Lecture 1 Review : Fluid Properties

Density $\rho \equiv$ mass / unit vol

Pressure $P \equiv$ force / unit area $\perp$ to any surface

$$\boxed{\text{Hydrostatic Pressure gradient } \frac{dP}{dy} = -\rho g} \quad [Pa/m]$$

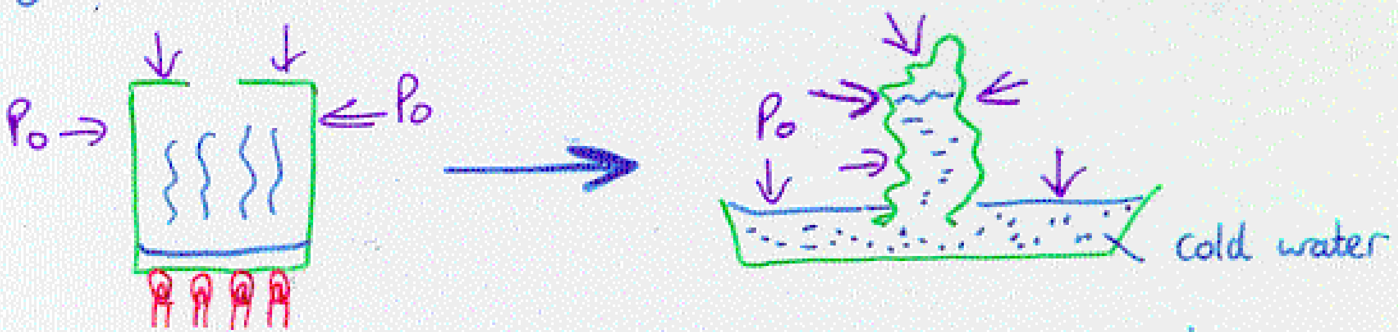
For many liquids $\rho \approx$ constant ("incompressible")

$$\Rightarrow \quad P_1 - P_2 = \rho g (y_2 - y_1) \quad \text{or} \quad \boxed{\Delta P = \rho g \underline{h}}$$

depth only

For gases, ρ changes with Pressure (and Temperature)

e.g. "Crushing Can" demo:



heat: steam at $P = 1\,atm$

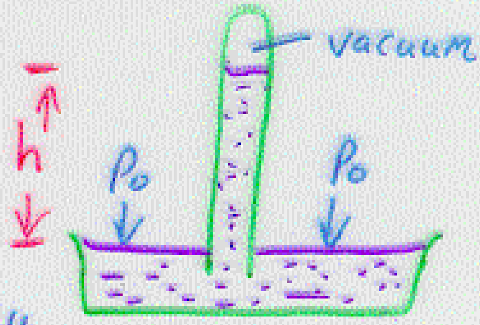
rapid cooling reduces steam pressure inside can

Results: • Can crushed by outside air pressure

• air pressure forces water from bath into can.

Using Fluids to Measure Pressure

1. Mercury (Hg) barometer:



atm. pressure supports fluid column above level of bath

$\Rightarrow P_0 = \rho g h$

Given standard values of ρ and g, can measure P_0 in terms of height h. 1 torr = 1 mm Hg

1 atm $\approx$ 760 torr $\approx 10^5$ Pa

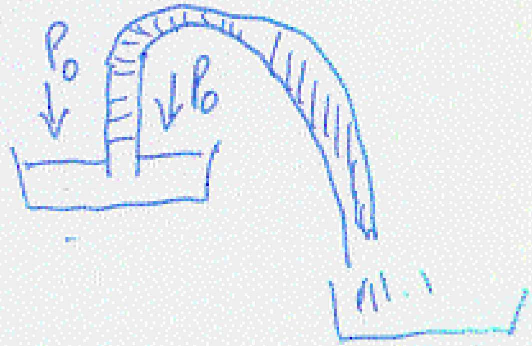
Q: Why not use water?

For 1 atm $\approx 10^5$ Pa, $\rho = 10^3\ \mathrm{kg/m^3}$, height of column $h = \dfrac{P_0}{\rho g} = 10\,\mathrm{m}$ or 33 ft !

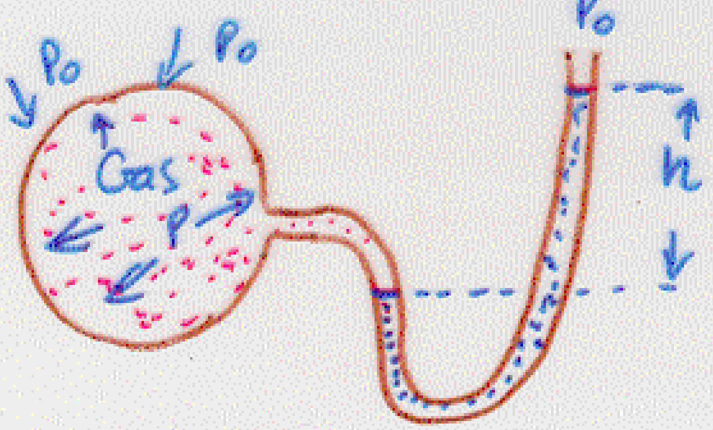
Also, water vapor destroys vacuum at top

BUT: Can use atm. pressure to "lift" water up over a barrier $\lessapprox$ 10 m high

i.e. a siphon



2. Open-tube Manometer: Pressure differences



Pressure difference between gas and atmosphere

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

- can measure h as a warning that gas vessel (aircraft cabin?) will explode if $(P-P_0)$ gets too high

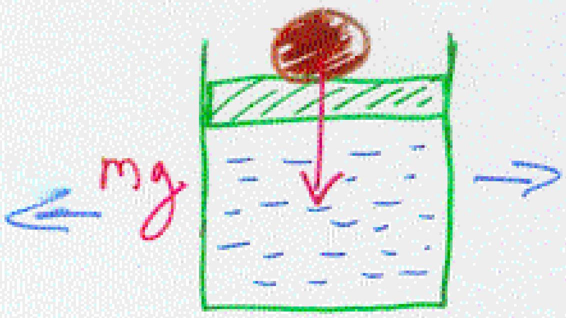
Pascal's Principle

- Already assumed / demo'd

"Change in pressure applied to incompressible fluid .....

..... transmitted to every portion of the fluid"

(transmitted at speed of sound - fast!)



e.g. add weight to top of fluid

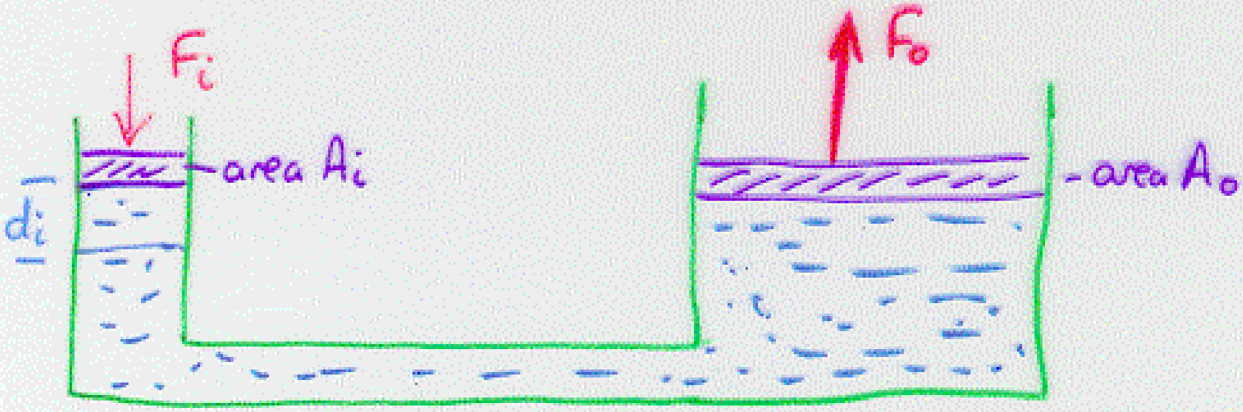
→ transmitted to bottom <u>and</u> side walls

(Remember: at any point in fluid, pressure supports weight of <u>everything</u> above it)

At top of fluid: $P = P_0 + \frac{mg}{A}$

At depth h $P = P_0 + \frac{mg}{A} + \rho g h$

Hydraulic Lever



Apply input force F_i $\Rightarrow$ increases P throughout fluid by $\Delta P = F_i / A_i$ (Pascal)

$\Rightarrow$ net force on larger pistion $F_o = \Delta P / A_o$

i.e. $F_o = \dfrac{A_o}{A_i} F_i$: force magnified !

But: no free lunch. If F_i moves piston down by d_i

input work $= F_i d_i$

volume displaced $= A_i d_i = V$

$\therefore$ output piston moves up by $d_o = \dfrac{V}{A_o} = \dfrac{A_i}{A_o} d_i$

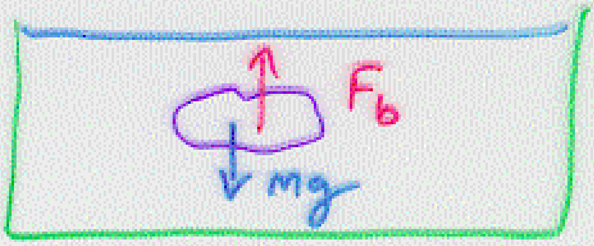
$\Rightarrow$ output work $F_o d_o = \dfrac{A_o}{A_i} F_i \cdot \dfrac{A_i}{A_o} d_i$

i.e. $F_o d_o = F_i d_i$

$\therefore$ Work (energy) conserved

Archimedes Principle - Eureka!

Buoyant Force



Isolate a piece of fluid, any shape or size

At eqm., weight of fluid piece is supported by pressure diff. above + below:

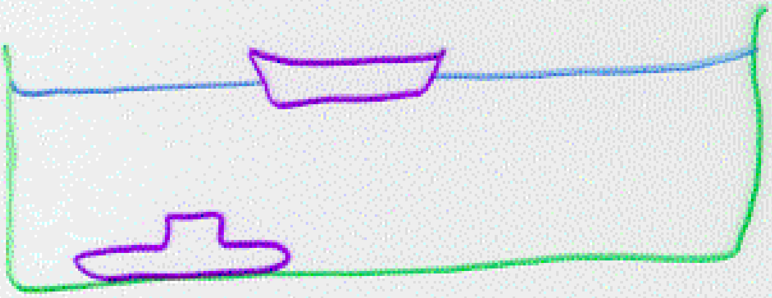
i.e. a buoyant force $F_b = \int P.dA = mg = \rho V g$

Now "remove" fluid piece and replace with something else, mass M

Buoyant force F_b still provided by fluid above / below

$\Rightarrow$ "A body immersed in a fluid experiences a buoyant force F_b = weight of the fluid displaced"
(occupying same volume)

Archimedes cont/d.



"Effective weight" of object (downwards)

$= Mg - \rho V g$

- Can be used to simulate reduced gravity
  (bottom of pool $\approx$ moon)

Or: if $M < \rho V$, i.e. $\rho_{obj} = \frac{M}{V} < \rho$,

object is pushed upwards until it floats,

displacing a mass $= M$ of fluid

e.g. ships with steel hulls

Subs, fishes, whales control F_b by changing their

average density relative to water

i.e. $\frac{M}{V}$