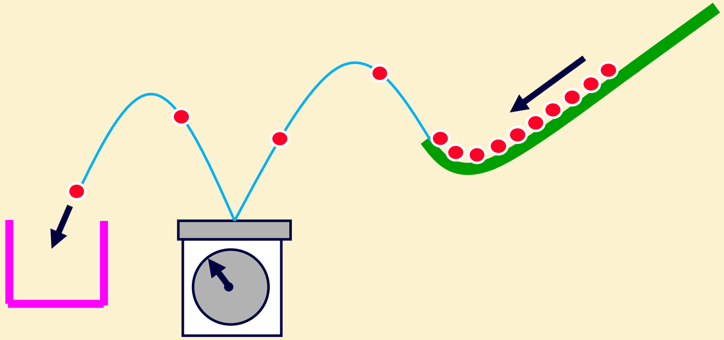
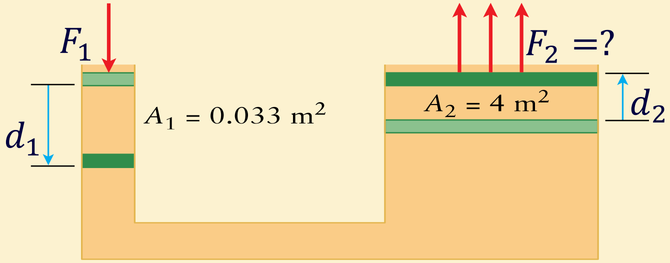
Physics 101: Lecture 19
Fluids II: Moving fluids

Review Static Fluids



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



Today:

- Archimedes: Buoyant force is "weight" of displaced fluid

$$F_{Buoyant} = \rho_{fluid}\, g\, V_{displaced\text{-}fluid}$$

- Moving Fluids

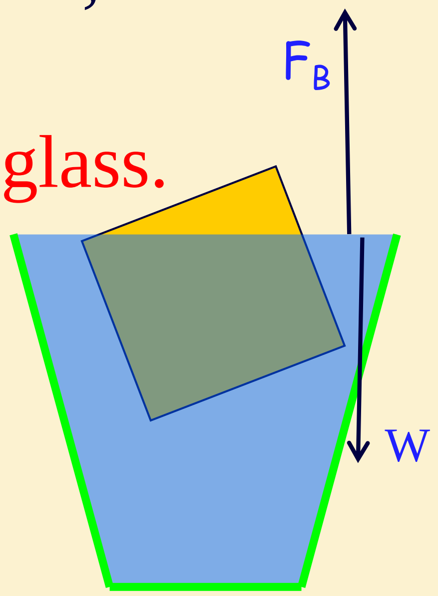
Archimedes' Principle

- 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: $V_{displ.}/V_{object} = \rho_{object} / \rho_{fluid}$

Clicker Q

Suppose you float a large ice-cube in a glass of water, and that after you place the ice in the glass the level of the water is at the very brim. When the ice melts, the level of the water in the glass will:

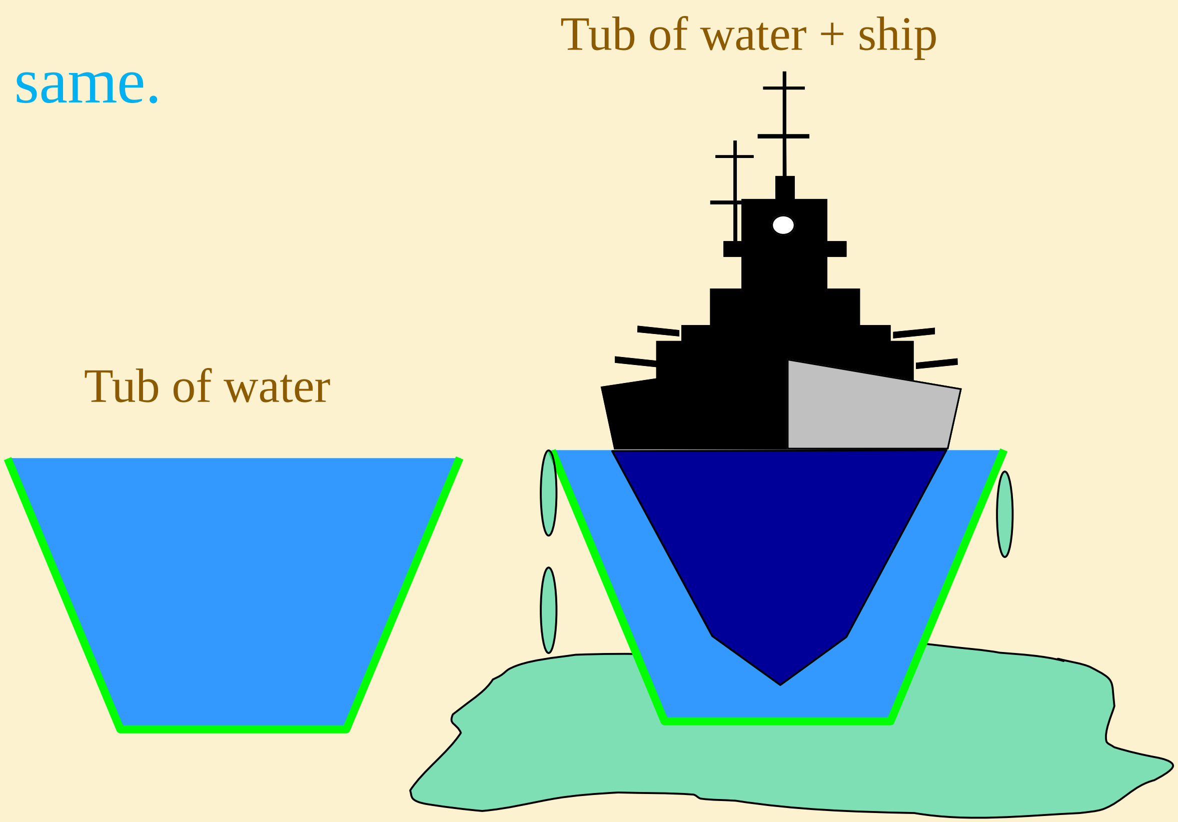
1. Go up, causing the water to spill out of the glass.
2. Go down.
3. Stay the same.



Clicker Q

Which weighs more:

1. A large bathtub filled to the brim with water.
2. A large bathtub filled to the brim with water with a battle-ship floating in it.
3. They will weigh the same.



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)

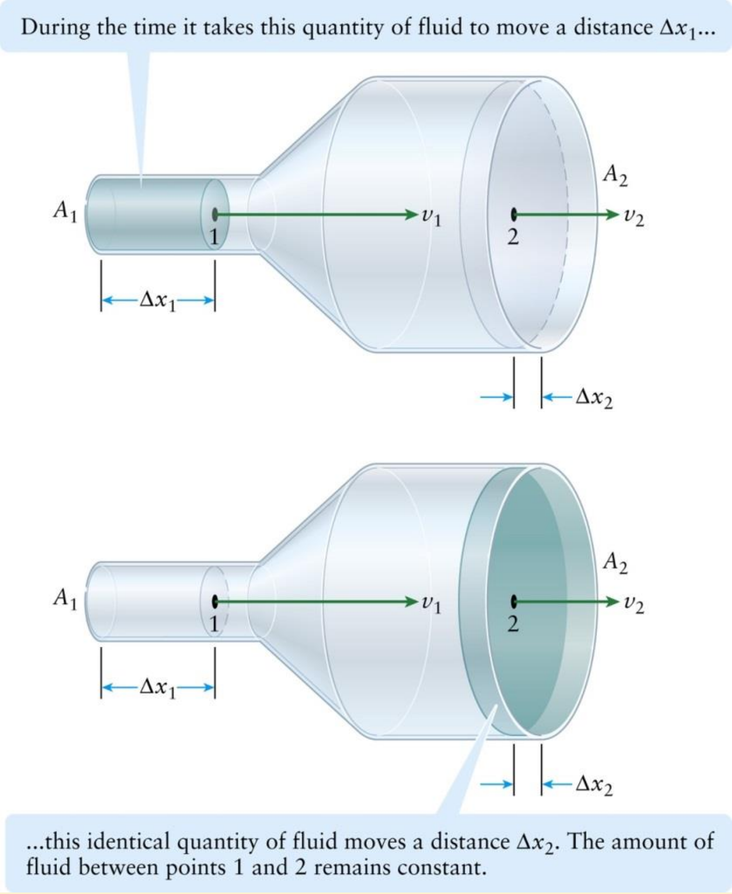
  •Distance a "particle" travels $x_2 = v_2 \Delta t$

  •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

$$\boxed{A_1 v_1 = A_2 v_2}$$

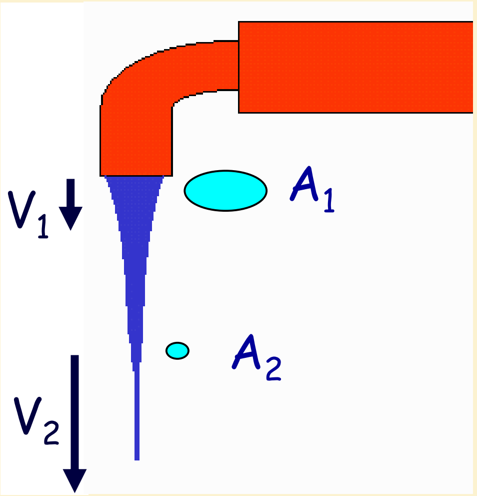
"What goes in must come out"



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.

$A_1 v_1 = A_2 v_2$

$A_2 = A_1 (v_1/v_2)$

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.

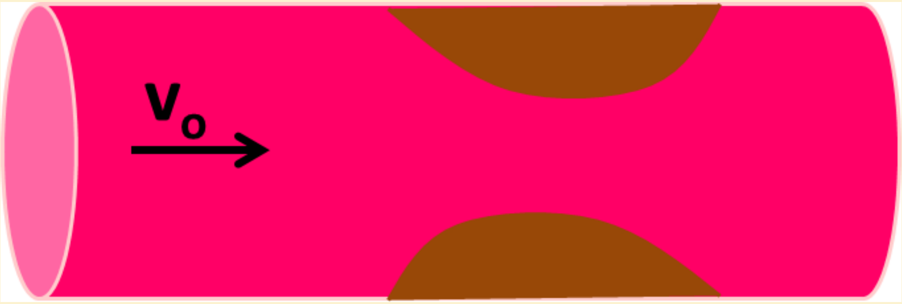
Checkpoint 1a

A cylindrical blood vessel is partially blocked by the buildup of plaque. At one point, the plaque decreases the diameter of the vessel by 60%. The blood approaching the blocked portion has speed v_0. Just as the blood enters the blocked portion of the vessel, the blood's velocity will:

A) increase.

B) decrease.

C) remain the same.



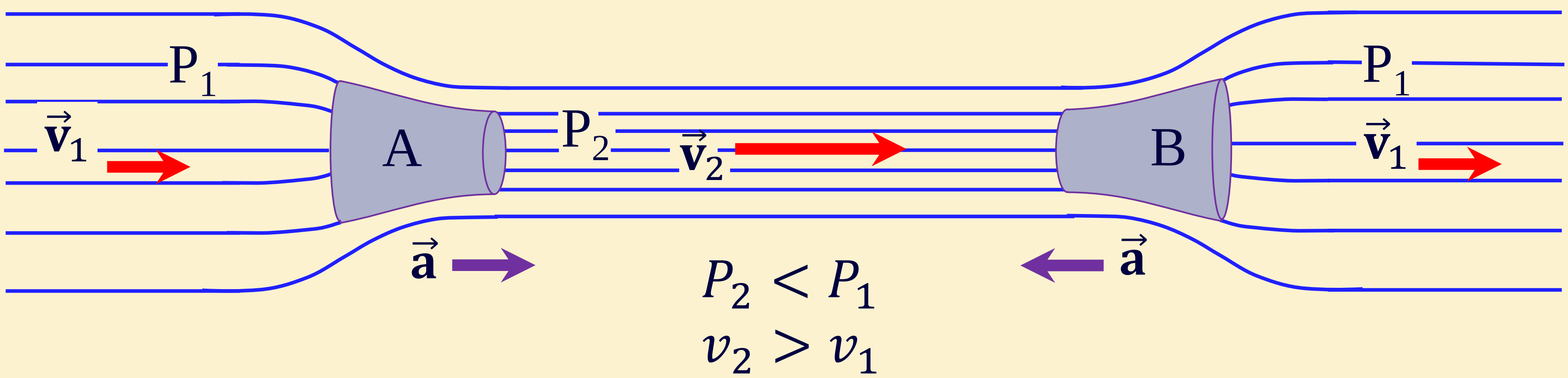
Pressure, Flow and Work

- 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!
  - ➔$W = (P_1 - P_2)V$

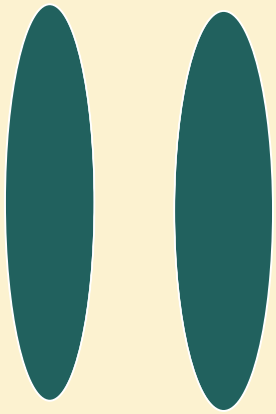
Recall:
W=F d
= PA d
= P V



Pressure Clicker Q

- What will happen when I “blow” air between the two pieces of paper?

A) Move Apart B) Come Together C) Nothing



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:

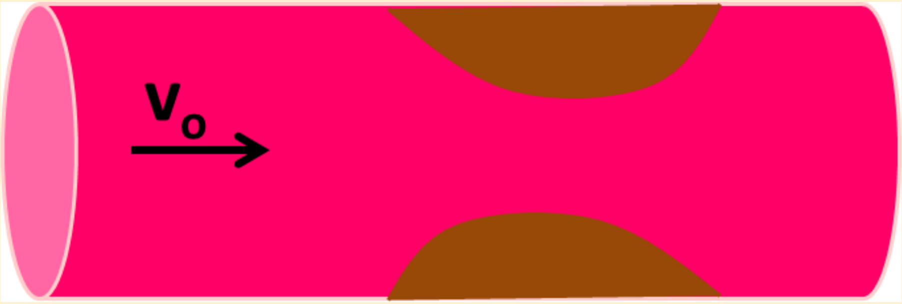
Checkpoint 1b

A cylindrical blood vessel is partially blocked by the buildup of plaque. At one point, the plaque decreases the diameter of the vessel by 60%. The blood approaching the blocked portion has speed v_0. Just as the blood enters the blocked portion of the vessel, the blood's pressure will

A) increase.

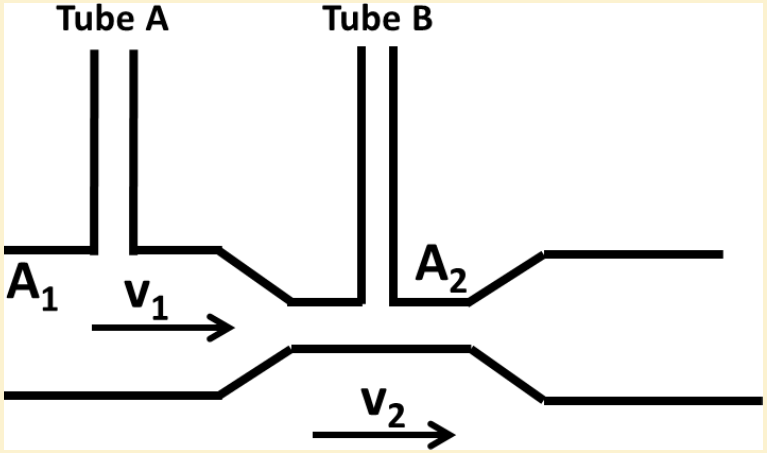
B) decrease.

C) remain the same.



Checkpoint 2

The figure below shows a simple device called a Venturi meter for measuring fluid velocity. The fluid flows from left to right through the horizontal pipe, from the section with large cross sectional area A_1 to the section with small cross sectional area A_2.



Through which tube does the fluid rise the highest?

A) Tube A
B) Tube B
C) Same for both

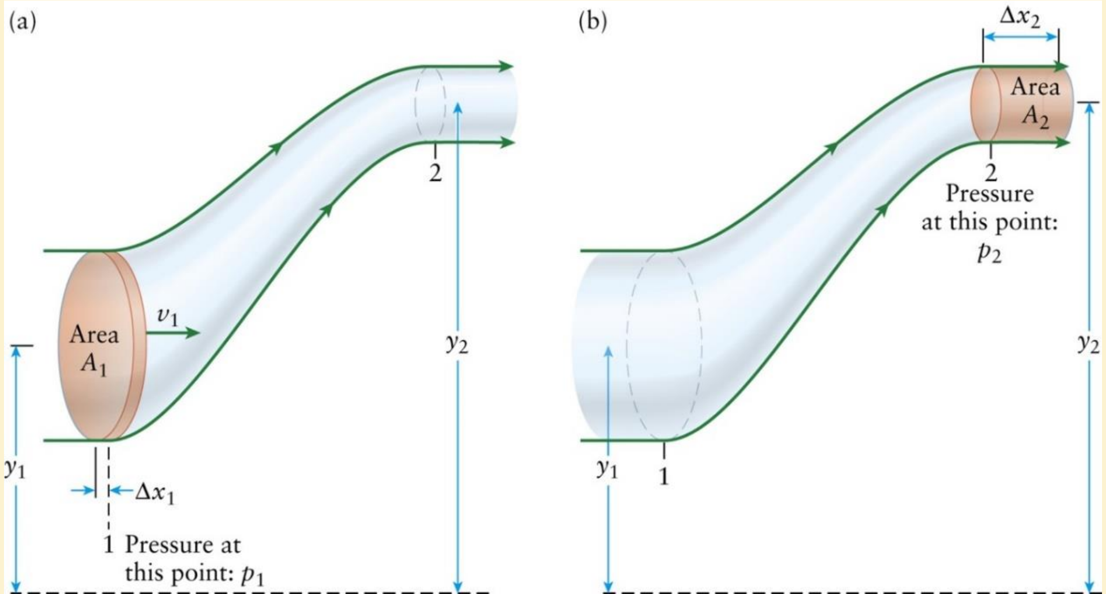
Bernoulli's Eqs. And Work

- Consider tube where both Area & height change and apply the Work-Kinetic Energy Theorem:
  - ➔ $W_{net} = W_{fluid} + W_{gravity} = \Delta K$

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

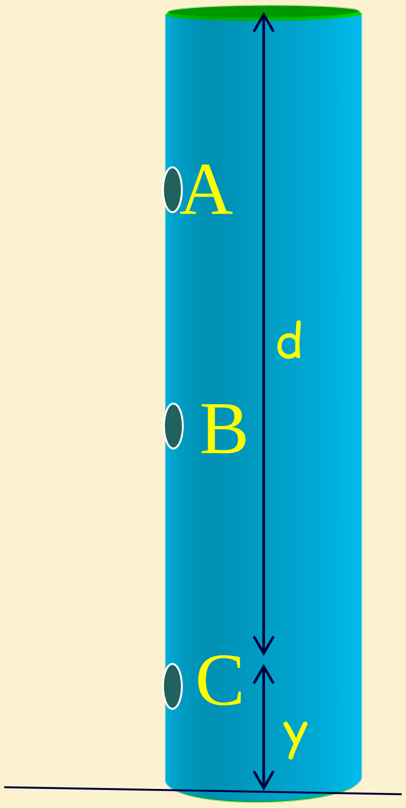
    $(P_1 - P_2)\,V - \rho V g(y_2 - y_1) = \frac{1}{2}\,\rho V\,(v_2^2 - v_1^2)$

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



Bernoulli Clicker Q

Through which hole will the water come out fastest?

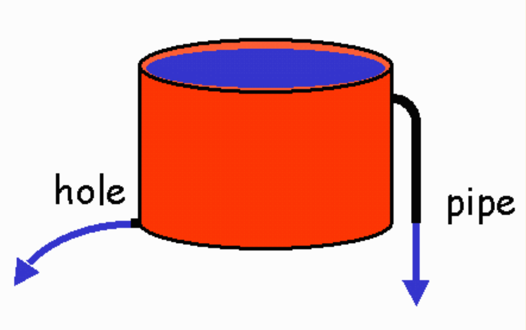


Clicker Q

A large bucket full of water has two drains. One is a hole in the side of the bucket at the bottom, and the other is a pipe coming out of the bucket near the top, which bent is downward such that the bottom of this pipe even with the other hole, like in the picture below:

Though which drain is the water spraying out with the highest speed?

1. The hole
2. The pipe
3. Same



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 $v_{below}=0$

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

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

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

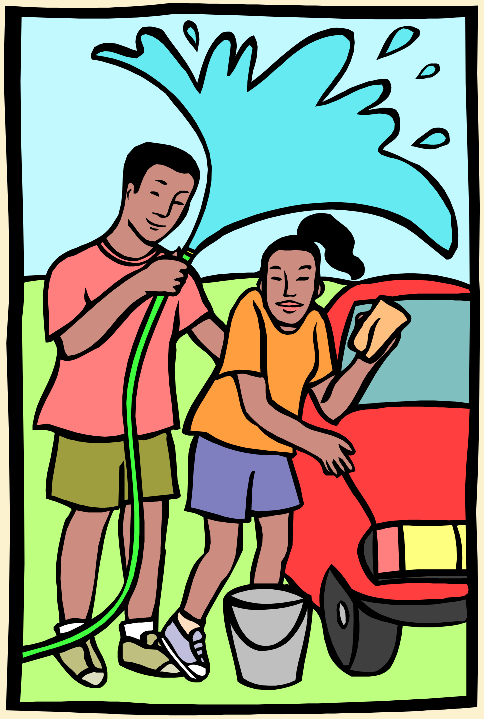
$F = P A$

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

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

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

$$A_1 v_1 = A_2 v_2$$

$$v_2 = v_1 (A_1/A_2)$$

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

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

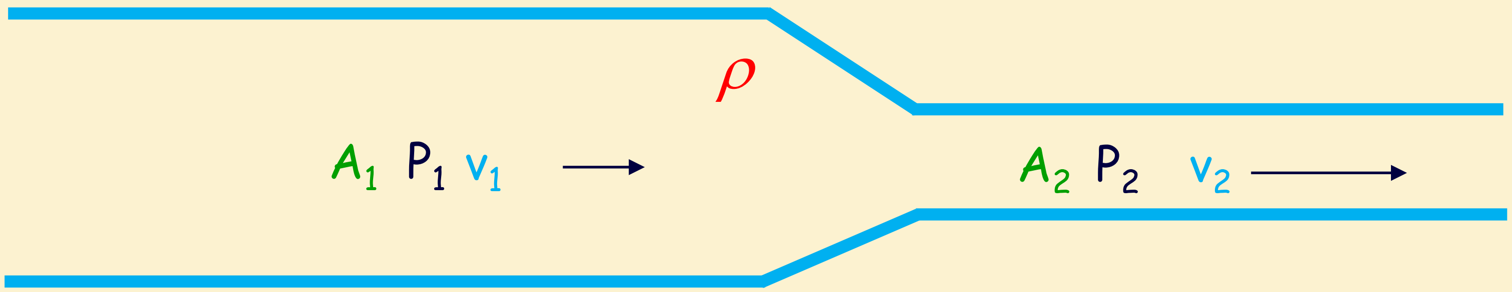
Bernoulli Equation

$$P_1+\rho gy + ½ \rho v_1^2 = P_2+\rho gy + ½\rho v_2^2$$

$$P_1 – P_2 = ½ \rho (v_2^2 – v_1^2)= ½ \rho (32^2 – 2^2)$$

$$= ½ \times (1000 \text{ kg/m}^3) (1020 \text{ m}^2/\text{s}^2) = 5.1 \times 10^5 \text{ PA}$$

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: $P_1 + {}^1/_2\, \rho v_1^2 + \rho g h_1 = P_2 + {}^1/_2\, \rho v_2^2 + \rho g h_2$