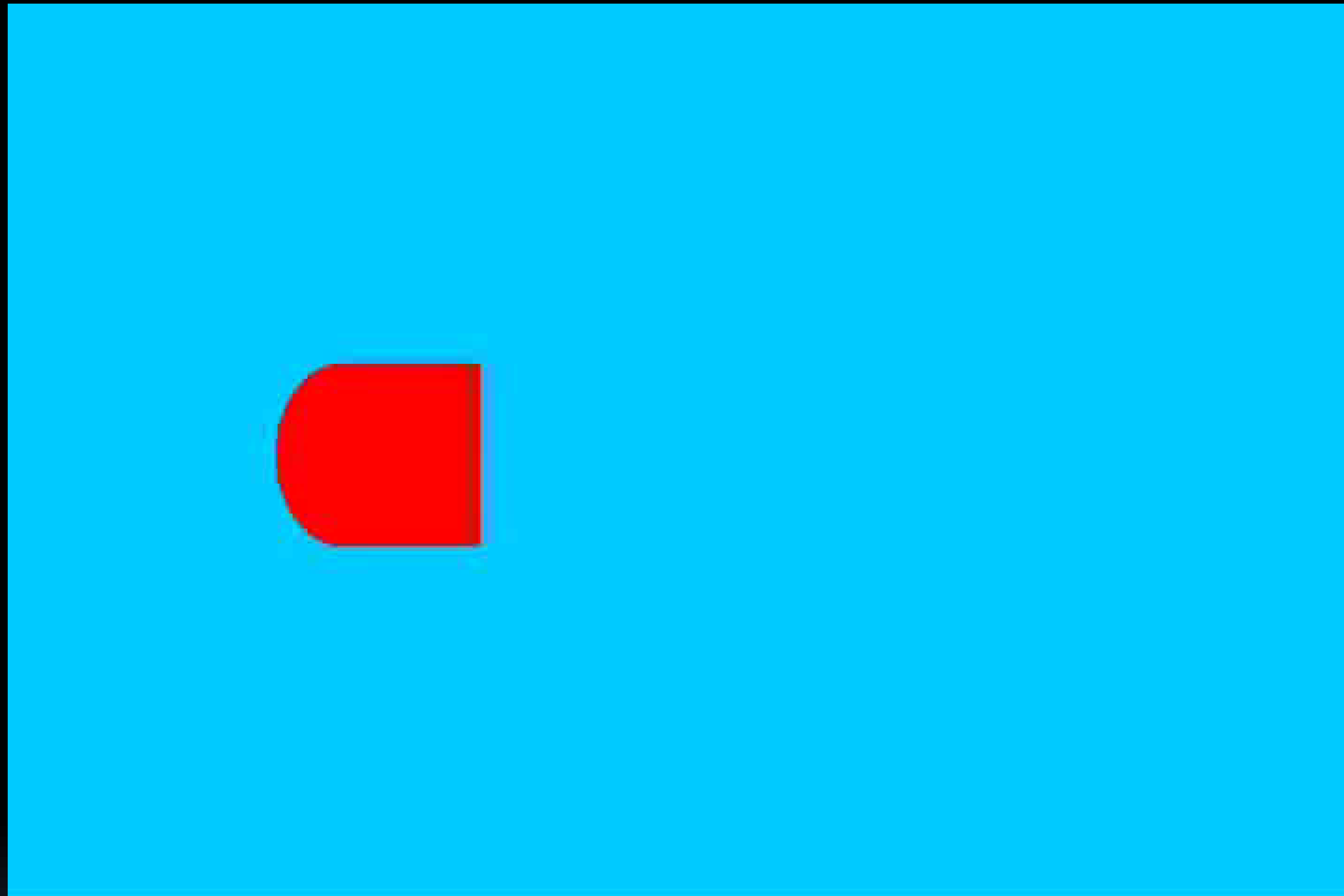
DEVIL PHYSICS
THE BADDEST CLASS ON CAMPUS
IB PHYSICS



OPTION B-3:
FLUIDS

Essential Idea:

- Fluids cannot be modelled as point particles. Their distinguishable response to compression from solids creates a set of characteristics that require an in-depth study.

Nature Of Science:

- Human understandings: Understanding and modelling fluid flow has been important in many technological developments such as designs of turbines, aerodynamics of cars and aircraft, and measurement of blood flow.

International-Mindedness:

- Water sources for dams and irrigation rely on the knowledge of fluid flow. These resources can cross national boundaries leading to sharing of water or disputes over ownership and use.

Theory Of Knowledge:

- The mythology behind the anecdote of Archimedes' "Eureka!" moment of discovery demonstrates one of the many ways scientific knowledge has been transmitted throughout the ages.
- What role can mythology and anecdotes play in passing on scientific knowledge?
- What role might they play in passing on scientific knowledge within indigenous knowledge systems?

Understandings:

- Density and pressure
- Buoyancy and Archimedes' principle
- Pascal's principle
- Hydrostatic equilibrium
- The ideal fluid
- Streamlines

Understandings:

- The continuity equation
- The Bernoulli equation and the Bernoulli effect
- Stokes’ law and viscosity
- Laminar and turbulent flow and the Reynolds number

Applications And Skills:

- Determining buoyancy forces using Archimedes’ principle
- Solving problems involving pressure, density and Pascal’s principle
- Solving problems using the Bernoulli equation and the continuity equation

Applications And Skills:

- Explaining situations involving the Bernoulli effect
- Describing the frictional drag force exerted on small spherical objects in laminar fluid flow
- Solving problems involving Stokes' law
- Determining the Reynolds number in simple situations

Guidance:

- Ideal fluids will be taken to mean fluids that are incompressible and non-viscous and have steady flows
- Applications of the Bernoulli equation will involve (but not be limited to) flow out of a container, determining the speed of a plane (pitot tubes), and venturi tubes

Guidance:

- Proof of the Bernoulli equation will not be required for examination purposes
- Laminar and turbulent flow will only be considered in simple situations
- Values of R 103 <will be taken to represent conditions for laminar flow

Data Booklet Reference:

$$B = \rho_f V_f g$$

$$P = P_0 + \rho_f g d$$

$$Av = cons\tan t$$

$$\frac{1}{2}\rho v^2 + \rho g z + p = cons\tan t$$

$$F_D = 6\pi\eta r v$$

$$R = \frac{v r \rho}{\eta}$$

Utilization:

- Hydroelectric power stations
- Aerodynamic design of aircraft and vehicles
- Fluid mechanics is essential in understanding blood flow in arteries
- Biomechanics (see Sports, exercise and health science SL sub-topic 4.3)

Aims:

- Aim 2: fluid dynamics is an essential part of any university physics or engineering course
- Aim 7: the complexity of fluid dynamics makes it an ideal topic to be visualized through computer software

Reading Activity Questions?

Pressure

- **Pressure, P, is defined as force per unit area where the force is understood to be acting perpendicular to the *surface area*, *A***

$$pressure = p = \frac{F}{A}$$

Pressure in Fluids

- Fluid exerts a pressure in all directions
- Fluid pressure is exerted perpendicular to whatever surface it is in contact with
- Fluid pressure increases with depth

Pressure in Fluids

- Think of a disk 5 cm (0.05 m) in diameter ($A = \pi r^2 = 1.96\ cm^2 = 0.00196\ m^2$)
- You place it in water 30 cm (0.30 m) below the surface
- The pressure on that disk is equal to the weight of a column of water that has a 5 cm diameter and is 30 cm high (*h* = height of water)

Pressure in Fluids

- Like a graduated cylinder
  - $A_{disk} = 0.00196\ m^2$
  - The volume of the cylinder is A x h ($\pi r^2 h$) = 589 $cm^3 = 5.89 \times 10^{-4}\ m^3$

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

$$\rho V = m$$

$$m = \left(1x10^3\,kg/m^3\right)\left(5.89x10^{-4}\,m^3\right)$$

$$m = 0.589kg$$

Pressure in Fluids

- Like a graduated cylinder
  - $A_{disk} = 0.00196\ m^2$
  - $V = 5.89 \times 10^{-4}\ m^3$
  - $m = 0.589\ kg$

$$F = ma = mg$$

$$F = (0.589kg)(9.81m/s^2)$$

$$F = 5.78N$$

Pressure in Fluids

- Like a graduated cylinder
  - $A_{disk} = 0.00196\ m^2$
  - $V = 5.89 \times 10^{-4}\ m^3$
  - $m = 0.589\ kg$
  - $F = 5.78\ N$

$$p = \frac{F}{A} = \frac{(5.78N)}{(0.00196m^2)}$$

$$p = 2.9x10^3\,N/m^2$$

- *That's way too much work!*
- *How about a formula?*

Pressure in Fluids

- Like a graduated cylinder
  - P = 2.9 x 10^3 N/m^2

- *That's way too much work!*
- *How about a formula?*

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

$$p = \frac{mg}{A}$$

$$p = \frac{\rho V g}{A}$$

$$p = \frac{\rho A h g}{A}$$

$$p = \rho g h$$

Pressure in Fluids

- Like a graduated cylinder
  - P = 2.9 x 10^3 N/m²

$$p = \rho g h$$
$$p = (1.0x10^3 kg/m^3)(9.81 m/s^2)(0.3m)$$
$$p = 2.9x10^3 N/m^2$$

- ***That's way too much work!***
- ***How about a formula?***

$$P = \rho g h$$

Pressure in Fluids

- **Pressure at equal depths within a uniform liquid is the same**

$$\boxed{p = p_0 + \rho g h}$$

- **<u>IMPORTANT</u>: The pressure the water exerts on an object at a certain depth is the same on all parts of a body.**
- ***In other words, if you hold a cube 30cm under water, each side of that cube will feel the same pressure exerted on it – not just the top, but the bottom and all four sides!!!***

Pressure in Fluids

- It follows from this that a change in depth is directly proportional to a change in pressure

$$P = \rho g h$$

$$\Delta P = \rho g \Delta h$$

- Note: *An important assumption here is that the fluid is incompressible, because if it were compressible, the density would change with depth!*

Pressure in Fluids

$$\Delta P = \rho g \Delta h$$

Pascal's Principle

- ***The pressure applied to a confined fluid increases the pressure throughout the fluid by the same amount.***
- Examples
  - A cube at the bottom of a bucket of water. It has the pressure of the water acting on it, but also the atmospheric pressure pushing on the water.
  - The brake system in a car. You apply pressure via the brake pedal and that pressure gets transmitted via a fluid to the brake pads on the wheel

Pascal's Principle

- ***The pressure applied to a confined fluid increases the pressure throughout the fluid by the same amount.***

$$P_{in} = P_{out}$$

$$\frac{F_{in}}{A_{in}} = \frac{F_{out}}{A_{out}}$$

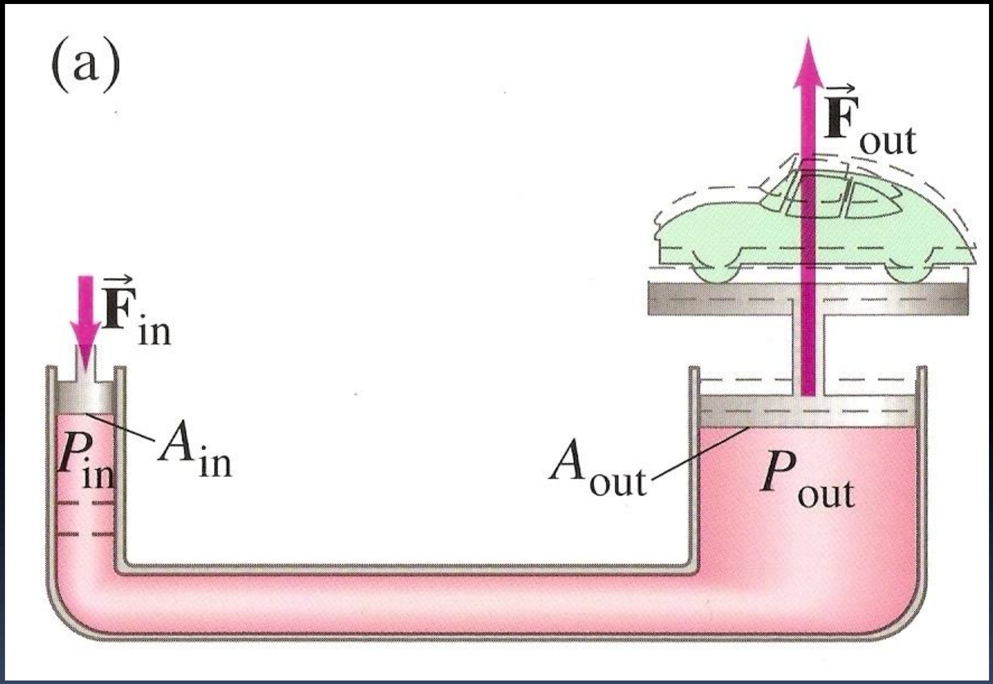
$$\frac{F_{in}}{F_{out}} = \frac{A_{in}}{A_{out}}$$

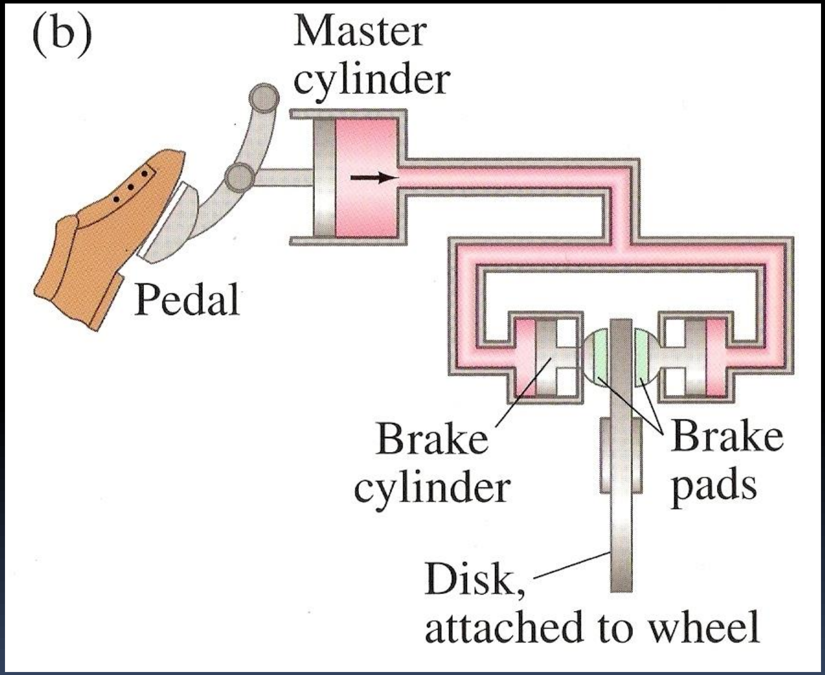
$$\frac{F_{out}}{F_{in}} = \frac{A_{out}}{A_{in}}$$

Pascal’s Principle

- Examples

$$\frac{F_{in}}{A_{in}} = \frac{F_{out}}{A_{out}}$$





Pascal's Principle

- ***If I want the force applied to my brakes to be 10 times the force I apply to the pedal, by what factor would the diameter of the piston at the brakes exceed that of the piston at the brake pedal?***

$$\frac{F_{out}}{F_{in}} = \frac{A_{out}}{A_{in}}$$

Pascal's Principle

- ***If I want the force applied to my brakes to be 10 times the force I apply to the pedal, by what factor would the diameter of the piston at the brakes exceed that of the piston at the brake pedal?***

$$\frac{F_{out}}{F_{in}} = \frac{A_{out}}{A_{in}}$$

$$\frac{10xF_{in}}{F_{in}} = \frac{\pi(xr)^2}{\pi r^2}$$

$$10 = x^2$$

$$x = 3.16$$

Video: Archimedes Principle

Buoyancy

- Stuff floats
- Stuff in water seems lighter than stuff on land
- This is because the fluid is exerting a pressure on the object that opposes the gravity force (weight)
- Fluid pressure increases with depth
- When the fluid pressure equals the weight, the object will stop sinking

Buoyant Force

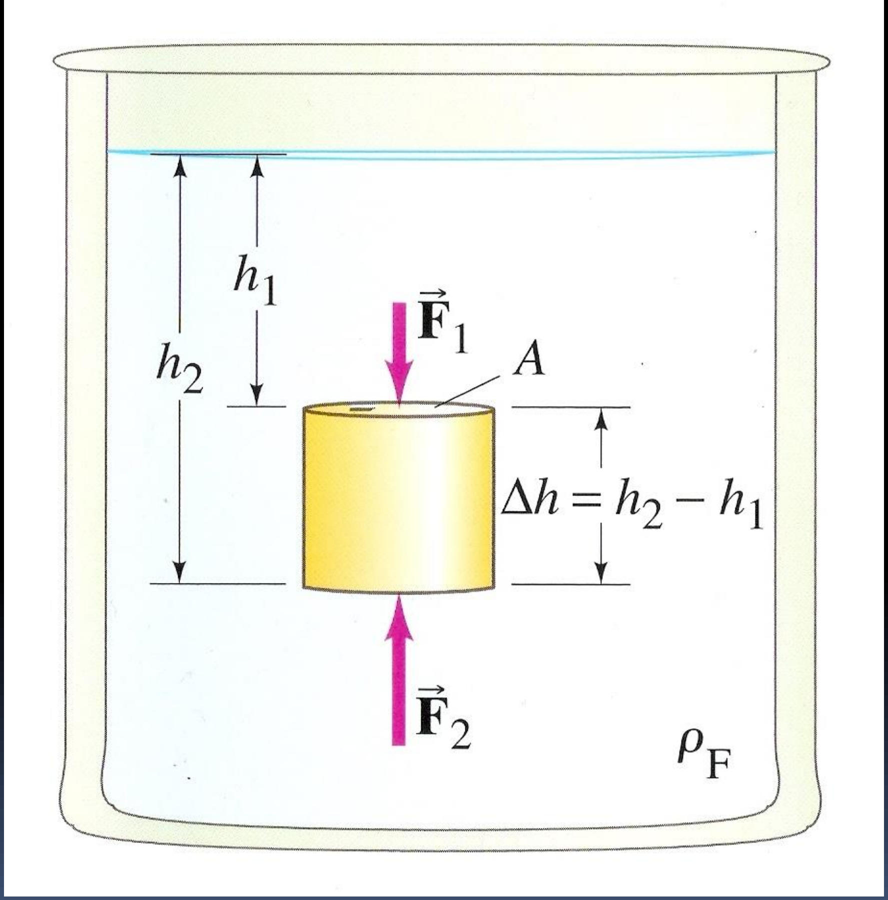
- The force of fluid pressure that opposes weight

$$P_1 = \rho_F g h_1$$

$$\frac{F_1}{A} = \rho_F g h_1$$

$$F_1 = \rho_F g h_1 A$$

$$F_2 = \rho_F g h_2 A$$



Buoyant Force

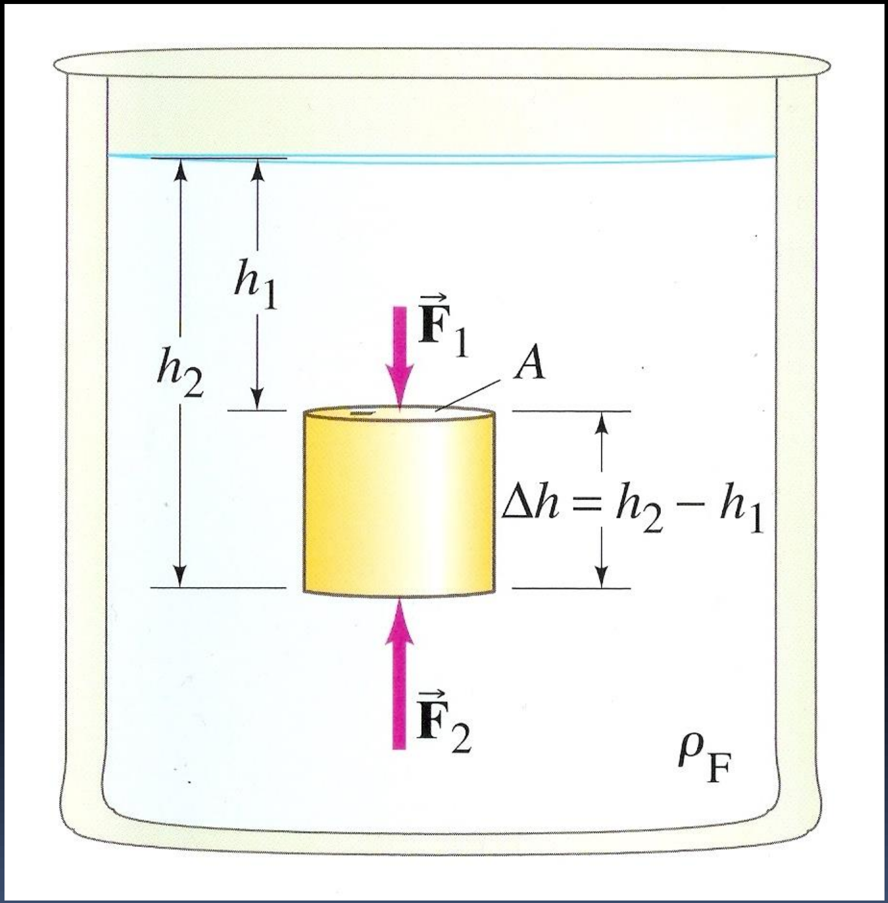
- The force of fluid pressure that opposes weight

$$F_1 = \rho_F g h_1 A$$

$$F_2 = \rho_F g h_2 A$$

$$F_{net} = F_2 - F_1$$

$$F_{net} = \rho_F g A (h_2 - h_1)$$



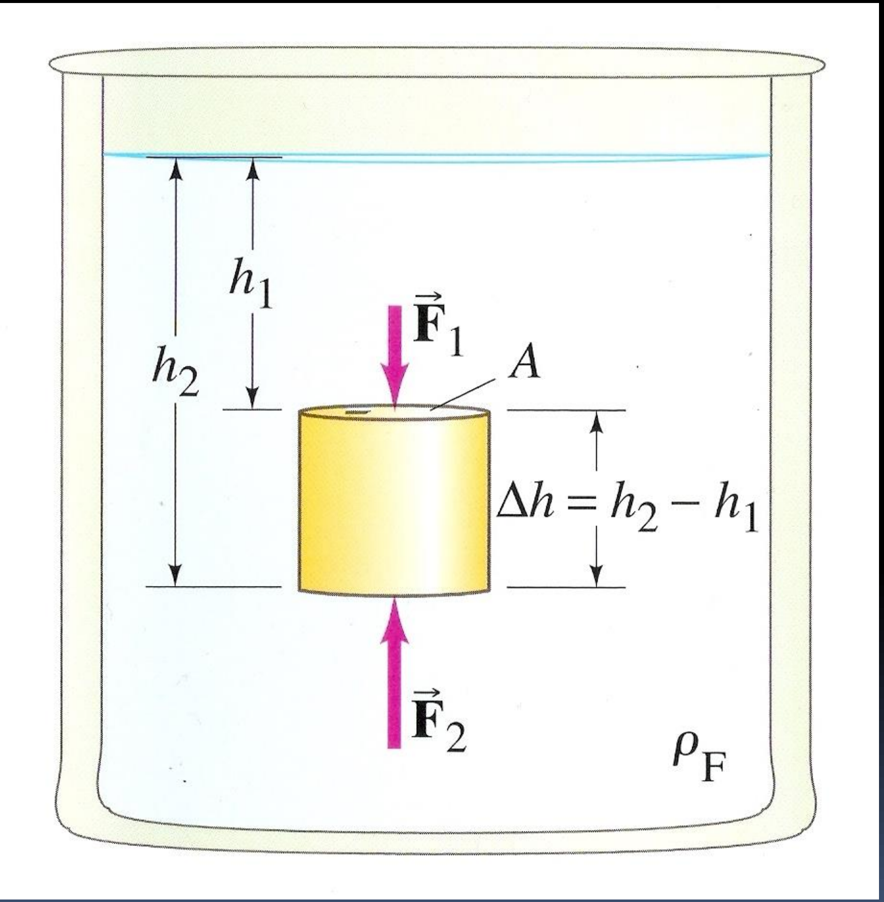
Buoyant Force

- The force of fluid pressure that opposes weight

$$F_{net} = \rho_F gA(h_2 - h_1)$$

$$F_{net} = \rho_F gAh_{cylinder}$$

$$F_{net} = \rho_F gV_{cylinder}$$

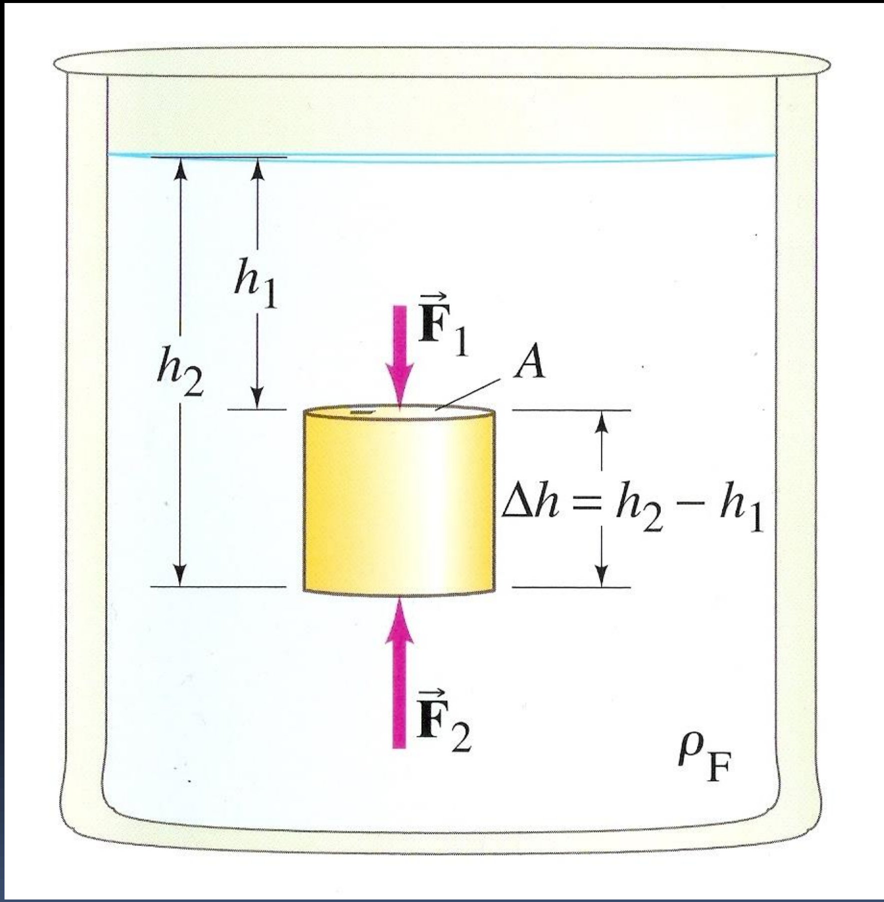


Buoyant Force

- The force of fluid pressure that opposes weight

$$F_{net} = \rho_F g V_{cylinder}$$

$$F_B = \rho_F g V_{cylinder}$$



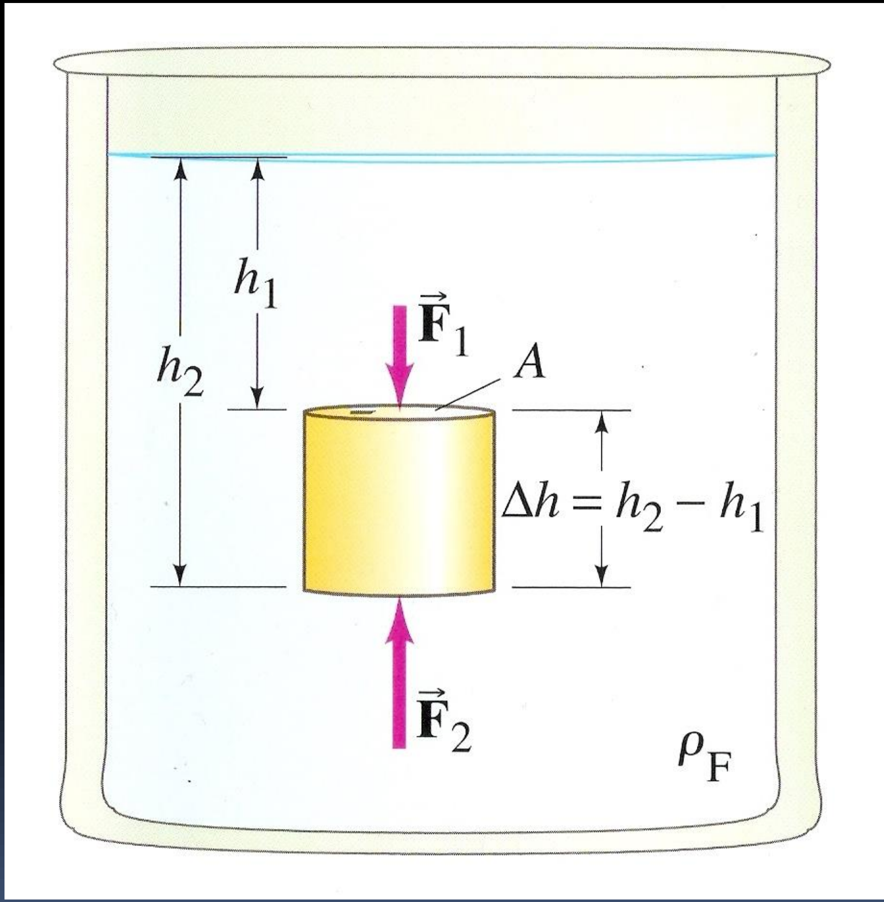
Archimedes' Principle

- The force of fluid pressure that opposes weight

$$F_{net} = \rho_F g V_{cylinder}$$

$$F_B = \rho_F g V_{cylinder}$$

- **The volume of the cylinder displaces the same volume of water that was there before the cylinder was immersed**



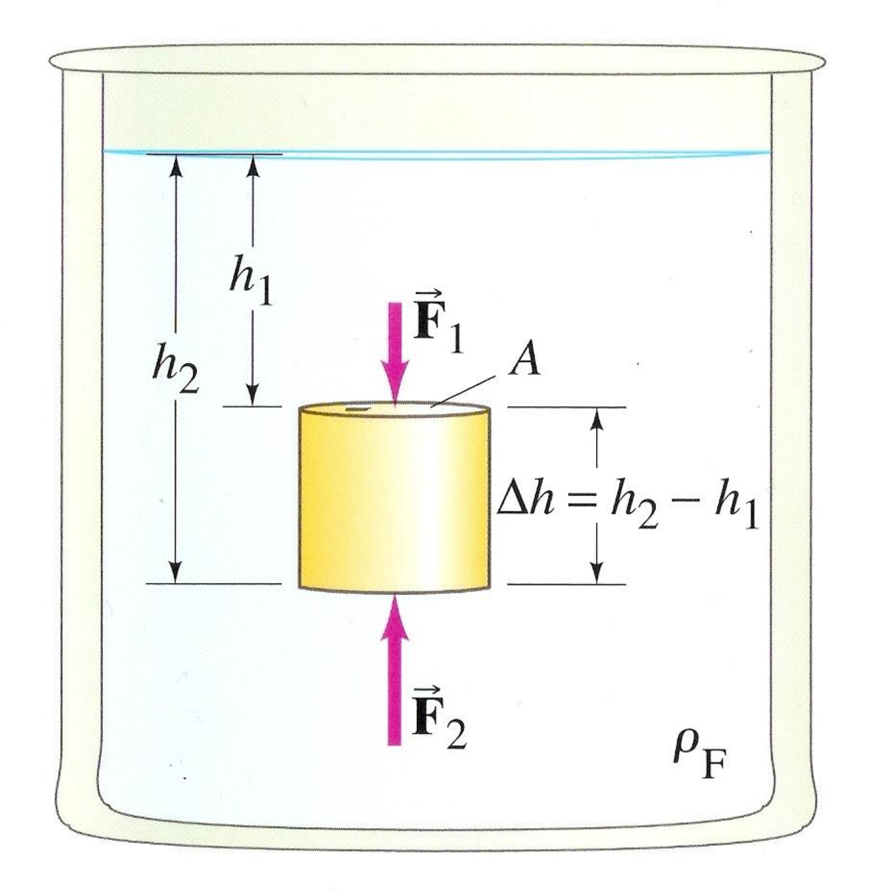
Archimedes' Principle

- The force of fluid pressure that opposes weight

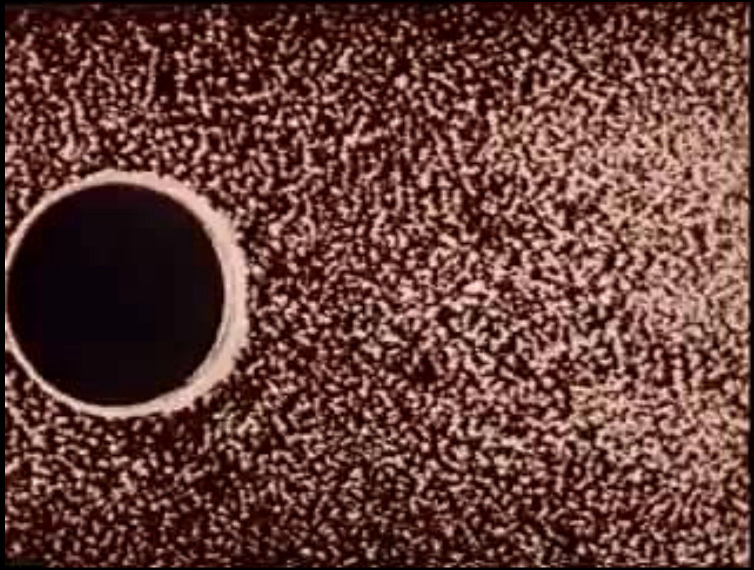
$$F_{net} = \rho_F g V_{cylinder}$$

$$F_B = \rho_F g V$$

- ***The buoyant force on a body immersed in a fluid is equal to the weight of the fluid displaced by that object***



Fluids In Motion



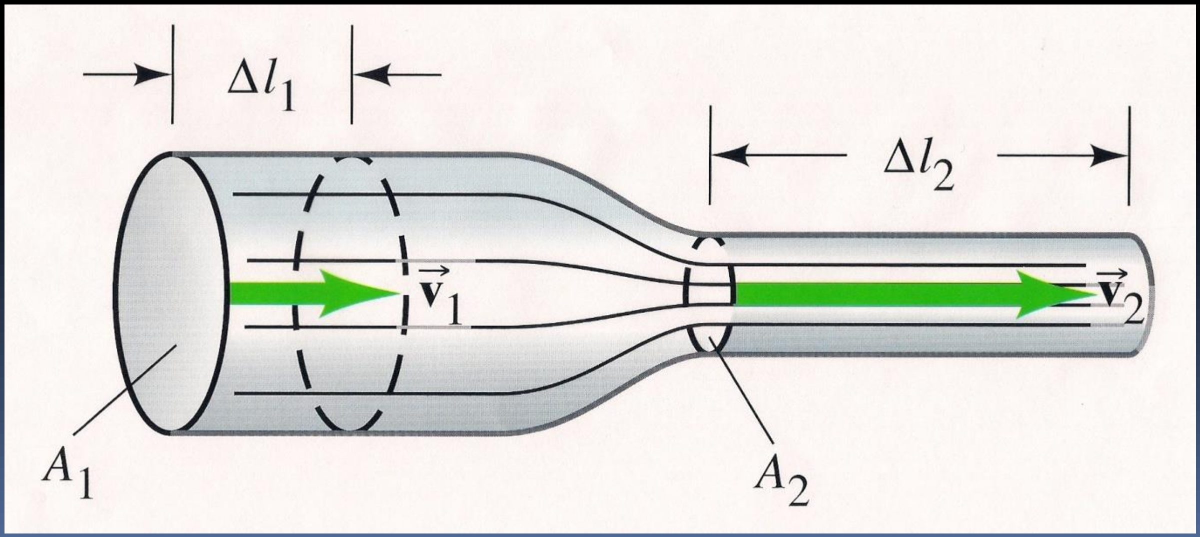
- ***Fluid Dynamics*** – study of fluids in motion
- ***Hydrodynamics*** – study of water in motion
- ***Streamline*** or ***laminar flow*** – flow is smooth, neighboring layers of fluid slide by each other smoothly, each particle of the fluid follows a smooth path and the paths do not cross over one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

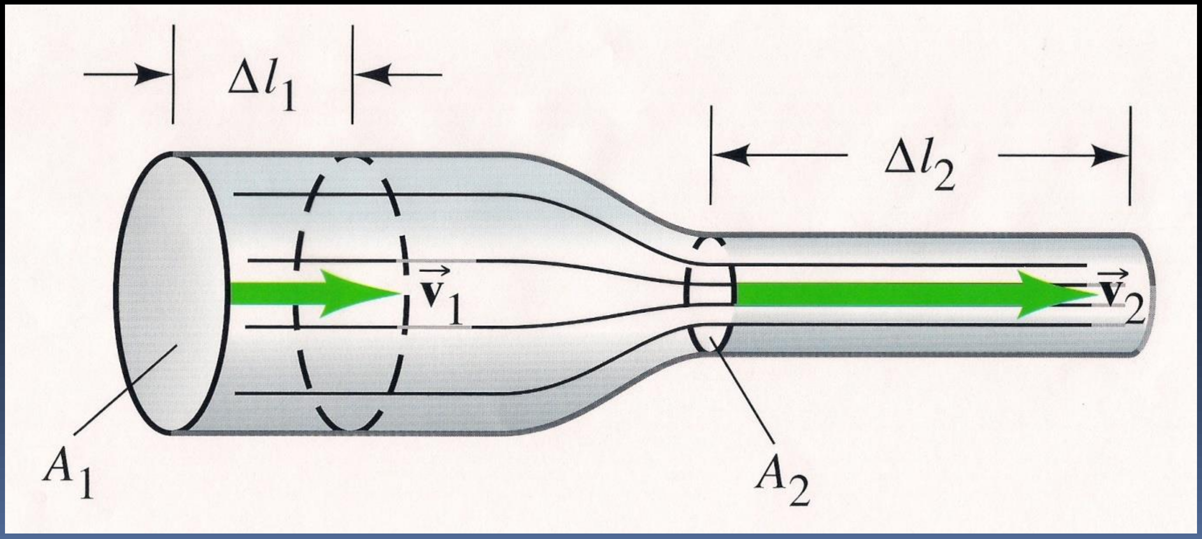
- **Mass is equal to density times volume**

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

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

$$\rho V = m$$

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



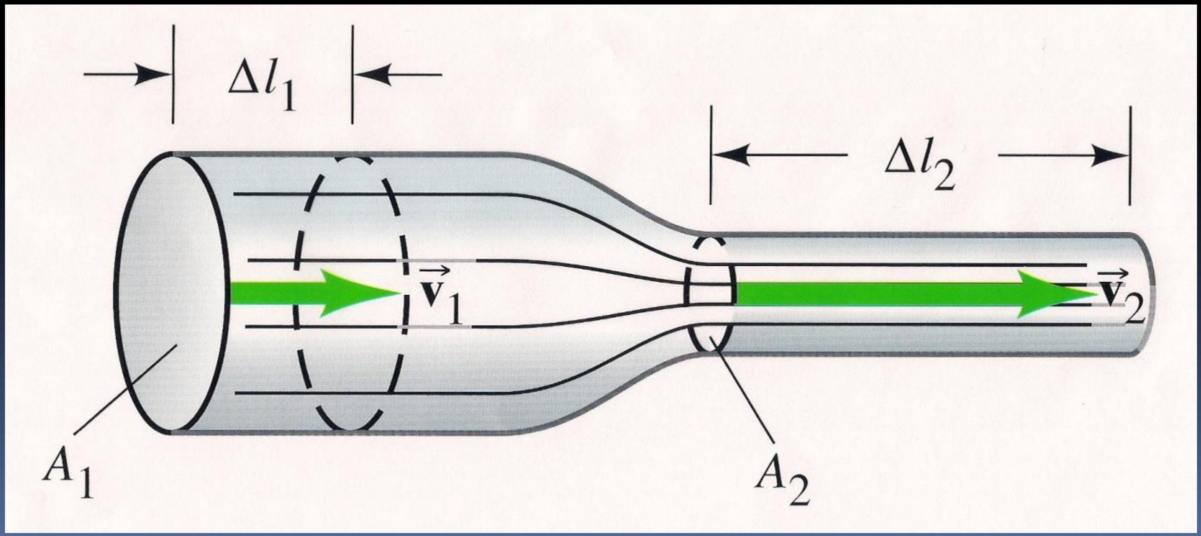
Speed Changes In Changing Diameter Of Tubes

- **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)**

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

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

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



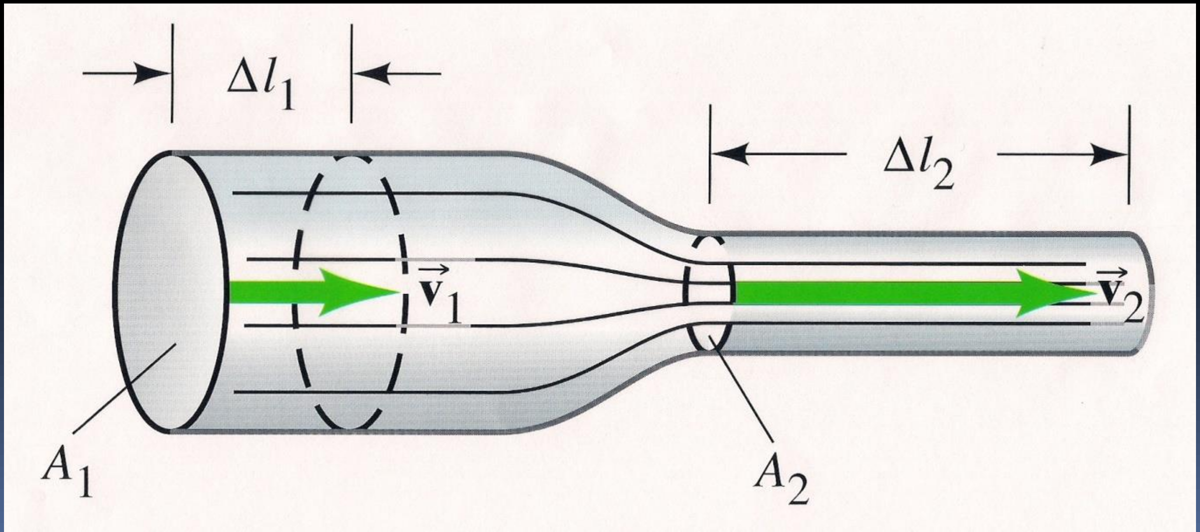
Speed Changes In Changing Diameter Of Tubes

- The velocity is equal to the distance divided by the time so, mass flow rate becomes $\rho A v$

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

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

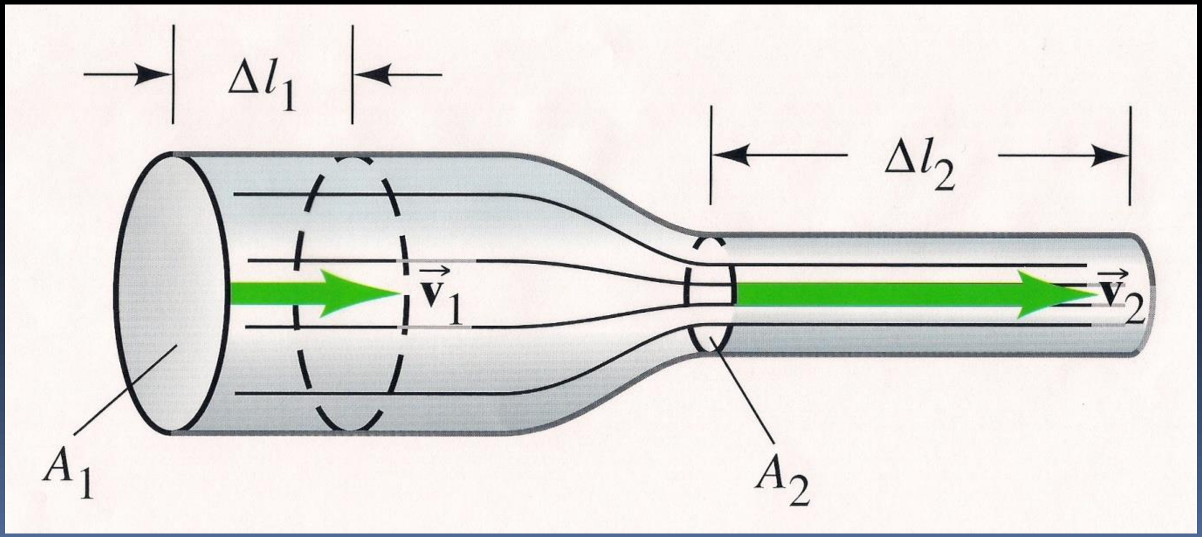
$$\rho A v$$



Speed Changes In Changing Diameter Of Tubes

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

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

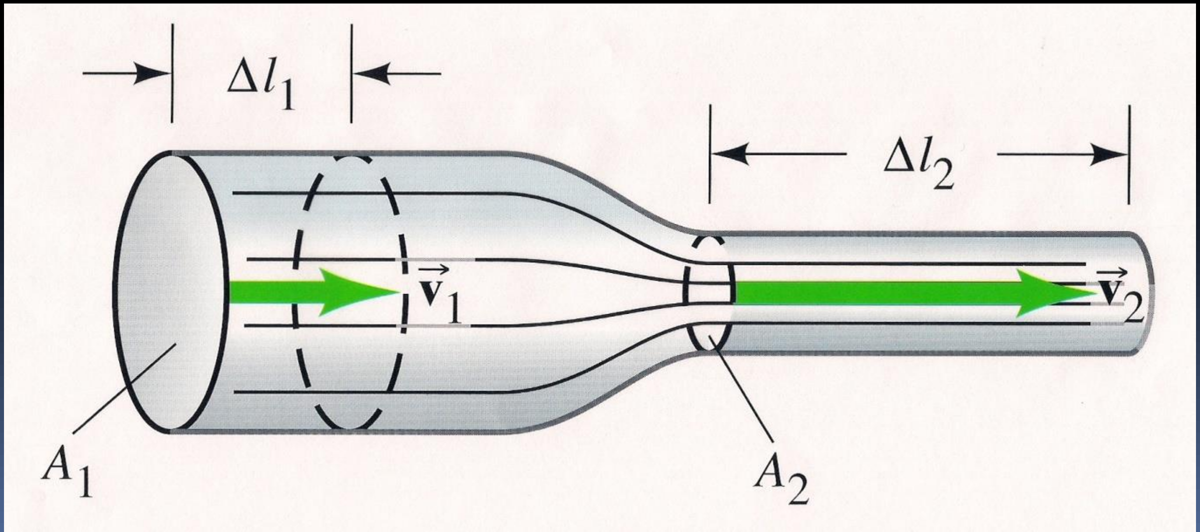


Speed Changes In Changing Diameter Of Tubes

- **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

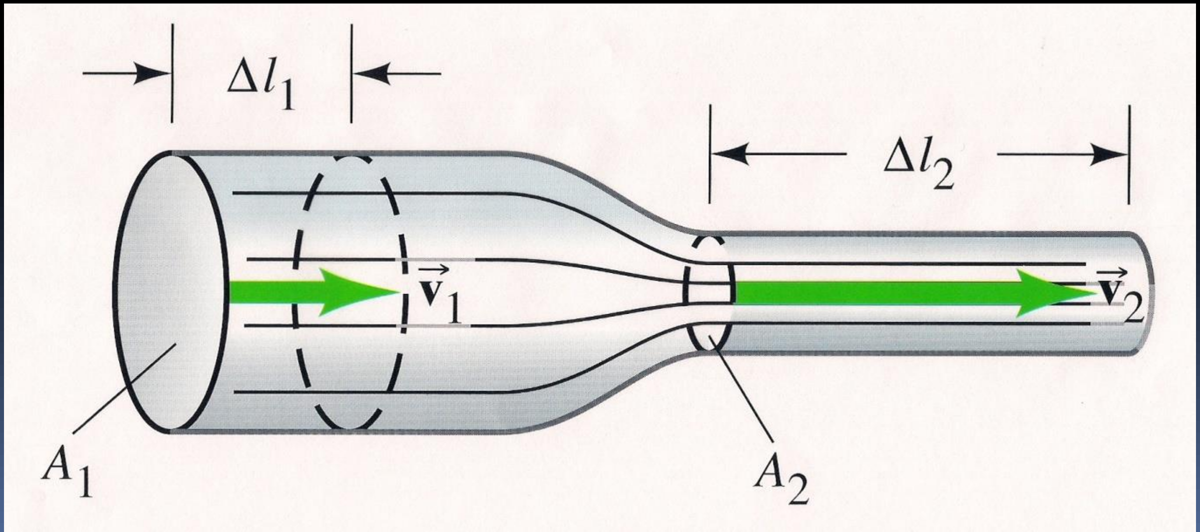
- ***Volume Rate of Flow***

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

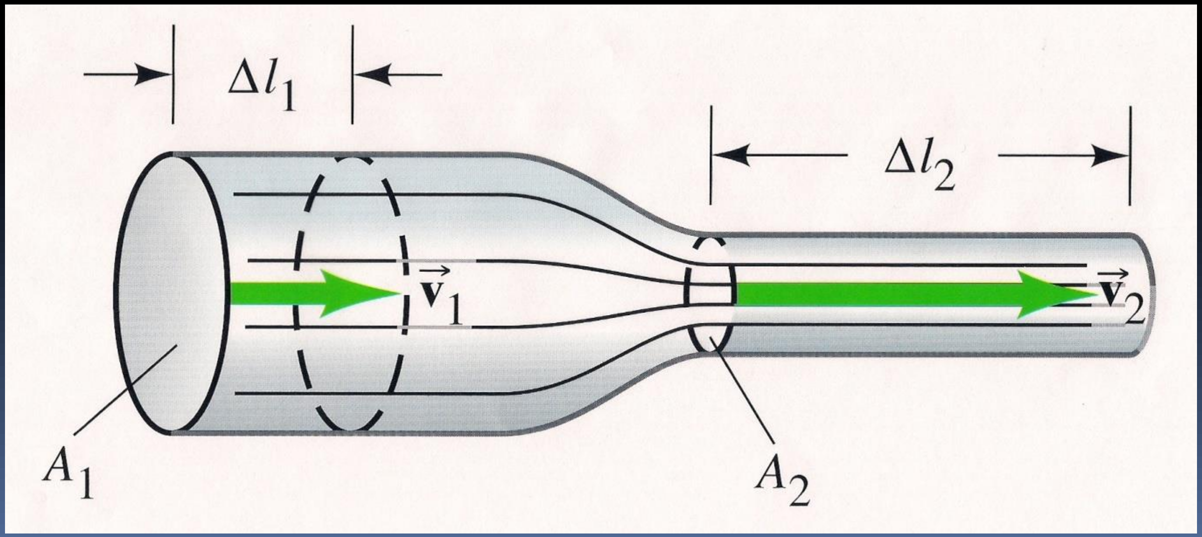
- ***Volume Rate of Flow***

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***

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

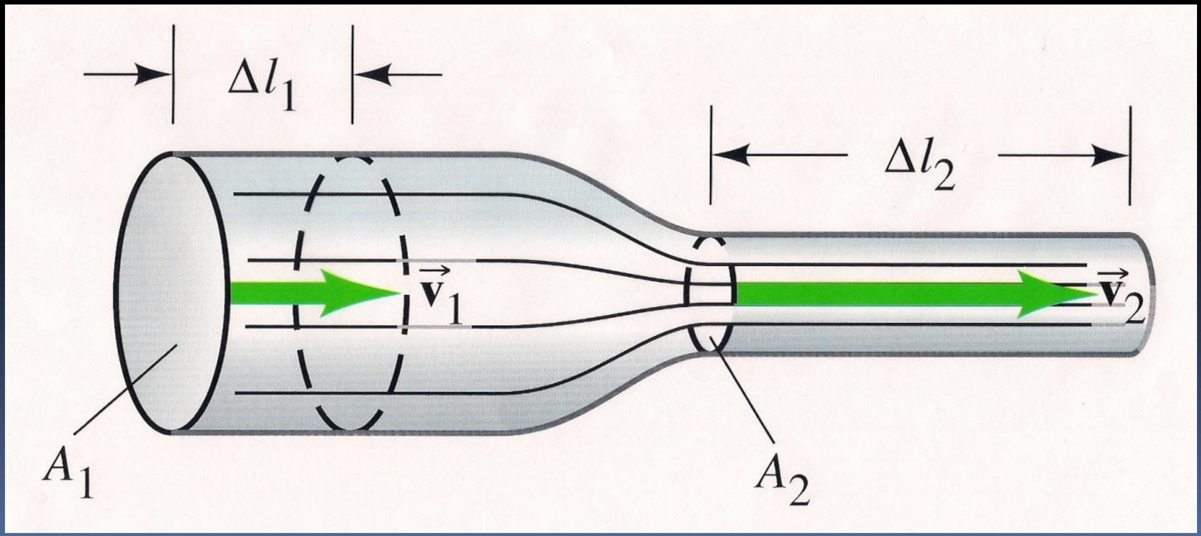
- ***<u>Bernoulli’s principle states, where the velocity of a fluid is high, the pressure is low, and where the velocity is low, the pressure is high</u>***

BLOWING PAPER DEMO

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

Bernoulli's Equation

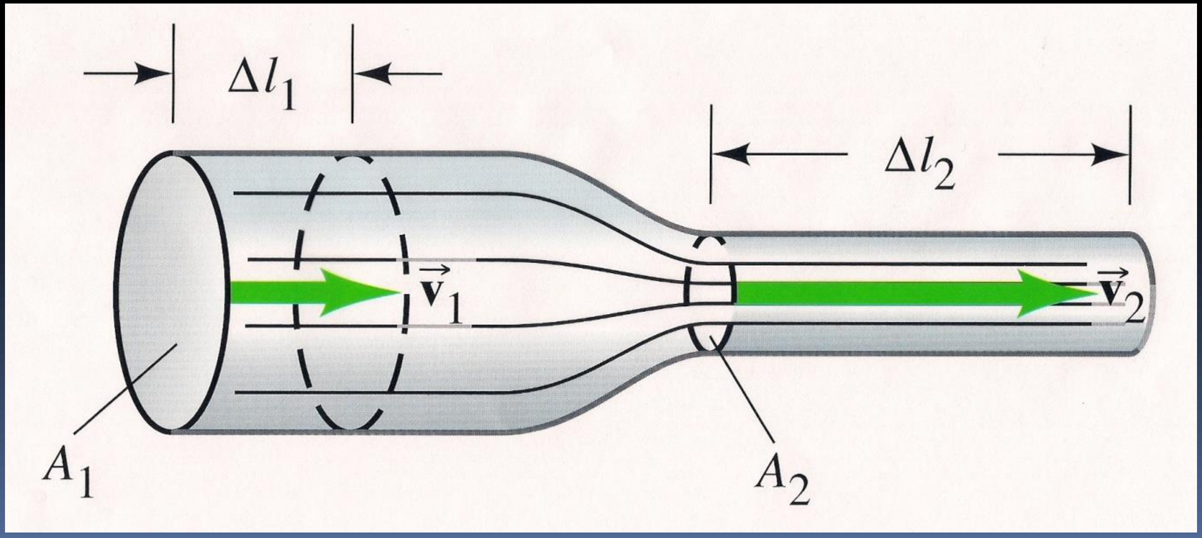
- We just said that as the fluid flows from left to right, the velocity of the fluid increases as the area gets smaller
- You would think the pressure would increase in the smaller area, but it doesn't, it gets smaller
- But, the pressure in area 1 does get larger



How come?

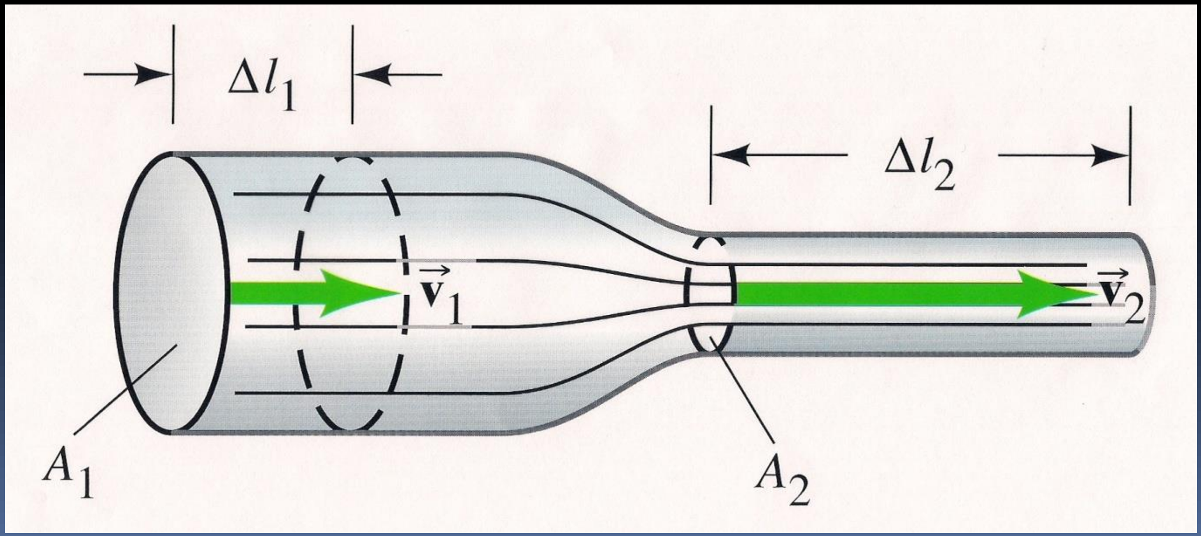
Bernoulli's Equation

- **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.**



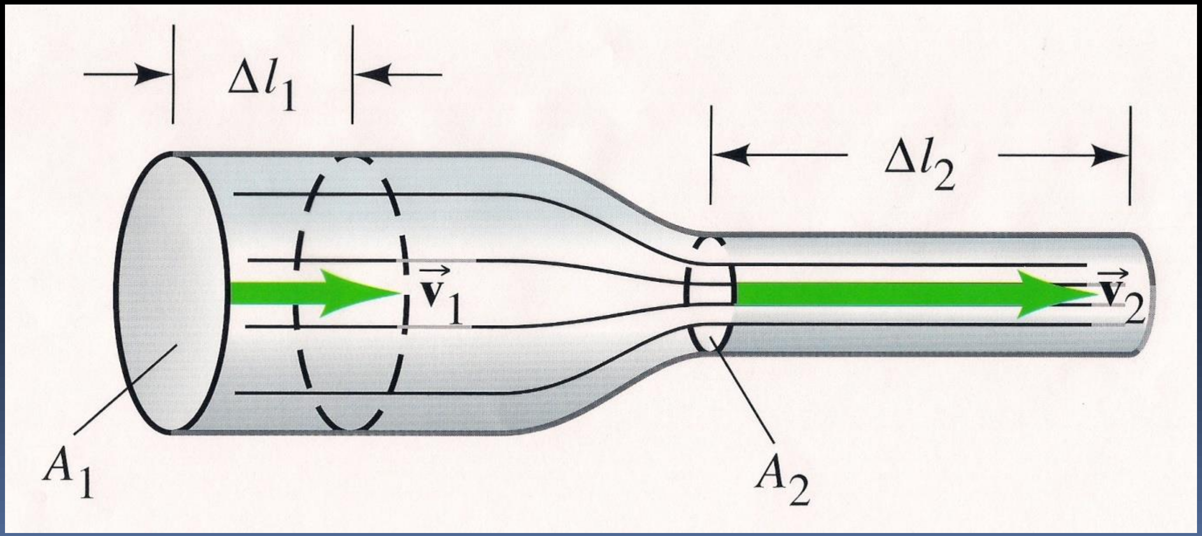
Bernoulli's Equation

- **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*



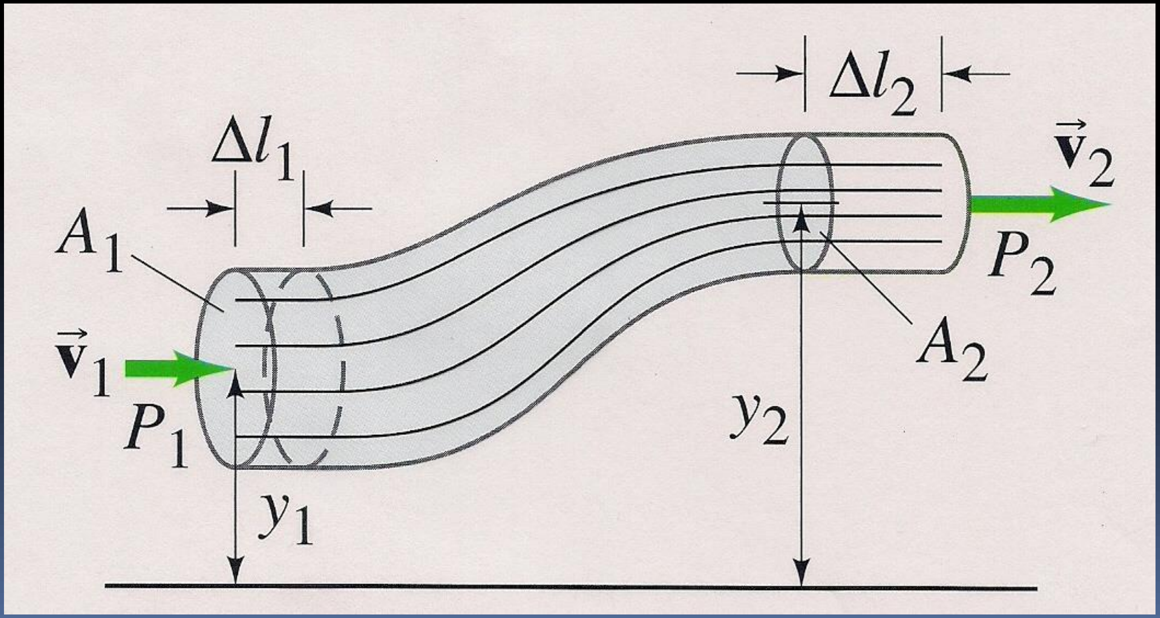
$$A_1 v_1 = A_2 v_2$$

$$\Sigma F = ma$$

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

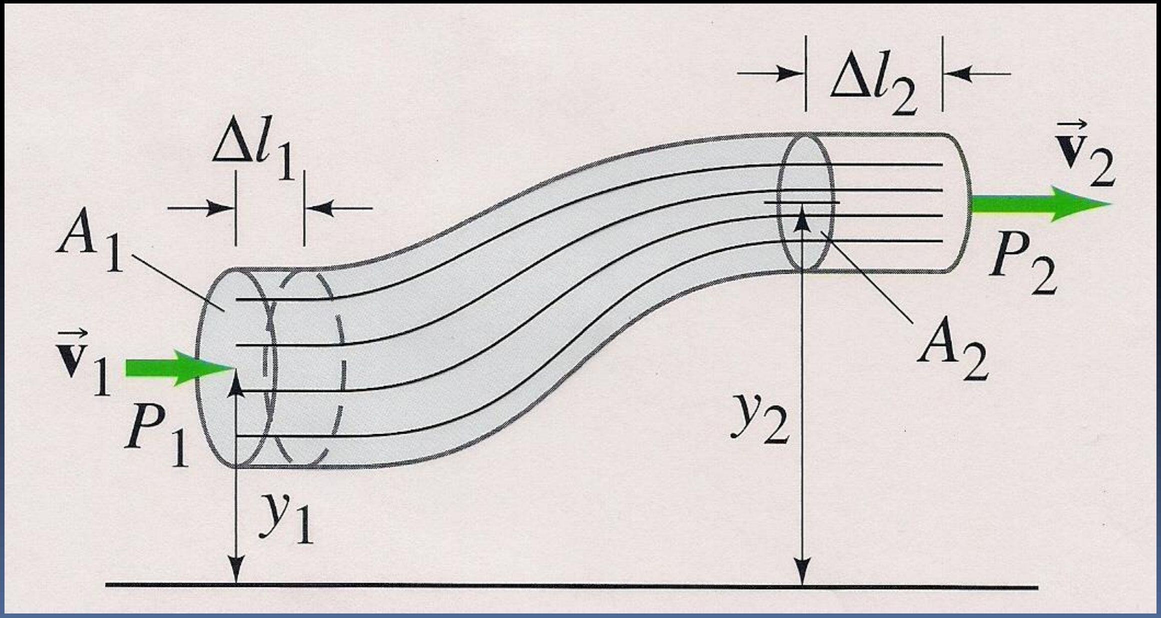
Bernoulli’s Equation

- **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**

$$W = Fd$$

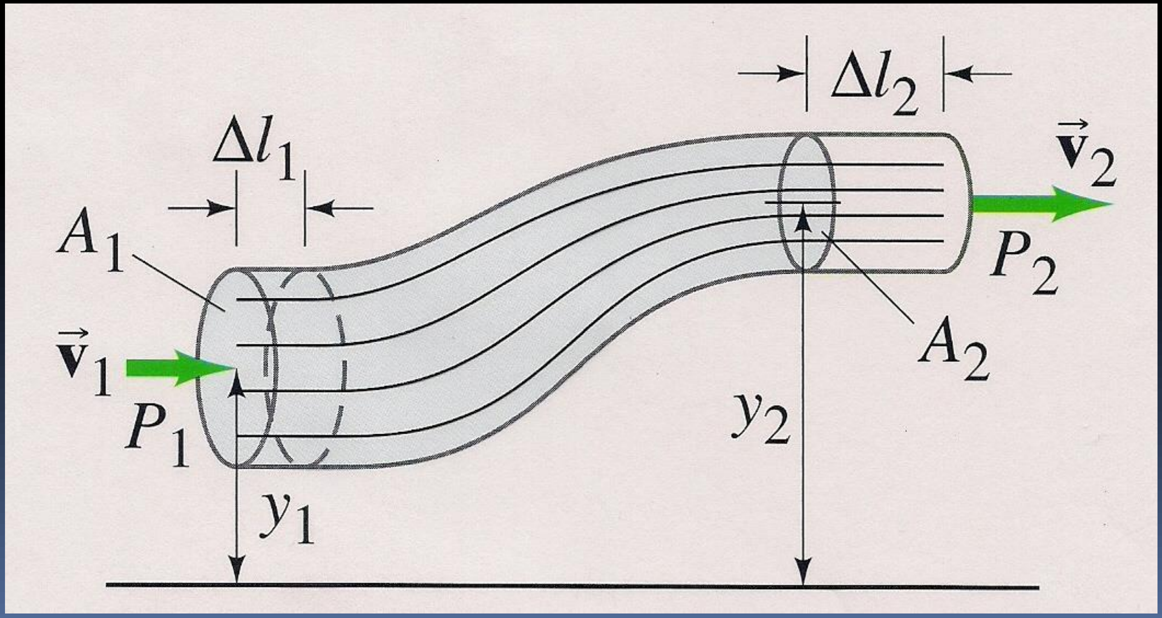
$$P = \frac{F}{A}$$

$$F = PA$$

$$d = \Delta l$$

$$W_1 = P_1 A_1 \Delta l_1$$

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



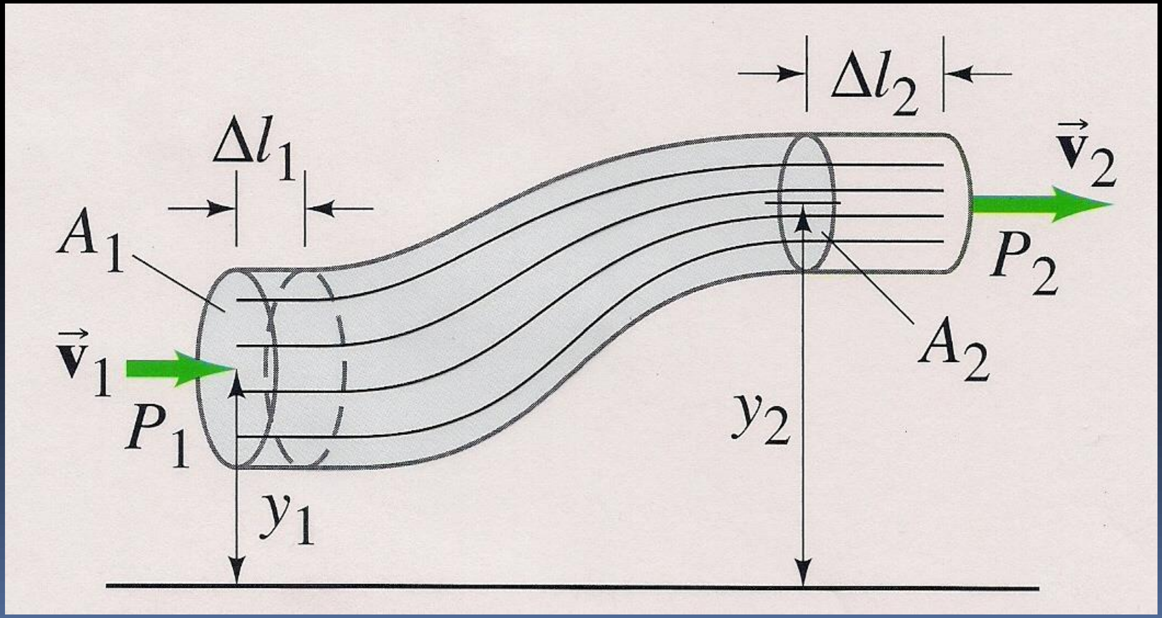
Bernoulli's Equation

- 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:

$$W_3 = Fd$$

$$W_3 = -mg(y_2 - y_1)$$

$$W_3 = -mgy_2 + mgy_1$$

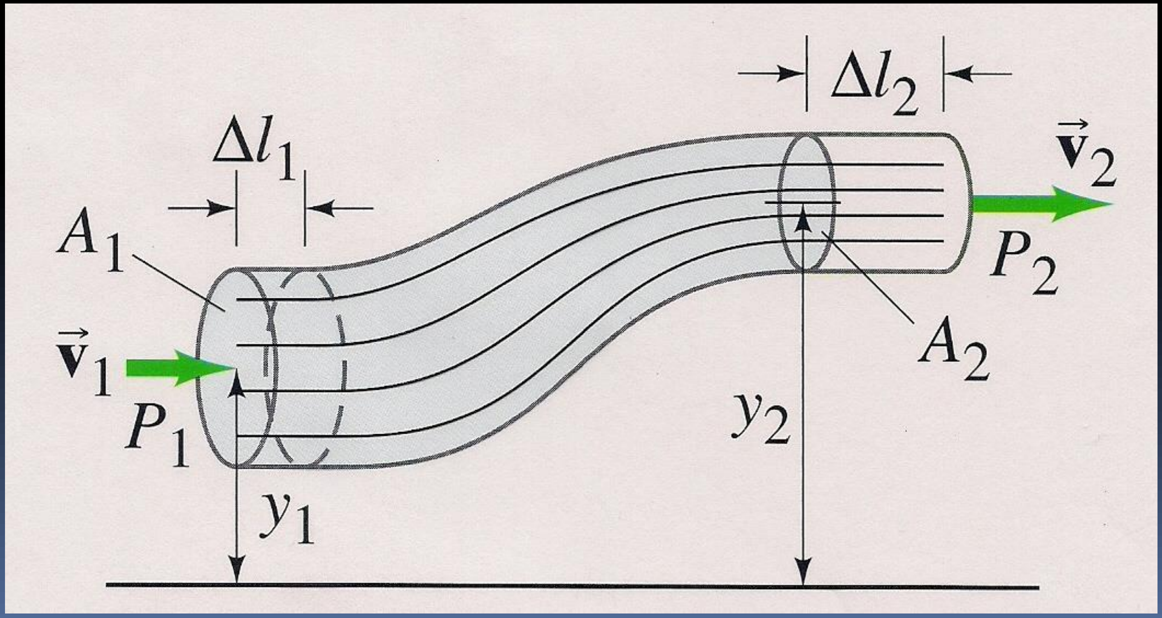


Bernoulli's Equation

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

$$W_T = W_1 + W_2 + W_3$$

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

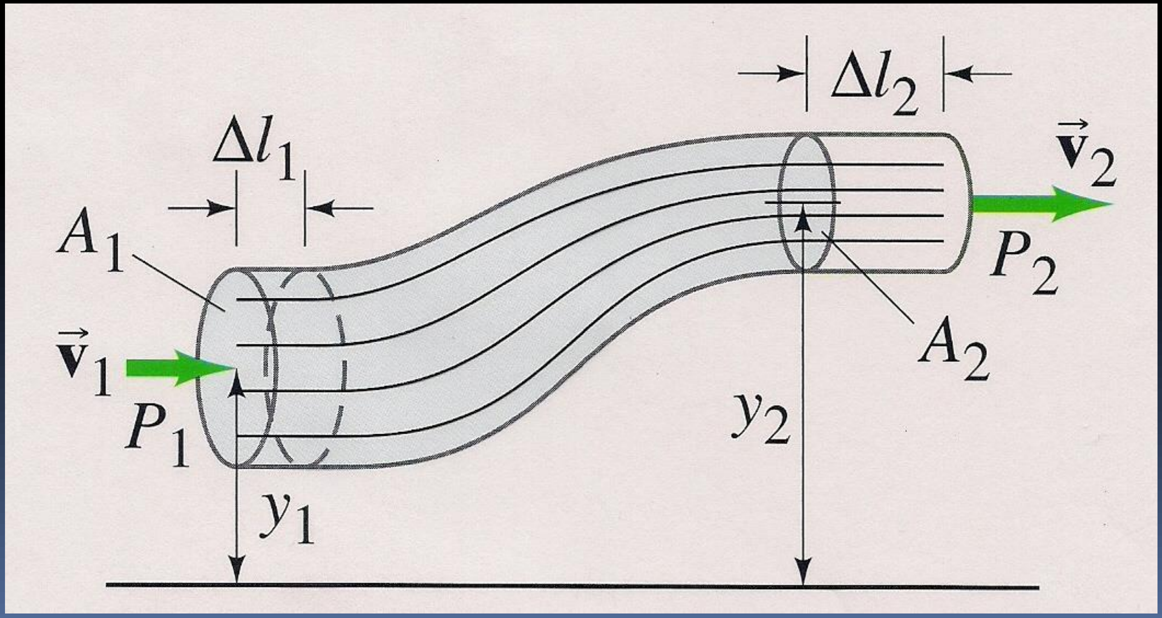


Bernoulli's Equation

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

$$W_T = W_1 + W_2 + W_3$$

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

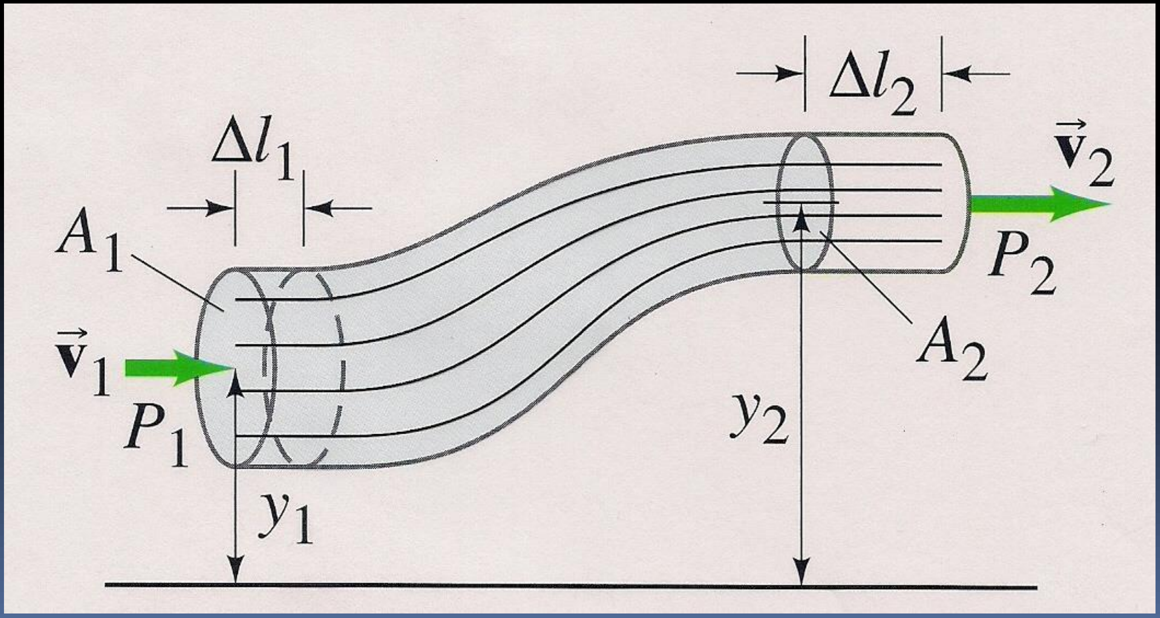


Bernoulli's Equation

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

$$W_T = \Delta KE$$

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



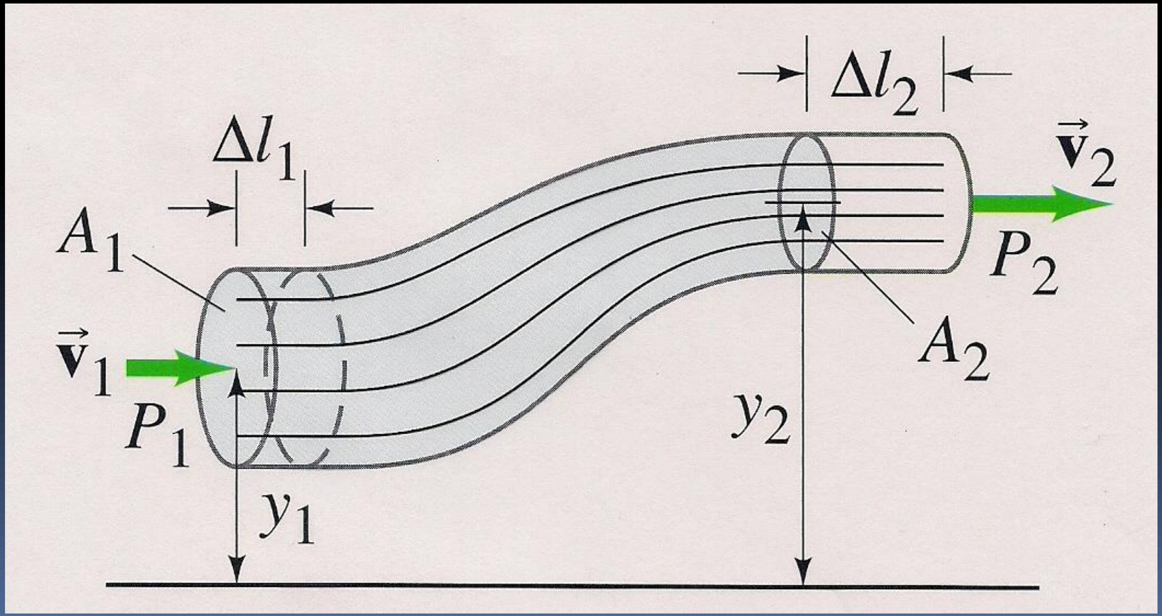
How about the work – energy principle?

Bernoulli's Equation

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

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

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



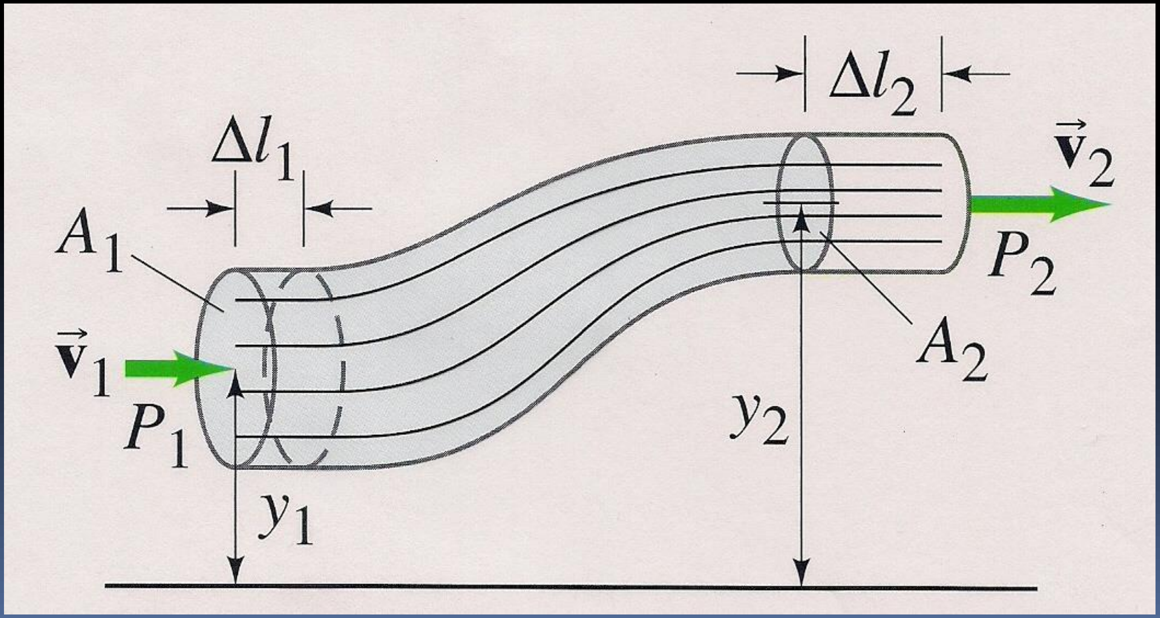
Substitute for m, then since $A_1\Delta l_1 = A_2\Delta l_2$, we can divide them out

Bernoulli's Equation

- *Manageable,*

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

$$\frac{1}{2}\rho v_2^2 - \frac{1}{2}\rho v_1^2 = P_1 - P_2 - \rho gy_2 + \rho gy_1$$

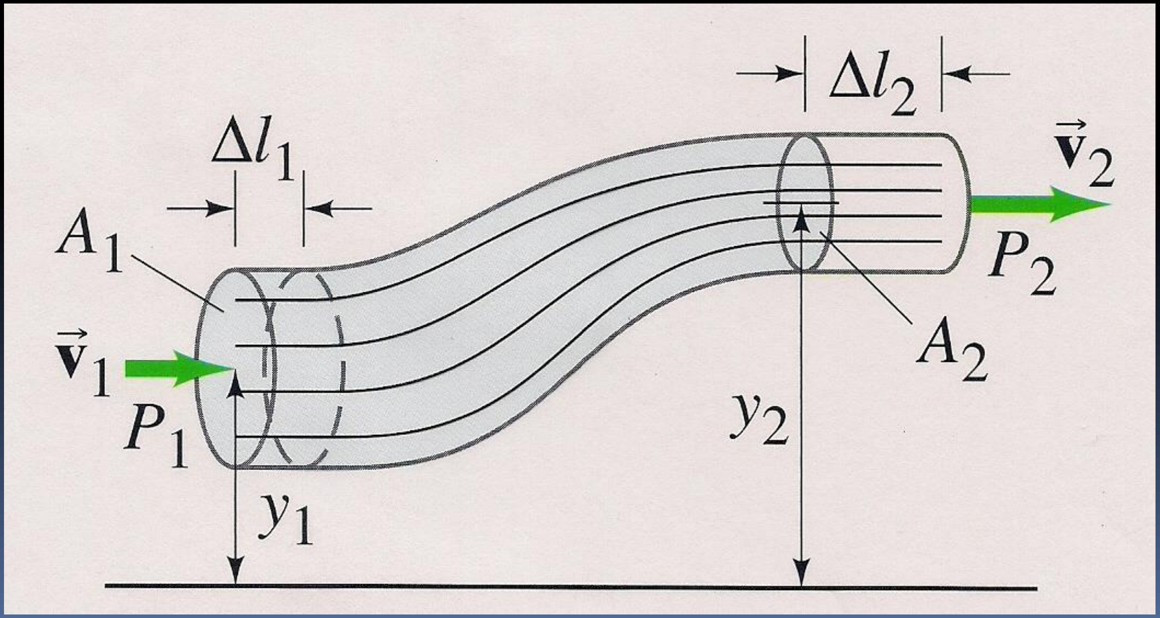


but let's make it look like something a little more familiar

Bernoulli's Equation

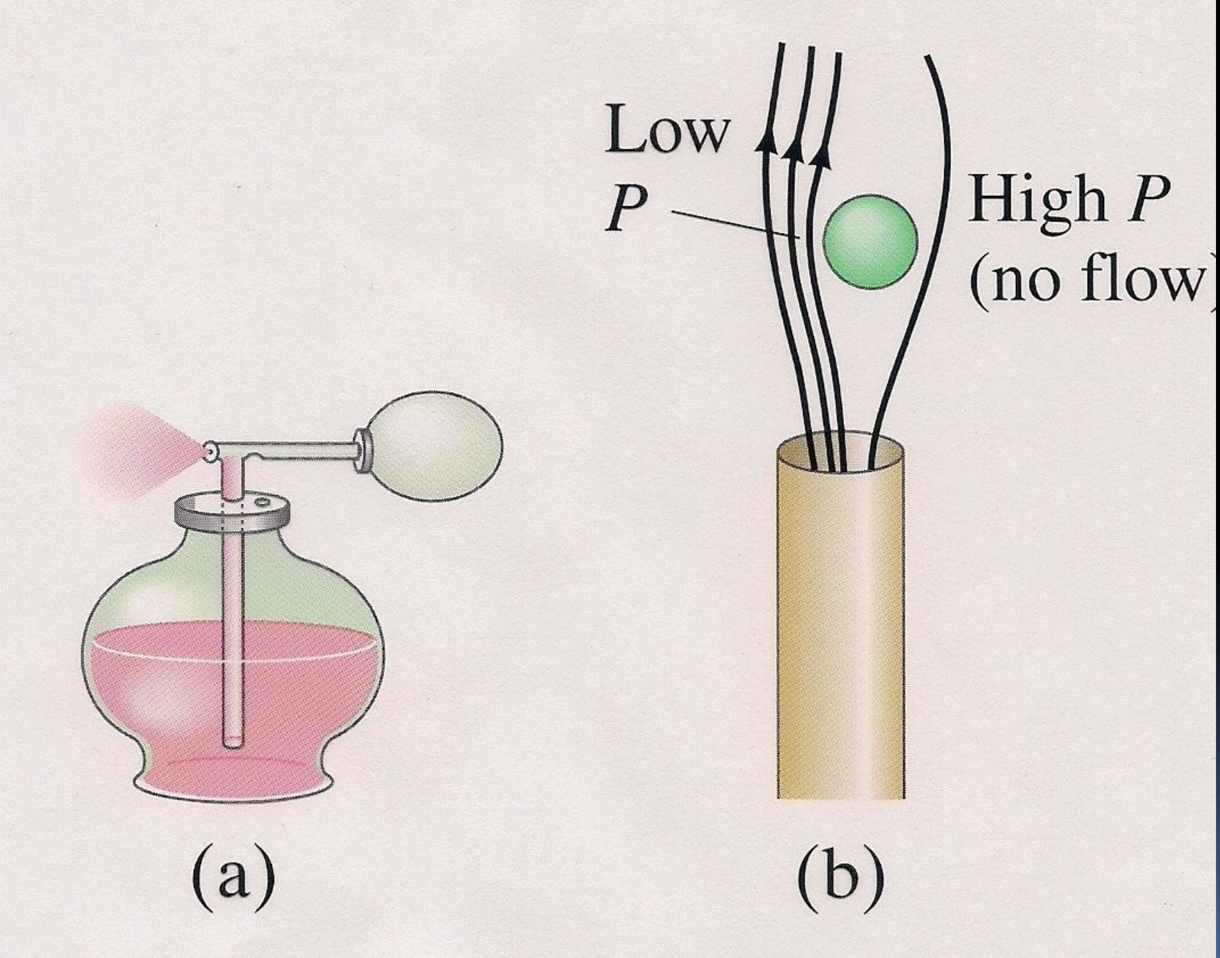
- *Look familiar,*

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

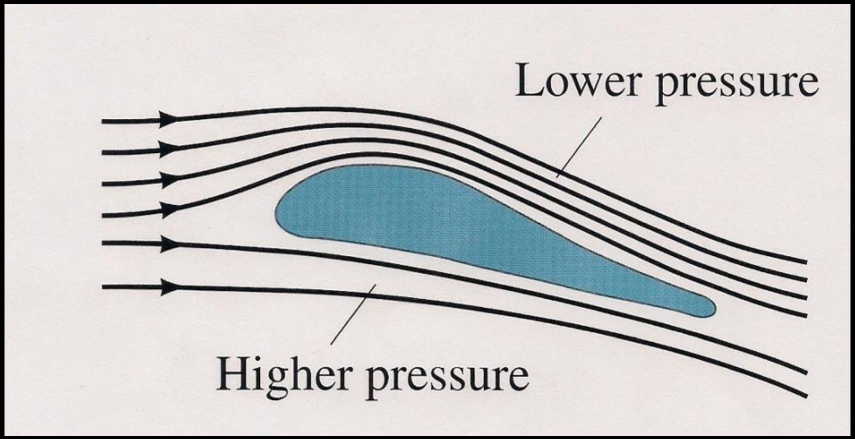


like Conservation of Energy?

Applications: Atomizers and Ping Pong Balls



Applications: Airfoils

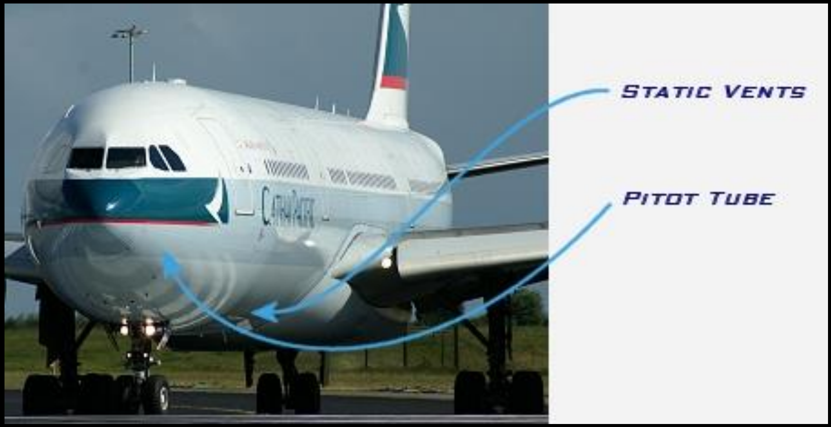


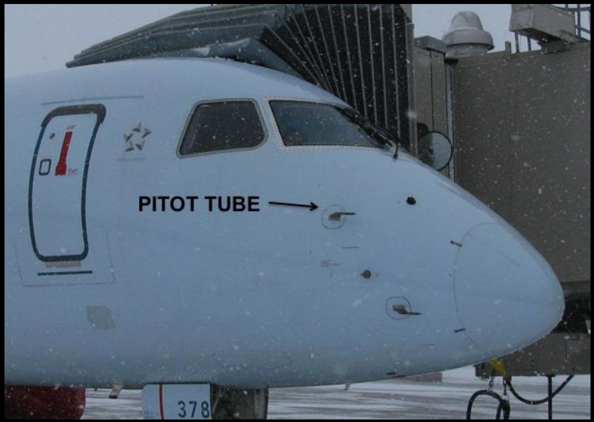
Pitot-Prandtl Tube

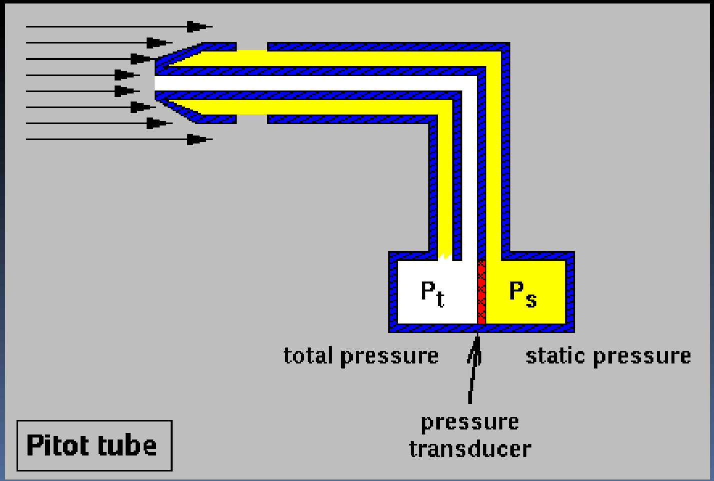
- Measures airspeed by comparing static and dynamic pressure

$$P_{static} + \frac{1}{2}\rho v^2 = P_{dynamic}$$

$$v = \sqrt{\frac{2\left(P_{dynamic} - P_{static}\right)}{\rho_{air}}}$$





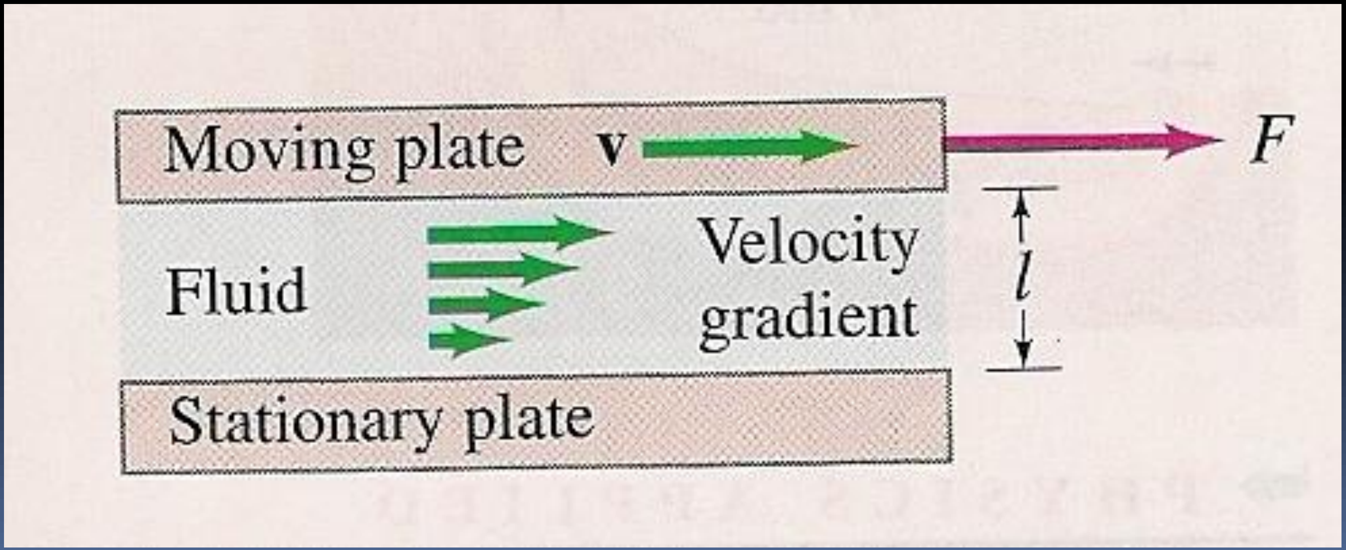


Viscosity

- A friction force between adjacent layers of fluid as the layers move past one another
- In liquids, it is mainly due to the cohesive forces between molecules
- In gases, it is caused by collisions between molecules.
- *Coefficient of viscosity*, η (lowercase eta) (Pa-s)

Viscosity

- **Determined by measuring the force required to move a plate over a stationary one with a given amount of liquid between them**



Coefficients of Viscosity

- Temperatures are specified because it has a strong effect on viscosity
- Viscosity for most fluids decreases rapidly with increase in temperature

TABLE 10–3 Coefficient of Viscosity for Various Fluids

Fluid	Temperature (°C)	Coefficient of Viscosity, η (Pa·s)†
Water	0	1.8×10^{-3}
	20	1.0×10^{-3}
	100	0.3×10^{-3}
Whole blood	37	$\approx 4 \times 10^{-3}$
Blood plasma	37	$\approx 1.5 \times 10^{-3}$
Ethyl alcohol	20	1.2×10^{-3}
Engine oil (SAE 10)	30	200×10^{-3}
Glycerine	20	1500×10^{-3}
Air	20	0.018×10^{-3}
Hydrogen	0	0.009×10^{-3}
Water vapor	100	0.013×10^{-3}

† 1 Pa·s = 10 P = 1000 cP

Drag Force

- For a small sphere, the drag force is

$$F_D = 6\pi\eta r v$$

- The net force on a sphere falling through a fluid is

$$F_{Net} = mg - 6\pi\eta r v - \rho g V$$

Terminal Speed

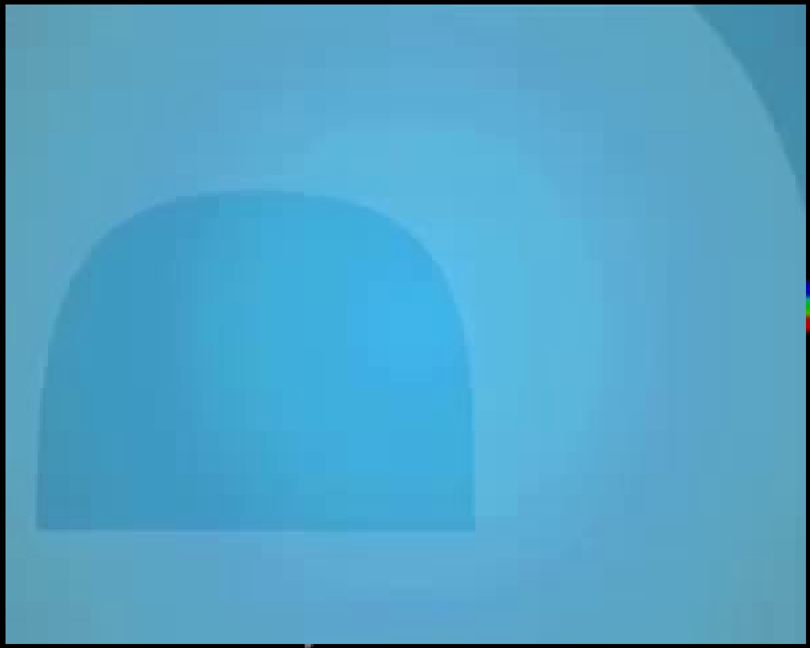
- Terminal speed occurs when the net force is equal to zero

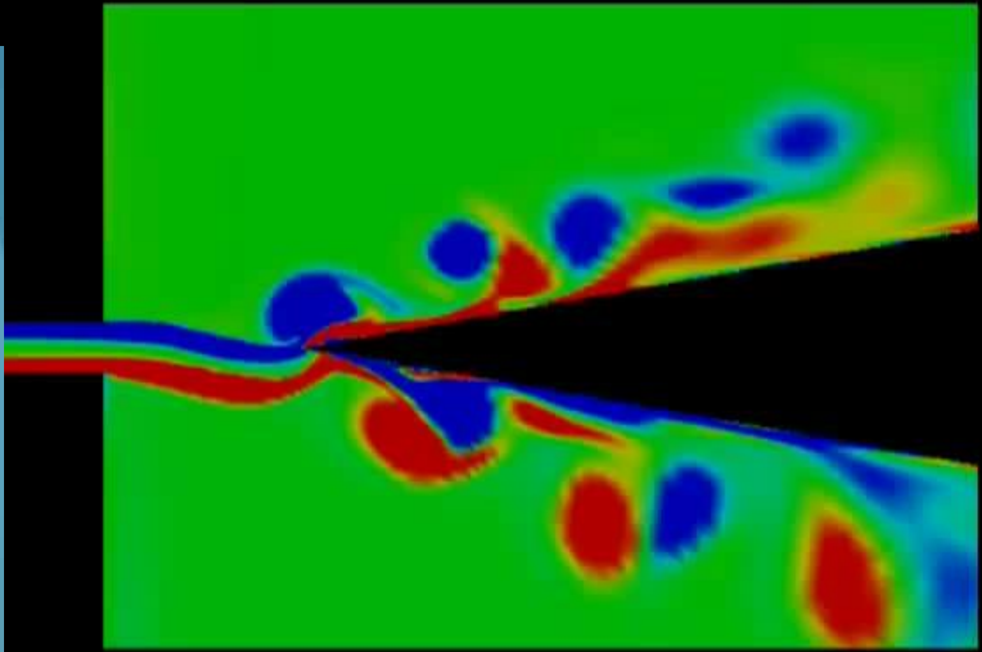
$$0 = mg - 6\pi\eta rv - \rho gV$$

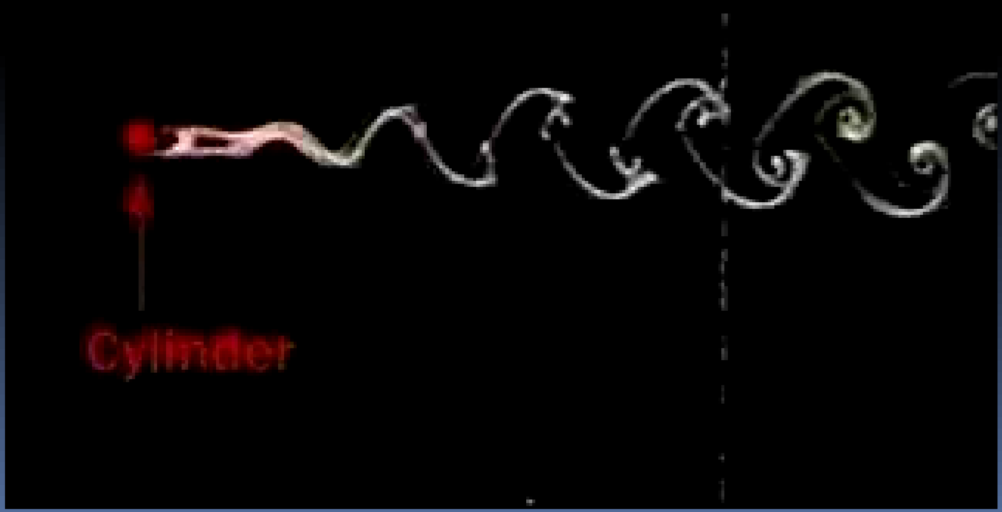
$$6\pi\eta rv = mg - \rho gV$$

$$v = \frac{mg - \rho gV}{6\pi\eta r}$$

Turbulent Flow

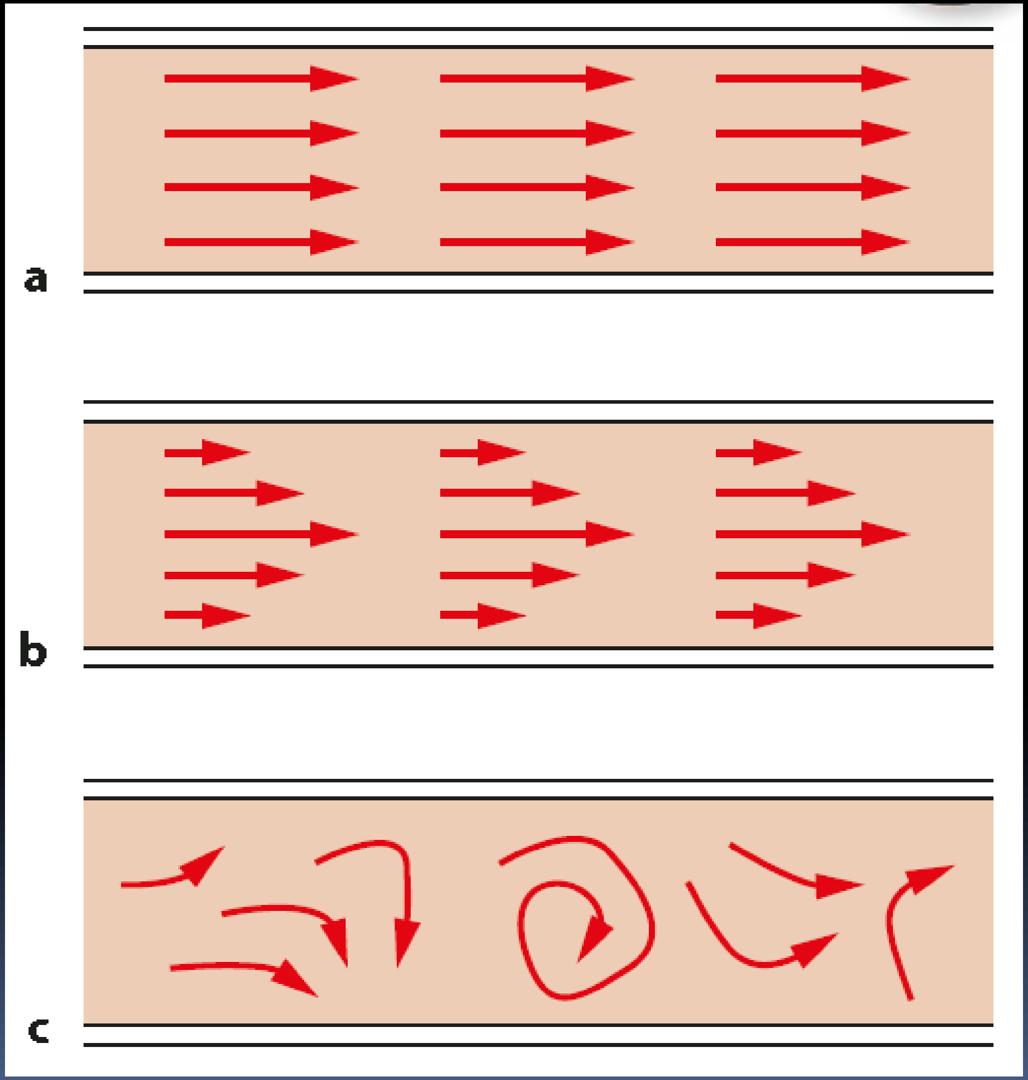






Turbulent Flow

- Non-Viscous Laminar Flow
- Viscous Laminar Flow
- Turbulent Flow



Reynolds Number

- A dimensionless number usually associated with aerodynamics for calculating drag
- Reynolds number for a pipe is,
- Turbulence in pipes occurs at speeds when Reynolds number exceeds 1000

$$R = \frac{v\rho r}{\eta}$$

$$v = \frac{\eta(R > 1000)}{\rho r}$$

Understandings:

- Density and pressure
- Buoyancy and Archimedes' principle
- Pascal's principle
- Hydrostatic equilibrium
- The ideal fluid
- Streamlines

Understandings:

- The continuity equation
- The Bernoulli equation and the Bernoulli effect
- Stokes’ law and viscosity
- Laminar and turbulent flow and the Reynolds number

Data Booklet Reference:

$$B = \rho_f V_f g$$

$$P = P_0 + \rho_f g d$$

$$Av = cons\tan t$$

$$\frac{1}{2}\rho v^2 + \rho g z + p = cons\tan t$$

$$F_D = 6\pi\eta r v$$

$$R = \frac{v r \rho}{\eta}$$

Applications And Skills:

- Determining buoyancy forces using Archimedes' principle
- Solving problems involving pressure, density and Pascal's principle
- Solving problems using the Bernoulli equation and the continuity equation

Applications And Skills:

- Explaining situations involving the Bernoulli effect
- Describing the frictional drag force exerted on small spherical objects in laminar fluid flow
- Solving problems involving Stokes' law
- Determining the Reynolds number in simple situations

Guidance:

- Ideal fluids will be taken to mean fluids that are incompressible and non-viscous and have steady flows
- Applications of the Bernoulli equation will involve (but not be limited to) flow out of a container, determining the speed of a plane (pitot tubes), and venturi tubes

Guidance:

- Proof of the Bernoulli equation will not be required for examination purposes
- Laminar and turbulent flow will only be considered in simple situations
- Values of R 103 <will be taken to represent conditions for laminar flow

Essential Idea:

- Fluids cannot be modelled as point particles. Their distinguishable response to compression from solids creates a set of characteristics that require an in-depth study.

QUESTIONS?

Homework

#38-57

STOPPED HERE 4/10/14