

PHY 117 HS2026

Today:

Fluids
Pressure
Pascal's principle
Hydraulic lifts
Barometers
Manometers
Hydrometers
Archimedes' principle
Buoyant force

Week 5, Lecture 1

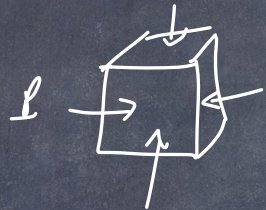
Oct. 13th, 2026

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Last time, we learned a bit about pressure and that fluids are hard to compress.

If we apply a pressure to a substance of volume V , it gets compressed by some amount ΔV .



we can define the Bulk modulus, B , to describe how much a substance resists compression.

$$B \equiv \frac{-P}{\frac{\Delta V}{V}}$$

If ΔV is large, then B is small.

The $(-)$ sign keeps B positive. (when you compress, ΔV is $(-)$)

gases: highly compressible
 $\Delta V_{\text{large}} \rightarrow B$ very small
 (depends on temp.)

liquids + solids: B is large because it is hard to compress them.

materials

iron
 lead
 → water
 air

B [GPa = 10^9 Pa]

100

8

2

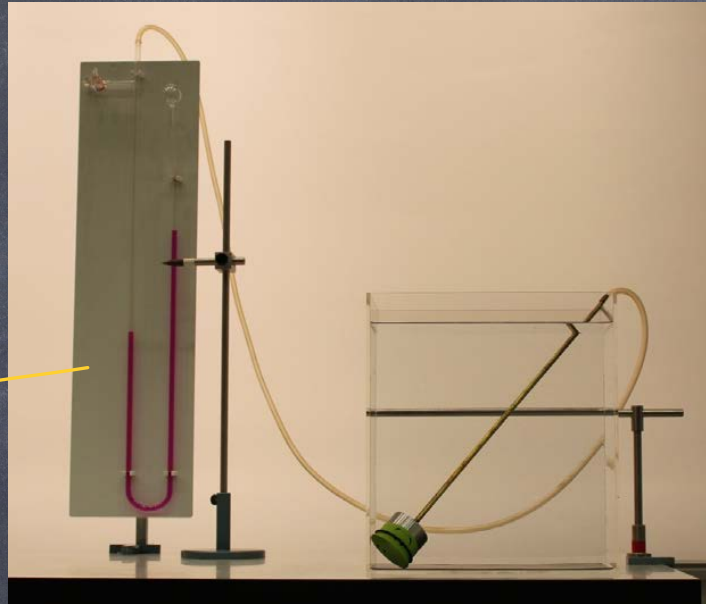
~ 0.0001

It takes 2000 N of force to make

1 cm^3 of water 1% smaller.

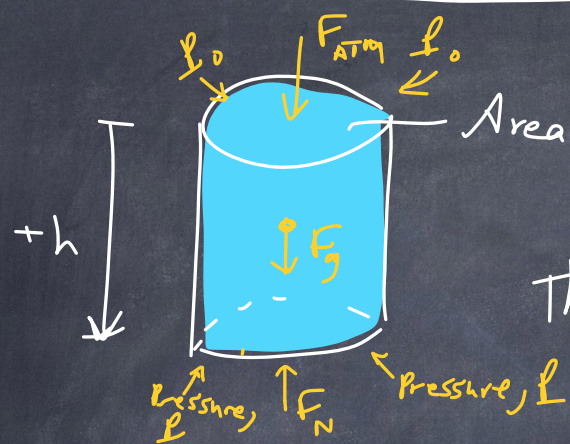
we can experimentally test how pressure changes according to depth in water.

U-tube
manometer
with immersion
probe



we can understand pressure in a fluid using the balance of forces. $P = \frac{F}{A}$

What is pressure in a fluid (starting with forces)?



- cylinder, closed at bottom, open on top.

$$\text{Volume} = V = \underbrace{A}_{\text{Area}} \cdot \underbrace{h}_{\text{height}}$$

The mass of the fluid is $M = \rho \cdot V$
 The weight of the fluid: $F_g = Mg = \rho A h g$

ρ ← density V ← volume

The atmosphere pushes down with $F_{ATM} = P_0 A$
 The normal force pushes up, F_N .

We can balance the forces:

$$F_N = F_g + F_{ATM}$$

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

$$P \cdot A = \rho A h g + P_0 A$$

$$P = P_0 + \rho g h$$

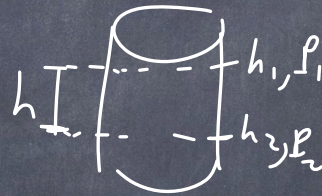
hydrostatic pressure equation

ρ : density of fluid
 g : gravity
 h : height of fluid
 P : pressure at bottom
 P_0 : pressure at top, atm. pressure

So pressure is greater as we get deeper.

But pressure is the same at all points with the same depth, pointing in all directions

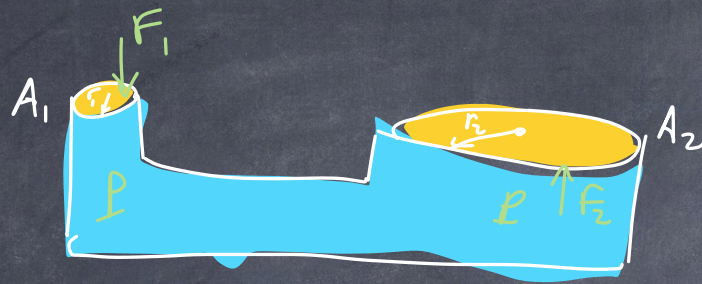
$$P_2 - P_1 = \Delta P = \rho g h$$



Pascal's principle: A pressure increase applied to an enclosed fluid is transmitted to every point in the fluid (and the walls) undiminished.

↑
same value

This is used in a hydraulic lift.



yellow disks slide up
& down
(pistons)

P is increase in pressure.

The force F_1 provides an increase in pressure on the small piston, this pressure increase is transmitted to the big piston, resulting in a different force on the large piston.

$$P = \frac{F_1}{A_1} = \frac{F_2}{A_2}$$

we can lift a heavy weight
with a light force.

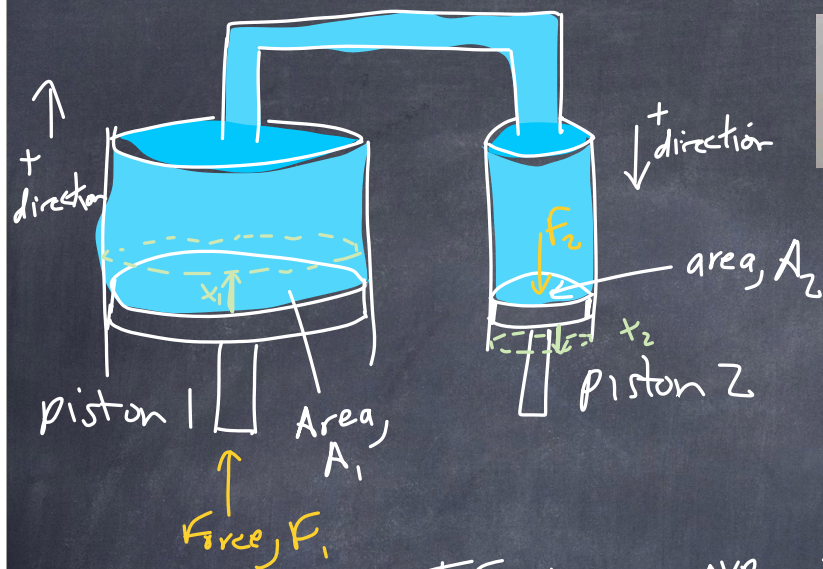
Let's say we want to lift a car with mass 1500 kg
(15000 N)

$$r_1 = 0.1 \text{ m}, r_2 = 4 \text{ m}$$

What force do we need to lift the car?

How can this be:

what about energy conservation?



pistons: freely moving
tightly fitting

Applying a force F_1 and
it pushes the other
piston with F_2

$$P = \frac{F_1}{A_1} = \frac{F_2}{A_2}$$

$$\boxed{\frac{F_1}{F_2} = \frac{A_1}{A_2}} \quad (1)$$

If we move the larger piston 1 a distance x_1 ,
how far does the smaller piston move?
(we can use work to solve this)

work done on fluid by piston 1: $W_1 = +F_1 x_1$

work done on fluid by piston 2: $W_2 = -F_2 x_2$

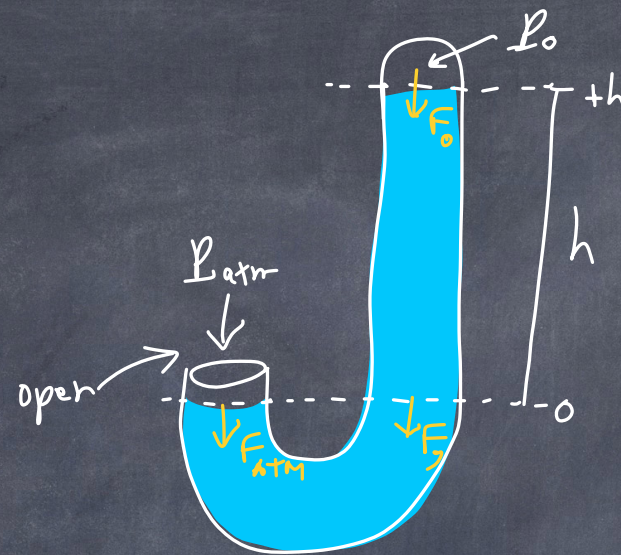
$$W_1 + W_2 = 0 \rightarrow F_1 x_1 + -F_2 x_2 = 0$$

(-) because
work is done
on piston 2

$$\rightarrow x_2 = x_1 \frac{F_1}{F_2} \text{ using } (1) \rightarrow x_2 = x_1 \frac{A_1}{A_2}$$

piston 2 moves
more by the ratio
of A_1 to A_2

U-tube
barometer
measures
 P_{atm}



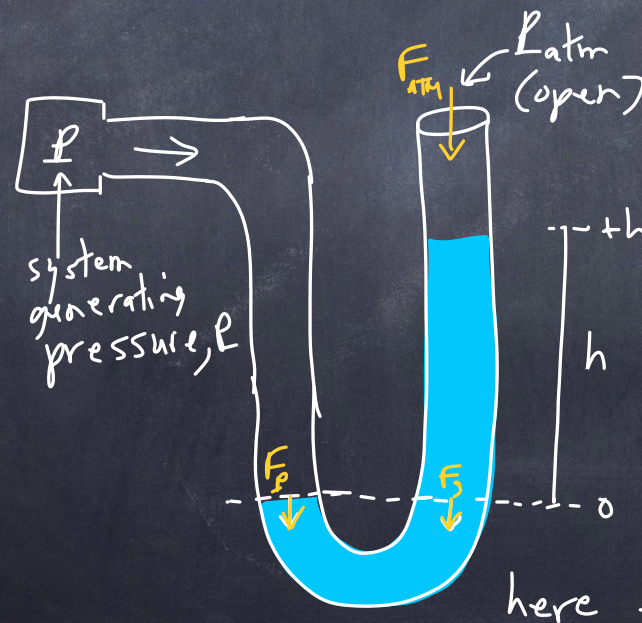
(vacuum or very small pressure)
 $P_{atm} = P_0 + \rho g h$

$$P_{atm} - \cancel{P_0} = \rho g h$$

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

$P_{atm} \propto$ height of the fluid.

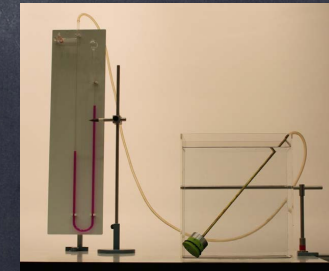
open-tube
manometer
measures
 P



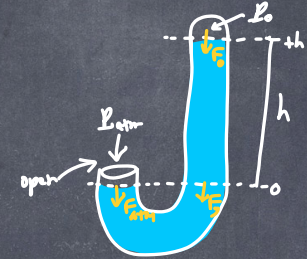
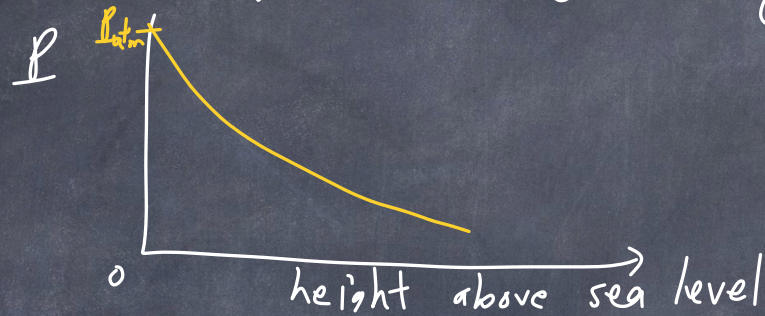
$$P = P_{atm} + \rho g h$$

$$P - P_{atm} = \rho g h$$

$P \propto$ height of the fluid.



Atmosphere : $P_{atm} = P_{at} / atm$
 can push up height of 10.3 m water (into evacuated tube)
 can push up Hg by 760 mm
 (Mercury more practical)



Below sea level

more precisely,
 $1 atm \rightarrow 10.35 m$
 of water depth

under water

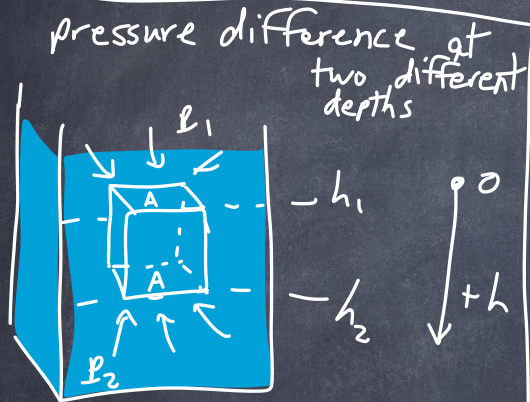


0 m, $P_{sea level} = 1 atm$

-10 m, $P_{-10m} = 2 atm$

-20 m, $P_{-20m} = 3 atm$

Archimedes principle: Body submerged in a fluid (partially or completely) is forced upward by a buoyant force that is equal to the weight of the fluid that is displaced.



$$p_2 > p_1 \quad p_2 = p_1 + \rho g h$$

ρ : density of fluid

$$p_2 - p_1 = \rho g h \quad (1)$$

There is a force due to the pressure difference.

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

use (1) * Area:

$$(p_2 - p_1) A = (\rho g h) A$$

$$F_2 - F_1 = (\rho g)(h A) = \rho g V_d$$

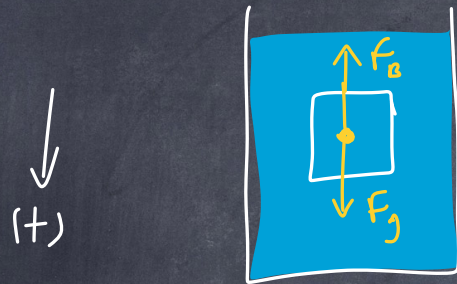
V_d : is the volume of the fluid displaced by the object.

If an object is fully submerged, then the volume of the object is the same as V_d .

The fluid pressure difference causes an upward force called the buoyant force:

$$F_2 - F_1 = F_B = \rho g V_d$$

Consider the buoyant force + the force of gravity



$$F_B = \rho_L g V_L$$

$$F_g = m_o g = \rho_o V_o g$$

m_o : mass of object ρ_o : density of object

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

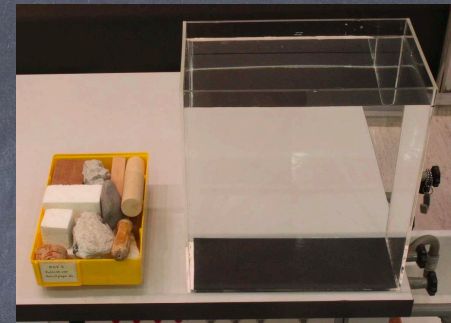
$$m_o = \rho_o V_o$$

here, $V_o = V_L = V$
because fully submerged.

$$\Sigma F = F_g - F_B = (\rho_o - \rho_L) g V$$

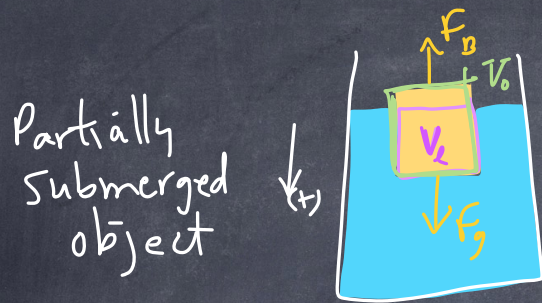
IF $\rho_o > \rho_L$, then $\Sigma \vec{F}$ points down. (+)
It sinks.

IF $\rho_o < \rho_L$, then $\Sigma \vec{F}$ points up. (-)
It floats.



GAME: WILL IT FLOAT?!

How much of the object is submerged?



V_e : volume of liquid that is displaced

V_o : volume of object

$$F_B = \rho_e g V_e$$

$$F_g = \rho_o g V_o$$

At equilibrium, $\Sigma F = 0 = F_g - F_B$ $F_g = F_B$

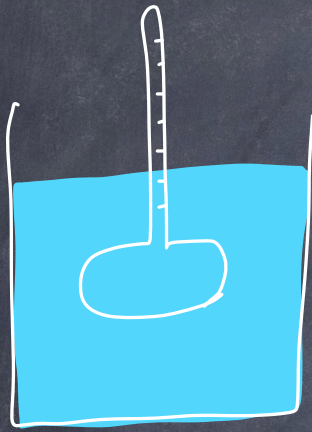
$$\text{so } \cancel{\rho_e g} V_e = \cancel{\rho_o g} V_o$$

$$\frac{V_e}{V_o} = \frac{\rho_o}{\rho_e}$$

"is defined as"

so the fraction submerged $\equiv \frac{V_e}{V_o}$ is just the inverse ratio of the densities.

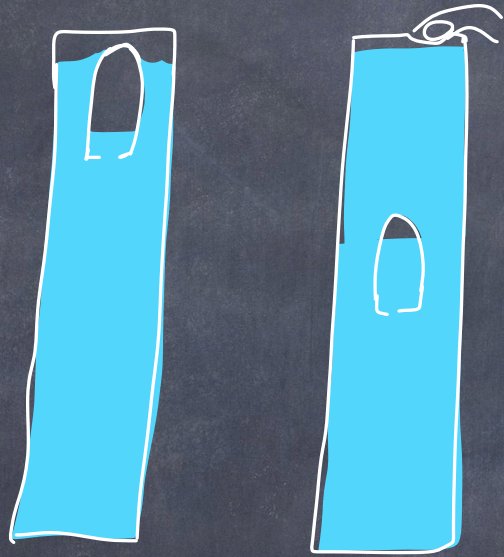
Hydrometer: measures the fraction submerged, f_s , and lets us measure the density of the fluid.



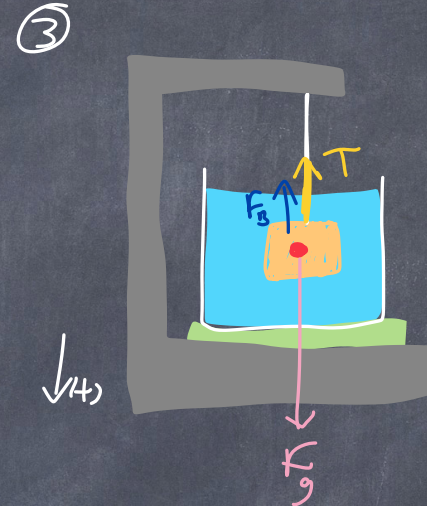
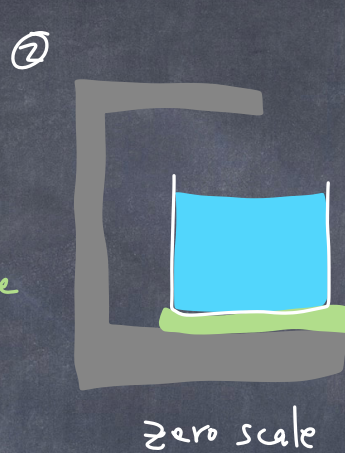
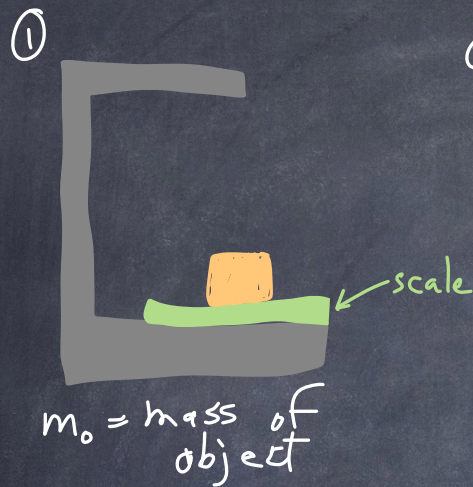
Ratio of density of fluid compared to that of water is called the "specific gravity",
$$= \frac{\rho}{\rho_{\text{water}}}$$



Cartesian diver



How to measure the density of object, ρ_{obj} ? $V_e = V_o$



$T = W_A = \text{apparent weight}$

$$F_B = W_e = \underbrace{\rho_e V g}_{m_e}$$

$$F_g = W_o = \underbrace{(\rho_o V) g}_{m_o}$$

At •, $\Sigma F = F_g - T - F_B = 0$

$$= W_o - W_A - W_e = 0 \quad W_e = W_o - W_A$$

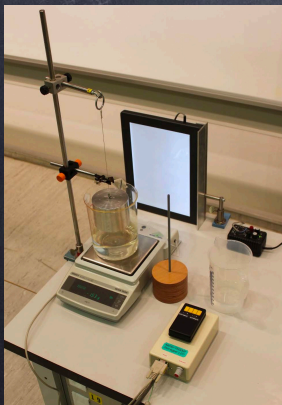
Now we want to calculate ρ_o :

$$\frac{\rho_o}{\rho_e} = \frac{g \cdot M_o / \cancel{V}}{g \cdot M_e / \cancel{V}} = \frac{W_o}{W_e}$$

②

$$\rho_o = \rho_e \frac{W_o}{W_e} = \rho_e \frac{M_o}{M_e}$$

In ③, the scale feels the force of $F_g - T = F_B = W_e$, so the scale measures M_e , the mass of displaced liquid.

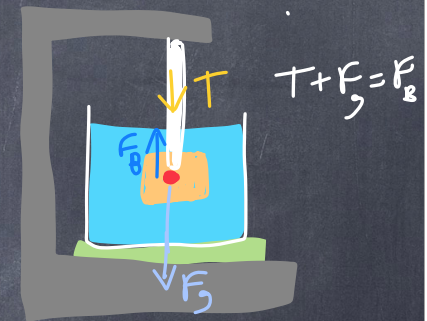
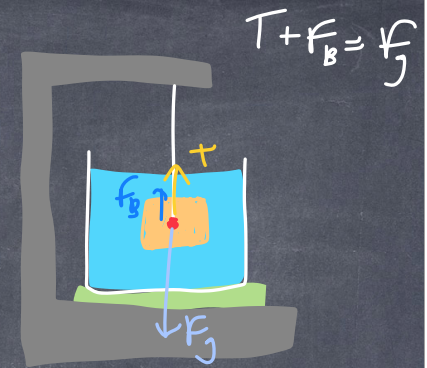


1) case of a sinking object $F_g > F_b$

$$\text{from (a)} \rightarrow \rho_o = \rho_{\text{water}} \cdot \frac{m_o}{m_e} =$$

2) Case of floating object $F_b > F_g$

$$\rho_o = \rho_e \frac{m_o}{m_e} =$$



So far, we have seen the buoyant of an object

$$F_B = \rho_e V g$$

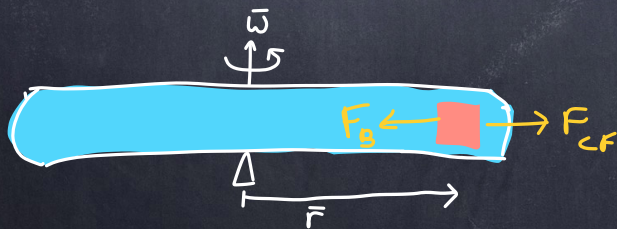
is opposite the gravitational force on the object

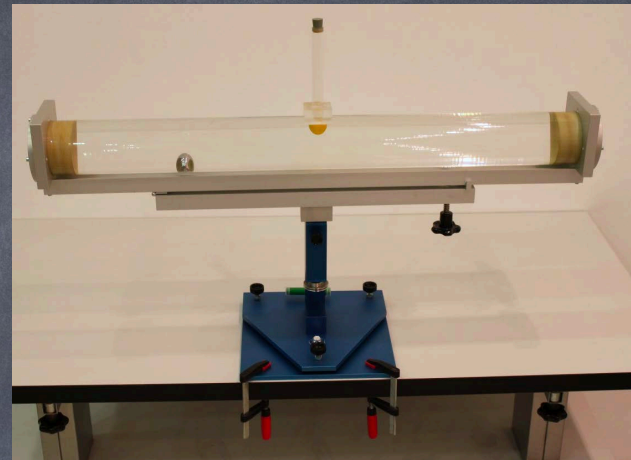
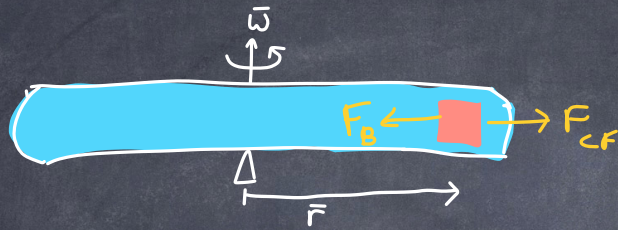
$$F_g = \rho_o V g$$

In a centrifuge, we have the same thing, but in a rotating frame, we replace gravitational acceleration g with centrifugal acceleration, $a_{cf} = \omega^2 r$

so $F_{cf} = \rho_o V (\omega^2 r)$ outward
and

$$F_B = \rho_e V (\omega^2 r) \text{ inward}$$





$$F_B = \rho_l V_l \omega^2 r$$

$$F_{cf} = \rho_o V_o \omega^2 r \quad (V_o = V_l)$$

Compare F_B & F_{cf} :

IF $\rho_l > \rho_o$, then $F_B > F_{cf} \Rightarrow$ object moves to center

IF $\rho_o > \rho_l$, then $F_{cf} > F_B \Rightarrow$ object moves outward

$\Rightarrow$ Dense objects move outward, less dense objects move inward.

End

