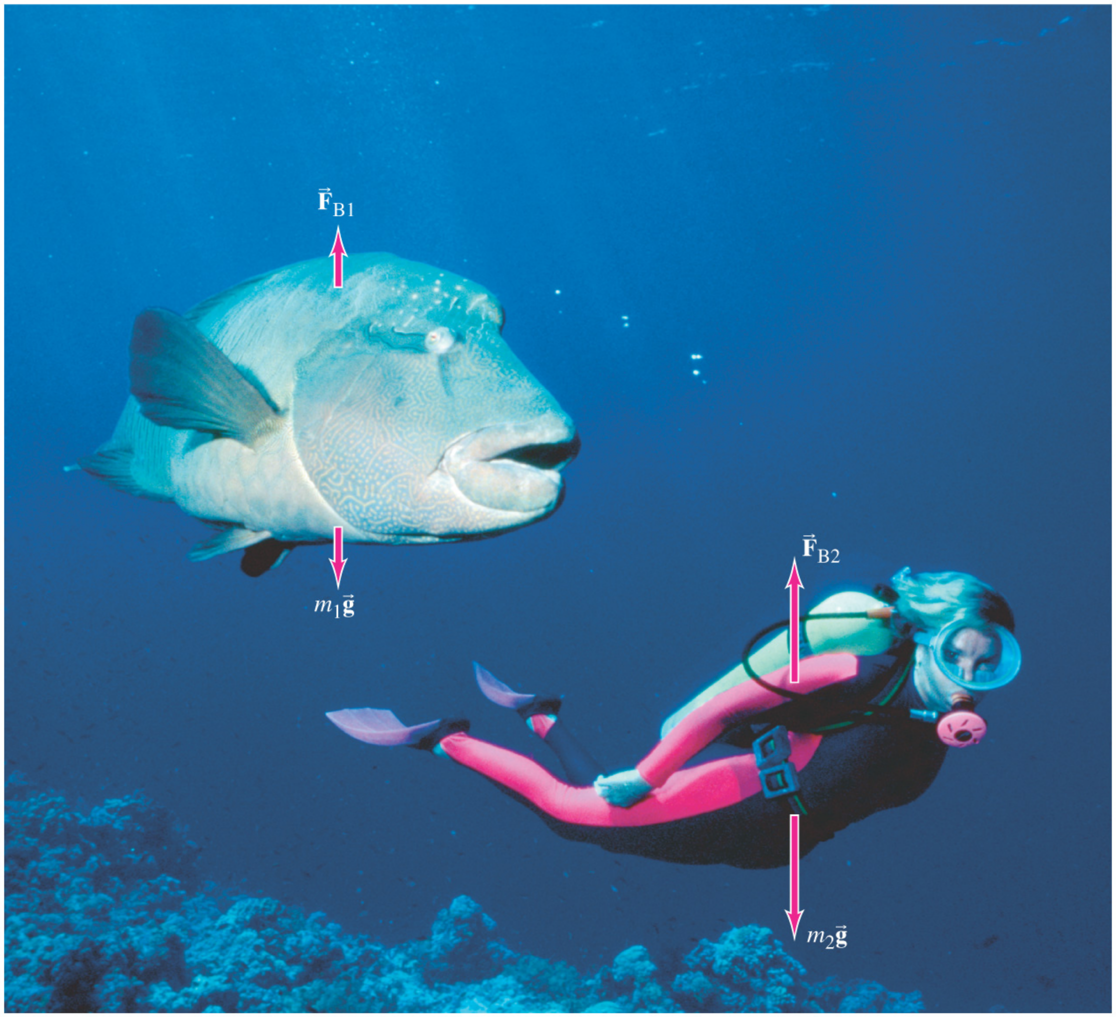
Chapter 10 part 2

Fluids in Motion



Energy Conservation for Fluids

For a volume of gas, with density ρ, we can apply the principle of Energy Conservation to discover how its Pressure, velocity, and height will change under different Circumstances.

Total Energy = Internal Energy + Kinetic Energy + Potential Energy.

$$= PV + \frac{1}{2}mv^2 + mgh$$

Since $\rho = \frac{m}{V}$ $\therefore$ $E = PV + \frac{1}{2}\rho V v^2 + \rho V g h$

$\therefore m = \rho V$

So the energy per unit volume $\frac{E}{V} = P + \frac{1}{2}\rho v^2 + \rho g h$

If our fluid flows from one place to another, its energy remains constant, it may speed up, or move downhill, so the Internal Energy, Kinetic, Potential will 'trade' as follows.

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

Which is Bernoulli's Principle.

For Horizontal Motion:

$$P_1 + \frac{1}{2}\rho v_1^2 = P_2 + \frac{1}{2}\rho v_2^2$$ → Examples: Aircraft wings, Wind

For vertical Height Difference in a Static fluid:

$$P_1 + \rho g h_1 = P_2 + \rho g h_2$$ → Blood Pressure, Plumbing

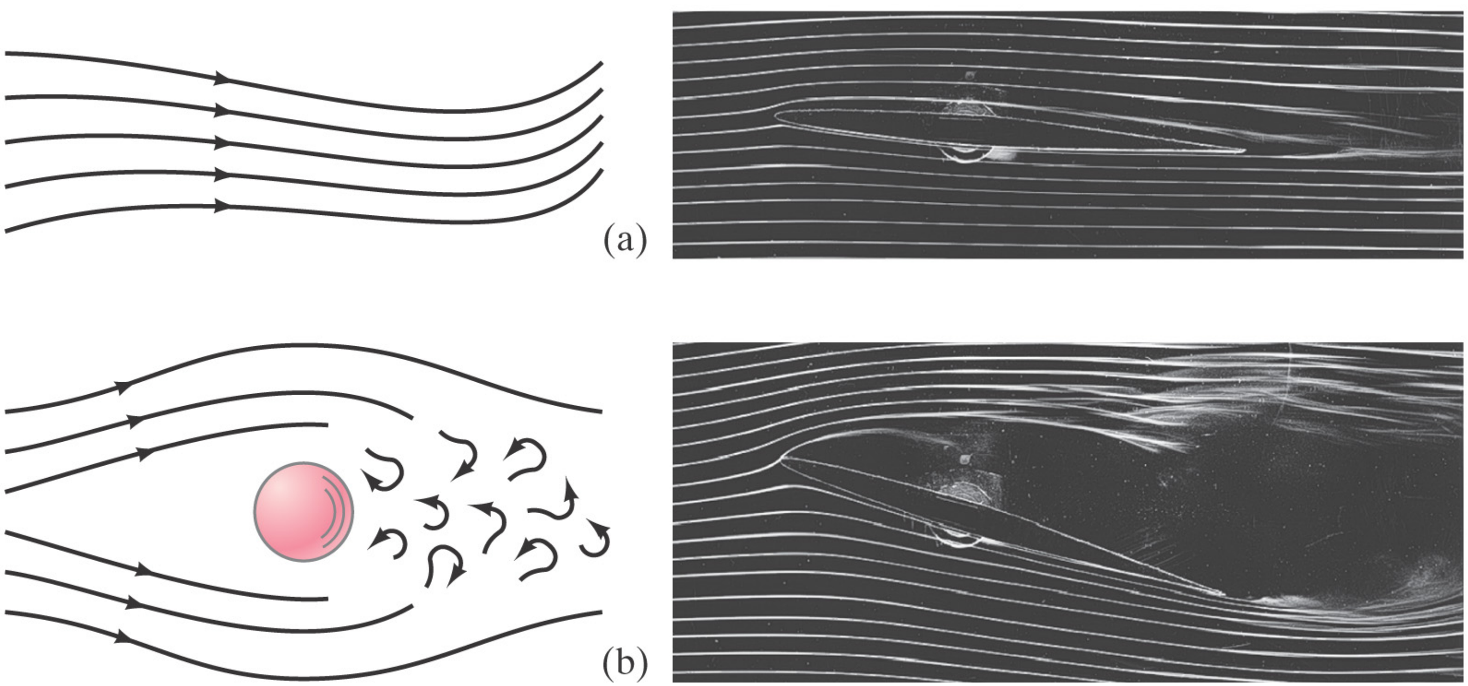
Fluids in Motion : Units of Chapter 10

- 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

10-8 Fluids in Motion; Flow Rate and the Equation of Continuity

If the flow of a fluid is smooth, it is called **streamline** or **laminar** flow (a).

Above a certain speed, the flow becomes **turbulent** (b). Turbulent flow has **eddies**; the **viscosity** of the fluid is much greater when eddies are present.



10-8 Fluids in Motion; Flow Rate and the Equation of Continuity

We will deal with laminar flow.

The mass flow rate is the mass that passes a given point per unit time.

$\Delta m / \Delta t = \rho \Delta V / \Delta t$

$= \rho A v$

The flow rates at any two points must be equal, as long as no fluid is being added or taken away.

$\rho A_1 v_1 = \rho A_2 v_2$

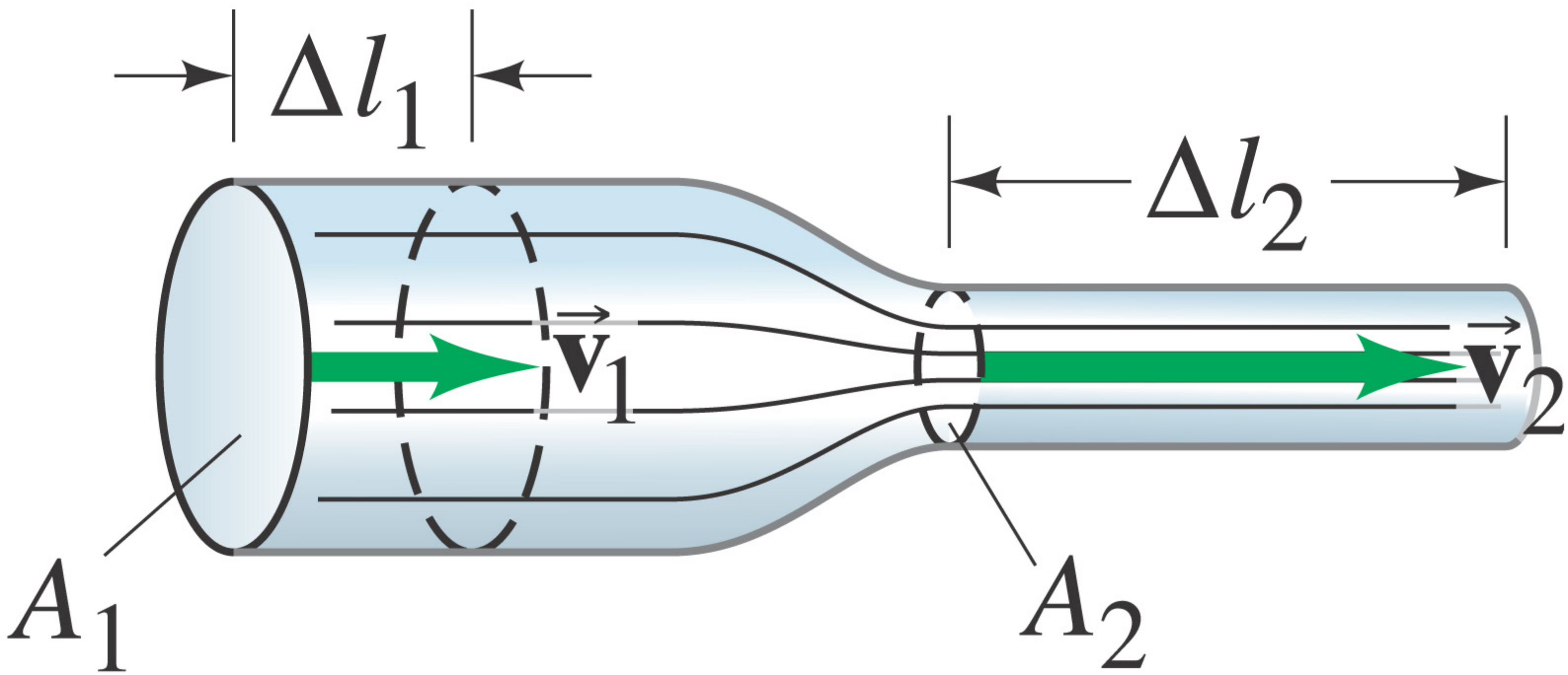
This is called the equation of continuity:

$$\rho_1 A_1 v_1 = \rho_2 A_2 v_2 \qquad \textbf{(10-4a)}$$

10-8 Fluids in Motion; Flow Rate and the Equation of Continuity

If the density doesn't change – typical for liquids – this simplifies to $A_1 v_1 = A_2 v_2$.

Where the pipe is **wider**, the flow is **slower**.



ConcepTest 10.15a Fluid Flow

Water flows through a 1-cm diameter pipe connected to a 1/2-cm diameter pipe. Compared to the speed of the water in the 1-cm pipe, the speed in the 1/2-cm pipe is:

(1) one quarter

(2) one half

(3) the same

(4) double

(5) four times

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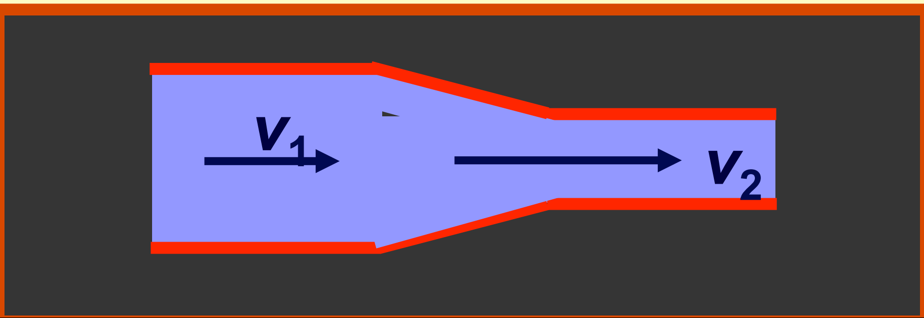
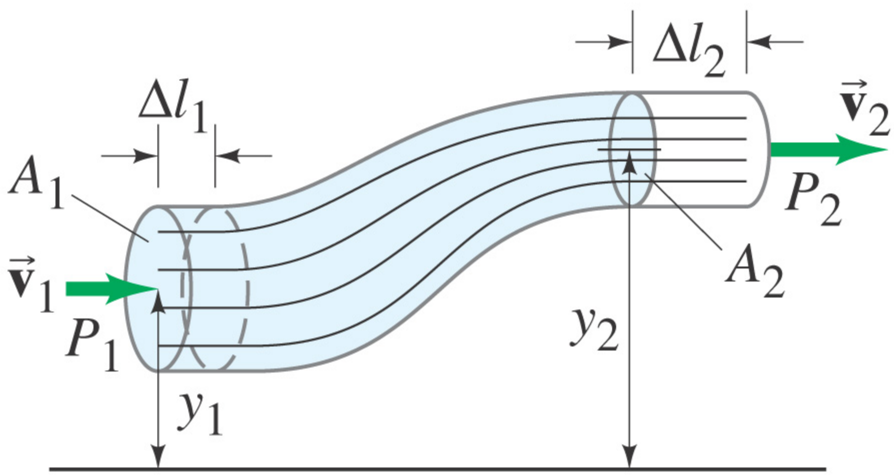


The area of the small pipe is *less*, so we know that the water will flow *faster* there. Since $A \propto r^2$, when the **radius is reduced by 1/2**, the **area is reduced by 1/4**, so the **speed must increase by 4 times** to keep the flow rate ($A \times v$) constant.

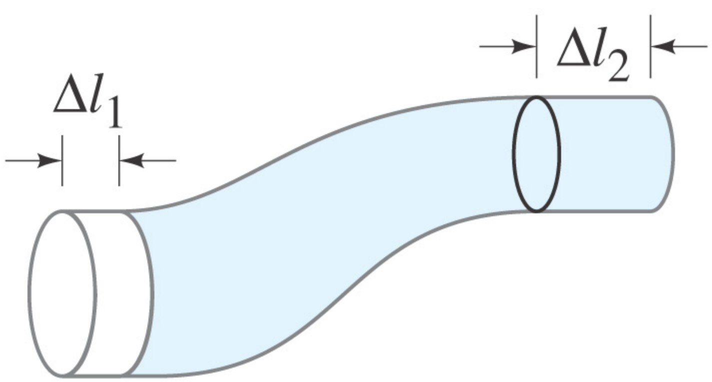
10-9 Bernoulli's Equation



(a)

A fluid can also change its **height**. By looking at the work done as it moves, we find:

$$P + \frac{1}{2}\rho v^2 + \rho g y = \text{constant}$$

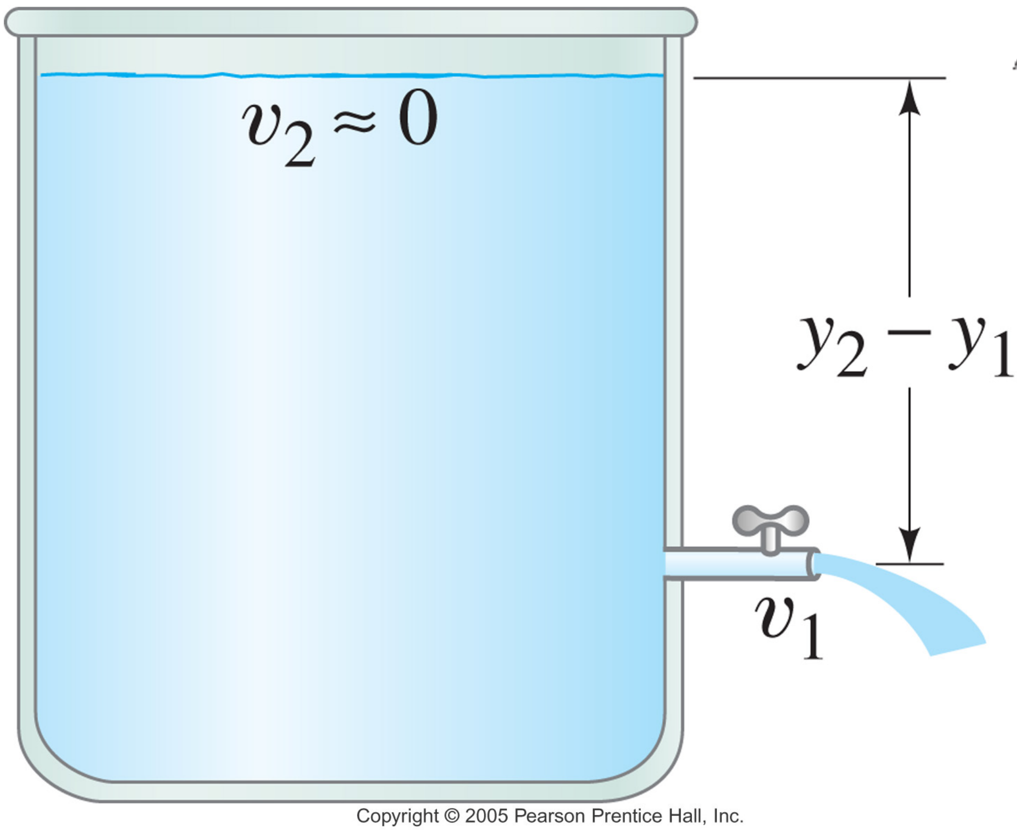


(b)

This is **Bernoulli's equation**. One thing it tells us is that as the **speed** goes up, the **pressure** goes down.

10-10 Applications of Bernoulli's Principle: Torricelli's Theorem

Using Bernoulli's principle, we find that the speed of fluid coming from a **spigot** on an **open** tank is:

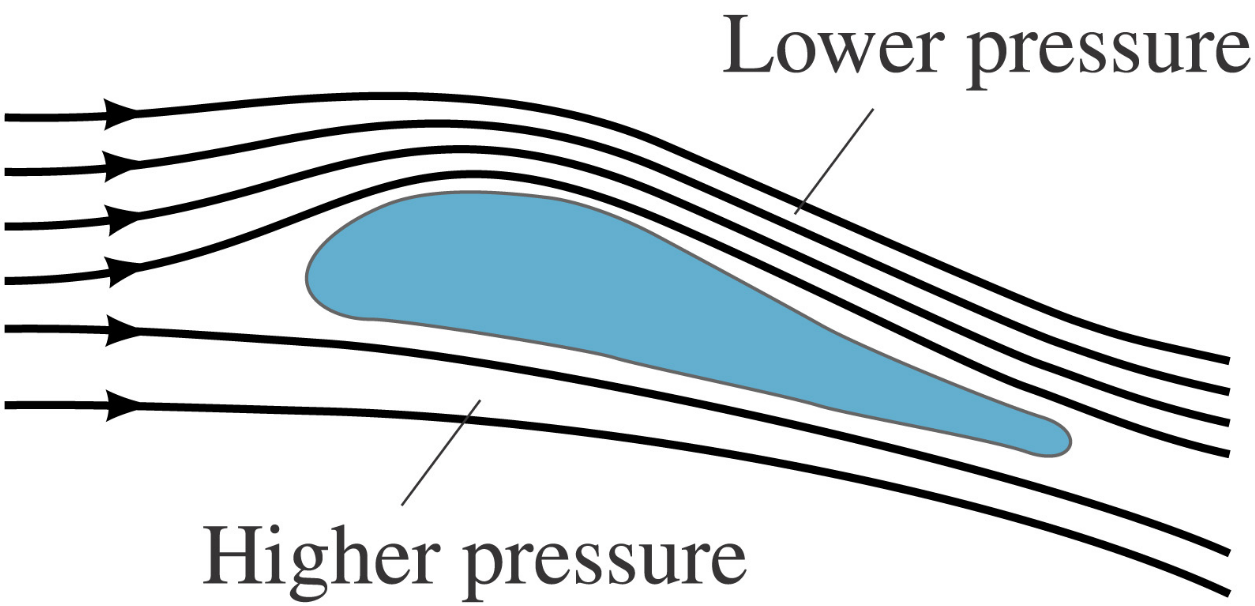


$$v_1 = \sqrt{2g(y_2 - y_1)} \qquad (10\text{-}6)$$

This is called **Torricelli's theorem.**

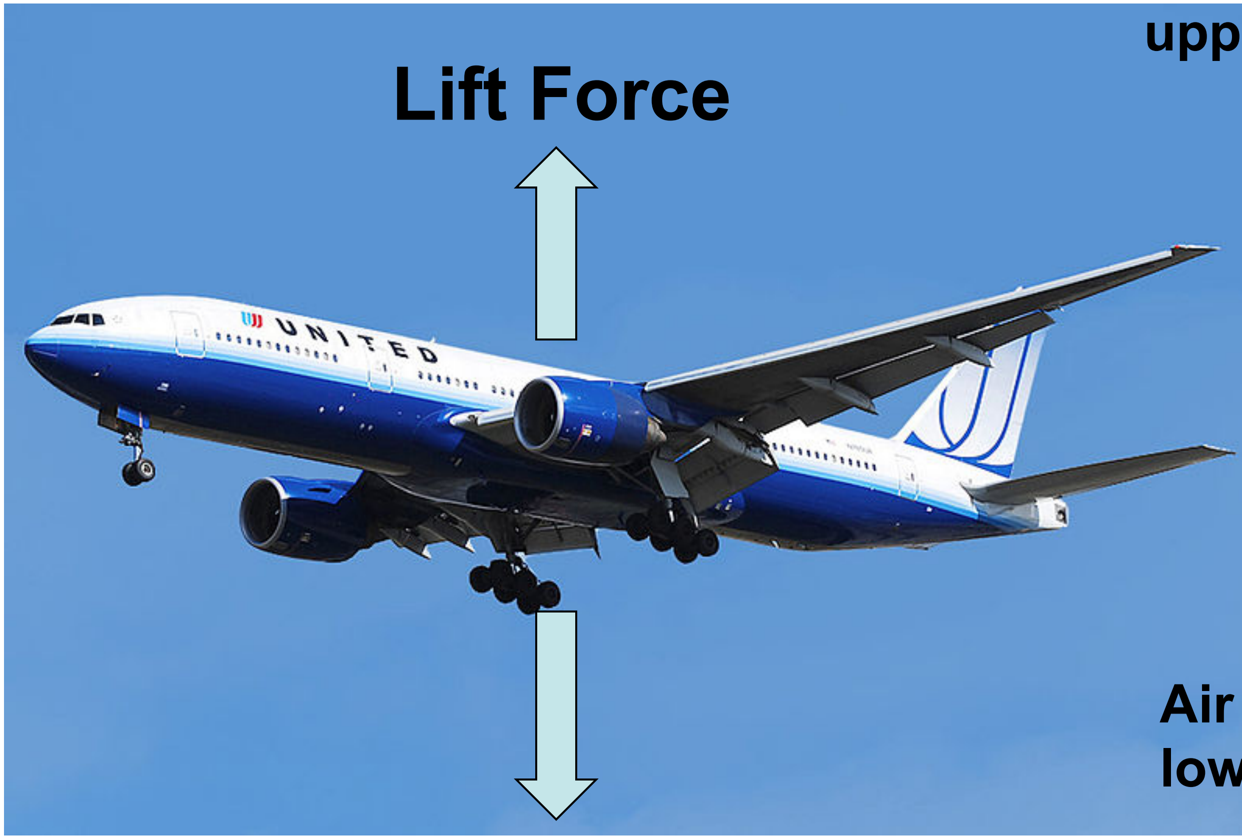
10-10 Applications of Bernoulli's Principle: from Torricelli to Airplanes, Baseballs, and TIA

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



Boeing 777

Air pressure on
upper wing surface



Weight

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.

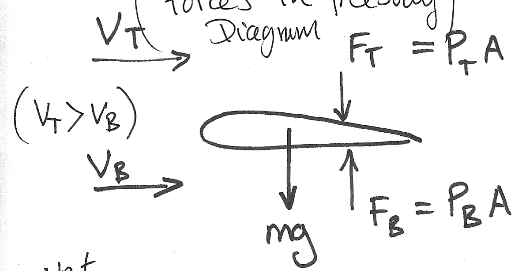
This difference in air pressure acts on the wing to create a net upward force, equal to the weight.

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

$F_B = mg + F_T$

$F_B - F_T = mg$ (weight of plane)

$P_B A - P_T A = mg$

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

$P_B - P_T = \frac{220 \times 10^3 \times 9.8}{427\ m^2}$

$= 5049$ 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.

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

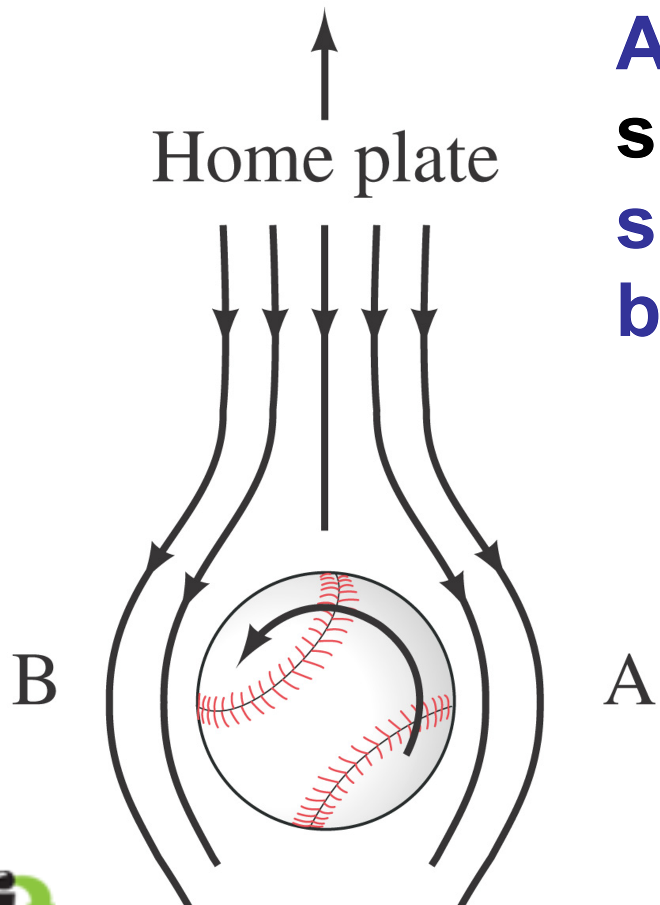
$$5049 = \frac{1}{2}\rho\left(V_T^2 - V_B^2\right)$$

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

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

$\therefore V_T = 265$ m/s (This is the speed of air passing over the top of the wing.)

Physics of Baseball



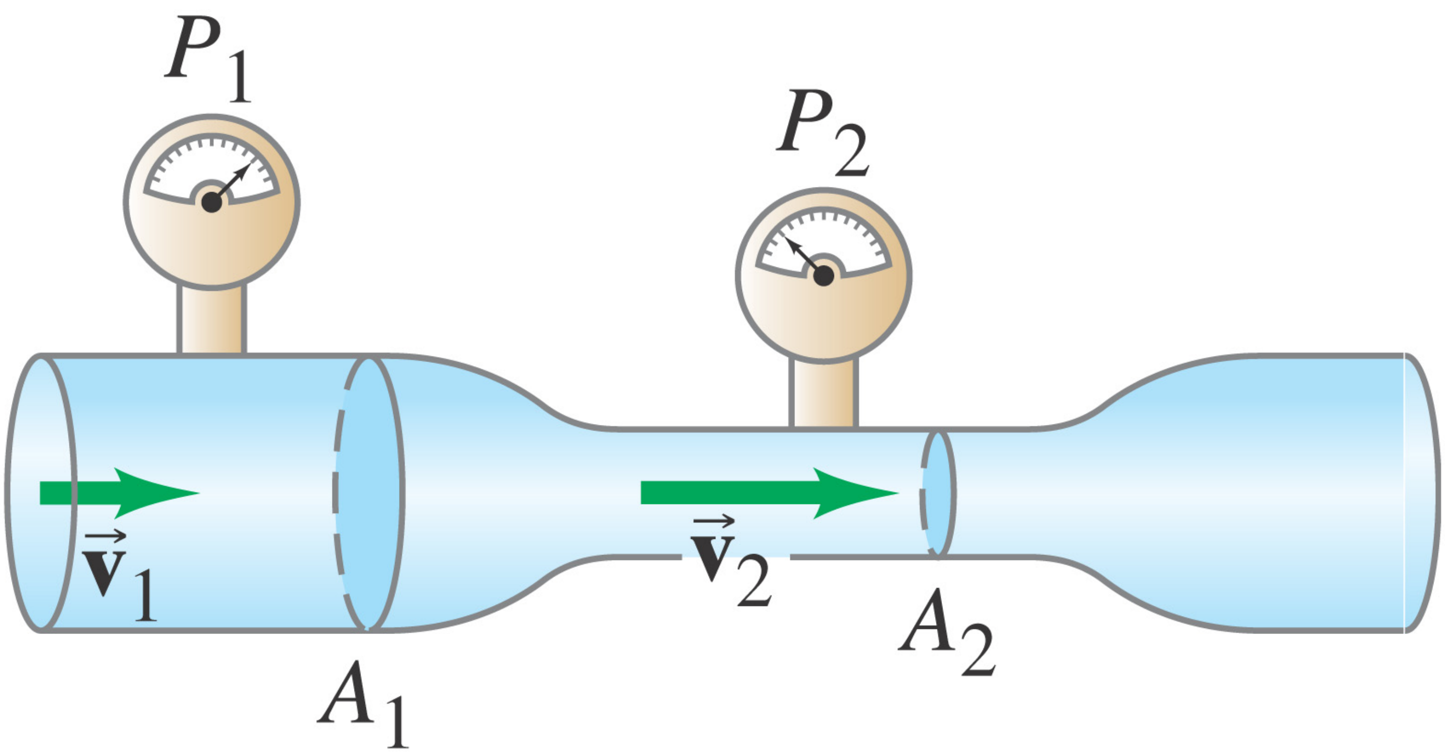
A ball's path will **curve** due to its **spin**, which results in the air speeds on the two sides of the ball not being equal.

Which way does this ball curve?

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

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

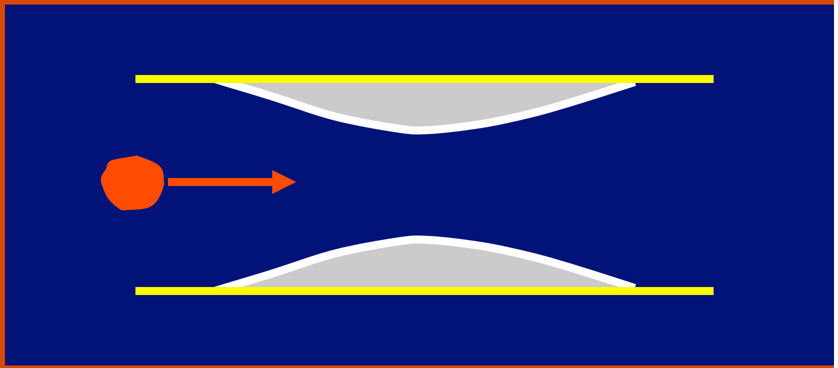
A venturi meter can be used to measure fluid flow by measuring pressure differences.



ConcepTest 10.15b Blood Pressure I

A blood platelet drifts along with the flow of blood through an artery that is partially blocked. As the platelet moves from the wide region into the narrow region, the blood pressure:

1) increases
2) decreases
3) stays the same
4) drops to zero



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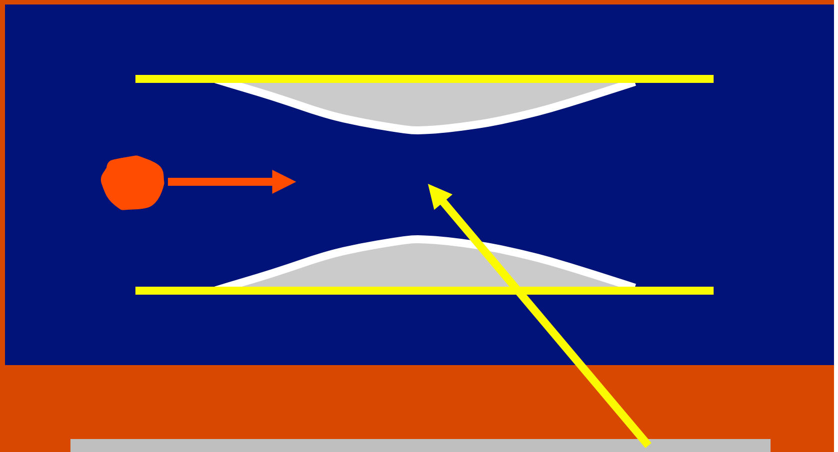
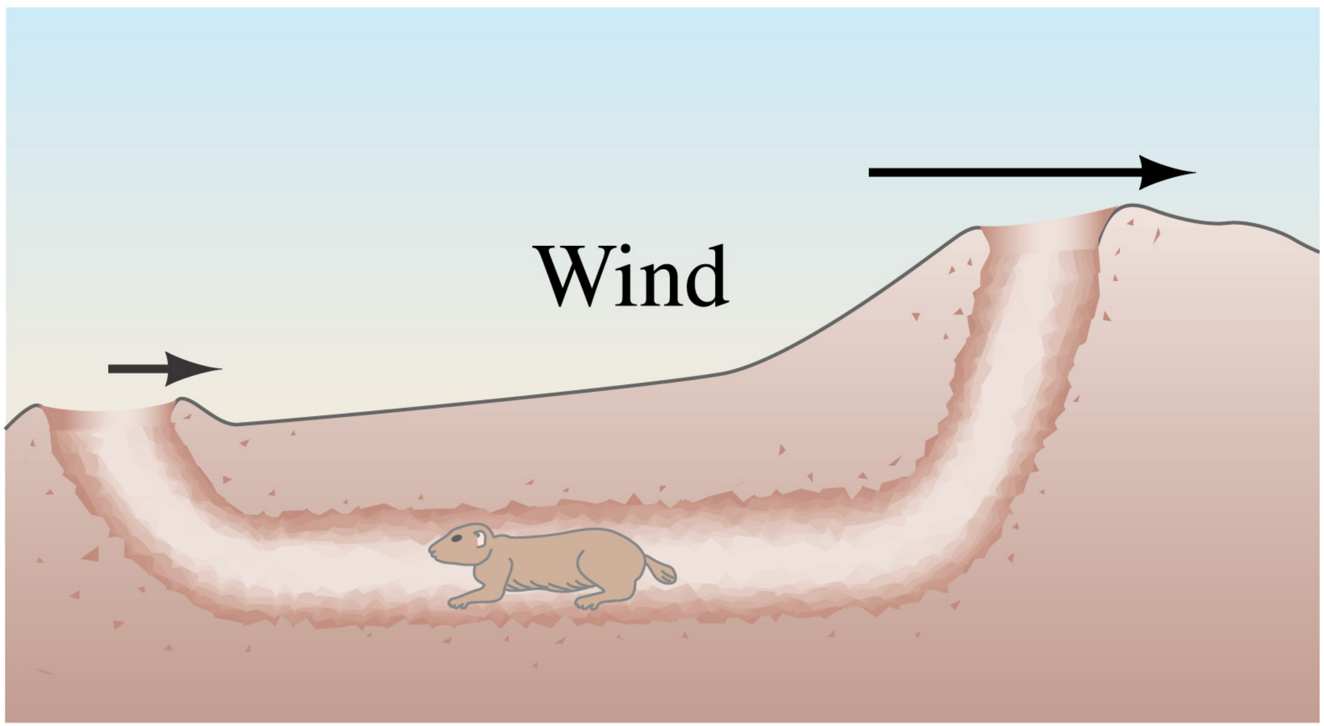
The speed increases in the narrow part, according to the continuity equation. Since the **speed is higher**, the **pressure is lower**, from Bernoulli's principle.



speed is higher here
(so pressure is lower)

Air out that Burrow!

Air flow across the top helps smoke go up a **chimney**, and air flow over multiple openings can provide the needed **circulation** in underground burrows.



Viscosity

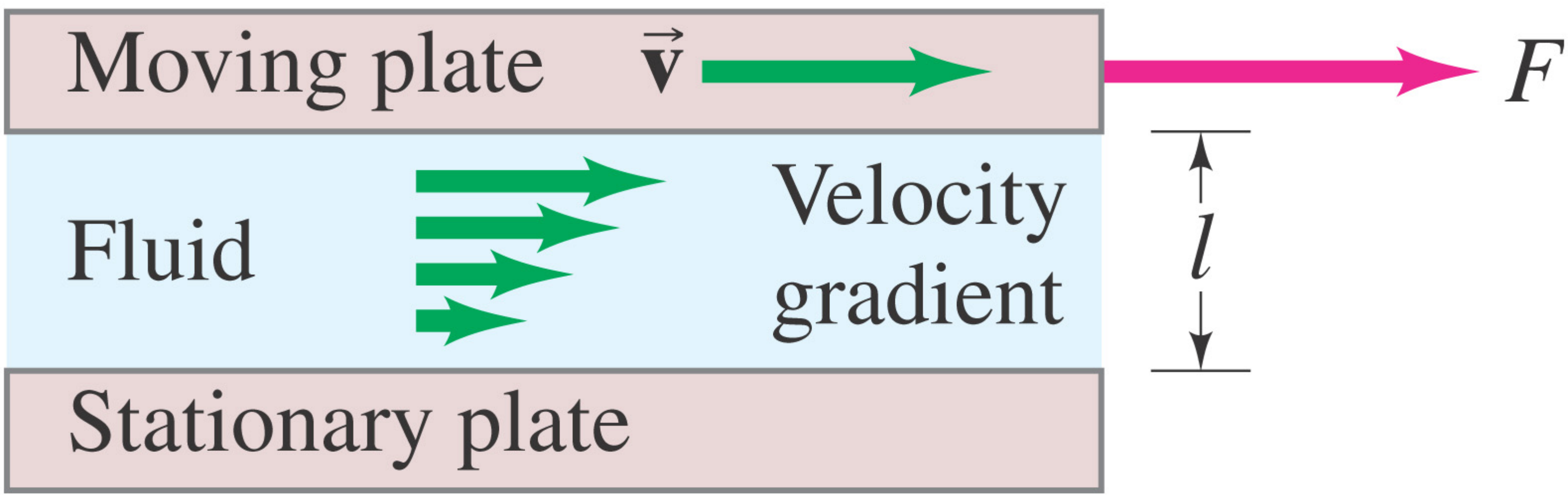
Real fluids have some **internal friction**, called **viscosity**.

Molasses is an example of a highly viscous fluid

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

$$F = \eta A \frac{v}{l} \qquad (10\text{-}8)$$

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.

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

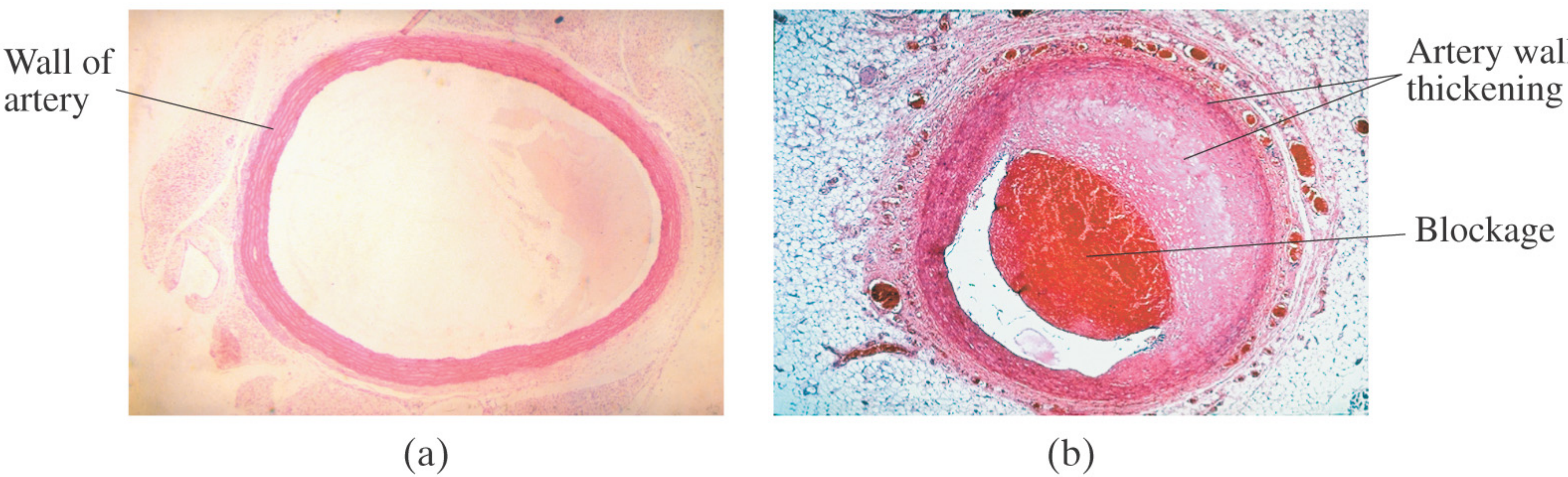
The volume flow rate is proportional to the **pressure difference**, inversely proportional to the **length** of the tube, and proportional to the **fourth** power of the radius of the tube.

See HW Problem 10.56

Flow in Tubes; Poiseuille's Equation, Blood Flow

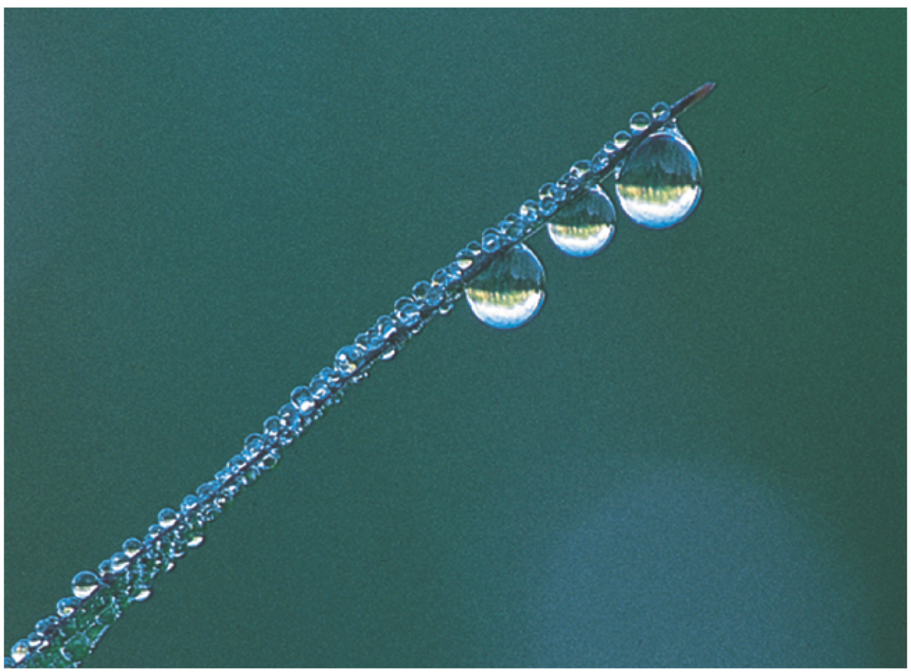
This has consequences for blood flow – if the radius of the artery is **half** what it should be, the **pressure** has to **increase by a factor of 16** to keep the **same flow rate**.

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



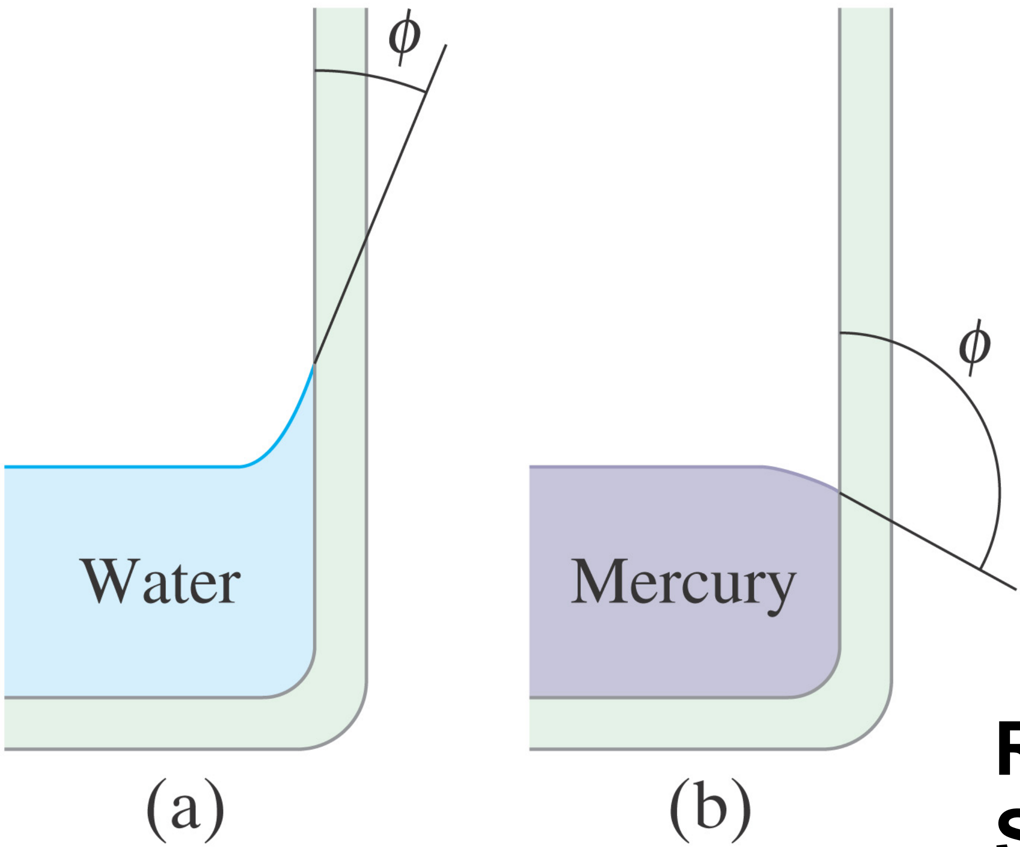
Surface Tension and Capillarity

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

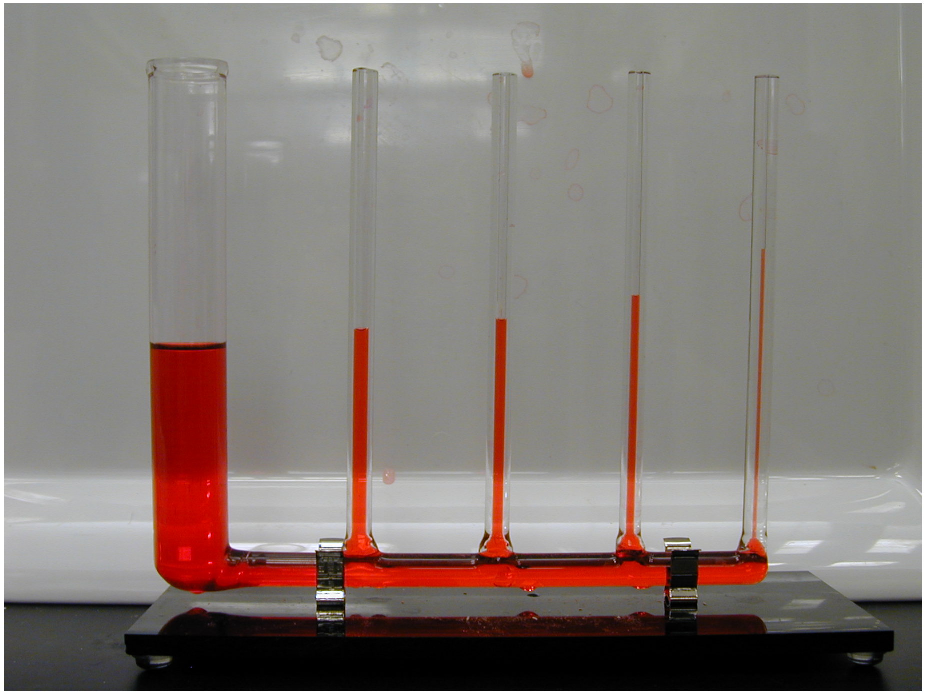
Soap and **detergents** lower the surface tension of water. This allows the water to penetrate materials more easily.



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

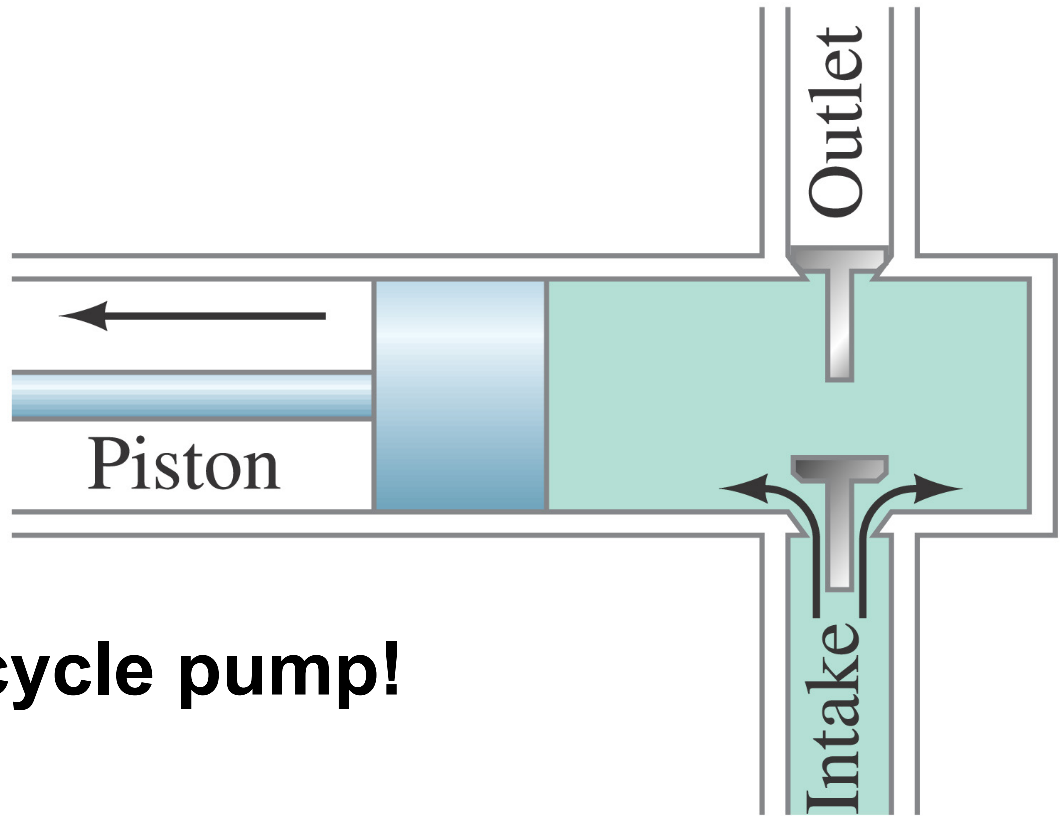
Remember the word Surfactant?

Capillary Action



10-14 Pumps, and the Heart

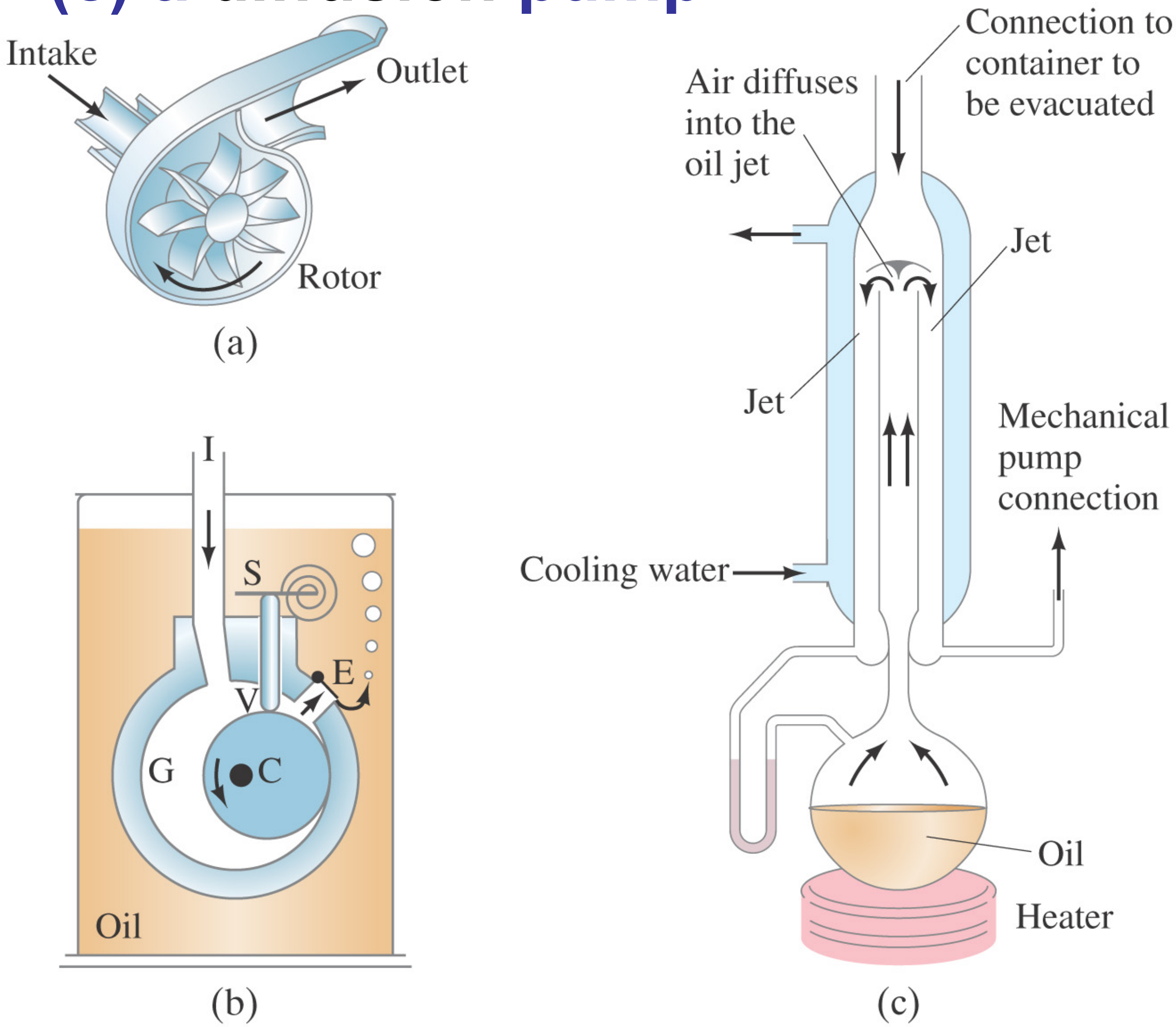
This is a simple **reciprocating** pump. If it is to be used as a **vacuum** pump, the vessel is connected to the **intake**; if it is to be used as a **pressure** pump, the vessel is connected to the **outlet**.



Think Bicycle pump!

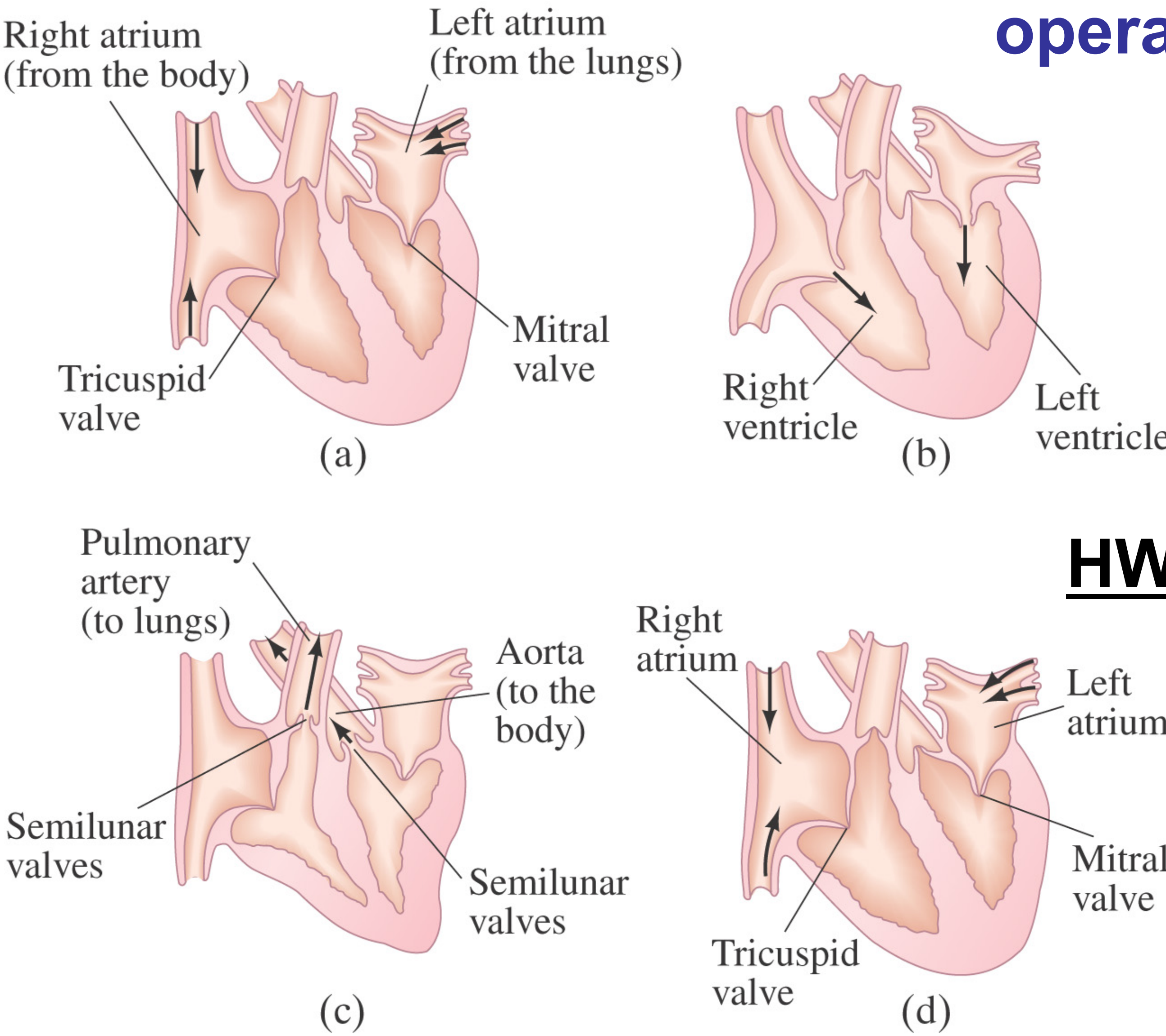
Pumps!

(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
- Poiseuille’ s Equation

Applications

Plumbing, Aircraft, Baseball, Blood flow, Weather