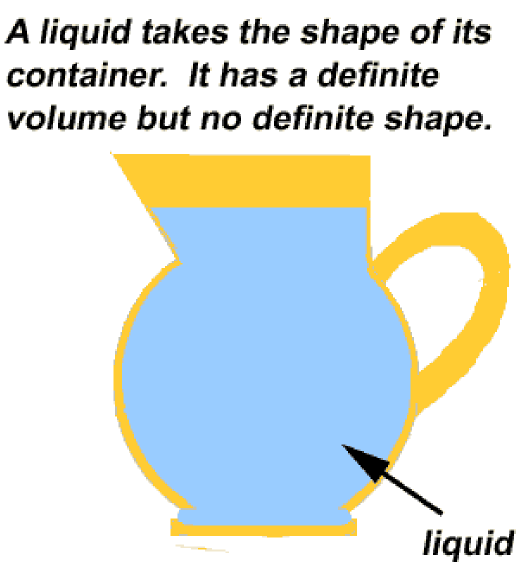
FLUID MECHANICS

Fluids: Liquids vs. Gases

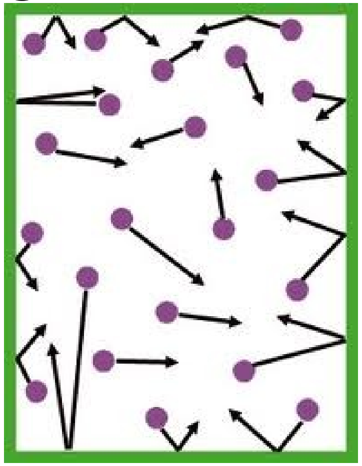
- Chemical bonds can break when heated
  - Leaving individual molecules free to "roam" randomly
- Liquids: Volume held constant due to surface tension
  - So density (mass / volume) is also constant (approximately)
  - Density of water → 1000 kg / m^3



- Gases: No surface tension
  - Molecules are completely free to roam
  - Volume of gas is not constant
  - So density (mass / volume) is not constant
  - Air → 1 kg / m^3 at sea level, 0 kg / m^3 at top of atmosphere

Pressure

- Fluids → molecules bounce off each other
  - Therefore exert forces on each other!
  - And exert forces on the container of the fluid



- To measure pressure:
  - Insert a detector with a known surface area into fluid
  - Measure force exerted on detector

$$Pressure = \frac{Force}{Area}$$

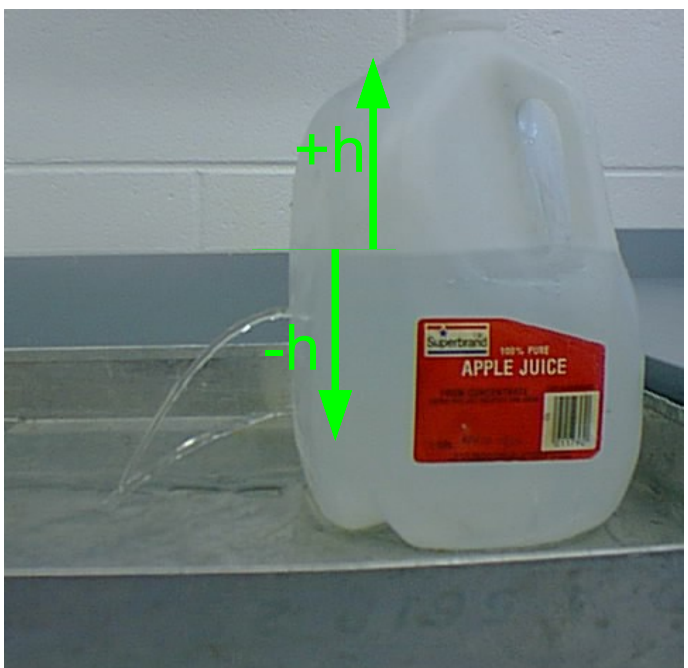
Units: 1 Pascal (Pa) = 1 N / m^2

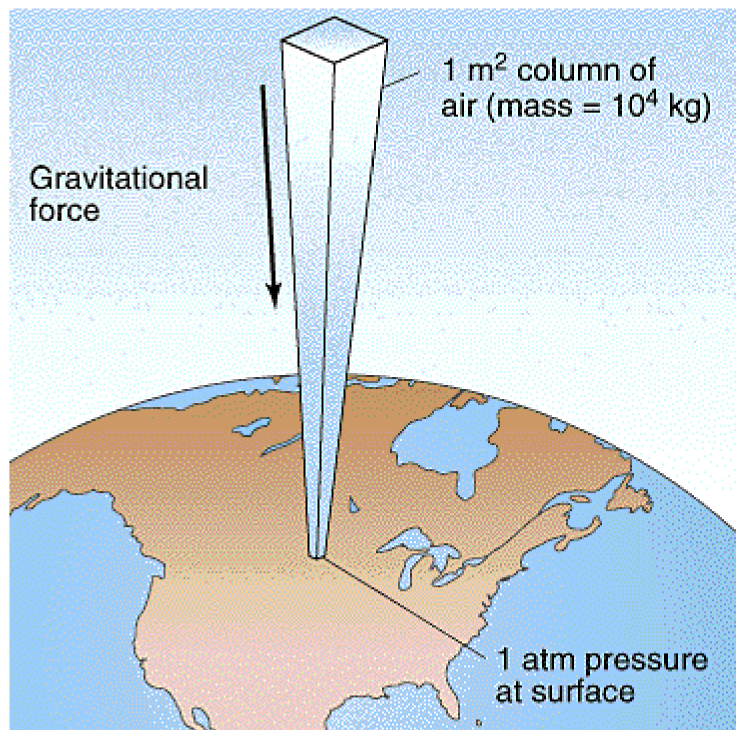
1 atmosphere (atm) ≈ 10^5 N / m^2

1 pound per square inch (psi) ≈ 6900 N / m^2

Pressure vs. Depth

- Deep under the surface of a fluid:
  - Lots of fluid above, weighing down
  - Fluid pressure is greater than it is near the surface





$$p = p_0 - \rho g h$$

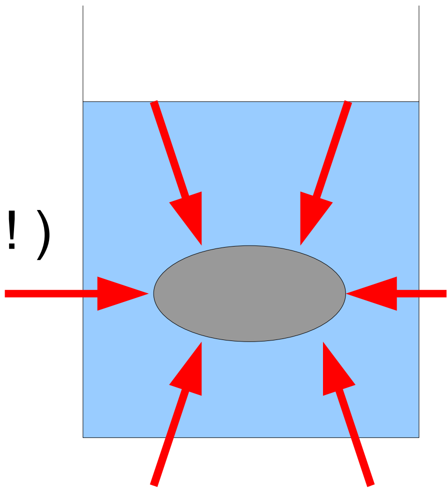
p_0 is the pressure at the surface of the fluid

ρ is the density of the fluid

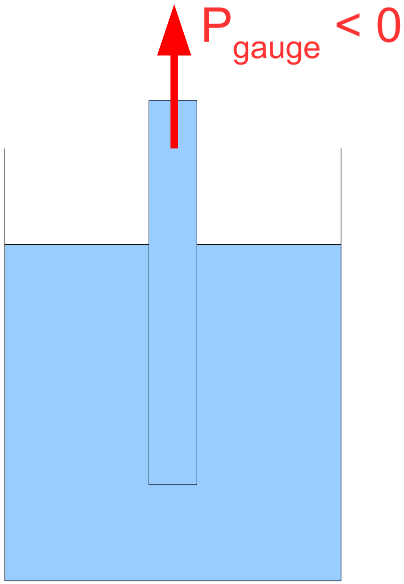
h is a negative number, meaning depth below the fluid surface

Absolute Pressure vs. Gauge Pressure

- Submerged object feels compressive stress
  - At large depths below the fluid surface:
  - Forces can become enormous (1 atm ≈ 10^5 N / m^2 !)
  - Expensive and dangerous to explore ocean floor

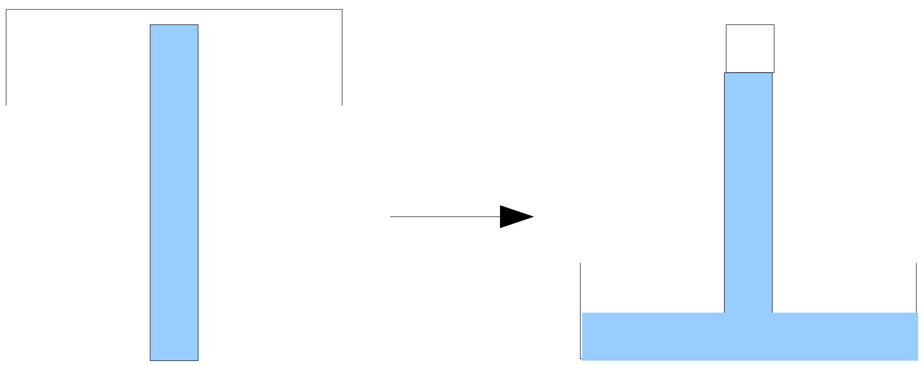


- Absolute Pressure
  - Actual pressure due to molecular collisions
- Gauge Pressure
  - Measured relative to surrounding pressure
  - Better measure for determining motions of fluids
  - Example: Drinking Straw



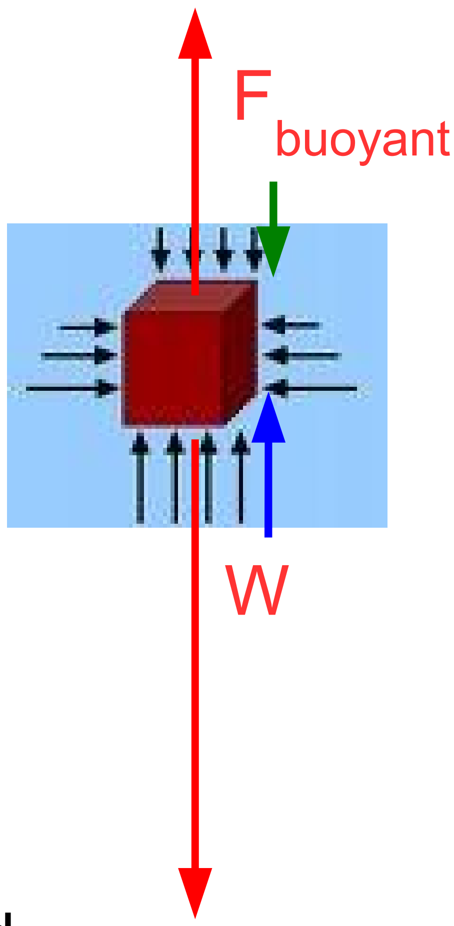
Measuring Pressure: Barometer

- One way to measure gas pressure:
  - Measure how much weight it can lift
- Simple Barometer
  - Fill tube with liquid...
  - Then flip it into a dish
  - No air bubbles allowed!



- Why doesn't all the liquid fall into the dish?
  - Empty space inside the tube is a vacuum → no pressure
  - Atmospheric pressure pushes on liquid in dish
  - Measure height of liquid in tube → can find P_{atm}

Buoyancy

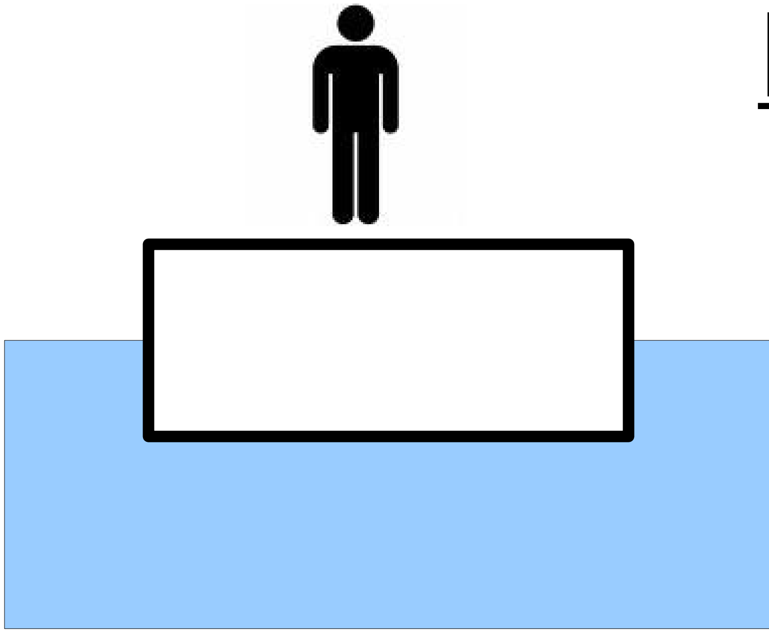


- Pressure increases with depth
  - So does force on an object!
  - Upward force > Downward force
  - Fluid exerts upward "buoyant" force!
- If weight > buoyant force
  - Object sinks!
  - Occurs if object is more dense than liquid

$$F_{buoyant} = \rho_{fluid}\, g\, Vol_{displaced}$$

→ "Archimedes' Principle"

Floating



Simple boat → steel box with air inside

$$Average\ Density = \frac{mass\ of\ steel + mass\ of\ air}{volume}$$

- Steel is heaver than water
  - But the average density of the steel/air combo is light
- Put a person on top
  - More water displaced to balance extra weight
  - Boat still floats, but now a little lower

Buoyant Force in Air

- Pressure gets weaker with height → buoyant force
  - Similar to liquids, pressure difference causes an upward force

- To "float" on air:
  - An object must be less dense than air! (very light)

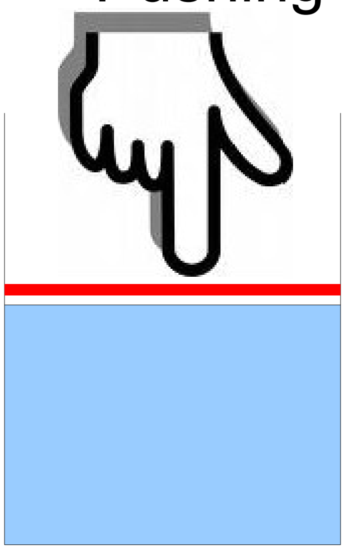
Common ways to do this:

1) Heat air inside a balloon
   - It expands and becomes less dense

2) Use a light gas like helium or hydrogen
   - Why is hydrogen a bad idea?

Pascal's Principle

- For a body of liquid:
  - Every point at the same height has the same pressure
  - Pushing on one edge increases the pressure everywhere

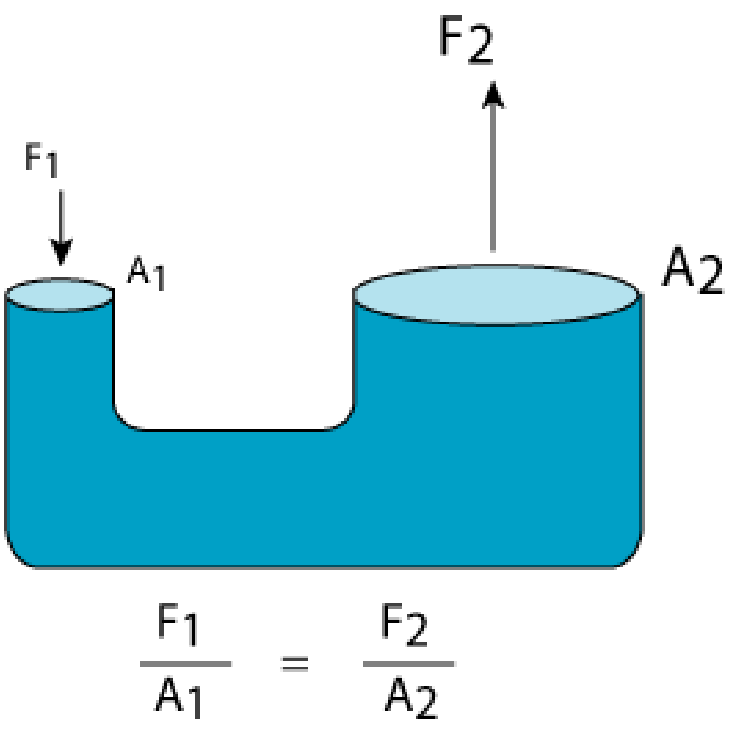


Pushing on the red piston will increase the pressure everywhere in the fluid by the same amount

- This is an excellent way to “transmit” force
  - Example: Car brakes (foot force → force on brake pads)

Hydraulics

- Hydraulics use Pascal's Principle as a "force multiplier"
  - Like a pulley or lever → greater force over shorter distance

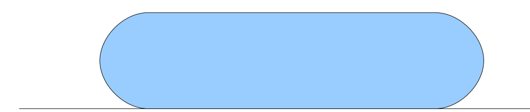


$$Work_{IN} = Work_{OUT}$$

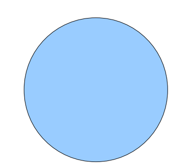
$$F_1d_1 = F_2d_2$$

Surface Tension

- Molecules in a liquid are free to bounce around
  - Except through the surface of the liquid
  - Glass of water → Why don't molecules “jump out”?
- Surface Tension



  - Edge of a liquid acts like a “loose balloon”
  - Holds liquid molecules to a confined volume
  - Due to weak molecular attraction at edges
- Example: Raindrop



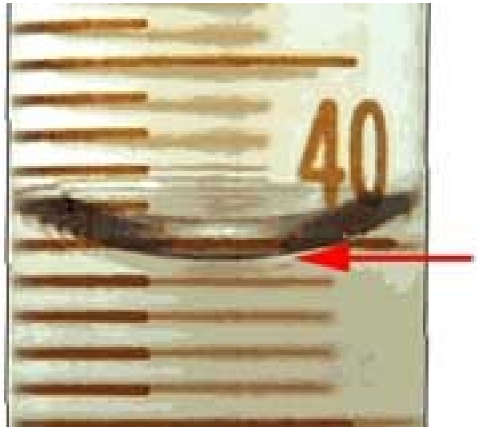
  - Molecules don't just “spread out” in the air
  - Near-spherical shape held together by surface tension

<u>Surface Tension Example</u>

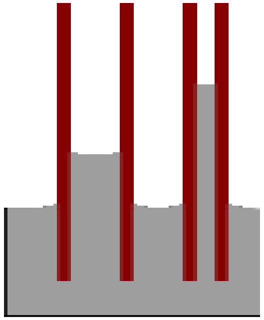
- Insects called <u>water striders</u> can use surface tension as a “floor”
  - Their legs are covered in fine hairs so they stay dry
  - Otherwise, surface tension couldn't support them
  - <u>Note</u>: insects are not floating, but standing on surface

Capillary Action ("Capillarity")

- Molecules in a liquid often "adhere" to surfaces
  - They "stick" to their container
  - Water level at edge rises up...
  - Until the extra weight of water balances the "stickiness"



- The thinner the tube → the higher the liquid lifts



This is how tall trees are able to lift water to the highest branches → through capillarity

Energy in Fluids (Liquids and Gases)

- 3 common forms of energy in fluids:
  - Kinetic Energy → motion of individual molecules
  - Potential Energy → height of molecules
  - "Pressure Energy" → unequal pressures can exert forces

- Energy in a fluid can change forms
  - Exhaling: Higher pressure in lungs → KE of air
  - Hot air balloon: Higher pressure on ground → PE

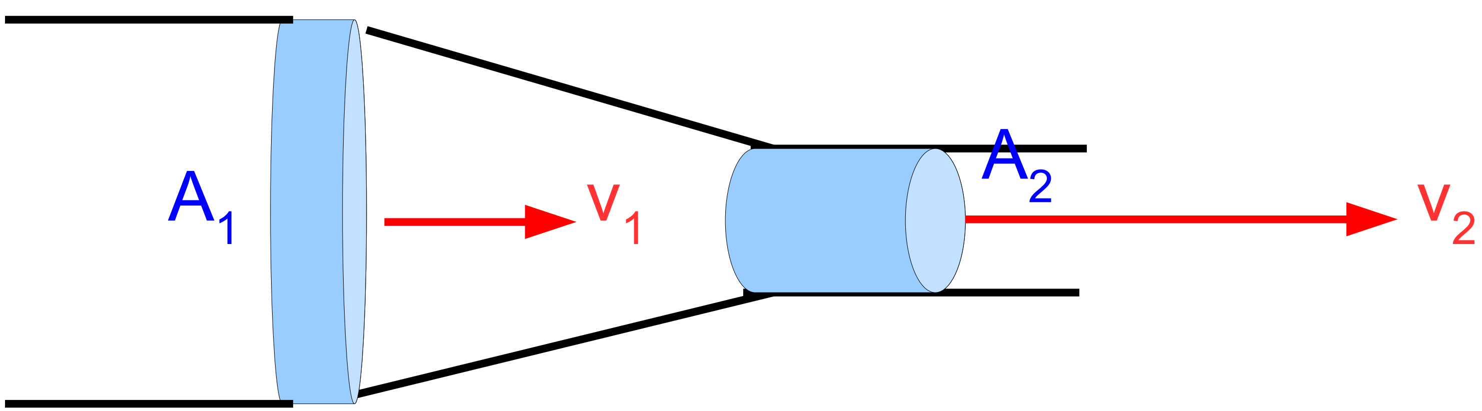
- Energy can also be converted into other forms
  - Wind turbine: KE of air → electrical energy

Fluid Flow

- When a moving fluid enters a tube or pipe:
  - It must eventually exit the other end
  - "Flow Rate" (volume / sec) must be constant

$$\frac{\Delta V}{\Delta t} = A_1 v_1 = A_2 v_2$$

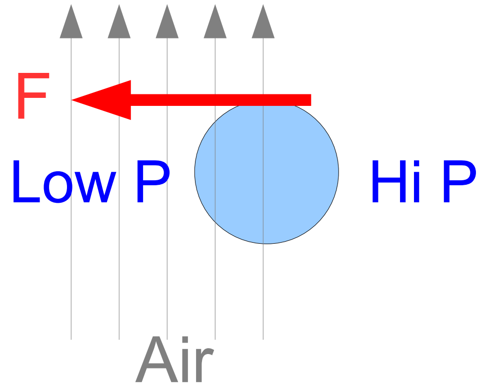
→ "Equation of Continuity"



Bernoulli's Principle

- Applies conservation of energy to fluids
  - Important for understanding flowing gases and liquids

$$p_1 + \rho g y_1 + \frac{1}{2}\rho v_1{}^2 = p_2 + \rho g y_2 + \frac{1}{2}\rho v_2{}^2$$



- Important result:
  - When the speed of a fluid increases...
  - The pressure of that fluid must decrease!

- Application: Fluid can exert a force perpendicular to flow
  - By creating unequal fluid speeds on 2 sides of an object
  - Object is pushed toward high speed region

Forces Exerted by Fluids

Using the fluid's KE

Put an object in the fluid's path → “pushing” force

Force is parallel to fluid motion

Using the fluid pressure

Can exert force by setting up unequal speeds

Force is perpendicular to fluid motion