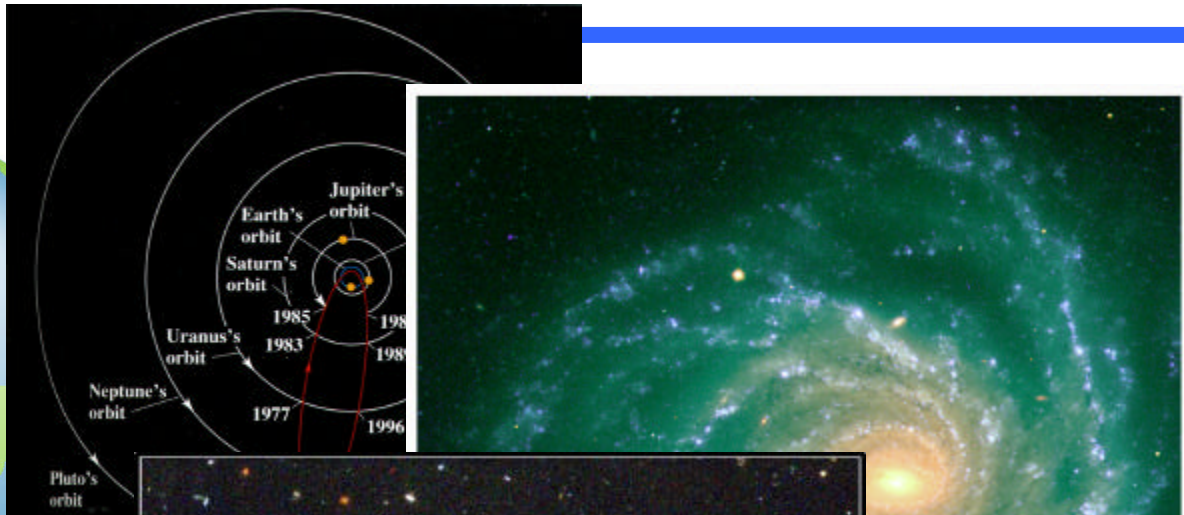
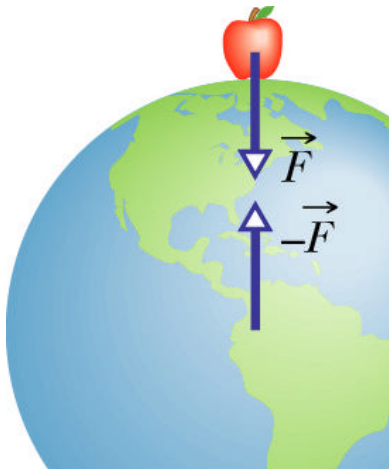


What did we learn?

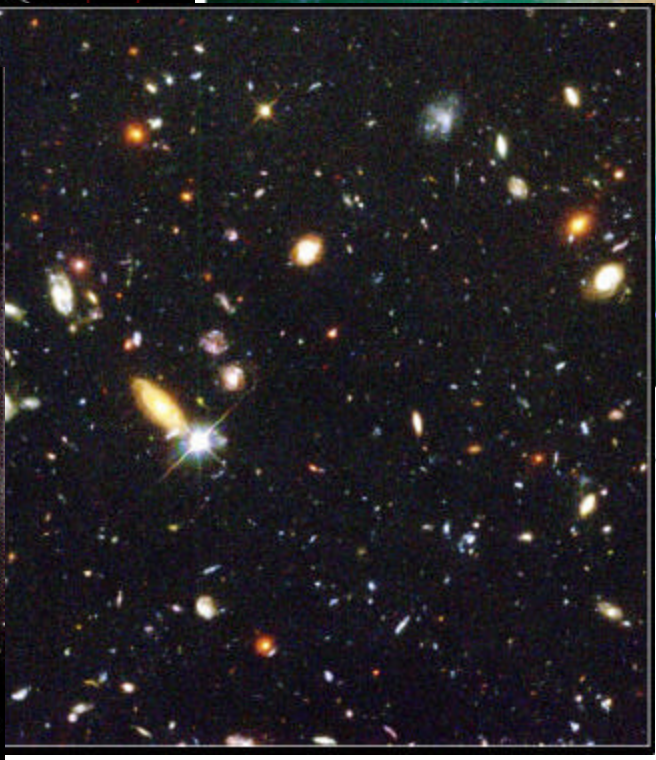
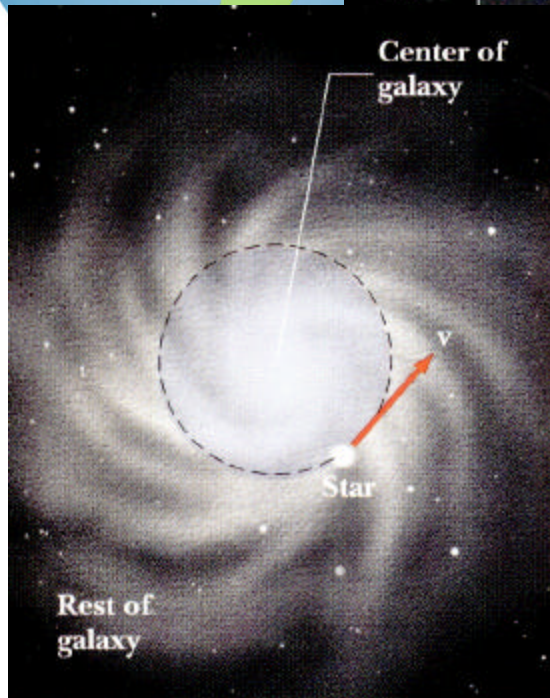


iverse

th no

ee and
he

it of the



IT 1 + FORS1

©European Southern Observatory



Fluids

Today's Agenda ... static and dynamic fluids

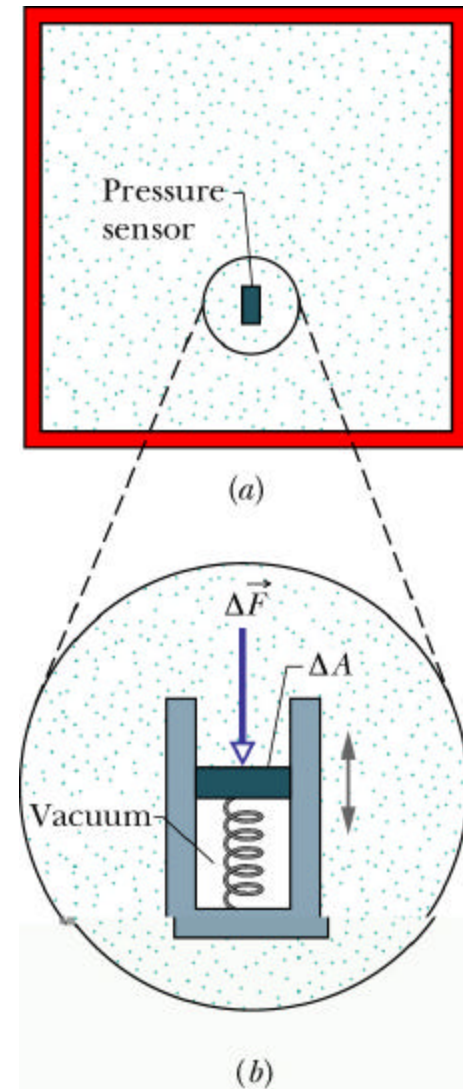
- Density, pressure, ...
- Pressure transmitted: Paschal's Principle
- Pressure vs depth for static liquid
- Bouyancy: (Archimedes)
- Fluids in motion
- Equation of continuity
- Bernouli's equation
- Illustrations

Fluids: Density and Pressure

- Physical materials are solids, liquids, and gases
- **Fluid** is a substance which **flows**
- Includes gases and liquids
- Characterized by density
 - ◆ Which we usually take to be uniform (same at all locations)
- Fluids also exert pressure (also often uniform)
 - ◆ Gas at right has pressure the same from all directions

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

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

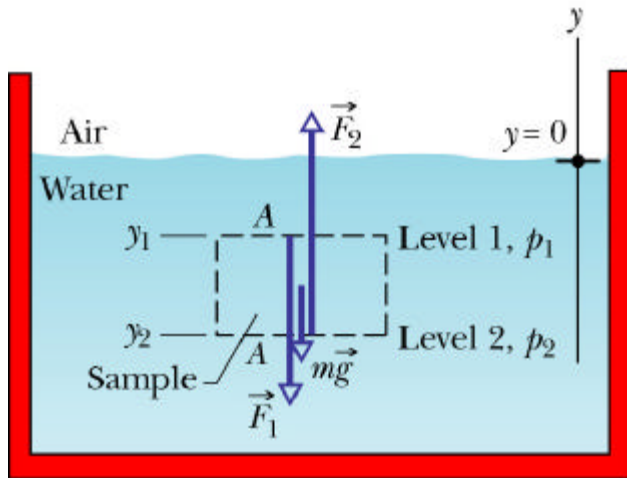


Units and Scales - Liquid vs Gas

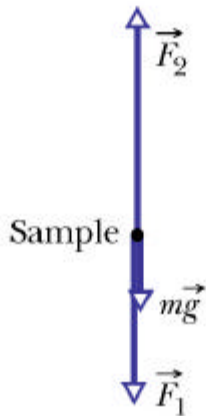
- Units
- Density
 - ◆ Mass/vol = kg/m^3
 - ◆ Typical real world density is water
 - $\rho = 1.00 \text{ g/cm}^3 = 1 \cdot 10^3 \text{ kg/m}^3$
- Pressure
 - ◆ Force/area= N/m^2
 - ◆ $1 \text{ N/m}^2 = 1 \text{ Paschal}$
 - ◆ Atmosphere and other units:
 - $1 \text{ atm} = 1.01 \cdot 10^5 \text{ Pa}$
 - $1 \text{ atm} = 14.7 \text{ lb/in}^2$
 - $1 \text{ atm} = 760 \text{ Torr (mm Hg)}$

- Liquids have molecules moving but collect near each other
- Gas molecules are "free"
- Check out tables 15-1 and 15-2 for typical real world densities and pressures

Weight of Liquid



(a)



(b)

- Take water density r
- Imaginary "box" (volume V) of water between levels 1 and 2 must have zero net force

◆ otherwise it must move

- Forces on it must sum to zero

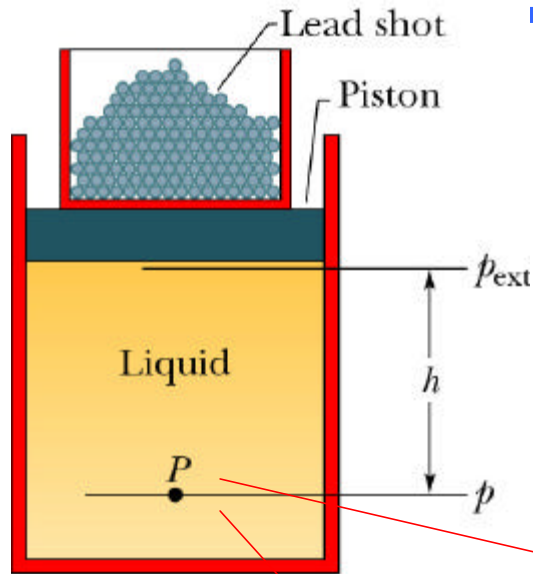
$$F_2 = F_1 + mg$$

$$m = rV = rA(y_2 - y_1)$$

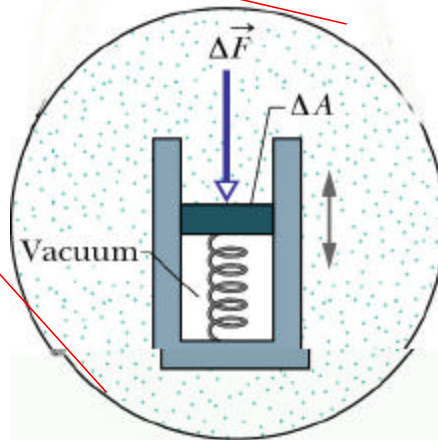
$$p_2 = p_1 + rg(y_2 - y_1)$$

pressure of liquid: $p = rgh$

Paschal's Principle

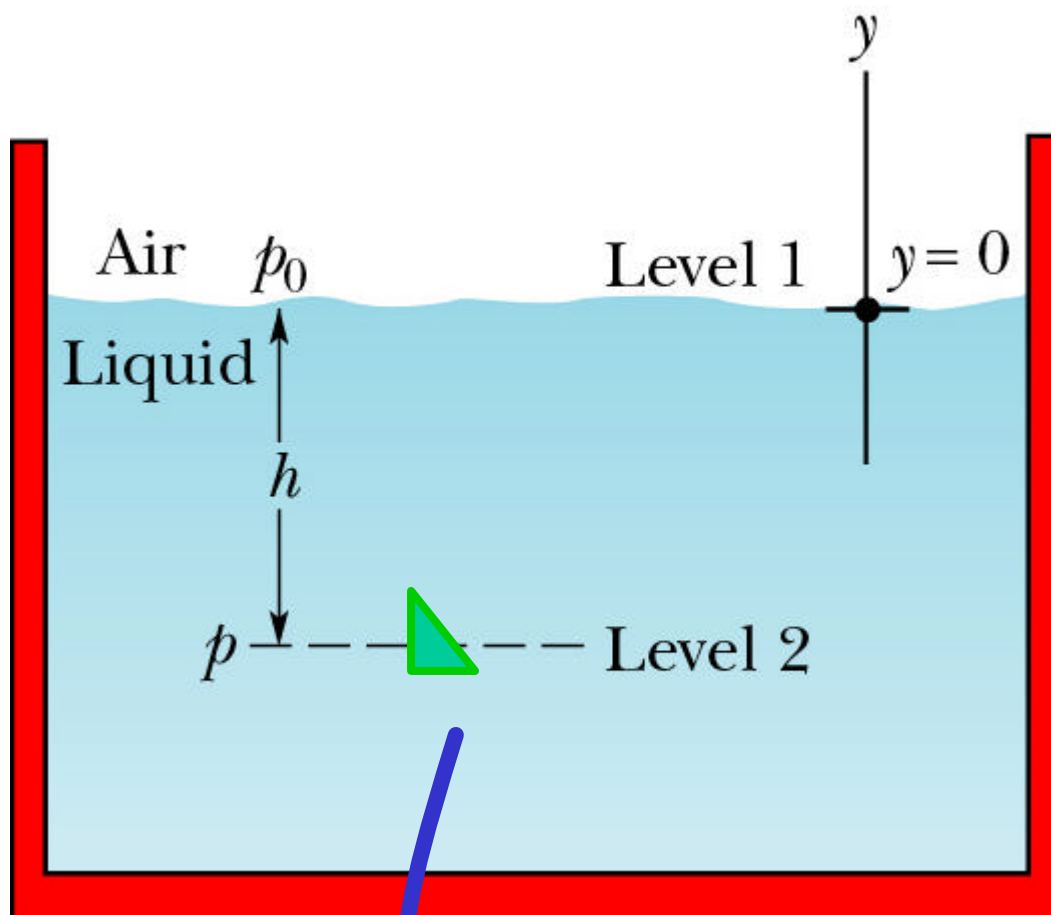


$$p = p_{ext} + \rho gh$$



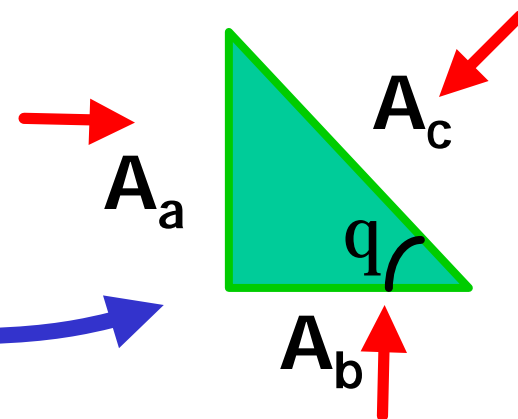
- Change in pressure in an incompressible fluid is transmitted undiminished to every portion.
 - ◆ Obvious from previous argument
- The pressure is exerted in all directions
 - ◆ Means that rotating device at left will result in same result
 - ◆ This is less obvious

Pressure in a Liquid

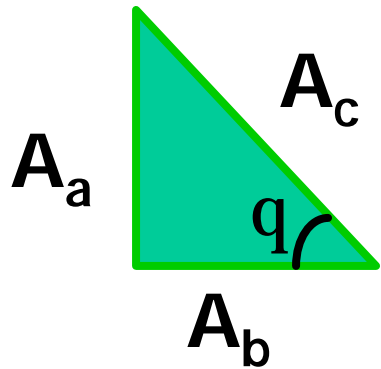


$$p = p_0 + rgh$$

- Less obvious feature of Paschal's Law is that pressure (at this depth) is in all directions!
- We will prove it.



Pressure in Fluid Same in All Directions



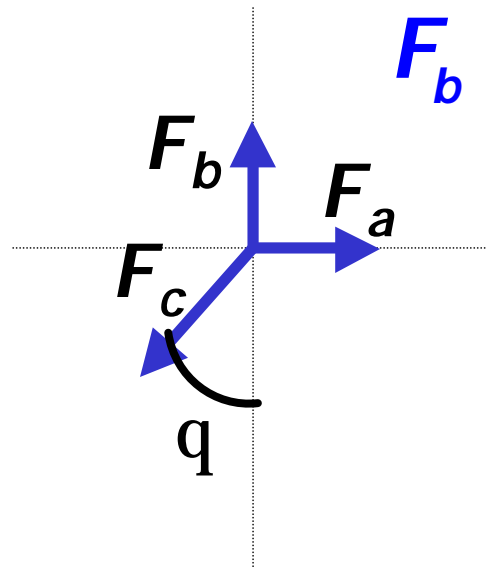
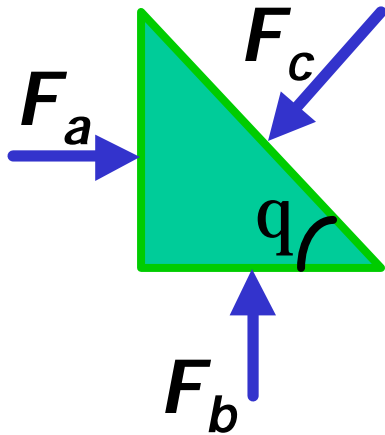
$$A_a = A_c \sin q$$

$$A_b = A_c \cos q$$

- Look at triangular shape carefully
- Vector forces sum to zero

$$F_a = F_c \sin q$$

$$F_b = F_c \cos q$$



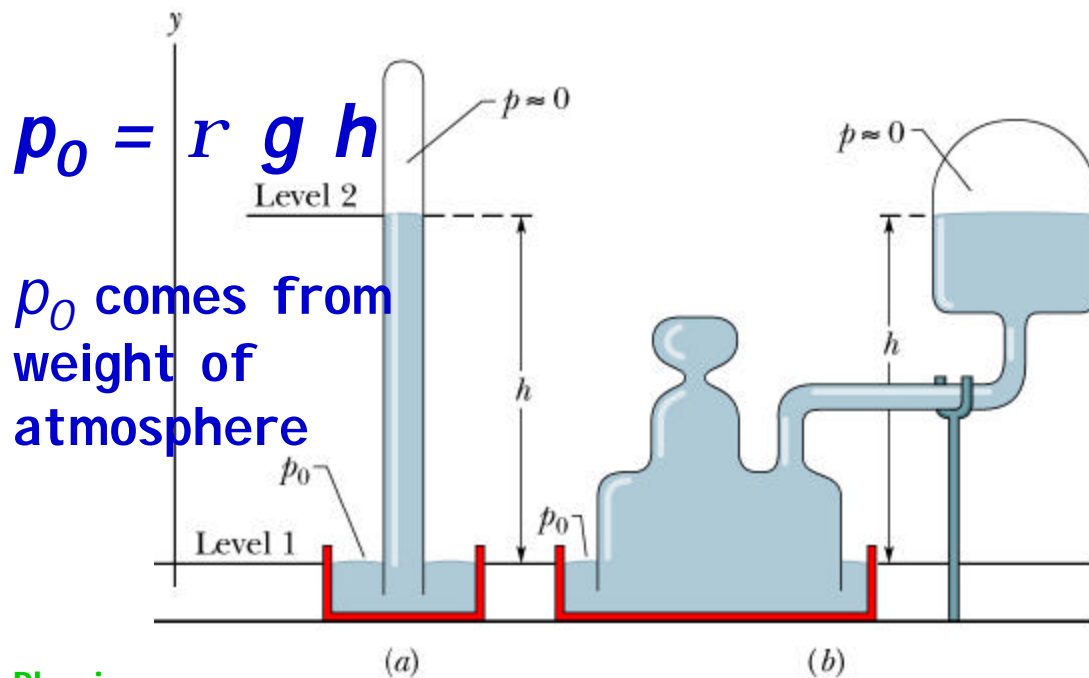
$$\frac{F_a}{A_a} = \frac{F_c}{A_c} = \frac{F_b}{A_b}$$

$$p_a = p_c = p_b$$

Pressure in Static Fluids

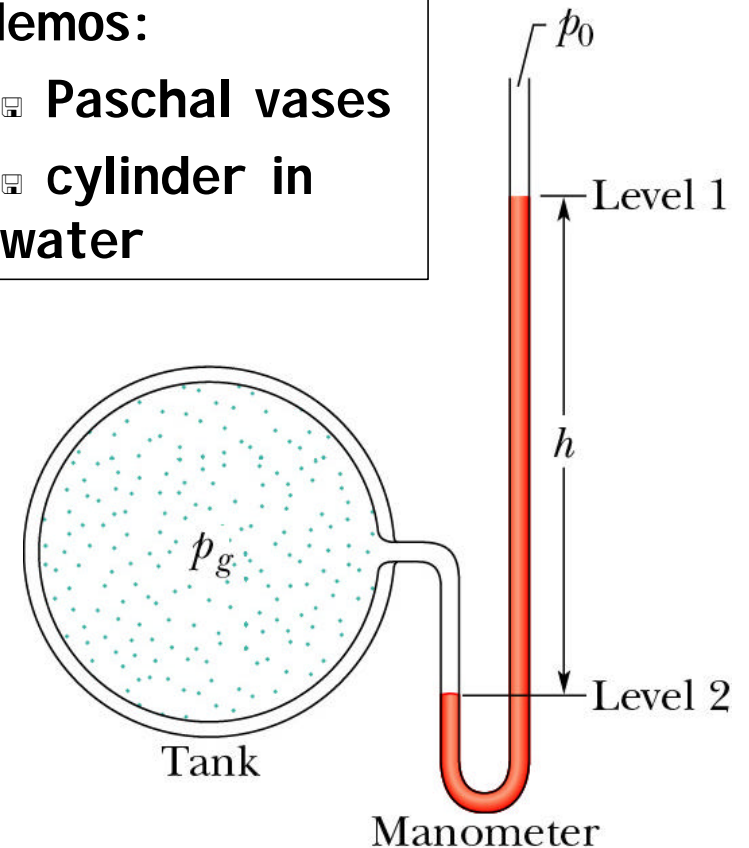
- Pressure at any point depends on depth
- Pressure is the same at a point in all directions
 - ◆ **Pascal's Principle**
- Measuring pressure

- demos:
 - ▣ Pascal vases
 - ▣ cylinder in water



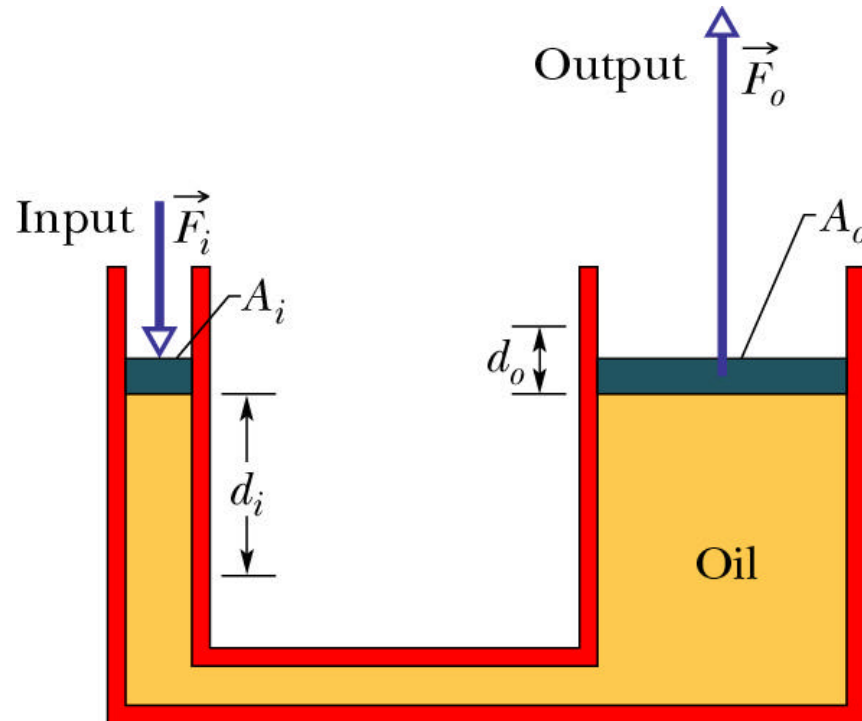
$$p_0 = \rho g h$$

p_0 comes from weight of atmosphere



$$p_g = p_0 + \rho g h$$

Examples & Mechanical Advantage



- eg. car on output platform, you push on input platform
 - ◆ Assume differences in height of oil can be neglected
- force is “amplified” by ratio of areas
- But note that work put in equals work done at output
 - ◆ known as “no free rides”

$$p_o = p_i$$

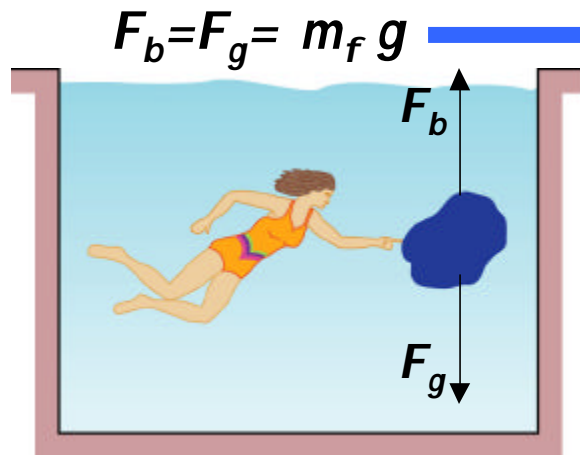
$$V = A_i d_i = A_o d_o$$

$$F_o = F_i \frac{A_o}{A_i}$$

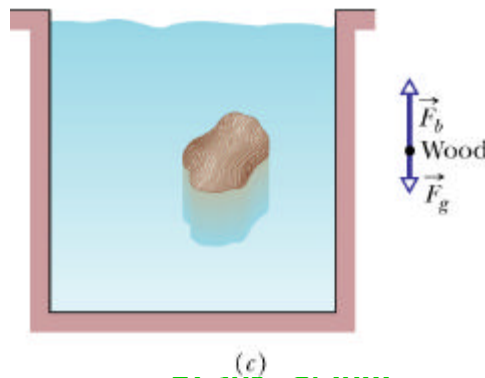
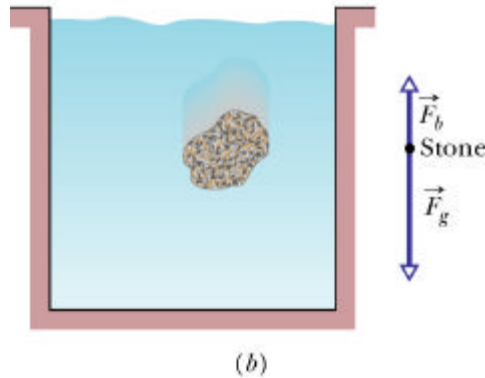
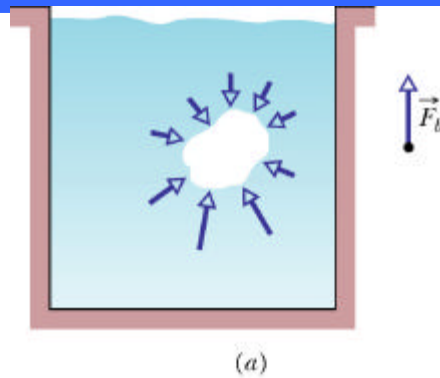
$$\frac{A_o}{A_i} = \frac{d_i}{d_o}$$

$$F_o d_o = F_i d_i$$

Archimedes Principle - Bouyant Forces



- Sack of water lays there
- Must have zero net force
- Gravity must be balanced by buoyant force



$$F_b = m_f g$$

$$F_b = \rho_f V g$$

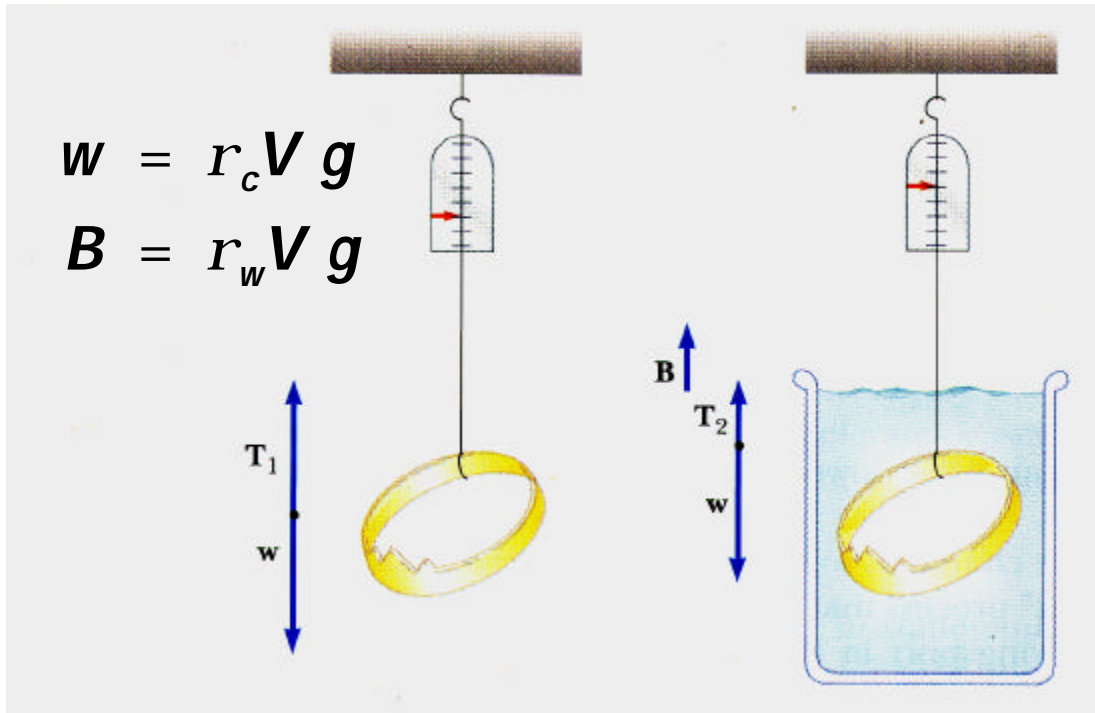
- $m_f =$ mass of displaced fluid
- Take away the sack (and leave hole), the upward (buoyant) force must still be there
- Any body of same volume feels same buoyant force

Problem of the King's Crown



- Archimedes (287-212BCE)
 - ◆ Inventor of “buoyancy”
 - ◆ technical advisor to the King
- King's challenge to Archimedes:
- Is the crown made of gold or is it fake?
- Don't ruin the crown
 - ◆ I.e., no chipping, bending, or mutilating!

Archimedes solution



$$w = r_c V g$$

$$B = r_w V g$$

$$r_c = (1.0 \cdot 10^3) \frac{7.84}{.98}$$

$$= 8.0 \cdot 10^3 \text{ kg/m}^3$$

NOT GOLD!!

• King's challenge: Is the crown made of gold or is it fake?

• Known:

◆ $r_{Au} = 19.3 \cdot 10^3 \text{ kg/m}^3$

◆ $r_{Pb} = 11.3 \cdot 10^3 \text{ kg/m}^3$

◆ $r_{Fe} = 7.86 \cdot 10^3 \text{ kg/m}^3$

◆ $r_{H_2O} = 1.0 \cdot 10^3 \text{ kg/m}^3$

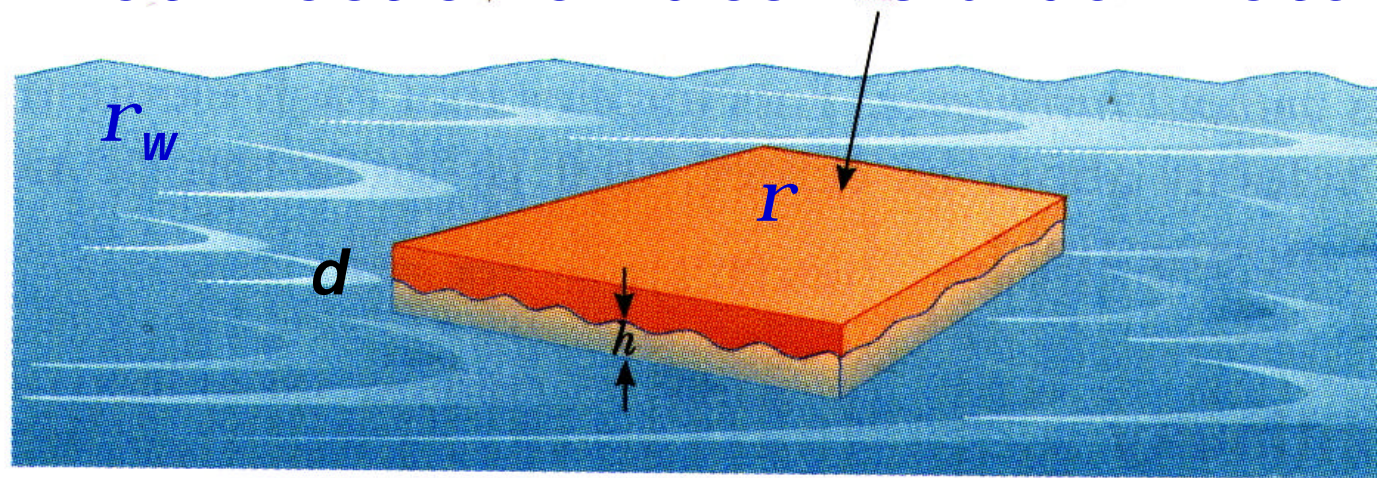
• Measured:

◆ $T_1 = 7.84 \text{ N}$

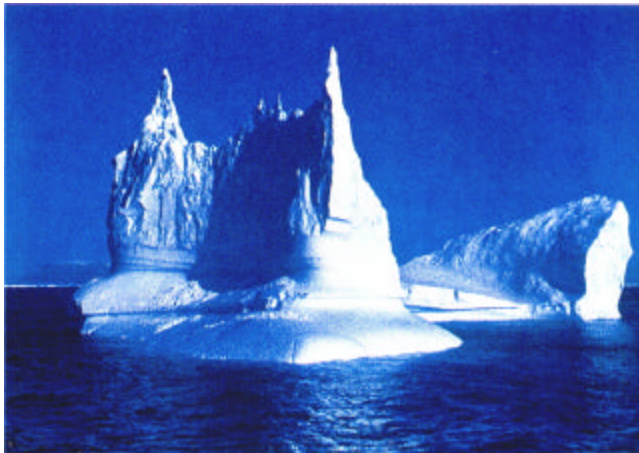
◆ $T_2 = 6.86 \text{ N}$

Floating - 2 questions

What fraction of block is under water?



What fraction of iceberg volume is above water?



Fluids in Motion

- Simple under specific assumptions

- ◆ Laminar (or steady and not turbulent)

- ◆ Incompressible

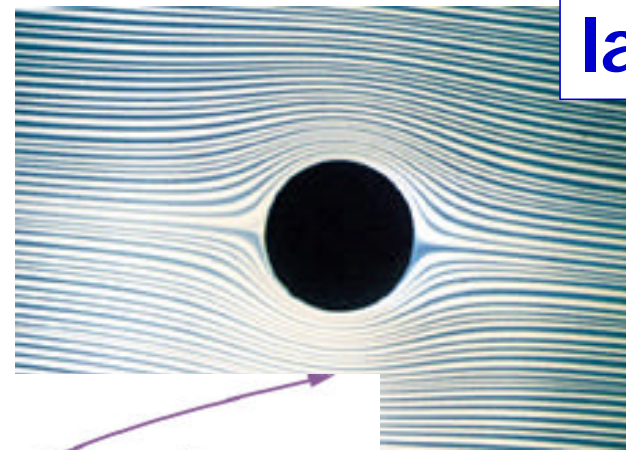
- liquids, not gases

- ◆ Nonviscous

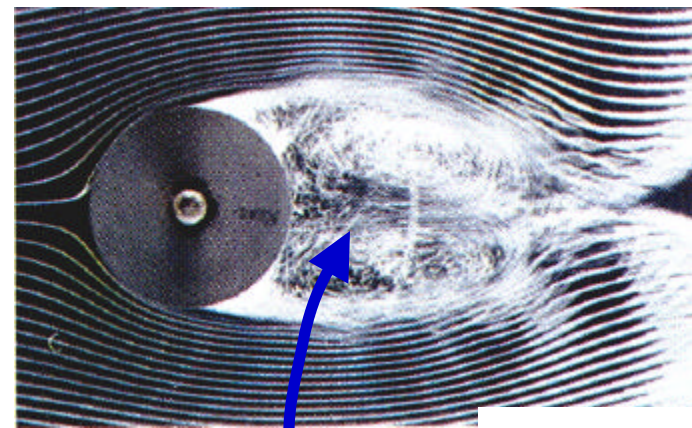
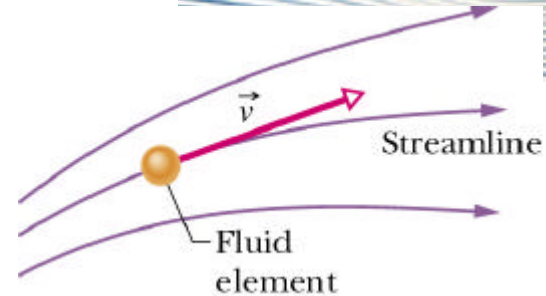
- viscosity = frictional property of fluid

- ◆ Irrotational

- rotational: fluid moves in circular motion (like turbulent vortices at right or whirlpools)



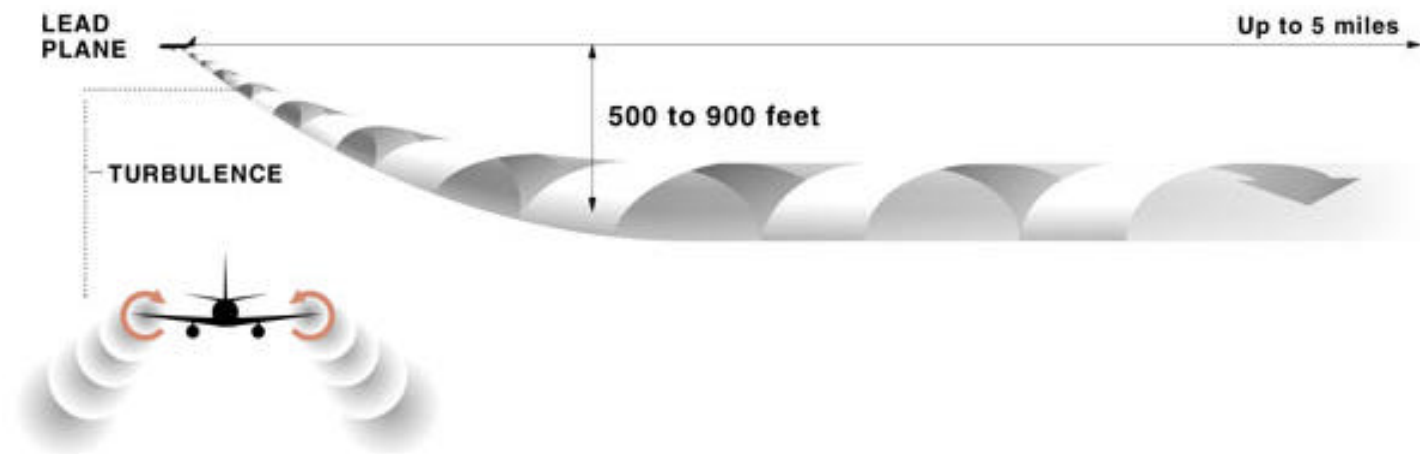
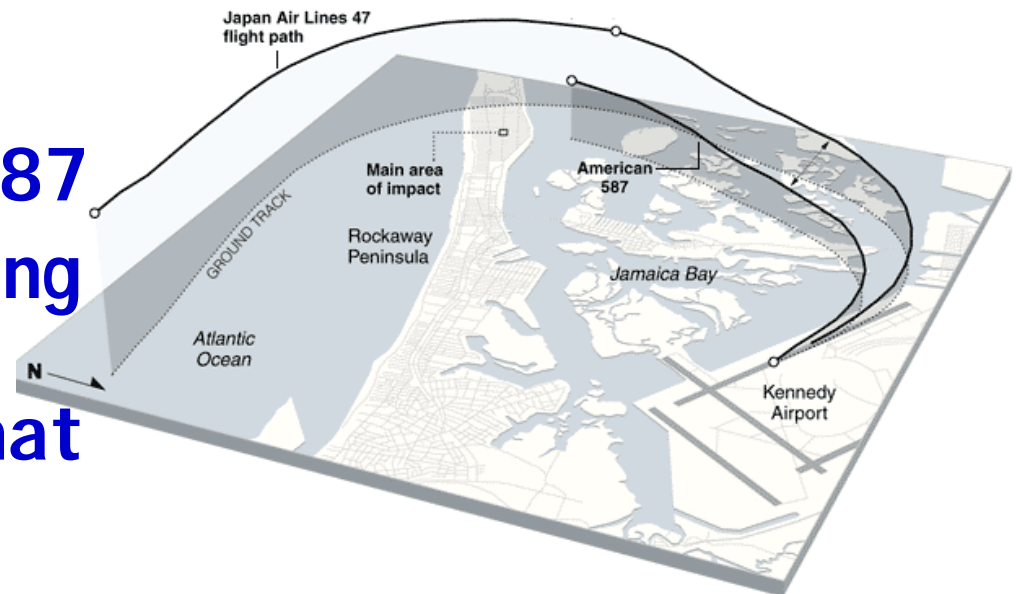
laminar



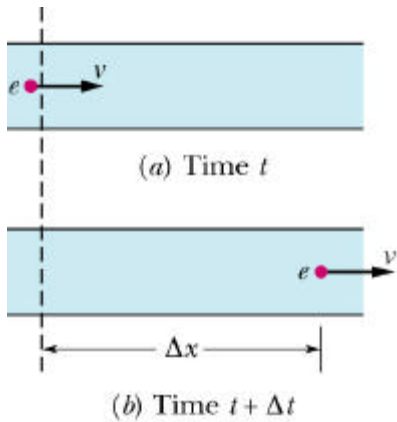
turbulent

Aside: Turbulence from Planes

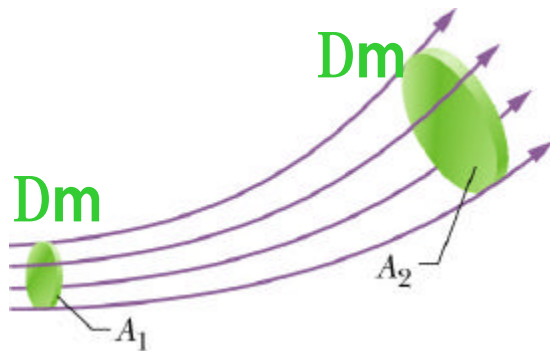
- NY Times Friday 11/16/01
- Crash of AA Flight 587
- Effect of twice passing through turbulence path of JAL FI 47 that left 2 min earlier



Continuity-Consequence of Liquid Incompressibility

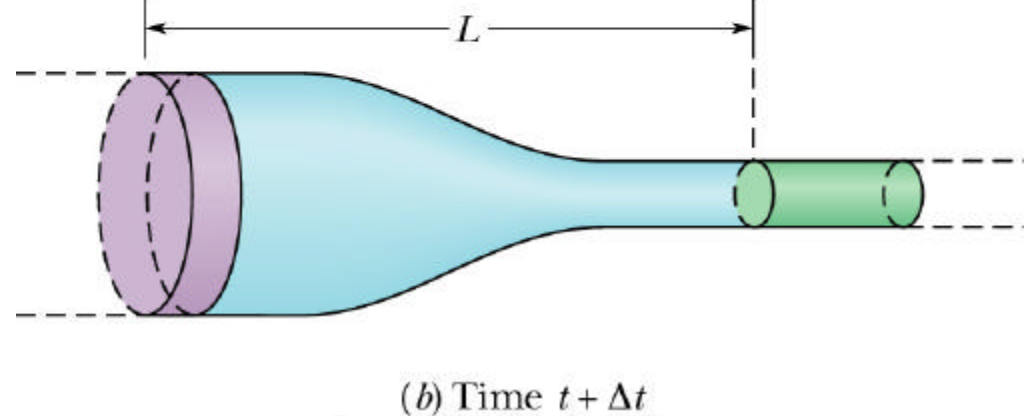
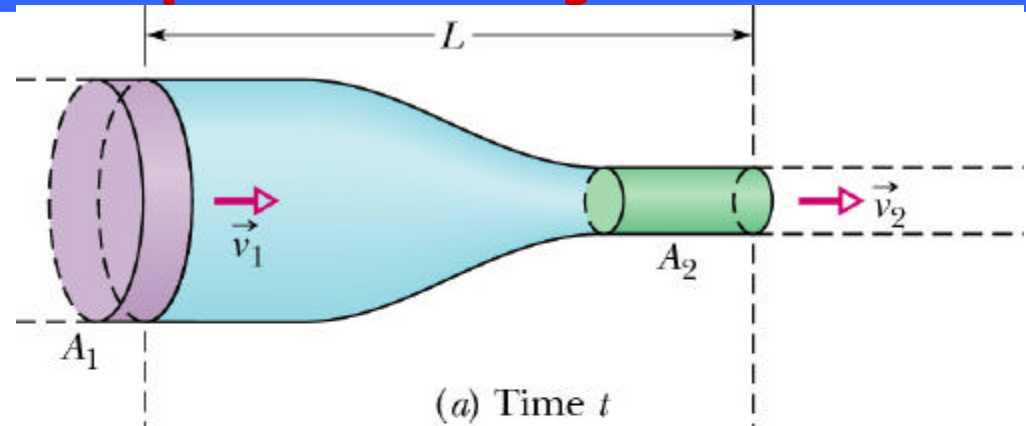


$$\begin{aligned} \frac{Dm}{Dt} &= r \frac{DV}{Dt} \\ &= rA \frac{Dx}{Dt} \\ &= rAv \end{aligned}$$



$$A_1 v_1 = A_2 v_2$$

Equation of Continuity



$$\begin{aligned} \hat{e} \frac{Dm}{Dt} \hat{u}_1 &= \hat{e} \frac{Dm}{Dt} \hat{u}_2 \\ rA_1 v_1 &= rA_2 v_2 \end{aligned}$$

Problem 15-40 (assigned)



- Merging of two streams to form river
- Know widths & depths of streams
- Know width of river
- Know velocity of all
- Find depth of river!

**Straightforward application of
Continuity requirement**

Bernoulli's Equation: Consequence of Energy



- 1700's: work-energy
- W = Work required to push (with force in pressure) fluid 1 \rightarrow 2
- Changes K
- Changes U

$$W_{12} = (K_2 - K_1) + (U_2 - U_1)$$

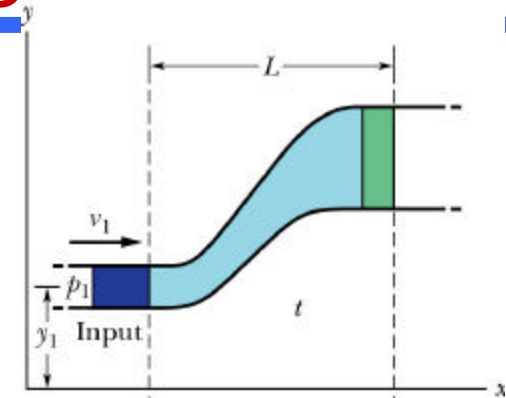
$$W = F D x = \frac{F}{A} A D x = p D V$$

$$K = \frac{1}{2} v^2 D m = \frac{1}{2} r v^2 D V$$

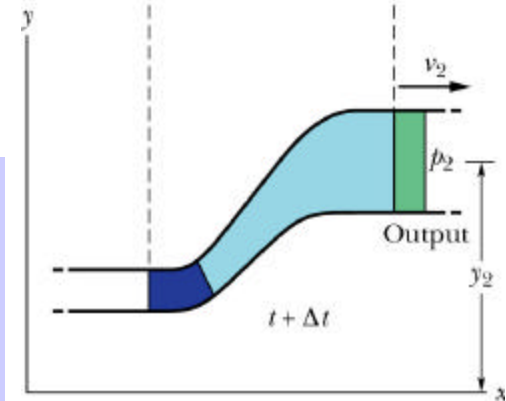
$$U = D m g y = r g y D V$$

$$p_1 + \frac{1}{2} r v_1^2 + r g y_1 = p_2 + \frac{1}{2} r v_2^2 + r g y_2$$

$$p + \frac{1}{2} r v^2 + r g y = \text{constant}$$



(a)



(b)

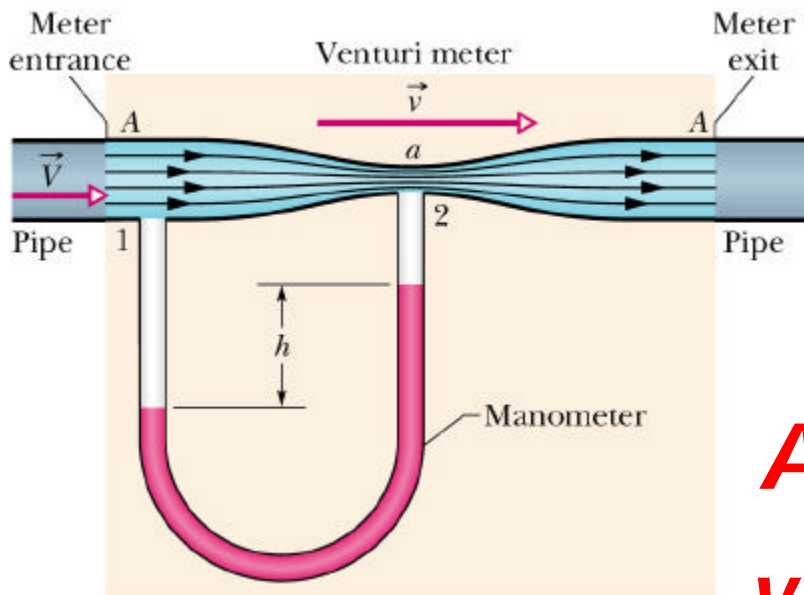
Detailed
derivation
in text

Illustrations of Bernoulli's Equation

$$A_1 v_1 = A_2 v_2$$

$$p_1 + \frac{1}{2} \rho v_1^2 + \rho g y_1 = p_2 + \frac{1}{2} \rho v_2^2 + \rho g y_2$$

- Demos (next time)
- Problems 15-55 and 15-56 use Venturi Meter



$$A_2 < A_1$$

$$v_2 > v_1$$

$$p_2 < p_1$$

Summary ... Fluids

- Density, pressure, ...
- Pressure transmitted uniformly and isotropically (all directions): Pascal's Principle
- Pressure vs depth for static liquid
- Bouyancy: upward force = weight of displaced liquid (Archimedes)
- Fluids in motion for ideal fluids (laminar, incompressible, nonviscous, ...)
- Equation of continuity ($vA = \text{constant}$)
- Work-energy requirement ($p^2 + \rho v^2/2 + \rho gy = \text{constant}$): Bernouli's equation
- Implications

Next time: Chapt. 19 ... Temperature, Heat, and the beginnings of Thermodynamics