DEVIL PHYSICS
THE BADDEST CLASS ON CAMPUS

AP PHYSICS

MOTIVATION

Introductory Video

Giancoli Lesson 10-8 to 10-10

10-8: Fluids In Motion; Flow Rate And Equation Of Continuity

10-9: Bernoulli's equation

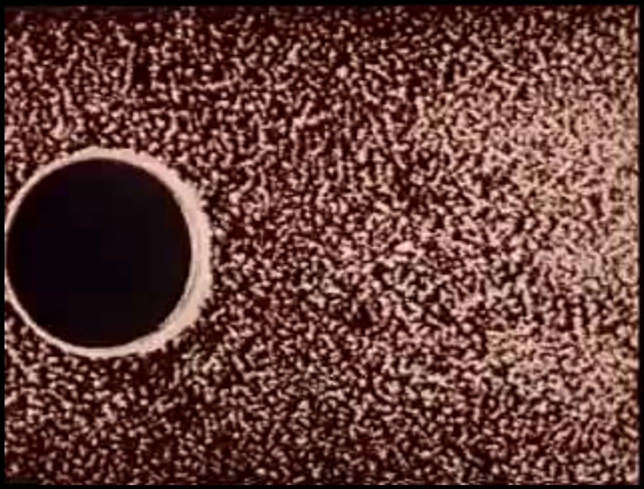
10-10: Applications of Bernoulli's Principle: From Torricelli To Sailboats, Airfoils, and TIA

Objectives

- Know stuff

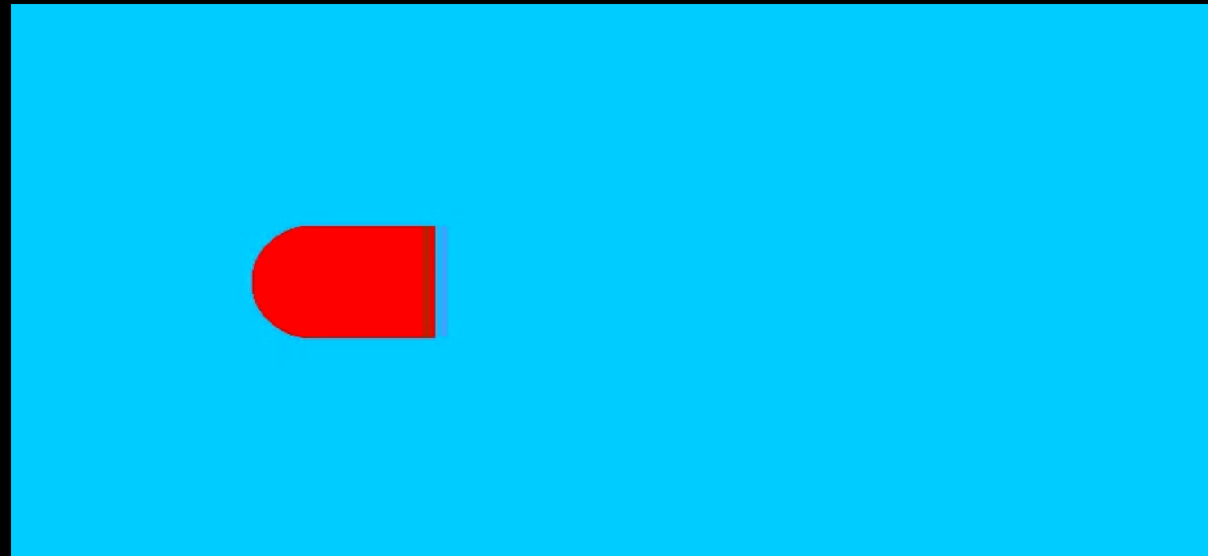
Reading Activity Questions?

Fluids In Motion



- ***Fluid Dynamics*** – study of fluids in motion
- ***Hydrodynamics*** – study of water in motion
- ***Streamline*** or ***laminar flow*** – flow is smooth, neighboring layers of fluid slide by each other smoothly, each particle of the fluid follows a smooth path and the paths do not cross over one another

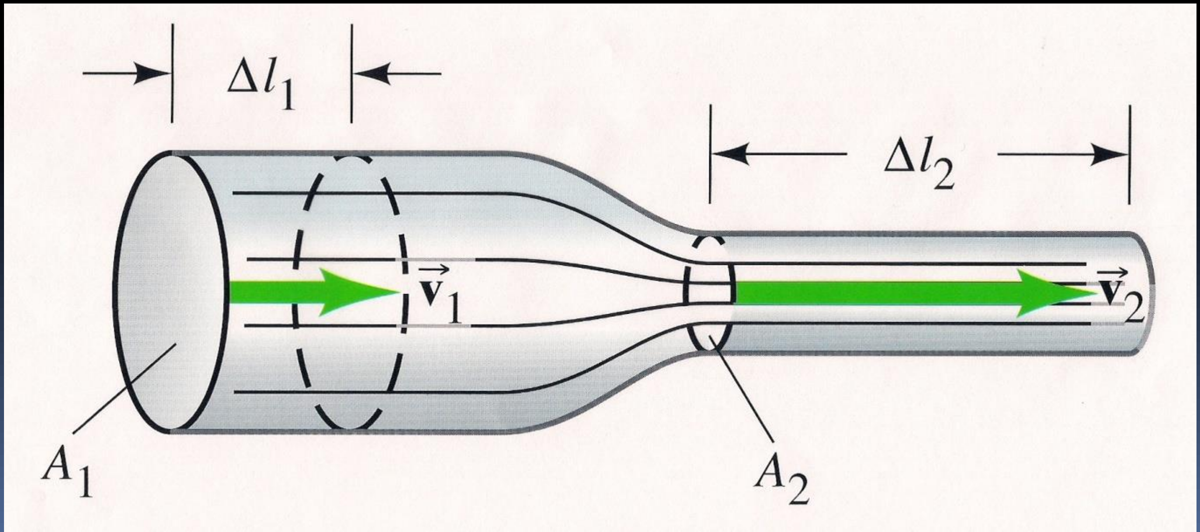
Fluids In Motion



- ***Turbulent flow*** – characterized by erratic, small whirlpool-like circles called ***eddy currents*** or ***eddies***
  - Eddies absorb a great deal energy through internal friction
- ***Viscosity*** – measure of the internal friction in a flow

Speed Changes In Changing Diameter Of Tubes

- **Assumes laminar flow**
- ***Flow rate*** **– the mass (Δm) of fluid that passes through a given point per unit time (Δt)**



$$\frac{\Delta m}{\Delta t}$$

Speed Changes In Changing Diameter Of Tubes

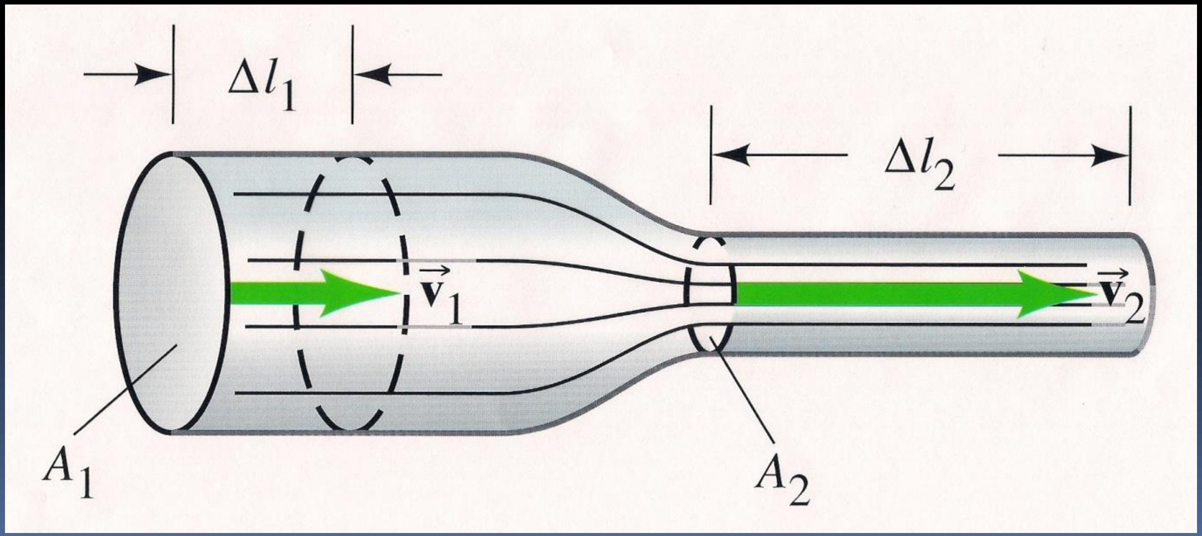
- **Mass is equal to density times volume**

$$\frac{\Delta m}{\Delta t}$$

$$\rho = \frac{m}{V}$$

$$\rho V = m$$

$$\frac{\rho \Delta V}{\Delta t}$$



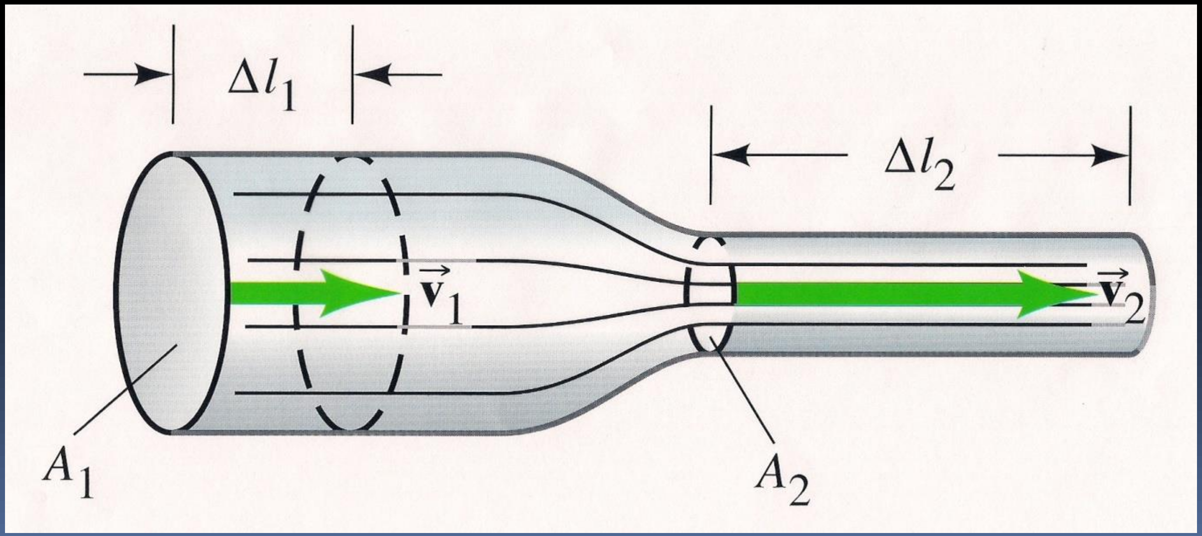
Speed Changes In Changing Diameter Of Tubes

- **The *volume* (*V*) of fluid passing that point in time (Δt) is the cross-sectional area of the pipe (A) times the distance (Δl) travelled over the time (Δt)**

$$\frac{\rho \Delta V}{\Delta t}$$

$$\Delta V = A \Delta l$$

$$\frac{\rho A \Delta l}{\Delta t}$$



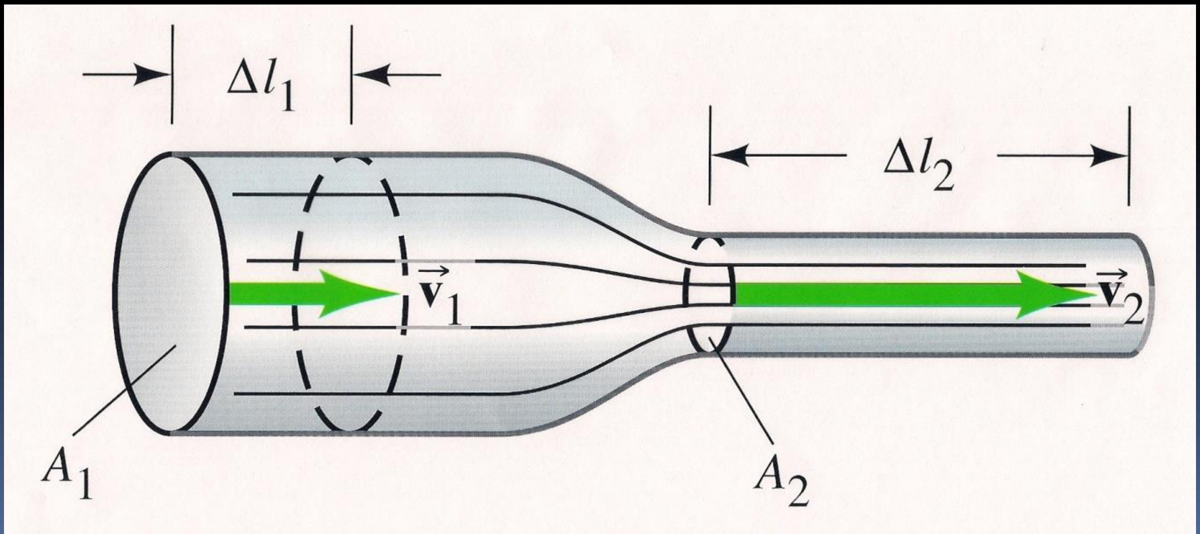
Speed Changes In Changing Diameter Of Tubes

- **The velocity is equal to the distance divided by the time so, mass flow rate becomes** ***ρAv***

$$\frac{\rho A \Delta l}{\Delta t}$$

$$v = \frac{\Delta l}{\Delta t}$$

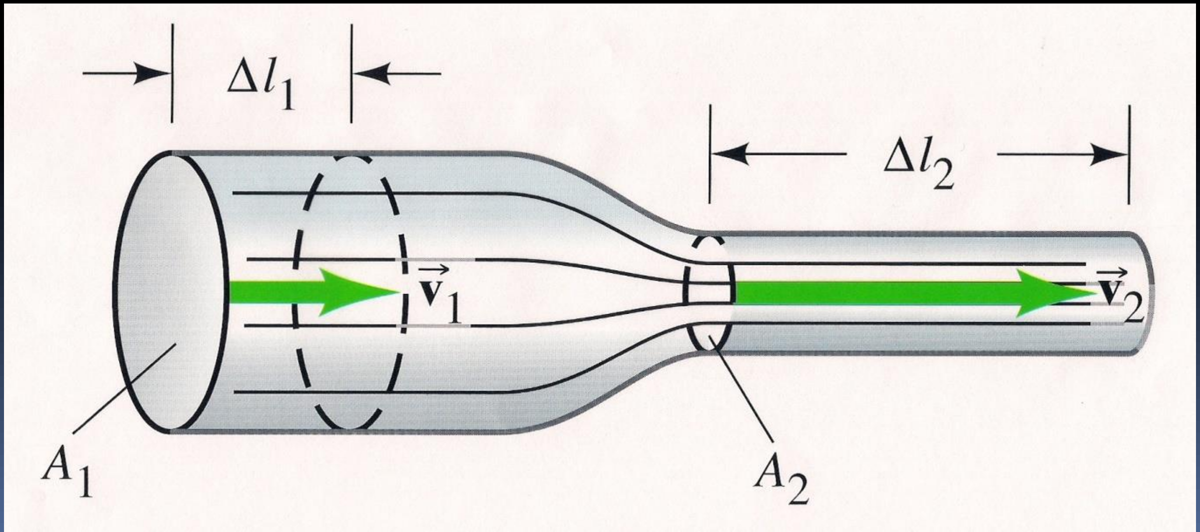
$$\rho A v$$



Speed Changes In Changing Diameter Of Tubes

- **Since no fluid escapes, the mass flow rate at both ends of this tube are the same**

$$\rho_1 A_1 v_1 = \rho_2 A_2 v_2$$

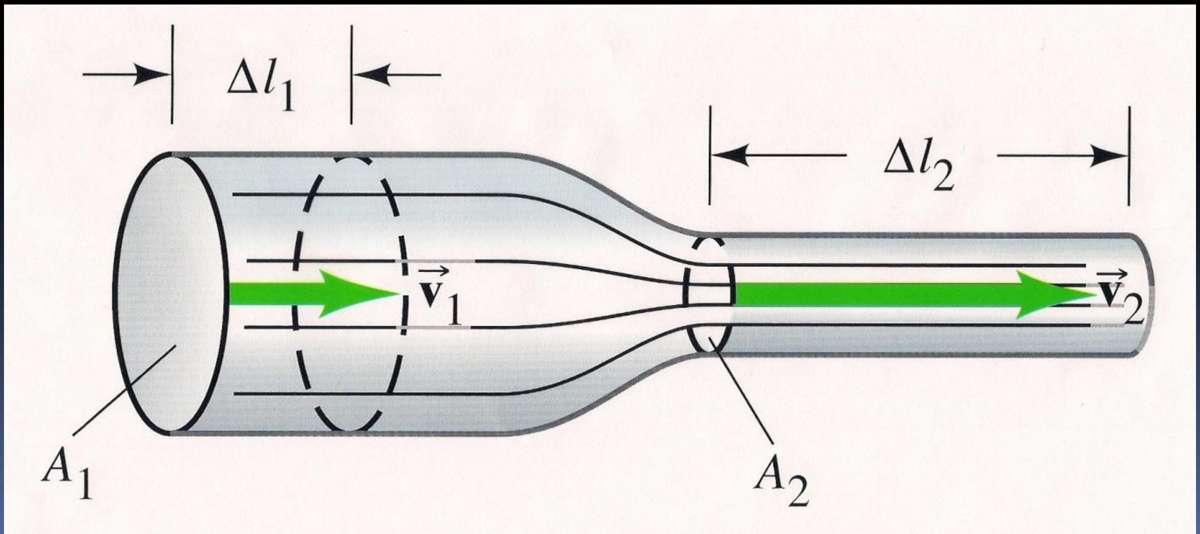


Speed Changes In Changing Diameter Of Tubes

- **If we assume the fluid is incompressible, density is the same and,**

$$\rho_1 A_1 v_1 = \rho_2 A_2 v_2$$

$$A_1 v_1 = A_2 v_2$$



- ***Equation of Continuity***

and

- ***Volume Rate of Flow***

Speed Changes In Changing Diameter Of Tubes

- **When cross-sectional area is large, velocity is small. When the cross-sectional area is small, velocity is high**

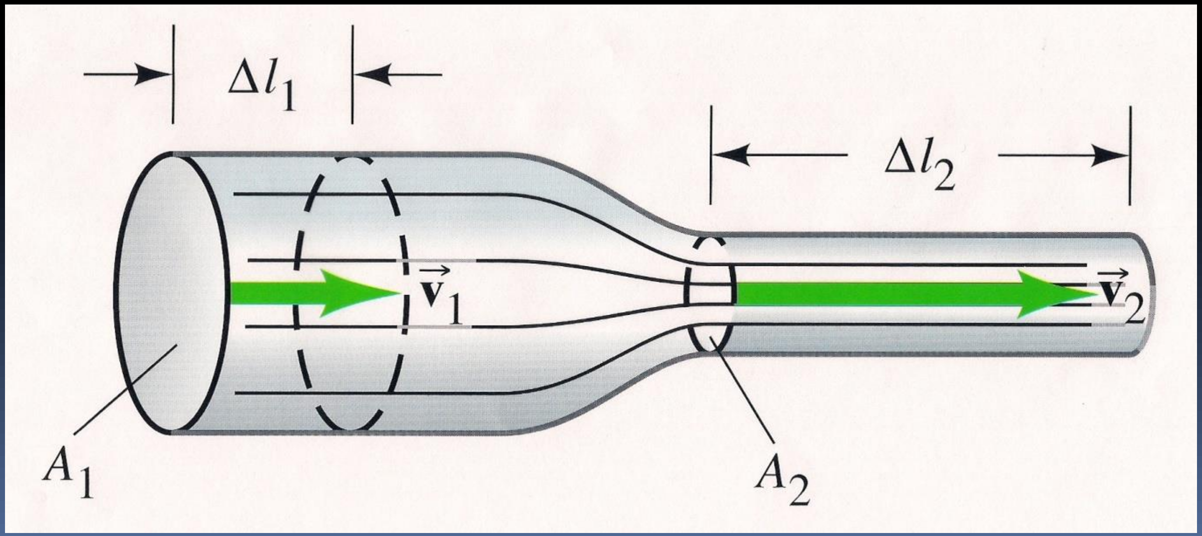
$$\rho_1 A_1 v_1 = \rho_2 A_2 v_2$$

$$A_1 v_1 = A_2 v_2$$

- ***Equation of Continuity***

and

- ***Volume Rate of Flow***

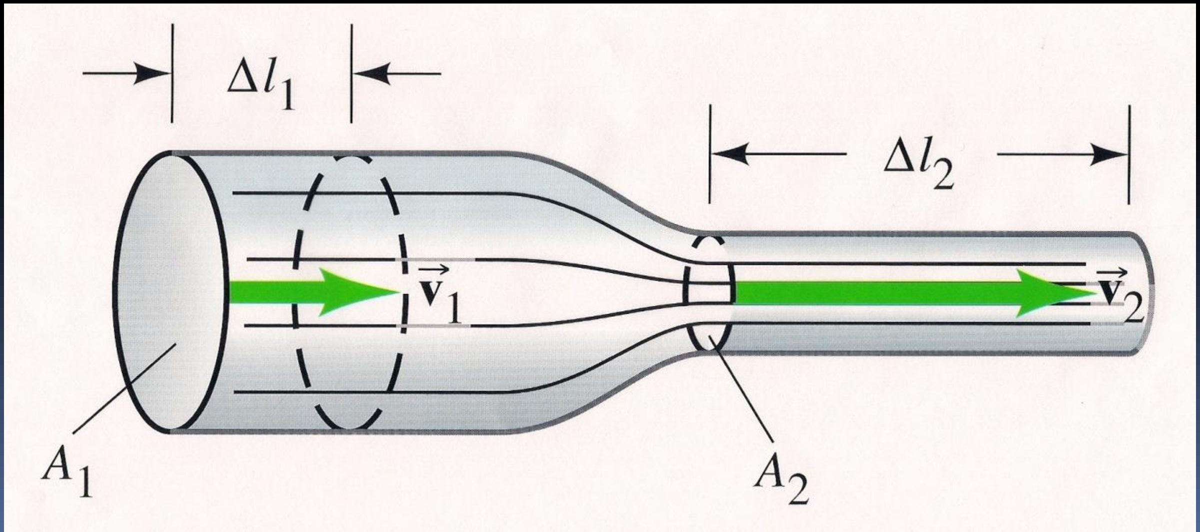


Speed Changes In Changing Diameter Of Tubes

- That's why you put your thumb over the end of the hose to squirt people at car washes

$$\rho_1 A_1 v_1 = \rho_2 A_2 v_2$$

$$A_1 v_1 = A_2 v_2$$



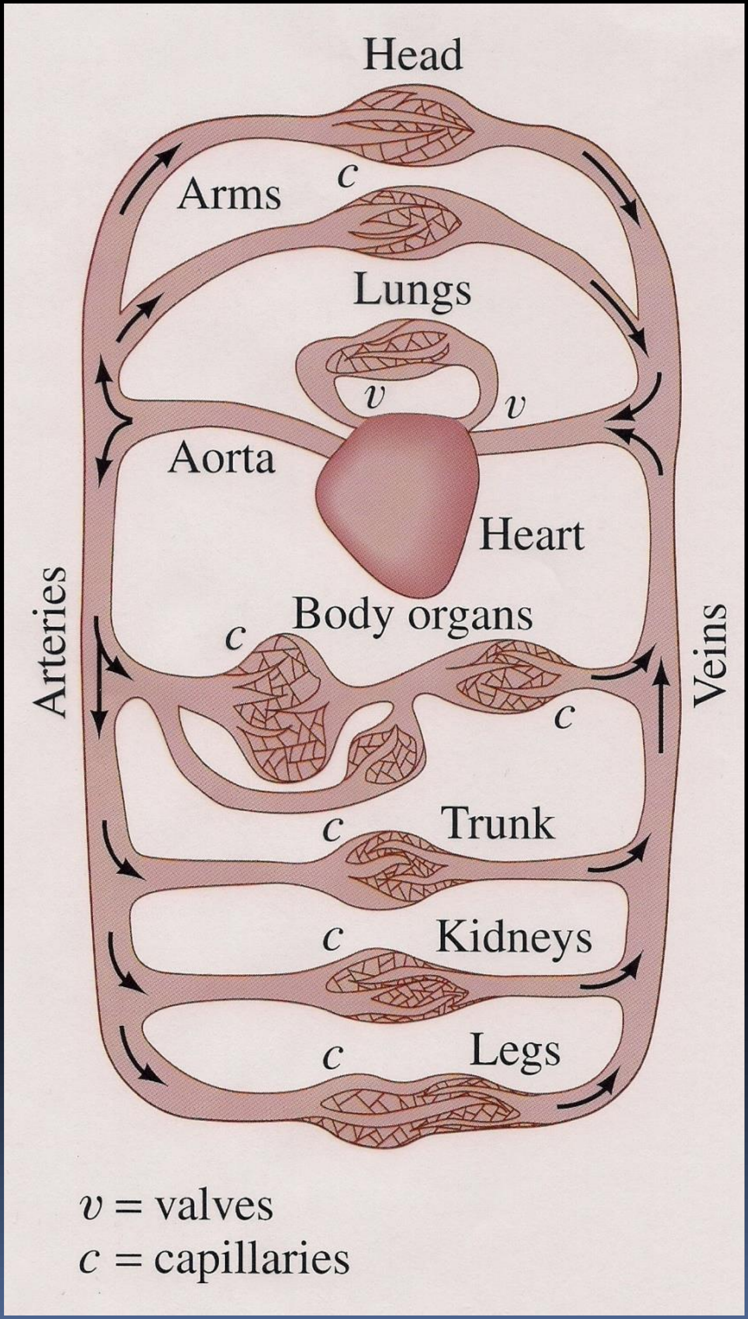
- ***Equation of Continuity***

and

- ***Volume Rate of Flow***

Sample Problem

Blood Flow.* *The radius of the aorta is about 1.0cm and the blood passing through it has a speed of about 30cm/s. A typical capillary has a radius of about 4×10^{-4}cm and blood flows through it at a speed of about 5×10^{-4}m/s. Estimate how many capillaries there are in the body.



Sample Problem

***Blood Flow.** The radius of the aorta is about 1.0cm and the blood passing through it has a speed of about 30cm/s. A typical capillary has a radius of about 4×10^{-4}cm and blood flows through it at a speed of about 5×10^{-4}m/s. Estimate how many capillaries there are in the body.*

$$A_a v_a = A_c v_c$$

$$\pi r_a^2 v_a = N_c \pi r_c^2 v_c$$

$$\frac{\pi r_a^2 v_a}{\pi r_c^2 v_c} = N$$

$$N = 4{,}000{,}000{,}000$$

NOTE: FOR ALL THE ~~BIOWEENIES~~ BIOLOGY STUDENTS NOT TAKING PHYSICS NEXT YEAR, IF YOU NEED HELP FILLING OUT YOUR WORKSHEETS OR DRAWING YOUR DIAGRAMS, YOU CAN ALWAYS STOP BY DEVIL PHYSICS FOR HELP.

Bernoulli's Equation

Bernoulli's Equation

- *Daniel Bernoulli (1700-1782) is the only reason airplanes can fly*
- Ever wonder why:
  - The shower curtain keeps creeping toward you?
  - Smoke goes up a chimney and not in your house?
  - When you see a guy driving with a piece of plastic covering a broken car window, that the plastic is always bulging out?

Bernoulli’s Equation

- Ever wonder why:
  - Why a punctured aorta will squirt blood up to 75 feet, but yet waste products can flow into the blood stream at the capillaries against the blood’s pressure?
  - How in the world Roberto Carlos made the impossible goal?
- It’s Bernoulli’s fault

Bernoulli's Principle

Bernoulli's Equation

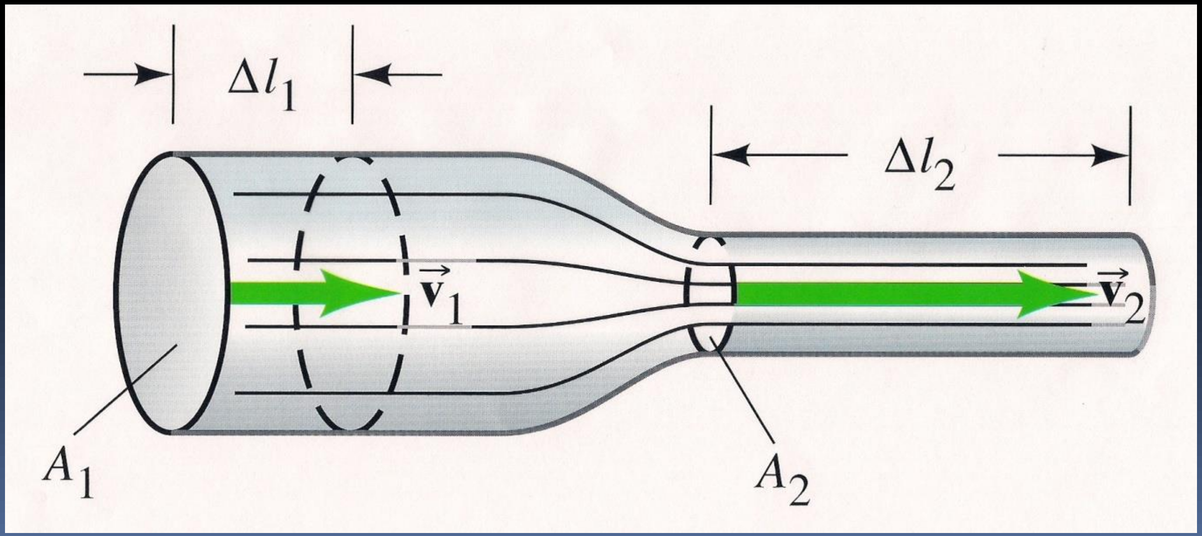
- ***<u>Bernoulli's principle states, where the velocity of a fluid is high, the pressure is low, and where the velocity is low, the pressure is high</u>***

BLOWING PAPER DEMO

- **Not as straight forward as it sounds**
- **Consider this,**

Bernoulli's Equation

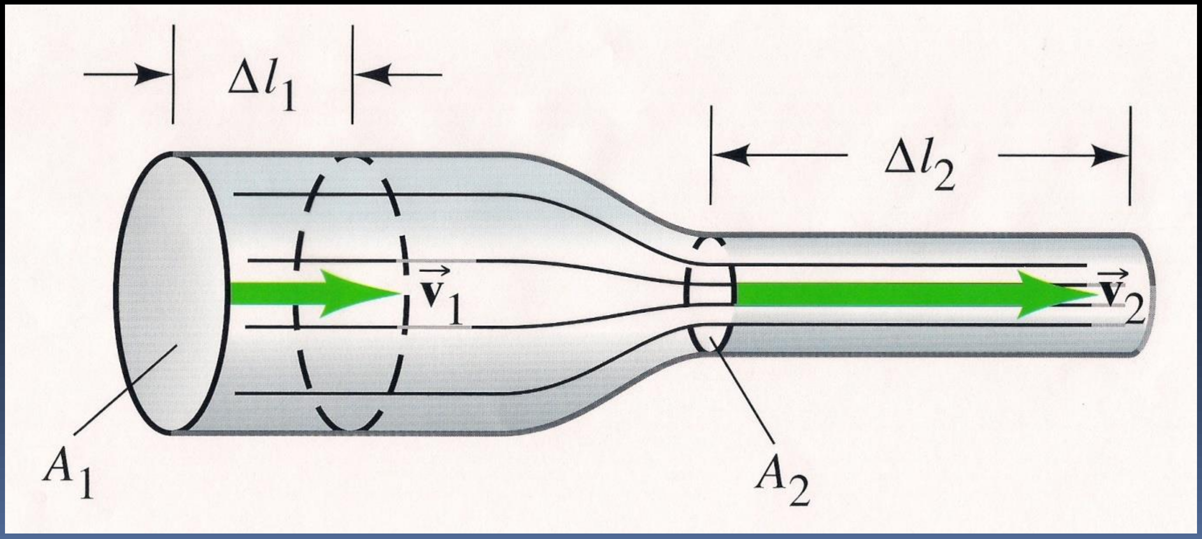
- We just said that as the fluid flows from left to right, the velocity of the fluid increases as the area gets smaller
- You would think the pressure would increase in the smaller area, but it doesn't, it gets smaller
- But, the pressure in area 1 does get larger



How come?

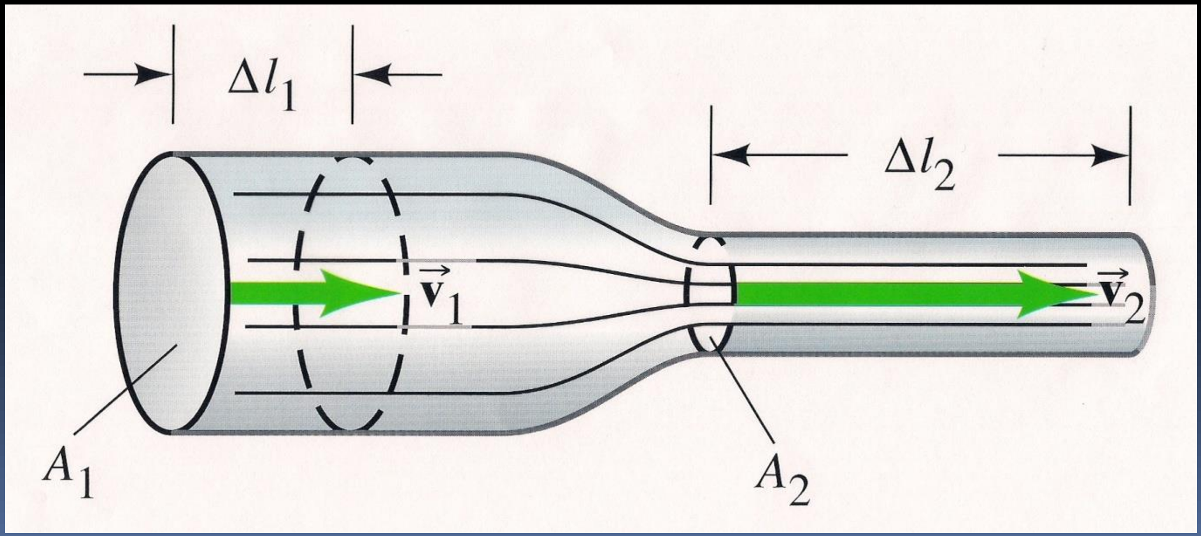
Bernoulli's Equation

- **When you wash a car, your thumb cramps up holding it over the end of the hose.**
  - **This is because of the pressure built up behind your thumb.**



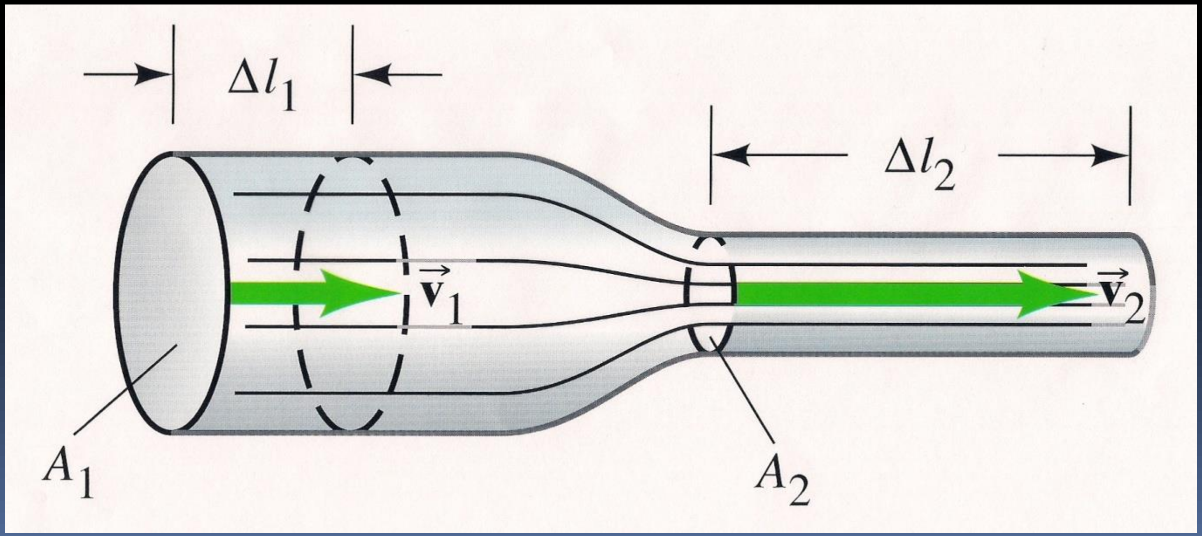
Bernoulli's Equation

- If you stuck your pinky inside the hose, you would feel pressure at the tip of your finger, a decrease in the pressure along the sides of your finger, and an increase in the velocity of the water coming out of the hose.
- *You would also get squirted in the face but that's your own fault for sticking your finger in a hose!*



Bernoulli’s Equation

- **It makes sense from Newton’s Second Law**
- ***In order for the mass flow to accelerate from the larger pipe to the smaller pipe, there must be a decrease in pressure***



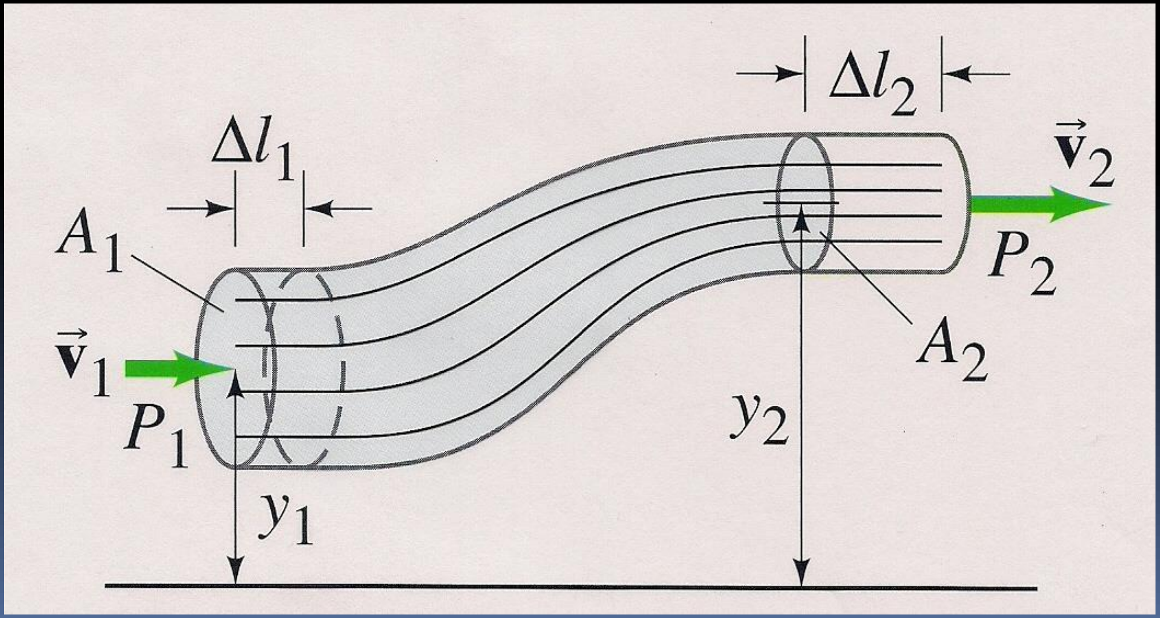
$$A_1 v_1 = A_2 v_2$$

$$\Sigma F = ma$$

$$P = \frac{F}{A}$$

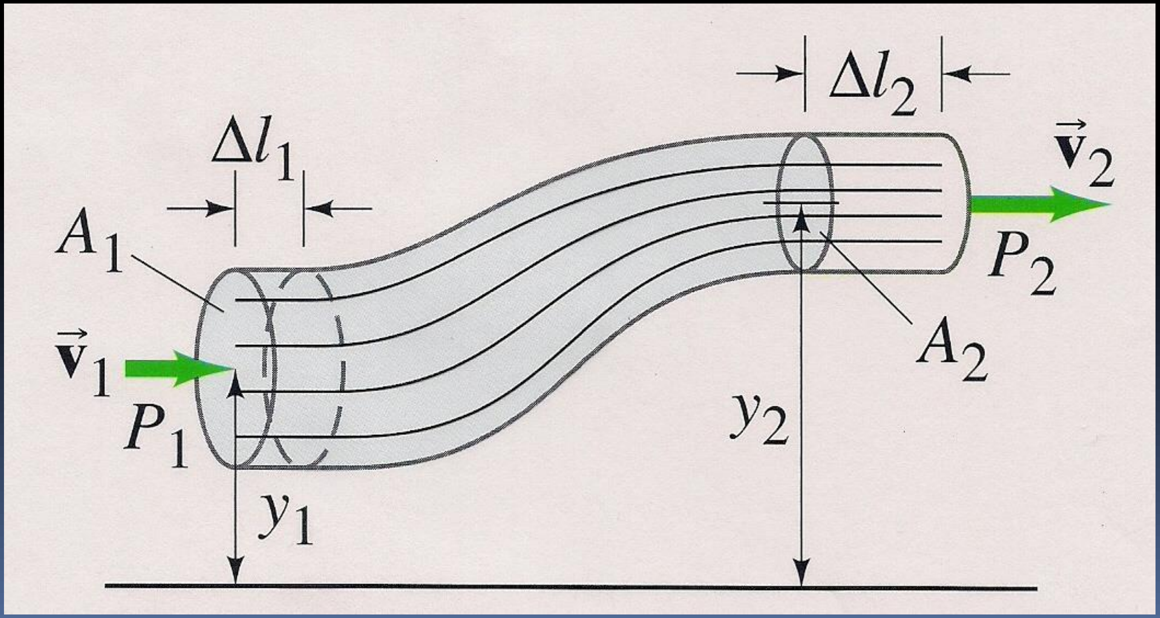
Bernoulli’s Equation

- Assumptions:
  - Flow is steady and laminar
  - Fluid is incompressible
  - Viscosity is small enough to be ignored
- Consider flow in the diagram below:



Bernoulli's Equation

- **We want to move the blue fluid on the left to the white area on the right**
  - **On the left, the fluid must move a distance of Δl_1**
  - **Since the right side of the tube is narrower, the fluid must move farther (Δl_2) in order to move the same volume that is in Δl_1**



Bernoulli's Equation

- **Work must be done to move the fluid along the tube and we have pressure available to do it**

$$W = Fd$$

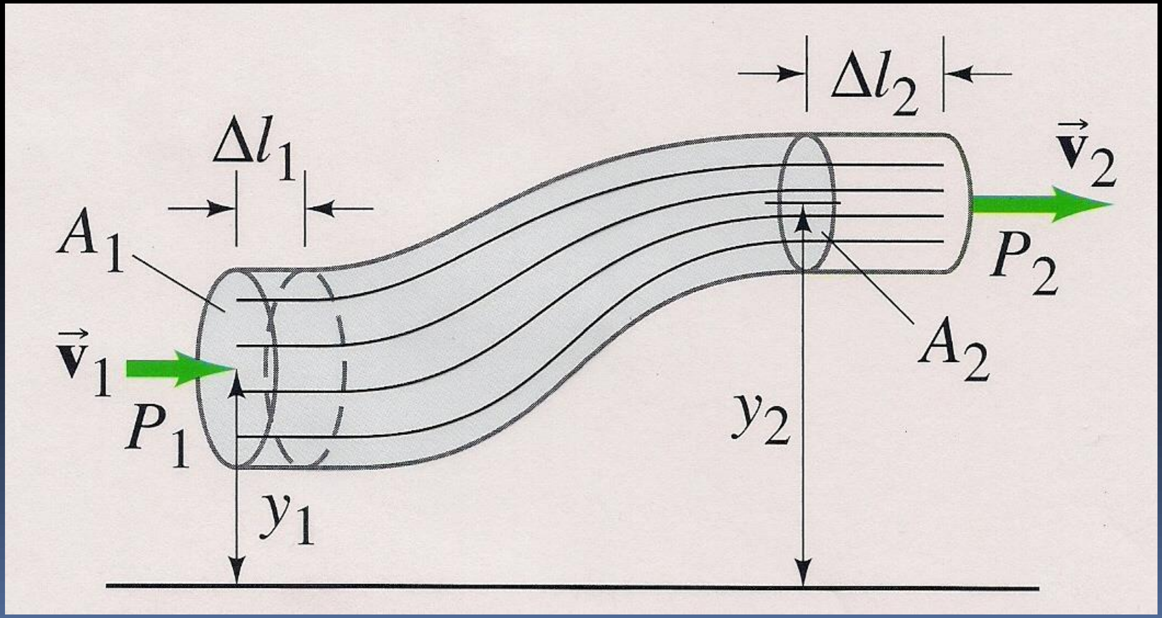
$$P = \frac{F}{A}$$

$$F = PA$$

$$d = \Delta l$$

$$W_1 = P_1 A_1 \Delta l_1$$

$$W_2 = -P_2 A_2 \Delta l_2$$



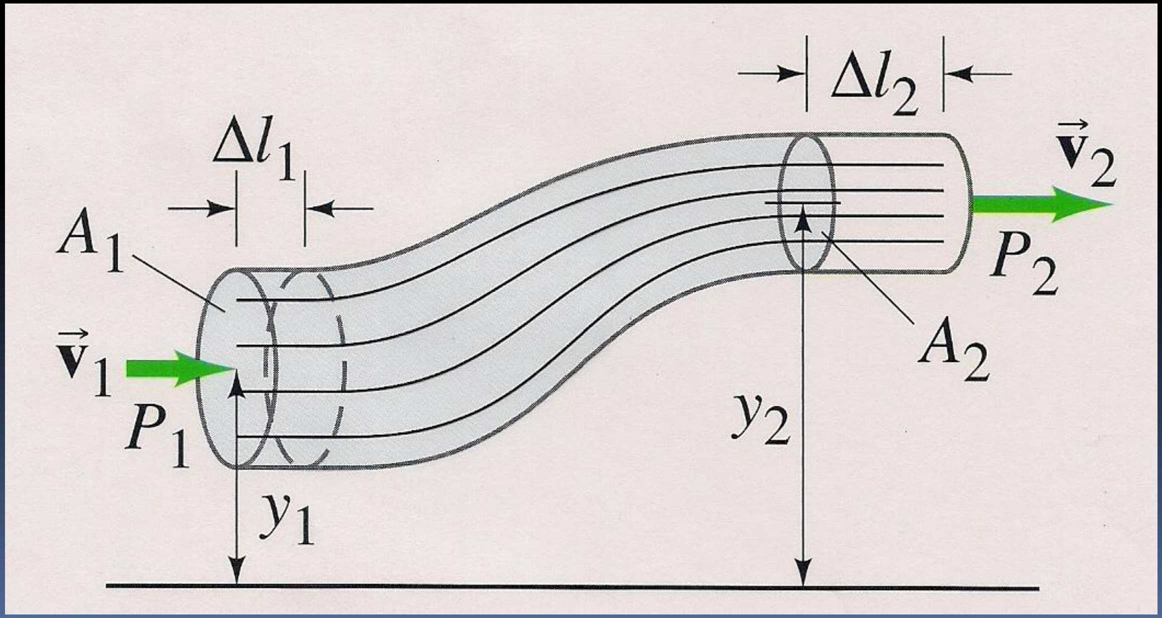
Bernoulli's Equation

- **There is also work done by gravity (since the pipe has an increase in elevation) which acts on the entire body of fluid that you are trying to move**
- **Force of gravity is mg, work is force times distance, so:**

$$W_3 = Fd$$

$$W_3 = -mg\left(y_2 - y_1\right)$$

$$W_3 = -mgy_2 + mgy_1$$

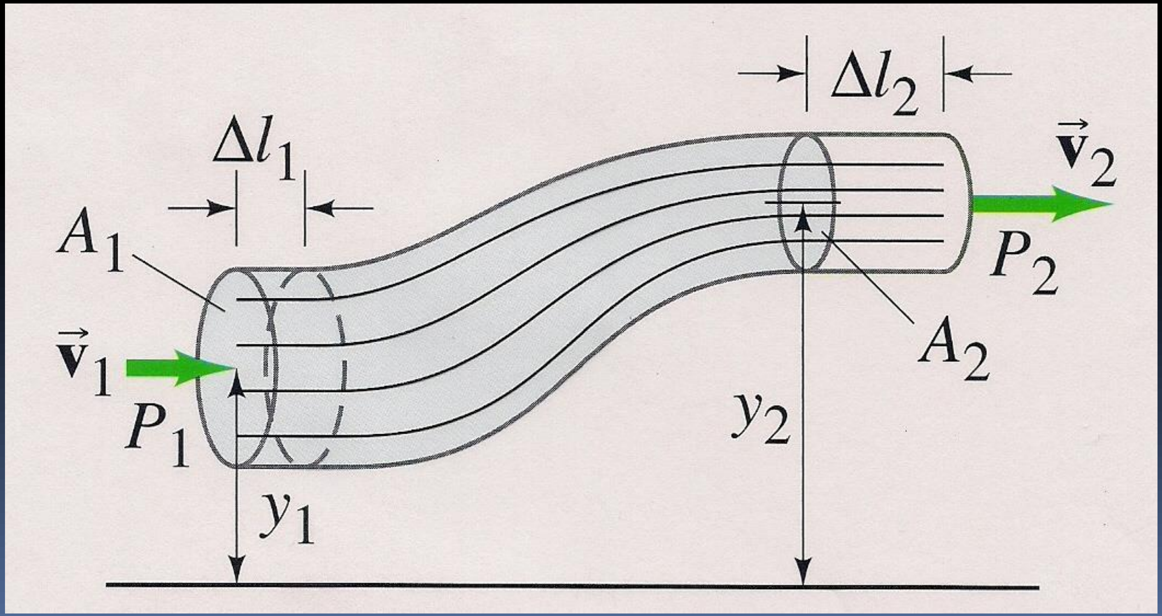


Bernoulli’s Equation

- **Total work done is then the sum of the three:**

$$W_T = W_1 + W_2 + W_3$$

$$W_T = P_1 A_1 \Delta l_1 - P_2 A_2 \Delta l_2 - mgy_2 + mgy_1$$

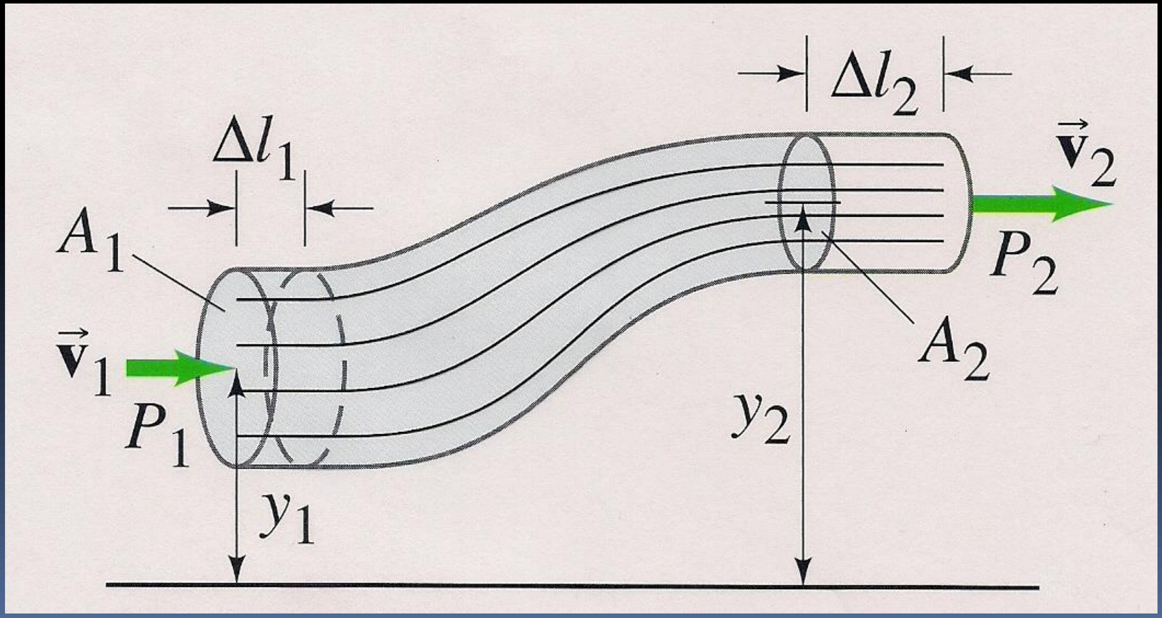


Bernoulli's Equation

- ***Anything we can do to make this longer?***

$$W_T = W_1 + W_2 + W_3$$

$$W_T = P_1 A_1 \Delta l_1 - P_2 A_2 \Delta l_2 - mgy_2 + mgy_1$$

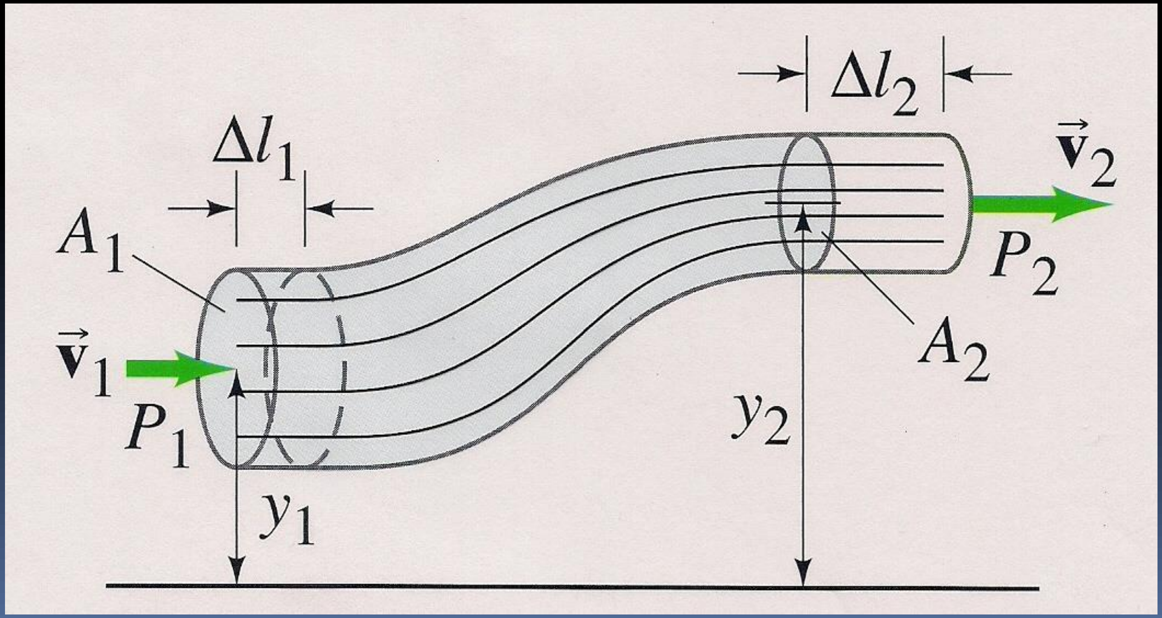


Bernoulli's Equation

- *Anything we can do to make this longer?*

$$W_T = \Delta KE$$

$$\frac{1}{2}mv_2^2 - \frac{1}{2}mv_1^2 = P_1A_1\Delta l_1 - P_2A_2\Delta l_2 - mgy_2 + mgy_1$$



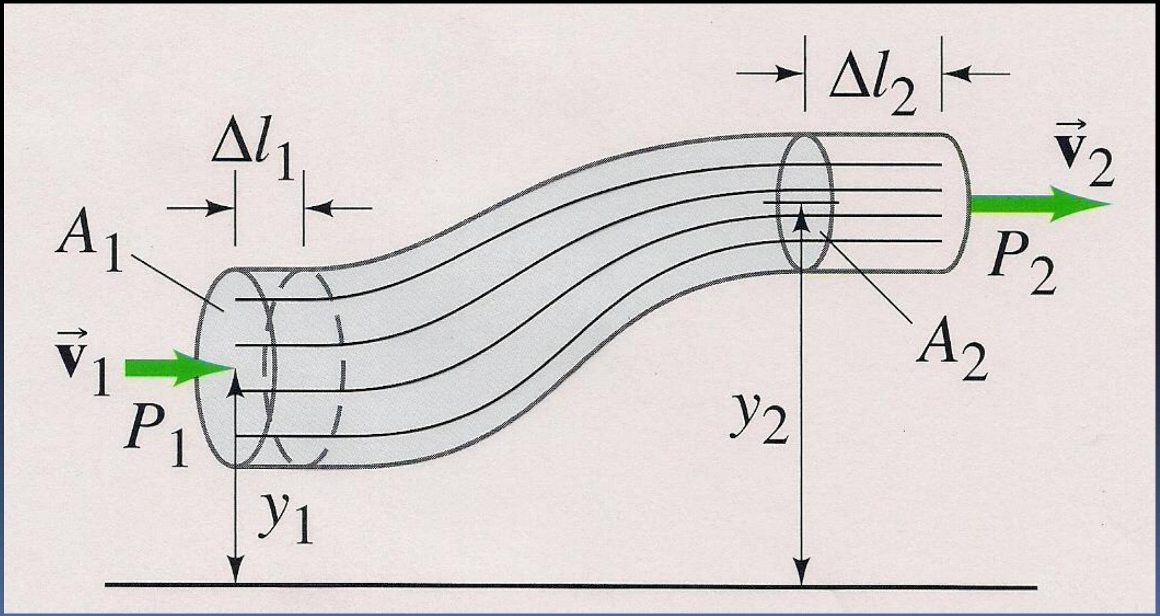
How about the work – energy principle?

Bernoulli's Equation

- *Better, but it needs to be cleaned up a little.*

$$\frac{1}{2}mv_2^2 - \frac{1}{2}mv_1^2 = P_1A_1\Delta l_1 - P_2A_2\Delta l_2 - mgy_2 + mgy_1$$

$$m = \rho A_1\Delta l_1 = \rho A_2\Delta l_2$$



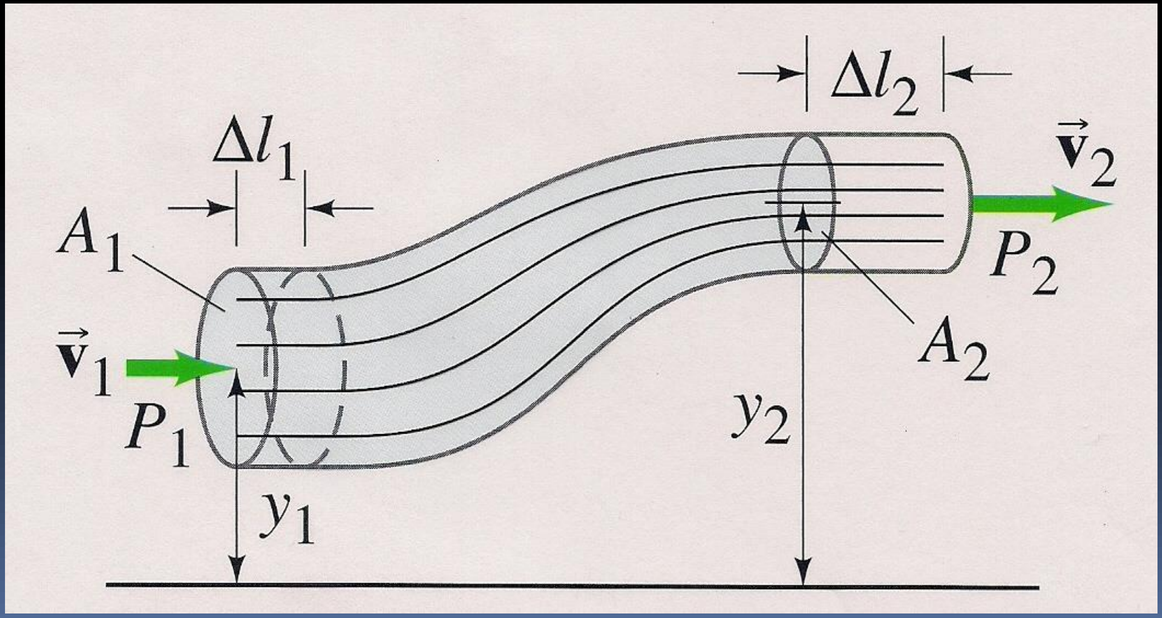
Substitute for m, then since $A_1\Delta l_1 = A_2\Delta l_2$, we can divide them out

Bernoulli's Equation

- ***Manageable,***

$$\frac{1}{2}mv_2^2 - \frac{1}{2}mv_1^2 = P_1A_1\Delta l_1 - P_2A_2\Delta l_2 - mgy_2 + mgy_1$$

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

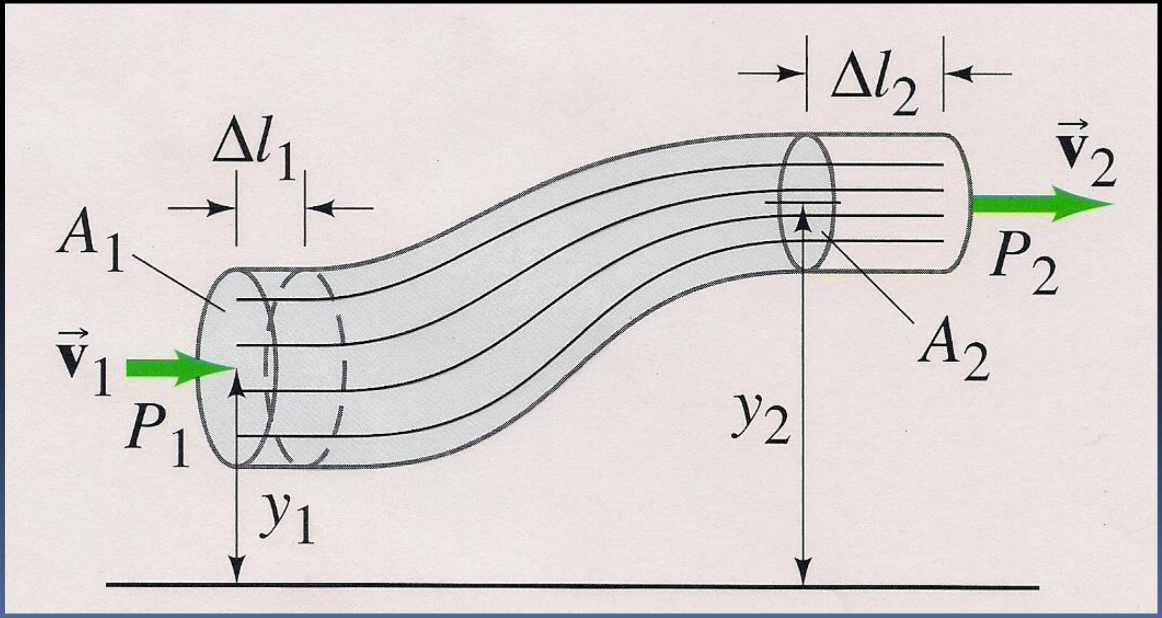


but let's make it look like something a little more familiar

Bernoulli's Equation

- *Look familiar,*

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



like Conservation of Energy?

Sample Problem

Water circulates throughout a house in a hot-water heating system (Iceland). If the water is pumped at a speed of 0.50 m/s through a 4.0 cm diameter pipe in the basement under a pressure of 3 atm, what will be the flow speed and pressure in a 2.6 cm diameter pipe on the second floor 5.0 m above?

$$A_1 v_1 = A_2 v_2$$

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

$$v_2 = \frac{\left(\pi r_1^{\,2}\right) v_1}{\left(\pi r_2^{\,2}\right)}$$

$$v_2 = \frac{(0.02)^2 (0.5)}{(0.013)^2}$$

$$v_2 = 1.2 m/s$$

Sample Problem

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

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

Sample Problem

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

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

Sample Problem

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

$$P_2 = \left(3x10^5\right) + (0.5)\left(1x10^3\right)\left(0.5^2 - 1.2^2\right)$$

$$+\left(1x10^3\right)(9.81)(-5.0)$$

Sample Problem

Water circulates throughout a house in a hot-water heating system (Iceland). If the water is pumped at a speed of 0.50 m/s through a 4.0 cm diameter pipe in the basement under a pressure of 3 atm, what will be the flow speed and pressure in a 2.6 cm diameter pipe on the second floor 5.0 m above?

$$P_2 = \left(3x10^5\right) + \left(0.5\right)\left(1x10^3\right)\left(0.5^2 - 1.2^2\right) + \left(1x10^3\right)\left(9.81\right)\left(-5.0\right)$$

$$P_2 = 2.5x10^5\ N/m^2 = 2.5atm$$

Whew!

Applications: Torricelli's Theorem

- Consider water flowing out of a "spigot" at the bottom of a reservoir
  - Because the diameter of the reservoir is extremely large in comparison to the spigot, velocity of reservoir can be neglected
  - Atmospheric pressure is the same at both ends ($P_1 = P_2$)
  - Bernoulli's equation becomes:
  - Now solve for v_s

$$\frac{1}{2}\rho v_s^2 + \rho g y_s = \rho g y_r$$

Applications: Torricelli's Theorem

- Consider water flowing out of a "spigot" at the bottom of a reservoir
  - Because the diameter of the reservoir is extremely large in comparison to the spigot, velocity of reservoir can be neglected
  - Atmospheric pressure is the same at both ends (P_1=P_2)
  - Bernoulli's equation becomes:

$$\frac{1}{2}\rho v_s^2 + \rho g y_s = \rho g y_r$$

  - Now solve for v_s

$$v_s = \sqrt{2g\left(y_r - y_s\right)}$$

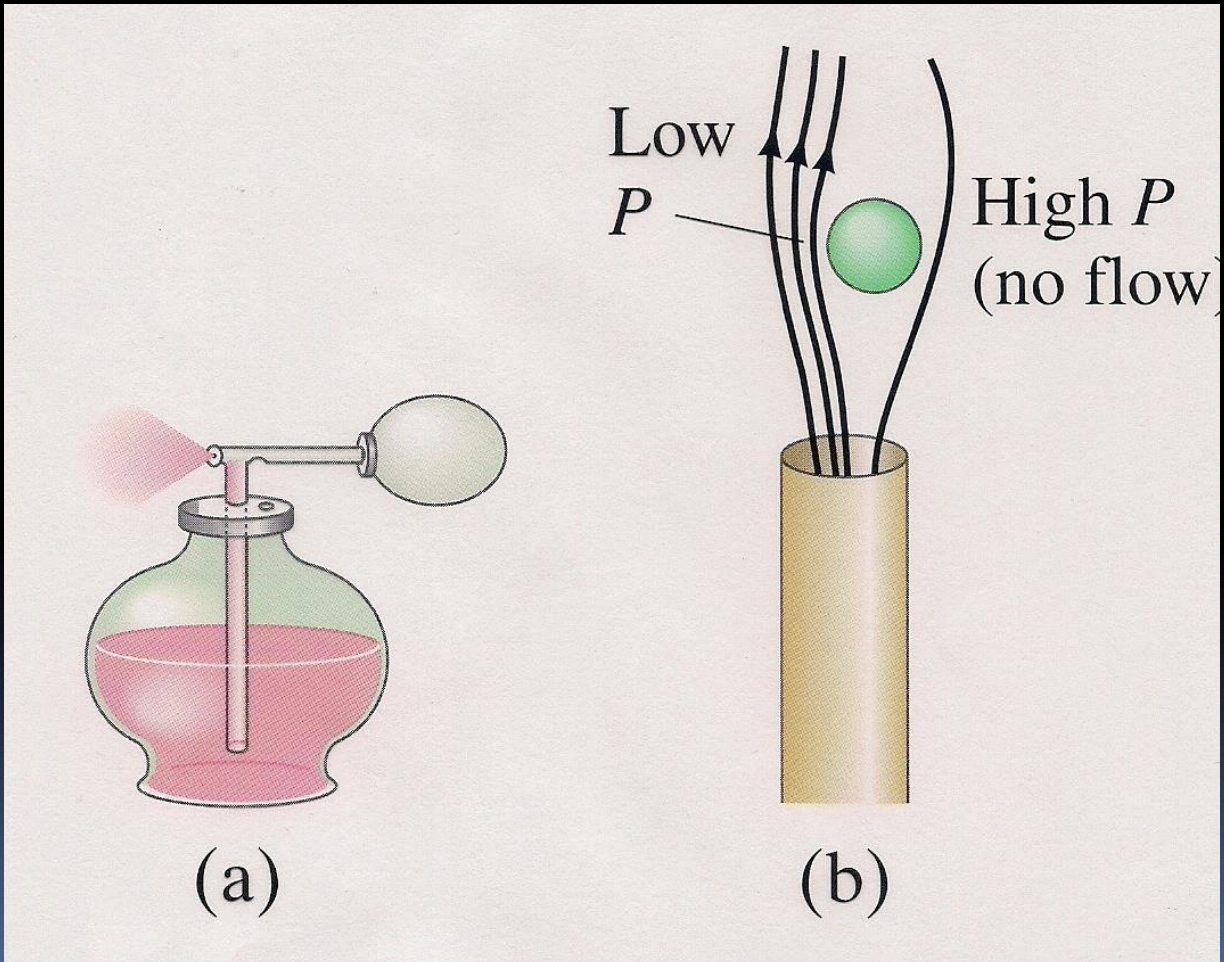
Applications: No Change in Height

- Bernoulli's equation becomes:

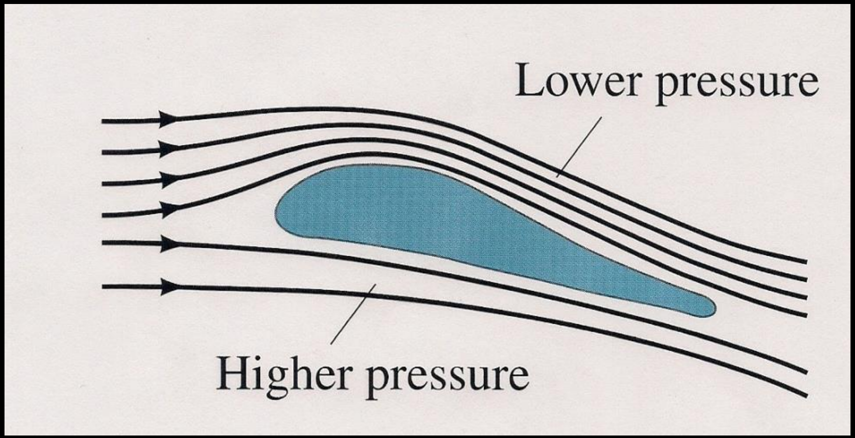
$$P_1 + \frac{1}{2}\rho v_1^2 = P_2 + \frac{1}{2}\rho v_2^2$$

- As velocity increases, pressure decreases
- As velocity decreases, pressure increases

Applications: Atomizers and Ping Pong Balls

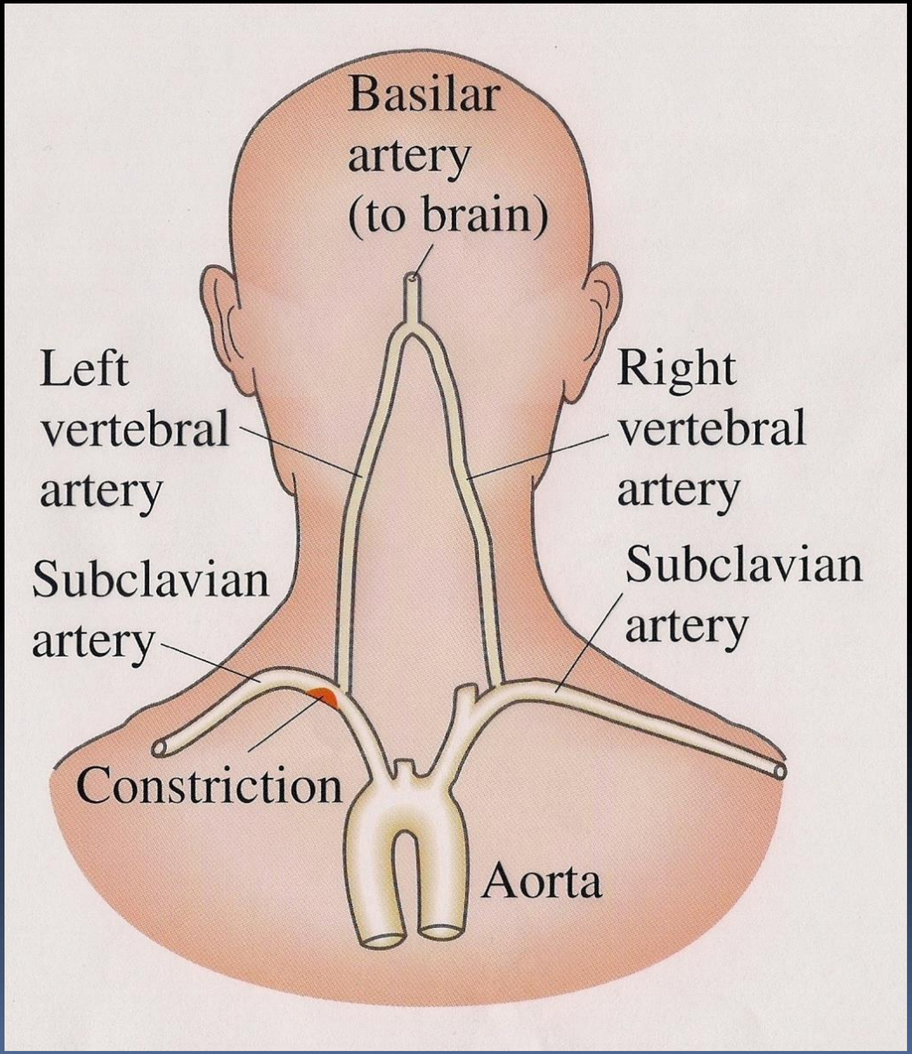


Applications: Airfoils



Applications: Transient Ischemic Attack

- **Temporary lack of blood supply to the brain**
- **WARNING: This discussion may make you feel faint! (feint attempt at humor)**



Summary Review

- Do you know more stuff than before?

QUESTIONS?

Homework *#35-45*