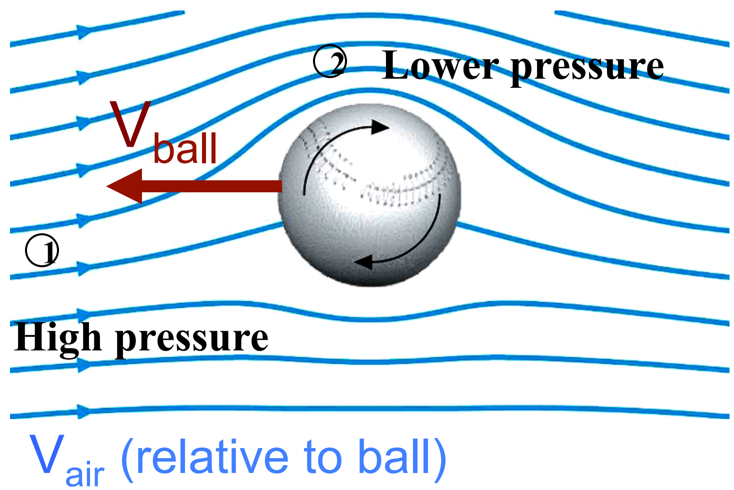
Physics 115
General Physics II

Session 5

Venturi effect
Surface tension
Viscosity



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Lecture Schedule (up to exam 1)

Date	Day	Lect.	Topic	readings in Walker
31-Mar	Mon	1	Introduction, Preview	
1-Apr	Tues	2	Density & Pressure	15.1-15.3
3-Apr	Thurs	3	Static Fluids, Buoyancy	15.4-15.5
4-Apr	Fri	4	Fluid Flow, Bernoulli	15.6-15.8
7-Apr	Mon	5	Viscosity, Flow, Capillaries	15.9
8-Apr	Tues	6	Temperature, expansion	16.1-16.3
10-Apr	Thurs	7	Heat, Conduction	16.4-16.6
11-Apr	Fri	8	Ideal gas	17.1-17.2
14-Apr	Mon	9	Heat, Evaporation	17.4-17.5
15-Apr	Tues	10	Phase change	17.6
17-Apr	Thurs	11	First Law Thermodynamics	18.1-18.3
18-Apr	**Fri**		**EXAM 1 Ch 15,16,17**	

Today

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courses.washington.edu/phy115a/
for course info, and slides from previous sessions

Last time:

Doing The Full Bernoulli

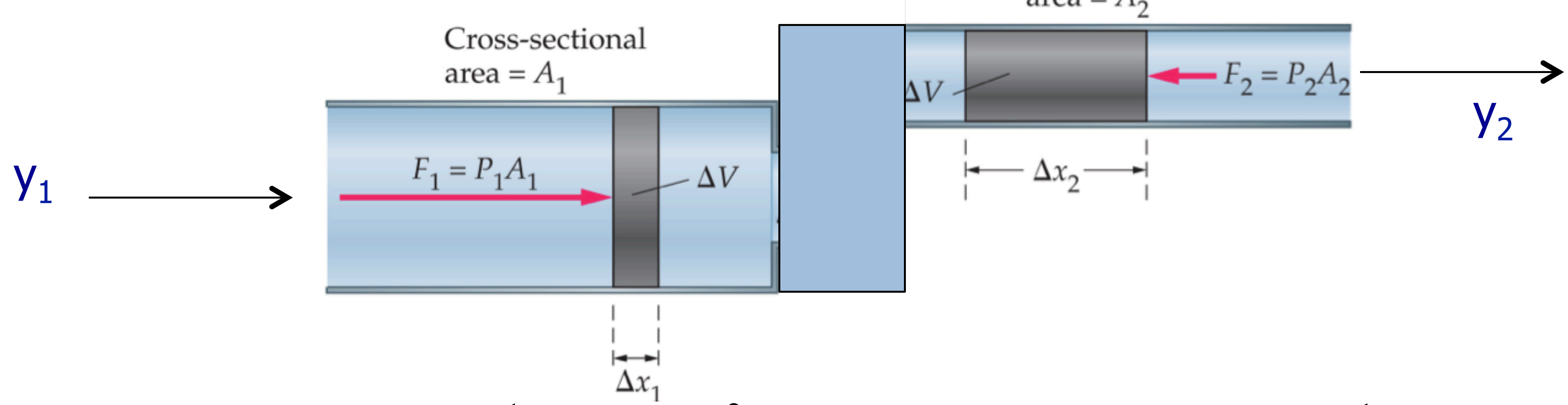
- We can combine both pieces: The Bernoulli Equation
  - Pressure vs speed
  - Pressure vs height

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

or

$$P + \rho g h + \tfrac{1}{2}\rho v^2 = \text{constant}$$

- This turns out to be conservation of total energy
  - Multiply both sides by $\Delta V = A\,\Delta x$



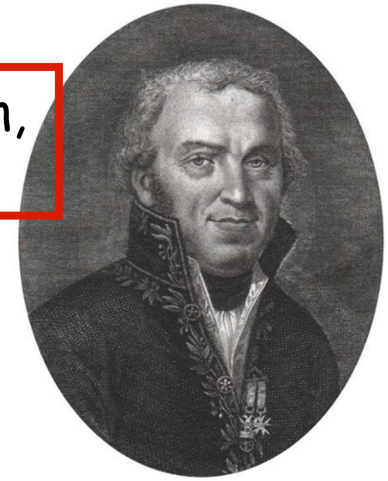
$$P_1 A_1 \Delta x_1 + \rho A_1 \Delta x_1 g h_1 + \tfrac{1}{2}\rho A_1 \Delta x_1 v_1^2 = P_2 A_2 \Delta x_2 + \rho A_2 \Delta x_2 g h_2 + \tfrac{1}{2}\rho A_2 \Delta x_2 v_2^2$$

$$F_1 \Delta x_1 + m g h_1 + \tfrac{1}{2} m v_1^2 = F_2 \Delta x_2 + m g h_2 + \tfrac{1}{2} m v_2^2$$

Work on m by upstream mass | PE | KE = Work by m on downstream mass | PE | KE

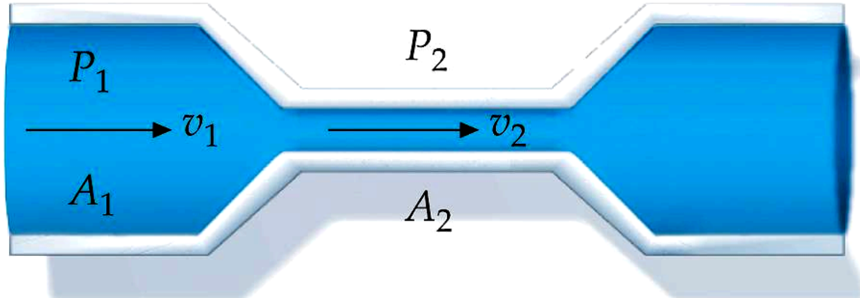
Bernoulli eq'n again: the Venturi effect

Venturi Effect: As fluid passes through a constriction, its speed increases and its pressure drops.



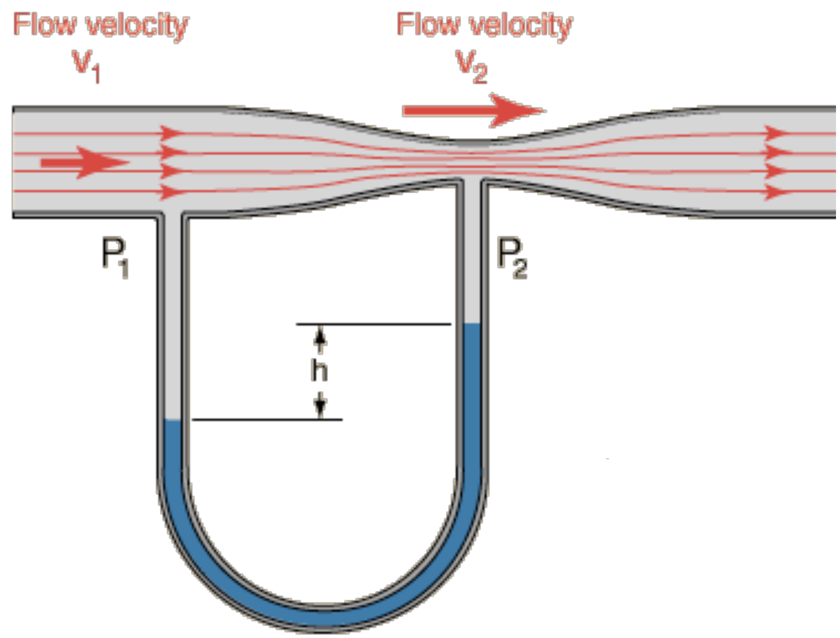
Giovanni Battista Venturi
(1746 - 1822)

For horizontal flow, $h_1 = h_2$



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

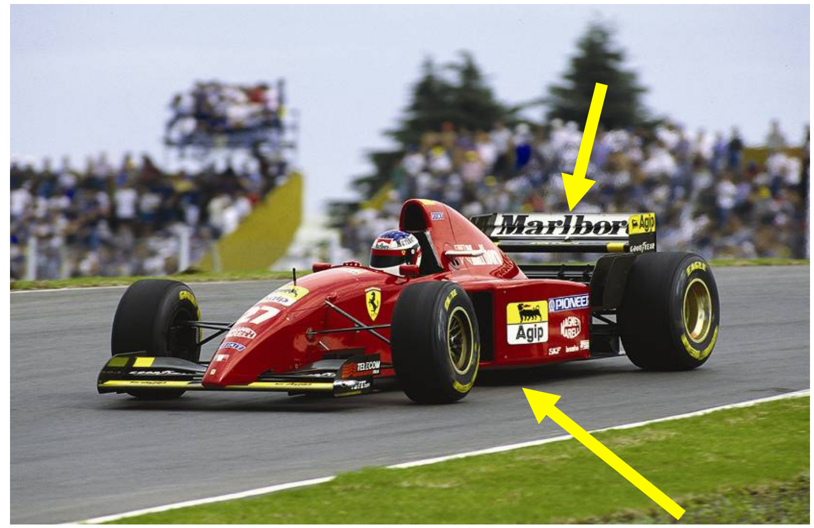
- Application: it is easier to accurately measure pressures than flow speed
  - SO: Use pressure drop in a Venturi tube to measure flow rates



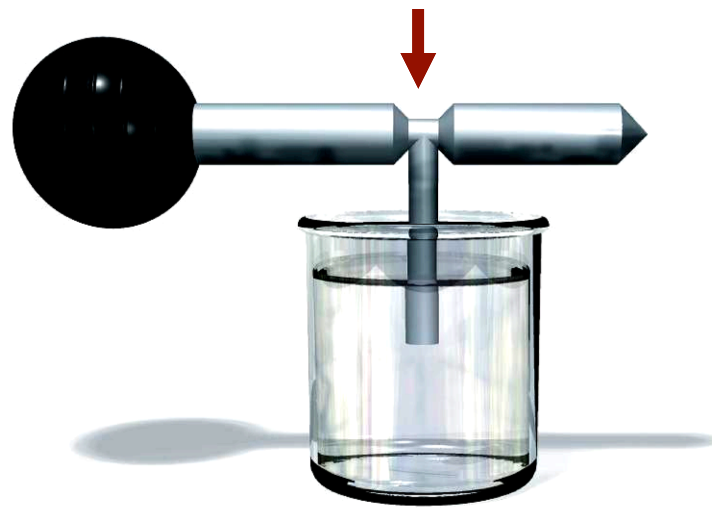
Venturi Effect examples

- The wing on a race car deflects air upward, increasing downward force on wheels for better control.

  Venturi effect also lowers the pressure under the car, pulling it toward the ground.

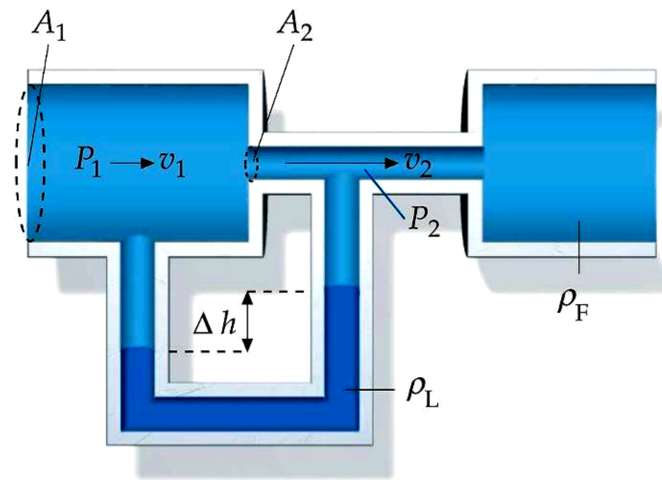


- When atomizer bulb is squeezed, airflow through the constriction drops pressure, pulling liquid from the jar into the airstream, to emerge as a spray from nozzle.



Application: Venturi Flow Rate Meter

- A "venturi meter" measures the flow rate of an incompressible non-viscous fluid.
- Fluid (density ρ_F) passes through a pipe of cross sectional area $\mathbf{A_1}$ that has a constriction of area $\mathbf{A_2}$, creating a pressure drop between the two regions.
- A U-tube manometer filled with liquid of density ρ_L develops a height difference $\Delta\mathbf{h}$, providing a measure of the flow rate $\boldsymbol{v_1}$.



$$P_1 + \tfrac{1}{2}\rho v_1^2 = P_2 + \tfrac{1}{2}\rho v_2^2 \qquad v_1 A_1 = v_2 A_2 \qquad v_2 = \frac{A_1}{A_2} v_1 = r v_1 \quad \text{where } r = \frac{A_1}{A_2}$$

$$\Delta P = P_1 - P_2 = \tfrac{1}{2}\rho_F (v_2^2 - v_1^2) = \tfrac{1}{2}\rho_F (r^2 - 1) v_1^2$$

$$\Delta P = \rho_L g \Delta h - \rho_F g \Delta h = (\rho_L - \rho_F) g \Delta h$$

$$\tfrac{1}{2}\rho_F (r^2 - 1) v_1^2 = (\rho_L - \rho_F) g \Delta h$$

$$v_1 = \sqrt{\frac{2(\rho_L - \rho_F) g \Delta h}{\rho_F (r^2 - 1)}}$$

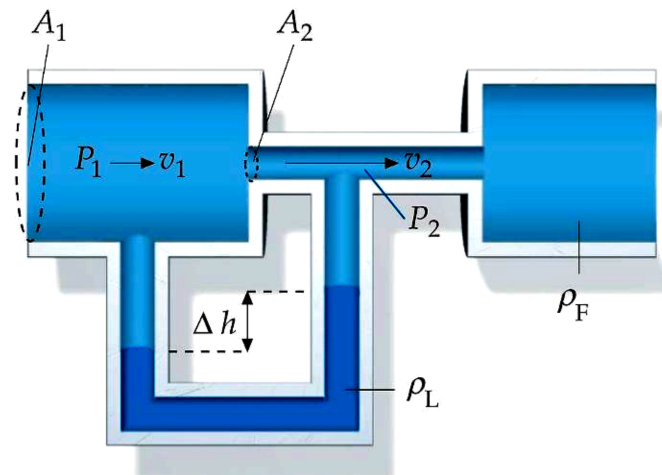
ρ_L =Density of liquid in manometer U-tube

ρ_F =Density of fluid in Venturi tube

$$r = \frac{A_1}{A_2}$$

Example: Venturi Flow Rate Meter

- A Venturi flowmeter is applied to a pipe of cross sectional area $\mathbf{A_1}$ = 0.01m^2 , carrying water (density ρ_F =1x10^3 kg/m^3).
- Venturi tube has area $\mathbf{A_2}$ = 0.001m^2
- A U-tube manometer is attached, filled with mercury, density ρ_L = 19.3 x10^3 ,
- The U-tube shows a mercury height difference Δh = 0.01m
- What is the water flow rate v_1?



ρ_L =Density of liquid in manometer U-tube

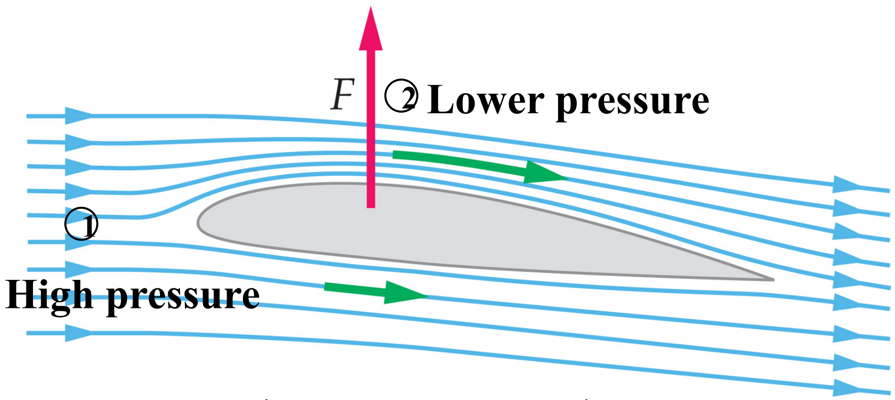
ρ_F =Density of fluid in Venturi tube

$$r = \frac{A_1}{A_2}$$

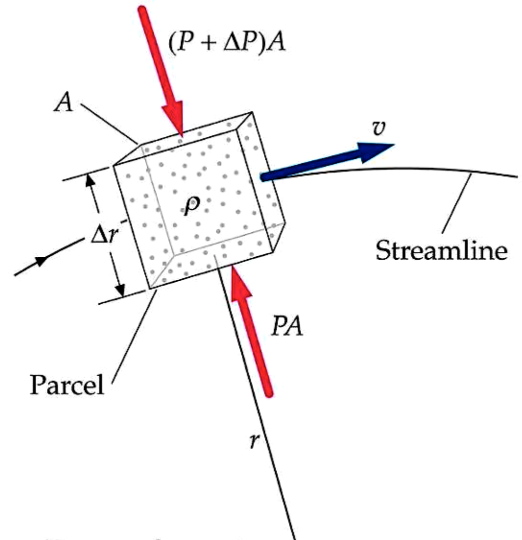
$$v_1 = \sqrt{\frac{2(\rho_L - \rho_F)g\Delta h}{\rho_F(r^2 - 1)}} = \sqrt{\frac{2(19.3 - 1.0)\times 10^3 kg/m^3\left(9.8m/s^2\right)\left(0.01m\right)}{1.0\times 10^3 kg/m^3(10^2 - 1)}}$$

$$= \sqrt{\frac{3.587\times 10^3 kg/m - s^2}{99\times 10^3 kg/m^3}} = \sqrt{0.0362m^2/s^2} = 0.19m/s$$

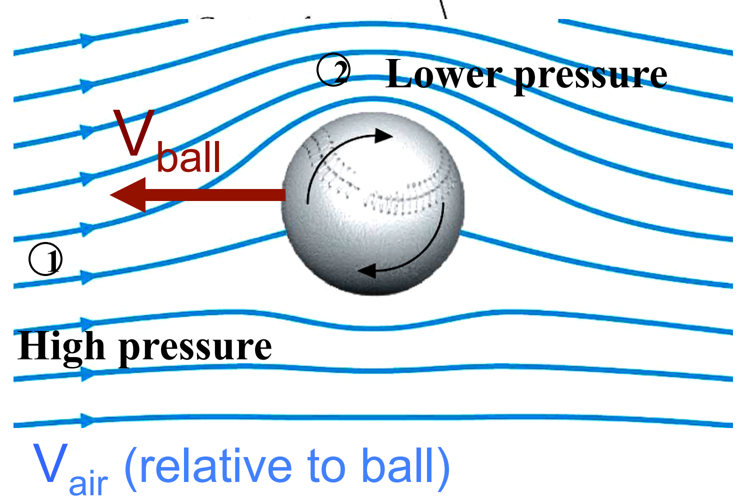
Curved Streamlines and Lift



$$P_1 + \tfrac{1}{2}\rho v_1^2 = P_2 + \tfrac{1}{2}\rho v_2^2$$



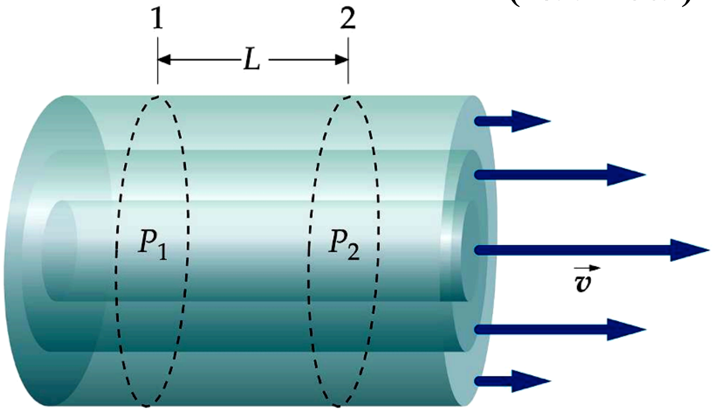
- Asymmetry of wing shape makes air travel faster over top than bottom: lower P → "lift"
- For the same reason: Backspin makes a baseball lift, resisting the pull of gravity.
  - Forward spin has the opposite effect, making the ball drop unexpectedly.
  - Sideways spin deflects the baseball's path to the side, producing curveballs.



Beyond simplest cases I: Viscosity

J. Poiseuille
(1799-1869)

- Ideal fluid: no viscosity (resistance to flow)
- Real fluid flow has friction with surfaces of container
  - Parcels of fluid at pipe surfaces slow down
    - v~0 right on surface
  - Parcels farther away slow down less
  - Pressure difference needed for flow
  - Experimental result: ΔP required is
    - Proportional to *average v*
    - Proportional to length of tube L
    - Inversely prop to *cross-sectional area A* :
      - "proportional to X" → " = (constant)•X "
  - We <u>define</u> coefficient of viscosity η such that



$$\Delta P = P_1 - P_2 \propto \frac{vL}{A}$$

$$P_1 - P_2 = 8\pi\eta\frac{vL}{A}$$

Units of η: $(Pa)/\{[(m)(m/s)]/(m^2)\} = Pa - s$

$1\ \text{Pa}\cdot\text{s} = 10\ \text{poise}$ $\quad (poise = CGS\ unit = 1\ dyne - s/cm^2)$

QUIZ TIME
Setting the RF channel (TX3100 model)

- Reminder: program your clickers to this room's RF channel = 01

1. Press and hold the ↓ button until the LED turns red
2. Press the J/0 button once.
3. Press the A/1 button once.
4. Press the ↓ button again. The LED will flash green a few times and then turn off.

You're done!

Programming H-ITT TX3200 Clickers

Set the channel: Punch “MNU” repeatedly until the display reads:

CH:x   MNU
RF CH x
NEW ■   (x = display channel you are currently set to)

- Punch 1 (in room A102) OR 2 (in room A118)
- Punch "SEND” - The LED should flash green, and your channel is set to 1 (or 2).

Punch "MNU" again until the display says: CH:1 MNU
Multiple Choice

- Punch and hold "ALT" and then punch "MNU" once (the combination that means "SEL" or "select")

The display will then show: CH:1
MC

You are now ready - your answer will be automatically sent, and you should get a green flash. No need to reset channels each class as long as the display shows you are on channel 1 (or 2).

Quiz

2. The Venturi Effect refers to

A) What happens when Rick Venturi coaches a football team.

B) Behavior of a fluid passing through a constriction in a pipe

C) The speed of water from a hole in the side of a water tank

D) Conservation of angular momentum in fluids.

E) None of the above

Quiz

2. The Venturi Effect refers to

A) What happens when Rick Venturi coaches a football team.

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Going a bit deeper: Flow Resistance and Viscosity

- Flow rate (fluid current I) is proportional to ΔP, and inversely proportional to resistance R to flow

"Ohms Law" for fluid flow (later)

$$\text{define } I = \frac{\Delta V}{\Delta t} = vA \qquad I = \frac{\Delta P}{R} = \frac{P_2 - P_1}{R}$$

$$P_2 - P_1 = I\ R$$

$$units: (m/s)(m^2) = m^3/s$$

TABLE 15–3
Viscosities (η) of Various Fluids ($N \cdot s/m^2$)

Honey	10
Glycerine (20 °C)	1.50
10-wt motor oil (30 °C)	0.250
Whole blood (37 °C)	2.72×10^{-3}
Water (0 °C)	1.79×10^{-3}
Water (20 °C)	1.0055×10^{-3}
Water (100 °C)	2.82×10^{-4}
Air (20 °C)	1.82×10^{-5}

– The relation between flow resistance and viscosity (laminar flow only) is given by Poiseuille's Law:

$$R = \frac{8\pi\eta L}{A^2}$$

– combined with $\Delta P = I\ R$

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

For circular pipes of radius r

Notice r ^{4} dependence! If pipe r is reduced by half, the pressure drop across it increases by a factor of 16.

Application: Resistance to Blood Flow

- Blood flows from the aorta through a series of major arteries, the small arteries, the capillaries, and the veins, until it reaches the right atrium.
- During that flow process, the (gauge) pressure drops from 100 torr* to zero.
- If the volume flow rate is 800 mL/s, find the total effective resistance ***R*** of the circulatory system.

$$R = \frac{\Delta P}{I_{\text{V}}} = \frac{100\ \text{torr}}{0.800\ \text{L/s}} \times \frac{101\ \text{kPa}}{760\ \text{torr}} \times \frac{1\ \text{L}}{0.001\ \text{m}^3} = 16.6\ \text{kPa} \cdot \text{s/m}^3$$

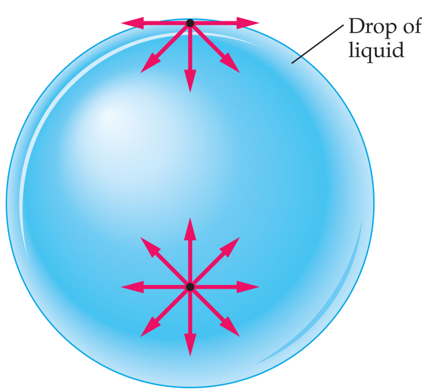
* Yet another pressure unit, used for small P's, named after Torricelli
1 torr = 1 mm of Hg = 1/760 of 1 atm = 139 Pa;   760 torr = 1 atm

Surface tension

- Surface environment of fluid differs from interior

  Example: open container of water

  – Water molecule inside has water molecules all around it
    - Net F = 0 on molecule (if no flow)
  – Water molecule on surface has water only below it, air above
    - Recall: liquids held together more than gases
      – Water molecules pull harder than air → net F downward
      – Takes work (energy) to remove molecule from surface
  – Equilibrium state for physical systems = minimum E state
    - Liquids will have minimal possible surface area unless acted upon by external forces
      – Droplets are spherical unless distorted by (eg) gravity force



Liquid in space station: