Physics 221, March 1

Key Concepts:

- Density and pressure
- Buoyancy
- Pumps and siphons
- Surface tension

Definitions

Fluids:

Liquids → Incompressible

Gases → Compressible

Particle density: $\rho_{particle} = N/V$

Density: $\rho = M/V$

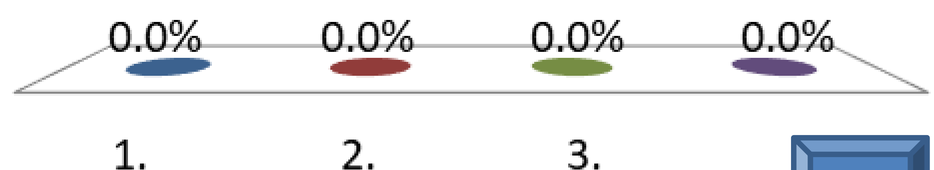
Pressure: $P = F/A$

Substance A has a density of 2.0 g/cm^3 and substance B has a density of 3.0 g/cm^3.

In order to obtain equal masses of these two substances, the ratio V_A/V_B of the volume of A to the volume of B has to be equal to

Hint:
$M = \rho V$

1. 3 : 2.
2. 2 : 3.
3. 1 : 2.
4. 1 : 3.



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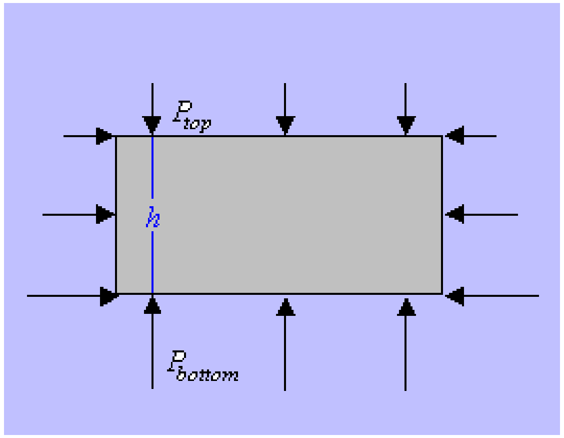
Hydrostatics



Hydrostatics (liquids at rest):

(no ordered kinetic energy)

$P_{bottom} - P_{top} = \rho g \Delta h$

or

$P_{bottom} = P_{top} + \rho g(h_{top} - h_{bottom})$

Units:

1 atmosphere = 101 kPa = 14.7 pounds per square inch (psi)

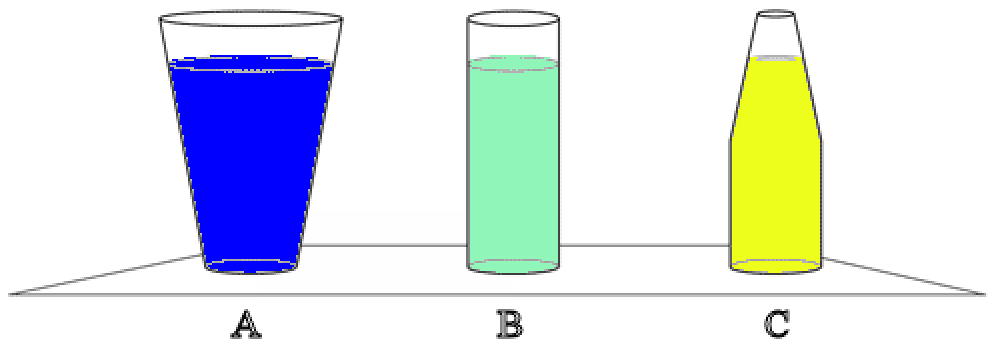
Note: ρ_{water}*g*(10 m) ~ (1000 kg/m^3)*(10 m/s^2)*(10 m) = 100 kPa

Pascal's law:

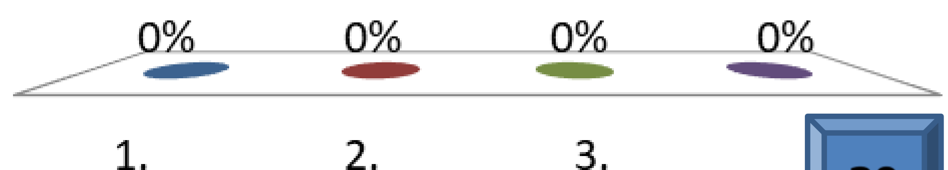
Any change in the pressure at the surface is transmitted to every point in the liquid.

P is the same everywhere at the same height.

Consider three drinking glasses. All three have the same area base, and all three are filled to the same depth with water. Glass A is wider at the top than at the bottom, glass B is cylindrical and so holds less water than A. Glass C is narrower at the top than at the bottom, and so holds less water than B. Which glass has the greatest liquid pressure at the bottom?



1. Glass A.
2. Glass B.
3. Glass C.
4. All three have equal pressure at the bottom.



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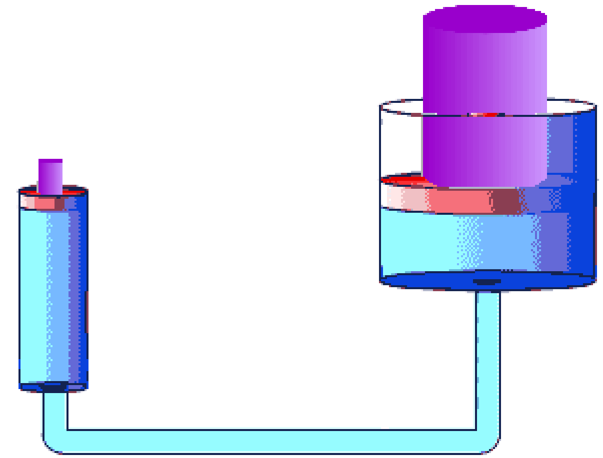
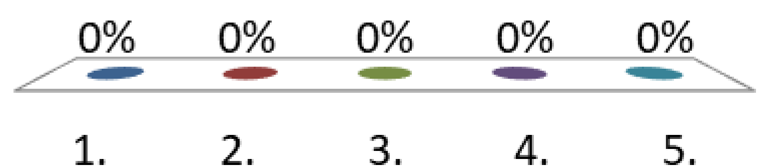
A 500 N weight sits on the small piston of a hydraulic machine in equilibrium. The small piston has area 2.0 cm^2. If the large piston has area 40 cm^2, how much weight does the large piston support ?



1. 500 N
2. 5000 N
3. 40 N
4. 10000 N
5. 40000 N



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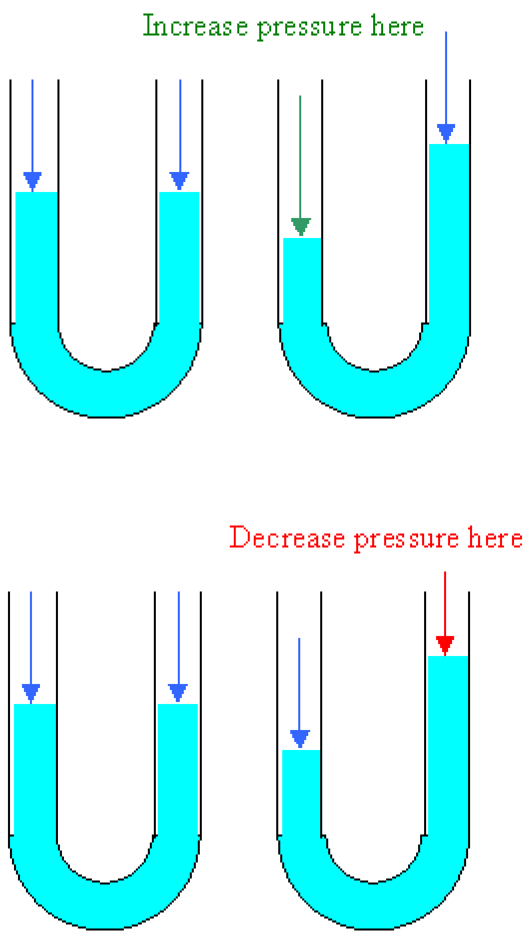
Pumps

How can you make the water level rise in the right leg and sink in the left leg?

If you remove all the air above one leg, you establish a pressure difference of 1 atm = 101 kPa.

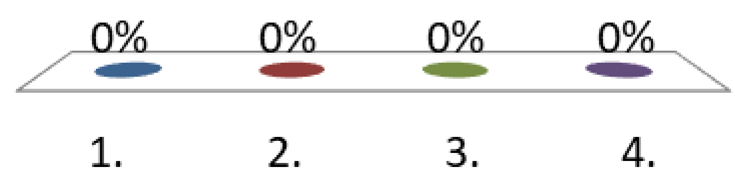
How high a column of water can you support?



The lungs can exert a negative pressure, with respect to atmospheric pressure, of up to 1.3 kPa. To what height can you suck water through a straw?

Remember: A 10 m high column of water exerts a pressure of ~100 kPa.

1. 13 cm
2. 1.3 m
3. 10 m
4. 10 mm



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Buoyancy

An object partially or wholly immersed in a gas or liquid is acted upon by an upward buoyant force **B** equal in magnitude to the weight w of the gas or liquid it displaces.

For the magnitudes we have

$$B = w.$$

Compare the densities of floating objects to the density of the liquid in which the objects are immersed.

Question:

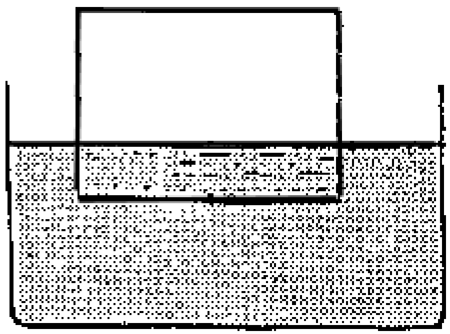
Will objects that float in water also float in methanol (density 790 kg/m^3)?

In saturated salt water (1200 kg/m^3)? Explain!

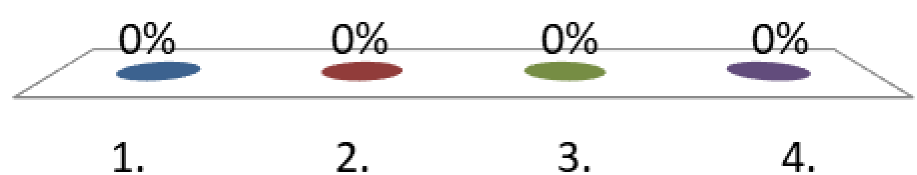
Demonstration:

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

A block of wood of uniform density floats so that exactly ¼ of its volume is underwater. What is the density of the block?



1. 0.25 kg/m^3
2. 0.5 kg/m^3
3. 250 kg/m^3
4. 500 kg/m^3



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A block of wood of uniform density floats so that exactly half of its volume is underwater. What is the density of the block?

Floating → no net force

buoyant force = weight of object

$$B = m_{object}*g = \rho_{object}*V_{object}*g$$

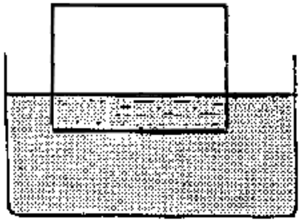
But we also have:

buoyant force B = weight w of the displaced water

$$B = m_{displaced\_water}*g$$

$$m_{displaced\_water} = \rho_{water}*¼V_{object}$$

$$B = \rho_{water}*¼V_{object}*g$$

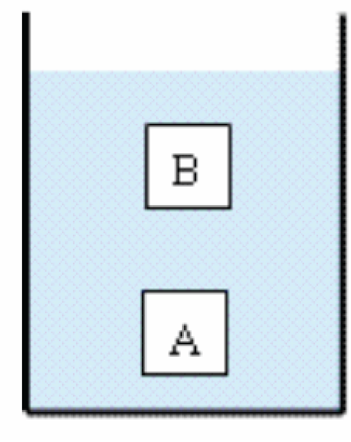


Setting the two expressions for B equal to each other:

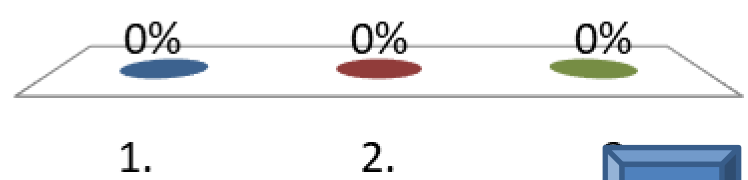
$$\rho_{object}*V_{object}*g = \rho_{water}*¼V_{object}*g$$

$$\rho_{object} = ¼\rho_{water}$$

Two objects, A and B, have the same volume and are completely submerged in a liquid, although A is deeper than B. Which object, if either, experiences the greater buoyant force?



1. Object B, because the closer an object is to the surface, the greater is the buoyant force.
2. Both objects experience the same buoyant force.
3. Object A, because, being at a greater depth, it experiences a greater pressure.



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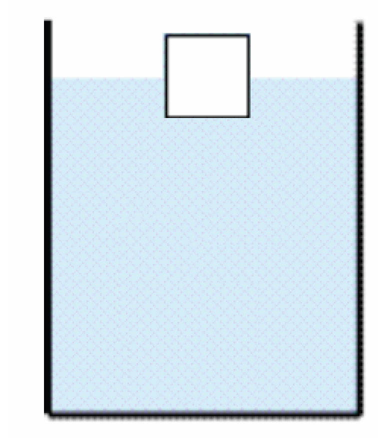
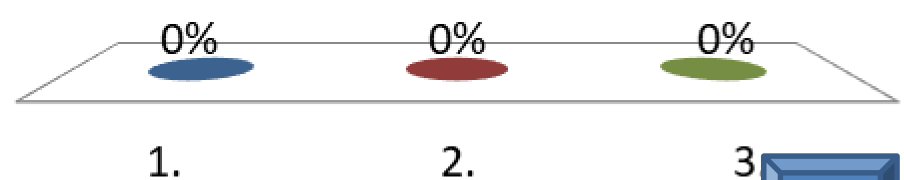
Consider a block of wood floating on water. If you push down on the top of the block until it is completely submerged, the buoyant force on it



1. increases.
2. decreases.
3. remains the same.



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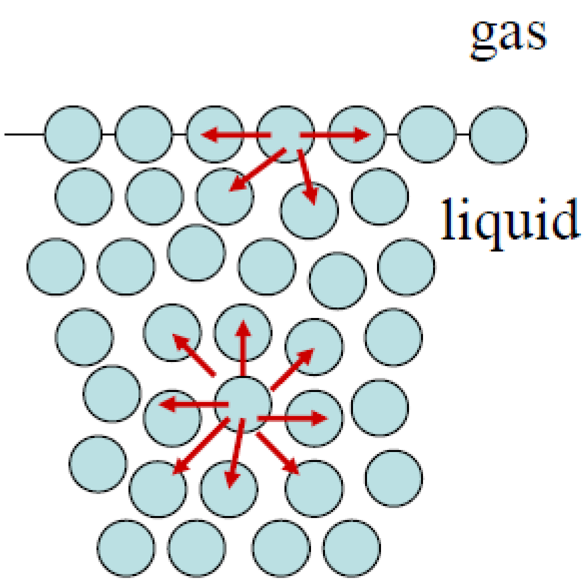
Surface tension

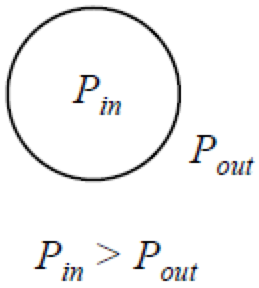
Cohesion, or attraction between molecules of the same kind leads to surface tension.

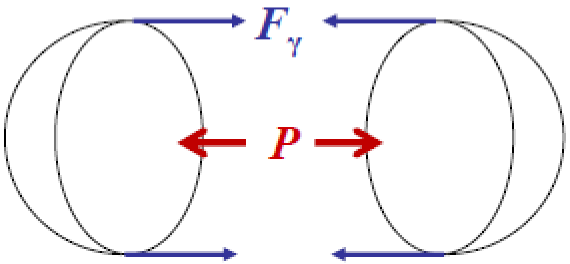
The surface tension γ is defined as the force along a line of unit length.

$\gamma = F/L$ (N/m)

Laplace's law for a single spherical membrane in equilibrium: $P_{in} - P_{out} = 2\gamma/r$

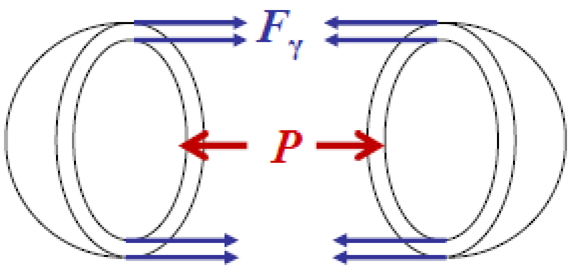






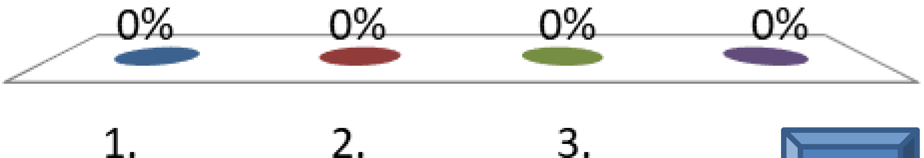
The smaller a soap bubble, the higher is the pressure inside.

A soap bubble with radius of 3.0 cm is floating in air. What is the pressure difference across the two surfaces of the bubble?
The surface tension of soapy water is $\gamma = 69 * 10^{-3}$ N/m.



Hint:
$P_{in} - P_{out} = 2\gamma/r$ for a single surface.
Here we have two surfaces.

1. 9.2 N/m^2
2. 2.6 N/m^2
3. $8.3*10^{-3}$ N/m^2
4. $9.2*10^{-2}$ N/m^2



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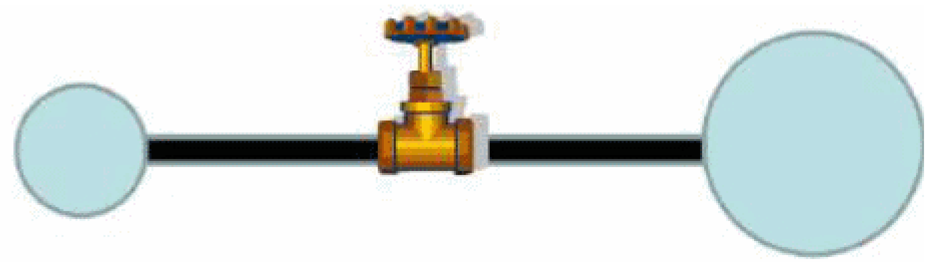
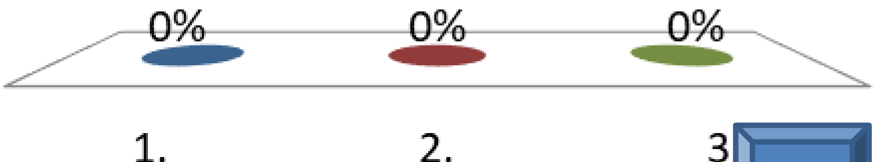
Two bubbles are connected by a hollow tube plus a valve. What will happen once the valve between the two is opened?



Remember:
The smaller a soap bubble, the higher is the pressure inside.

1. The small bubble will drain into the big bubble.
2. The big bubble will empty into the small bubble until the two are equal in size.
3. Nothing will happen – the bubbles will stay the same size.



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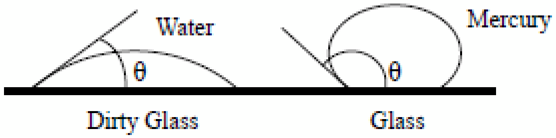
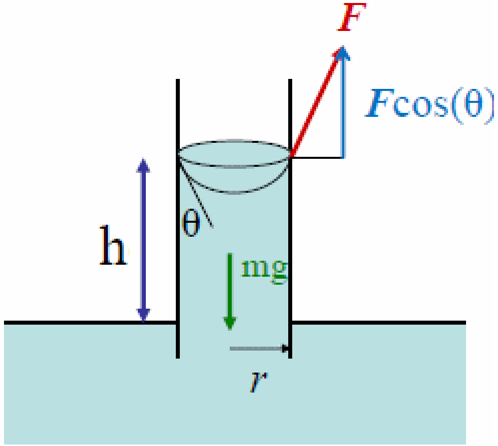
Capillary action

- Adhesion is the attraction between unlike molecules.
- Adhesive and cohesive forces determine the contact angle between a liquid and a solid surface.
- Adhesion and surface tension together can produce capillary action.
- The maximum height to which a liquid will rise through capillary action is given by $h = 2\gamma\cos\theta/(\rho g r)$.





$$h = \frac{2\gamma\cos\theta}{\rho g r}$$

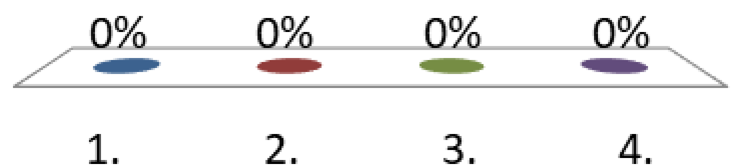
Derivation:

$mg = (F/L)\cos\theta\, 2\pi r$ (net force = 0)

$\rho\pi r^2 h\, g = \gamma\cos\theta\, 2\pi r$ (solve for h)]

In an experiment water rose by capillary attraction through two columns of soils, one with coarse grains (column 1) and the other with fine gains (column 2).
In which column did the water rise to greater height?

1. column 1
2. column 2
3. It rises to the same height in both columns.
4. It is impossible to tell.



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Blood and water have the same contact angle with glass. The density of blood is 5% higher than that of water. ($\rho_{blood} = 1.05\ \rho_{water}$)

While you make your capillary action measurements you find that water rises in the same tube a factor 1.69 higher than a blood sample.
The surface tension of water at the same temperature is 0.073 N/m. What is the surface tension of the blood sample?

Hint: $h = 2\gamma\cos\theta/(\rho g r)$
$h_1/h_2 = (\gamma_1\cos\theta_1\rho_2 r_2)/(\gamma_2\cos\theta_2\rho_1 r_1)$ Here $\theta_1 = \theta_2$ and $r_1 = r_2$.
Let substance 1 be water and substance 2 be blood.

1. 0.045 N/m
2. 0.117 N/m
3. 0.073 N/m