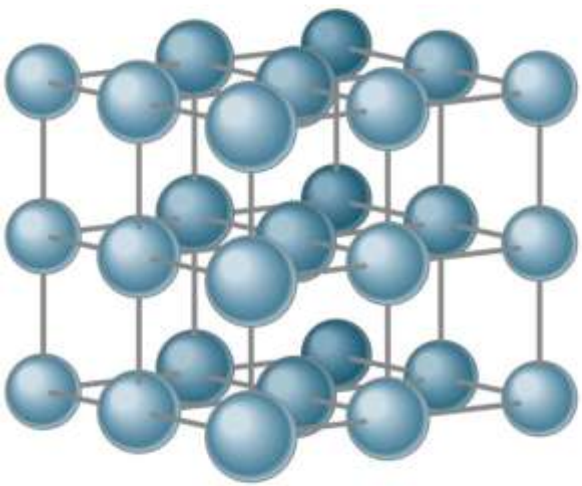
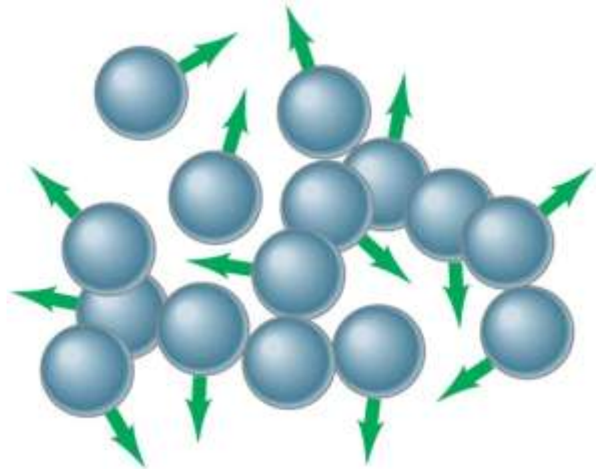
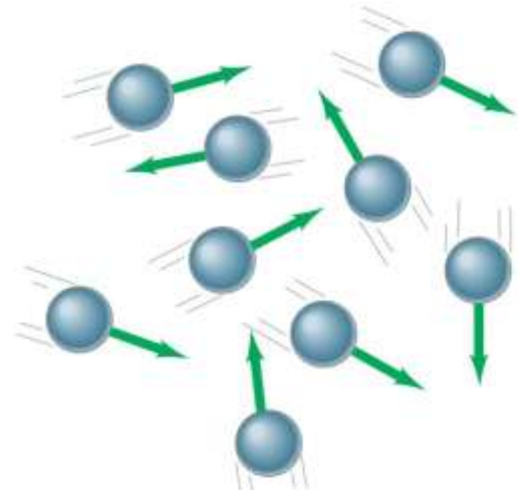
Matter



(a)



(b)



(c)

Solid
Fixed positions
Fixed shape
Fixed volume

Liquid
Free to move but bound together
Shape not fixed
Fixed volume

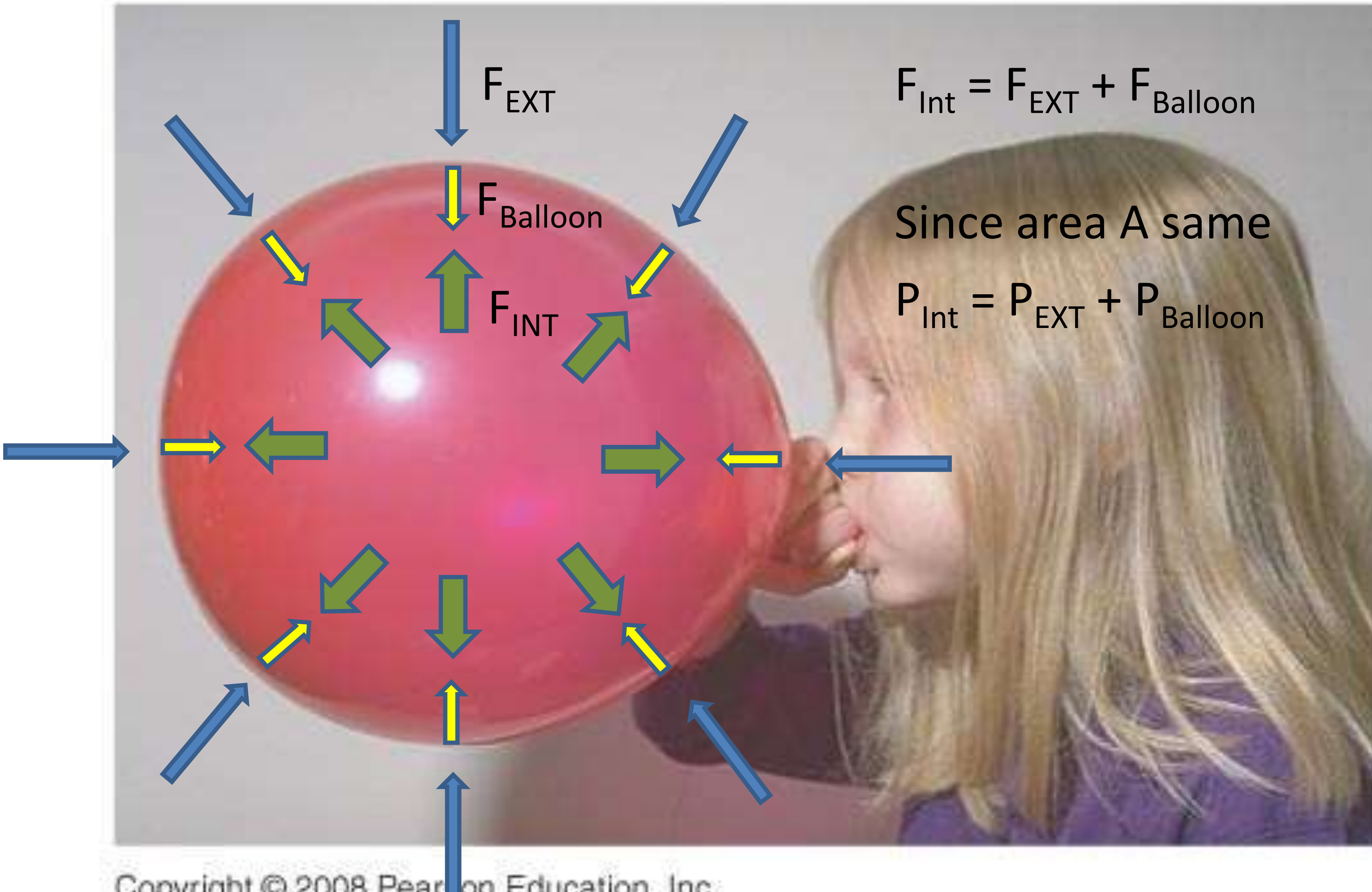
Gas
Free to move
Unbound
Shape not fixed
Volume not fixed

Fluids – can flow

TABLE 13–1
Densities of Substances[†]

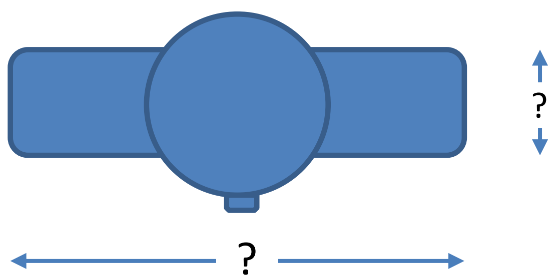
Substance	Density, ρ (kg/m^3)
Solids	
Aluminum	2.70×10^3
Iron and steel	7.8×10^3
Copper	8.9×10^3
Lead	11.3×10^3
Gold	19.3×10^3
Concrete	2.3×10^3
Granite	2.7×10^3
Wood (typical)	$0.3-0.9 \times 10^3$
Glass, common	$2.4-2.8 \times 10^3$
Ice (H_2O)	0.917×10^3
Bone	$1.7-2.0 \times 10^3$
Liquids	
Water (4°C)	1.00×10^3
Blood, plasma	1.03×10^3
Blood, whole	1.05×10^3
Sea water	1.025×10^3
Mercury	13.6×10^3
Alcohol, ethyl	0.79×10^3
Gasoline	0.68×10^3
Gases	
Air	1.29
Helium	0.179
Carbon dioxide	1.98
Steam (water, 100°C)	0.598

[†]Densities are given at 0°C and 1 atm pressure unless otherwise specified.


F_{EXT}
$F_{Balloon}$
F_{INT}
$F_{Int} = F_{EXT} + F_{Balloon}$
Since area A same
$P_{Int} = P_{EXT} + P_{Balloon}$

How much air is pressing down on you?

- Know the pressure (P = 1 Atm = 101 000 N/m^2)
- Know F (weight) = $P \times A$
- Need to estimate area A looking from above



- Why aren't you crushed?

Why aren’t you crushed?

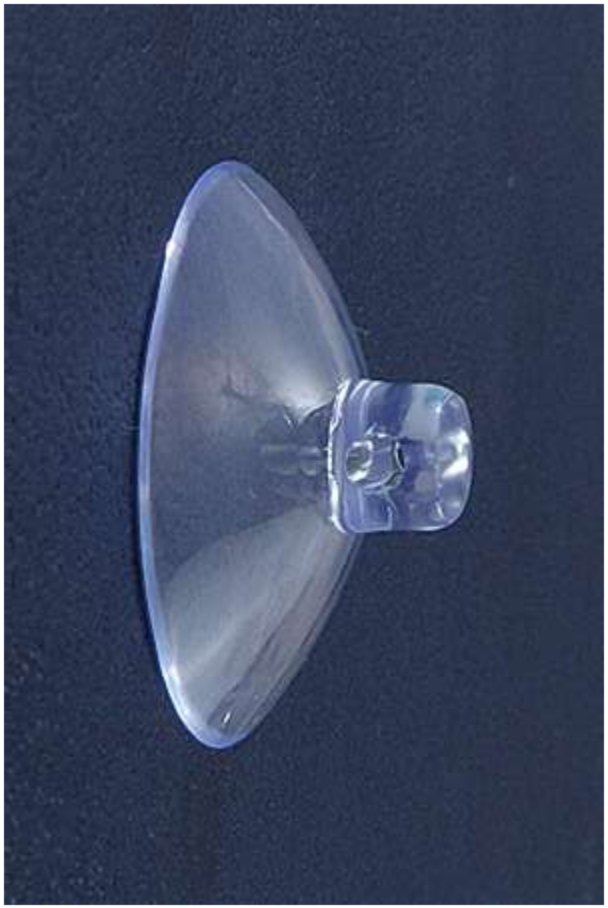
Made of

- Bone (incompressible)
- Bags of liquid (eyes, blood in arteries, cells, etc.) (incompressible)
- Air-filled cavity (but air is at 1 Atm, too)

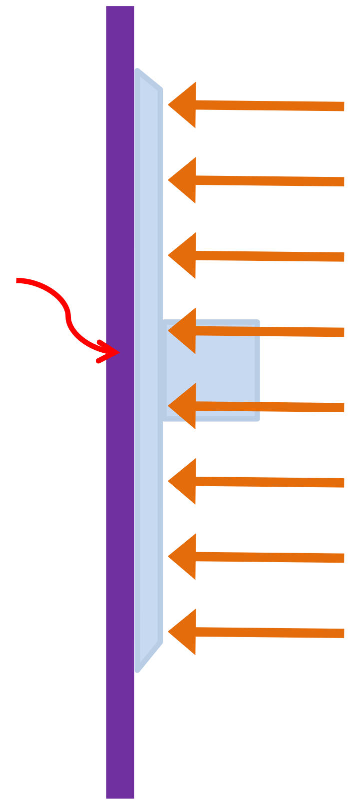
Will you explode in a vacuum?

- No, your skin is tougher than a balloon and it doesn't stretch much.
- People have been exposed to short periods of vacuum without ill effect.

Vacuums Do Not Suck!



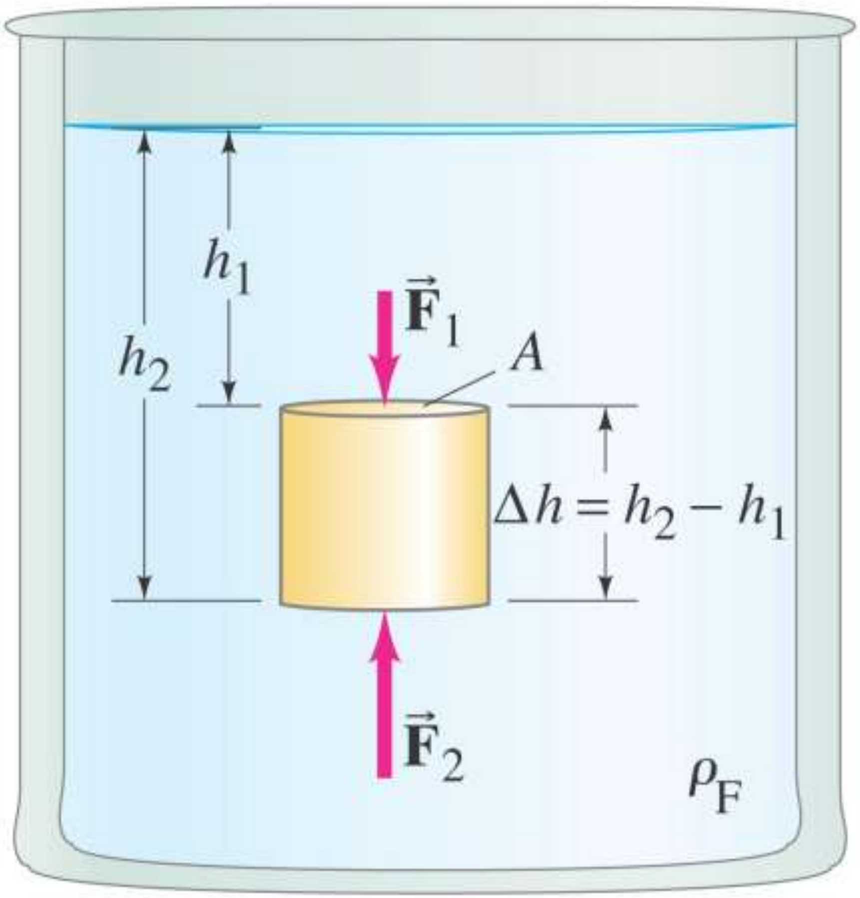
Air squeezed out. $P_{inside} \sim 0$



P = 1 Atm

F = PA

Hydrostatic Pressure



$F_2 = F_1 + mg$

$P_2A = P_1A + \rho A\Delta hg$

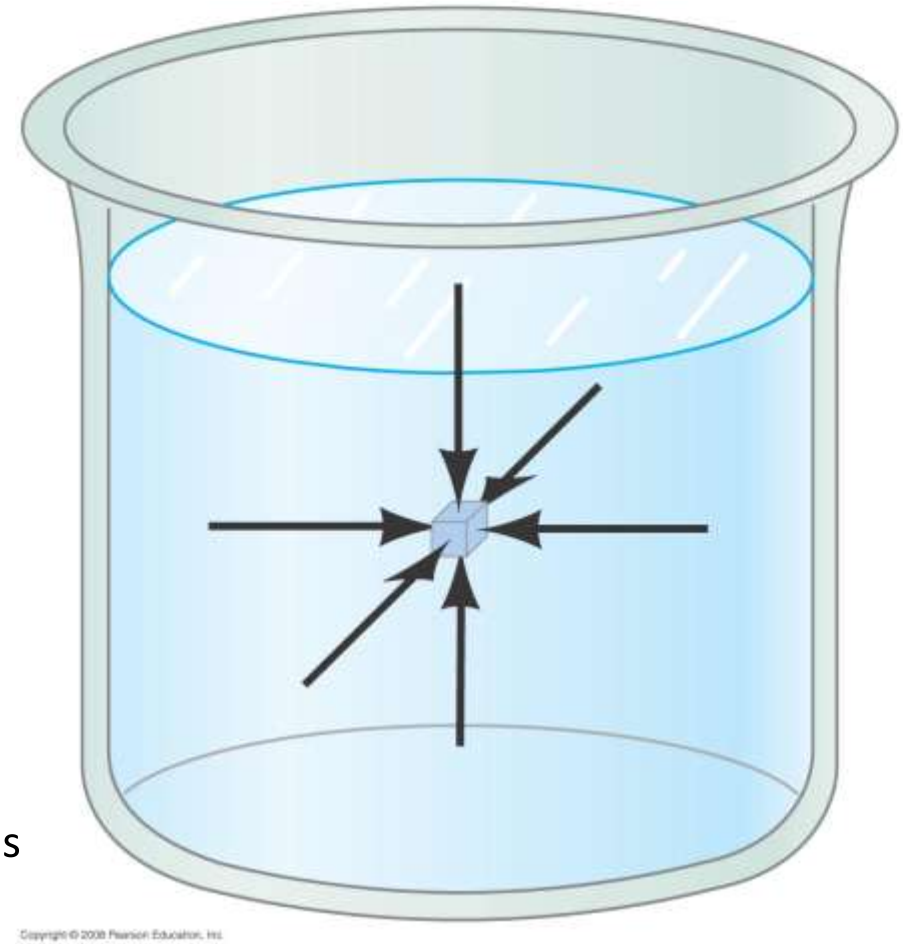
$P_2 = P_1 + \rho g\Delta h$

$P = P_0 + \rho gh$

P_0 is pressure at surface, often 1 Atm.

Some Consequences

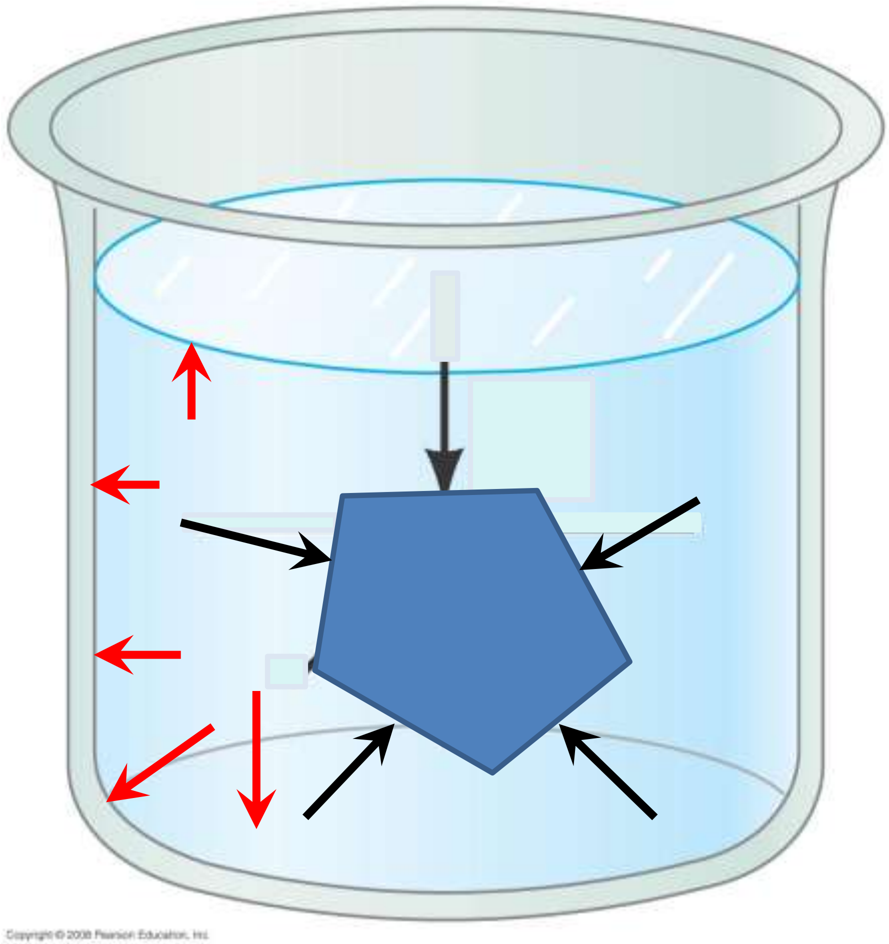
Pressure is the same in every direction in a non-moving (i.e. in equilibrium) fluid at a given depth. If not, fluid would be in motion.



Tiny cube of water, side length L is miniscule and mass is negligible
$P_{below} = P_{above} + \rho g L$ and $L \cong 0$
so $P_{below} = P_{above}$

Pressure acts on all directions on an object immersed in a fluid and on walls of container.

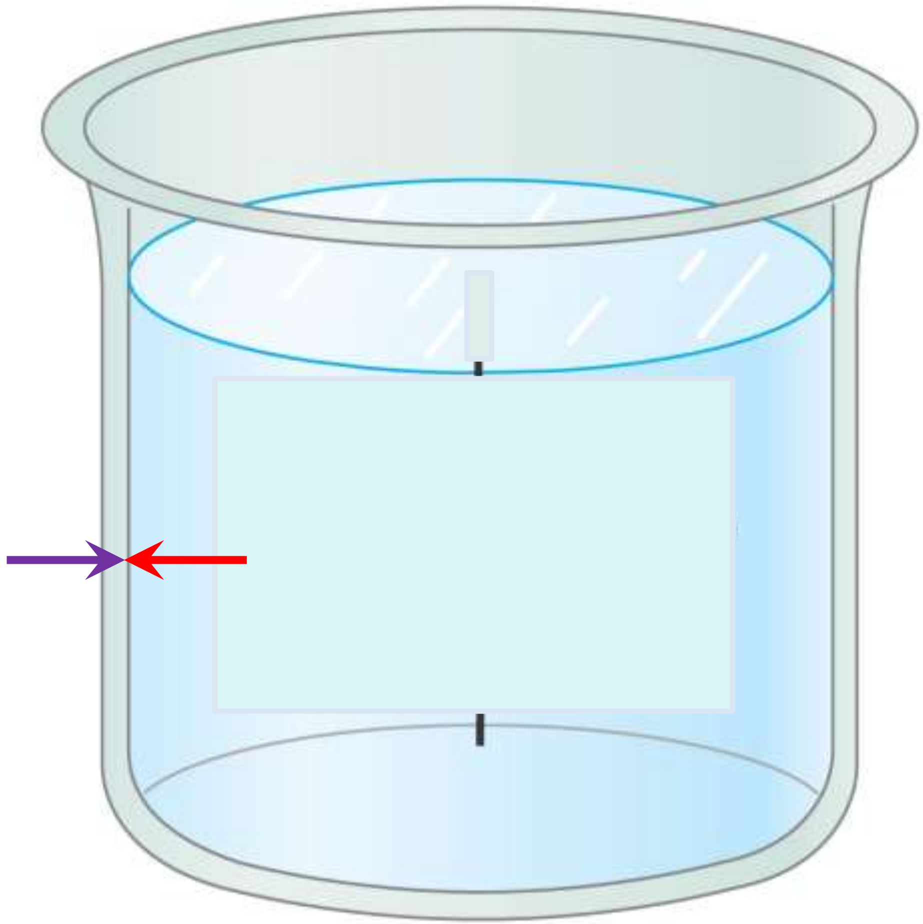
Pressure will vary with depth though.



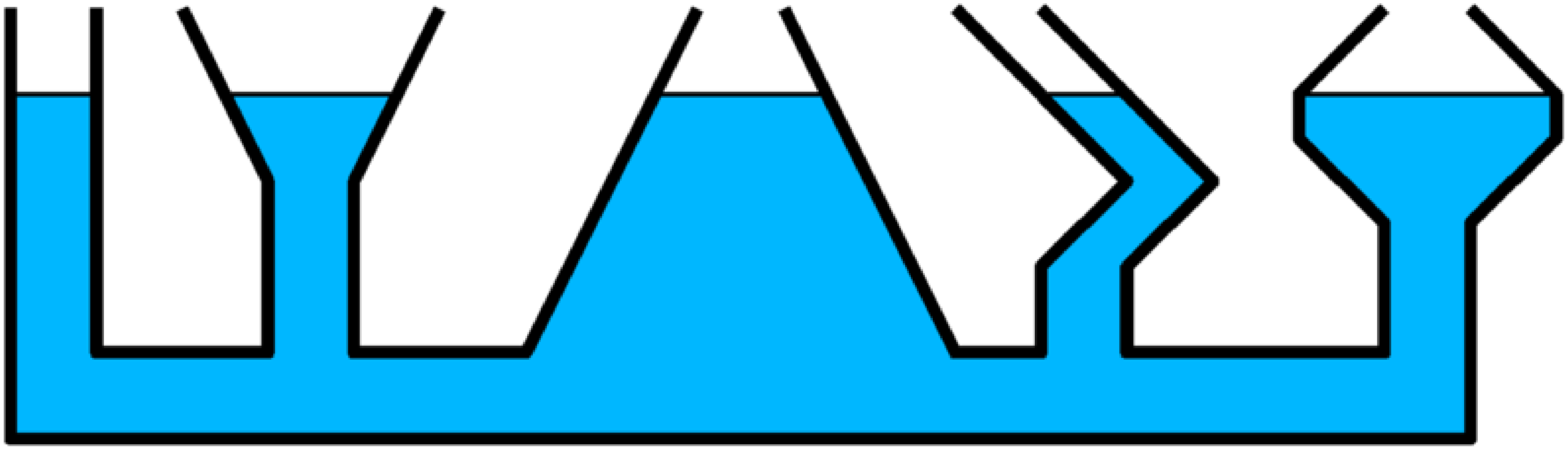
Pressure & force of non-moving fluid on container is always perpendicular to walls of container.

Reaction force of container on fluid is therefore also perpendicular.

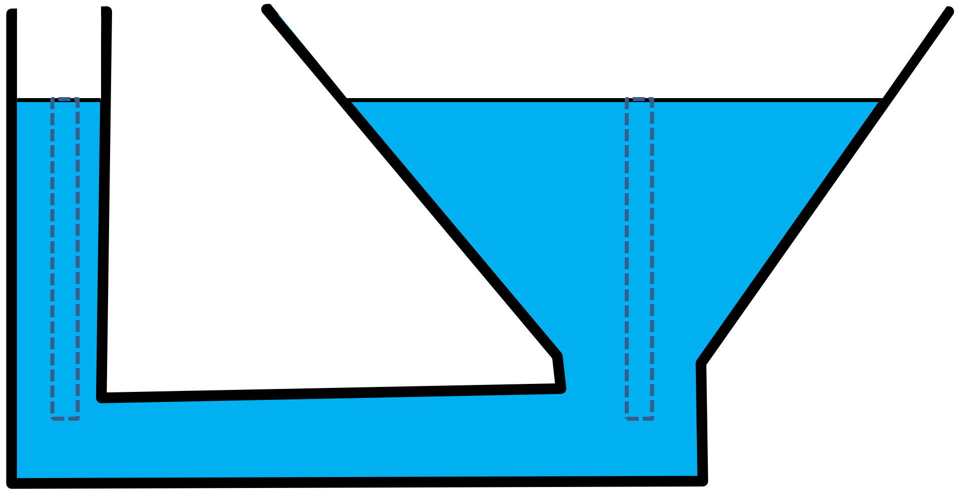
If these forces were not perpendicular, there would be a net force that moves the fluid.



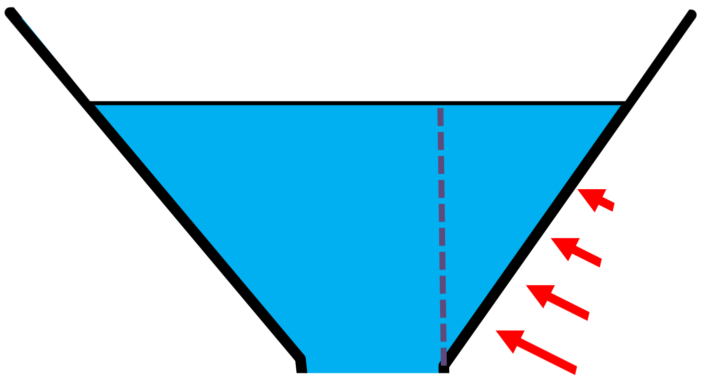
A connected liquid in equilibrium rises to the same height



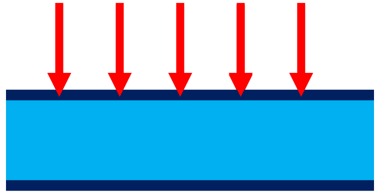
Columns have same height, base, and so same weight of liquid and same pressure



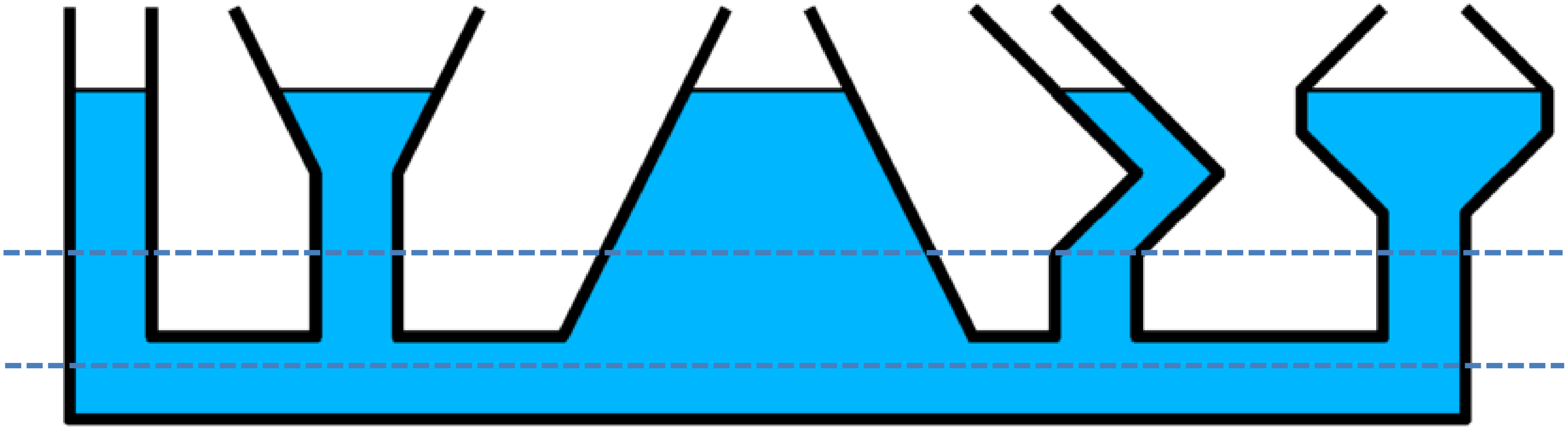
Container walls support some of the weight



Container walls also exert extra pressure



The pressure is the same at all points on a horizontal line through a connected liquid in equilibrium is the same



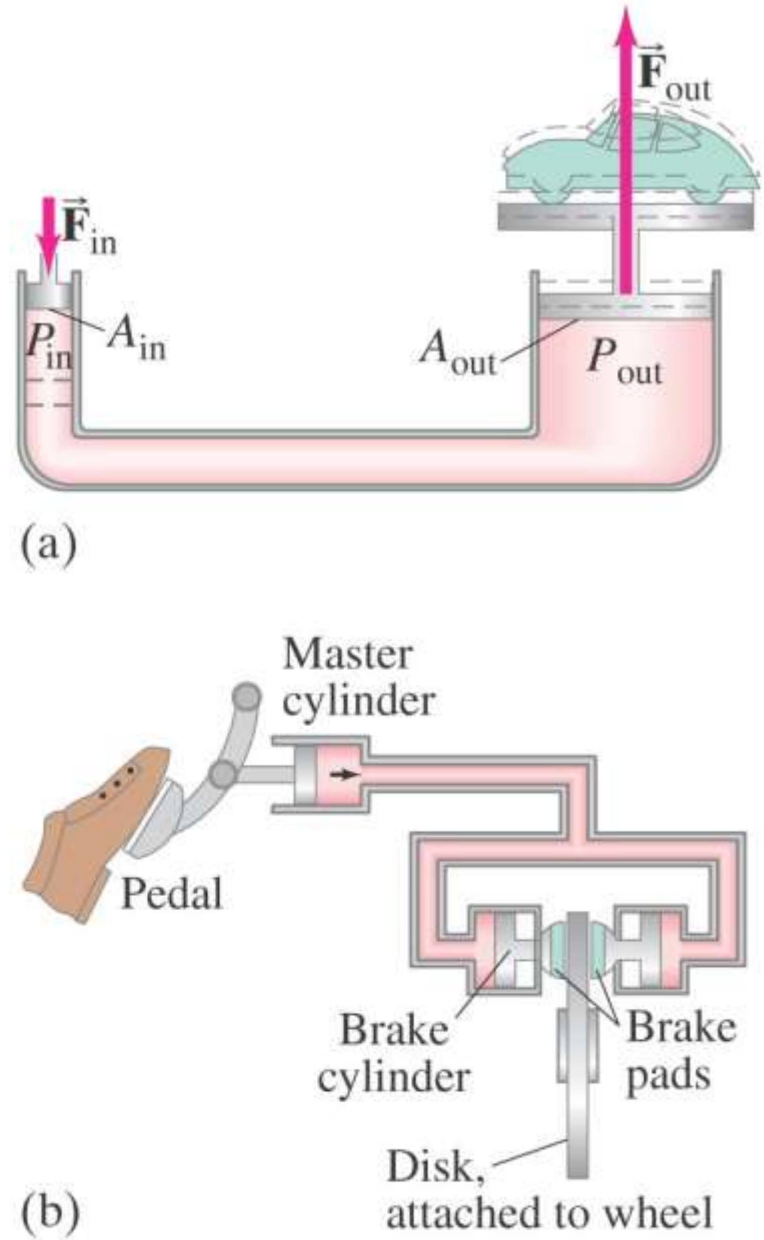
Pascal's Principle

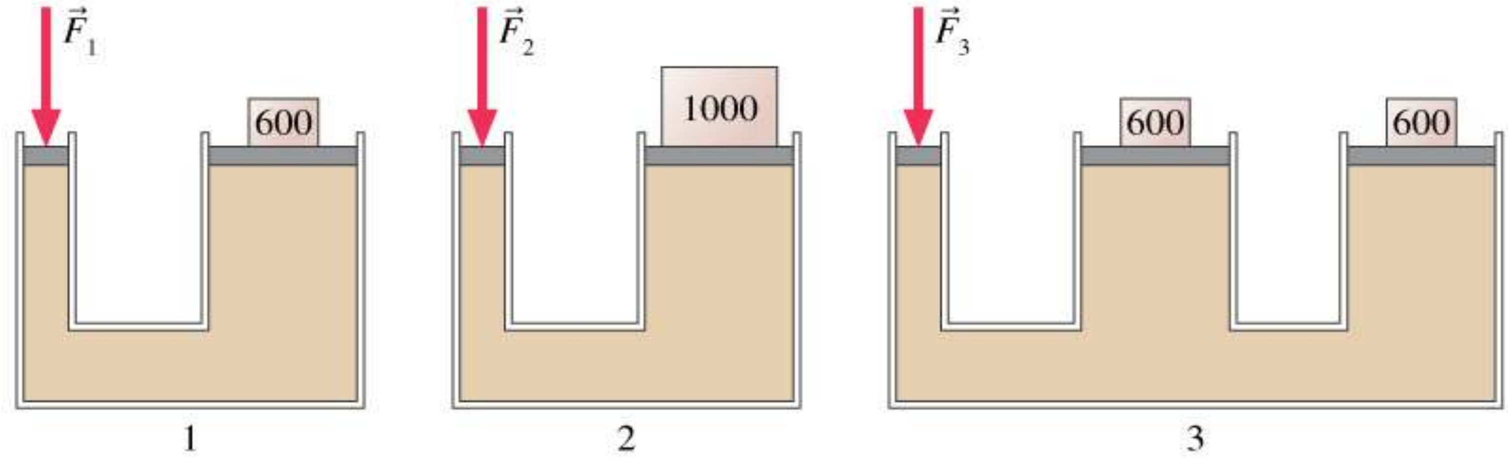
If external pressure is applied to a confined fluid, the pressure at every point within the fluid increases by that much.

Mechanical advantage

Since $P_{in} = P_{out}$,

$F_{out}/F_{in} = A_{out}/A_{in}$





Rank in order, from largest to smallest, the magnitudes of the forces $\vec{F}_1, \vec{F}_2$ and $\vec{F}_3$ required to balance the masses. The masses are in kilograms.

A. $F_2 > F_1 > F_3$

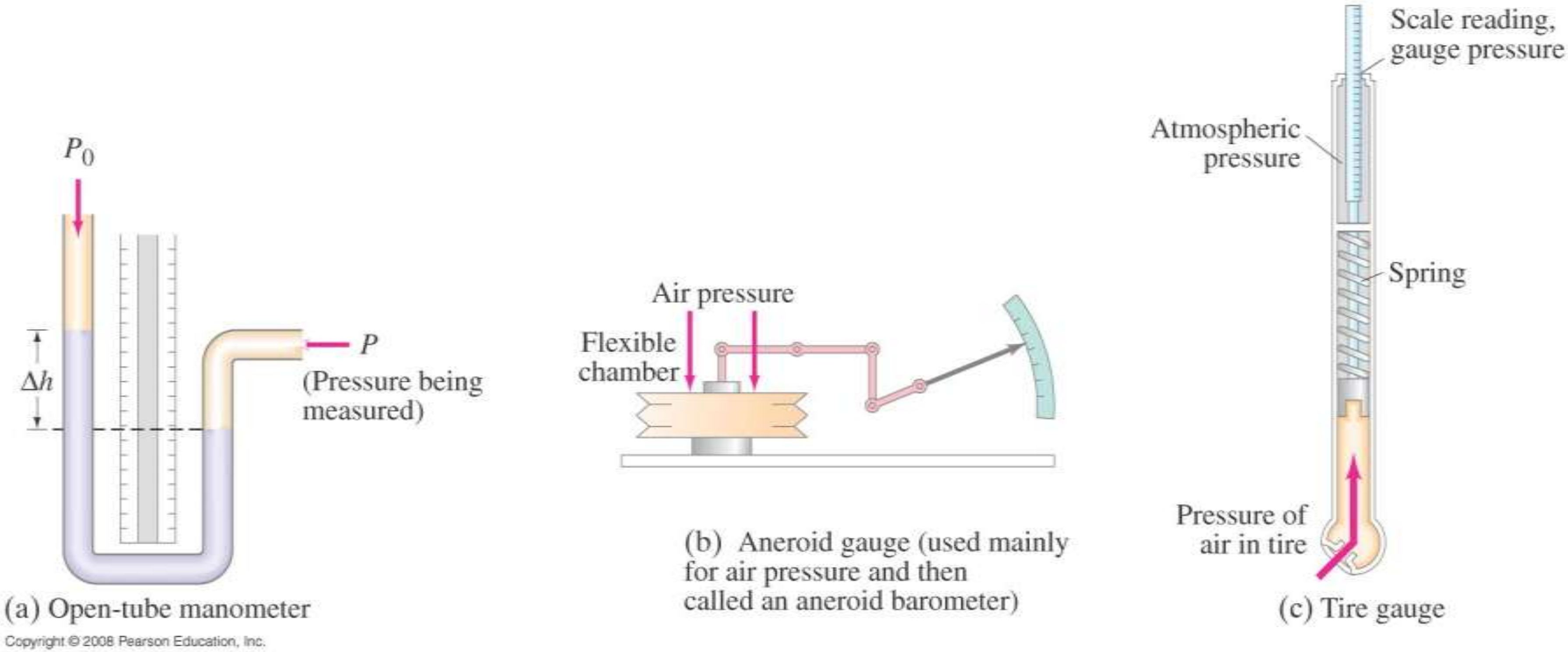
B. $F_2 > F_1 = F_3$

C. $F_3 > F_2 > F_1$

D. $F_3 > F_1 > F_2$

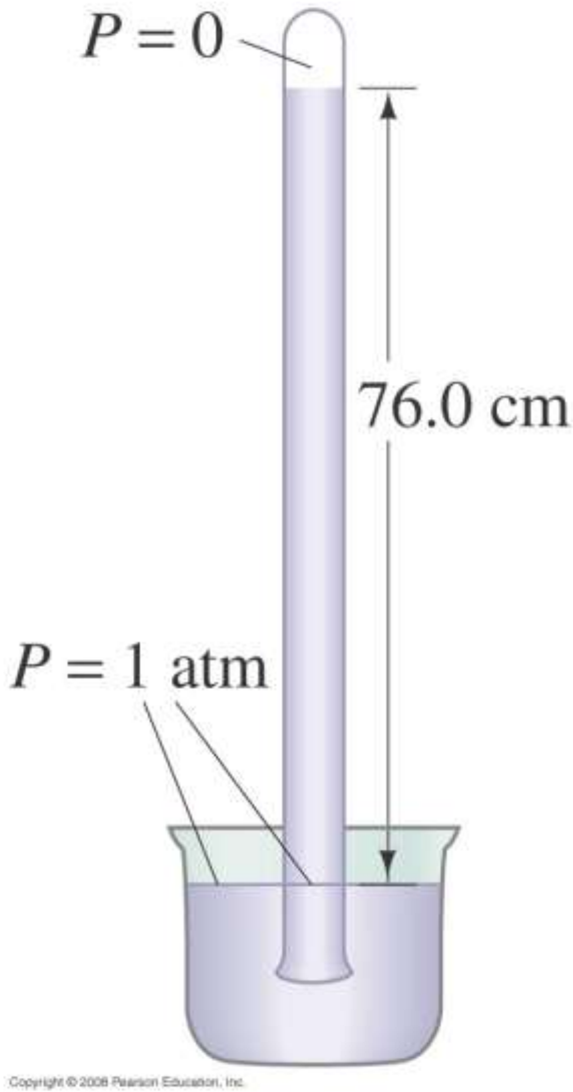
E. $F_1 = F_2 = F_3$

Measuring Pressure



- Absolute Pressure: $P = P_0 + \rho g \Delta h$
- Gauge Pressure: $\Delta P = P - P_0 = \rho g \Delta h$

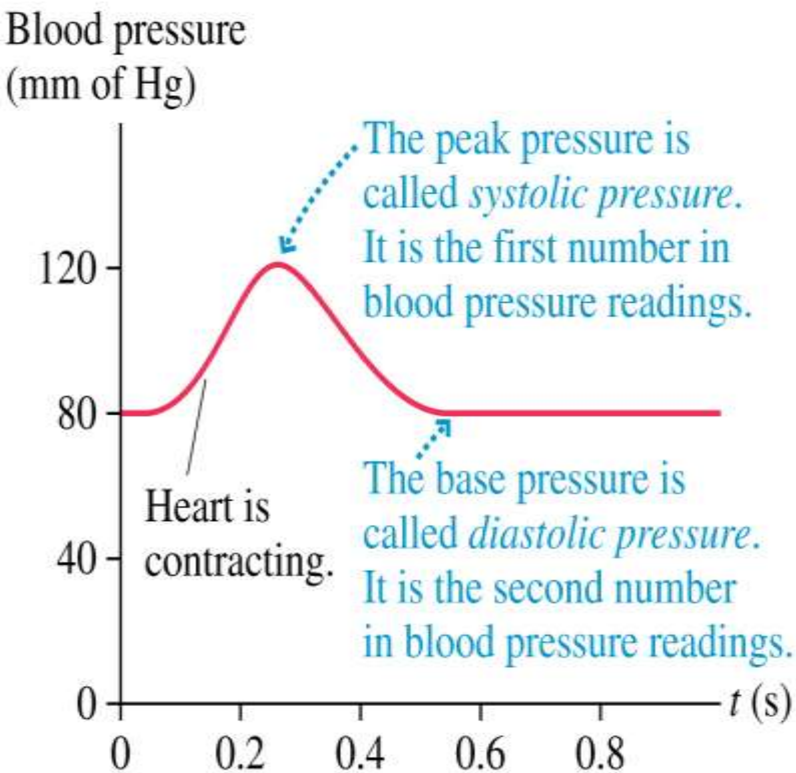
Mercury Barometer

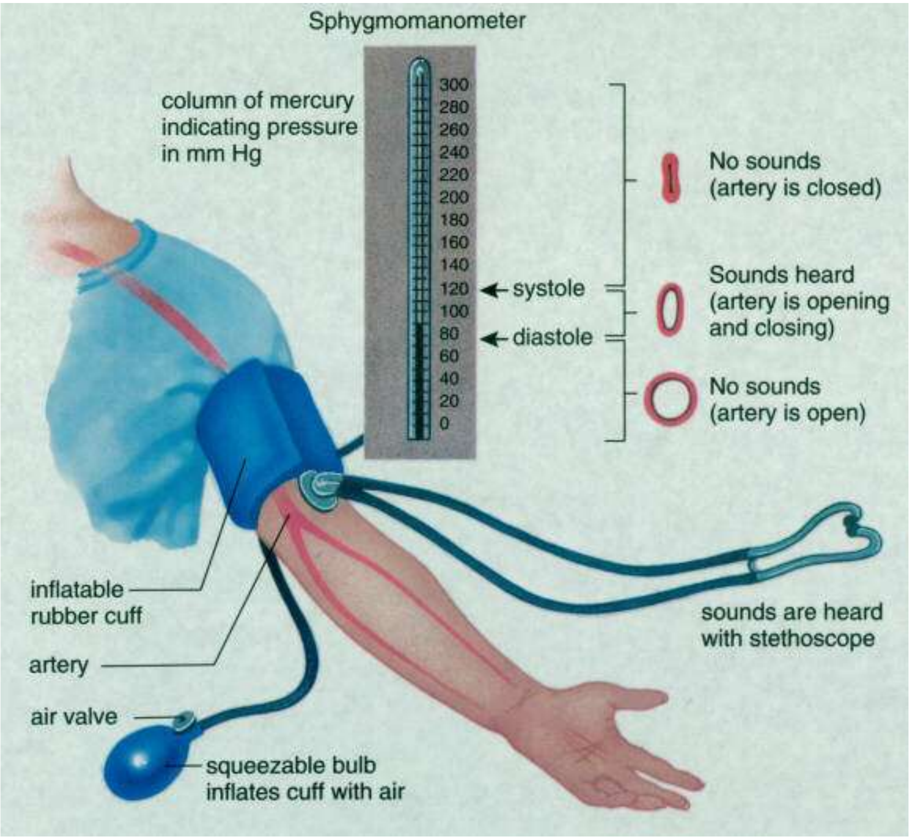


- Use Hg because ρ is large, Δh is reasonably small
- $\Delta P = \rho_{Hg}\, g\, \Delta h$
- So common Δh became measurement of pressure
- 1 Atm = 760 mm Hg (torr)

Measuring Blood Pressure

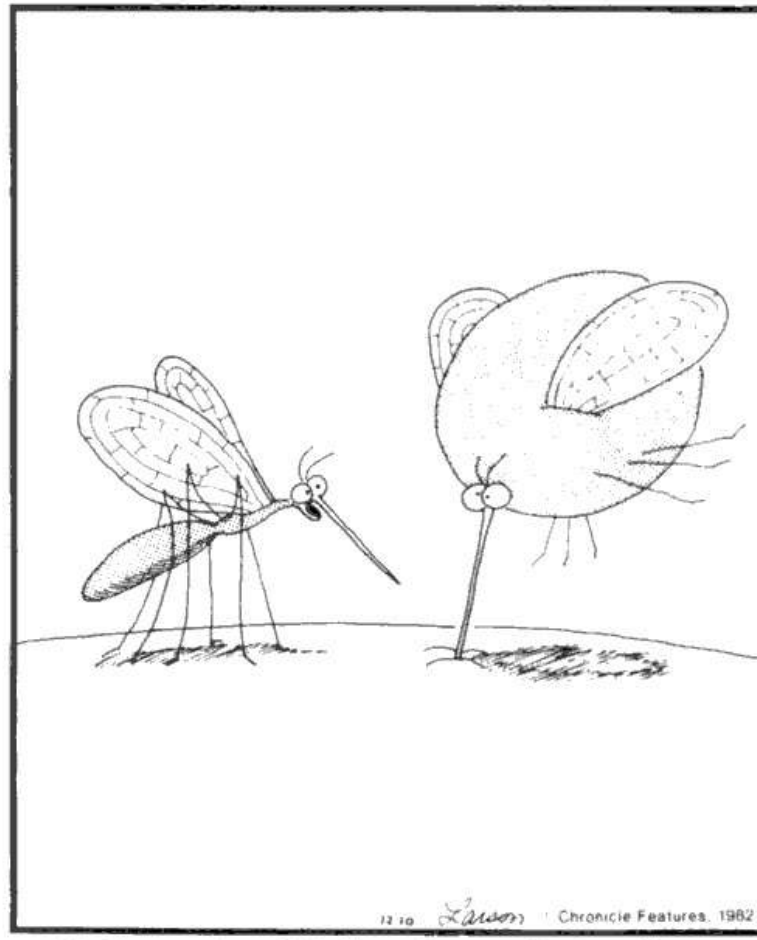
Typical BP is 120/80





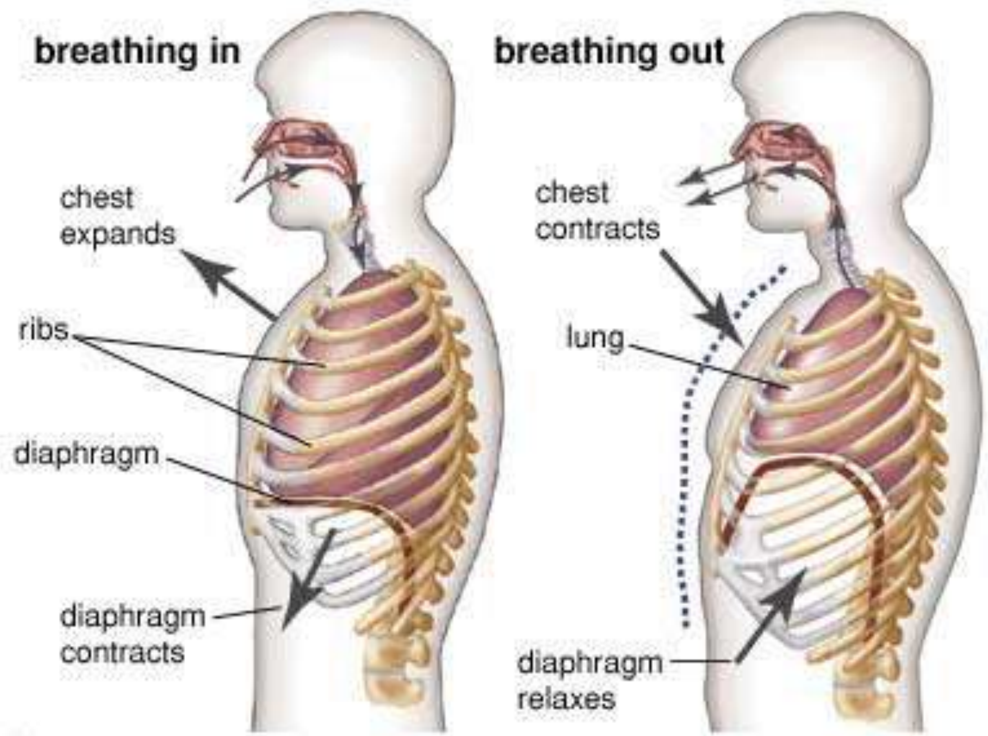
- BP is a gauge pressure. Values are above atmospheric pressure.
- Artery pressure
- Vein pressure much lower: 5 to 10 mmHg.

THE FAR SIDE By GARY LARSON



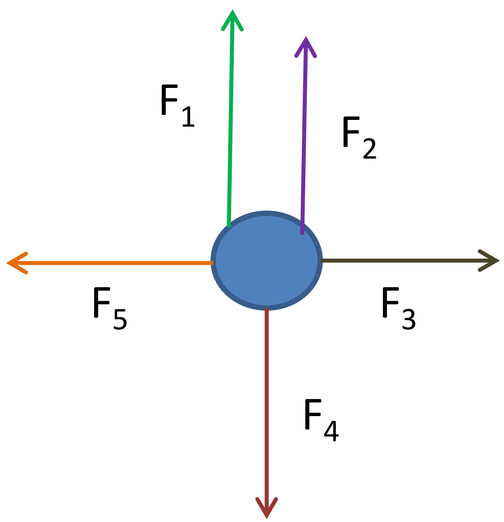
"Pull out, Betty! Pull out! . . . You've hit an artery!"

Breathing



Pressure change is ~100 Pa

Working with Forces In Equilibrium



Stationary, a = 0

- Upward force components must balance downward force components

$$F_1 + F_2 = F_4$$

- Right force components must balance left force components

$$F_3 = F_5$$

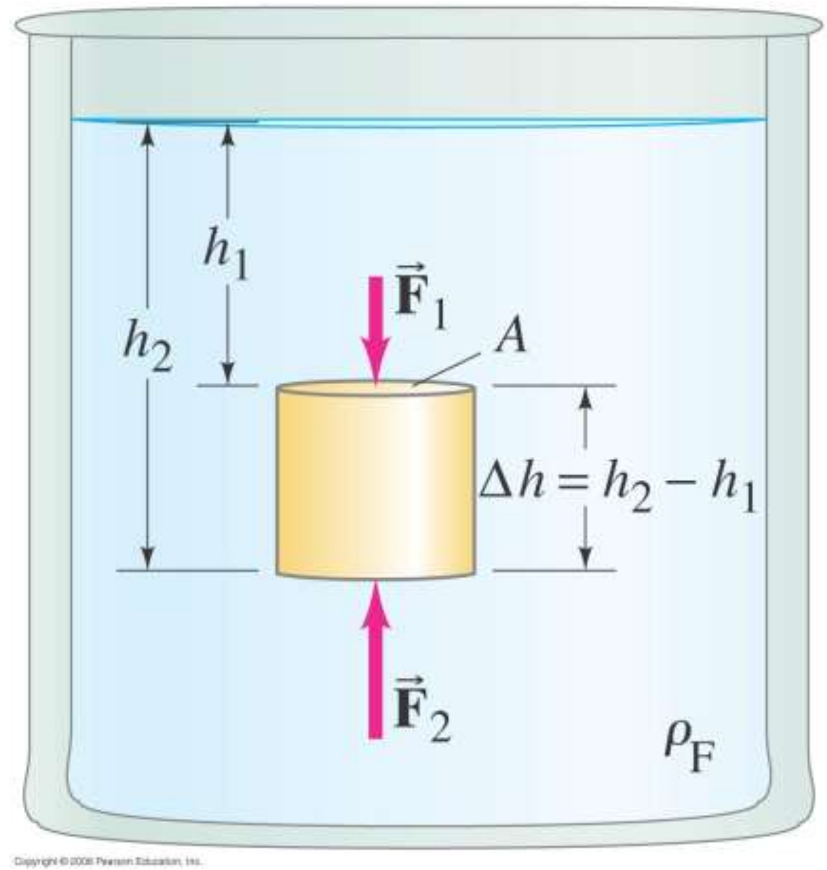
Buoyant Force

$P_2 = P_1 + \rho g h$

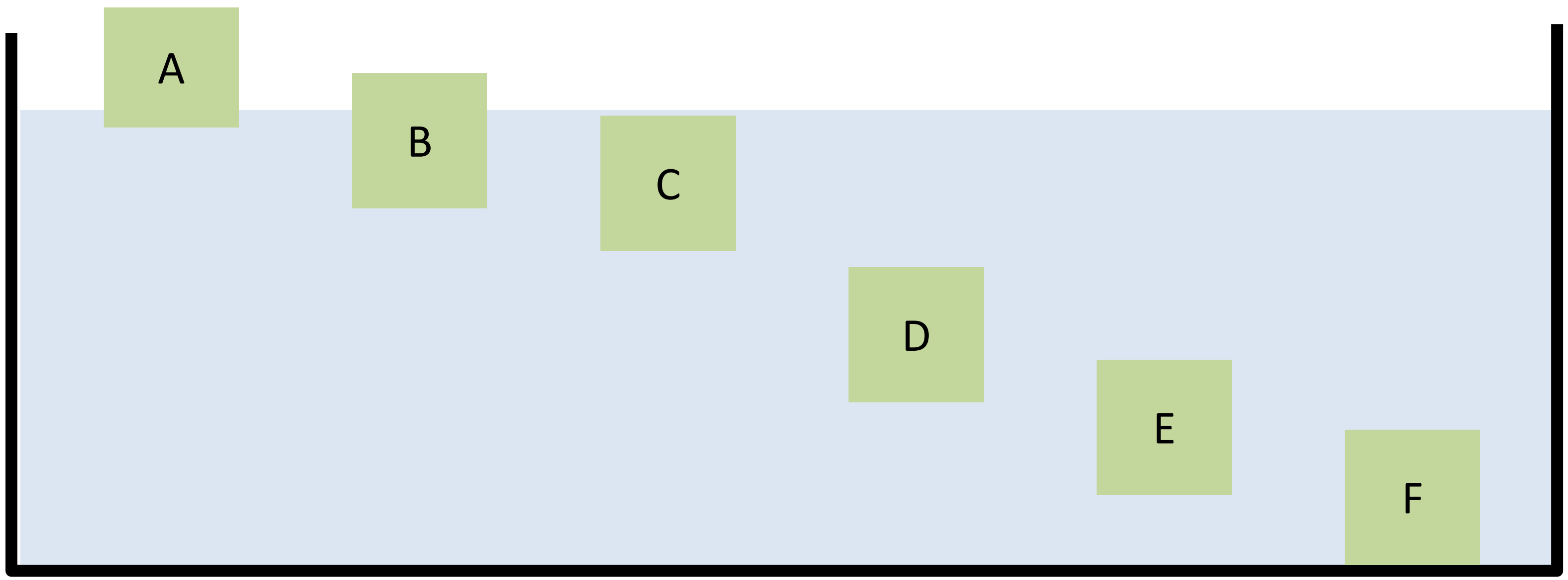
$P_2 A = P_1 A + \rho g h A$

$F_2 – F_1 = \rho g V_{\text{displaced fluid}}$

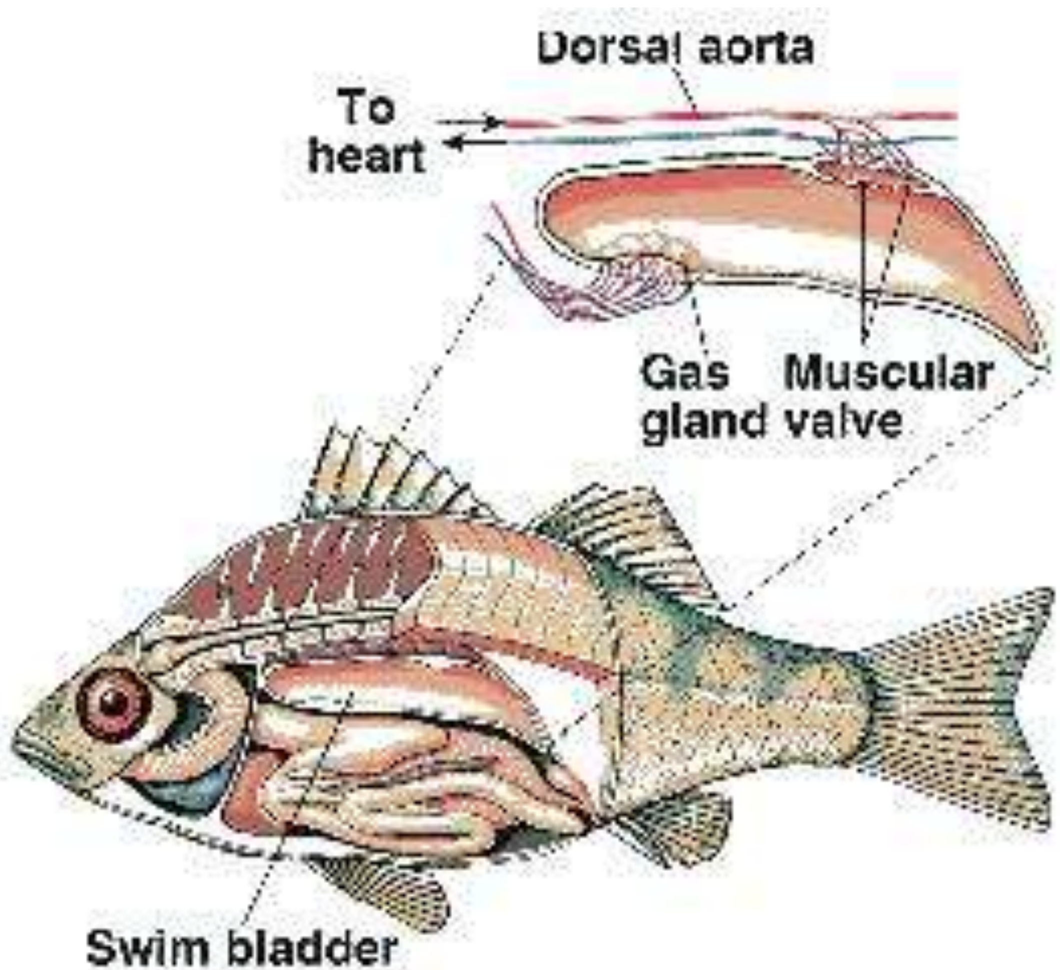
$F_B = \rho g V_{\text{displaced fluid}}$



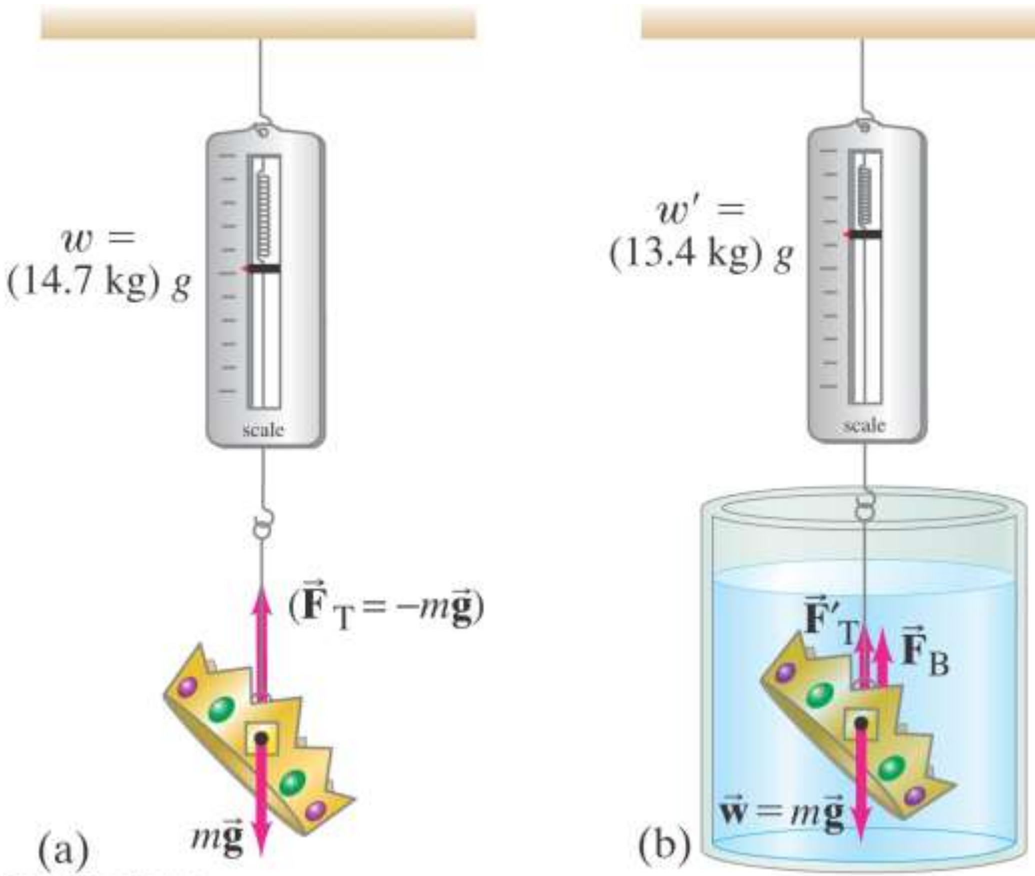
- If $\rho_{object} < \rho_{fluid}$, object floats
- If $\rho_{object} > \rho_{fluid}$, object sinks (but still experience buoyant force)
- If $\rho_{object} = \rho_{fluid}$, object will stay at any level (neutral bouyancy)



A. Rank the buoyant force on each block from largest to smallest.
B. Rank the density force of each block from largest to smallest.


Dorsal aorta
To heart
Gas gland
Muscular valve
Swim bladder

Determining Density



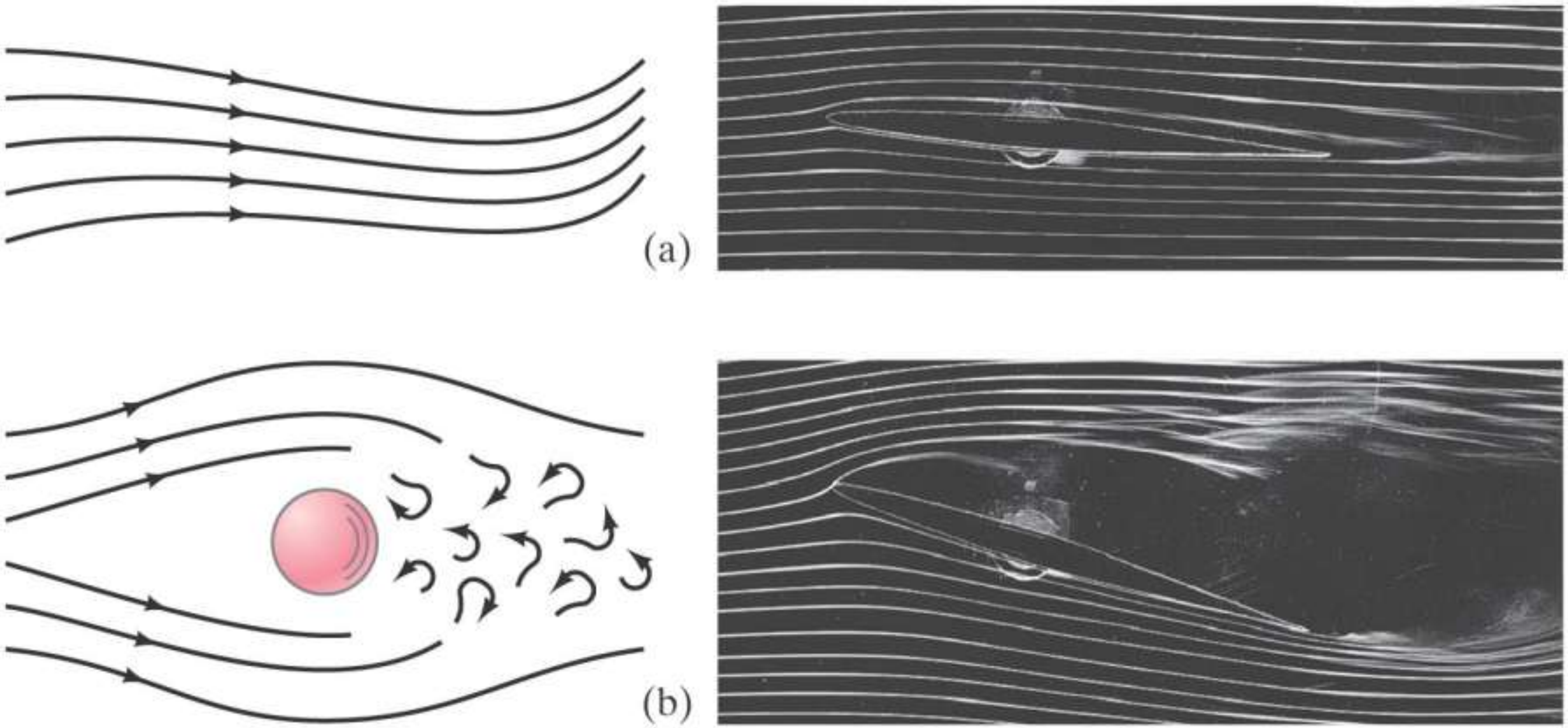
$$w = mg = \rho_O g V_O$$

$$w' = \rho_O g V_O - \rho_F g V_O$$

$$\frac{w}{w - w'} = \frac{\rho_O}{\rho_F}$$

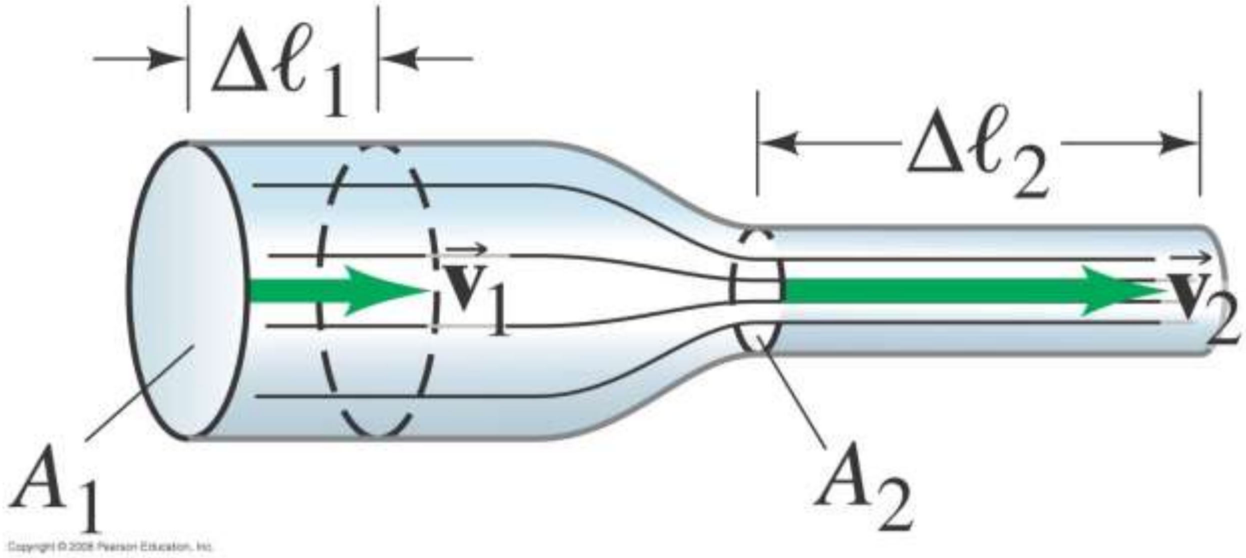
Flowing Fluids

Laminar flow versus Turbulence
(low speed) (high speed)



Equation of Continuity

- Consequence of incompressibility

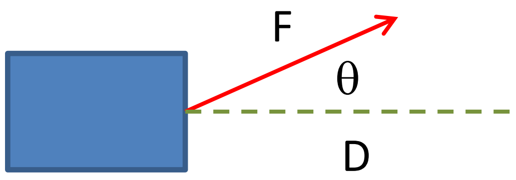


- $M_{in} = M_{out} \Rightarrow V_{in} = V_{out} \Rightarrow A_1\Delta\ell_1 = A_2\Delta\ell_2$
- $A_1\Delta\ell_1/\Delta t = A_2\Delta\ell_2/\Delta t$ (same time involved)
- $A_1 v_1 = A_2 v_2$

Bernoulli's Equation

- Application of Conservation of Energy to moving fluids
- Assumes incompressibility, laminar flow, and no loss to internal fluid friction (viscosity)
- *Where the velocity of a fluid is high, the pressure is low, and vice versa*

Recall



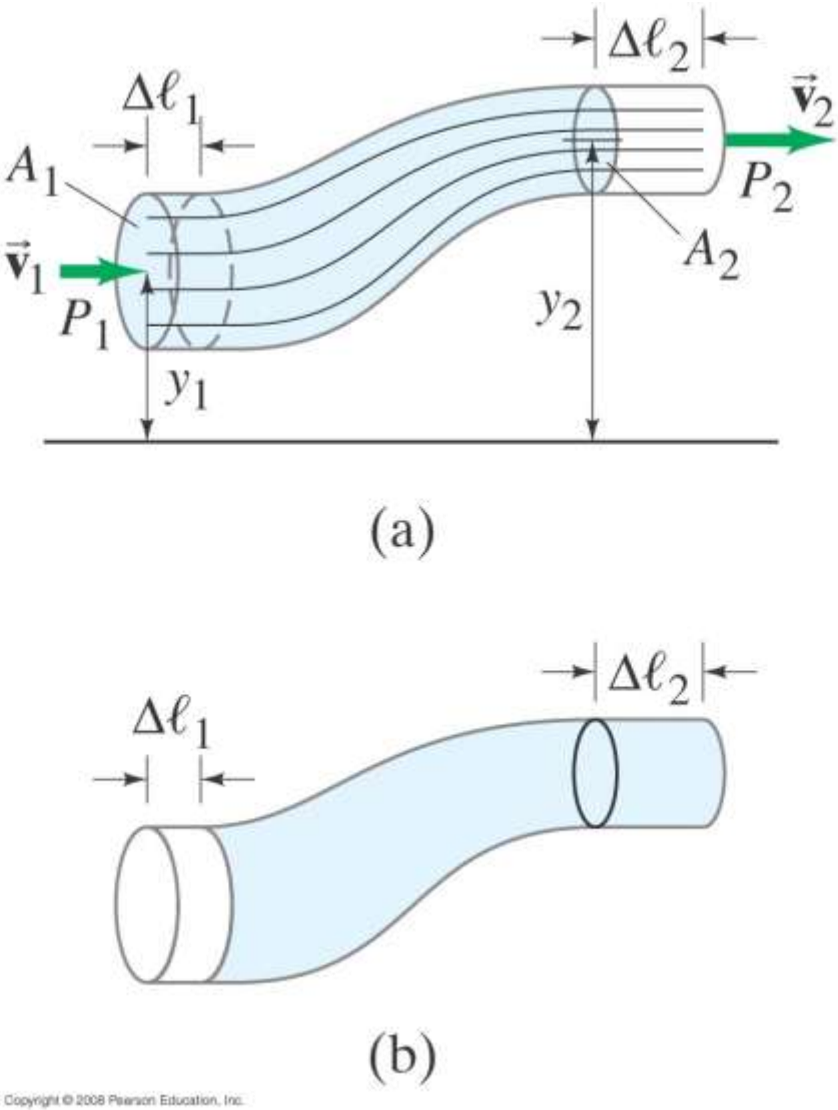
Work, W = FDcosθ

W > 0 if θ < 90°
W = 0 if θ = 90
W < 0 if θ > 90°

Work-Energy Theorem

Work changes the Kinetic Energy of an object

$$W = \frac{1}{2}mv_{final}^2 - \frac{1}{2}mv_{initial}^2$$



- Pressure does work at each end (+ in, – out)

  $F \times \Delta\ell = P \times A \times \Delta\ell = P \times V$

- Gravity does work

  $-\, mg(y_2 - y_1) = -\, \rho Vg(y_2 - y_1)$

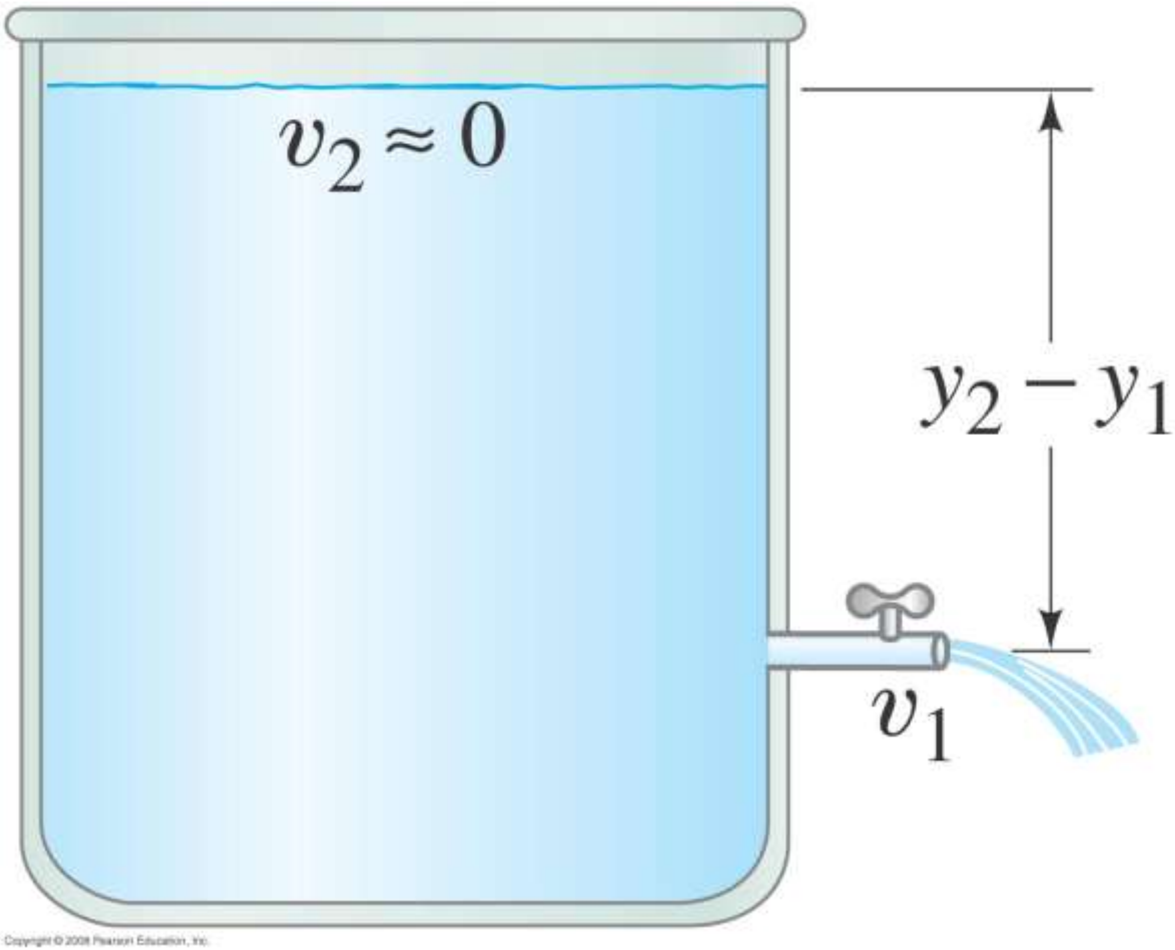
- KE changes

  $\frac{1}{2}m(v_2^2 - v_1^2) = \frac{1}{2}\rho V\,(v_2^2 - v_1^2)$

- $P_1V - P_2V - \rho Vg(y_2 - y_1) = \frac{1}{2}\rho V\,(v_2^2 - v_1^2)$
- Eliminate V and separate 1 and 2 terms

$P_1 + \rho g y_1 + \frac{1}{2}\rho v_1^2 = P_2 + \rho g y_2 + \frac{1}{2}\rho v_2^2$

Outlet Speed (Dams & Water Towers)



$$P_1 + \rho g y_1 + \tfrac{1}{2}\rho v_1^2 = P_2 + \rho g y_2 + \tfrac{1}{2}\rho v_2^2$$

$P_1 = P_2 = P_{ATM}$

$v_2 \cong 0 \quad (A_2 >> A_1)$

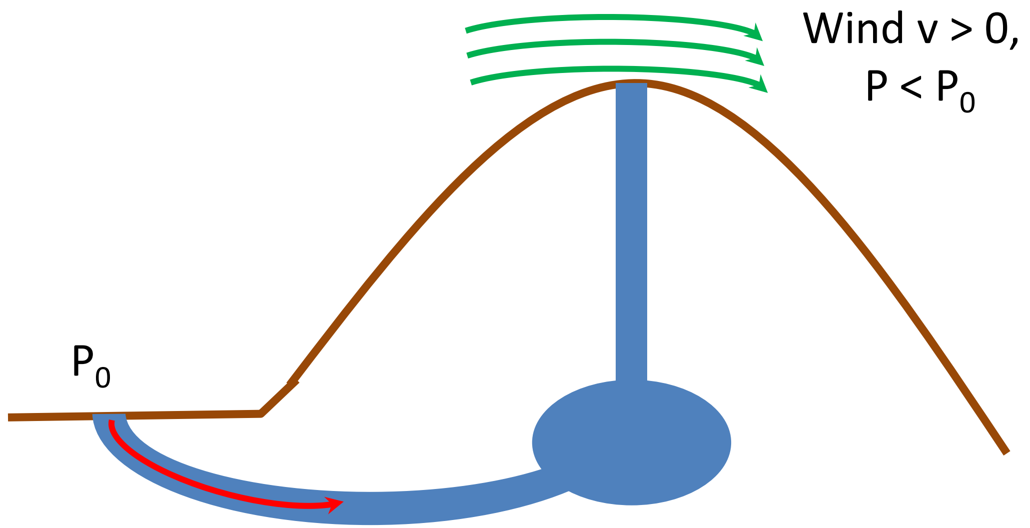
$$\rho g y_1 + \tfrac{1}{2}\rho v_1^2 = \rho g y_2$$

$$v_1^2 = 2g\Delta y$$

Same as if liquid fell that height!

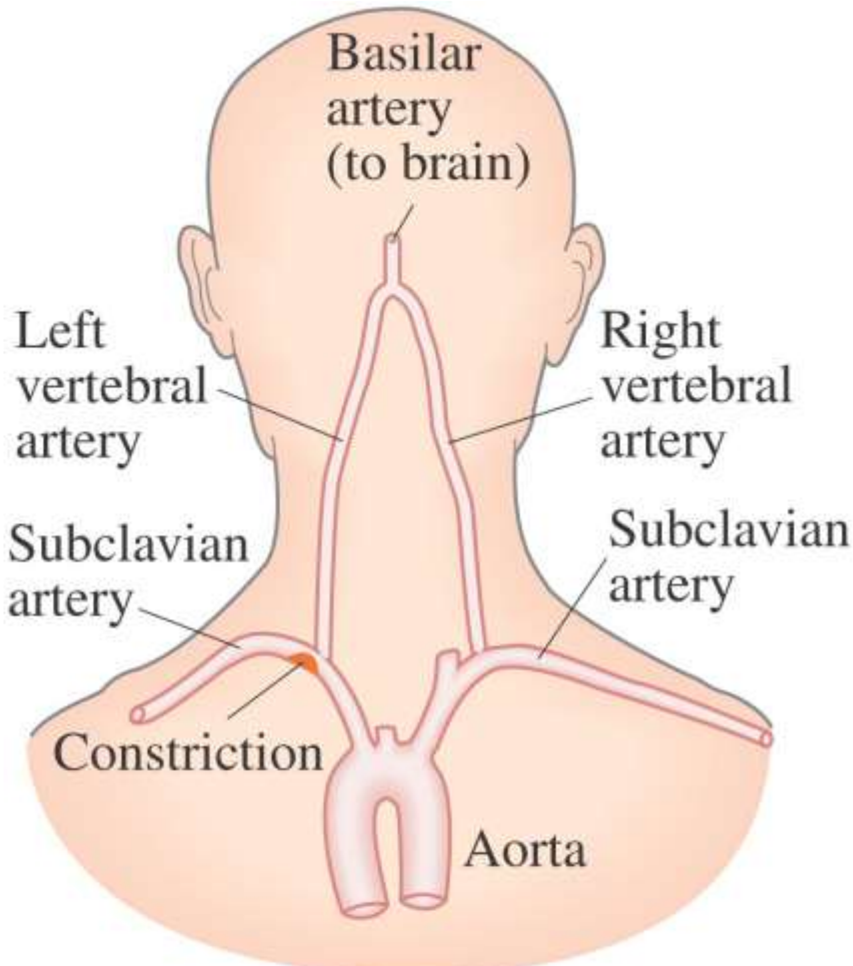
Natural Air Conditioning

- Termite mounds, prairie dog mounds, chimneys
- Wind speeds increase with height



Air drawn in by
pressure difference

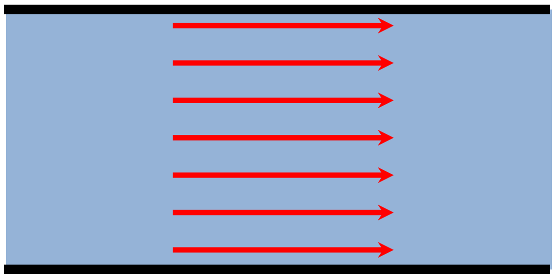
Transient Ischemic Attack



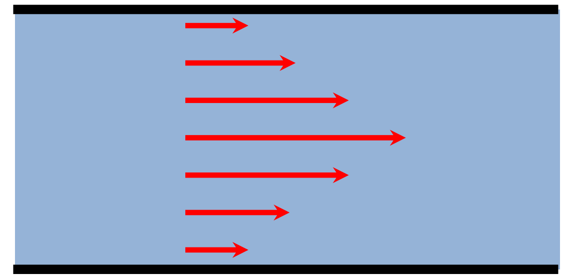
- Constriction, A↓, v↑, P↓
- Blood on the unblocked side has higher P.
- Blood to brain gets diverted to low P side
- Dizziness, blackout

Viscosity (internal fluid friction)

fluid velocity profiles

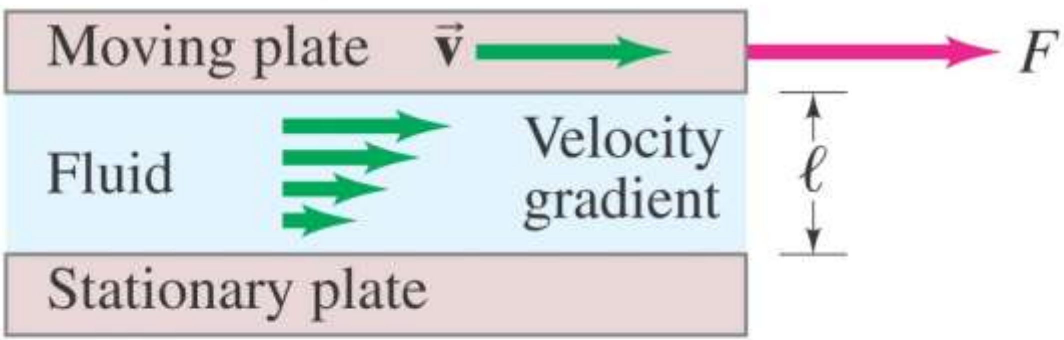


Ideal fluid – no friction



Real fluid
Velocity changes with distance from walls.
Has a *velocity gradient.*

Viscosity (internal fluid friction)



- Need F to keep plate moving because of viscosity
- $F = \eta A v / \ell$
- A area of fluid in contact with plate
- T has a strong effect

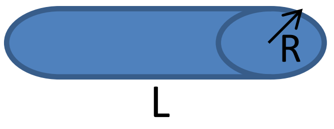
TABLE 13–3
Coefficients of Viscosity

Fluid (temperature in °C)	Coefficient of Viscosity, η (Pa·s)†
Water (0°)	1.8×10^{-3}
(20°)	1.0×10^{-3}
(100°)	0.3×10^{-3}
Whole blood (37°)	$\approx 4 \times 10^{-3}$
Blood plasma (37°)	$\approx 1.5 \times 10^{-3}$
Ethyl alcohol (20°)	1.2×10^{-3}
Engine oil (30°) (SAE 10)	200×10^{-3}
Glycerine (20°)	1500×10^{-3}
Air (20°)	0.018×10^{-3}
Hydrogen (0°)	0.009×10^{-3}
Water vapor (100°)	0.013×10^{-3}

† 1 Pa·s = 10 P = 1000 cP.

Poiseuille's Equation

- Viscosity slows moving fluids down
- So a ΔP needed to keep fluid flowing in pipe or artery



- $Q = \frac{\pi R^4 (P_1 - P_2)}{8\eta L}$, Q is flow rate = volume/time
- Very sensitive to radius R
- Clogged arteries, R $\downarrow$, so need higher BP to move blood. Heart needs to work harder.

Note

- Use Poiseuille's Equation when there is viscosity and R does not change over length of tube
- Otherwise use Bernoulli and hope viscosity is not a big factor!
- 1 litre = 1×10^{-3} m^3