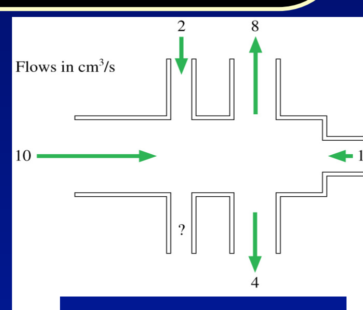
Physics 1021

Spring 2012, 15b

ConcepTest 15.b.1 What goes in must come out

The figure shows volume flow rates (in cm^3/s) for all but one tube. What is the volume flow rate through the unmarked tube? Is the flow direction in or out?

A. 1 cm^3/s, in
B. 1 cm^3/s, out
C. 10 cm^3/s, in
D. 10 cm^3/s, out
E. It depends on the relative size of the tubes.



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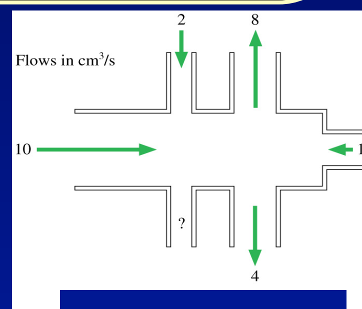
E. It depends on the relative size of the tubes.

What goes in must come out, so if 13 cm^3/s of fluid are shown going in and cm^2/s of fluid coming out. That leaves 1 cm^3/s coming out.



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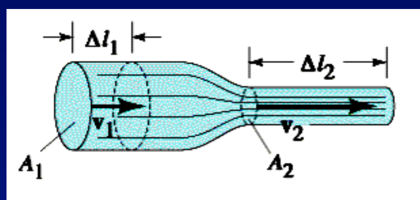
Fluids in Motion conservation in flow

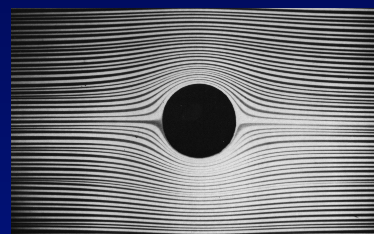
New Topic

Fluids in motion

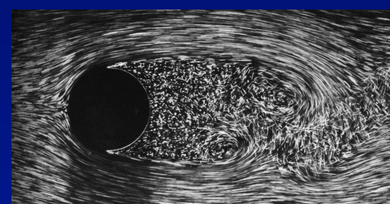
Two main types of fluid flow:

1) streamline (laminar)





2) turbulent



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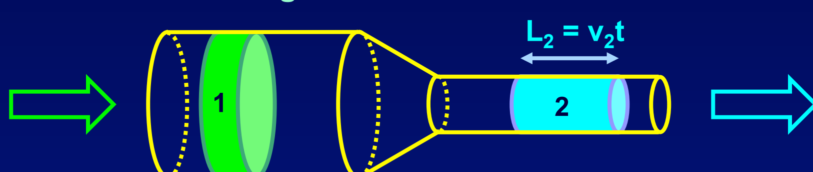
Continuity Equation

Consider water flowing in a pipe with a changing diameter:
What goes in must come out



Volume per second here = Volume per second here

volume V = A × L = A × vt

V / t = A × v is a ***constant*** !!

volume flow rate

Why are volumes equal?

- water is incompressible
- no leaks or ruptures

smaller area ⇒ greater speed

$$A_1 v_1 = A_2 v_2$$

Continuity Equation

PHYS 1021: Chap. 15, Pg 6

Water spigot

- Water velocity increases as it drops further from the faucet
- ⟹ Stream of water must narrow

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ConcepTest 15.b.2 Human circulatory system

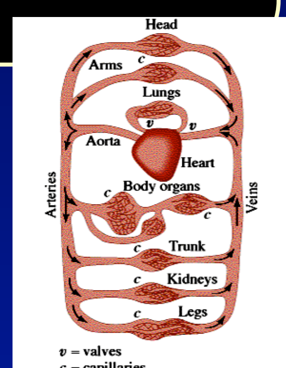
A single capillary is much smaller than the aorta, but The total cross-sectional area of all the capillaries in the body is several hundred times that of the aorta.
Where is the blood flow the slowest?

(1) aorta

(2) capillaries

(3)veins

(4) All are equal



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ConcepTest 15.b.2 Human circulatory system

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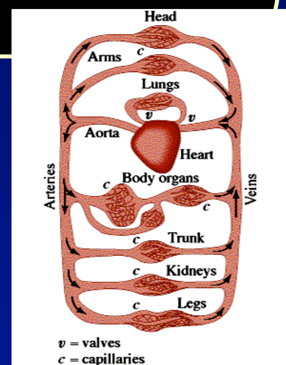
What goes in must come out, so the flow gets divided by each branching, which makes it hard to calculate. However, the flow rate depends upon the total area, which means that it is slowest in the capillaries



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Example: Blood flow rate

The radius of the aorta is 1 cm and that of the capillaries is 7 μm. If the average speed of blood in the aorta is 40 cm/s and in the capillaries is about 0.6 mm/s, what is the number of capillaries in the human body?

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Example: Blood flow rate

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Blood flow: $v_A A_A = v_c A_c = v_c n A_{c1}$

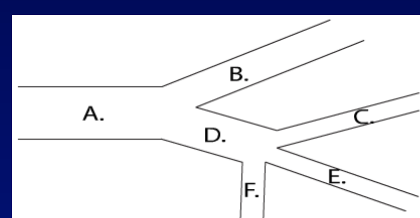
~~$v_A A_A / A_{c1} v_c = 0.4\,m/s \times (10\,mm)^2 / 6\times10^{-5} \times (7\times10^{-4})^2 = 2.04$~~

$n = v_A A_A / v_c A_{c1} = 0.4\,m/s \times (10\,mm)^2 / 6\times10^{-4} \times (7\times10^{-3})^2$

$n = 1.4 \times 10^9$ capillaries

Ponderable: Fluid flow

Water flows from pipe A, with diameter D, into pipes B and D, each with diameter D/2. From D the water flows into pipes C, E, and F, each of which has a diameter D/6. Rank the speed of the water from least to greatest at points A, B, C, D, E. (Assume there is no viscosity and that all five locations are at the same height.)



For a real fluid, would you expect the flow rate to be the same in B as in D? Why?

Ponderable: Fluid flow

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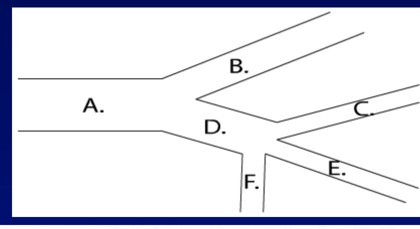
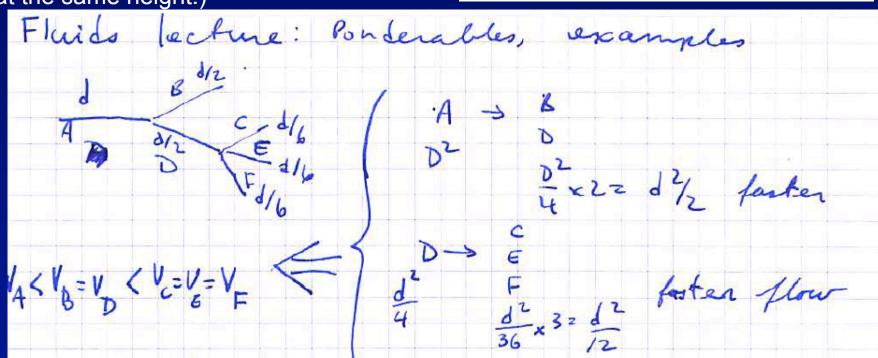


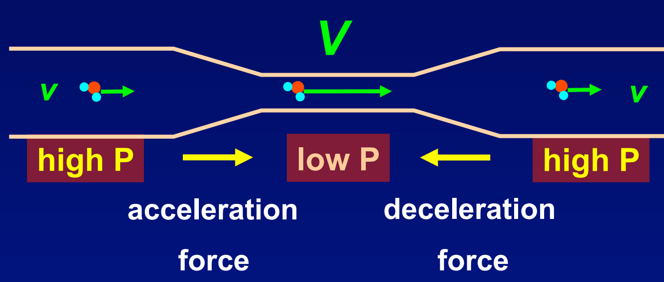


Ponderable: Water spigot

- To see the largest narrowing effect, should the faucet be running fast or slow?
- Calculate the speed at which the water leaves the faucet.
- Try this at home.

Bernoulli's Principle

Fluid speeds up in narrow part of pipe:



as speed in fluid increases, pressure in fluid decreases

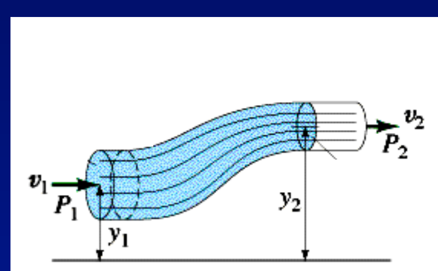
Bernoulli's Principle

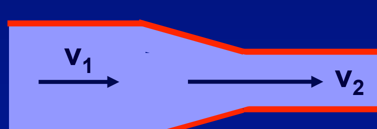
Apply *energy conservation* to a fluid moving through a pipe:

$$P\Delta V + \frac{1}{2}\rho \Delta V v^2 + \rho \Delta V g y ==>> F\Delta x + \frac{1}{2}mv^2 + mgy$$

$$P_1 + \frac{1}{2}\rho v_1^2 + \rho g y_1 = P_2 + \frac{1}{2}\rho v_2^2 + \rho g y_2 = const.$$

work by pressure — kinetic energy — potential energy





If $y_2 = y_1$ we find that:

$P_2 = P_1 + ½\rho(v_1^2 - v_2^2) < P_1$ ✓

Another way to look at this
Summary of Fluid Motion

- *Continuity equation*: *A v = constant*

  what goes in must come out – matter conservation

wide (BIG area) → low speed

narrow (small area) → high speed

- *Bernoulli's equation*: $P + \frac{1}{2}\rho v^2 + \rho g y = \text{constant}$

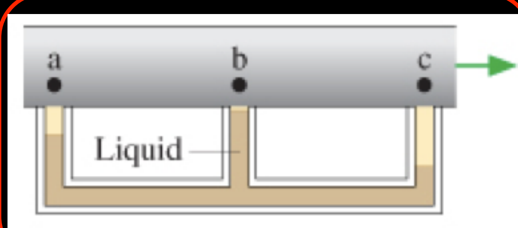
$$P\Delta V + \frac{1}{2}\rho\Delta V v^2 + \rho\Delta V g y ==>> F\Delta x + \frac{1}{2}mv^2 + mgy$$

W + KE +PE = constant – energy conservation

high speed (fast) → low pressure

low speed (slow) → high pressure

ConcepTest 15.b.3 Rank the gas speeds



From high to low:

(1) a,b,c

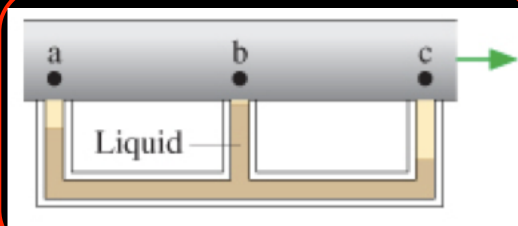
(2) c,b,a

(3) All are equal

(4) b,a,c

(5) a,c,b

ConcepTest 15.b.3 Rank the gas speeds



From high to low:

(1) a,b,c

(2) c,b,a

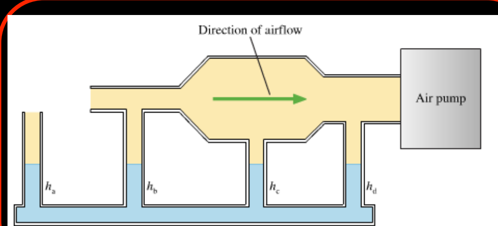
(3) All are equal

(4) b,a,c

(5) a,c,b

The lower the velocity of fluid, the higher the pressure at a given point in the pipe. The velocities from highest to smallest are b,a,c. This can be seen from Bernoulli's principle. The kinetic energy of a fluid element balances with the work done by the pressure force..

ConcepTest 15.b.4 Rank the liquid heights



From high to low:

(1) d,b,c

(2) c,d,b

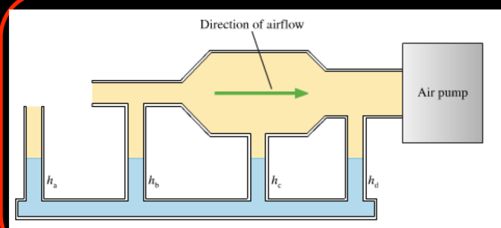
(3) All are equal

(4) b,d,c

(5) d,c,b

ConcepTest 15.b.4

Rank the liquid heights



From high to low:

(1) d,b,c

(2) c,d,b

(3) All are equal

(4) b,d,c

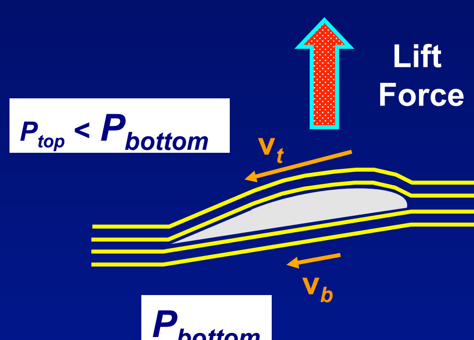
(5) d,c,b

The lower the velocity of fluid, the higher the pressure at a given point in the pipe. The velocity is highest at b, from the continuity equation. Thus the pressure is the lowest there. This combines the idea of continuity with Bernoulli's principle ➔ Conservation of mass with conservation of energy.

PHYS 1021: Chap. 15, Pg 21

Bernoulli's Principle
Applications: Airplanes

An airplane wing (airfoil) is shaped so that the air above the wing travels faster than the air below:



So the air over the top of the wing is at a lower pressure

This upward force is called "lift"

PHYS 1021: Chap. 15, Pg 22

ConcepTest 15.b.5 Human circulatory system

As people get older plaque can build up in the major arteries. In the region of the buildup, how do the blood flow rate and pressure change

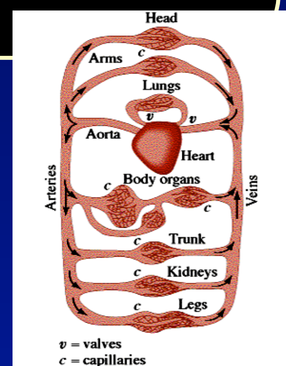
Flow rate, pressure

(1) Increases, increases

(2) increases, decreases

(3) decreases, increases

(4) decreases, decreases



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Flow rate, pressure

(1) Increases, increases

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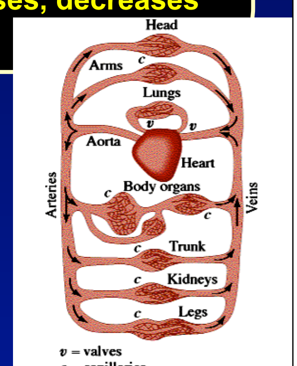
(4) decreases, decreases

The continuity principle tells us that the velocity must increase, Bernoulli tells us that when the velocity increases, the pressure must decrease, in the region of the constriction.

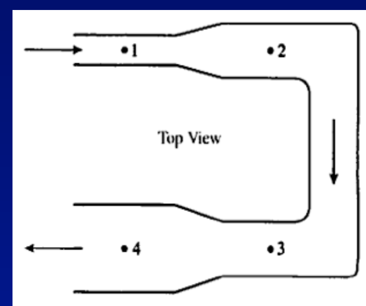


Oh really??? I thought the pressure went up as people age !!!

Ponderable: Bernoulli

Liquid flows through this pipe and the picture below is an overhead view – all points are at the same height.

1. Rank in order, from largest to smallest, the flow speeds v_1 to v_4 at points 1 to 4.
2. Rank in order, from largest to smallest, the pressures p_1 to p_4 at points 1 to 4.



PHYS 1021: Chap. 15, Pg 25

Ponderable: Bernoulli

Liquid flows through this pipe and the picture below is an overhead view – all points are at the same height.

1. Rank in order, from largest to smallest, the flow speeds v_1 to v_4 at points 1 to 4.
2. Rank in order, from largest to smallest, the pressures p_1 to p_4 at points 1 to 4.

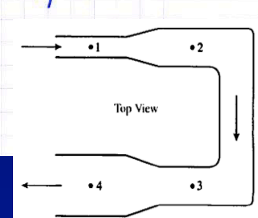
$A_1 < A_2 = A_3 < A_4$ ∴ $V_1 > V_2 = V_3 > V_4$ continuity

$P > P_2 = P_3 > P_1$

$P_2 > P_1 > P_3$

∴ $V_3 > V_1 > V_2$ Bernoulli

$A_2 > A_1 > A_3$ Continuity



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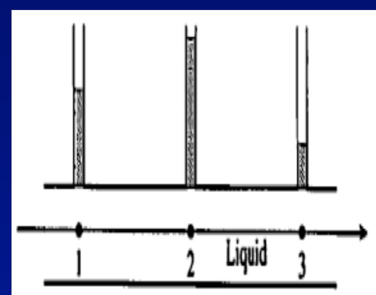
Ponderable: pressure to area

Liquid flows through a pipe. You can't see into the pipe to know how the inner diameter changes. A) Rank in order, from largest to smallest, the fluid speeds v_1 to v_3 at points 1, 2, and 3. B) Rank in order, from largest to smallest, the diameters d_1 to d_3 at points 1, 2, and 3.



Example: Blood pressure in aneurism

In an aortic aneurism, a bulge forms where the walls of the aorta are weakened. If blood flowing through the aorta (radius 1.2 cm) enters an aneurism with a radius of 3.1 cm, what is the average increase in the blood pressure inside the aneurism relative to that in the healthy part of the aorta? Assume that the average flow rate through the aorta is 120 cm^3/s, that the blood is not viscous, and that the patient is lying down (no change in height. The density of blood is 1060 kg/m^3.

The average blood pressure is about 100 mm Hg = 1.32×10^4 Pa. Why is the pressure change so small?

……Because most of the work done ($P\Delta V = F\Delta x$) is used to overcome viscosity, not increase the kinetic energy of the blood.

Ponderable: Blood pressure and arteriosclerosis

The diameter of an artery is decreased by 20% due to arteriosclerosis. A) If the same amount of blood flow passes through the artery in any time period as before it was obstructed, will the pressure in the obstructed area increase or decrease? B) By what percentage? C) Will there be a pressure drop across the partially obstructed section? C) Is this realistic?

Ponderable: Blood pressure and arteriosclerosis

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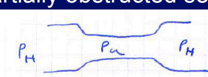
$r_u = 0.8\, r_H$

$\frac{dV_{flow}}{dt} = \text{constant}$



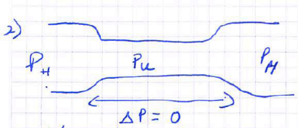
$P_H + \frac{1}{2}\rho v_H^2 = P_u + \frac{1}{2}\rho v_u^2 \quad ; \quad \frac{dV}{dt} = vA$

$P_u = P_H = \frac{1}{2}\rho(v_u^2 - v_H^2) = \frac{1}{2}\rho\frac{dV}{dt}\left(\frac{1}{A_u^2} - \frac{1}{A_H^2}\right)$

$= \frac{1}{2}\frac{\rho}{\pi^2}\frac{dV}{dt}\left(\frac{1}{r_u^2} - \frac{1}{r_H^2}\right) = \frac{1}{2}\frac{\rho}{\pi^2}\frac{dV}{dt}\left(\frac{1}{0.8^2} - 1\right)\frac{1}{r_H^2}$

1) Blood pressure drops in the obstruction because velocity must increase

2)



$P_u < P_H$

3) not realistic because we know blood pressure goes up in ~~arterial~~ artereosclerosis.
Viscosity must be considered, then energy is lost to dissipation when blood is moved along the artery ⇒ ~~work done = P·ΔV~~