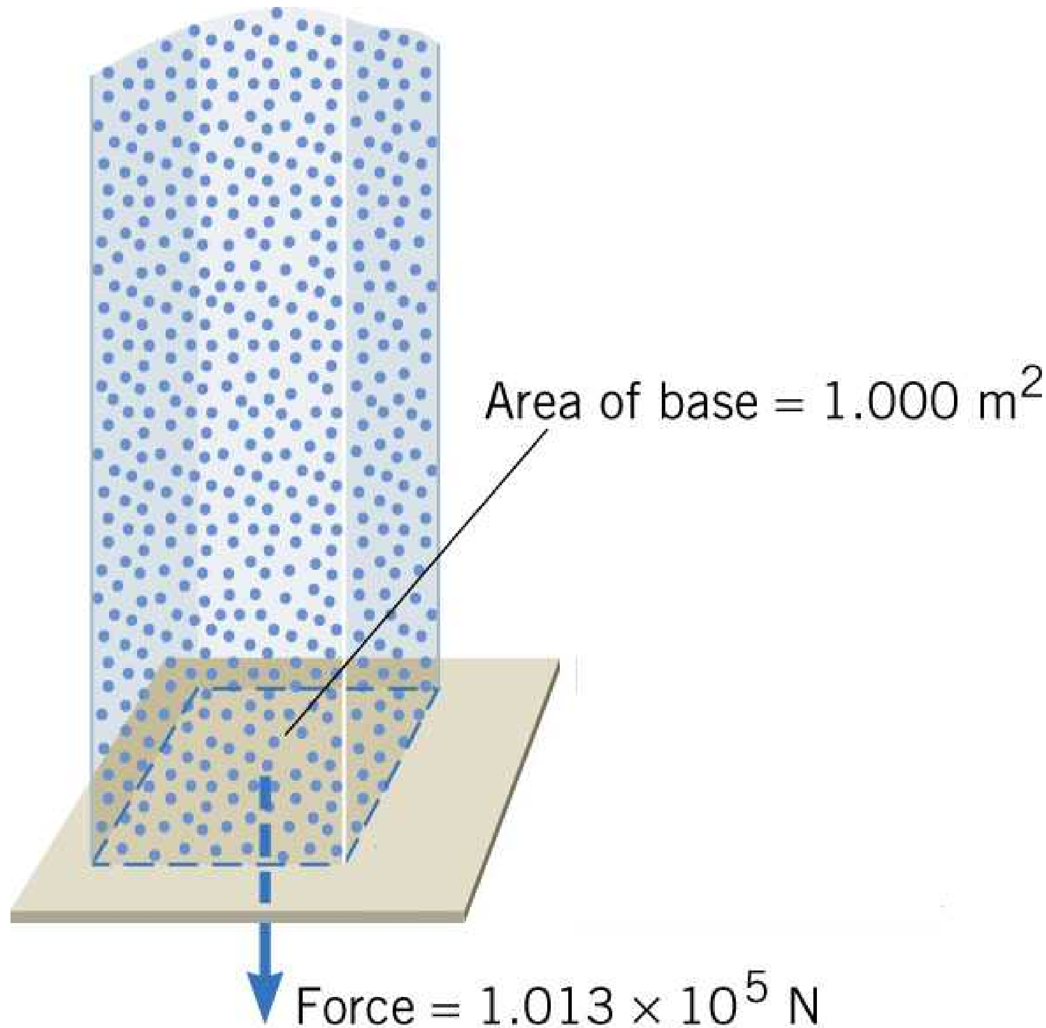


The Atmosphere

$$1atm = 1.013x10^5\,Pa = 14.7\,psi$$

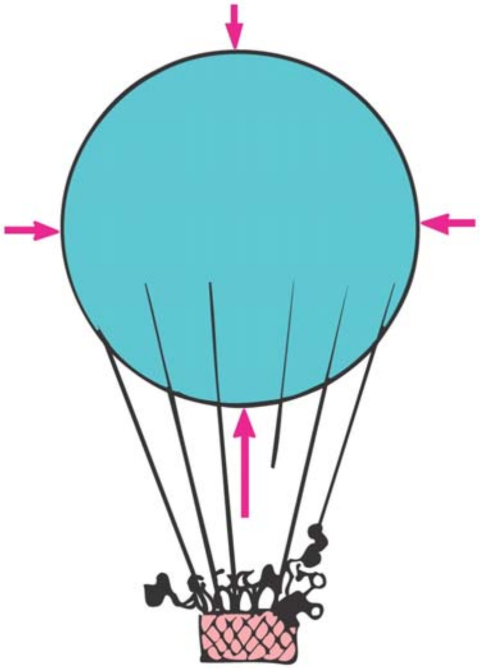
A square meter extending up through the atmosphere has a mass of about 10,000 kg and a weight of about 100,000 N.
1 N/m^2 is a *Pascal*.





Archimedes' Principle

- applies in air
  - the more air an object displaces, the greater the buoyant force on it
  - if an object displaces its weight, it hovers at a constant altitude
  - if an object displaces less air, it descends



Archimedes' Principle
CHECK YOUR NEIGHBOR

As you sit in class, is there a buoyant force acting on you?

A. no, as evidenced by an absence of lift
B. yes, due to displacement of air

Archimedes' Prinicple
CHECK YOUR ANSWER

As you sit in class, is there a buoyant force acting on you?

A. no, as evidenced by an absence of lift

B. yes, due to displacement of air

Explanation:

There *is* a buoyant force on you due to air displacement, but much less than your weight.

Measuring Pressure $1atm = 1.013x10^5 \, Pa$

Why is the pressure at X equal to atmospheric pressure?

Because if it didn't, the mercury would be pushed out of the dish!

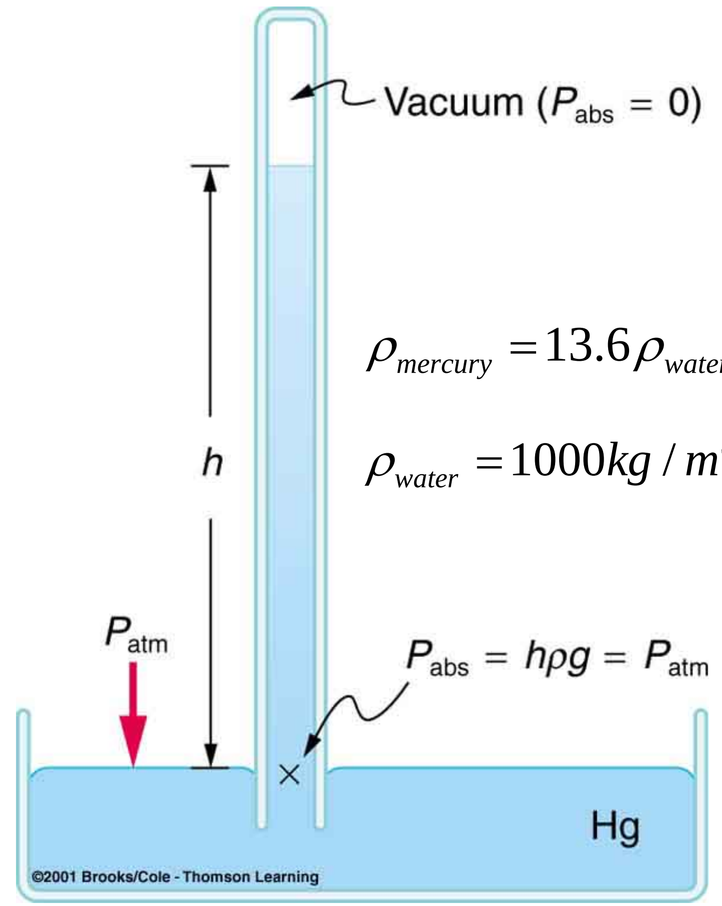
$$P = \rho g h$$

$$P = \rho_{mercury} g h$$

$$h = \frac{P}{\rho_{mercury} g}$$

$$h = \frac{101,300 N/m^2}{13,600 kg/m^3 x 9.8 m/s^2}$$

$$h = 760mm$$



$$\rho_{mercury} = 13.6 \rho_{water}$$

$$\rho_{water} = 1000 kg/m^3$$

Measuring Pressure

Can a barometer be made with Water instead of Mercury?

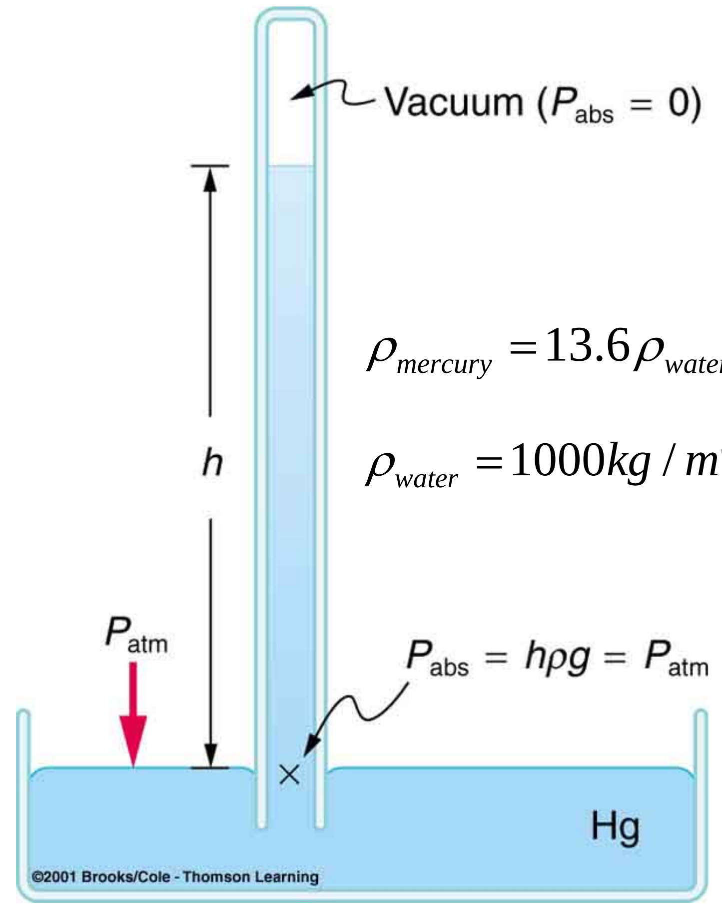
$$P = \rho_{water} g h$$

$$h = \frac{P}{\rho_{water} g}$$

$$h = \frac{101,300 N/m^2}{1000 kg/m^3 x 9.8 m/s^2}$$

$$\boxed{h = 10.3 m}$$

(Notice: 10.3m is just 13.6 x 760mm!)



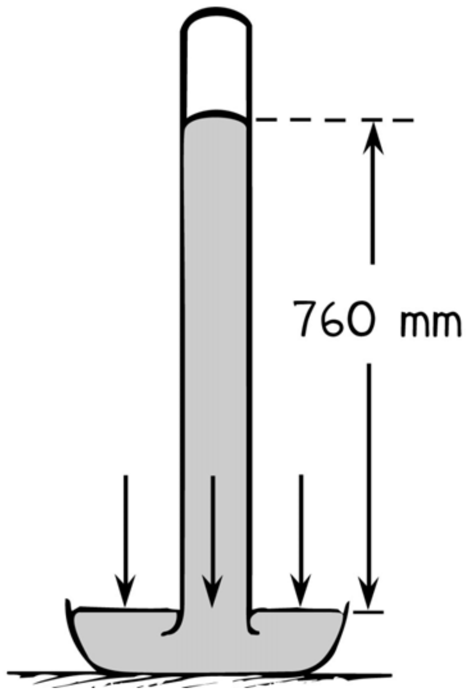
$$\rho_{mercury} = 13.6 \rho_{water}$$

$$\rho_{water} = 1000 kg/m^3$$

Barometers

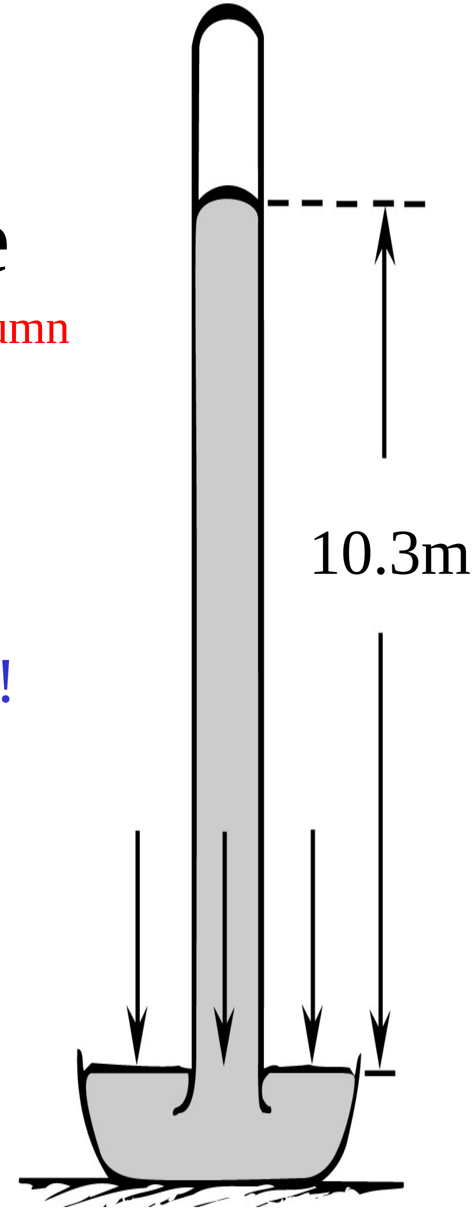
Measuring Air Pressure

Fluid in the tube adjusts until the weight of the fluid column balances the atmospheric force exerted on the reservoir.



Mercury Barometer

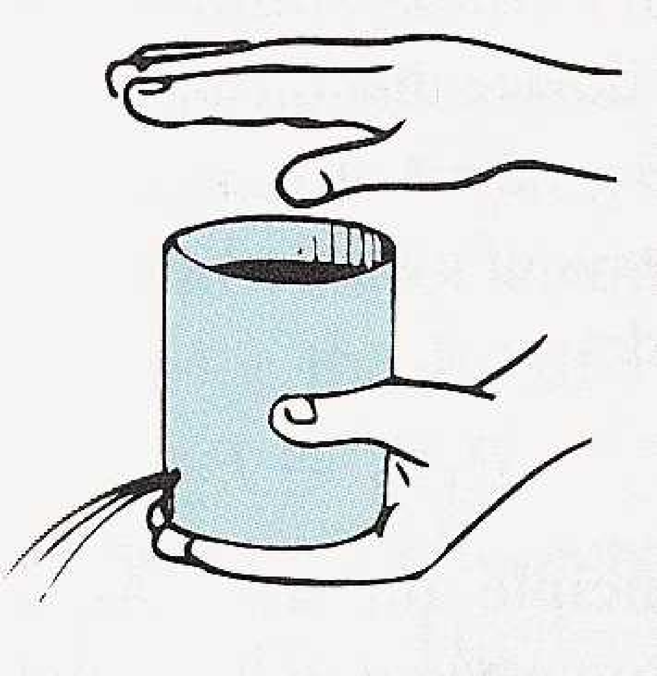
Not to Scale!!!



Water Barometer

$$1atm = 1.013x10^5\, Pa = 760mm$$

Why does the water stop when the top is closed?



Pressure is greater in the fluid at the spout due to weight of water so water flows. Hand covers top and water keeps flowing until the pressure is reduced to 1 atm by increasing volume of air above the fluid just like with a closed barometer!

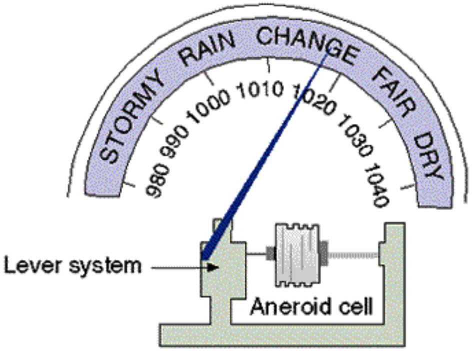
Barometers & The Weather

Goethe's Barometer

A barometer is an instrument used to measure atmospheric pressure. It can measure the pressure exerted by the atmosphere by using water, air, or mercury. Pressure tendency can forecast short term changes in the weather. A barometer is commonly used for weather prediction, as high air pressure in a region indicates fair weather while low pressure indicates that storms are more likely.

"The arts are an even better barometer of what is happening in our world than the stock market or the debates in congress."

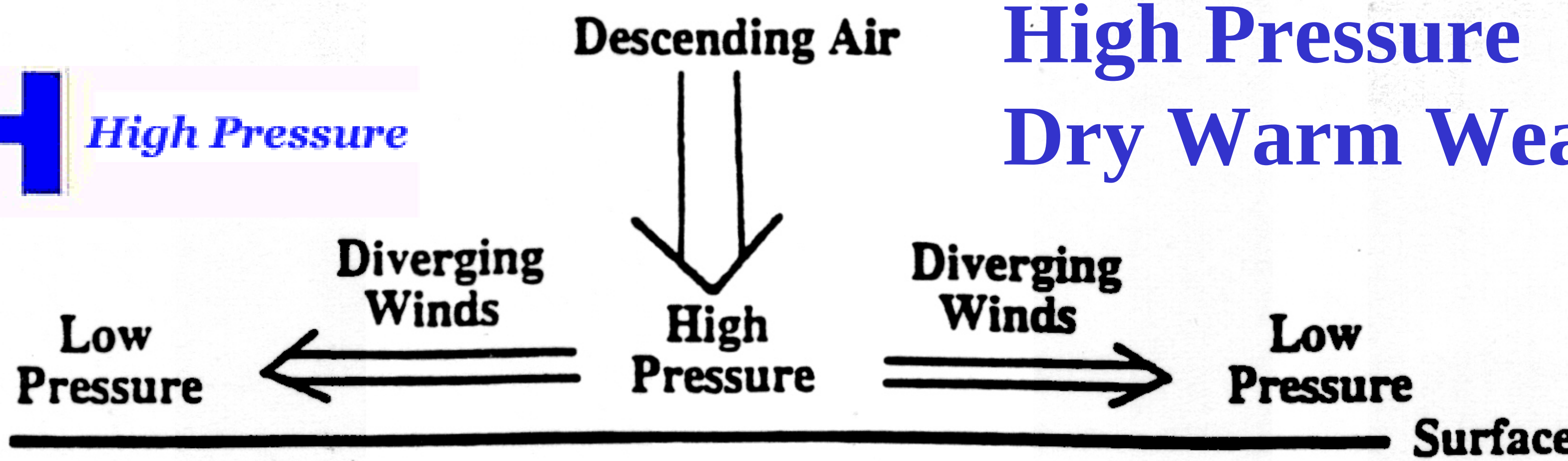
Hendrik Willem Van Loon



High Pressure
Dry Warm Weather

1)

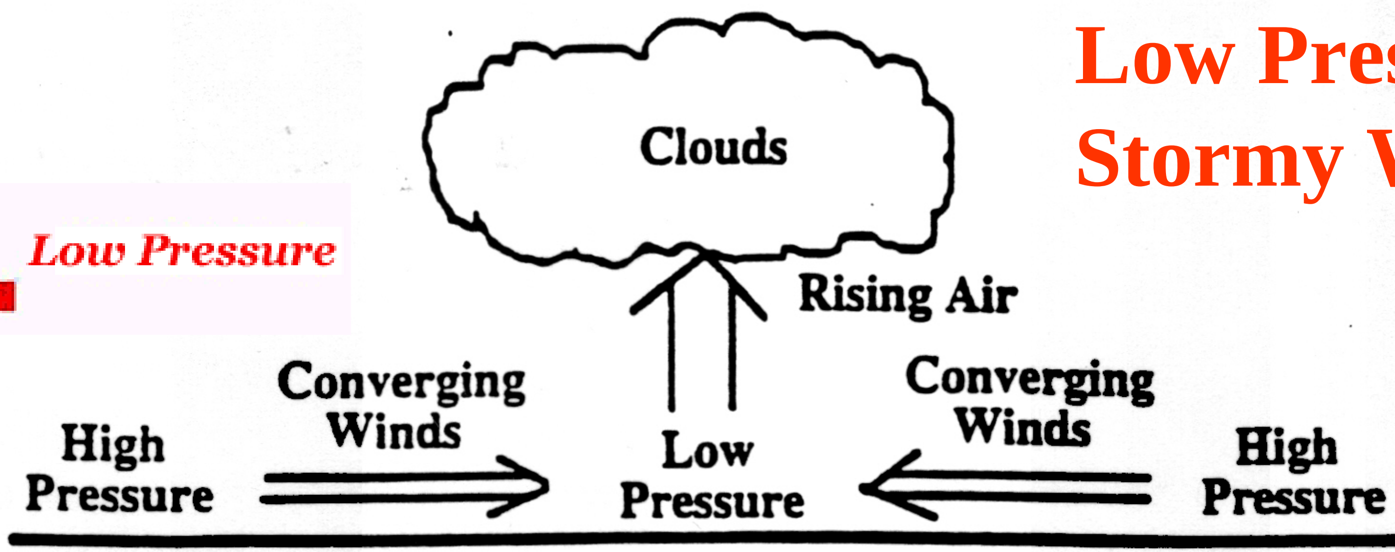
H *High Pressure*

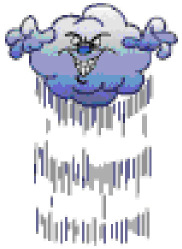


Low Pressure
Stormy Weather

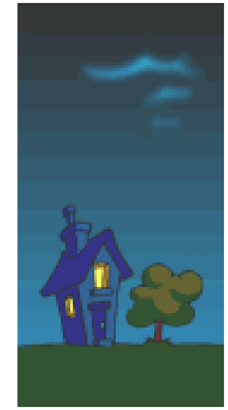
2)

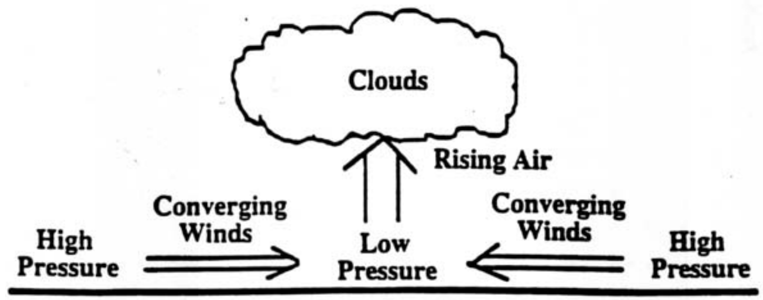
L *Low Pressure*





Stormy Weather





When warm air rises, it expands and cools. The water vapor in the air soon condense into water droplets, which form clouds and eventually these droplets fall from the sky as RAIN.

More about weather in Chapter 9!!

Pressure Altimeter

A pressure altimeter (also called barometric altimeter) is the traditional altimeter found in most aircraft. In it, an aneroid barometer measures the air pressure from a static port outside the aircraft. Air pressure decreases with an increase of altitude — about one millibar (0.03 inches of mercury) per 27 feet (8.23 m) near sea level.

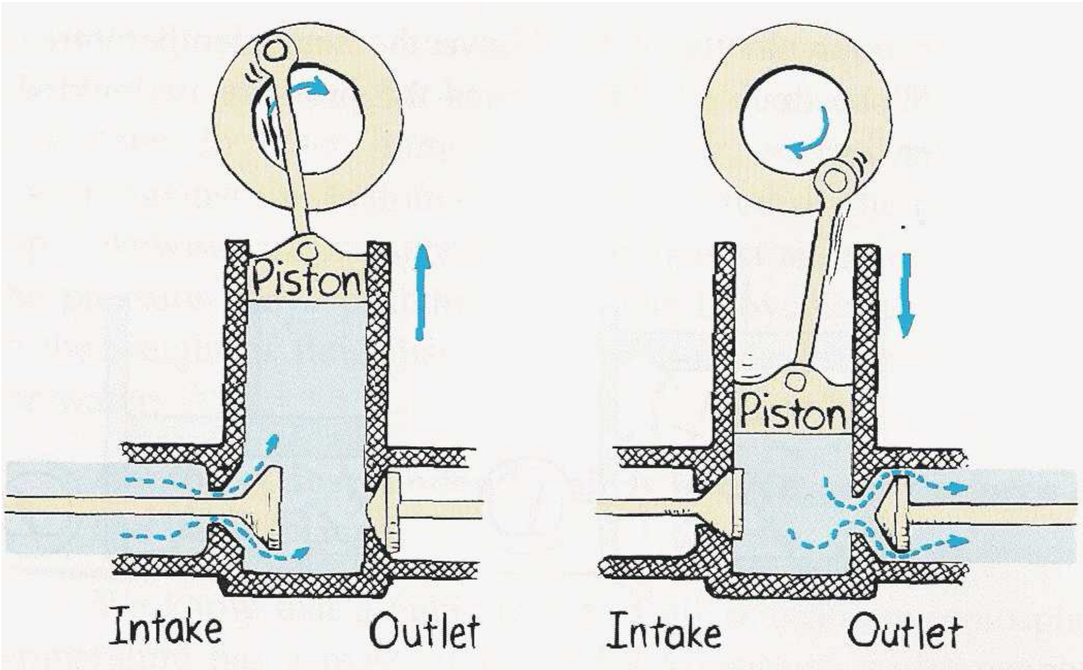
How Low can the pressure go?

Nature abhors a Vacuum.

-Aristotle

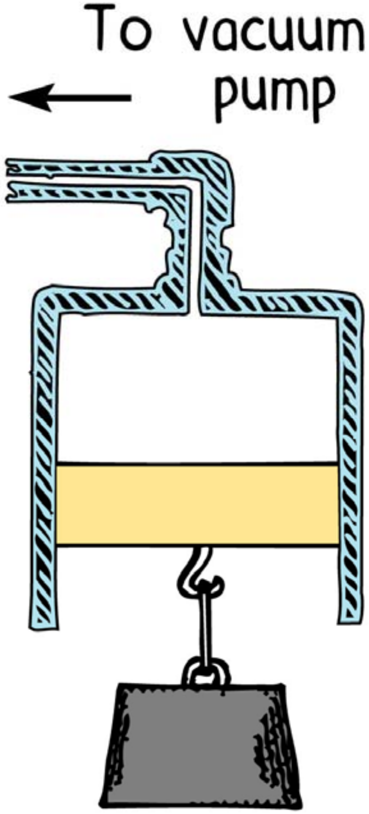
Zero Pressure: Making A Vacuum

Mechanical Vacuum Pump



Minimum pressure produced by mechanical pump:~1Pa
Minimum pressure produced by hi tech: 10^{-12} Pa
Zero pressure not allowed by Quantum Uncertainty!
Absolute pressure cannot be negative: Pressure pushes not pulls!
Gauge pressure can be negative because it is a *relative* pressure.

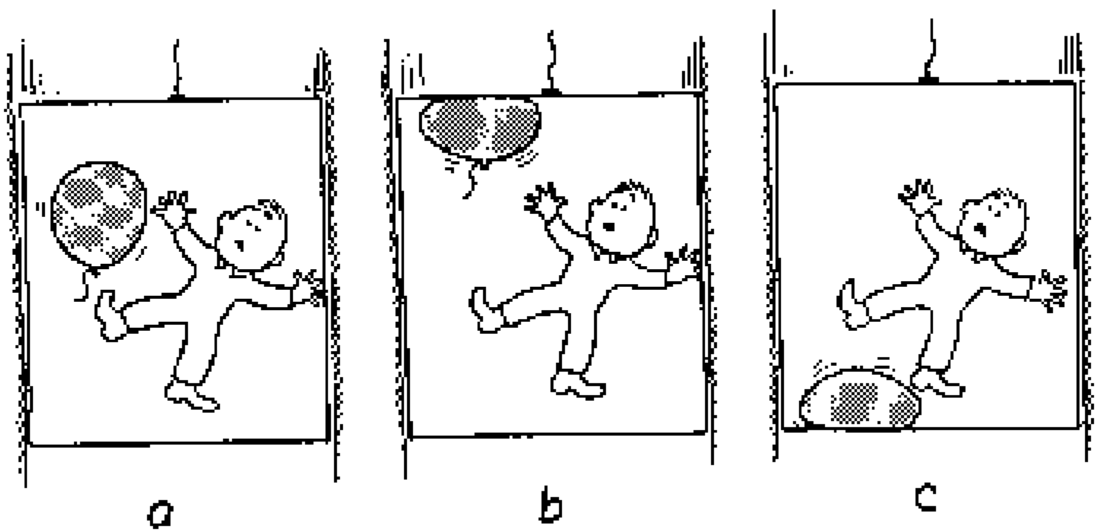
Is the piston that supports the load pulled up or pushed out?



Is the soda sucked or pushed up the straw?

If you release a ball inside a freely-falling elevator, it stays in front of you instead of "falling to the floor" because you, the ball, and the elevator are all accelerating downward at the same acceleration, **g**. If you similarly release a helium-filled balloon, the balloon will

a) also stay in front of you
b) press against the ceiling
c) press against the floor



Question

If you release a ball inside a freely-falling elevator, it stays in front of you instead of "falling to the floor" because you, the ball, and the elevator are all accelerating downward at the same acceleration, **g**. If you similarly release a helium-filled balloon, the balloon will

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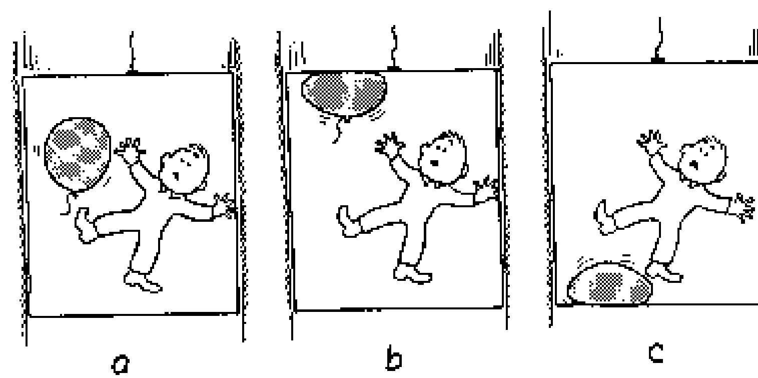

Answer:

a) The balloon stays in front of you because it, along with you and the air and the elevator, is in free fall. When the air is in free fall it has no weight, therefore it cannot provide a buoyant force. Therefore, the balloon falls with everything else.