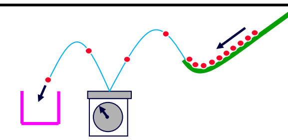
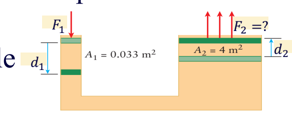
Physics 101: Lecture 19
Fluids II: Moving fluids

Review Static Fluids



- Pressure: force from molecules "bouncing" off container
  - ➡ $P = F/A$
- Gravity/weight affects pressure
  - ➡ $P = P_0 + \rho g d$
- Pascal's Principle
  - ➡ $\Delta P_1 = \Delta P_2$



Today:

- Buoyant force is "weight" of displaced fluid (Archimedes' principle)
  - ➡ $F_{Buoyant} = \rho_{fluid}\, g\, V_{displaced\text{-}fluid}$
- Moving Fluids

Archimedes' Principle

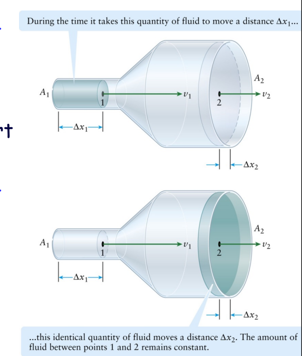
- Buoyant Force (F_B)
  - ➡ weight of fluid displaced
  - ➡ $F_B = \rho_{fluid} V_{displaced}\, g$
  - ➡ $F_g = mg = \rho_{object} V_{object}\, g$
  - ➡ If object sinks then
    - » $V_{displaced} = V_{object}$
    - » $\rho_{object} > \rho_{fluid}$
  - ➡ Object floats if $\rho_{object} < \rho_{fluid}$, in which case $V_{displaced} < V_{object}$, and also $F_B = F_g$
    - » Therefore: $\rho_{fluid}\, g\, V_{displ.} = \rho_{object}\, g\, V_{object}$
    - » Therefore: $V_{displ.}/V_{object} = \rho_{object} / \rho_{fluid}$

Moving fluids: Continuity of Fluid Flow

- Watch fluid moving through the narrow part of the tube (A_1)
  - •Distance a "particle" travels $x_1 = v_1 \Delta t$
  - •Mass of fluid in "plug" $m_1 = \rho V_1 = \rho A_1 x_1$ or $m_1 = \rho A_1 v_1 \Delta t$
- Watch fluid moving through the wide part of tube (A_2)
  - •Distance a "particle" travels $x_2 = v_2 \Delta t$
  - •Mass of fluid in "plug" $m_2 = \rho V_2 = \rho A_2 x_2$ or $m_2 = \rho A_2 v_2 \Delta t$
- "Continuity" Equation says $m_1 = m_2$ fluid isn't building up or disappearing

$$A_1 v_1 = A_2 v_2$$

"What goes in must come out"



Faucet water stream

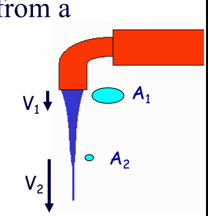
A stream of water gets narrower as it falls from a faucet (try it & see).

This phenomenon can be explained using the equation of continuity

The velocity increases as the water flows down and the area decreases to compensate for the increase in velocity.

Another way of putting it:

As the water flows down, gravity makes the velocity of the water go faster so the area of the water decreases.



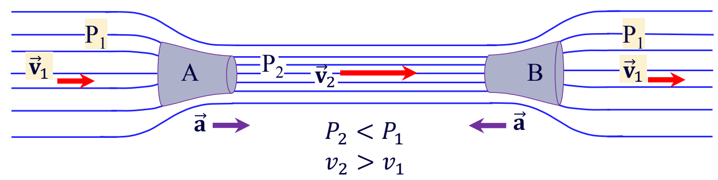
$A_1 v_1 = A_2 v_2$

$A_2 = A_1 (v_1/v_2)$

Pressure, Flow and Work

- Continuity Equation says fluid speeds up going to smaller opening, slows down going to larger opening
  - $A_1 v_1 = A_2 v_2$
  - $v_2 = v_1(A_1/A_2)$
- Acceleration due to change in pressure. $P_1 > P_2$
  - Demo: Smaller tube has faster water and LOWER pressure
- Change in pressure does work!
  - $W = (P_1 - P_2)V$

Recall:
W=F d
= PA d
= P V



More demos showing regions of high velocity fluid have low pressure

- Soda cans: blow air between them
- Big metal plates: Blow lots of air between them

- Balancing objects with streams of air
  - a ping pong ball,
  - add a funnel and now balance
  - a screwdriver
  - a bigger ball.
- Blow air across one end of a "U" tube with water in it:

Bernoulli's Eqs. And Work

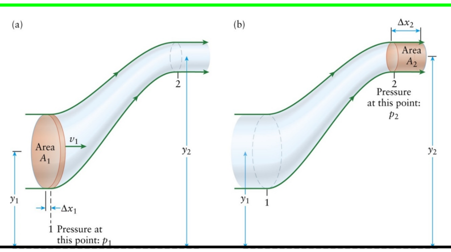
- Consider tube where both Area & height change and apply the Work-Kinetic Energy Theorem:

$W_{net} = W_{fluid} + W_{gravity} = \Delta K$

$(P_1 - P_2)\, V - mg(y_2 - y_1) = \frac{1}{2}\, m\, (v_2^2 - v_1^2)$

$(P_1 - P_2)\, V - \rho V g(y_2 - y_1) = \frac{1}{2}\, \rho V\, (v_2^2 - v_1^2)$

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



Demo: The pressure cannon

- This demo shows that atmospheric pressure is substantial and can do some damage.

Example: Lift a House

Calculate the net lifting force on a 15 m x 15 m house when a 30 m/s (67 mph) wind (1.29 kg/m^3) blows over the top. Write Bernoulli eqn just above roof and just below roof:

$P_{below} + \rho g y + \frac{1}{2}\rho v_{below}^2 = P_{above} + \rho g y + \frac{1}{2}\rho v_{above}^2$

Just below roof the air has no velocity so $v_{below}=0$

$P_{below} - P_{above} = \frac{1}{2}\rho v_{above}^2$

$= \frac{1}{2}(1.29)(30^2)\ \text{N/m}^2$

$= 581\ \text{N/m}^2$

$F = P A$

$= 581\ \text{N/m}^2\ (15\ \text{m})(15\ \text{m}) = 131{,}000\ \text{N}$

= 29,450 pounds! (note roof weighs 15,000 lbs)

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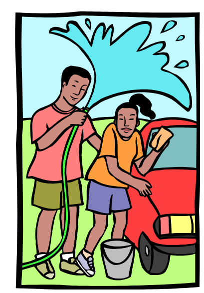
Example

A garden hose w/ inner diameter 2 cm, carries water at 2.0 m/s. To spray your friend, you place your thumb over the nozzle giving an effective opening diameter of 0.5 cm. What is the speed of the water exiting the hose? What is the pressure difference between inside the hose and outside?



Continuity Equation

$A_1 v_1 = A_2 v_2$

$v_2 = v_1 (A_1/A_2)$

$= v_1 (\pi r_1^2 / \pi r_2^2)$

$= 2\ \text{m/s} \times 16 = 32\ \text{m/s}$

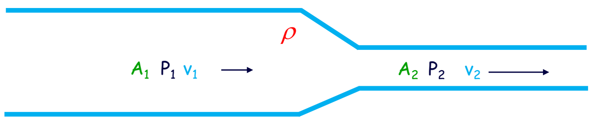
Bernoulli Equation

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

$P_1 - P_2 = \frac{1}{2}\rho (v_2^2 - v_1^2) = \frac{1}{2}\rho (32^2 - 2^2)$

$= \frac{1}{2} \times (1000\ \text{kg/m}^3)(1020\ \text{m}^2/\text{s}^2) = 5.1 \times 10^5$ PA

Fluid Flow Summary



- Mass flow rate: $\rho A v$ (kg/s)
- Volume flow rate: Av (m^3/s)
- Continuity: $\rho A_1 v_1 = \rho A_2 v_2$
- Bernoulli: $P_1 + {}^1/_2\, \rho v_1^2 + \rho g h_1 = P_2 + {}^1/_2\, \rho v_2^2 + \rho g h_2$

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