Physics 1021

Spring 2012– 15c

ConcepTest 9.1 Narrow straw

A water is pulled through a very narrow, straight tube by a pump. The inlet and outlet of the tube are at the same height. What do we know about the pressure of the water in the tube?

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2. It varies from being low at the inlet to high at the outlet
3. The pressure is constant throughout because the height does not change

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The water has viscosity, which causes it to stick to the walls of the tube. This leads to a loss in energy of the fluid, which causes the pressure to drop along the length of the tube

ConcepTest 9.2 Large Pipe

A water pumped down a very large pipeThe inlet and outlet of the tube are at the same height. What do we know about the pressure of the water in the tube?

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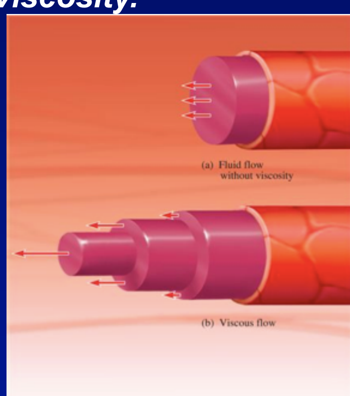
The water has viscosity, but since most of the flow is far from the walls, no much energy is lost and the pressure remains constant.

Flow and Viscosity
What is it?

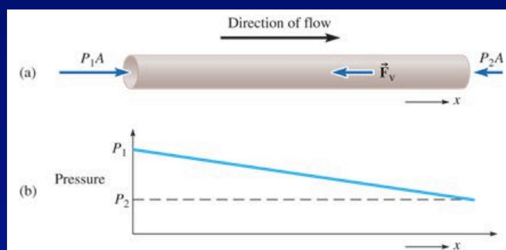
- The ***viscosity of a liquid is a liquid's resistance to flow.***
- ***Viscosity is the result of an attraction between molecules.***
- ***The stronger the intermolecular forces, the higher the viscosity.***



The because of the attraction, the fluid sticks to the walls of its container … v = at the wall, v is maximum in the center

Flow and Viscosity
What is it?

The viscosity of a fluid measures how much drag it exerts either on the tube through which it flows
OR …
On objects traveling through it (same things, really)



To maintain the flow rate, the pressure will drops across the length of the tube … energy is lost

Poiseuille's Law:

$$\frac{\Delta V}{\Delta t} = \frac{\pi}{8}\frac{\Delta P/L}{\eta} r^4$$

V is volume, P is pressure, L is length, r is radius, η = viscosity

Flow and Viscosity
Terminal velocity

We know that the viscous force can have two forms:

$$drag = \frac{1}{2}C\rho A v^2$$

High speed (low viscosity)

$$drag = 6\pi\eta r v = 3\pi\eta D v$$

Low speed (high viscosity)

Now set the applied force (in this case gravity) equal to the viscous (low speed) force:

$$mg = 3\pi\eta D v_{term}$$

or

$$drag = 6\pi\eta r v_{term} = \frac{mg}{3\pi\eta D}$$

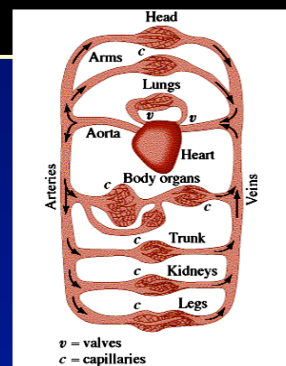
This is sometimes called the sedimentation velocity

v is velocity, ρ is masss density, r is radius, η = viscosity

ConcepTest 9.3 Cholesterol in the arteries

As cholesterol on the walls of the aorta increases, a partial blockage develops that reduces the inner diameter of the aorta by a factor of 2. We know that without viscosity, the pressure in the section will decrease. What really happens to the pressure drop across the constricted section

1. Increases by a factor of 2
2. Increases by a factor of 4
3. Increases by a factor of 8
4. Increases by a factor of 16
5. Increases by a factor of 32



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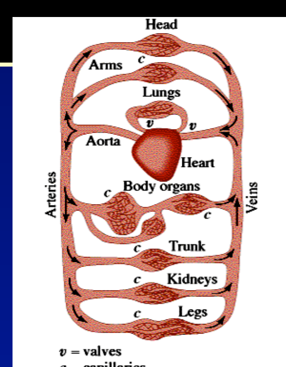

Example: Viscosity of a tube

Water flows through a horizontal 25.0-cm-long tube with an insidediameter of 1.20 mm at 0.300 mL/s. Find the pressure difference required to drive this flow if the viscosity of water is 1.00 mPa·s. Assume laminar flow.

Find the diameter of a tube that would give double the flow rate for the pressure difference in Problem 70.

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Example: Viscosity of a tube

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$$\Delta P = \frac{8\eta L}{\pi r^4} I_V$$

$$\Delta P = \frac{8(1.00\,\mathrm{mPa\cdot s})(0.250\,\mathrm{m})}{\pi\left(\frac{1.20\times10^{-3}\,\mathrm{m}}{2}\right)^4}(0.300\,\mathrm{mL/s}) = \boxed{1.47\,\mathrm{kPa}}$$

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Ponderable: Viscosity of a tube

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$$d' = \sqrt[4]{2}(1.20\,\text{mm}) = \boxed{1.43\,\text{mm}}$$

Ponderable: Viscosity of blood

Blood takes about 1.00 s to pass through a 1.00-mm-long capillary in the human circulatory system. If the diameter of the capillary is 7.00 μm and the pressure drop is 2.60 kPa, find the viscosity of blood. Assume laminar flow.

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$$\eta = \frac{r^2 \Delta P}{8Lv}$$

$$\eta = \frac{\left(3.50\times10^{-6}\,\mathrm{m}\right)^2 \left(2.60\,\mathrm{kPa}\right)}{8\left(1.00\times10^{-3}\,\mathrm{m}\right)\left(\frac{1.00\times10^{-3}\,\mathrm{m}}{1.00\,\mathrm{s}}\right)}$$

$$= \boxed{3.98\,\mathrm{mPa\cdot s}}$$

About 4 time larger than water

Reynold's number
Is your life dominated by inertia or by viscosity

Let's take the ratio of the inertial force to the viscous force:

First consider the inertia of the object: what size force does it take to stop it?

$$Ma = (\rho L^3)a \approx (\rho L^3)(v/\Delta t) \approx (\rho L^3)v/(L/v) = \rho L^2 v^2$$

Viscous forces: what size force is available to stop it?

$$F/A = \eta(v/L) \quad \text{implies} \quad F = \eta(v/L)L^2 = \eta v L$$

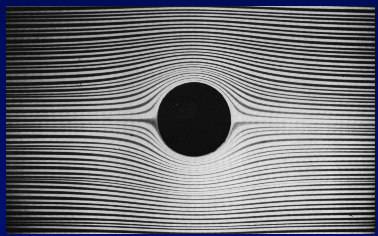
$$R = (\text{inertial properties})/(\text{viscous forces}) = (\rho L^2 v^2)/(\eta v L) = \rho L v/\eta$$

L is a critical length, e.g. the diameter of an object undergoing drag, the inner diameter of a pipe, v is the velocity

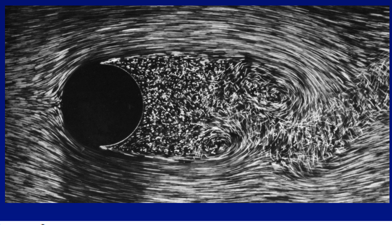
Fluids in motion

Two main types of fluid flow:

1) streamline (laminar)
………Low R
Drag is due to fluid interactions



2) Turbulent
……….High R
Drag is due to collisions with molecules in the fluid (air)



R < 1/1000	Viscous forces completely dominate
1/10 < R < 10	Mixed behavior
1000 < R < 3000	Drag negligible, but still influences large scale flow patterns
3000 < R	Flow is "fully" turbulent

ConcepTest 9.4 Laminar flow

As the water stream increases in length, what happens?

(1) It narrows more and remains smooth

(2) It thickens and remains smooth

(3) It narrows and breaks up

(4) It thickens and breaks up

(5) None of the above

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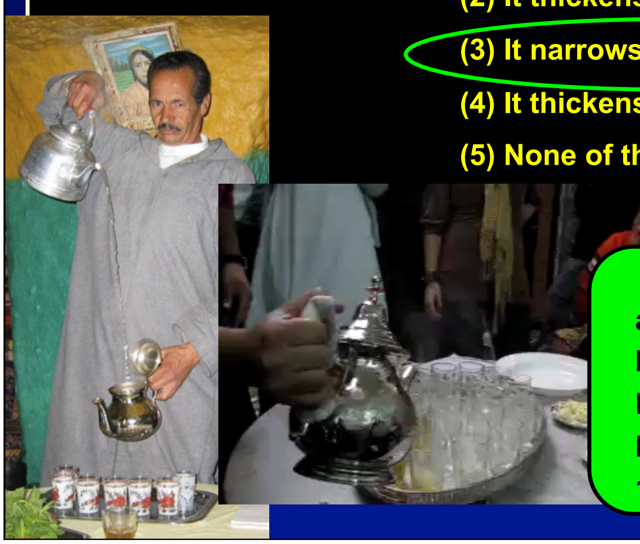

Inertia takes over and the water stream breaks up. The Reynolds number is high, approaching 1000

ConcepTest 9.5 Laminar flow

What happens when if the viscosity of the fluid increases?

(1) The flow becomes smooth again

(2) The flow remains as turbulent

(3) The flow becomes more turbulent

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ConcepTest 9.5 Laminar flow

What happens when if the water is replaced by glycerol?

(1) The flow becomes smooth again

(2) The flow remains as turbulent

(3) The flow becomes more turbulent

The viscosity is 1000 times higher, viscous (sticky) forces take over and the fluid stream is very regular. The Reynolds number is high, goes back to 1

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