Typhoon (JMA)

Category 5 super typhoon (SSHS)

Typhoon Haiyan approaching the Philippines on November 7, 2013

Formed	November 3, 2013
Dissipated	November 11, 2013
Highest winds	*10-minute sustained:* 230 km/h (145 mph) *1-minute sustained:* 315 km/h (195 mph)
Lowest pressure	895 mbar (hPa); 26.43 inHg (Estimated)
Fatalities	1,866 confirmed
Damage	$865.4 million (2013 USD) (Preliminary total)
Areas affected	Micronesia · Philippines · Southern China · Vietnam

Typhoon Haiyan

1. Force of wind blowing against vertical structure
2. Destructive Pressure exerted on Buildings
3. Atmospheric Pressure variation driving the Typhoon's winds
4. Energy of Typhoon
5. Height of Storm Surge

1. Force of wind blowing against vertical structure

Wind blowing against a wall or a tree evidently exerts a force.

How large a force?

Can we calculate it?

For v = 80 m/s

The mean density of Air at sea level is 1.225 kg/m^3

①

Force exerted by moving air (wind)

$F = \Delta P$

$= mv$

$= (\text{volume of air} \times \text{density}) \times \text{velocity}$

$= (\text{Area} \times \text{velocity} \times \text{density}) \times \text{velocity}$

$= A \times \rho V \times V$

$F = A\rho V^2$

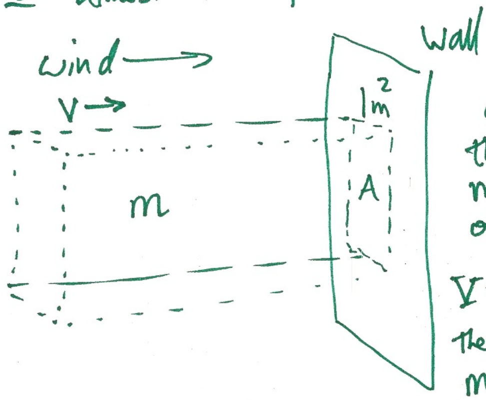
∴ Force proportional to $(\text{wind speed})^2$

$F = 1{\cdot}225\,(\text{kg/m}^3) \times (90)^2$

Per m^2 $= 9922\text{ N}$

at 90 m/s

$F \simeq$ Equivalent to the weight of almost 1 ton per m^2



at velocity v the volume of air molecules hitting $A\,m^2$ of the wall is

$V = A \times V$

The mass of air is

$m = \rho V\ (= \rho A V)$

The momentum of this air is

$P = mV$

$= \rho A V \times V$

$= \rho A V^2$

I'm sure someone will point out that F= Δp/Δt

In my calculation I'm finding the momentum supplied by the air every second. So Δt=1

Here is the same argument made in in words, with a diagram.

- **At 2 m/s an air molecule can travel 2 m before hitting the wall.**
- **All of the molecules between it and the wall also hit in the same time interval. Thus 2 m^3 of air hits each square meter of the wall every 2 sec**
- **At 3 m/s by the same logic, 3m^3 of air hits the wall per second.**
- **So…. At v m/s, v m^3 of air hits the wall per second!**

2. Destructive Pressure exerted on Buildings

Many houses and buildings had their roofs torn off leaving the walls standing

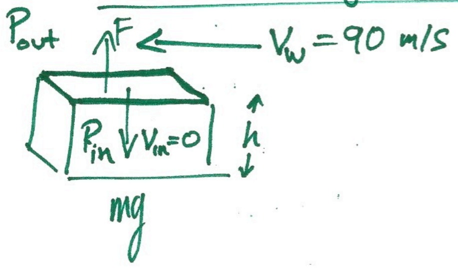
Evidently just the wind blowing over the top of a house in a built-up neighborhood can take it off. Even if the structure is otherwise sheltered from the wind

Using Bernoulli's principle we can estimate the pressure difference between the inside of a house, and the outside when a 90 m/s wind blows across the roof.

Will the roof be able to hang on?

②

Wind blowing over a roof



$$\text{Pressure} = \frac{F}{A}$$

$$\therefore F = P \times A$$

Force lifting Roof

$$F = \Delta P A$$

Force holding roof on

weight of roof = mg

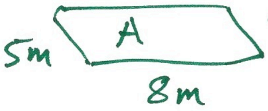
Bernoulli's Principle

$$P_{out} + \frac{1}{2}\rho V_{out}^2 + \cancel{\rho g h} = P_{in} + \overset{=0}{\cancel{\frac{1}{2}\rho V_{in}^2}} + \cancel{\rho g h}$$

$$\Delta P = P_{out} - P_{inside} = \frac{1}{2}\rho V_{wind}^2$$

$$\therefore \Delta P = \frac{1}{2} \times 1.225 \times (90)^2$$

Pressure Difference → $\Delta P = 4961$ Pa



for This roof $F = A\,\Delta P$

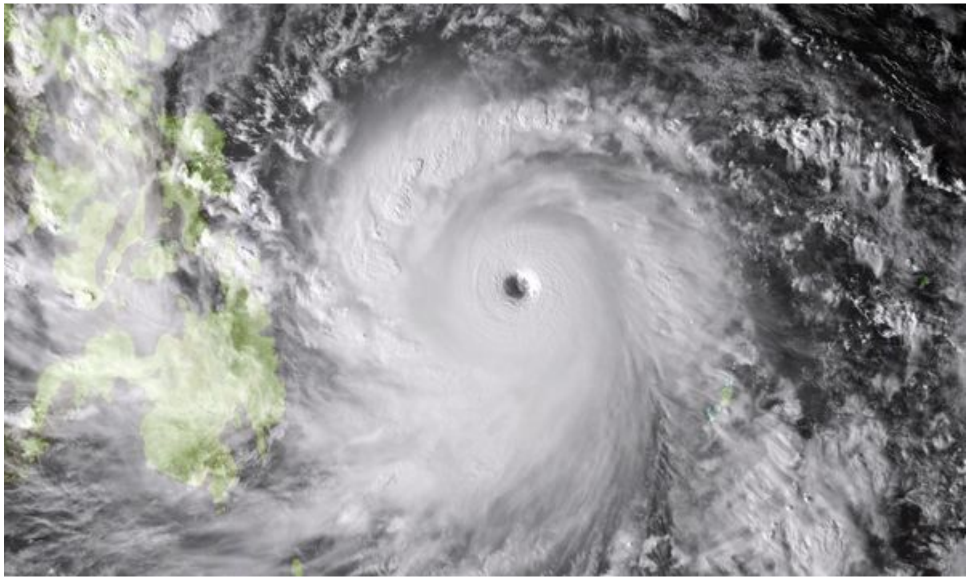
$$= 5 \times 8 \times \Delta P$$

$$F = 40 \times 4961$$

$$F = 20{,}000 \text{ N}$$

Hurricane straps Fix the roof to the walls and foundation, so the whole weight of the house can oppose the pressure force.

3. Atmospheric Pressure variation driving the Typhoon's winds



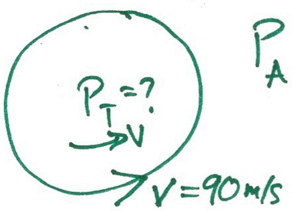
Near the "eye" of the storm the winds blow fastest, circling a region of unusually low air pressure.

Outside the Typhoon, in the free atmosphere the air pressure remains normal.

Using Bernoulli's Principle we can estimate the pressure drop driving the reported wind speeds of 40-90 m/s

③

Central pressure in a typhoon



$P_A \simeq 101$ kPa

$$P_T + \tfrac{1}{2}\rho V_T^2 + \cancel{\rho g h} = P_A + \underbrace{\cancel{\tfrac{1}{2}\rho V_A^2}}_{}\overset{=0}{} + \cancel{\rho g h}$$

$$P_T = P_A - \left(\tfrac{1}{2}\rho V_T^2\right)$$

$$= P_A - \left(\tfrac{1}{2}\, 1.225 \times 90^2\right)$$

$$P_T = P_A - \Delta P$$

$$\Delta P = 4961 \text{ Pa}$$

$$\therefore P_T = 101 \times 10^3 - 4.96 \times 10^3$$

$$= 96.38 \text{ kpa}$$

$$\frac{\Delta P}{P} = \frac{4.96}{101}$$

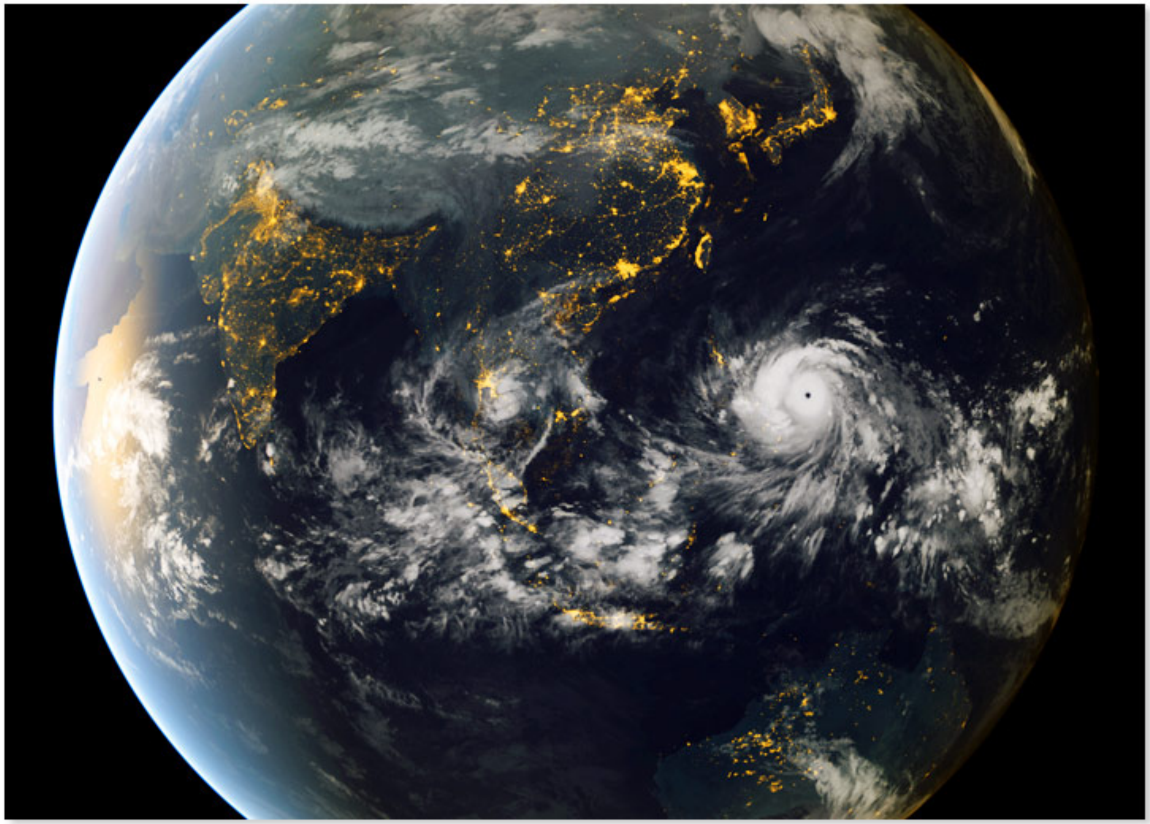
$$\simeq 5\%$$

The national weather service with their equipment and supercomputers estimated

$P_T \simeq 90$ kPa

$\frac{\Delta P}{P} \simeq 9\text{-}10\ \%$

4. Energy of Typhoon



Highest sustained winds 80 m/s

Say the average wind speed was 40 m/s

Radius of the inner most destructive part of the Typhoon ~ 300 km

We can model the typhoon as a rotating cylinder of air

Hence find the total kinetic energy

Destructive events are often compared in terms of equivalent explosive energy or “nuclear bomb” units.
1 ton of high explosive releases 4.2 x10^9 Joules
Nukes pack 100,000 to 1 million times this energy

What was the Equivalent Energy of Typhoon Haiyan?

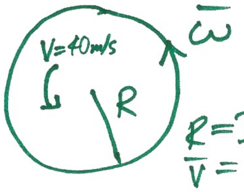
④

Kinetic Energy of Typhoon Haiyan

$$KE = \frac{1}{2} I \bar{\omega}^2$$

← average angular velocity.

↑ Rotational Inertia



$R = 300$ km
$V = 40$ m/s

$$\omega = \frac{V}{R}$$

For a Cylinder

$$I = \frac{1}{2} MR^2 \longrightarrow KE = \frac{1}{2}\left(\frac{1}{2}MR^2\right)\left(\frac{V}{R}\right)^2$$

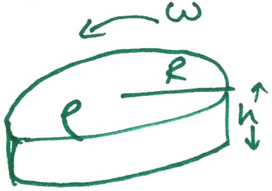
~~$= \frac{1}{4} \frac{M^2RV^2}{R^2}$~~

~~$= \frac{1}{4} M^2 V^2$~~

$$= \frac{1}{4} M \cancel{R^2} \frac{V^2}{\cancel{R^2}}$$

$$KE = \frac{1}{4} MV^2$$

Rotating Cylinder Model



Mass of air in Cylinder $= \text{Volume} \times \rho$

$= \pi R^2 \times h \times \rho$

$= \pi (300 \times 10^3)^2 \times 8000 \times 1.225$

$m = 2.77 \times 10^{15}$ kg

$\therefore KE = \frac{1}{4}\, 2.77 \times 10^{15} \times 40^2$

$KE \approx 10^{18}$ J

$\approx \frac{10^{18}}{10^9} \approx 10^9$ Tons of TNT

≈ 1000 megatons.

1 Ton 10^3 kg TNT releases 4.2×10^9 J

For Comparison, Nuclear Weapons release 100-500 kilotons equivalent

You can think for yourself about the assumptions going into this model

How reasonable do you think they are?

How reliable is the result?

5. Height of Storm Surge

- **We already found that the atmospheric pressure inside a typhoon is lower than normal.**
- **With less pressure of air pushing down on the ocean, the surface will rise up.**
- **How high ?**

Storm Surge

$\Delta P = 10\%$ of $P_{Atmospheric}$ ← (weather service)

$P_{Atmos} \simeq 101$ kPa

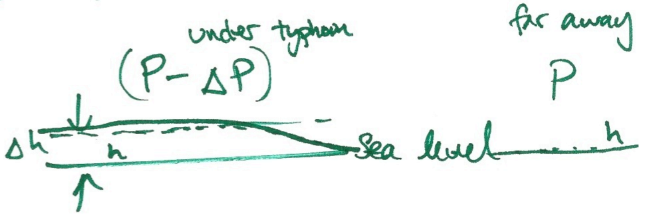
(us)

$\Delta P_{Calculated} \simeq 5000$ Pa

$\simeq 5$ kPa

$P = \rho g h$

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



$$\Delta h = \frac{\Delta P}{\rho g}$$

$$= \frac{5000}{1000 \times 9.8}$$

Density of water

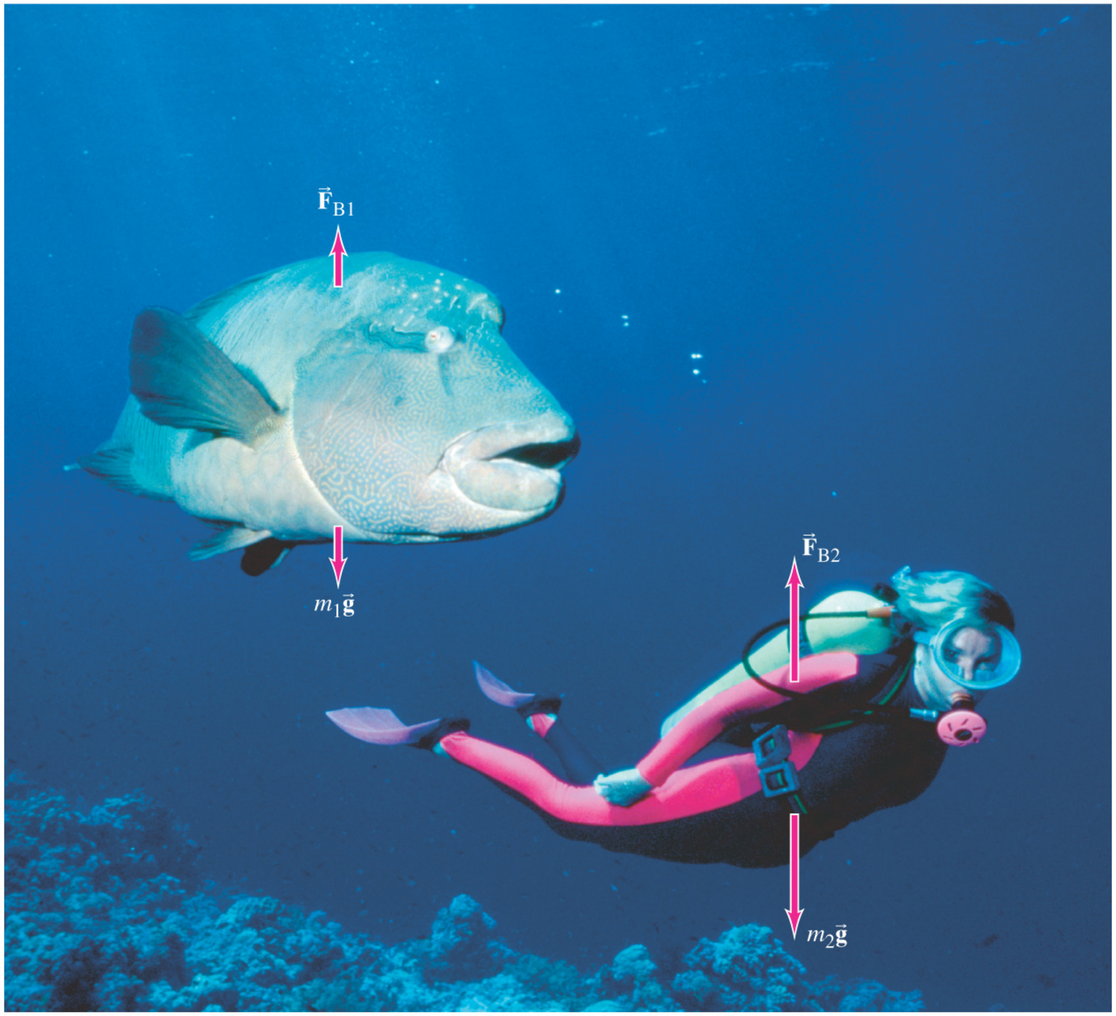
$\rho_{water} = 10^3$ kg/m^3

$$\Delta h = \frac{5000}{10,000} \simeq \frac{5}{10} \simeq \frac{1}{2}$$ meter sea level rise.

for $\frac{\Delta P}{P} \simeq 10\%$ we would get 1m of surge.

Chapter 10 part 3

Fluids in Motion

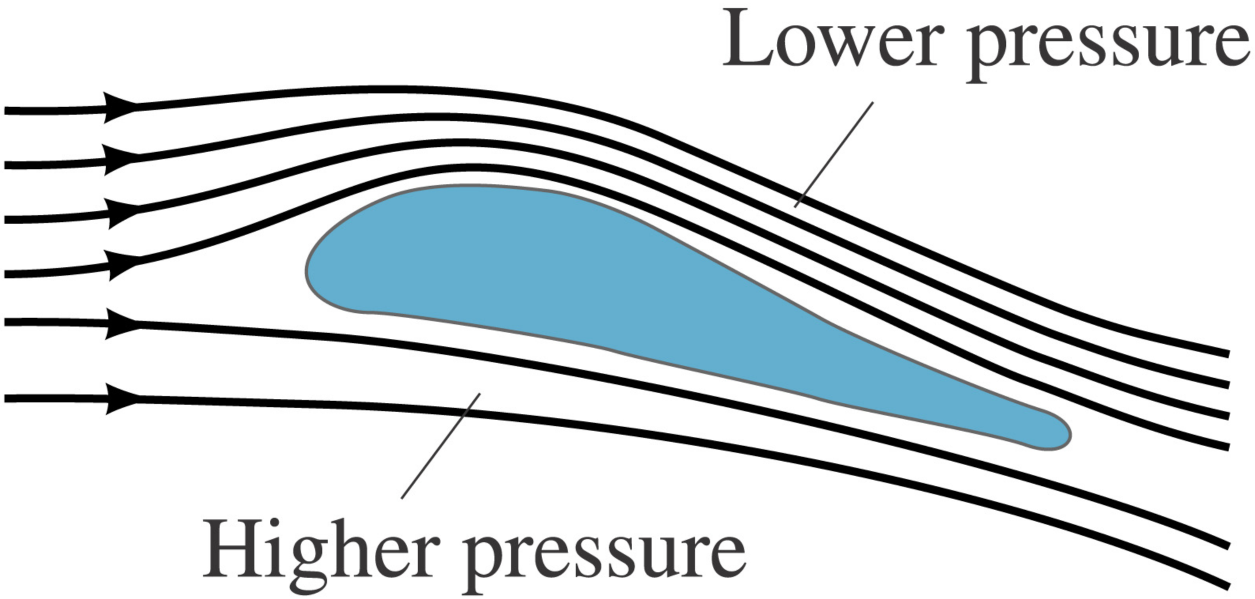


Fluids in Motion : Units of Chapter 10

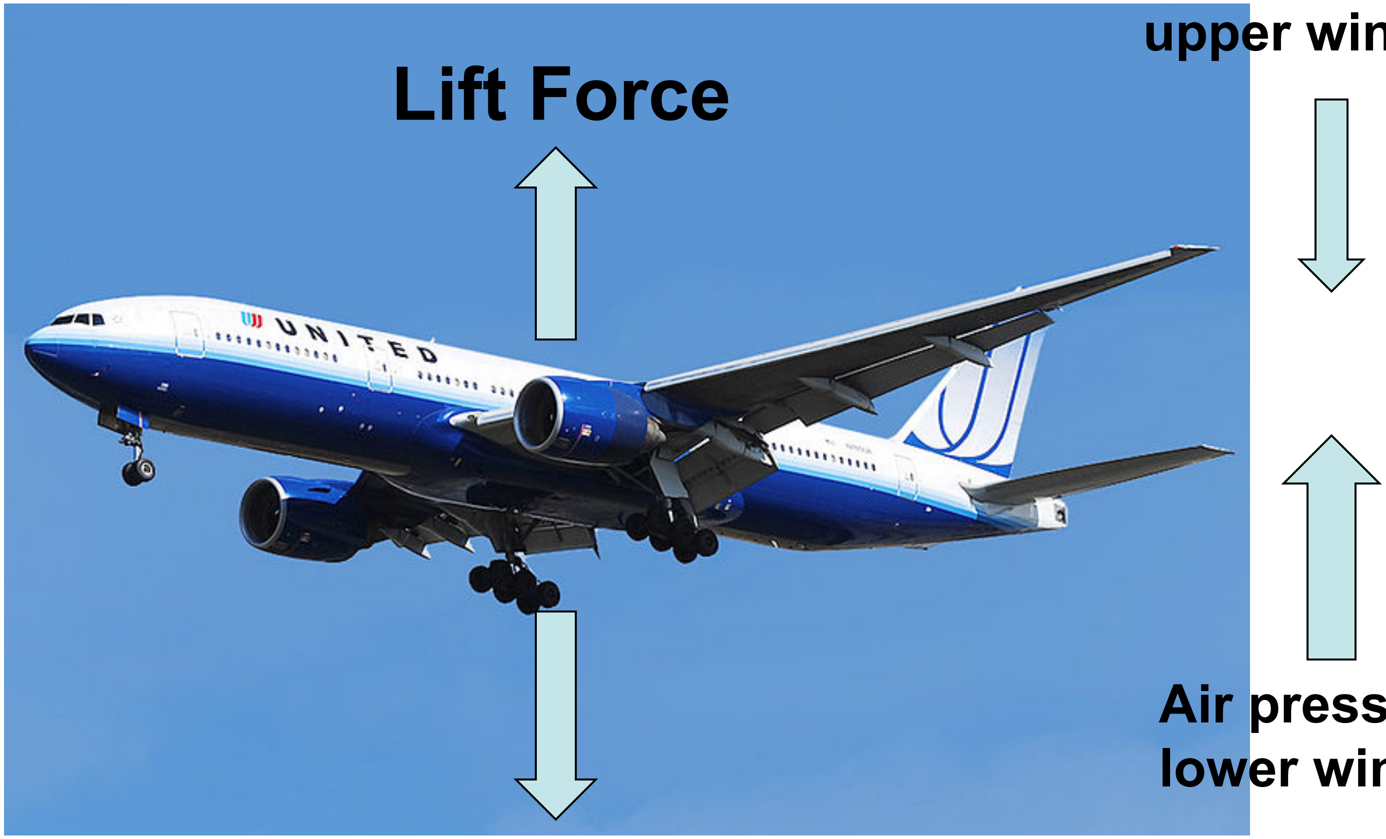
- Flow Rate and the Equation of Continuity
- Bernoulli’s Equation
- Applications of Bernoulli’s Principle
- Airplanes, Baseballs
- Torricelli’s Theorem
- Viscosity
- Flow in Tubes: Poiseuille’s Equation, Blood Flow
- Surface Tension and Capillarity
- Pumps, and the Heart

10-10 Applications of Bernoulli's Principle: from Torricelli to Airplanes, Baseballs, and TIA

Lift on an airplane **wing** can be ascribed to the different air **speeds** and **pressures** on the two surfaces of the wing.



Boeing 777



Lift Force

Weight

Air pressure on
upper wing surface

Air pressure on
lower wing surface

Mass= 220,000 kg
Wing Area = 427 m^2
Speed = 905 km/h

Range = 17,370 km
Altitude = 12 km
5.6 million flights

By **drawing a free body diagram** and identifying the vertical forces (weight, and the force exerted by air pressure above & below the wing) we discover that a large air pressure difference is required to support the plane during level flight.

Notice the relationship between weight and wing area.

This Newtonian analysis leaves the question “what causes this pressure difference?” unanswered.

Bernoulli’s principle provides the solution. Faster moving air above the wing creates a region of lower pressure.

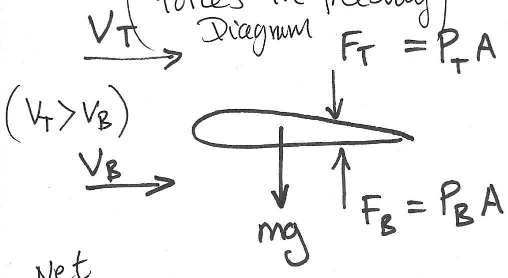
This difference in air pressure acts on the wing to create a net upward force, equal to the weight.

Finally we calculate how much faster the air above the wing must be moving.

In practice this is accomplished by making the upper surface of the wing curved, forcing the air to travel further, and hence faster.

Using Bernoulli's Principle to analyze the flight of a Boeing 777 Jetliner

(Resolve vertical Forces in freebody Diagram)



$V_B = 905$ km/h

$= 251$ m/s

(Speed of the plane)

Net Lift Force

$$F_B = mg + F_T$$

$$\boxed{F_B - F_T} = \boxed{mg}$$

weight of plane

$$P_B A - P_T A = mg$$

$$P_B - P_T = \frac{mg}{A}$$

$$P_B - P_T = \frac{220\times10^3 \times 9.8}{427 \text{ m}^2}$$

$$= 5049 \text{ Pa}$$

(This is the difference in air pressure above and below the wing)

$$P_T + \frac{1}{2}\rho_{air} V_T^2 = P_B + \frac{1}{2}\rho_{air} V_B^2$$

Bernoulli applied to Calculate how that Pressure difference is Created.

$$P_B - P_T = \frac{1}{2}\rho\left(V_T^2 - V_B^2\right)$$

$$5049 = \frac{1}{2}\rho\left(V_T^2 - V_B^2\right)$$

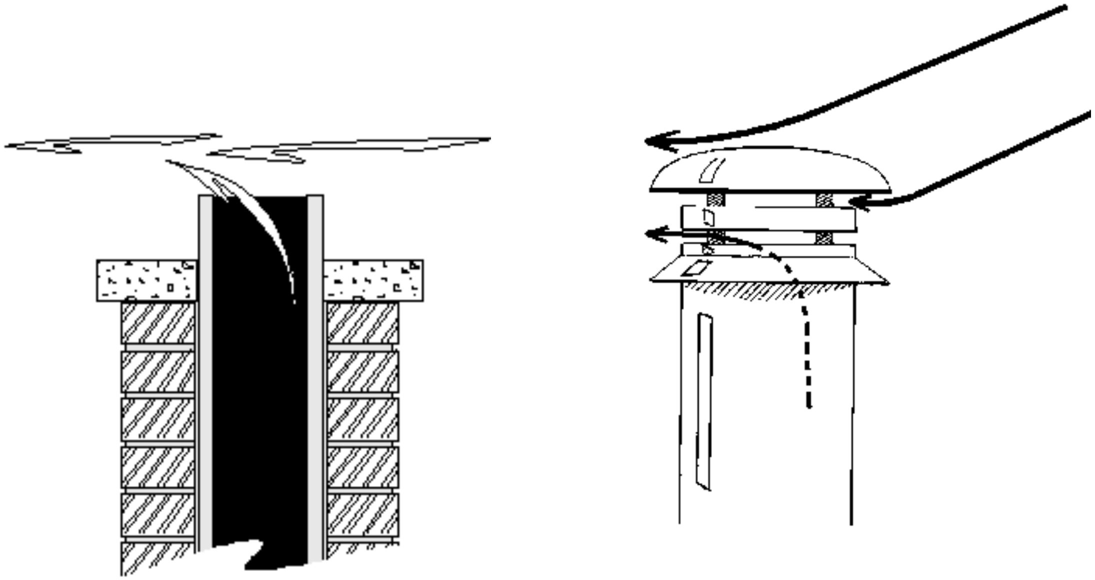
$$\left(V_T^2 - V_B^2\right) = \frac{2\times5049}{\rho}$$

$\rho_{air} = 1.29$ kg/m3

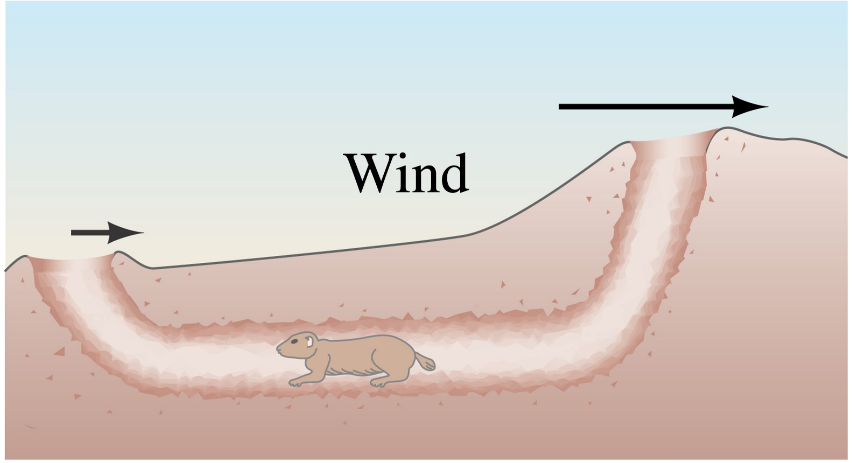
$\therefore V_T = 265$ m/s

(This is the Speed of air passing over the top of the wing.)

Chimneys and Burrows



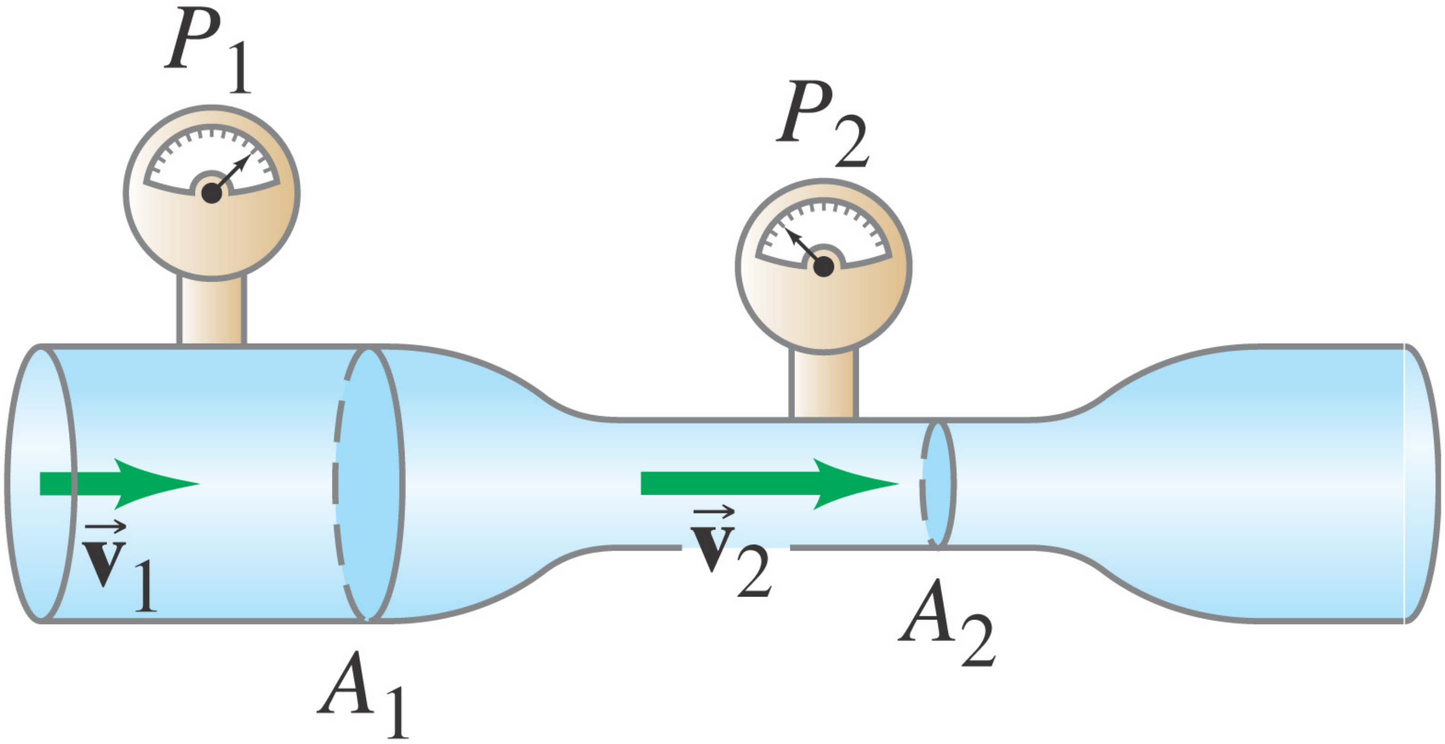
- Air flow across the top helps smoke go up a chimney
- Many chimneys have caps like this to force the airflow to be horizontal over the opening
- The fast moving air creates a low pressure region that draws smoke up and out.



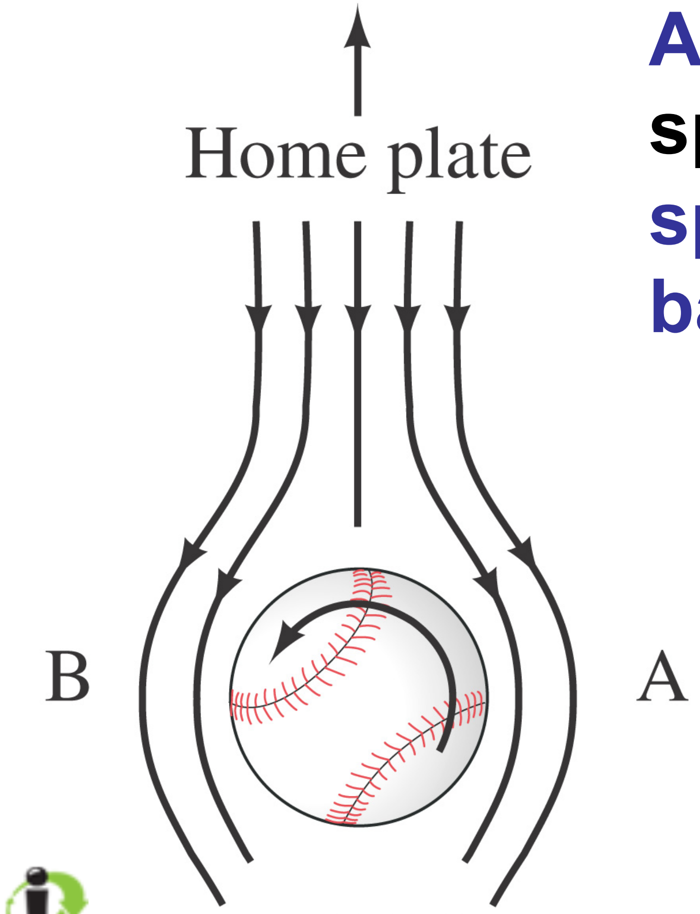
Air flow over multiple openings can provide the needed circulation in underground burrows.

Venturi’ s Effect. Wind velocity and pressure: A special case of the foregoing

A **venturi meter** can be used to measure fluid **flow** by measuring **pressure** differences.



Physics of Baseball



A ball's path will **curve** due to its **spin**, which results in the air speeds on the two sides of the ball not being equal.

Which way does this ball curve?

1. Towards A
2. Towards B
3. Up
4. Down

Viscosity

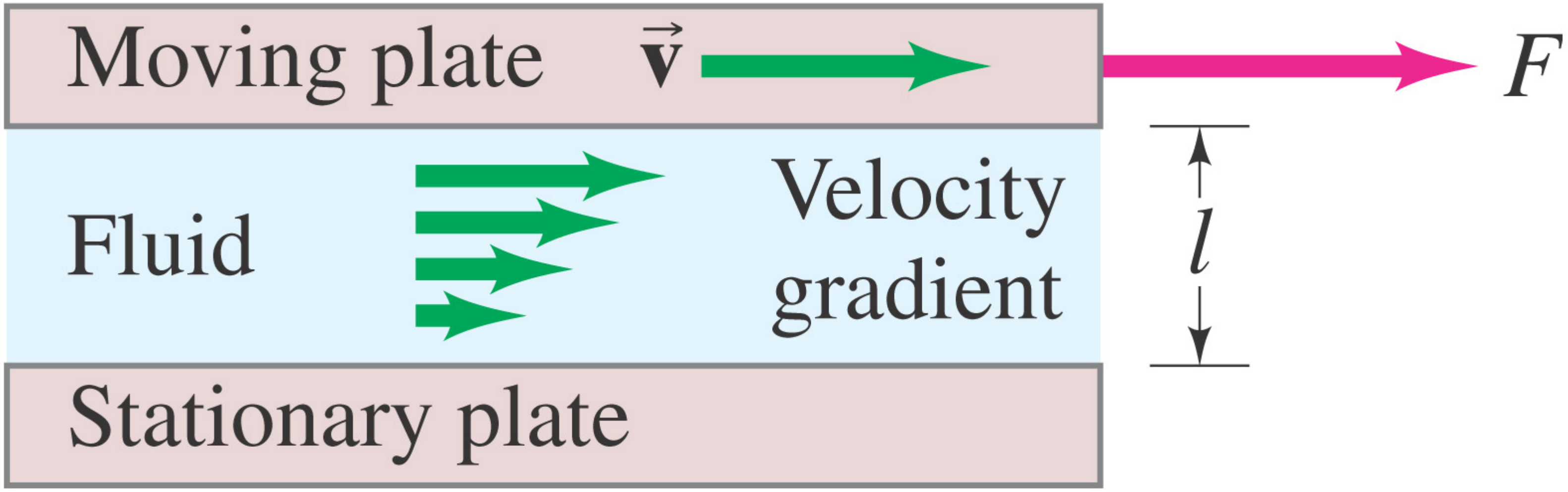
Real fluids have some internal friction, called viscosity.

Molasses is an example of a highly viscous fluid

The viscosity can be measured; it is found from the relation

$$F = \eta A \frac{v}{l} \tag{10-8}$$

where η is the coefficient of viscosity.



Flow in Tubes; Poiseuille's Equation,

The **rate of flow** in a fluid in a round tube depends on the **viscosity** of the fluid, the **pressure** difference, and the **dimensions** of the tube.

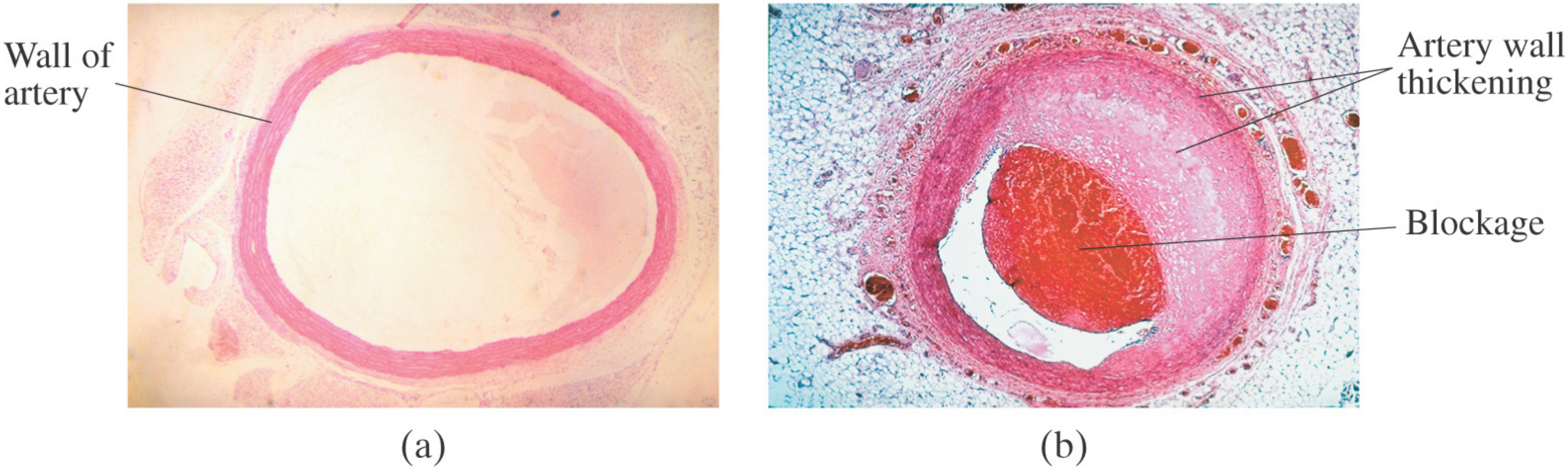
$$Q = \frac{\pi R^4 \Delta P}{8 \eta L}$$

The volume flow rate is proportional to the **pressure difference**, inversely proportional to the **length** of the tube, and proportional to the **fourth** power of the radius of the tube.

Flow in Tubes; Poiseuille's Equation, Blood Flow

This has consequences for blood flow – if the radius of the artery is **half** what it should be, the **pressure** has to **increase by a factor of 16** to keep the **same flow rate**.

Usually the heart cannot work that hard, but **blood pressure goes up** as it tries.

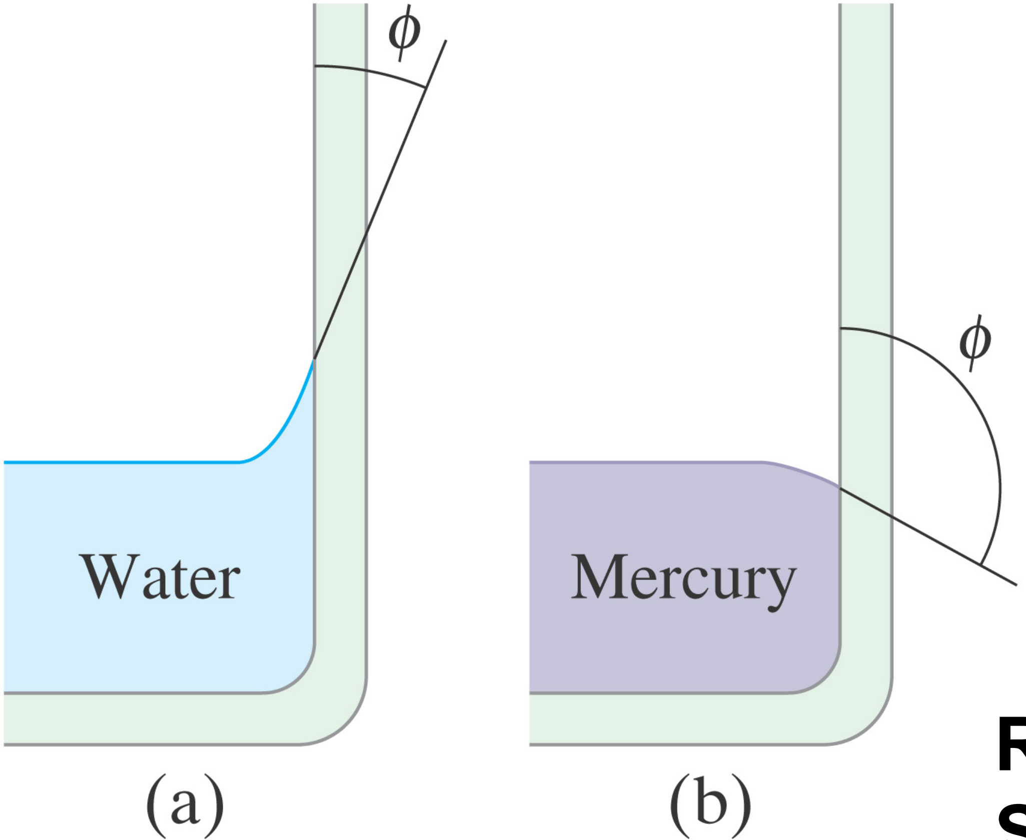


Surface Tension and Capillarity

The **surface** of a liquid at rest is not perfectly flat; it **curves** either up or down at the **walls** of the container. This is the result of **surface tension**, which makes the surface behave somewhat elastically.

Surface Tension and Capillarity

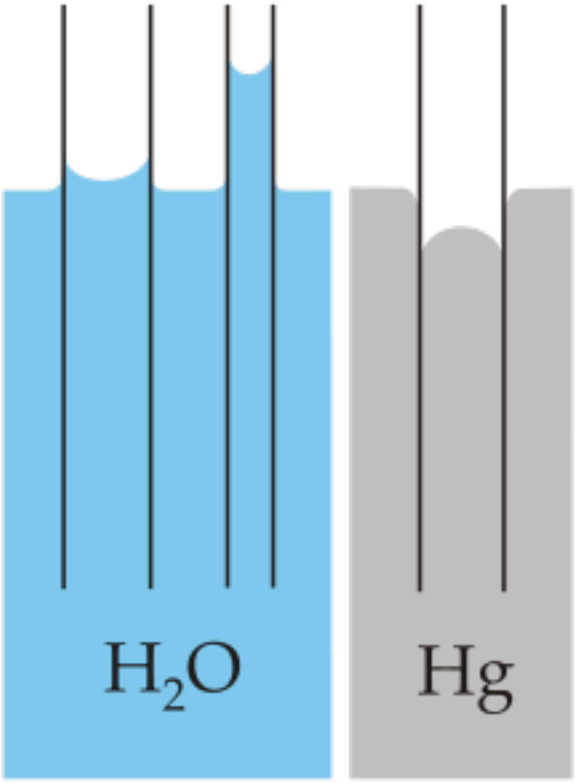
Soap and **detergents** lower the surface tension of water. This allows the water to penetrate materials more easily.



Water molecules are more strongly attracted to **glass** than they are to each other; just the opposite is true for **mercury**.

Remember the word Surfactant?

Capillary Action



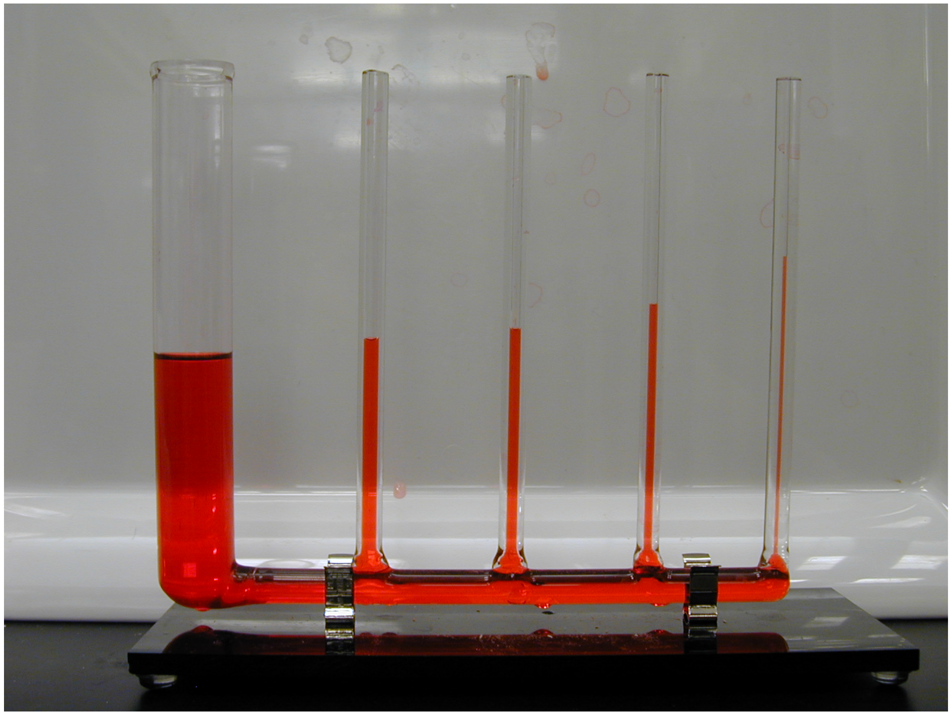
- If the molecules of a liquid attract both each other, and the walls of the container (a consequence of electrostatics and polarity – see next semester) this attractive force pulls the surface of the fluid up the side of the container, until the weight of column of liquid exceeds the available force.

- If the tube is narrow, there is more surface area in contact, and hence the force per unit volume is greater.

- If the tube is wider, there is less surface area per unit volume, and the fluid does not rise as far.

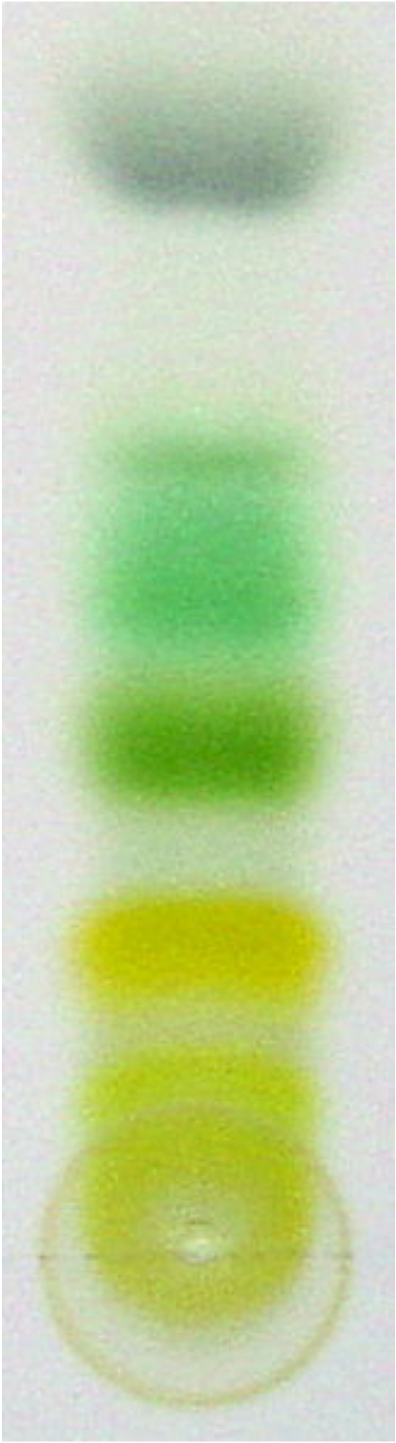
- On the other hand if the fluid molecules are repelled by the wall of the container, then the force will push the fluid surface down!

Capillary Action and Biology



- Surface tension can draw liquid up a narrow tube.
- The thinner the tube, the higher the fluid will travel
- There is a limit, and even tubes the diameter of a Xylem cell (around 500 μm) can lift water only a few cm.
- Plants and trees need to create a large negative pressure in their fluid carrying tubes (several atmospheres worth since roughly 1 ATM of pressure is needed per 10 meters of height.
- Evaporation of water molecules from pores in the leaves “drags” additional water molecules up the tube.
- Osmotic pressure from the roots can help or hinder depending on the circumstances.

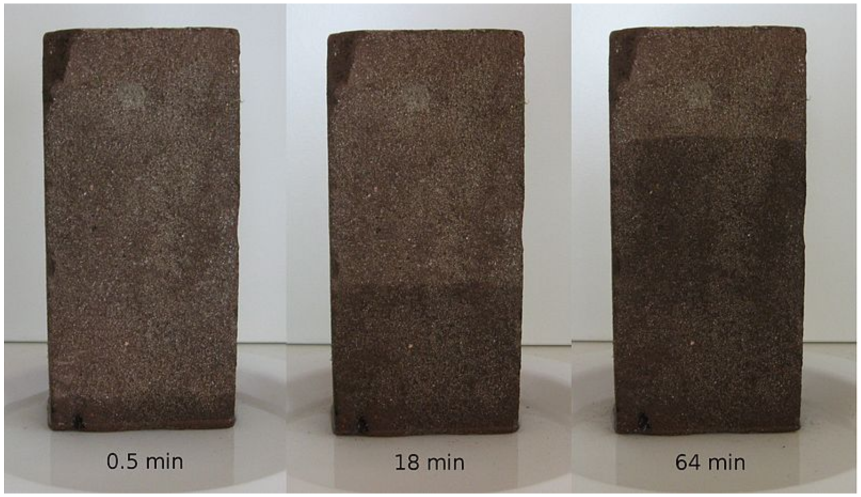
Capillary Action and Uptake of Fluids by Porous Materials



- Porous materials such as paper, cloth, brick, wood etc. tend to soak up water
- These materials are filled with microscopic tubes (such as fibers or xylem tubes), cracks, and pores.

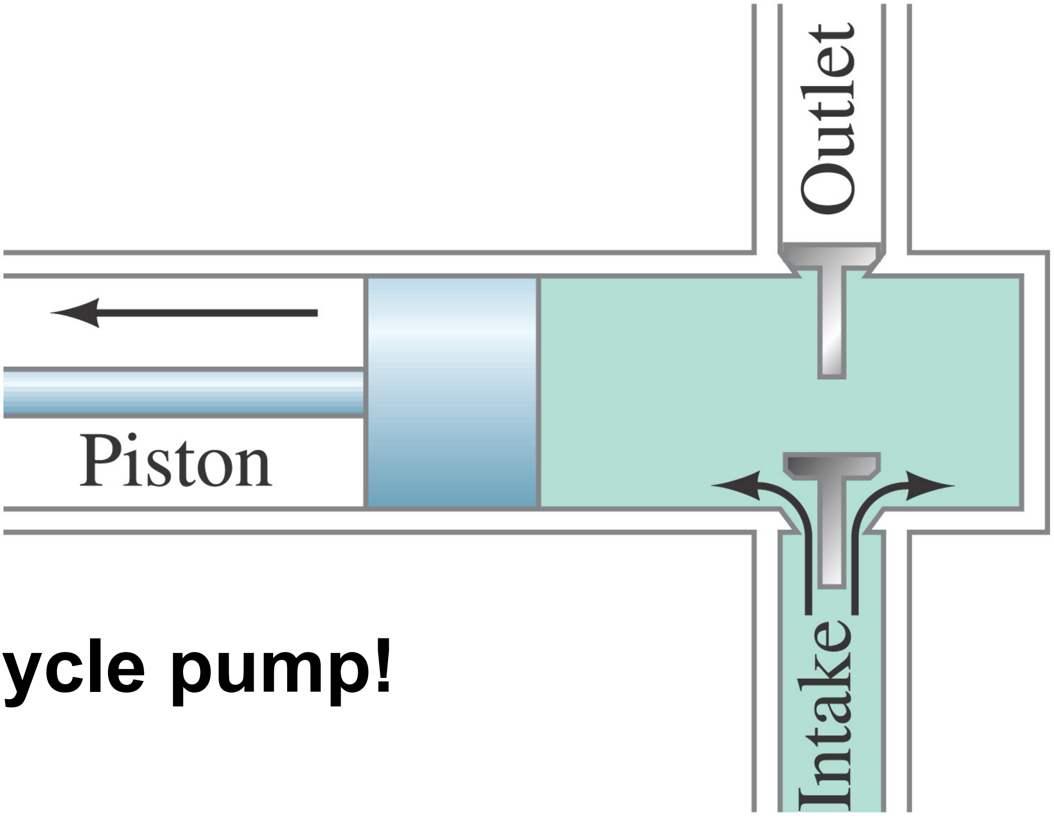
- Being so narrow these structures pull water and other fluids via capillary action.

- Capillary action can be used to sort dissolved molecules by mass or density, as in Chromatography.



10-14 Pumps, and the Heart

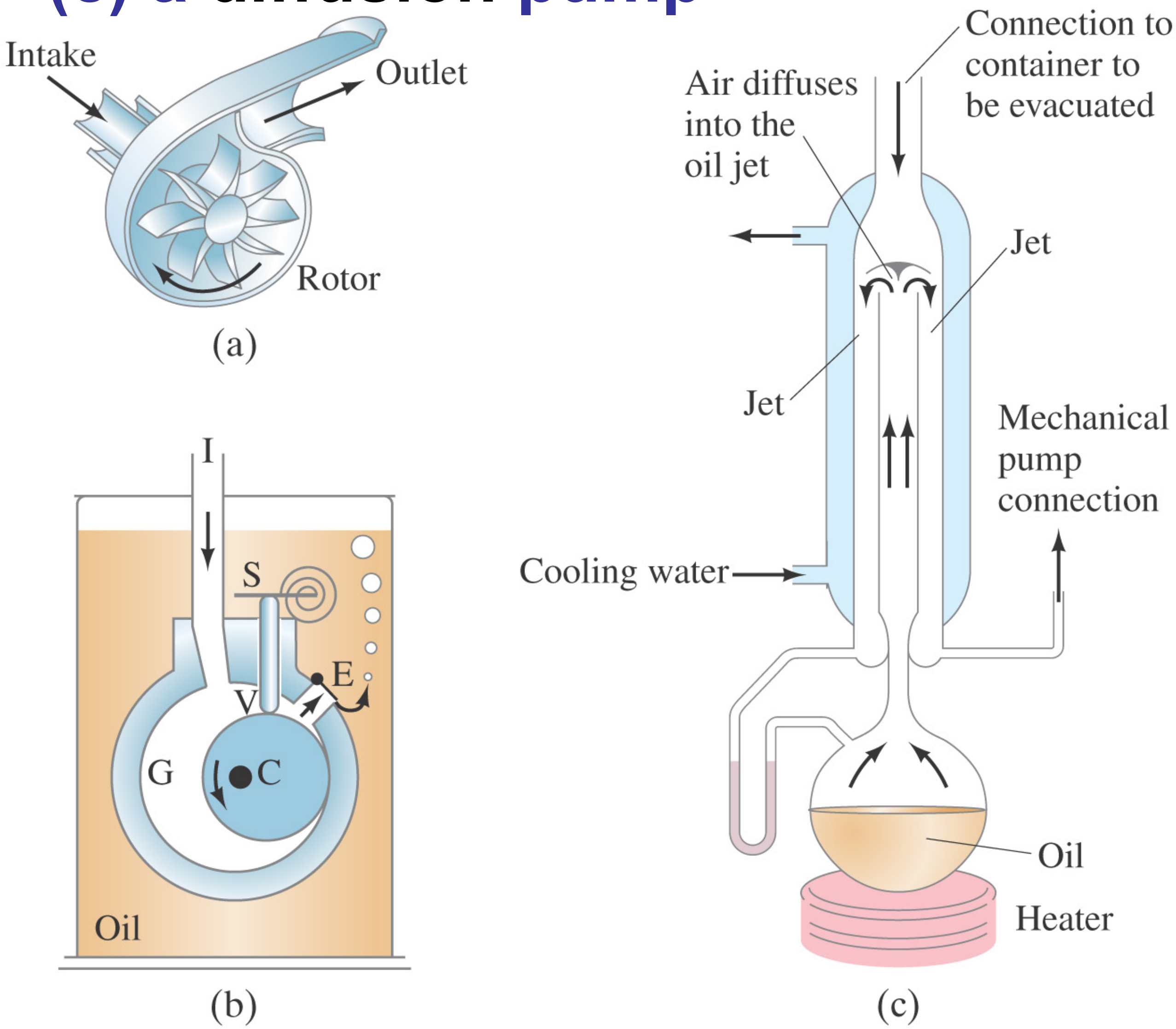
This is a simple **reciprocating** pump. If it is to be used as a **vacuum** pump, the vessel is connected to the **intake**; if it is to be used as a **pressure** pump, the vessel is connected to the **outlet**.



Think Bicycle pump!

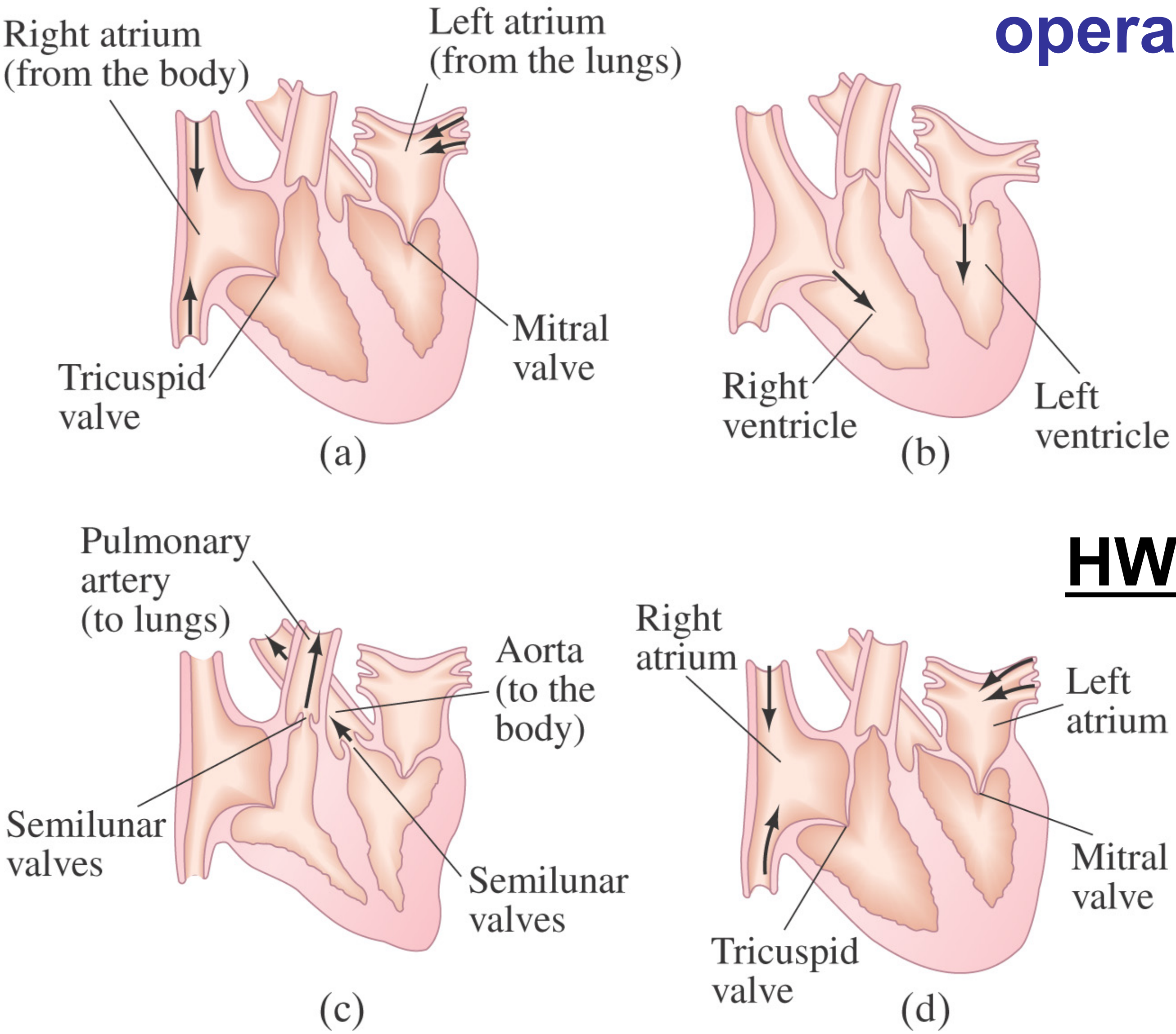
Pumps!

(a) is a centrifugal pump; (b) a rotary oil-seal pump; (c) a diffusion pump



10-14 Pumps, and the Heart

The **heart** of a human, or any other animal, also operates as a **pump**.



HW Problem 10.73

Summary

Main Concepts

- The Equation of Continuity
- Bernoulli's Principle
- Torricelli's Theorem
- Viscosity
- Pouiseuille' s Equation

Applications

Plumbing, Aircraft, Baseball, Blood flow, Weather