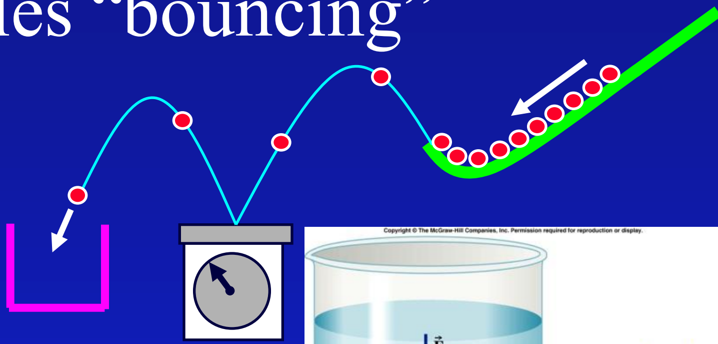
Physics 101: Lecture 18
Fluids II

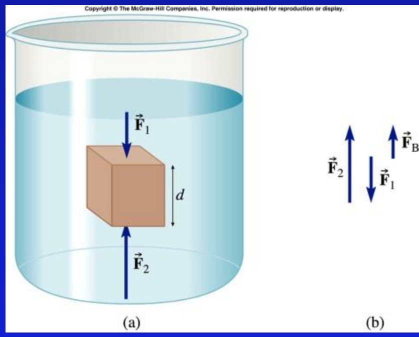
Textbook Sections 9.6 – 9.8

Review Static Fluids

- Pressure is force exerted by molecules "bouncing" off container $P = F/A$



- Gravity/weight effects pressure
  - ➔ $P = P_0 + \rho g d$



- Buoyant force is "weight" of displaced fluid.
  - ➔ $F = \rho\, g\, V$

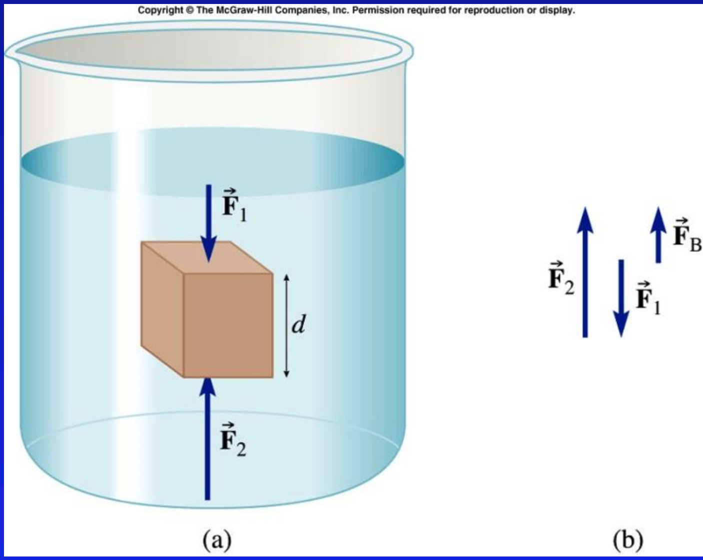
Today include moving fluids!

$$A_1 v_1 = A_2\, v_2$$

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

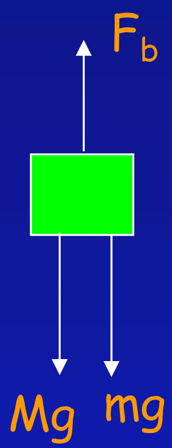
Archimedes' Principle

- Determine force of fluid on immersed cube
  - ➔ Draw FBD
    - » $F_B = F_2 - F_1$
    - » $\quad = P_2 A - P_1 A$
    - » $\quad = (P_2 - P_1)A$
    - » $\quad = \rho\, g\, d\, A$
    - » $\quad = \rho\, g\, V$

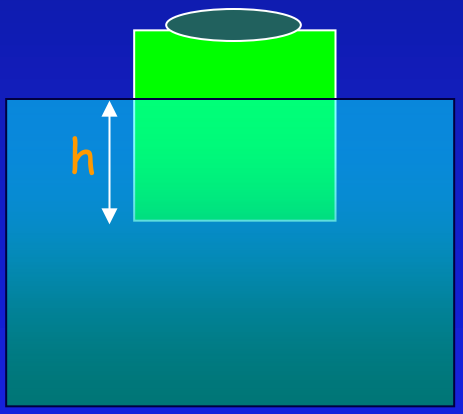


- Buoyant force is weight of displaced fluid!

Archimedes Example



A cube of plastic 4.0 cm on a side with density = 0.8 g/cm^3 is floating in the water. When a 9 gram coin is placed on the block, how much does it sink below the water surface?



$M = \rho_{plastic} V_{cube}$

$= 4 \times 4 \times 4 \times 0.8$

$= 51.2\ g$

$F_{Net} = m\ a$

$F_b - Mg - mg = 0$

$\rho\ g\ V_{disp} = (M+m)\ g$

$V_{disp} = (M+m)\ /\ \rho$

$h\ A = (M+m)\ /\ \rho$

$h = (M + m)/\ (\rho\ A)$

$= (51.2+9)/(1 \times 4 \times 4) = 3.76$ cm

Archimedes' Principle

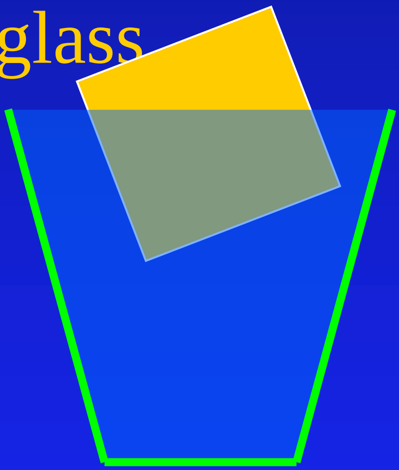
- Buoyant Force (F_B)
  - ➔ weight of fluid displaced
  - ➔ $F_B = \rho_{fluid} V_{displaced}\, g$
  - ➔ $F_g = mg = \rho_{object} V_{object}\, g$
  - ➔ object sinks if $\rho_{object} > \rho_{fluid}$
  - ➔ object floats if $\rho_{object} < \rho_{fluid}$

- If object floats…
  - ➔ $F_B = F_g$
  - ➔ Therefore: $\rho_{fluid}\, g\, Vol_{displ.} = \rho_{object}\, g\, Vol_{object}$
  - ➔ Therefore: $Vol_{displ.}/Vol_{object} = \rho_{object} / \rho_{fluid}$

Checkpoint Q1

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:

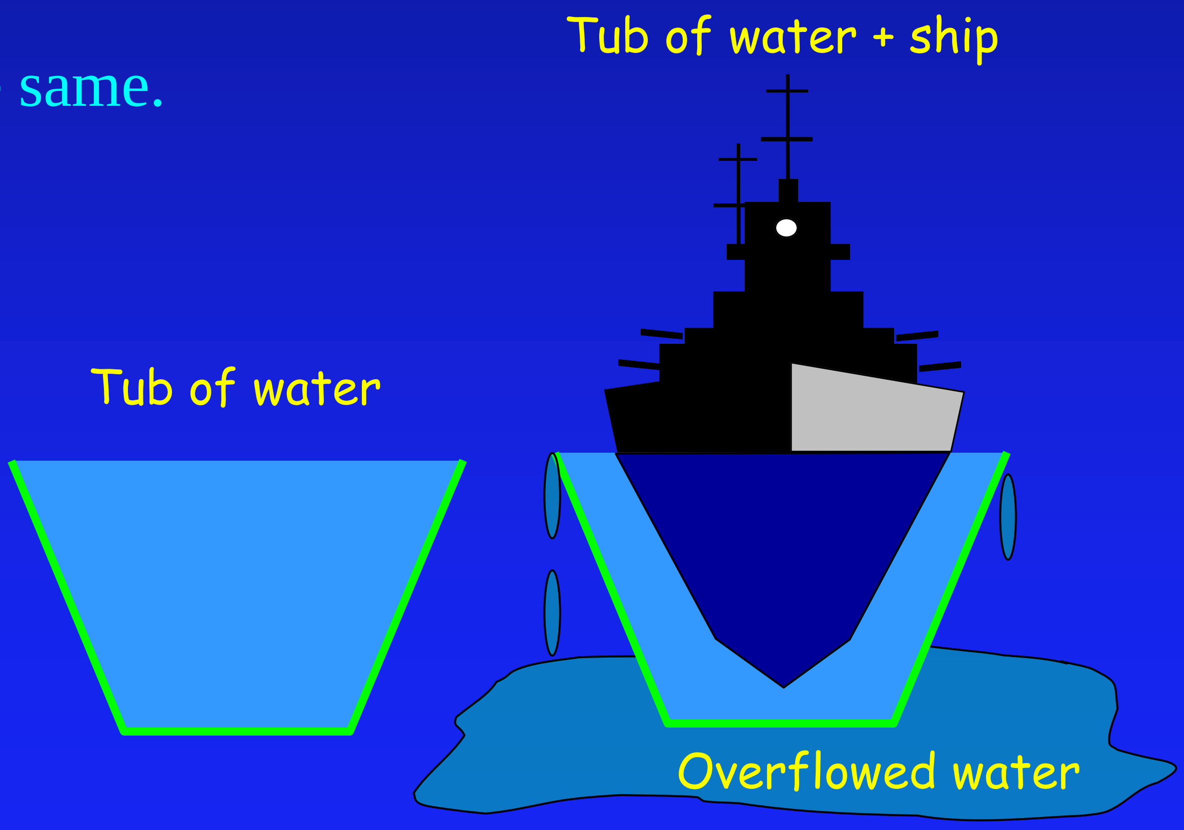
1. Go up, causing the water to spill out of the glass.
2. Go down.
3. Stay the same.



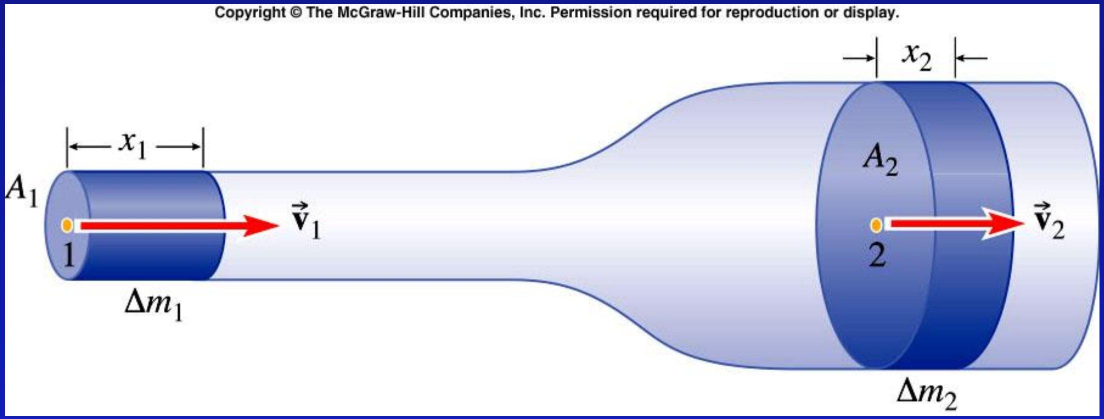
Checkpoint Q2

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.



Continuity of Fluid Flow

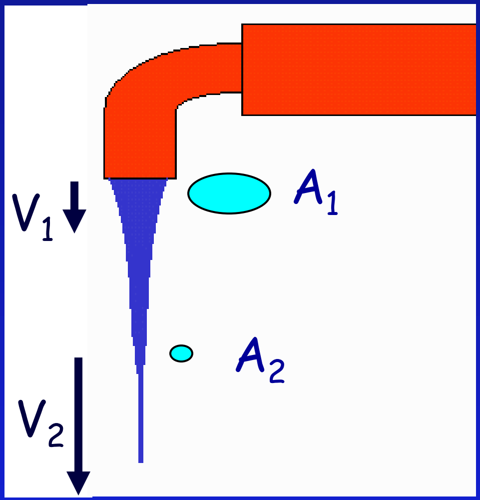


- Watch "plug" of fluid moving through the narrow part of the tube (A_1)
  - Time for "plug" to pass point $\Delta t = x_1 / v_1$
  - Mass of fluid in "plug" $m_1 = \rho V_1 = \rho A_1 x_1$ or $m_1 = \rho A_1 v_1 \Delta t$
- Watch "plug" of fluid moving through the wide part of the tube (A_2)
  - Time for "plug" to pass point $\Delta t = x_2 / v_2$
  - 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
  - $A_1 v_1 = A_2 v_2$

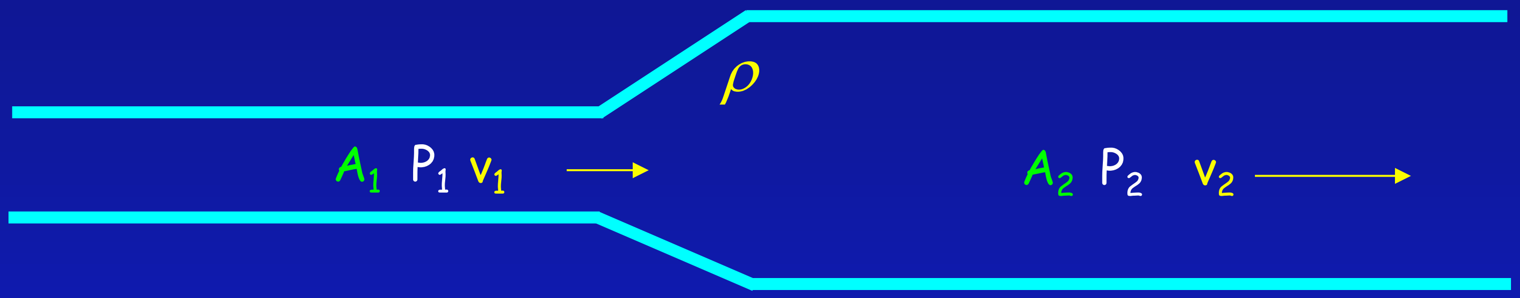
Faucet Prelecture

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

Explain this phenomenon using the equation of continuity



Fluid Flow Concepts



- Mass flow rate: ρAv (kg/s)
- Volume flow rate: Av (m^3/s)
- Continuity: $\rho A_1 v_1 = \rho A_2 v_2$

  i.e., mass flow rate the same everywhere

  e.g., flow of river

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

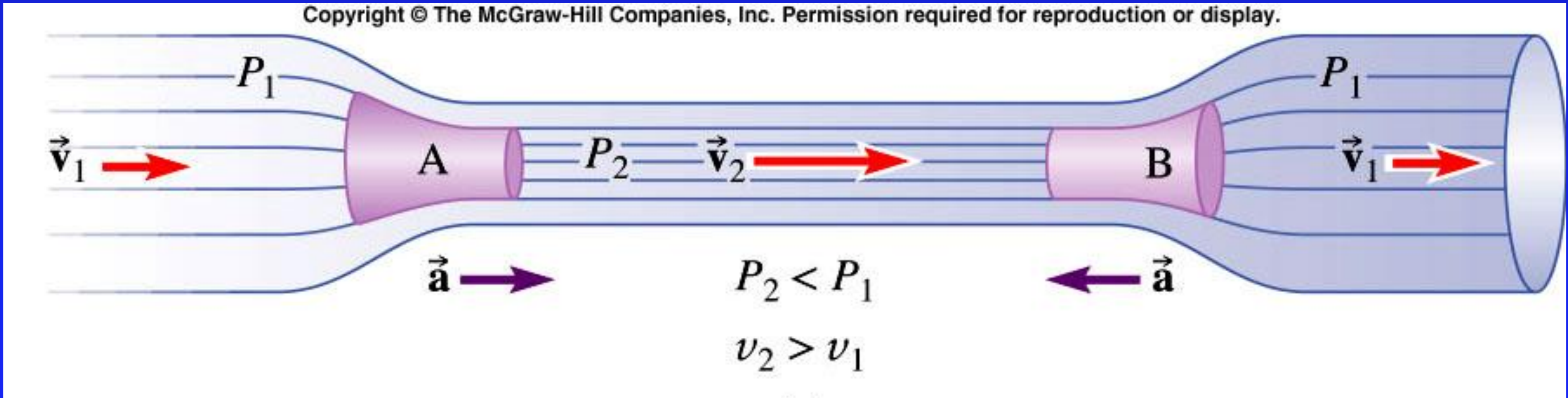
- Change in pressure does work!
  - ➔ $W = (P_1 - P_2)V_{olume}$

Recall:

W=F d

= PA d

= P Vol

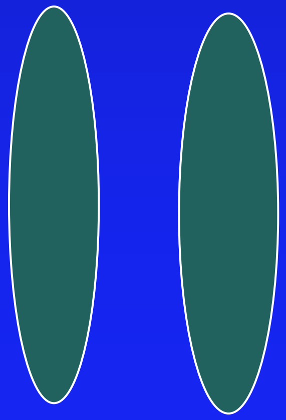


(a)

Pressure ACT

- What will happen when I "blow" air between the two plates?

A) Move Apart B) Come Together C) Nothing



Bernoulli's Eqs. And Work

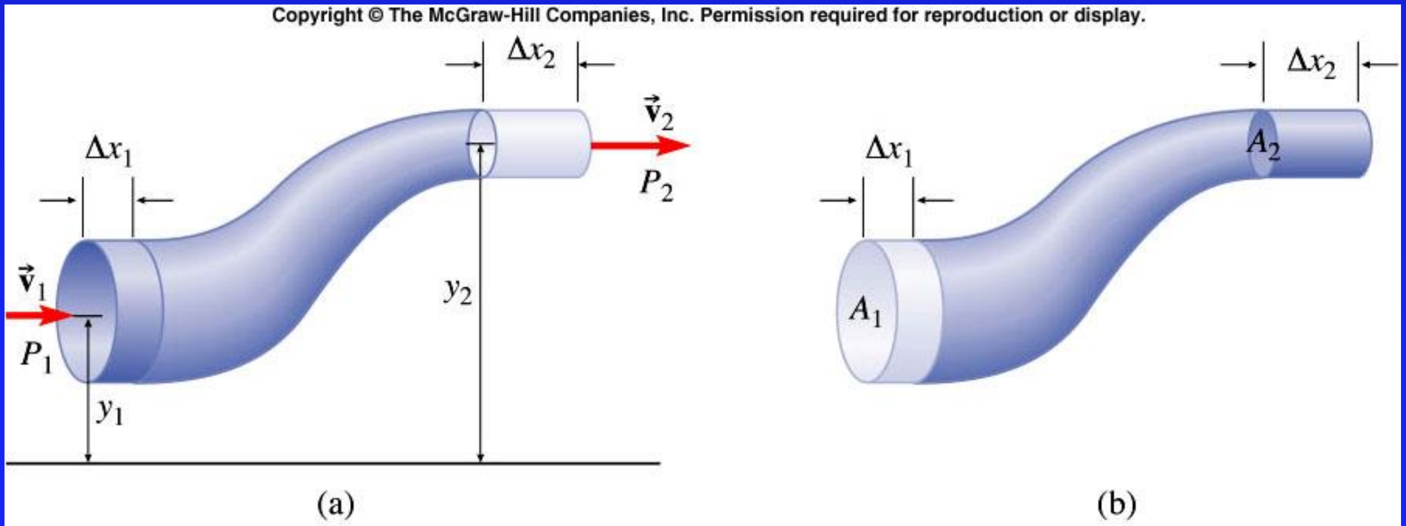
- Consider tube where both Area, height change.
  - ➔ $W = \Delta K + \Delta U$

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

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

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

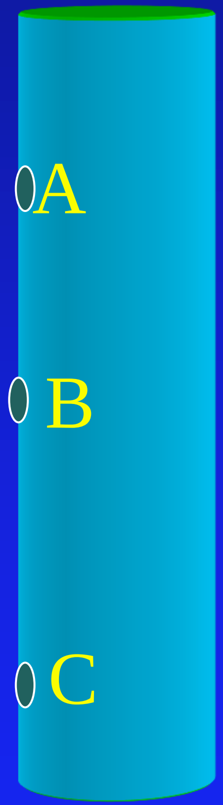
Note:
$W = F\, d$
$= PA\, d$
$= P\, V$



Bernoulli ACT

- Through which hole will the water come out fastest?

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



Note: All three holes have same pressure
P=1 Atmosphere

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

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

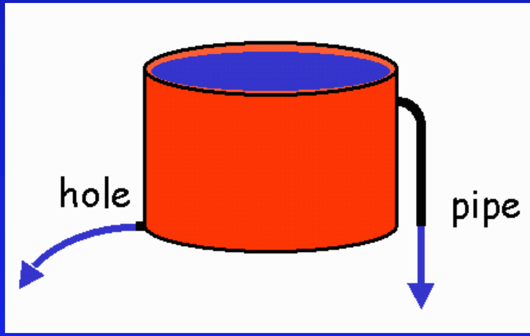
Smaller y gives larger v. Hole C is fastest

Act

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



Lift a House

Calculate the net lift on a 15 m x 15 m house when a 30 m/s wind (1.29 kg/m^3) blows over the top.

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

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

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

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

$= 581$ N/ m^2

$F = P A$

$= 581$ N/ m^2 (15 m)(15 m) = 131,000 N

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

Example (like HW)

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

$$A_1 v_1 = A_2 v_2$$

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

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

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

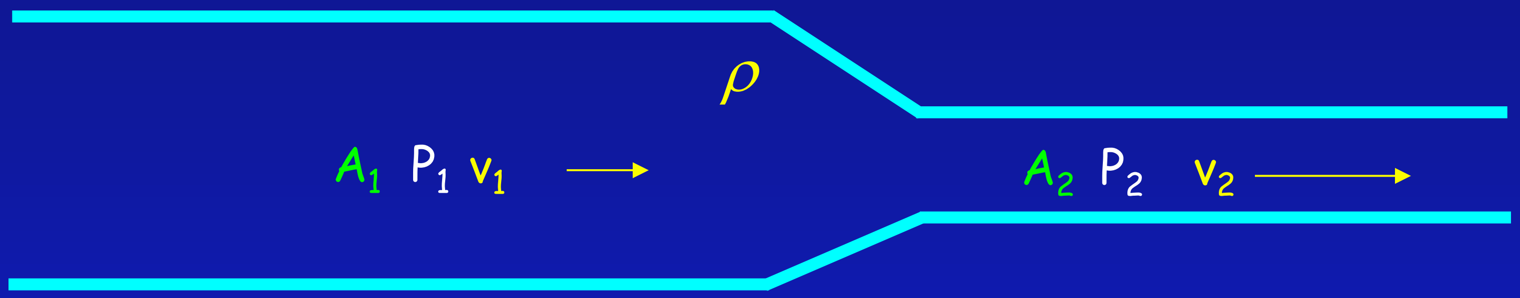
Bernoulli Equation

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

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

$$= \tfrac{1}{2} \times (1000 \text{ kg/m}^3) (1020 \text{ m}^2/\text{s}^2) = 5.1\times10^5 \text{ PA}$$

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