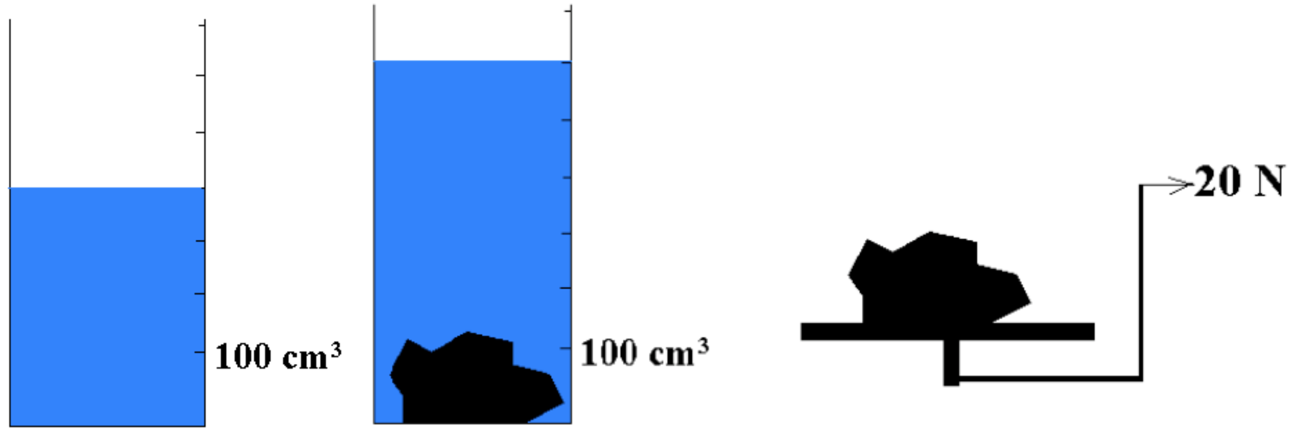
Work Together

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



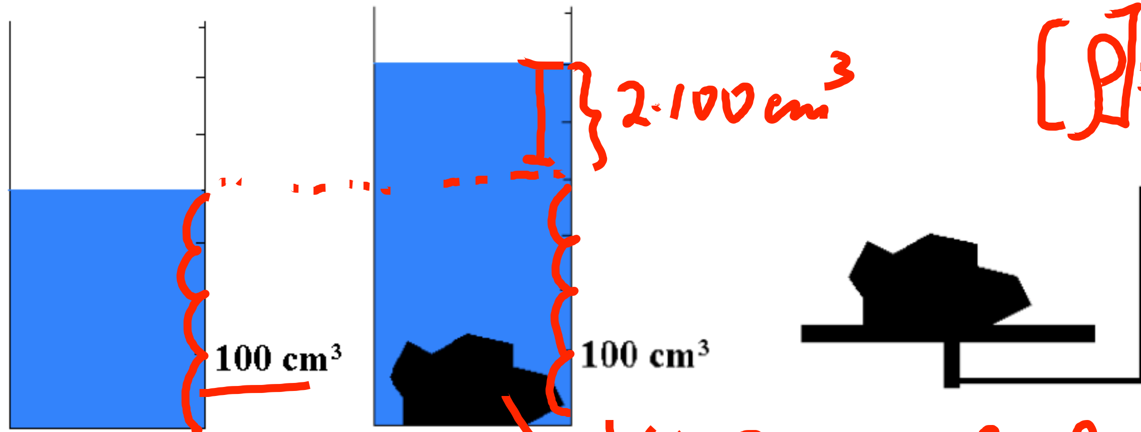
Use the readings shown in the picture and g = 10 m/s² and try to find the average density of the object on the scale.

(kg/m³)

1. 10^3 2. 10^4 3. 10^5 4. ...

Work Together

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



Use the readings shown in the picture and $g = 10\ m/s^2$ and try to find the average density of the object on the scale.

(kg/m^3)

1. 10^3 2. 10^4 3. 10^5 4. …

$$\rho = \frac{2\ kg}{2 \cdot 10^{-4}\ m^3} = 10^4 \frac{kg}{m^3}$$

Fluid's mechanics

To describe how much matter (or how many elementary particles) there are on average in the medium the physical quantity *Density* is used.

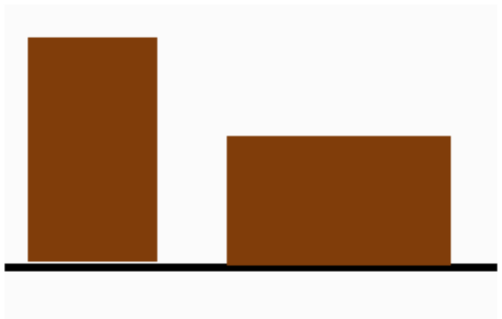
Density (ro) $\rho = \dfrac{m}{V}$ (kg/m^3)

Some Densities

Material (or object)	Density (kg/m^3)
Air (20^{0}C and 1 atmosphere)	1.21
Water (4^{0}C and 1 atmosphere)	1000
Iron	7900
Mercury (the metal)	13600
Earth (the planet, on average)	5500

PRS

Pressure $P = \frac{F}{A}$



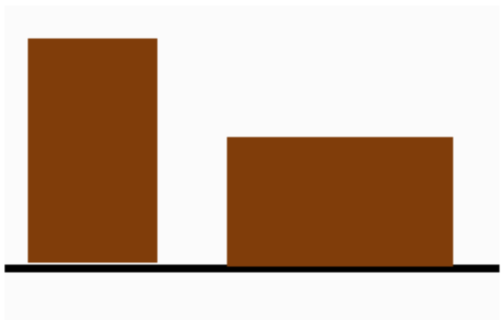
The same force vs. different area!

Which of the two identical blocks (see the picture) exerts a higher pressure on the table?

1 the vertical block
2 the horizontal block
3 the pressure is the same
4 impossible to answer

PRS

Pressure $P_V = \frac{F_V}{A_V}$ $P_H = \frac{F_H}{A_H}$



$F_V = F_H$ $A_V < A_H$ => $P_V > P_H$

(Here, A is the area of the face touching the table)

Which of the two identical blocks (see the picture) exerts a higher pressure on the table?

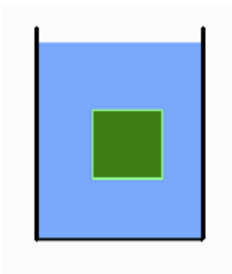
The blocks are identical, i.e. have the same mass, hence exert the same force on the table. But the vertical block has smaller area of contact, hence its pressure is greater.

A) the vertical block

Properties of media and Objects in a medium

Pressure and Density

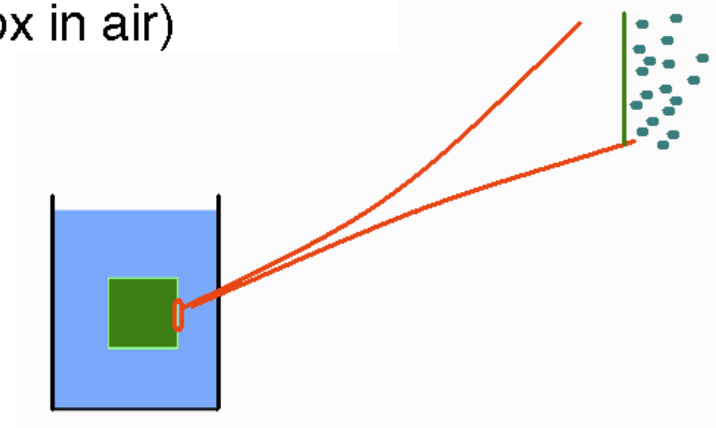
A medium is a substance made of tiny particles, so tiny that we treat the substance as continues.



An object in a liquid.

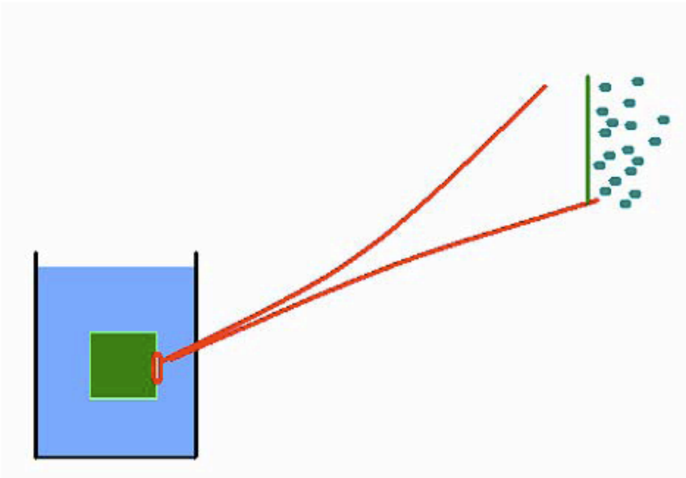
(A box in water; a box in air)

The same object seen with a help of a strong microscope.



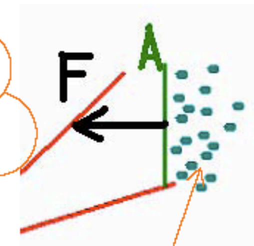
The blue dots represent atoms or molecules of the medium which constantly hit the object creating an average force on it.

Pressure



To describe the force acting from the fluid on the object the physical quantity PRESSURE is used.

Pressure $P = \frac{F}{A}$



The SI unit for pressure is the pascal.
$1\ Pa = 1\ N/m^2$

Some other units:

$1\ atm = 1.01 \times 10^5\ Pa = 14.7\ lb/in^2 = 760\ torr = 760\ mm\ Hg$

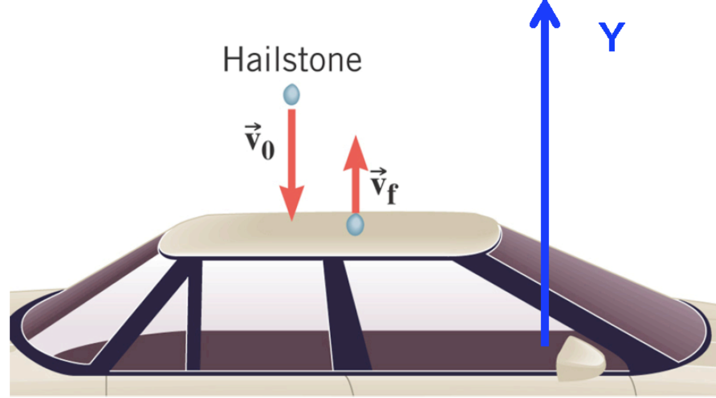
psi = pounds/(square inch) = lb/in^2

1 torr = 1 millimeter of mercury = 1 mm Hg.

Can we connect the motion of particles and pressure?

(A mechanical model)

The net force on a hailstone is related to the change in the momentum as



$$\overline{\vec{\mathbf{F}}}\Delta t = m\vec{\mathbf{v}}_f - m\vec{\mathbf{v}}_o$$

Force on hail stones

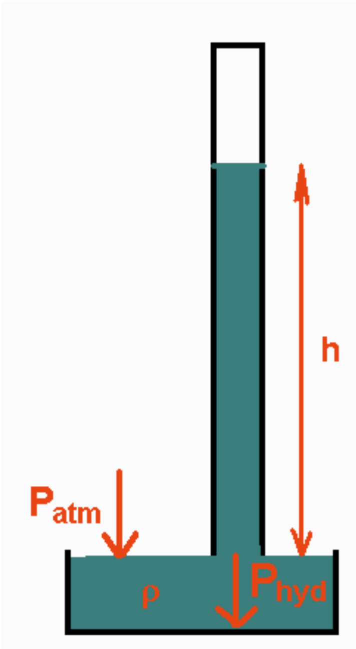
$$\Rightarrow \overline{\vec{\mathbf{F}}} = \left(\frac{m\vec{\mathbf{v}}_f - m\vec{\mathbf{v}}_o}{\Delta t}\right) = \left(\frac{m}{\Delta t}\right)\vec{\mathbf{v}}_f - \left(\frac{m}{\Delta t}\right)\vec{\mathbf{v}}_o$$

$$\overline{\vec{\mathbf{F}}} = (0.060\,\text{kg/s})(15\,\text{m/s}) - (0.060\,\text{kg/s})(-15\,\text{m/s}) = +1.8\ \text{N}$$

Force from hail stones on the roof has the same magnitude!

$$P = \frac{F}{A} = \frac{1.8}{2} = 0.9\,Pa$$

Measuring Pressure



A standard mercury barometer to measure atmospheric pressure is a tube with one end sealed.

The sealed end is close to zero pressure, while the other end is open to the atmosphere. The pressure difference between the two ends of the tube can maintain a column of fluid in the tube, with the height of the column being proportional to the pressure difference.

$$P_{atm} = P_{hyd} = \rho g h$$

1 atm = 1.01×10^5 Pa = 14.7 lb/in^2 = 760 torr = 760 mm Hg

1 torr = 1 millimeter of mercury = 1 mm Hg

Atmospheric Pressure

Air is a fluid (gas).

At the sea level atmospheric pressure is:

$$1 \text{ atm} = 1.013 \times 10^5 \text{ Pa}$$

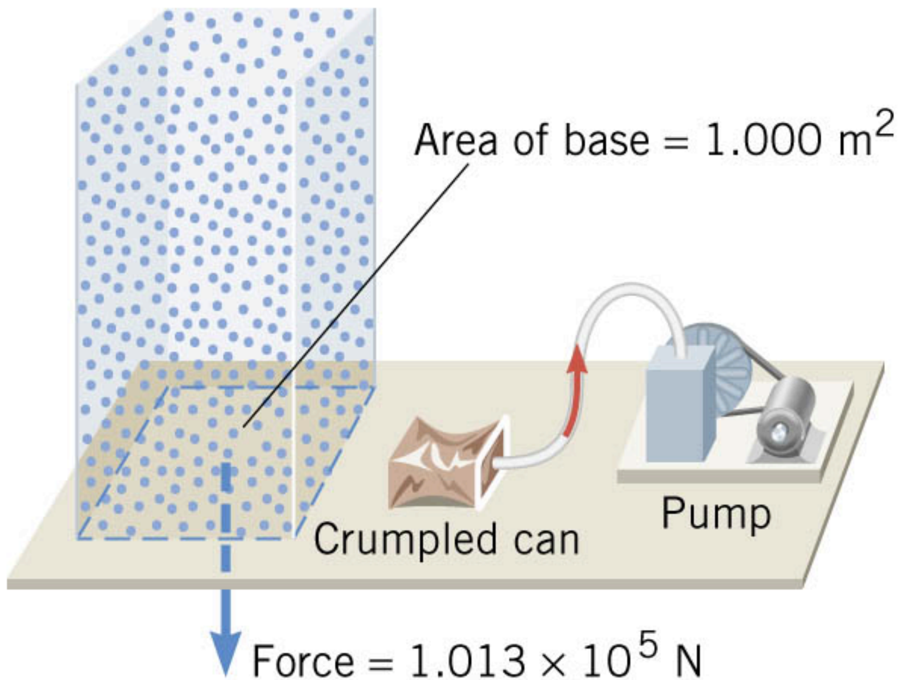
This is an average value, and the pressure fluctuates somewhat. In good weather the pressure is higher than average and in bad weather it is lower than average.

Every square meter feels a force of over 100,000 N from the weight of all the air above it. This is a huge force, so why don't things (including ourselves) collapse from the force?

There's usually air on all sides of an object (from inside as well as outside), so for the most part the forces balance.

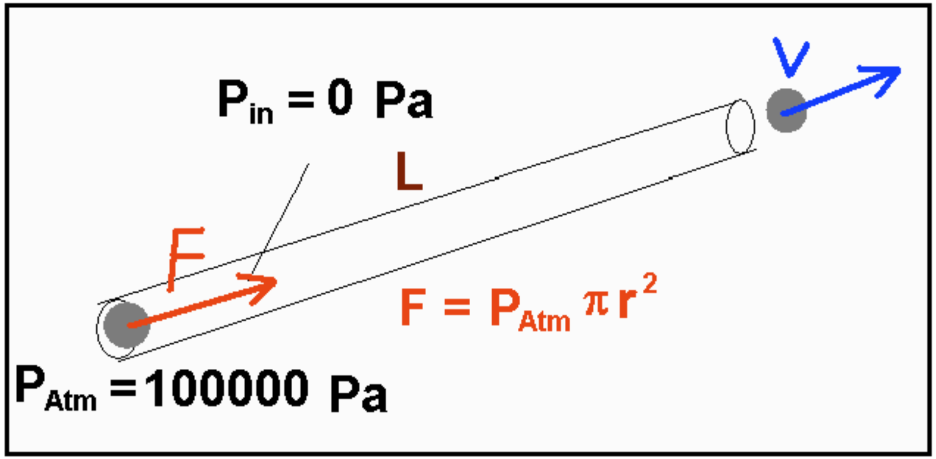
Crush the Can

Atmospheric Pressure at Sea Level: 1.013×10^5 Pa = 1 atmosphere



Scary Physics

Air cannon



$r \approx 1.5$ cm $\quad m \approx 4$ gram $\quad L \approx 3$ m

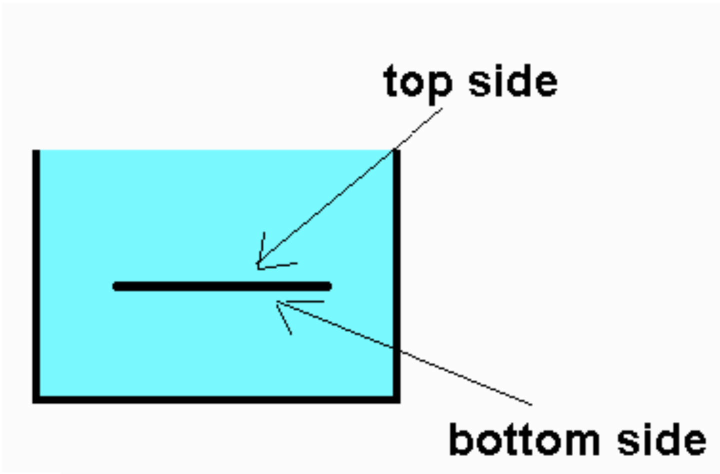
$A \approx 0.0007\ m^2 \quad F \approx 70$ N

$a = F/m \approx 17662\ m/s^2$

$v = \sqrt{[2La]} \approx 325$ m/s

Almost the seed of sound in the air!

Pressure in a medium



A plate is immersed into a medium.

Which side experiences the higher pressure?

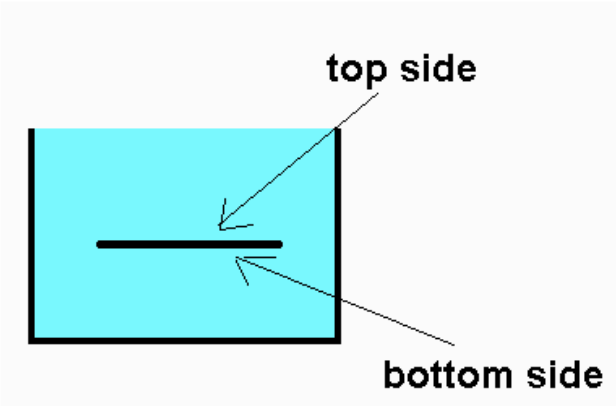
1 the top side

2 the bottom side

3 the pressure is equal

4 hard to say

Pressure in a medium



A plate is immersed into a medium.

Which side experiences the higher pressure?

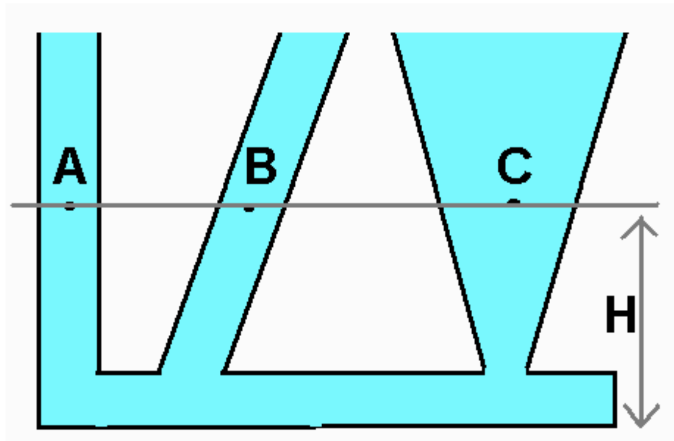
The liquid is not moving (a static liquid, hence all the pressure can be produced only by the motion of the particles moving randomly in all directions)

The plate is so thin so we treat it as it has no thickness.

Both side are located *at the same level* in the liquid, hence there is no reason for the pressure being different.

C) the pressure is equal

$P_h = P_A + \rho g h$ $\quad P = \dfrac{F}{A}$

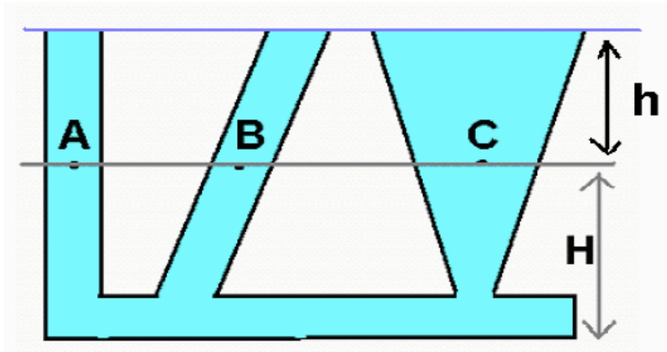


Points A, B and C are located at the same height from the surface of the table. At which pint the pressure is the greatest?

1) A 2) B 3) C 4) the pressure is the same

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

$$P_h = P_A + \rho g h$$



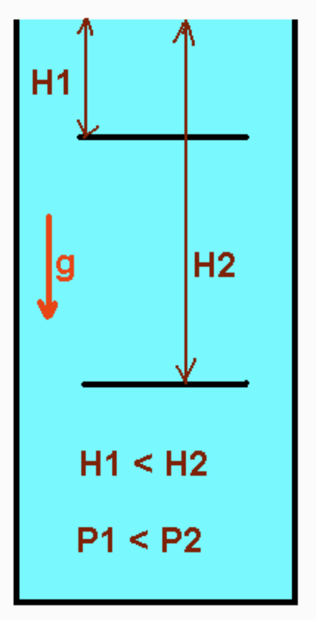
Points A, B and C are located at the same height from the surface of the table. At which pint the pressure is the greatest?

Pressure in *a static fluid* depends ONLY on the level *h*!

E) the pressure is the same

If we had the pressure at the same levels being different, the difference in the pressure would lead for the liquid being into a motion!!!

Pressure in a medium



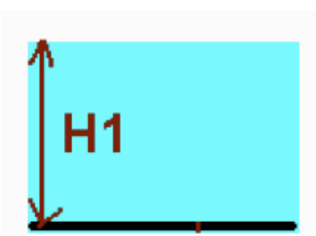
The lower the level is (deeper in fluid), the more is the pressure provided by the fluid.

The reason is the force of gravity acting on the liquid.

The top plate has less fluid above it then the bottom plate!

The amount of the fluid acting on the bottom plate.

The amount of the fluid acting on the top plate.



$$P = \frac{F_{mg}}{A}$$

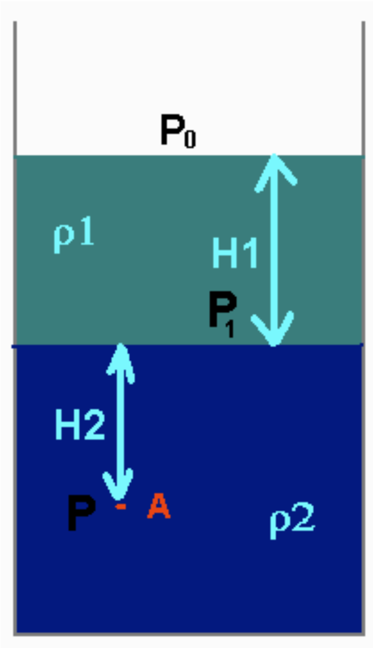
$$P = \frac{mg}{A} = \frac{\rho V g}{A}$$

$$P = \frac{\rho A h g}{A} = \underline{\rho g h}$$

gauge pressure

$$P_h = P_A + \rho g h$$

Two (or more) liquids



To find the pressure at the point A we can consider liquids by layers (starting from the lowest point).

The pressure at the point A can be found as

$$P_A = P_1 + \rho_2 g h_2$$

But the pressure P_1 can be found as

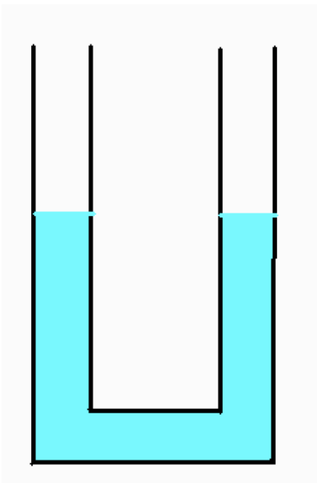
$$P_1 = P_0 + \rho_1 g h_2$$

Hence: $P_A = P_0 + \rho_1 g h_1 + \rho_2 g h_2$

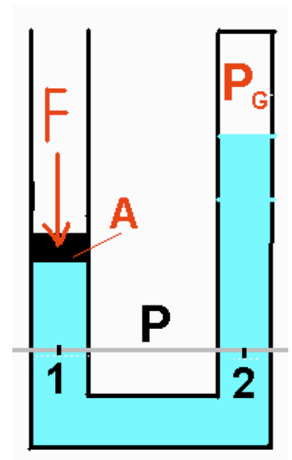
Pascal's Principle

Pressure applied to an enclosed fluid is transmitted undiminished to every part of the fluid, as well as to the walls of the container.

The liquid in an open vessel has the same level every tube.



Now we seal one of the tubes and put a piston into another in and push it down.



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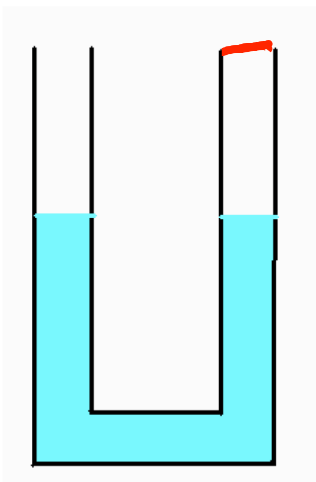

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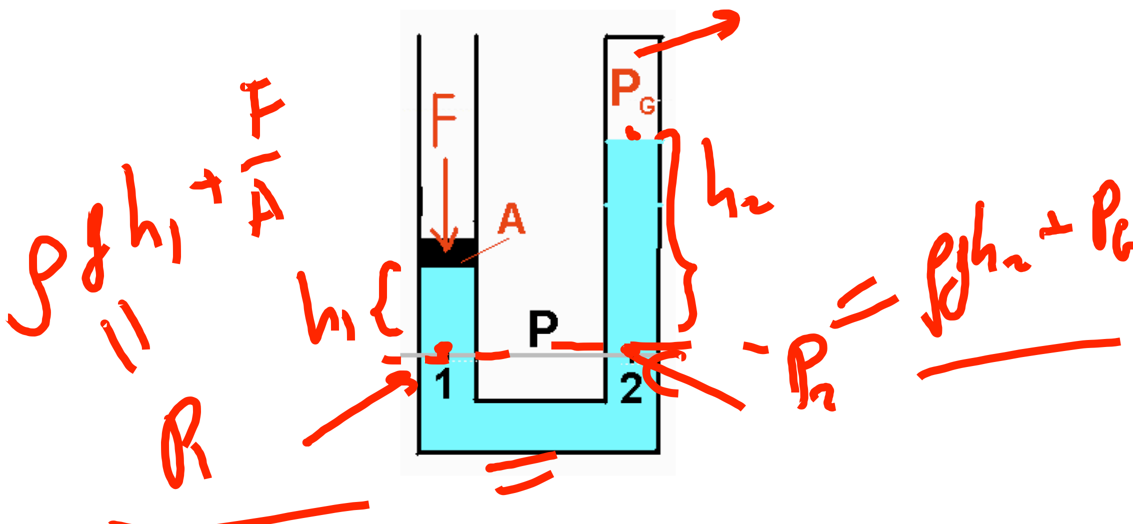
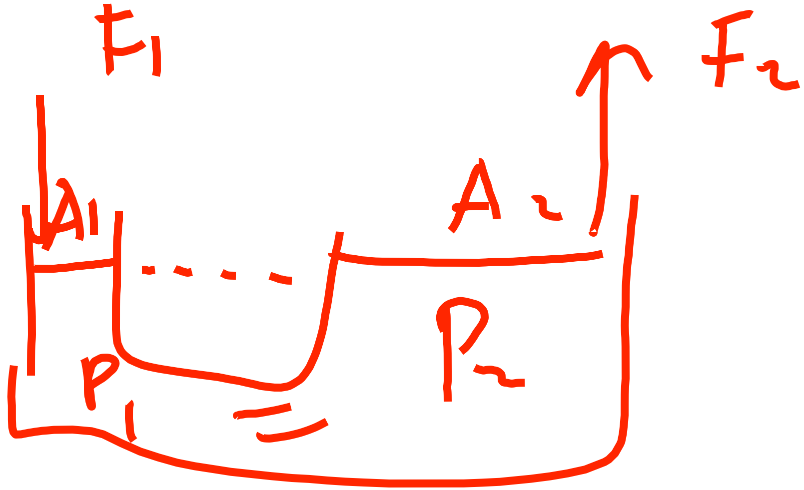


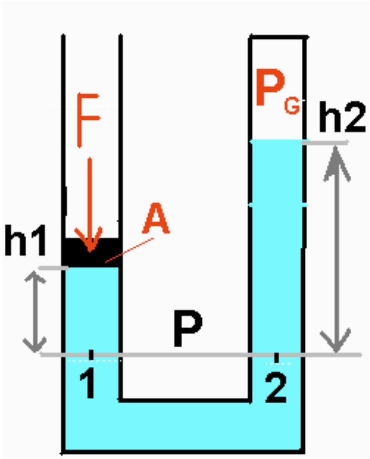
That is because the liquid is *static!*



$$P_1 = P_2$$

$$\Downarrow$$

$$\frac{F_1}{A_1} = \frac{F_2}{A_2} \; ; \quad F_1 \cdot \frac{A_2}{A_1} = F_2$$



The pressure applied by the force F is transmitted to every part of the fluid.

$$P_F = F/A$$

For the point 1 we can write $P = P_F + \rho g h_1$

The pressure P_g applied by the gas stored in the right tube also is transmitted to every part of the fluid.

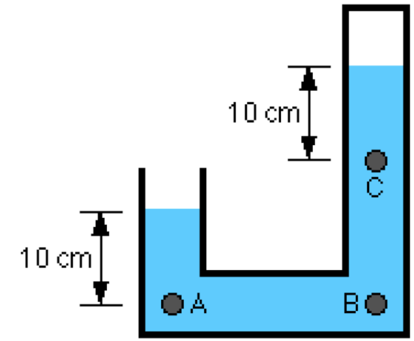
For the point 2 we can write $P = P_G + \rho g h_2$

Because the point 1 and 2 are at the same level

$$P_F + \rho g h_1 = P_G + \rho g h_2$$

Question

A container, closed on the right side but open to the atmosphere on the left, is almost completely filled with water, as shown. Three points are marked in the container. Rank these according to the pressure at the points, from highest pressure to lowest.



1) A = B = C

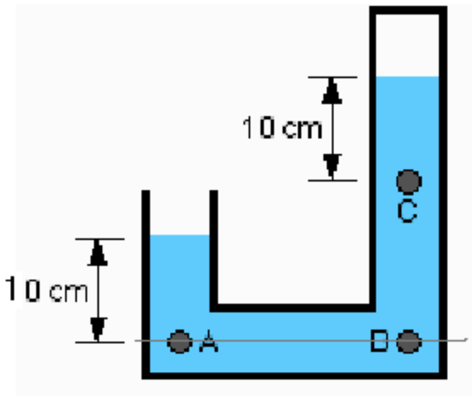
2) A = B > C

3) A > B = C

4) A > B > C

5) some other order

Question



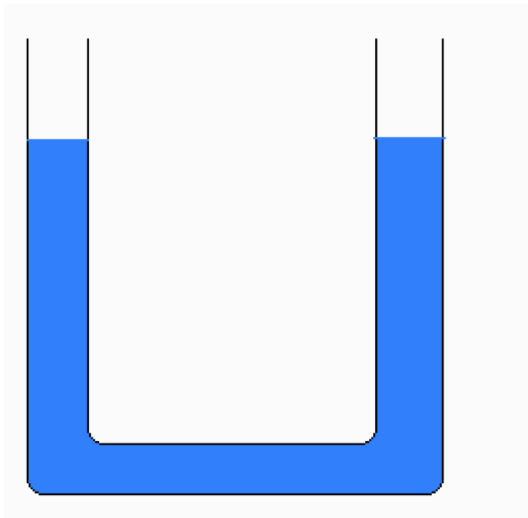
The liquid is not moving (static); hence the pressure at the points located the same level is the same.

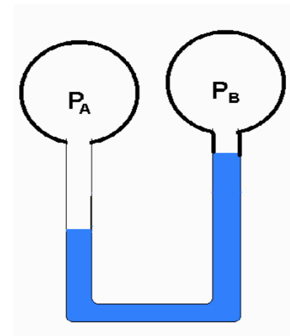
$P_A = P_B$ (otherwise the liquid would be moving form one point to another)

But the point B (as well as the point A) is located deeper than the point C, hence $P_B > P_C$ (the point B has an additional amount of liquid relative to the point C)

Hence, $P_A = P_B > P_C$ or 2 A = B > C

Question



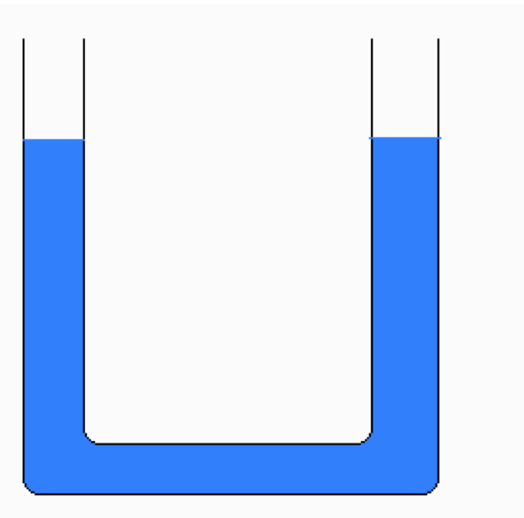


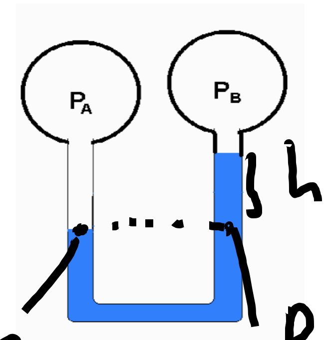
Liquid in the U-shaped tube is at rest.
When two chambers are attached to the ends of the tube, the new equilibrium is reached.

In which chamber the pressure is higher?

1) $P_A = P_B$ 2) $P_A < P_B$ 3) $P_A > P_B$ 4) **Hard to say**

Question





$P_A = P_1 = P_2 = P_B + \rho g h$

$P_A > P_B$

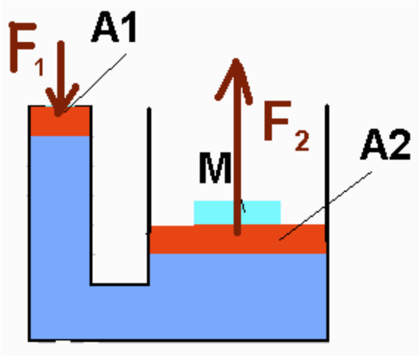
Liquid in the U-shaped tube is at rest.
When two chambers are attached to the ends of the tube, the new equilibrium is reached.

In which chamber the pressure is higher?

C) $P_A > P_B$

Hydraulic Lift

SIM



A very heavy object of mass M sits on the piston of the area A_2

To lift the object we apply the force F to the small piston with the area A_1

The pressure $P_1 = F_1/A_1$ produced by the force is transmitted to every part of the fluid, including the second piston. This pressure (exerted by the force) is normally much higher then the gauge pressure of the liquid itself.

Hence, we can say that this exactly pressure pulls the large piston up.

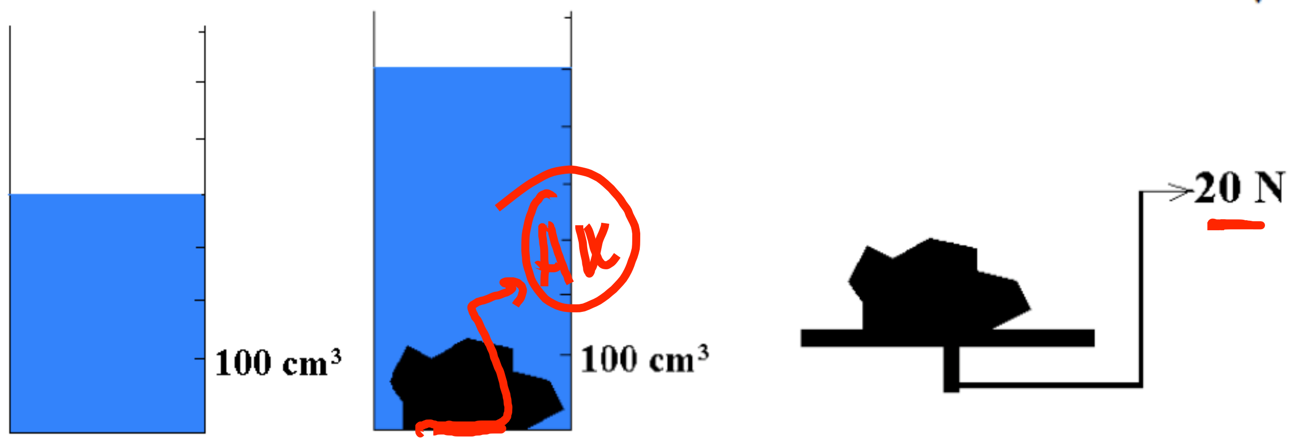
Hence, $F_1/A_1 = \mathbf{P_1} = \mathbf{P_2} = F_2/A_2$

This leads to $$F_2 = F_1 \frac{A_2}{A_1}$$

If we make the second piston large enough, the force F_2 might be very strong.

Work Together

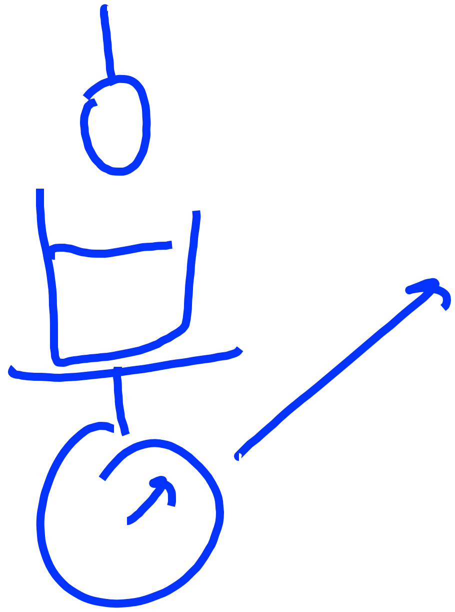
$$\rho = \frac{m}{V}$$



Use the readings shown in the picture and $g = 10\ m/s^2$ and try to find the average density of the object on the scale.

1. AK = 20 2. AK > 20 3. AK < 20

When measured in water, would be the apparent weight of this rock 20 N again?

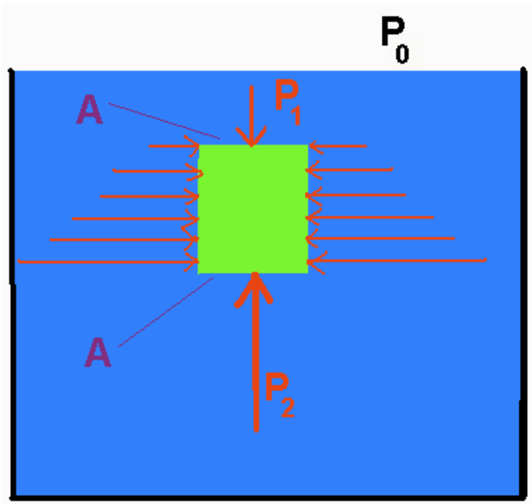


1. =

2. <

3. >

The buoyant force



Let's consider an object immersed into a liquid.

The liquid exerts a pressure on each face of the object.

All the horizontal arrows cancel each other out!

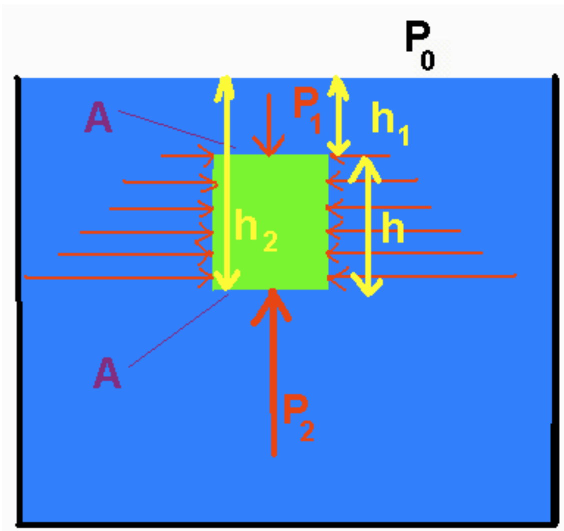
Only the pressure at the top face P_1 and the pressure at the bottom face P_2 are unbalanced!

These two pressures create the forces $F_1 = P_1 * A$ and $F_2 = P_2 * A$.

The net force acting on the object from the liquid has the magnitude of $F = F_2 - F_1$ and directed straight up.

This force pushes the object upward and is called *a buoyant force.*

The buoyant force (mathematically)



$$F_1 = P_1 * A$$

$$F_2 = P_2 * A$$

The buoyant force

$$F_b = F_2 - F_1$$

Hence,

$$F_b = P_2 * A - P_1 * A = (P_2 - P_1) * A = \Delta P * A$$

$$\Delta P = P_2 - P_1 = (P_0 + \rho g h_2) - (P_0 + \rho g h_1) = \rho g (h_2 - h_1) = \rho g h$$

so

$$F_b = \rho g h * A$$

But $h * A = V_{\text{of-the-object-in-the-liquid}}$ and $\rho = \rho_{\text{liquid}}$

$$\mathbf{F_b = \rho_{liquid} g V_{of\text{-}the\text{-}object\text{-}in\text{-}the\text{-}liquid}}$$

Something to Remember

The question:

"What is the total pressure acting on the object?"

does *not* make any sense!!!

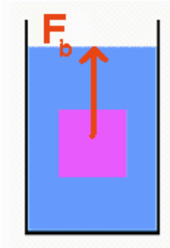
We can ask instead:

"What is the (total) force acting on the object?"

or

"What is the pressure at this point or level?"

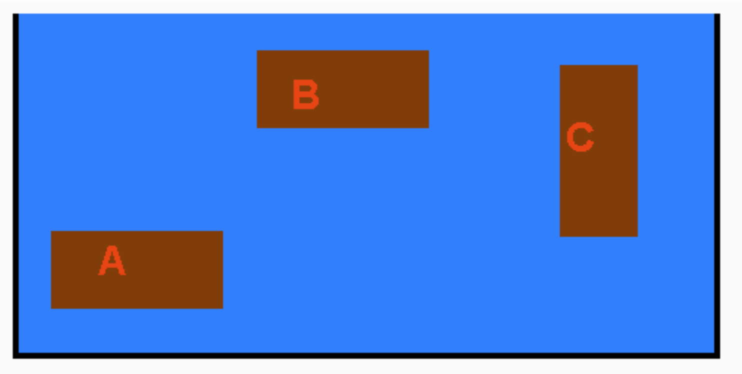
The buoyant force



$$F_b = \rho_{liquid} g V_{of\text{-}the\text{-}object\text{-}in\text{-}the\text{-}liquid}$$

The density ρ_{liquid} is the density of the fluid.

The volume $V_{of\text{-}the\text{-}object\text{-}in\text{-}the\text{-}liquid}$ here is the entire volume of that part of the object which is immersed into the liquid.

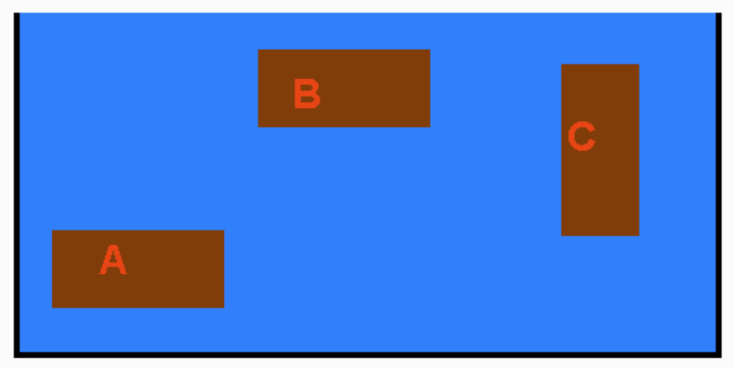


Three identical blocks are immersed into a liquid.

Which experience larger buoyant force?

1 A 2 B 3 C

4 the buoyant force is the same



Three identical blocks are immersed into a liquid.

Which experience larger buoyant force?

$$F_b = \rho_{liquid} g V_{of\text{-}the\text{-}object\text{-}in\text{-}the\text{-}liquid}$$

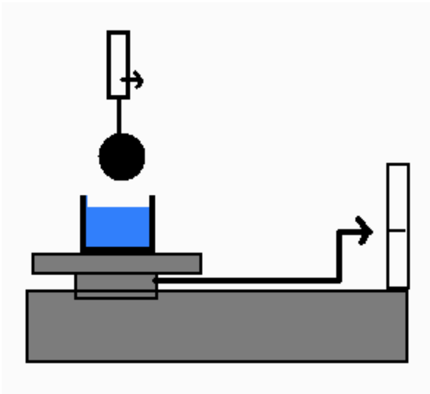
Density of the liquid around the blocks is the same. (the height is almost the same!)

The volume of the immersed into the liquid objects is the same.

the buoyant force is the same

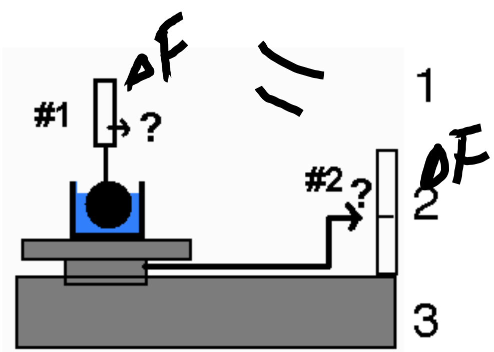
Beaker on a scale

A beaker of water sits on a scale.



Compare the reading on the scales:

Which of the scales show the bigger change?



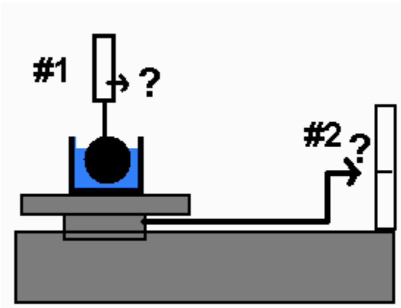
1 The scale #1

2 The scale #2

3 The scales show the same change

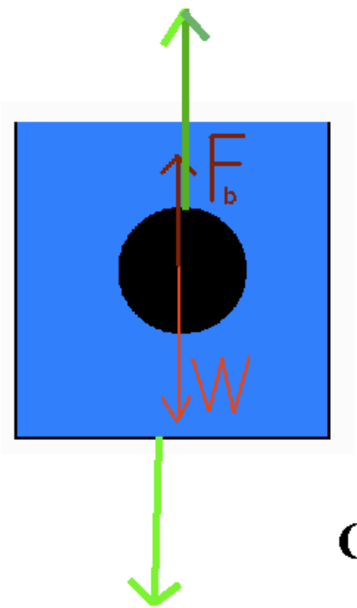
4 Inpossible to answer

Beaker on a scale



A beaker of water sits on a scale.

Which of the scales has the bigger change?



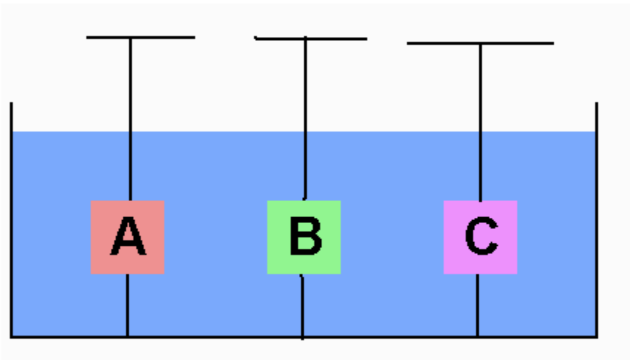
The buoyant force (*force acting on the object from the liquid*) decreases the reading of the scale #1.

By the Newton's III Law, *exactly same additional force* is acting from the object on the liquid, and, hence, on the scale #2.

C) The scales show the same change

When an object of density ρ_o is immersed into a fluid (liquid or gas) of density ρ_l, only three situations are possible:

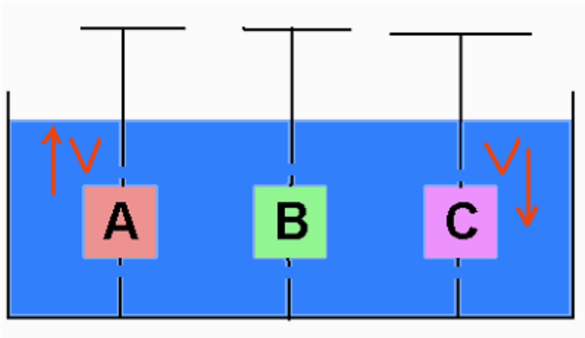
$\rho_o < \rho_l$ $\rho_o = \rho_l$ $\rho_o > \rho_l$



Question

Three objects are immersed into a liquid and are kept at rest by the strings (see the picture).

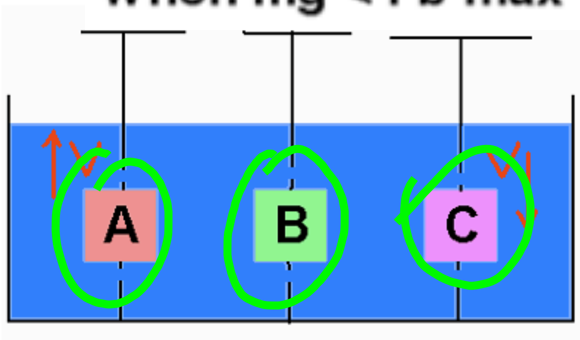
If we cut of all the strings, the object A floats up, the object B stays motionless, the object C sinks down.



Which of the objects has the greatest density?

1 A
2 B
3 C
4 The liquid has

When mg < Fb max - floats   When mg > Fb max - sinks



Let's start from the object B.

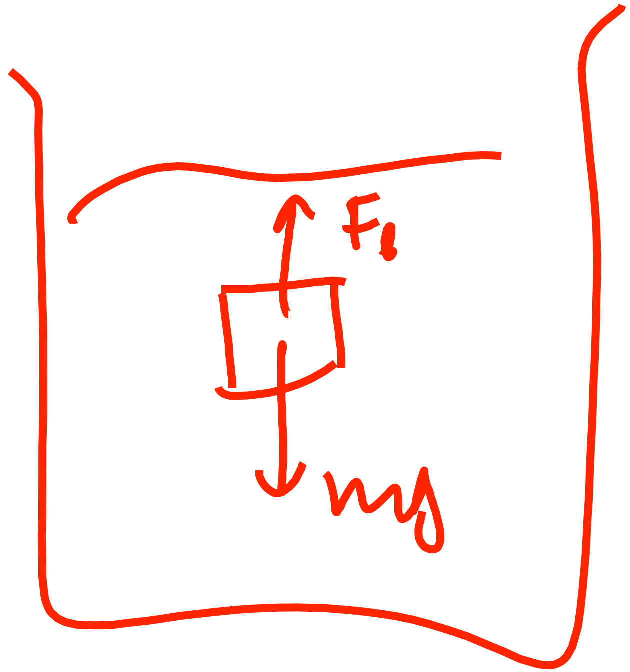
It is not moving even when it is free, exactly like the rest of the liquid; hence its density is equal to the density of the liquid $\rho_B = \rho_l$

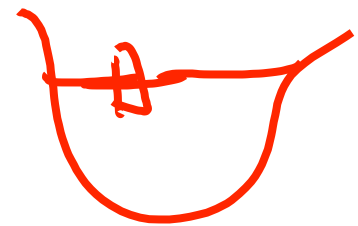
The block C sinks, hence its density is $\rho_C > \rho_l$, hence $\rho_C > \rho_B$.

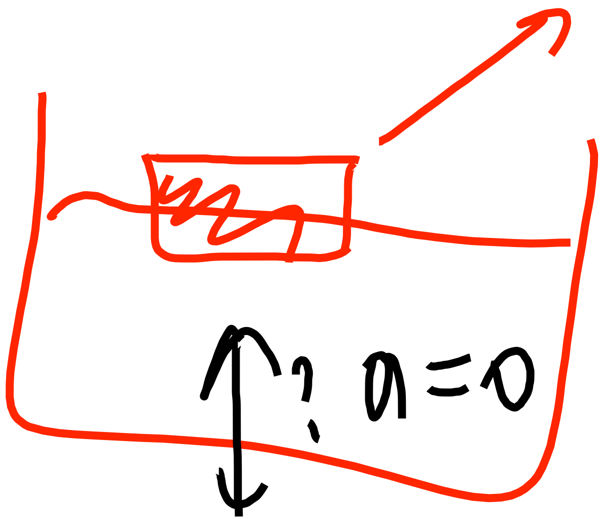
The block A floats up, hence $\rho_A < \rho_l$, hence $\rho_A < \rho_B$.

Now we see that $\rho_A < \rho_B < \rho_C$; **The bock C has the greatest density**.

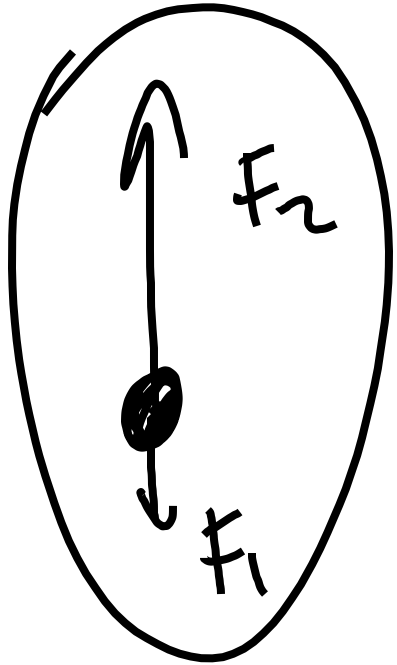
$F_B > mg$







1. $F_{\ell} > mg$
2. $F_{\ell} < mg$
3. $F_{\ell} = mg$
4.



1. ↑ $a \neq 0$
2. →
3. ←
4. ↓
5. ◠