Physics 221, March 2

Key Concepts:

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

Definitions

Fluids:

Liquids → Incompressible

Gases → Compressible

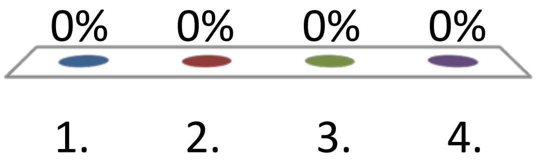
Particle density: $\rho_{particle} = N/V$

Density: $\rho = M/V$

Pressure: $P = F/A$

A metal body of mass 38.8 g occupies a volume of 2 cm^3. Identify the metal.

1. Lead with density = 11.4 g/cm^3 .
2. Tungsten with density = 19.4 g/cm^3
3. Iron with density = 7.9 g/cm^3
4. Aluminum with density = 2.7 g/cm^3



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Hydrostatics

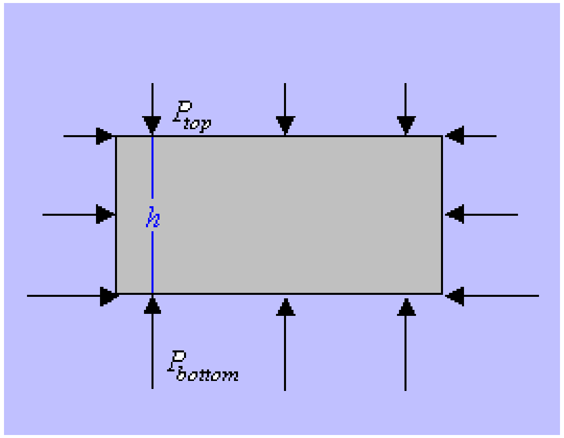
Hydrostatics (liquids at rest):

(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)

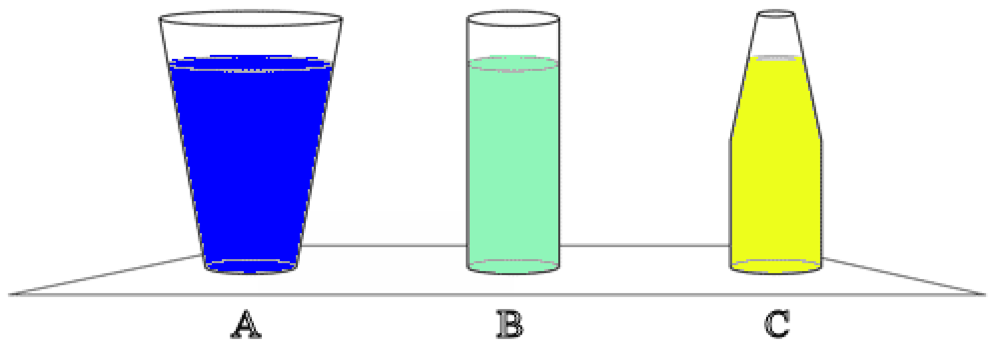
Note: ρ_{water}*g*(10 m) ~ (1000 kg/m^3)*(10 m/s^2)*(10 m) = 100 kPa

Pascal's law:

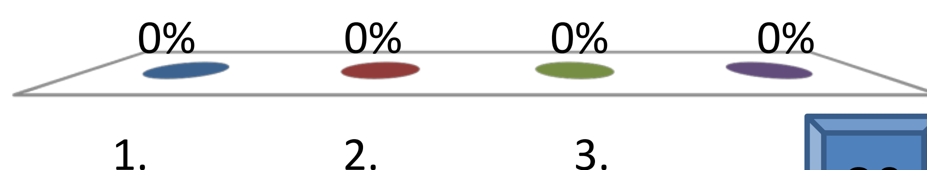
Any change in the pressure at the surface is transmitted to every point in the liquid.

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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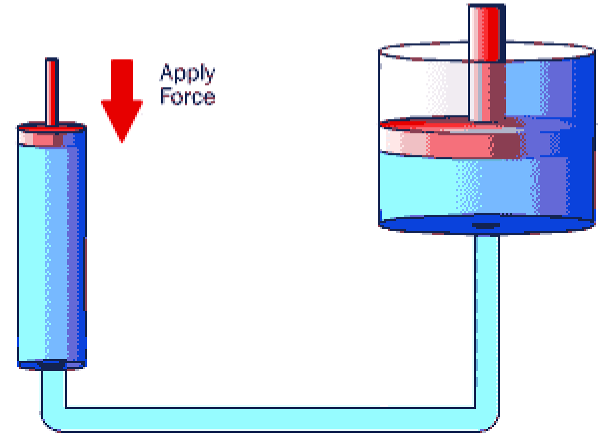
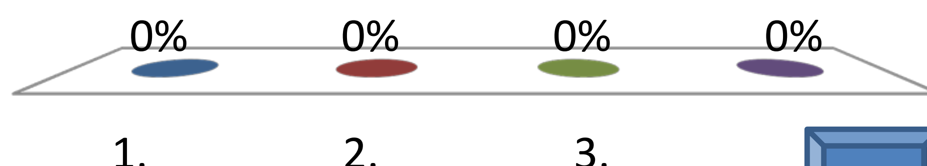
The brake system in most cars makes use of a hydraulic system. This system consists of a fluid filled tube connected at each end to a piston. Assume that the piston attached to the brake pedal has a cross sectional area of one half a square inch and the piston attached to the brake pad has a cross section area of two square inches. When you apply a force of 10 pounds to the piston attached to the brake pedal, the force at the brake pad will be



1. 5 pounds.
2. 10 pounds.
3. 20 pounds.
4. 40 pounds.



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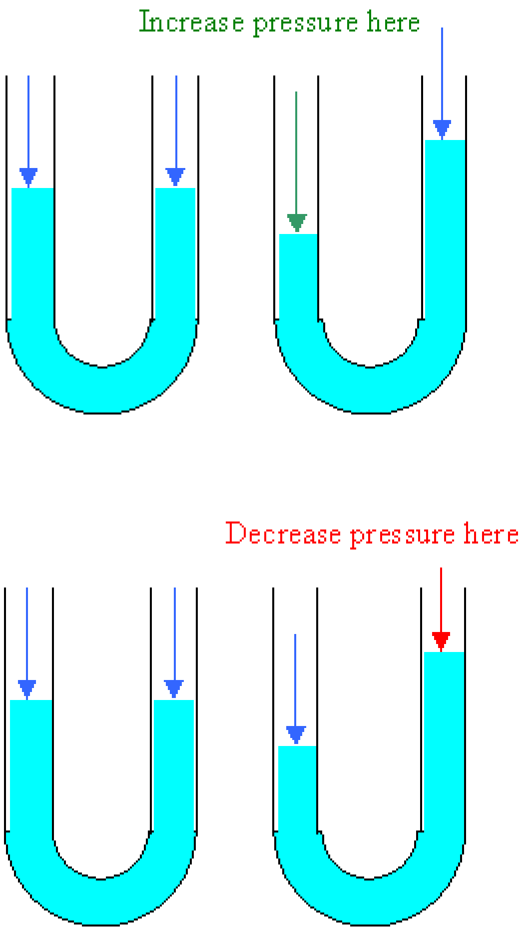
Pumps

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.

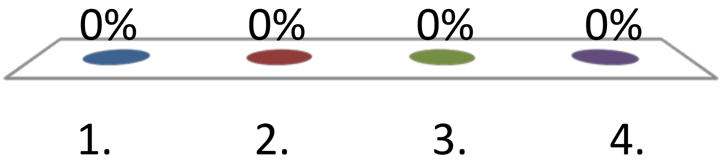
How high a column of water can you support?



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)?

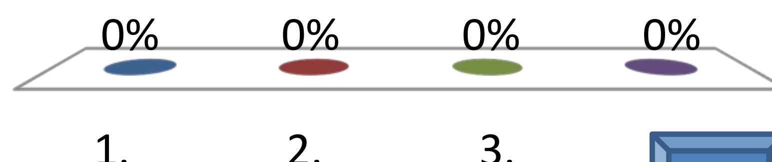
In saturated salt water (1200kg/m^3)? Explain!

Demonstration:

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

The density of freshwater is 1 g/cm^3 and the density of seawater is 1.03 g/cm^3. A ship will float

1. at the same level in freshwater as in seawater.
2. higher in freshwater than in seawater.
3. higher, lower, or at the same level in freshwater as in seawater, depending on its shape.
4. lower in freshwater than in seawater.



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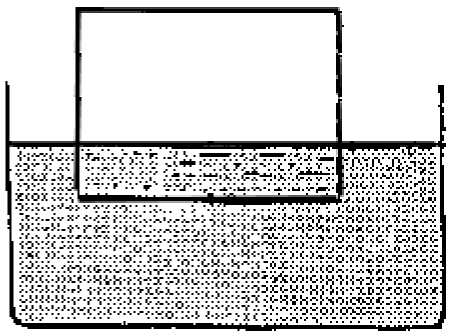
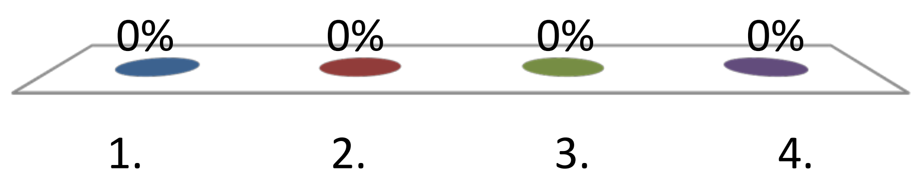
A block of wood of uniform density floats so that exactly ¼ of its volume is underwater. What is the density of the block?



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

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

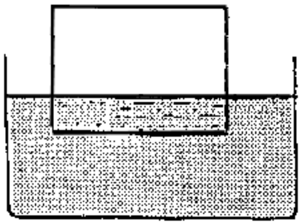
But we also have:

buoyant force B = weight w of the displaced water

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

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

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

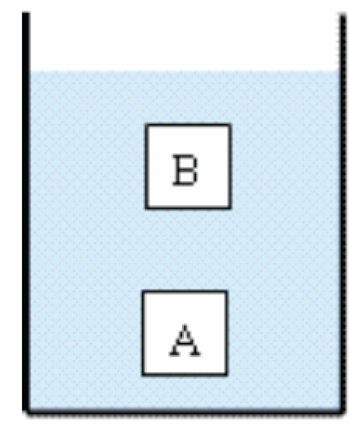


Setting the two expressions for B equal to each other:

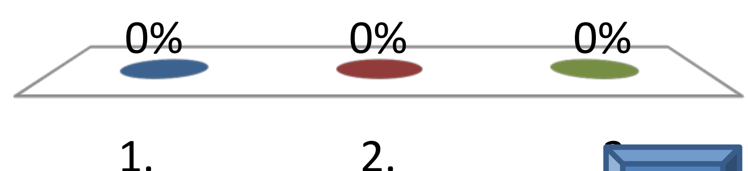
$$\rho_{object} * V_{object} * g = \rho_{water} * ¼V_{object} * g$$

$$\rho_{object} = ¼\rho_{water}$$

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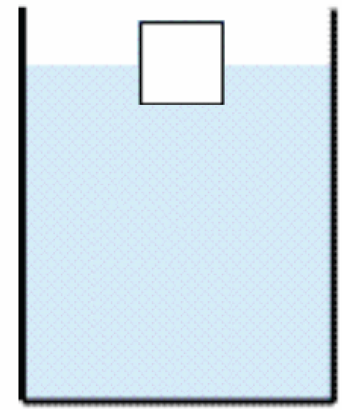
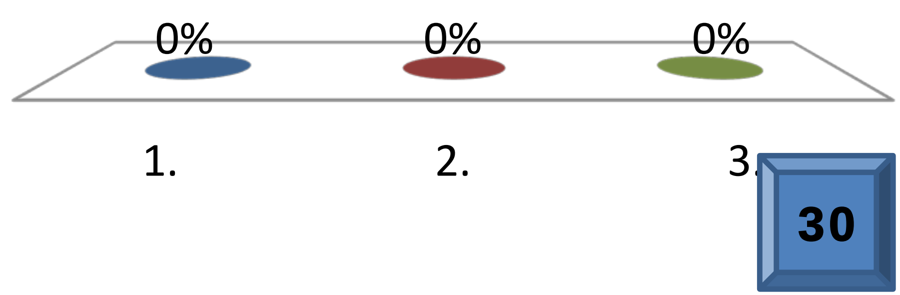
Consider a block of wood floating on water. If you push down on the top of the block until it is completely submerged, the buoyant force on it



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



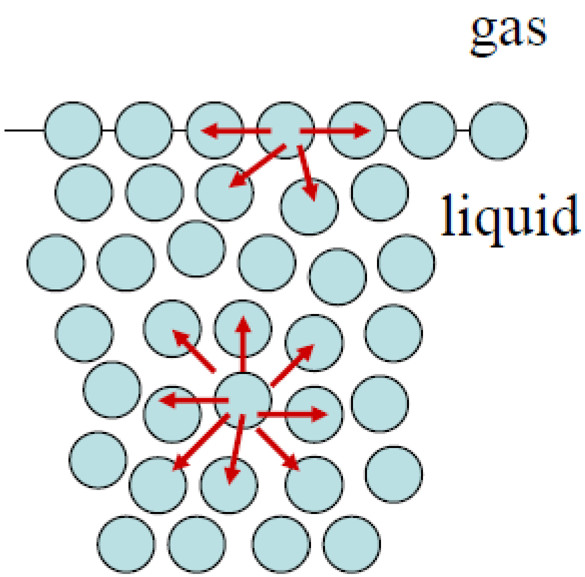
Surface tension

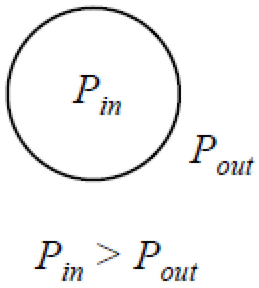
Cohesion, or attraction between molecules of the same kind leads to surface tension.

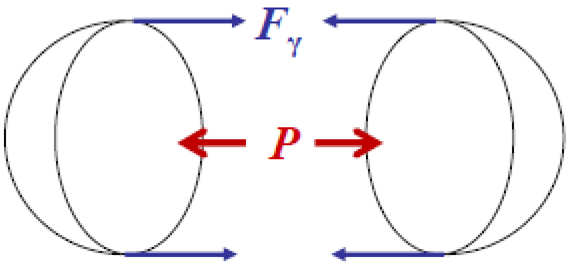
The surface tension γ is defined as the force along a line of unit length.

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

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







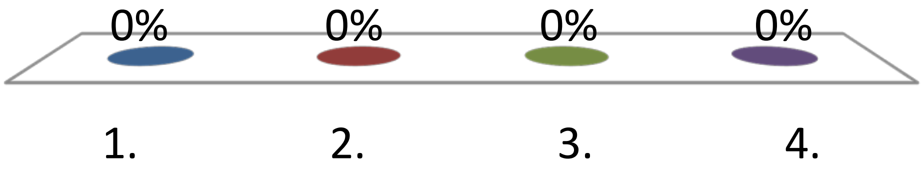
The smaller a soap bubble, the higher is the pressure inside.

Mercury has an unusually large surface tension $\gamma = 0.465$ N/m. Calculate the excess pressure inside a drop of mercury 4 mm in diameter.

Hint:

$P_{in} - P_{out} = 2\gamma/r$

1. 0.23 Pa
2. 465 Pa
3. 233 Pa
4. 1.23 kPa



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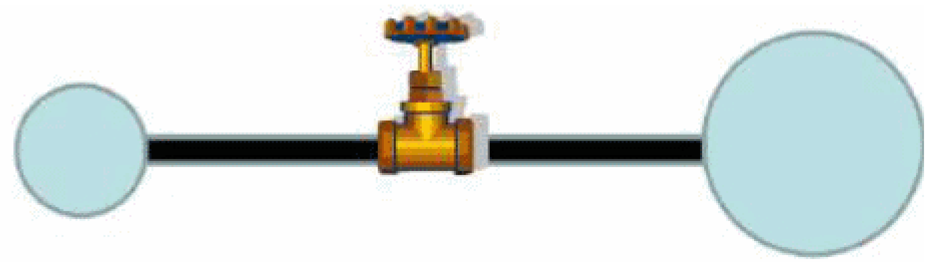
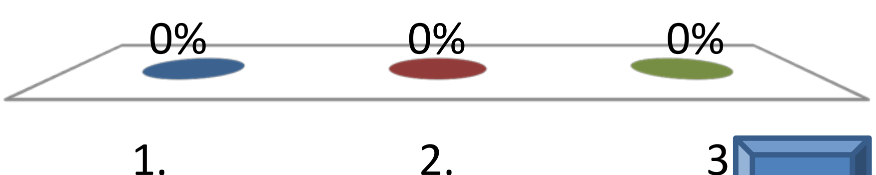
Two bubbles are connected by a hollow tube plus a valve. What will happen once the valve between the two is opened?



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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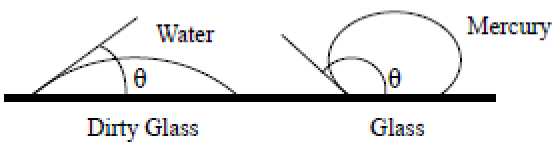
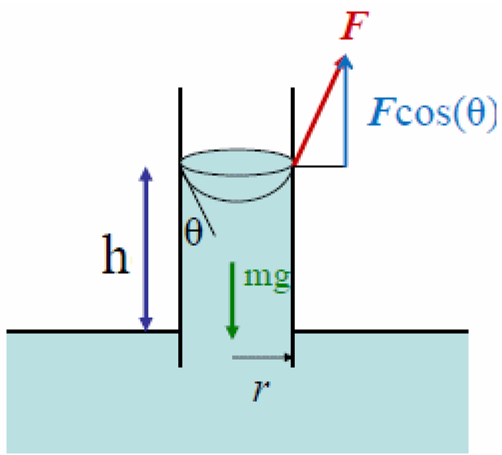
Capillary action

- 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)]

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