Thursday April 6

<u>Topics for this Lecture</u>:

- *Fluids*
  - *Buoyancy*
  - *Fluids in motion*
    - *Bernoulli's equation*
    - *Hagen-Poiseuille equation*
    - *Viscosity*

- Assignment 12 due Friday
- Pre-class due 15min before class
- Help Room: Here, 6-9pm Wed/Thurs
- SI: Morton 326, M&W 7:15-8:45pm
- Office Hours: 204 EAL, 10-11am Wed or by appointment (meisel@ohio.edu)

- Continuity: ρ*A*v = constant
- Bernoulli: $\mathrm{P} + \rho g h + \frac{1}{2}\rho v^2$ = constant
- F_{lift} = (ΔP)*A
- Hagen-Poiseuille:

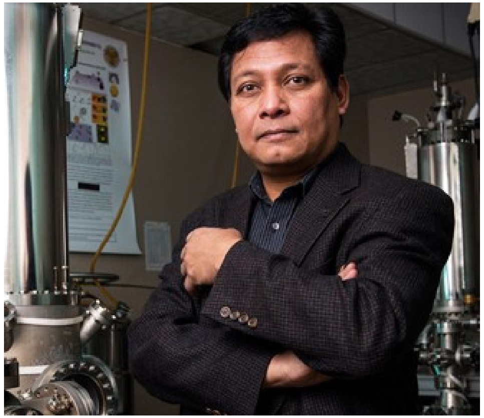
$$Q = \frac{\pi R^4 (P_{upstream} - P_{downstream})}{8\eta L}$$

Next week's lectures, guest starring:

Shiv Subedi (PHYS2001 TA)

Tuesday

Prof. Hla (Section 102 Instructor)



Thursday

You want to salvage your yacht. You don't have traditional salvaging equipment, but you did recently inherit a ping pong ball empire.
You decide to pump ping pong balls (V_{ball} ~$3 \times 10^{-5} m^3$) into your yacht (M_{yacht}=1500kg) in order to raise it from the sea floor.
How many ping pong balls do you need to pump into the yacht?
Consider the yacht buoyancy to be negligible and the ball mass to be small.

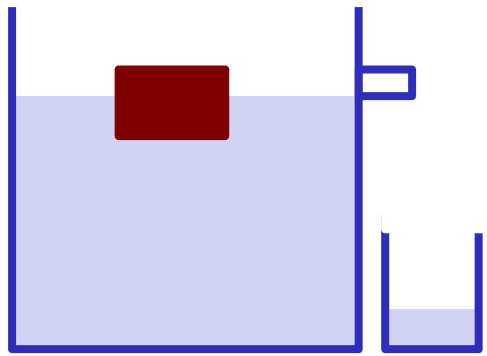
(A) 500 (B) 5,000

(C) 50,000 (D) 500,000

Mythbusters, E21

1. To make the ship float: $F_{buoyancy} = F_{gravity}$
2. Since the ping-pong balls make-up most of the displaced volume and the ship makes-up most of the mass:
   $\rho_{water} V_{balls} g = M_{yacht} g$
3. $V_{balls} = (M_{yacht})/\rho_{water}$
4. $V_{balls} = (1500kg)/(1000kg/m^3) = 1.5m^3$
5. One ping-pong ball has a volume of ~ $3 \times 10^{-5} m^3$,
6. So, the number of ping-pong balls is: $V_{balls}/V_{ball} = 1.5m^3/(3 \times 10^{-5} m^3)$ ~ 50,000 balls
7. …it turns out a fiberglass hull would provide almost half that much buoyancy, so you would only need ~25K ping-pong balls.

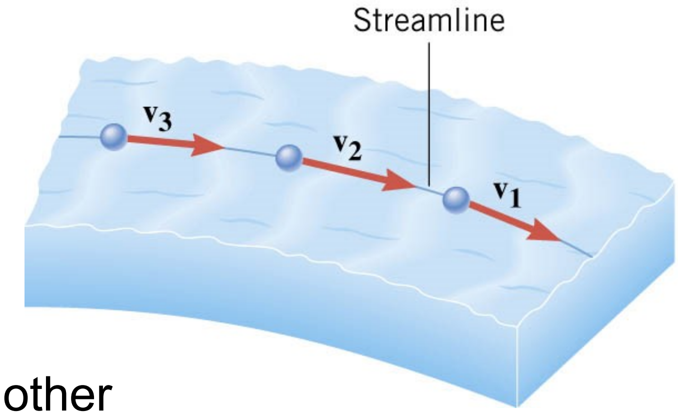
A beaker is filled with water up to the level of the spigot.
A block of wood weighing 2N is placed in the beaker and floats in the fluid.
The weight of the water which spills out the spigot is:



A. less than 2N
B. $\boxed{\text{2N}}$
C. greater than 2N

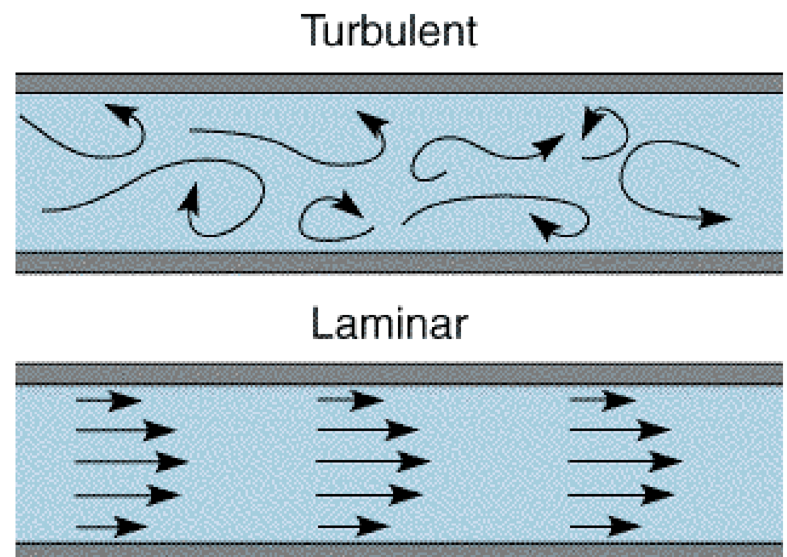
1. The wood block is floating in equilibrium, so
2. $F_{buoyancy} = F_{gravity}$
3. $[\rho_{fluid} V_{displaced}]g = m_{block}g$
4. $m_{fluid}g = m_{block}g$
5. Weight of fluid displaced= weight of block

Fluids in Motion: Flow



- Typically consider “**ideal fluid**”:
    - Incompressible: has a constant density
    - Non-viscous: no friction between layers of fluid

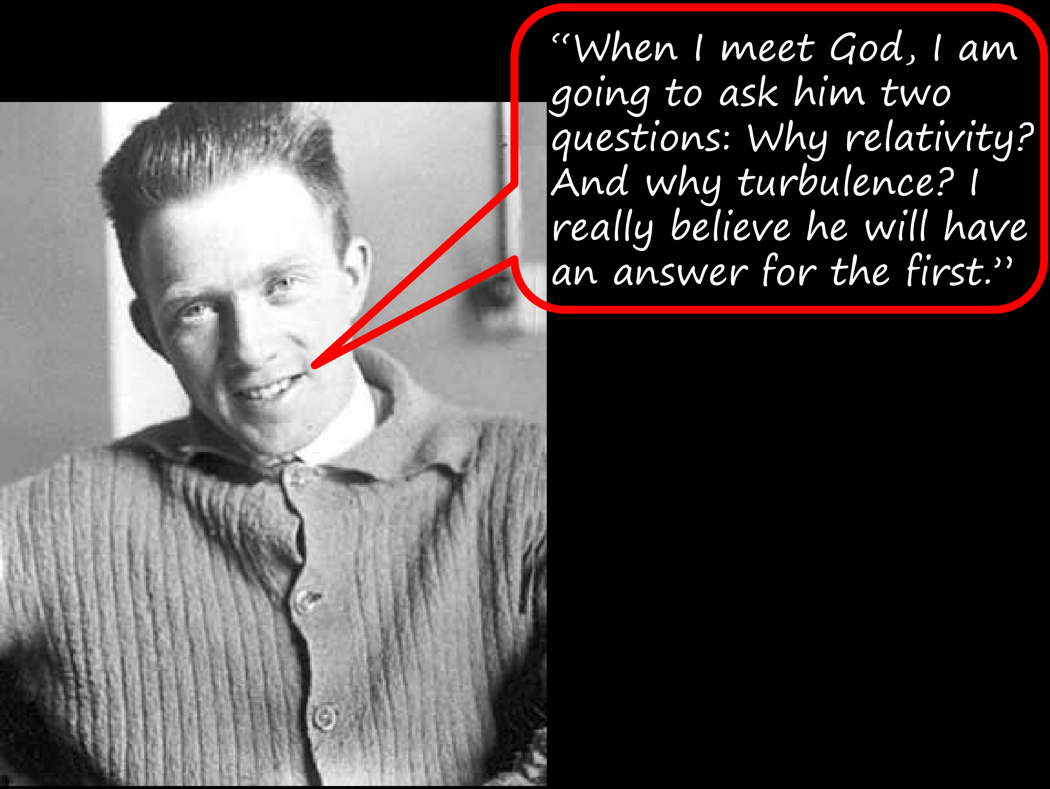
- **Flow**: How components of a fluid move relative to each other
    - Describe the direction of travel with “streamline”s
    - Classify types of flow based on streamlines:
        - Steady: velocity constant at a point.
            - i.e. the fluid properties aren’t changing
        - Unsteady: velocity changes magnitude
            - fluid may be speeding up or slowing down
        - Turbulent: erratic changes in velocity
            - technically a type of unsteady flow



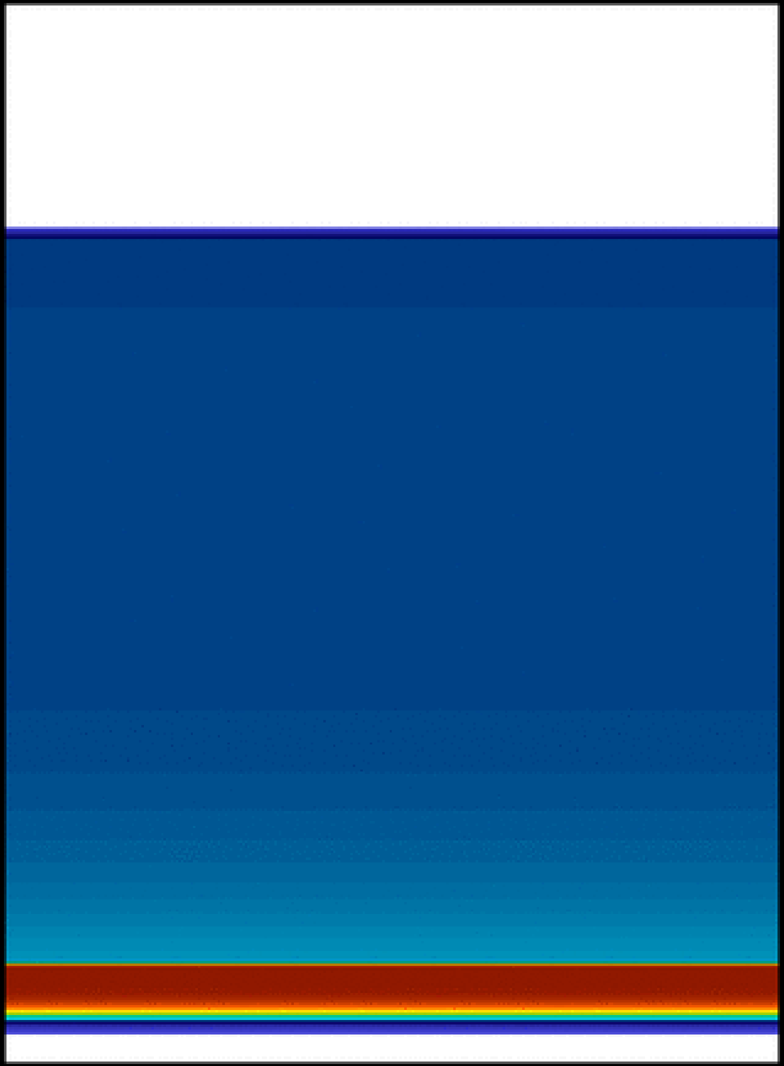
Univ Cambridge

- Fluids exhibiting turbulence are “turbulent”
- Fluids not exhibiting turbulence are “laminar”

Turbulence



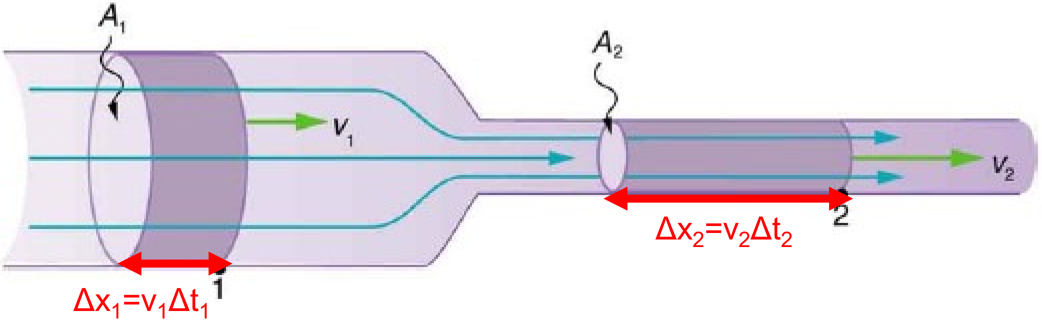
Werner Heisenberg



C. Malone et al. ApJ 2011

Fluids in Motion: Continuity

- Continuity:
  - Mass leaves a system at the same rate that it enters (if in a steady state, for an incompressible fluid)
  - For example, the same amount of stuff flows in a hose as flows out. The hose doesn't gain mass over time.
  - $m/\Delta t$ = constant
- Considering fluid flowing through a pipe:
  - $m = \rho V = \rho * A * \Delta x$
  - $m/\Delta t = \rho * A * \Delta x/\Delta t \boxed{= \rho * A * v = \text{constant}}$
  - So, my pipe decreases in diameter, the fluid will speed up at that location

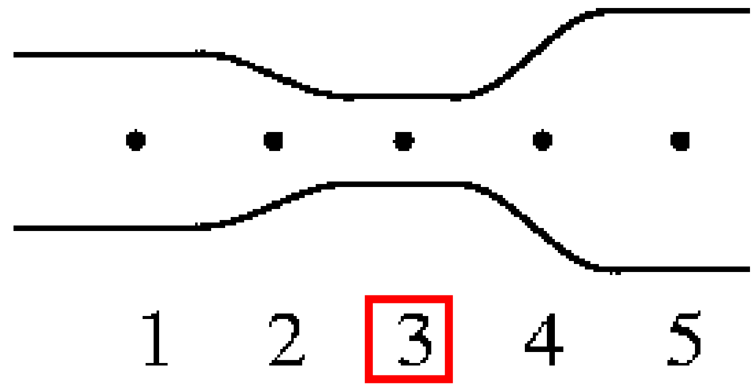


- For a fluid flowing through a pipe of changing area:
  - $\boxed{\rho_1 * A_1 * v_1 = \rho_2 * A_2 * v_2}$
  - i.e. the mass-flow rate is constant
  - if ρ=constant ("incompressible)
  - volume flow is constant: $\boxed{Q = A_1 * v_1 = A_2 * v_2}$

3

An incompressible fluid is flowing through a pipe.
At which point is the fluid traveling the fastest?

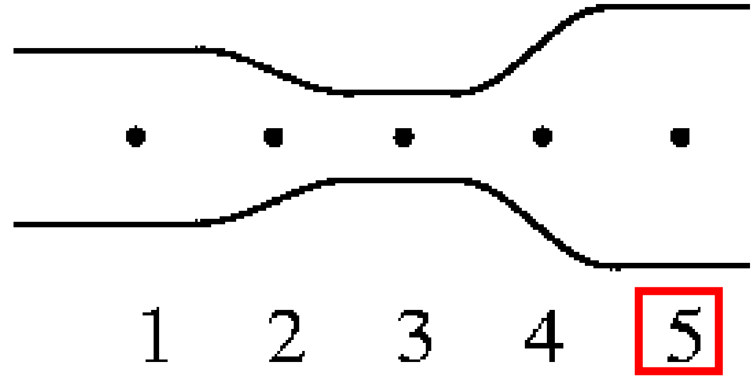
(A) 1 (B) 2 (C) 3
(D) 4 (E) 5 (6) All the same



1. ρ*A*v = constant
2. Incompressible: ρ = constant
3. Cross sectional area A is smallest at 3, so v must be largest there.

An incompressible fluid is flowing through a pipe.
At which point is the fluid traveling the slowest?

(A) 1 (B) 2 (C) 3
(D) 4 (E) 5 (6) All the same



1. ρ*A*v = constant
2. Incompressible: ρ = constant
3. Cross sectional area A is largest at 5, so v must be smallest there.

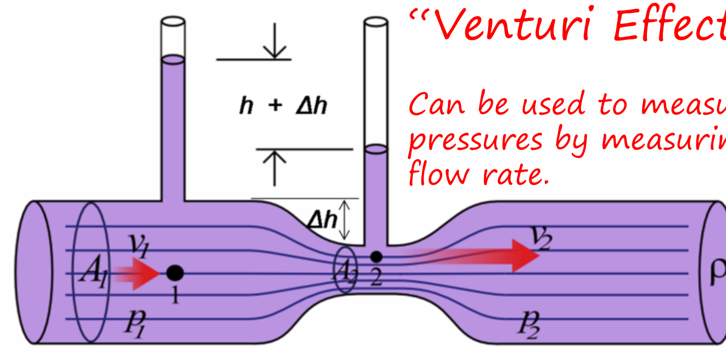
Fluids in Motion: Conservation of Energy & Bernoulli's equation

- Energy in a system is conserved, except for energy removed by nonconserving forces.
- A moving fluid has:
  - kinetic energy, from motion
  - potential energy, from height
- Changes in pressure for a moving fluid correspond to work by a non-conserving force
- Therefore,
  1. $E_i = E_f + W_{NC}$
  2. $PE_i + KE_i = PE_f + KE_f + \Delta E$
  3. $mgh_i + \frac{1}{2}mv_i^2 = mgh_f + \frac{1}{2}mv_f^2 + Fd$
  4. Since ρ is constant for incompressible fluid, divide everything by volume
  5. $(m/V)gh_i + \frac{1}{2}(m/V)v_i^2 = (m/V)gh_f + \frac{1}{2}(m/V)v_f^2 + F(d/V)$
  6. $\rho gh_i + \frac{1}{2}\rho v_i^2 = \rho gh_f + \frac{1}{2}\rho v_f^2 + \Delta P$
  7. $\boxed{P_i + \rho gh_i + \frac{1}{2}\rho v_i^2 = P_f + \rho gh_f + \frac{1}{2}\rho v_f^2}$ Bernoulli's Equation

Bernoulli's Equation: Implications

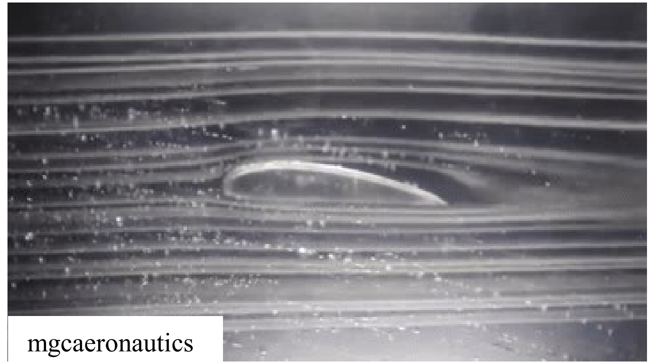
- $P_i + \rho g h_i + \frac{1}{2}\rho v_i^2 = P_f + \rho g h_f + \frac{1}{2}\rho v_f^2$

"Venturi Effect"



Can be used to measure pressures by measuring flow rate.

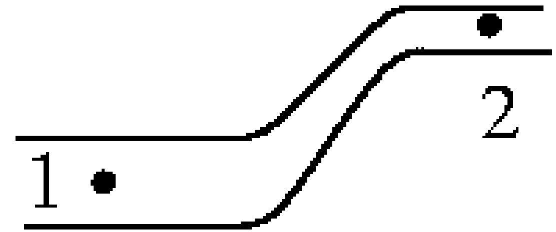
- What happens if the velocity increases?
  (by decreasing the pipe area [ρ*A*v = constant])
  - KE term ($\frac{1}{2}\rho v^2$) will increase
  - height & density are unchanged,
    so PE term (ρgh) will stay the same
  - But energy is conserved, so pressure must change
  - Pressure decreases to: $P_f = P_i - \frac{1}{2}\rho\left(v_f^2 - v_i^2\right)$
  - Higher fluid speed leads to a lower pressure!



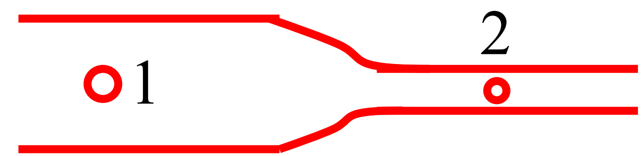
This means we can test the lift a wing generates by measuring P above & below a wing in a wind tunnel.

- If a fluid is made to flow at different speeds on opposite sides of a barrier:
  - there will be different pressures on the opposite sides.
  - therefore, the force from pressure will be different
  - The difference in forces is: $F_{net} = F_1 - F_2 = P_1 A - P_2 A = \boxed{(\Delta P)A = F_{lift}}$

An incompressible fluid flows through a pipe.
Which point is the pressure greater at?



(A) 1 (B) 2 (C) Same at both
(D) Not enough information



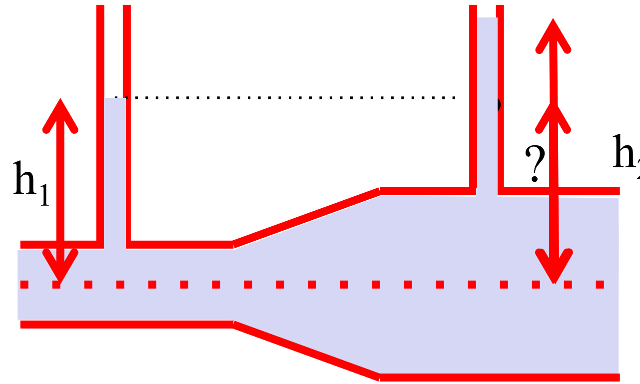
1. ρ*A*v = constant
2. Incompressible: ρ = constant
3. Cross sectional area A is largest at 1, so v must be smallest there.
4. $\mathrm{P} + \rho g h + \frac{1}{2}\rho v^2$ = constant
5. Since ρgh=constant, if v gets smaller, P must get larger.
6. Therefore, the pressure P is largest at point 1.

An incompressible fluid flows through a pipe. At two different points, small tubes are attached above the pipe to allow for the observation of the pressure in the pipe. How does the height of the fluid in the second pipe compare to the height of the fluid in the first pipe?

A. $h_2 < h_1$

B. $h_2 = h_1$

C. $h_2 > h_1$



1. ρ*A*v = constant
2. Incompressible: ρ = constant
3. Cross sectional area A is larger at 2, so v must be smaller there.
4. $P + \rho g h + \frac{1}{2}\rho v^2$ = constant
5. Since ρgh=constant, if v is smaller, P is larger.
6. Therefore, the pressure P is larger on the centerline at point 2.
7. The larger pressure can support a larger (heavier) column of fluid, so $h_2 > h_1$.

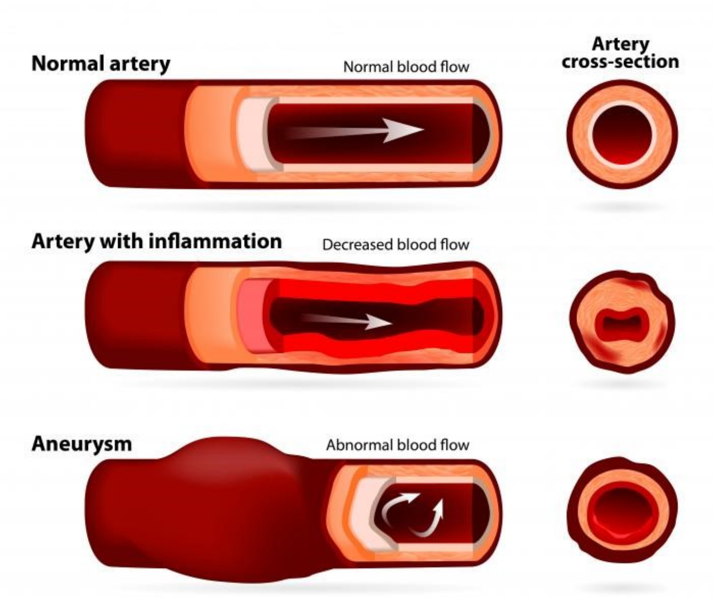
Consider a blood vessel which has a weakened wall, allowing the vessel to expand. What happens to the pressure in the vessel?

A. $\boxed{\text{Pressure increases}}$

B. Pressure decreases

C. Pressure stays the same

1. From continuity: ρ*A*v = constant
2. Incompressible: ρ = constant
3. Cross sectional area A increases, so v decrease.
4. Bernoulli equation: $\mathrm{P} + \rho g h + \frac{1}{2}\rho v^2$ = constant
5. Since ρgh=constant, if the velocity decreases, the pressure must increase.



MedicalNewsToday

As you can imagine, the increased pressure can cause the weakened blood vessel to expand even more.
This is known as an aneurysm.
(If it is in the brain & bursts, that causes a stroke.)

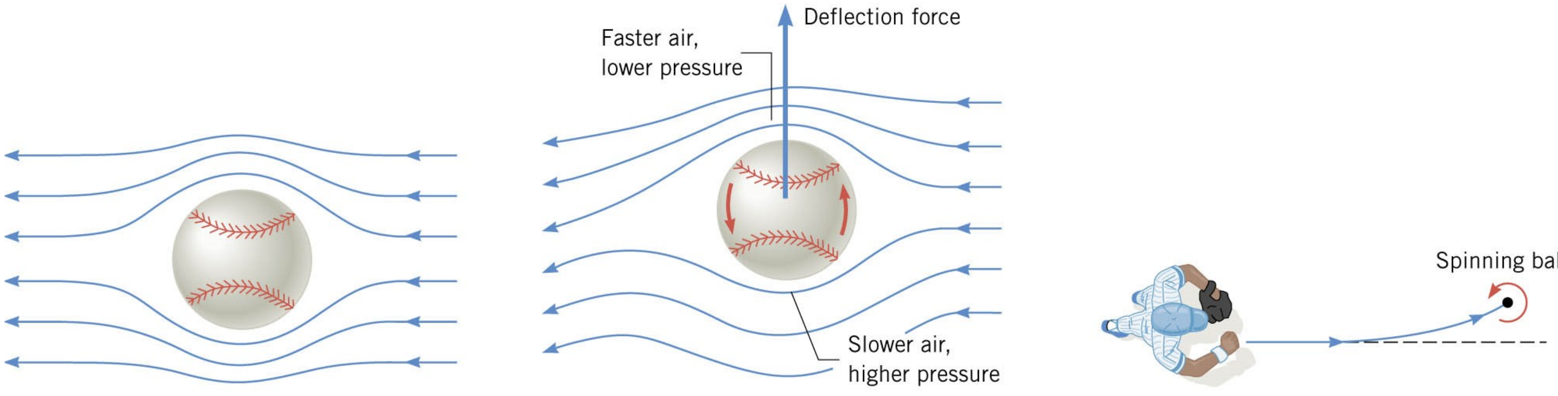
An air mattress pump blows air above a beach ball at 8m/s.
The air below the beach ball is moving at ~0m/s.
Assuming the beach ball diameter is 0.1m, meaning the areas for the top & bottom are each ~$0.03m^2$, and the density of air is $1kg/m^3$,
what is the lift force on the beach ball?

(A) 0.1N (B) 1N (C) 10N (D) 100N

https://www.youtube.com/watch?v=PKdUZfy4irM

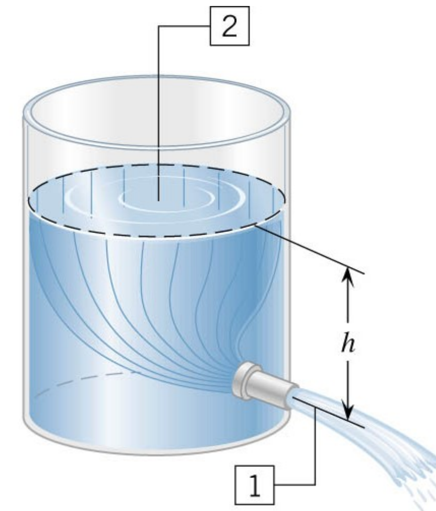
1. $F_{lift} = (\Delta P)*A$
2. $P_{above} + \rho g h_{above} + \frac{1}{2}\rho v_{above}^2 = P_{below} + \rho g h_{below} + \frac{1}{2}\rho v_{below}^2$
3. $P_{below} - P_{above} = \Delta P = \rho g(h_{above} - h_{below}) + \frac{1}{2}\rho(v_{above}^2 - v_{below}^2)$
4. $(\Delta P)*A = \{(1kg/m^3)(9.8m/s^2)(0.1m) + (0.5)(1kg/m^3)(8m/s)^2\}(0.03m^2)$
5. $F_{lift} = (0.98Pa + 32Pa)(0.03m^2) = 0.99N \sim 1N.$
6. A beach ball has a mass of ~0.1kg, so weighs ~1N, thus you can float it.

The Magnus Effect: A consequence of forces from Bernoulli's principle



(*a*) Without spin (*b*) With spin (*c*)

You have a giant cask of water with a spigot some height below the water surface. The surface of the water, which is essentially at rest, is exposed to atmosphere (~10^5Pa). The water density is ~1000kg/m^3.
The water pours out of the spigot at 3m/s.
How far below the water surface is the spigot positioned?



(A) 0.046m (B) 0.46m (C) 4.6m (D) 46m

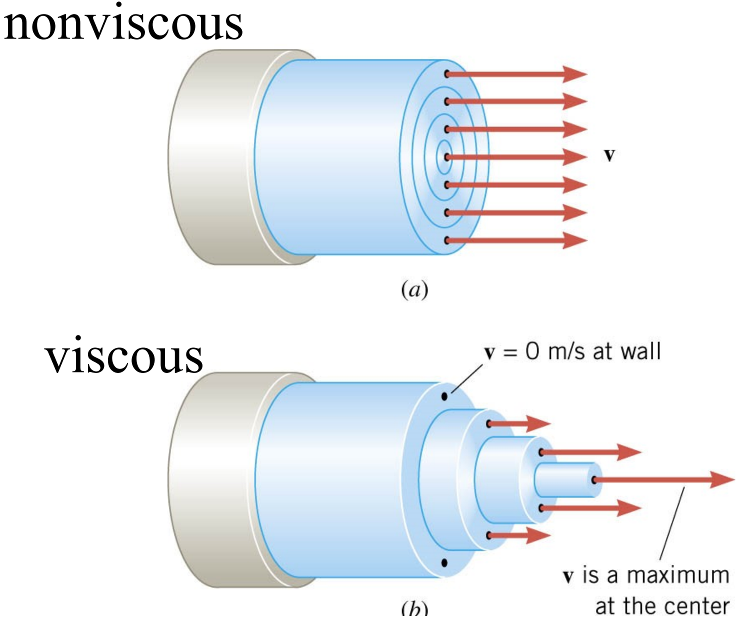
1. $P_{atmosphere} + \rho g h_{surface} + \frac{1}{2}\rho v^2_{surface} = P_{atmosphere} + \rho g h_{spigot} + \frac{1}{2}\rho v^2_{spigot}$
2. Atmospheric pressure is going to be negligible compared to the water pressure near the spigot and the water is nearly at rest at the surface.
   Also, we can define the spigot height $h_{spigot} = 0$. So,
3. $\rho g h_{surface} = \frac{1}{2}\rho v^2_{spigot}$
4. $h_{surface} = \frac{v^2_{spigot}}{2g} = 0.46m$

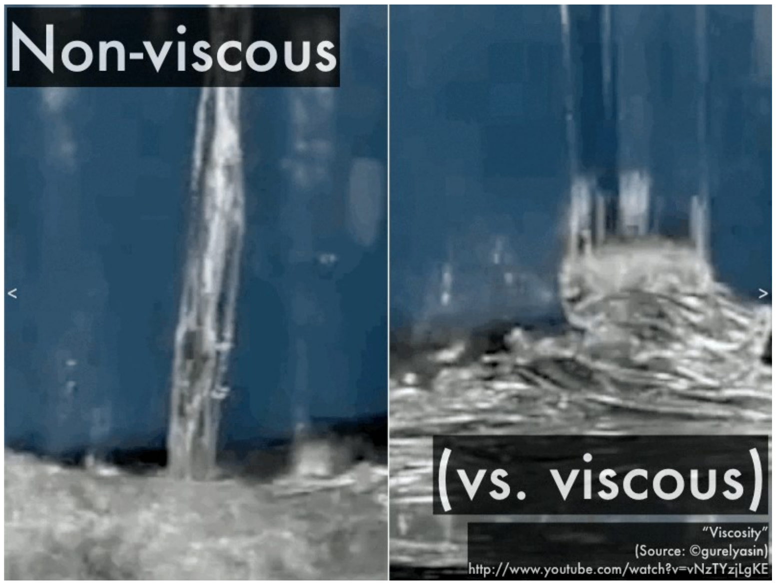
You'll note this is the height you got on homework & exam questions when you convert an object with only kinetic energy to a situation with only potential energy.

Viscosity - η

- Frictional forces between layers in a fluid.
- Causes zero speed at the boundaries…
- and means speed is greatest at the flow center.
- The SI unit is: (Pa)s

- The more resistant to flow, the greater the viscosity.





Hagen-Poiseuille Equation:

Volumetric flow rate due to a pressure gradient for a viscous non-turbulent fluid.

- You can only flow a limited amount of fluid through a pipe in a given amount of time.
- For a non-turbulent viscous liquid, this limiting flow rate is described by the Hagen-Poiseuille Equation
  - $\boxed{Q = \frac{\pi R^4 (P_{upstream} - P_{downstream})}{8 \eta L}}$
  - where Q is the volumetric-flow rate, R is the pipe radius, L is the pipe length, η is the fluid viscosity, and P_u-P_d is the pressure difference before & after the pipe (i.e. at positions x=0 and x=L).
  - Since the units for viscosity are commonly (Pa)s, it is usually easiest to specify pressure in Pa, so the pressure unit cancels.
- Hagen-Poiseulle is somewhat intuitive:
  - More flow for a larger radius pipe
  - More flow for a larger pressure difference ((ΔP*A = F))
  - Less flow for a more viscous fluid.
  - Less flow for a longer pipe (More friction between the fluid & the walls).
- This can be inverted to get the pressure drop along a pipe for a given volume-flow rate.
  - $\boxed{\Delta P = \frac{8 \eta L}{Q \pi R^4}}$

Atherosclerosis is a process in which fats (& other junk) build-up on your blood vessel walls, decreasing the effective radius for blood to flow through. If your effective blood vessel radius decreases to 0.8x its original radius
(i.e. R --> 0.8*R),
by how much does your blood flow decrease?

(A) 2%   (B) 20% $\boxed{\text{(C) 60\%}}$ (D) 80%

1. $Q = \frac{\pi R^4 (P_{upstream} - P_{downstream})}{8\eta L}$
2. If R --> 0.8*R, then R^4 --> $(0.8*R)^4$.
3. So, Q --> (0.8)4*Q ≈ 0.41Q.
4. This corresponds to a reduction by ~60%.

A 20% reduction in blood vessel radius leads to a 60% reduction in blood flow rate.
A 50% reduction in vessel radius leads to a 94% decrease in blood flow rate!

Hagen-Poiseuille Equation: *Practical example*

- Consider several tanks of fluid with some volume V.
- The tanks are each drained by a different pipe with different radii R and lengths L, and the pressure at the upstream side of each pipe is the same.
- The volume is proportional to the pipe length, so V is proportional to L^3.
- Then flow rate for fluid to drain a given tank will be: $Q = \frac{\pi R^4 \Delta P}{8\eta L} = \frac{\Delta V}{\Delta t}$
- If the upstream pressure (in the tank) is much higher than the pressure at the exit of the pipe, then $\Delta P \approx P_{upstream}$.
- Then, ignoring the scaling factors and doing some algebra: $\Delta t \propto \frac{L^4}{R^4}$
- If each of the different tanks have a fixed L/R ratio, then they would take the same time to drain.

BBC NEWS

'Universal urination duration' wins Ig Nobel prize

By Jonathan Webb 18 September 2015
Science reporter, BBC News

Duration of urination does not change with body size

Patricia J. Yang[a], Jonathan Pham[a], Jerome Choo[a], and David L. Hu[a,b,1]

PNAS