Solids: do not change shape

Fluids: can change shape

- liquids: do not change volume
- gases: do change volume

Density

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

mass
Volume

rho → not P

capital V

ρ

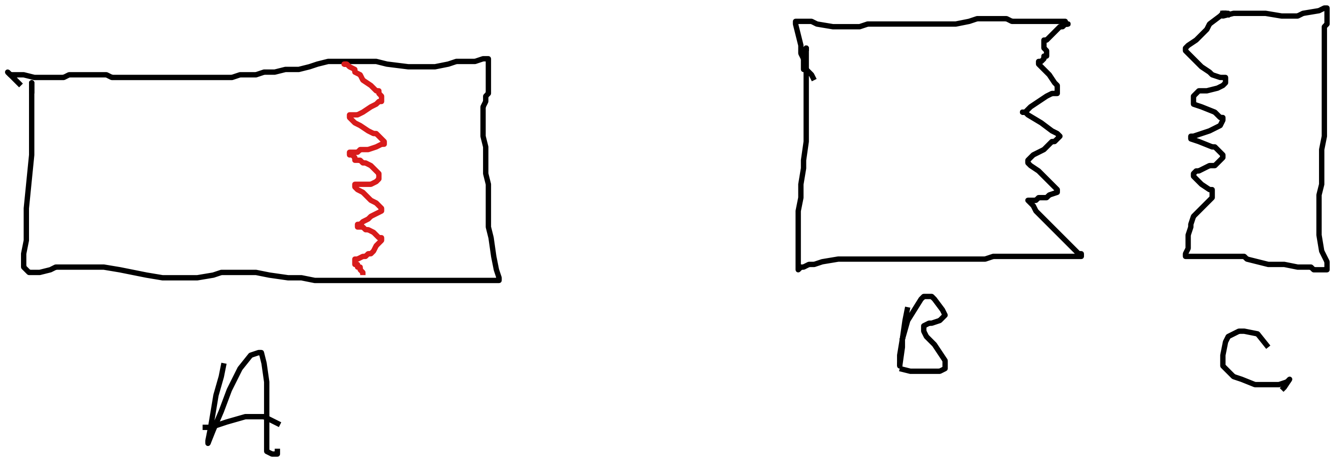
$$\rho_{water} = 1000 \, kg/m^3$$

varies very little

$$\rho_{air} = 1.2 \, kg/m^3$$

in free air

Block of wood



Which has the largest density?

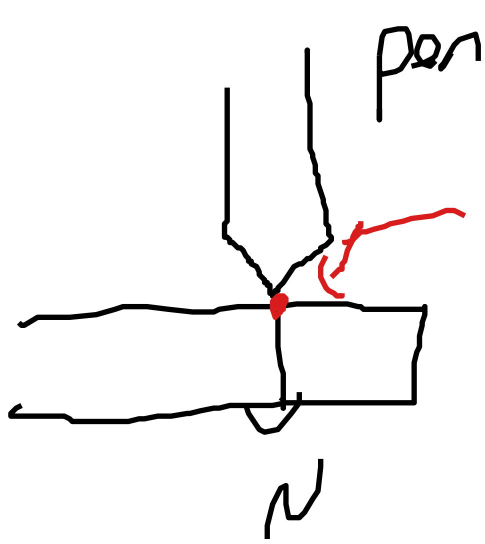
All have the same density

Density is an intrinsic property of the material,

Pressure

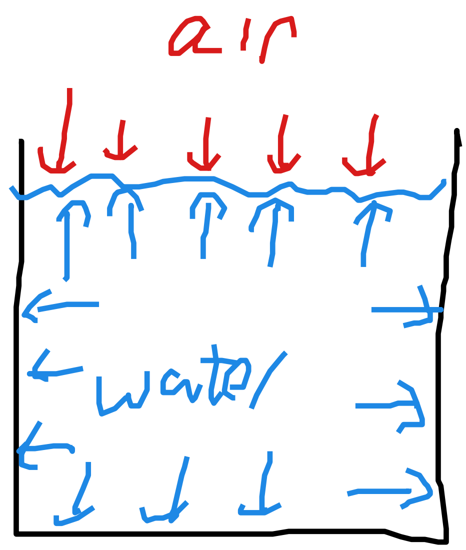
on a surface due to a normal force

$$P = \frac{N}{A} \quad \frac{\text{normal force}}{\text{area of application}}$$

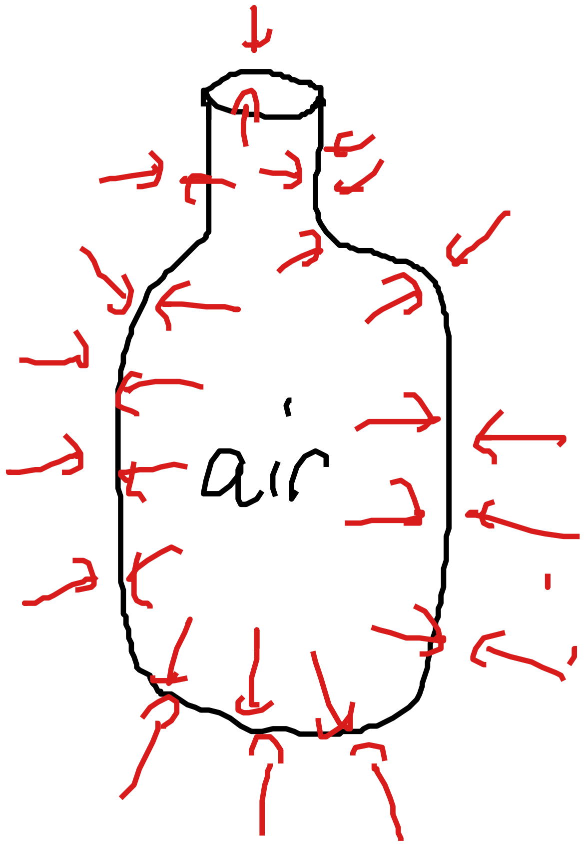


smaller area of contact $\rightarrow$ larger pressure

Fluids apply a pressure to everything they touch



If we remove the air from the top, the water will rise.



bottle of air - pressures balance

Remove the air

bottle collapses due to atmospheric pressure "suction"

Atmospheric Pressure

$$P_{atm} = 1.01 \times 10^5 \text{ Pa}$$

$1 \text{ Pascal} = 1 \frac{N}{m^2}$

$$P_{atm} = 101 \text{ kPa}$$

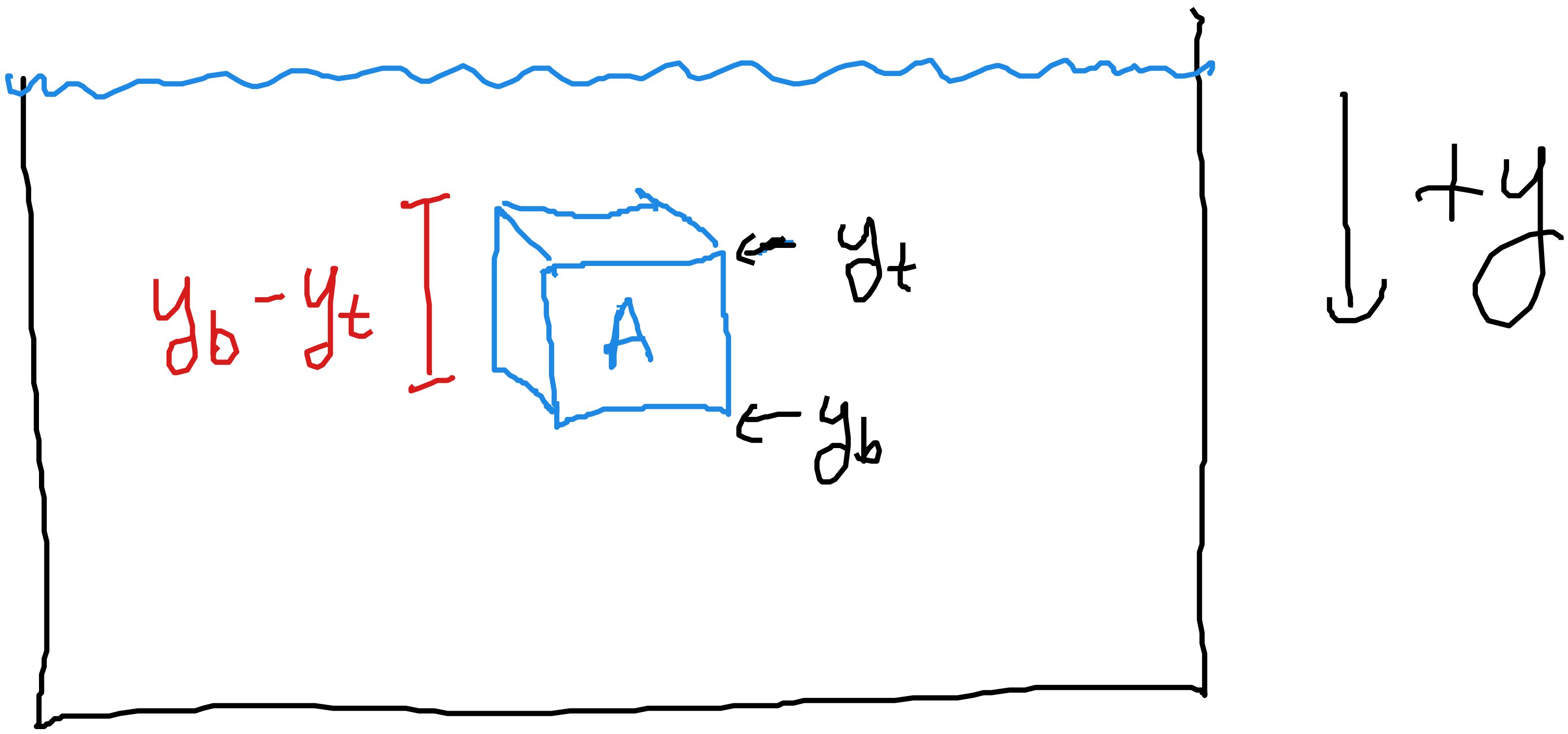
$$P_{atm} = 1 \text{ atm}$$ (atmosphere)

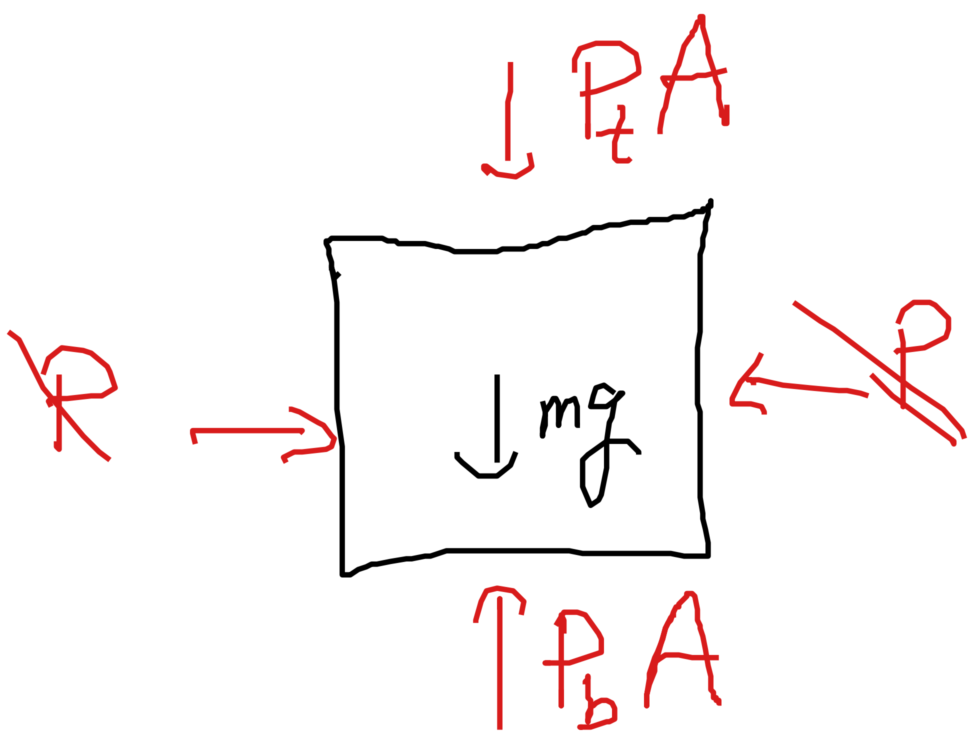
$$1 \text{ bar} = 10^5 \text{ Pa}$$ "millibars"

"mm Hg"

P.S.I.

other pressure units





$$F_{net} = +P_t A + mg - P_b A = 0$$

equilibrium

$$\frac{mg}{\cancel{A}} = \frac{(P_b - P_t)\cancel{A}}{\cancel{A}}$$

$$\frac{mg}{A} = P_b - P_t = \Delta P$$

$$\frac{\rho_f V g}{A} = \Delta P$$

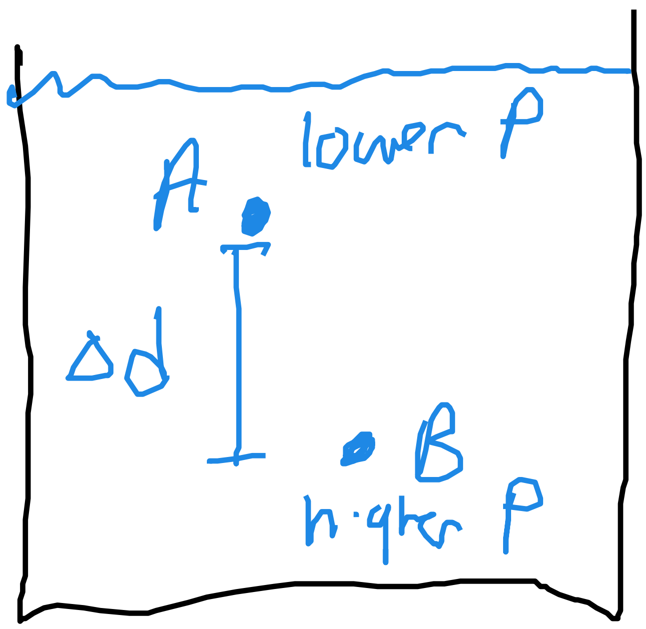
$$\frac{\rho_f A(y_b - y_t)g}{A} = P_b - P_t$$

$$\rho_f g (y_b - y_t) = P_b - P_t$$

$$\boxed{\Delta P = \rho_f g \Delta d}$$

$d = y$

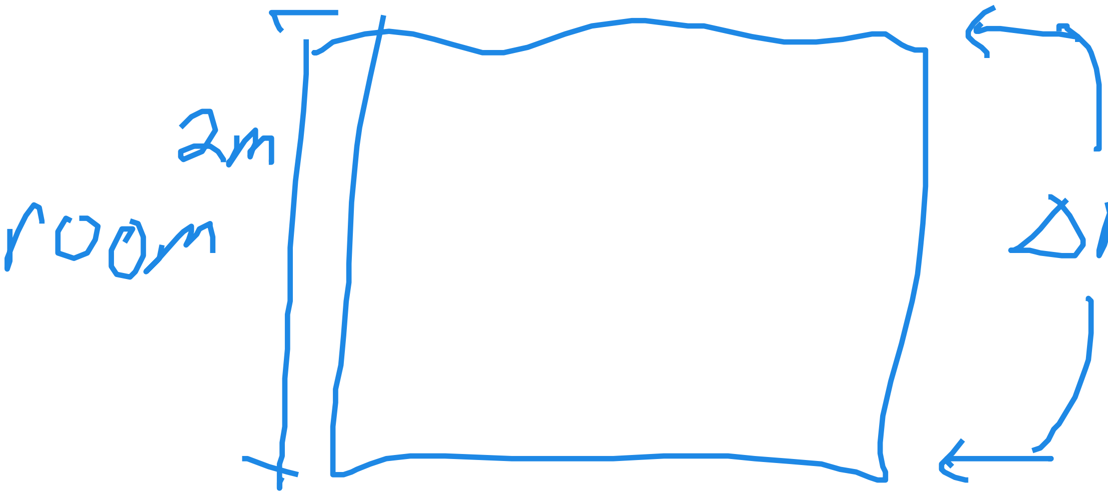
"depth"



$$P_B - P_A = \rho_f g \Delta d$$

In air,

$$\rho_f = 1.2 \text{ kg/m}^3$$



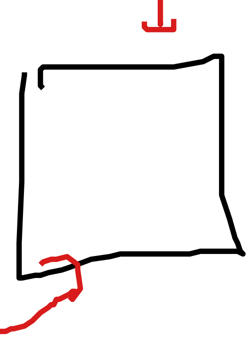
$$\Delta P = (1.2)(9.8)(1)$$
$$= 11.8 \text{ Pa}$$

compare with
101 kPa

We will typically treat P_{atm} as a constant, independent of height, in room-scale experiments.

$$P_b - P_t = \rho_f g (y_b - y_t)$$

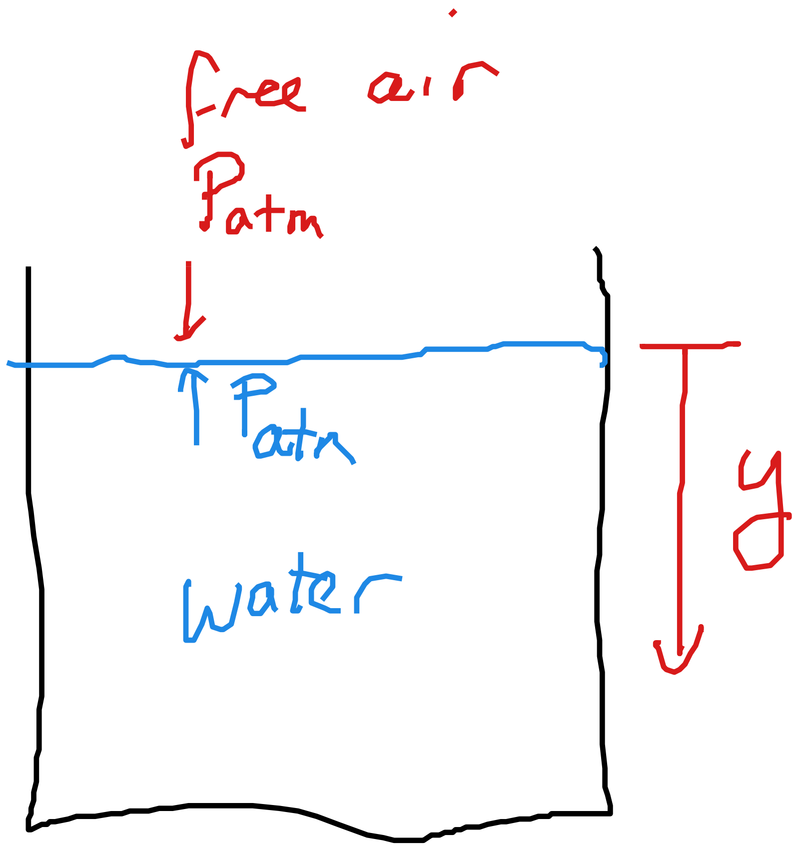
$$P_b - \rho_f g y_b = P_t - \rho_f g y_t$$



$$P - \rho_f g y = \text{constant}$$

If we know the pressure at one location, we can calculate it everywhere else.

Example



Surface of a fluid in contact with free air is at pressure P_{atm}

If $y = 0$ at surface,

$$P_{atm} - \rho_f g(0) = \text{constant}$$

Anywhere in this water, $P(y)$

$$P - \rho_f g y = P_{atm}$$

$$\boxed{P(y) = P_{atm} + \rho_f g y}$$

anywhere in fluid

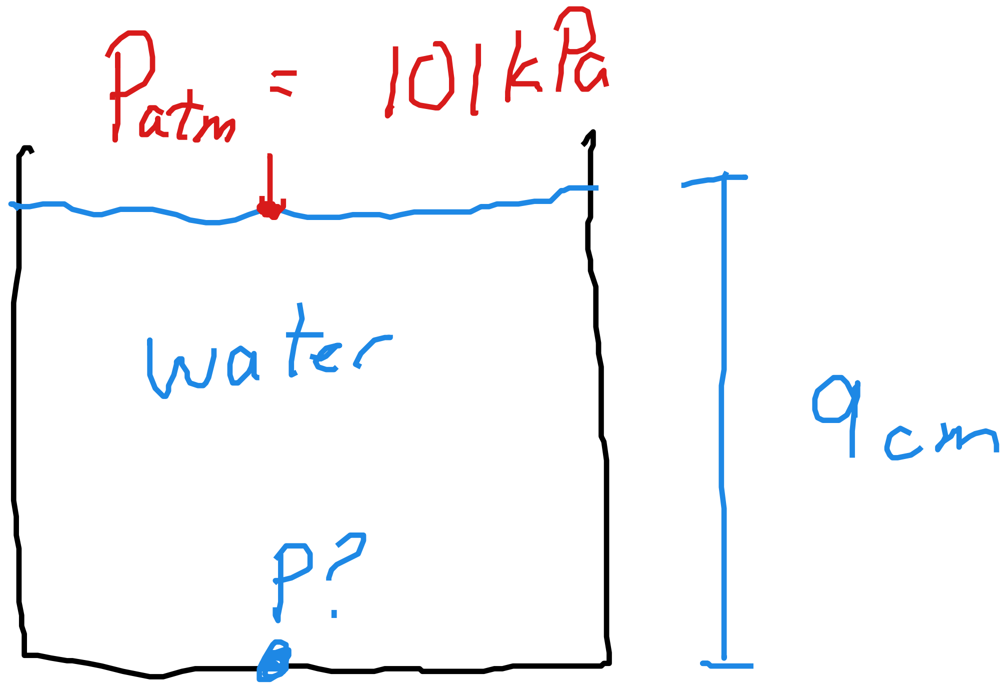
where y is depth below surface in contact with free air

$$\rho_f \; g \; y$$

$$\frac{\cancel{kg}}{m^{\cancel{3}\,2}} \; \frac{N}{\cancel{kg}} \; \cancel{m}$$

$$\frac{N}{m^2}$$

e.g.



Density of water

$$\rho_f = 1000 \frac{kg}{m^3}$$

ponytail — bald

$$P = P_{atm} + \rho_f\, g\, d$$

$$= 101\,kPa + \left(1000\frac{kg}{m^3}\right)\left(9.8\frac{N}{kg}\right)(9\,cm)$$

$$= 101\,kPa + \left(1000\frac{\cancel{kg}}{m^{\cancel{3}\,2}}\right)\left(9.8\frac{N}{\cancel{kg}}\right)(0.09\,\cancel{m})$$

$$= 101\,kPa + (1000)(0.882)\frac{N}{m^2}$$

$$= 101\,kPa + 882\,Pa$$

$$= 101\,kPa + 0.882\,kPa$$

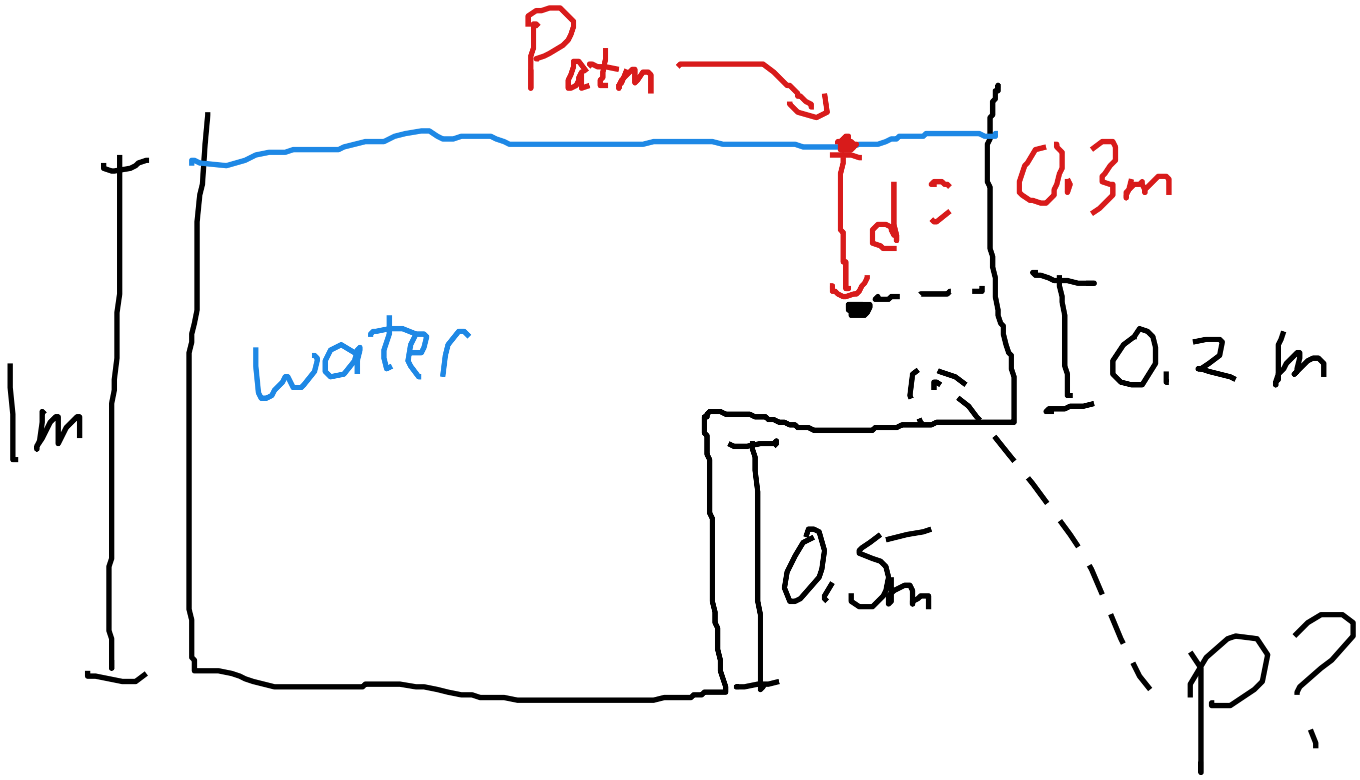
$$= 101.9\,kPa$$

If this were filled with ethanol,

$$\rho_f = 800 \frac{kg}{m^3}$$

$$P = 101 kPa + (800)(0.882) \frac{N}{m^2}$$

$$P = 101.7 kPa$$



$\rho_f = 1000\ kg/m^3$

$$\underbrace{P = \overbrace{P_0}^{\text{reference pressure}} + \rho_f g \overbrace{d}^{\text{depth below reference}}}$$

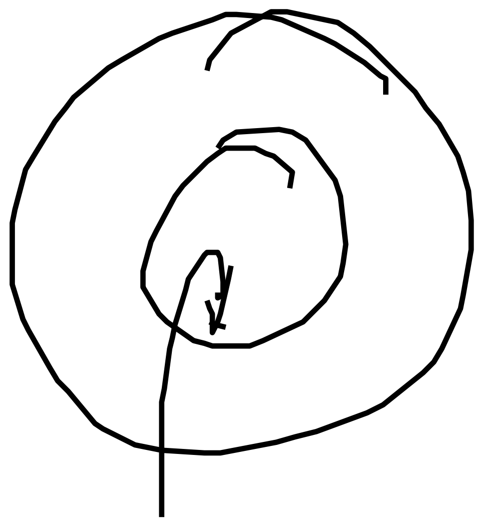
$$= 101\ kPa + (1000)(9.8)(0.3)$$

$$= 101\ kPa + 2.94\ kPa$$

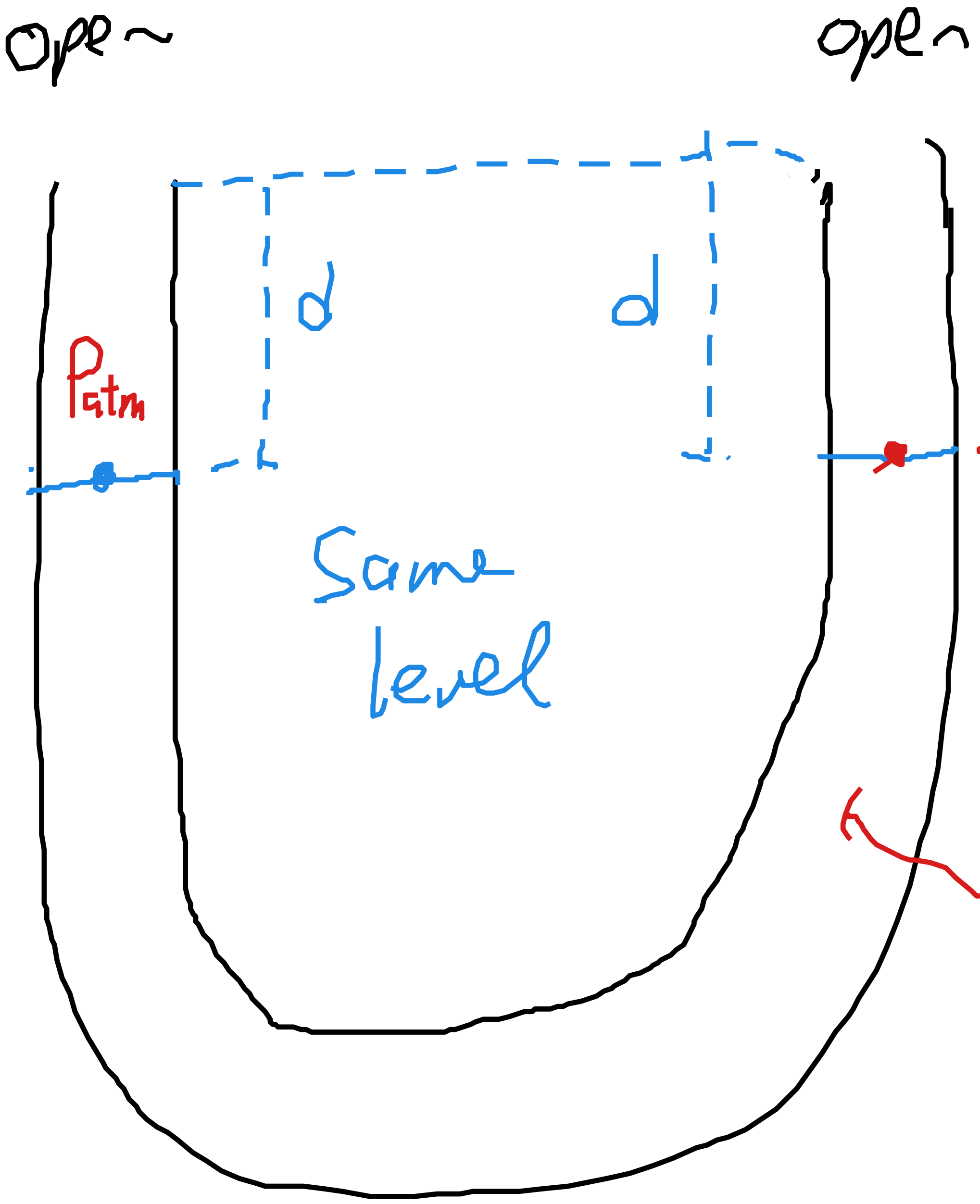
$$= 104\ kPa$$

$P - P_{atm}$ = gauge pressure

usually what is measured

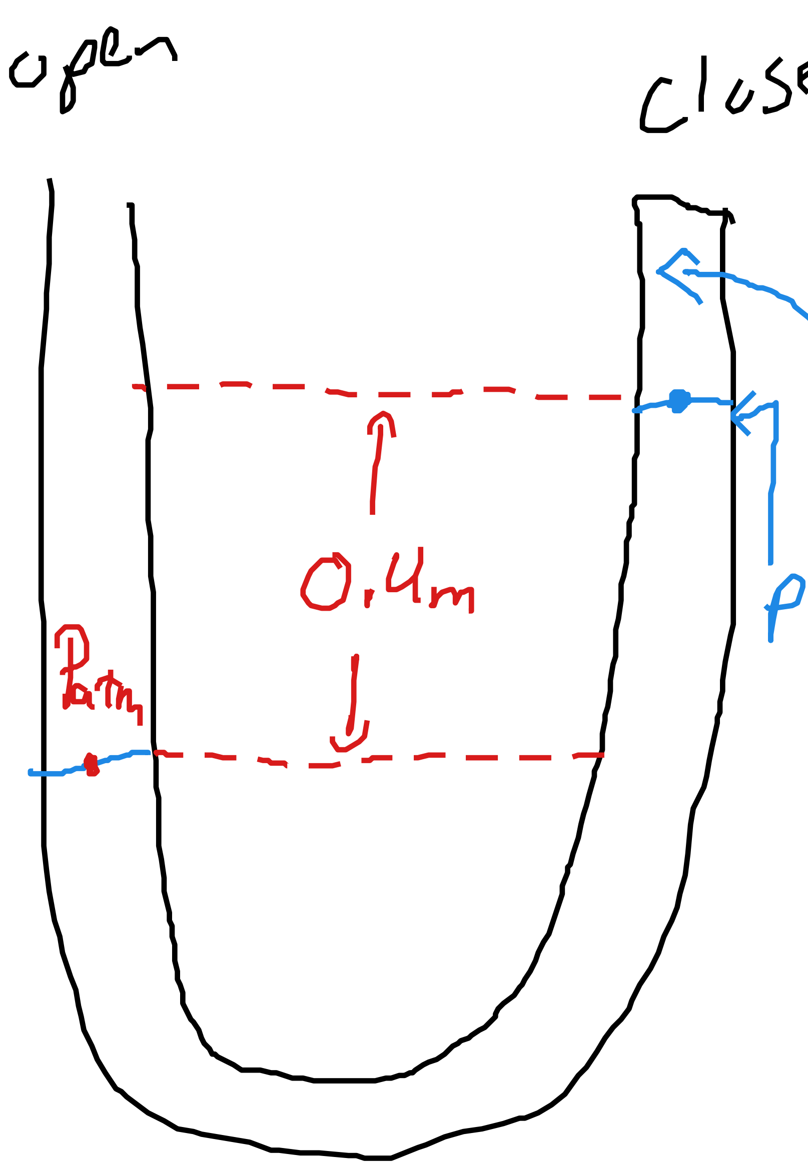


P inside tire "10 Pa"
means $P = P_{atm} + 10\ Pa$



$$P = P_{atm} + \rho_f g d$$
$$= P_{atm} \text{ (open)}$$
$$\rightarrow d = 0$$

$$P = P_{atm} + \rho_f g d$$



water levels can be different because $P \neq P_{atm}$

$P < P_{atm}$

$$P = P_{atm} + \rho_f g d$$

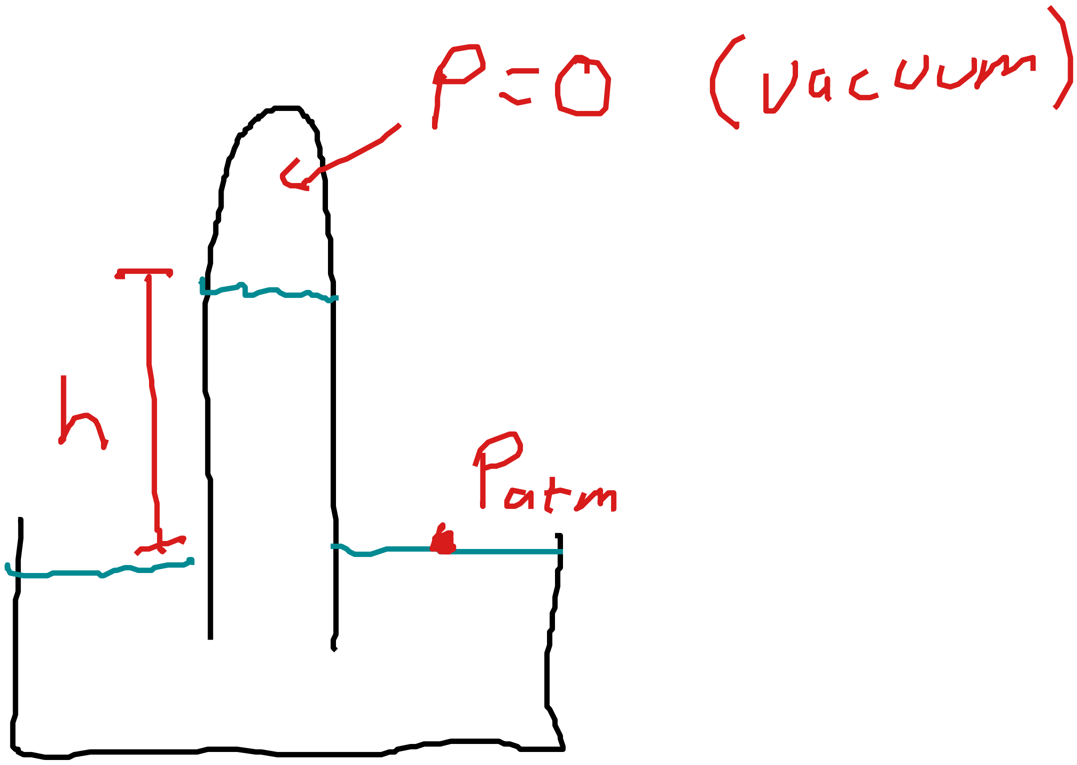
above reference point

$$= 101\,\text{kPa} + (1000)(9.8)(-0.4)$$

$$= 101\,\text{kPa} - 3.92\,\text{kPa}$$

$$= 97\,\text{kPa}$$

Barometer



$$0 = P_{atm} - \rho g h$$

$$h = \frac{P_{atm}}{\rho_F g}$$

$$h = \frac{101\,kPa}{(1000\,\frac{kg}{m^3})(9.8)} = \frac{101\,kPa}{9.8\,kPa/m} = 10.3\,m$$

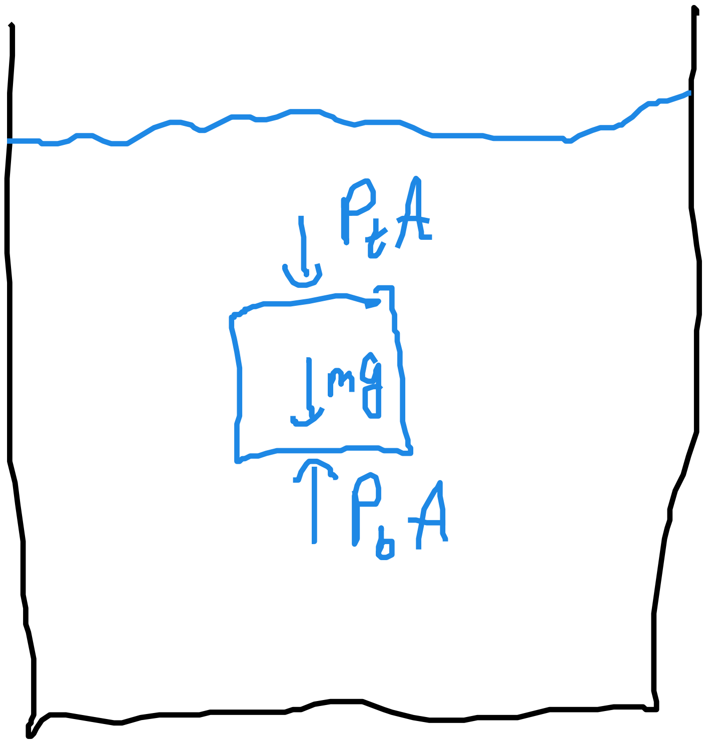
very tall!

Instead use mercury,

$$\rho_f = 13{,}500 \ \frac{kg}{m^3}$$

$$h = \frac{101\,kPa}{(13{,}500)(9.8)} = 0.76\,m$$

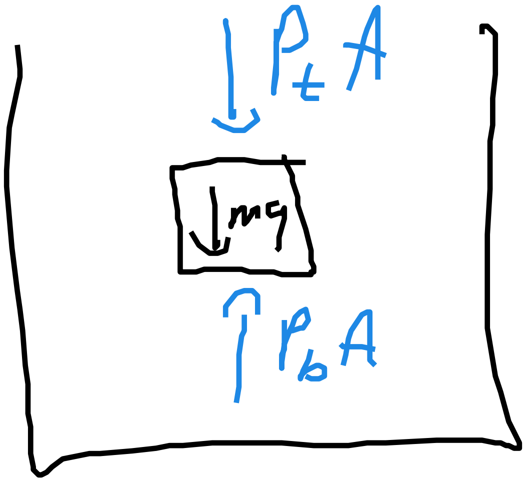
$$= 760\,mm \ Hg$$



$$P_t A + mg = P_b A$$

$$P_t A + \rho_f \bar{V} g = P_b A$$

Replace cube of water with wood.



$$\vec{F}_{net} = mg + P_t A - P_b A$$

Pressures are the same

$$P_t A - P_b A = -\underbrace{\rho_f V g}_{\text{weight of water that is displaced}}$$

on wood

$$\vec{F}_{net} = mg - \boxed{\rho_f V g}$$

$$= \rho_{wood} V g - \rho_f V g$$

$$= (\rho_{wood} - \rho_f) V g$$

if $\rho_{wood} > \rho_f$

then $\vec{F}_{net} \downarrow$ sinks

if $\rho_{wood} < \rho_f$

then $\vec{F}_{net} \uparrow$ floats

Buoyancy Force

$$\vec{B} = \rho_f \bar{V}_{displaced}\, g \uparrow$$

occurs in all fluids including air