$\boxed{\text{Chapter 10}}$ Fluids — 10a Static Fluids, 10b Dynamic Fluids

$\boxed{\text{10a}}$ $\boxed{\text{Fluid - Statics}}$ hydrostatics

Mediums of matter that cannot maintain their shapes are called Fluids.

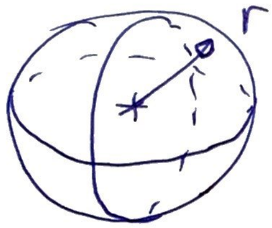
Forms of matter:

- Solids : maintain shape & volume (fixed)
- Liquids: fixed volume but not shape
- Gas: neither a fixed volume nor shape
- Plasma: ionized atoms
- Liquid Crystals: A phase between liquid and solid
- Bose - Einstein Condensate: Low Temp & involves Quantum Mechanics.
- Others are being evaluated

⊛ **Density**: $\rho \equiv \dfrac{\text{mass}}{\text{Volume}}$ → Fluids, Solids, Gases.

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

EX Solid iron of a wrecking ball of diameter of 36 cm. Q: What is its weight?



$r = 0.36\,m$, $\rho_{iron} = 7{,}873\ kg/m^3$

{cubic meter roughly the size of the box that your dishwasher came in

{BTW: $\rho_{water} = 1000\ kg/m^3$, $V_{sphere} = \frac{4}{3}\pi r$

(i) mass of sphere $= \rho V = \left(7.87\times10^3 \frac{kg}{m^3}\right)\left(\frac{4}{3}\pi (0.36m)^3\right)$

$m = 190.5\ kg$

(ii) Weight $= mg = (190.5\,kg)(9.8\ m/s^2) = \boxed{1867\,N}$

~450 lb.

* $\boxed{\text{Specific Gravity} = \frac{\text{density of material}}{\text{density of water}}}$ ← ratio

EX Specific Gravity of Lead (Pb)

$$= \frac{\rho_{Pb}}{\rho_{H_2O}} = \frac{(11.3\,gm/ml)\left(\frac{1\,kg}{\cancel{1000}\,gm}\right)\left(\frac{\cancel{1000}\,ml}{l}\right)\left(\frac{\cancel{1000}\,l}{m^3}\right)}{1\cancel{000}\,kg/m^3}$$

• $SpG_{Pb} = \boxed{11.3}$ dimensionless

Basically lead is 11.3 * more dense than water

Recall in the previous example

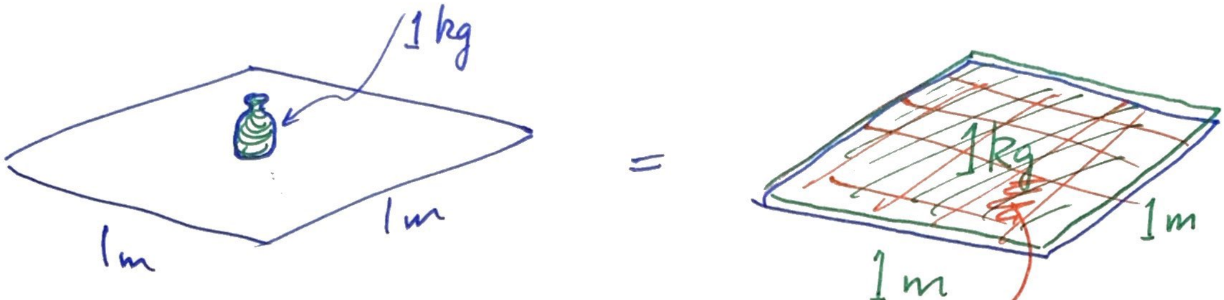
$$\rho_{iron} = 7.87\ kg/m^3$$

• $\boxed{SpG_{Fe} = 7.9}$

⊛ Pressure

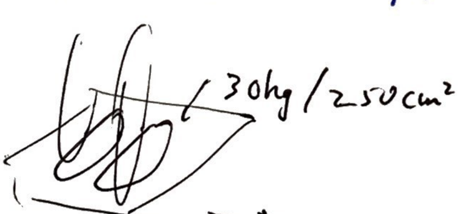
pressure is the force per unit area.

$$\boxed{P \equiv F/A} \qquad [P] = \frac{N}{m^2} \equiv \text{Pascal}$$



Ex A persons 60kg mass is divided across both feet. If a foot is roughly 250 cm² in area, what is the pressure felt on one foot when you have your Birkenstock on?

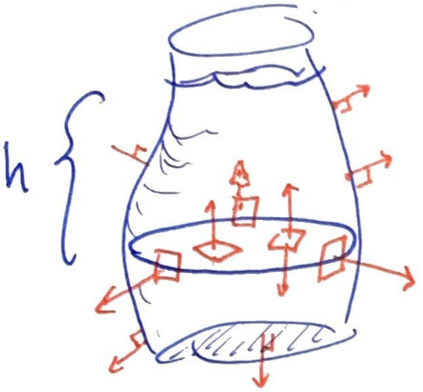
$$P = F/A = \frac{mg}{A} = \frac{[60\,kg/2](9.8\,m/s^2)}{(250\,cm^2)\left(\frac{1\,m}{100\,cm}\right)^2} = \boxed{11{,}700\,N/m^2}$$



$\underbrace{\text{24 feet}}_{}$ 12 people – 24 feet on one sq. meter.

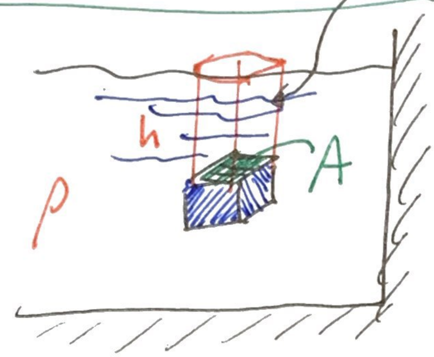
= 11,700 N of people on that one sq. meter.

* In liquid the pressure exerts itself equally in all directions. F is $\perp$ surfaces.



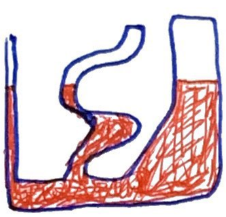
More depth, more pressure.

$V_{\text{rectang. box}} = h \cdot A$



$$P_{\substack{\text{TOP}\\ \text{of}\\ \text{Block}}} = \frac{F}{A} = \frac{mg}{A}$$

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



but $V/A = h$

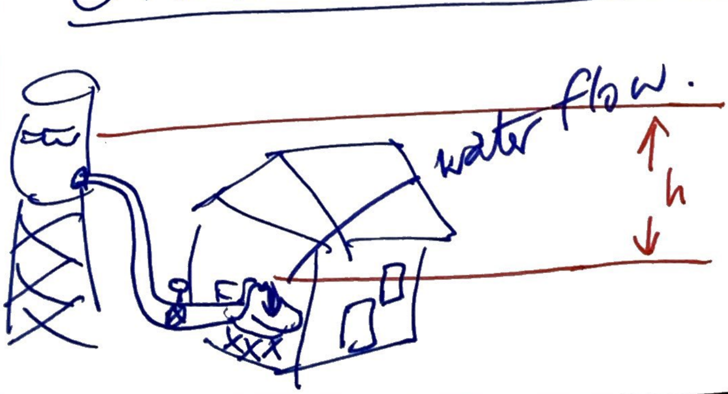
$$\Rightarrow P = \rho\left(\frac{V}{A}\right)g = \rho h g$$

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

pressure felt at a depth of h units in a liquid of density ρ on a planet with "g".

EX your house is next to a water tower that has its water surface 30 m above your faucet.

Q: what is the water pressure @ the faucet?

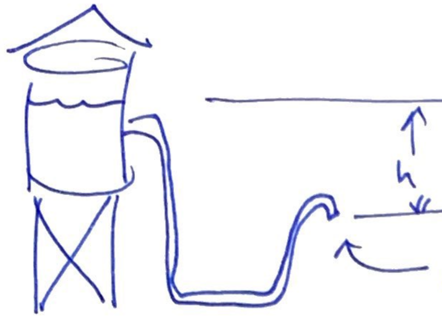


$$\Delta P = \rho g h$$

$$= \left(1000\,\frac{kg}{m^3}\right)\left(9.8\,m/s^2\right)(30\,m)$$

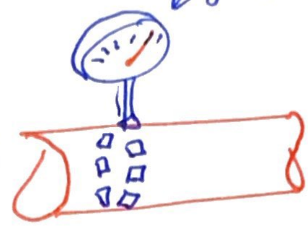
$$= \underline{290{,}000\,Pa} = \underline{290\,kPa}$$

* Gauge Pressure

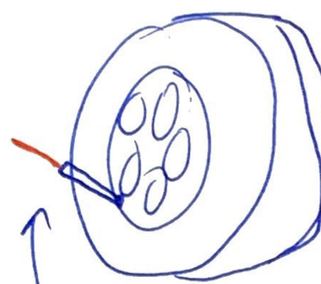


ΔP gauge Pressure

pressure gauge



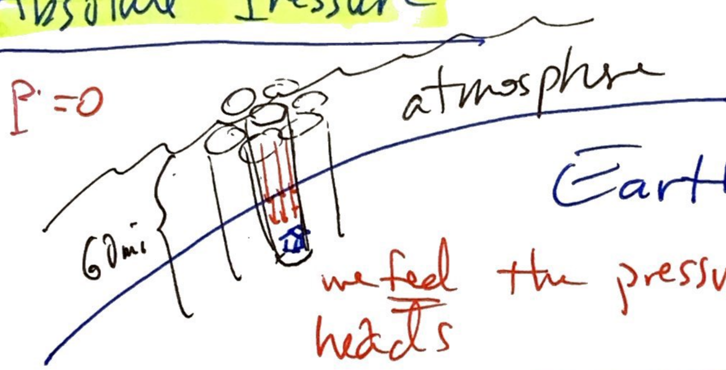
Tire



90% of pressure usages use Gauge Pressure

shows inside vs outside pressure changes

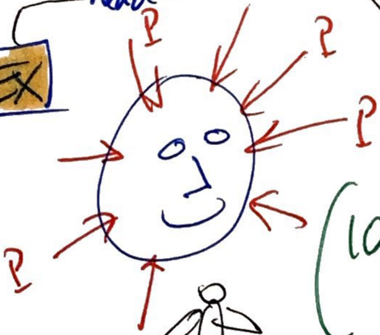
* Absolute Pressure



we feel the pressure of the entire atm on our heads

abs. $P_{head} = 1\,atm$ but $\boxed{1\,atm = 1.013 \times 10^5\,Pa} = N/m^2$

EX



$lbs/in^2 \leftrightarrow N/m^2 = Pascal$

$$\left(101{,}300\ \frac{N}{m^2}\right)\left(\frac{lb}{4.4N}\right)\left(\frac{1m}{39.4in}\right)^2 = 16.7.6\,lbs/in^2$$

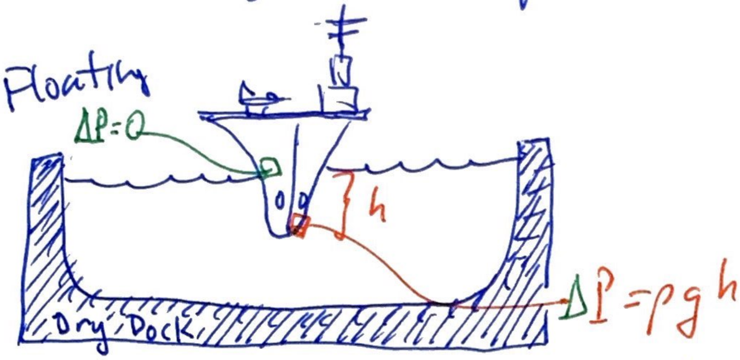
absolute pressure

Focus pressure onto one in²

$$\boxed{P_{abs} = \Delta P_{gauge} + P_{atm}}$$

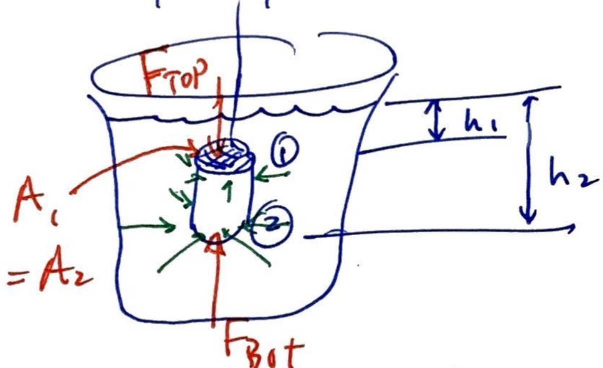
* Archimedes Principle

The "buoyant force" on a floating object is the net force acting on the object due to the height differences and densities of the object in or floating on a liquid (or gas)



Net effect is a vector that pushes upwards.

* Buoyancy Force Formula



$$P_1 = \rho g h_1$$
$$\ominus P_2 = \rho g h_2$$
$$P_1 - P_2 = \rho g (h_1 - h_2)$$

$$(\Delta P = \rho g \Delta h) * A$$

$$\underline{\underline{\Delta F}} = \rho g \underline{\underline{A \cdot \Delta h}} = \rho g \underline{\underline{\Delta V}}$$

Buoyant Force

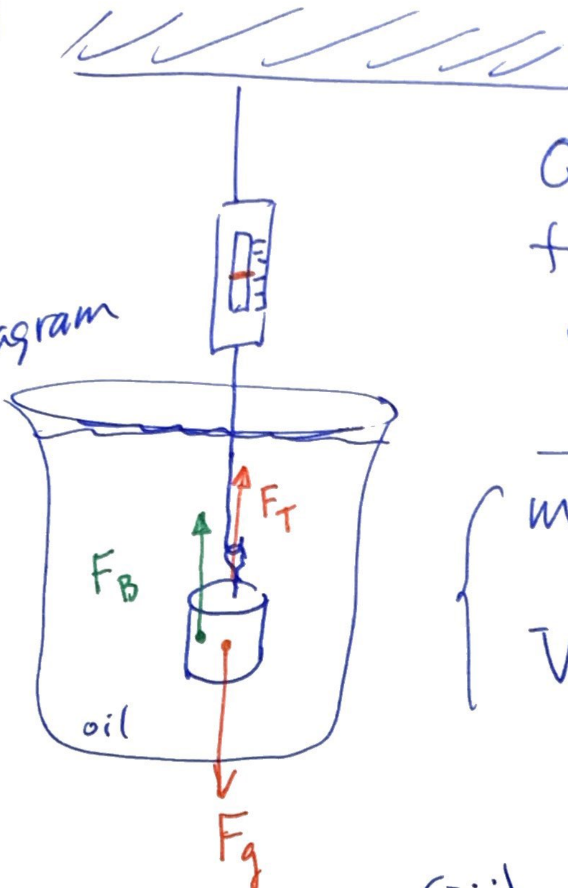
$$\boxed{F_B = m_{\substack{\text{fluid}\\ \text{displaced}}} \cdot g}$$

Archimedes Principle

works for immersed & floating objects.

EX

(i) diagram



Q: What is the tension in the spring scale when we submerge the object in liquid.

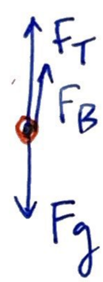
$$\left\{ \begin{array}{l} m = 9\,kg \qquad \rho_{oil} = 860\,kg/m^3 \\ V_{obj} = 0.01\,m^3 \end{array} \right.$$

(about 1 ft³!)

$\rho_{object} = \frac{9}{0.01\,m^3} = 900\,kg/m^3$

(ii)

(+)↑



(iii)

$\sum F = m\cancel{a}$ "0" hangs still

$F_T + F_B - F_g = 0$

$$\boxed{F_T = F_g - F_B}$$

Buoyancy force relieves the tension

$V = \frac{1}{100}\,m^3$

$= \frac{1}{100}\,m^3 \left(\frac{100\,cm}{m}\right)^3$

$= 10{,}000\,cm^3$

$s = \sqrt[3]{V} = 22\,cm$ on a side

$\approx \boxed{1\,ft^3}$

(iv) $\boxed{F_B = \underbrace{m_{oil}}_{displaced} \cdot g}$

$F_B = \underbrace{(V_{obj})\,\rho_{oil}}\,g = (0.01\,m^3)(860\,kg/m^3)(9.8\,m/s^2)$

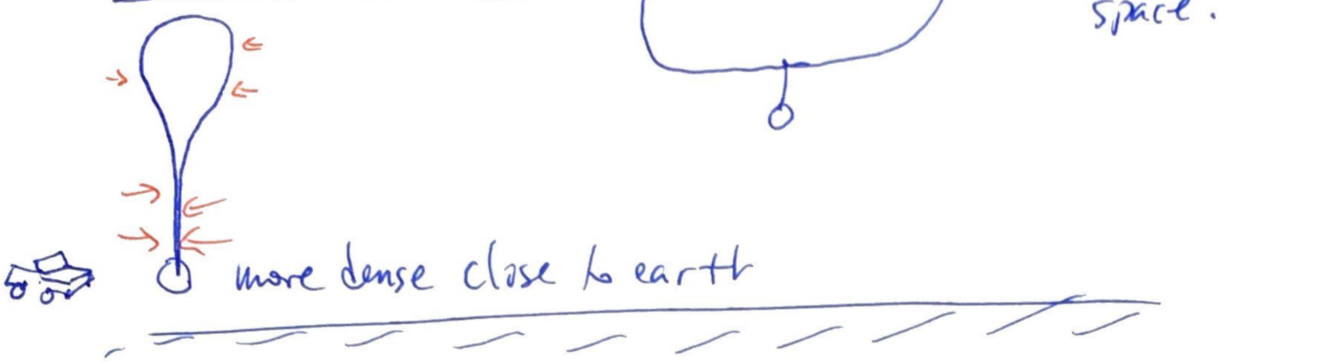
$F_B = 84.28\,N$

So

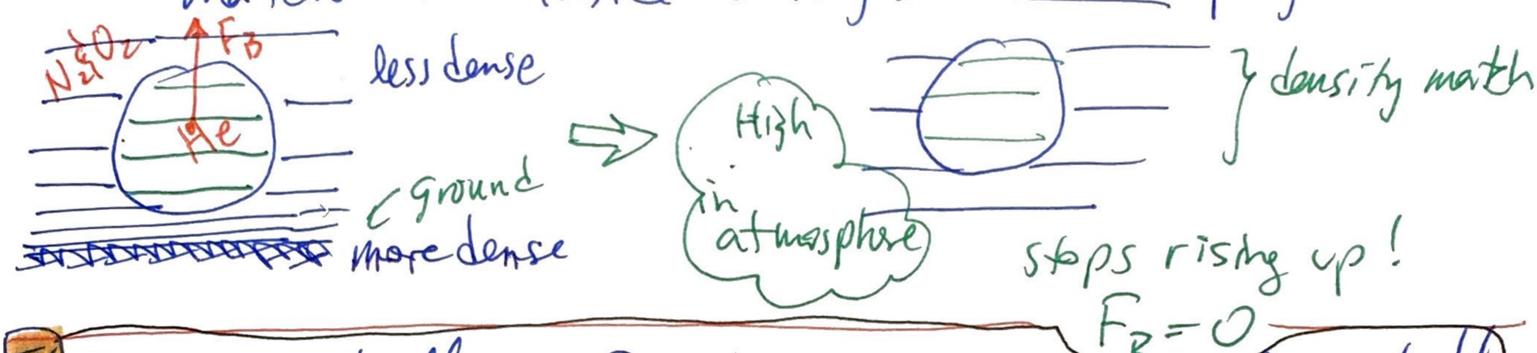
$F_T = F_g - F_B = mg - 84.28\,N = \underbrace{(9\,kg)(9.8\,m/s^2)}_{88.2\,N} - 84.28\,N = \underline{4\,N}$

Almost floats...

A Helium Balloon



The balloon floats when the outside density matches the inside density minus the payload.



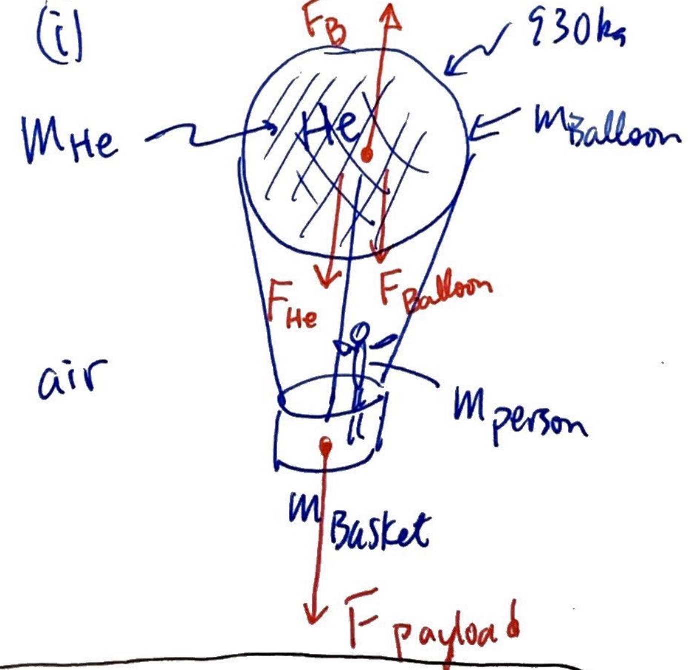
EX

A spherical balloon of radius 7.15 m is filled with He.

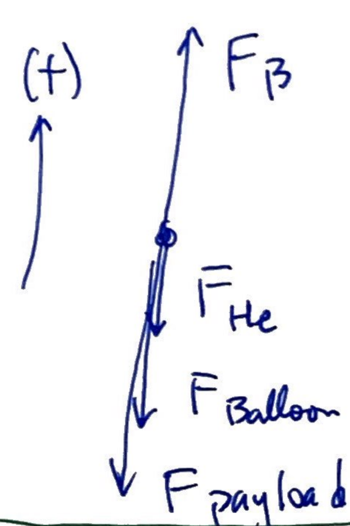
Q: How large of payload can it lift assuming the material of the balloon, cables & basket is 930 kg

{ Neglect the F_B of the payload }

(i)



(ii)



(iii)

$$\boxed{F_B - F_{He} - F_{pay} - F_{balloon} = 0}$$

EX cont

(iv) • $F_B = \rho_{\substack{\text{air} \\ \text{displaced}}} \cdot Vol_{\text{balloon}} \cdot g$

$$V = \frac{4}{3}\pi R^3 = \frac{4}{3}\pi (7.15m)^3 = \underline{\underline{1531.1}}\ m^3$$

$$\rho_{air} = 1.29\ kg/m^3$$

$$= (1.29\ kg/m^3)(1531.1\ m^3)(9.8\ \tfrac{m}{s^2})$$

$$= \boxed{19{,}355.98N}$$

• $F_{He} = \rho_{He}\, Vol \cdot g$

$$\rho_{He} = 0.179\ kg/m^3$$
$$Vol = 1531.1\ m^3$$

$$= \left(0.179\ \tfrac{kg}{m^3}\right)(1531.1\ m^3)\,9.8\ \tfrac{m}{s^2}$$

$$= \boxed{2686.2N} \approx 584 lbs$$

• $F_{Balloon} = m \cdot g = (930kg)(9.8m/s^2) = \boxed{9114N}$

skin, cables, Basket

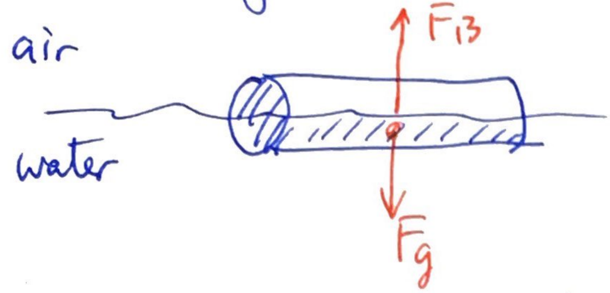
$\Rightarrow$ $F_{payload} = F_B - F_{He} - F_{balloon}$

$$= 19355.98N - 2686.2N - 9{,}114N$$

$$= \boxed{7555.8N} \div g$$

$$= \boxed{\boxed{771\ kg}}$$

⊛ Floating Objects



$$F_B - F_g = 0$$

$$\boxed{F_B = F_g}$$ Floating objects on a liquid.

- $F_B = (\rho_{fluid} Vol)\, g$

$$F_B = (m_{Fluid\ displaced})\, g$$

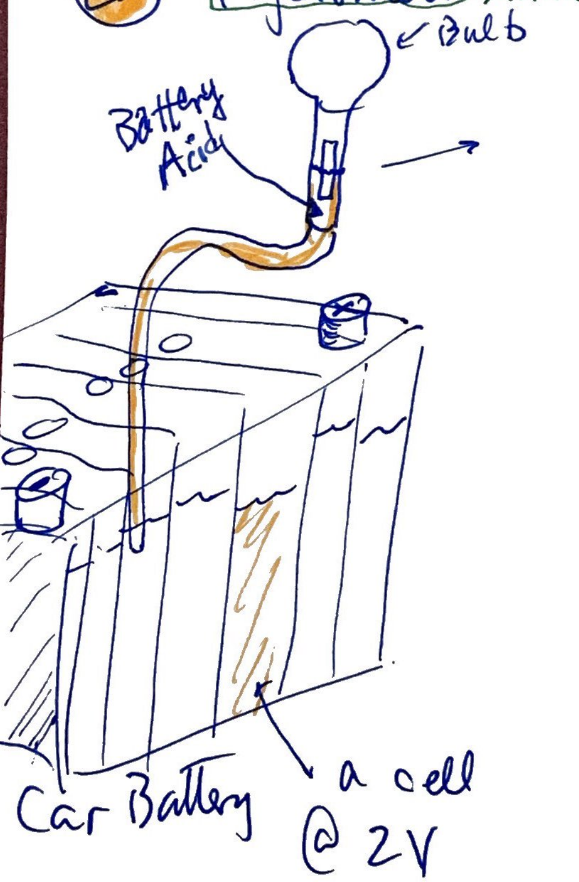
$F_B = F_g$

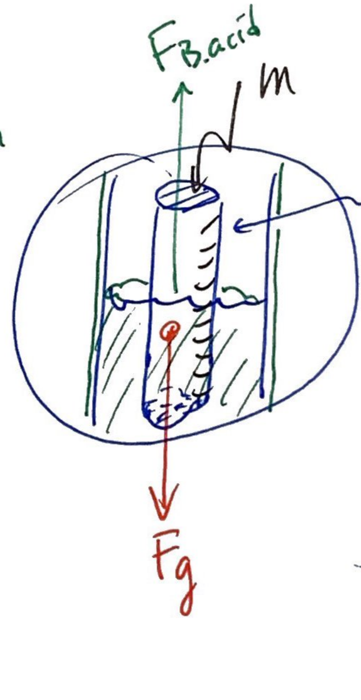
$$F_g = m_F\, g$$

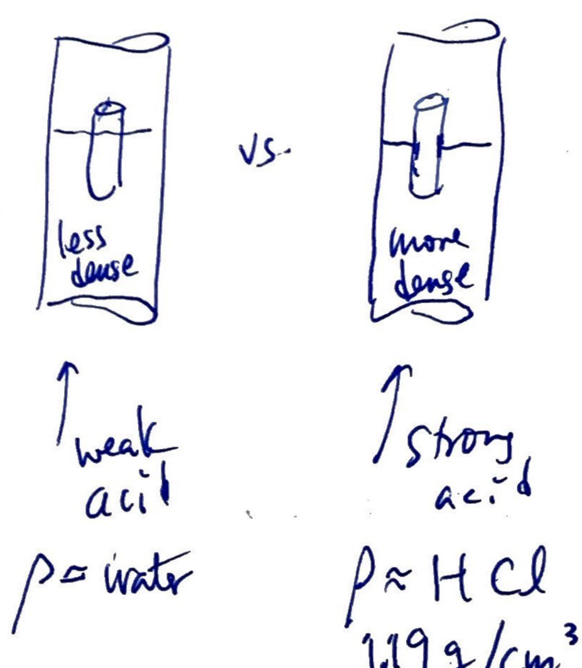
$$m_{object} \cancel{g} = m_F \cancel{g}$$

$$\rho_{object} V_{object} = \rho_{Fluid} V_{Fluid\ Displaced} \Rightarrow \boxed{\frac{V_{disp.Fluid}}{V_{object}} = \frac{\rho_{obj}}{\rho_{fluid}}}$$

Ex $\boxed{\text{Hydrometer}}$







see "Cody's Lab" Floating an anvil in Mercury

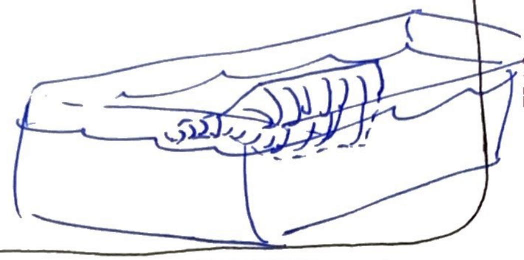
ex

$$\rho_{Hg} \approx 2\rho_{steel}$$

then

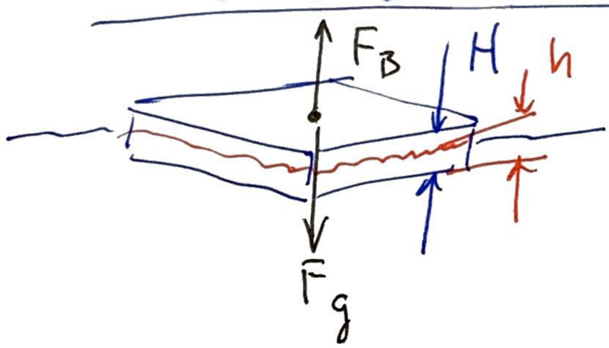
$$\frac{V_{disp.\,Fluid}}{V_{object}} = \frac{\rho_{steel}}{\rho_{fluid}} = \frac{1}{2}$$

$$\Rightarrow \boxed{V_{disp.\,Fluid} = \frac{1}{2} V_{object}}$$

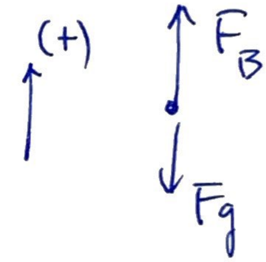


ex A block of density $\rho = 800\,\mathrm{kg/m^3}$ floats face down in a fluid of density $\rho_f = 1200\,\mathrm{kg/m^3}$. The Block is of height H. By what depth "h" will the block be submerged?

(i)



(ii)



(iii) $\sum F = 0 \rightarrow F_B - F_g = 0 \rightarrow \boxed{F_B = F_g}$ floats

(iv) $\rho_{fl} V_{\substack{fluid\\disp.}} \cdot g = \rho_{block} \cdot V_{TOTAL} \cdot g$

but $V_{obj} = \cancel{A} H$ & $V_{fluid} = \cancel{A} h$

$$\Rightarrow \rho_{fl} \cancel{A} h \cancel{g} = \rho_{block} \cancel{A} H \cancel{g}$$

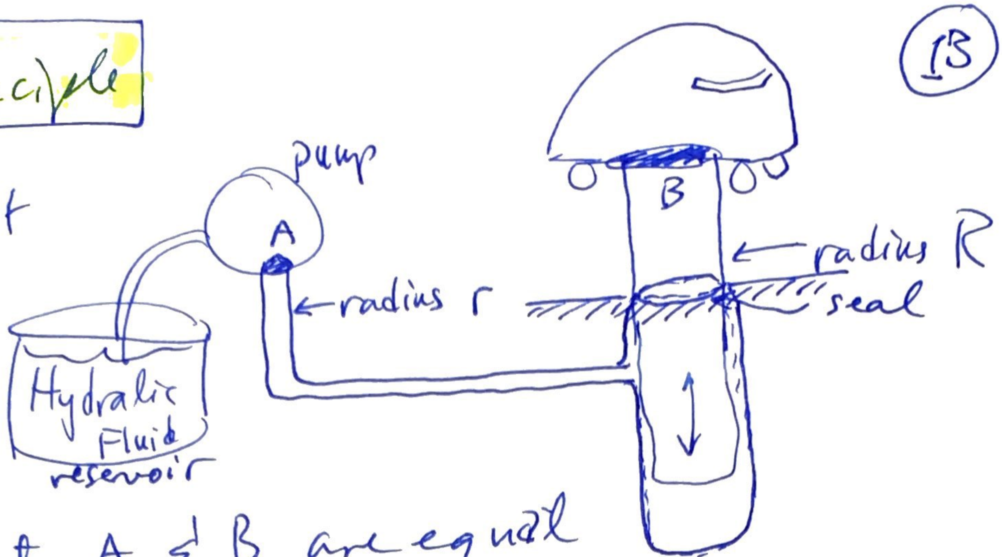
$$\Rightarrow \boxed{h = \left(\frac{\rho_{object}}{\rho_{fluid}}\right) H}$$

let $H = 6\,\mathrm{cm}$ the $h = \frac{800}{1200} \cdot 6 = 4\,\mathrm{cm}$ below surface

$\frac{2}{3}$ below

Pascal's Principle

Hydraulic Lift



the pressures at A & B are equal

$$\boxed{P_A = P_B}$$ pascal's principle

$$\frac{F_A}{A_A} = \frac{F_B}{A_B} \rightarrow \boxed{F_B = \left(\frac{A_A}{A_B}\right) F_A}$$

using circular shapes : $A = \pi r^2$

B = lift
A = pump

$$\boxed{F_{lift} = \left(\frac{r_{lift}}{r_{pump}}\right)^2 F_{pump}}$$

Ex What force is needed by the pump to push the plunger in the pump down so as to lift the car up? $r_{pump} = 1cm$, $r_{lift} = 15cm$ let the car be 2000 N

$$F_{pump} = \left(\frac{r_{pump}}{r_{lift}}\right)^2 F_{lift}$$

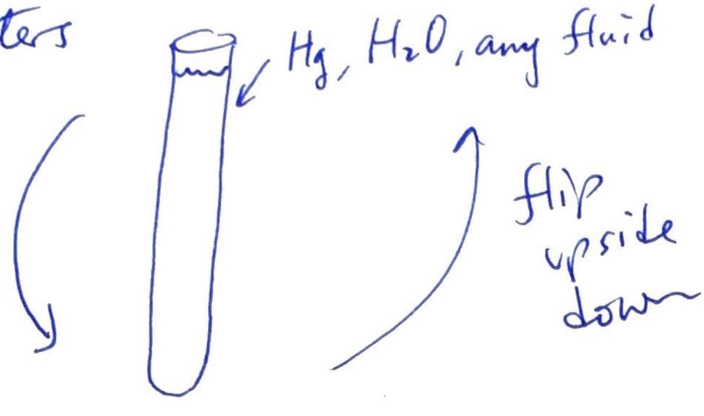
$$= \left(\frac{1cm}{15cm}\right)^2 2000N$$

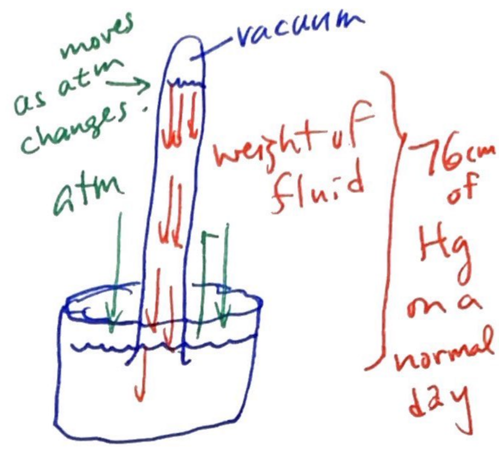
$\rightarrow$ $\underline{8.9N \approx 10N}$

$\boxed{\text{So we lift 2000N by apply only 10 N}}$

- trade-off is that a lot of fluid needs to be taken from the reservoir

⊛ Barometers





The weight of the column is balanced by the pressure of the atmosphere.

Ex What is the atmospheric pressure if we see 72 cm of Hg in the barometer tube?

$$P = \rho g \Delta h$$

$$= \underbrace{(13.6\times10^3\ kg/m^3)(9.8\ m/s^2)}(0.72\ m)$$

$$= [1.01\ kPa / 0.76m]\ 0.72\ m$$

$$= 1.01\ kPa\left(\frac{72\ cm}{76\ cm}\right)$$

$$= \boxed{95.9\ kPa}$$ A storm is approaching

95,900 Pa

* Concepts.

How does a straw work?

we do not "suck" the fluid into our mouth, instead we lower the pressure and let the atmosphere push the fluid into our mouth.