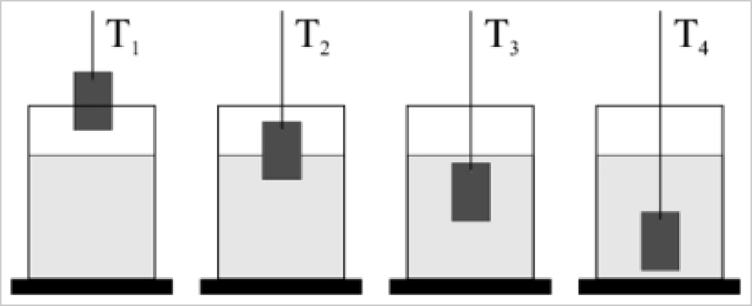
Physics 9 — Monday, October 15, 2018

- HW5 due Friday.
- For last Monday, you read Giancoli ch10 (fluids)
- For last Wednesday, you read PTFP ch2 (atoms & heat)
- For today, you read PTFP ch9 (invisible light)
- For Wed, read Giancoli ch13 (temperature & kinetic theory)
- If you'd like to do some extra-credit reading on Architectural Acoustics, you can read one or more chapters of a nicely illustrated (more drawings, less text) textbook I have (by Egan). For each chapter you read, you can collect extra credit by writing a few paragraphs (1–2 pages) to summarize what you learned from the chapter. Email me if you're interested.
- I found a way to run both Odeon and CATT-Acoustic on MacOS without a virtual machine! Stay tuned.

A Lucite block sinks when it is dropped into a bucket of water. Suppose that the same block is supported by a string and slowly lowered (at constant speed) into a bucket of water. How do the tensions in the string compare at the four positions shown?



(A) $T_1 > T_2 > T_3 > T_4$

(B) $T_1 < T_2 < T_3 < T_4$

(C) $T_1 > T_2 > T_3 = T_4$

(D) $T_1 = T_2 = T_3 = T_4$

A boat carrying a large boulder is floating on a small lake. The boulder is thrown overboard and sinks. As a result, the water level (with respect to the bottom of the lake)

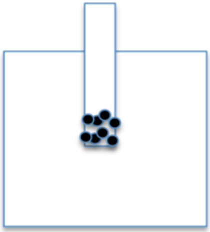
(A) rises

(B) drops

(C) remains the same

Hint: What volume of water is displaced by floating the boulder inside the boat? What volume of water is displaced by sinking the boulder into the lake?

A glass tube of square cross-section 1 cm $\times$ 1 cm floats vertically in water. What mass of lead pellets would you need to add to the tube in order to make it sink by 2 cm? (Assume that the top is initially more than 2 cm above the surface.)



How does pressure P vary with depth h beneath water surface?

What is the difference in pressure forces exerted on the bottom of the tube by the water vs. on the top of the tube by the atmosphere, as a function of immersed depth h?

What is the condition for static equilibrium?

depth h below water surface

$$P(h) = P_{atm} + \rho g h$$

A = tube's cross-sectional area

force on top $= P_{atm} \cdot A$ (downward)

force on bottom $= (P_{atm} + \rho g h) \cdot A$ (upward)

gravitational force on lead pellets $= Mg$ (downward)

$$(P_{atm} + \rho g h) A - P_{atm} \cdot A - Mg = 0 \Rightarrow \rho g h A = Mg$$

$$(\rho_{water})(Ah) = M_{lead}$$

Ah ← volume of displaced water

$(\rho_{water})(Ah)$ ← mass of displaced water

$$(\rho_{water})(A \cdot \Delta h) = \Delta M_{lead} = \left(1 \tfrac{g}{cm^3}\right)(1 cm^2 \cdot 2 cm)$$

$$= \boxed{2 \text{ grams}}$$

When a sphere of volume $1\ \mathrm{m}^3$ floats in water, 75% of its volume is submerged beneath the surface. What is the mass of the sphere?

Notice that pressure and stress are both force-per-unit-area.

Suppose lumber has density ρ (measured in $\mathrm{kg/m^3}$) and will crush if the force-per-unit-area exceeds the compressive strength S (measured in $\mathrm{N/m^2}$). [Compressive strength $S \approx 3 \times 10^6\,\mathrm{N/m^2}$ for eastern white pine, compressed perpendicular to grain; density (dry) is about $\rho \approx 400\,\mathrm{kg/m^3}$.]

If you build a rectangular pile of lumber, of height h and cross-section A, how much weight (measured in newtons) does the bottom of the pile need to support?

How much pressure, or stress, measured in $\mathrm{N/m^2}$, does the bottom surface need to support?

How big is h when the pressure (or stress) on the bottom reaches the maximum allowed value, S ?

You have a cubic box, 1 meter on a side. Its mass is 1500 kg.

When it is on the ground, how much force must you exert to lift it (at constant velocity, i.e. negligible acceleration)? (Let's use $g = 10\ \mathrm{m/s^2}$ for convenience.)

If you put this box in water, will it float?

You have a cubic box, 1 meter on a side. Its mass is 1500 kg.

When it is on the ground, how much force must you exert to lift it (at constant velocity, i.e. negligible acceleration)? (Let's use $g = 10 \text{ m/s}^2$ for convenience.)

If you put this box in water, will it float?

If the box is sitting on the bottom of a swimming pool, what is the buoyant force acting on the box? In which direction?

If you want to lift the box while it is fully immersed in water, how large a force must you exert?

Once you start lifting, how high can you go before the box requires a larger force to continue lifting?

Equation of continuity

Expresses the fact that mass is not accumulating anywhere, for a steady flow of fluid. Time rate of mass flowing past a given surface of cross-sectional area A is constant:

$$\frac{\Delta m}{\Delta t} = \text{constant}$$

$$\frac{\Delta m}{\Delta t} = \rho \; A \; \frac{\Delta x}{\Delta t} = \rho \; A \; v = \text{constant}$$

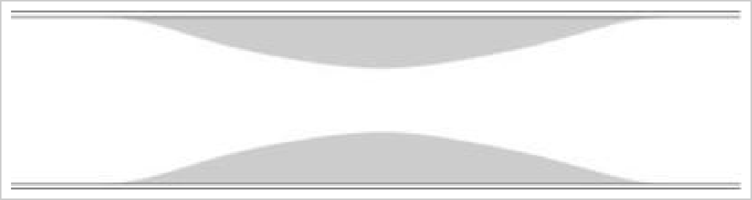
And if density ρ is constant (i.e. incompressible fluid), then

$$A \; v = \text{constant} \quad \Rightarrow \quad A_1 v_1 = A_2 v_2$$

For example, the water running out of your faucet is accelerating (gravity), so the area must decrease as the speed increases.

Another example: river flows at higher speed where it is narrower.

Water flows through an old plumbing pipe that is partially blocked by mineral deposits along the wall of the pipe. Through which part of the pipe is the fluid speed largest?

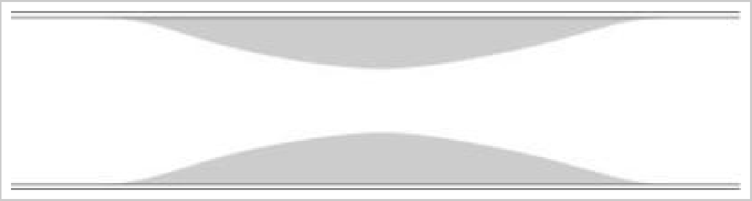


(A) Fastest in the narrow part.

(B) Fastest in the wide part.

(C) The speed is the same in both parts.

Water flows through an old plumbing pipe that is partially blocked by mineral deposits along the wall of the pipe. Through which part of the pipe is the flux (volume of water per unit time) largest?



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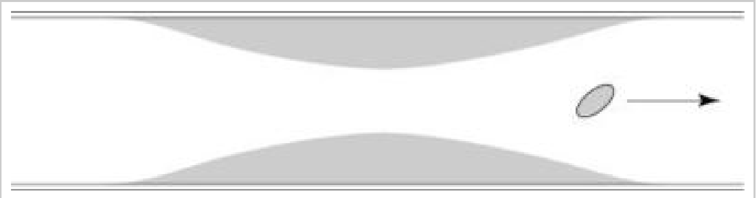
A water-borne insect drifts along with the flow of water through a pipe that is partially blocked by deposits. As the insect drifts from the narrow region to the wider region, it experiences



(A) a forward acceleration (it speeds up)

(B) a backward acceleration (it slows down)

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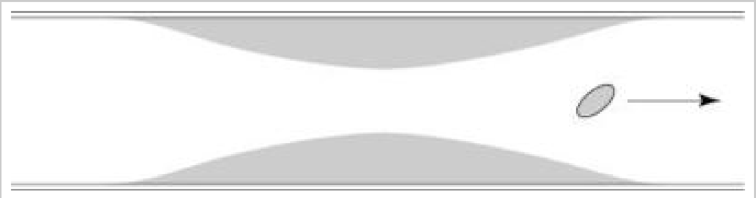

(A) a forward acceleration (it speeds up)

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If you said that the speed changes, now ask yourself: Is there a net force (per unit area) that causes this change in speed?

This one is trickier

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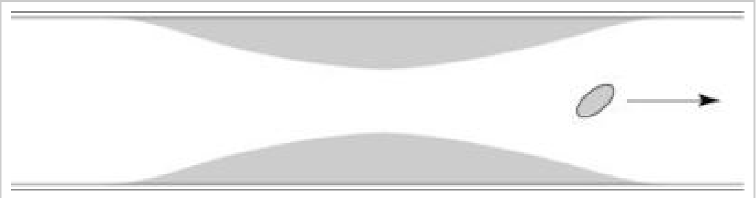

(A) an increase in water pressure ($P_{\text{wide}} > P_{\text{narrow}}$)

(B) no change in water pressure ($P_{\text{wide}} = P_{\text{narrow}}$)

(C) a decrease in water pressure ($P_{\text{wide}} < P_{\text{narrow}}$)

Hint: is the speed the same or different? Is there a net force (per unit area) that causes this change in speed?

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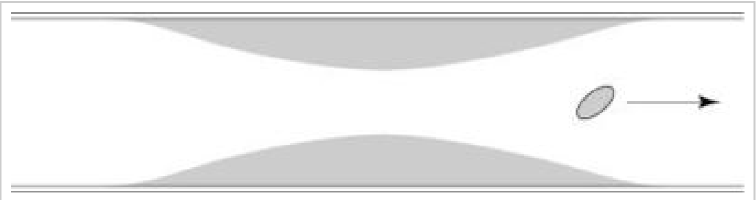

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Hint: is the speed the same or different? Is there a net force (per unit area) that causes this change in speed?

Stop to ponder the net force acting on the insect when insect is just upstream of vs. just downstream of the narrow region.

Buoyancy demo: bottle of blue water; diet coke; coke; pepsi.

How can we make the water a bit more dense? Hint: swim at ocean vs. lake/pool.

We've been looking for a while now at the equation

$$\Delta P = -\rho g \Delta y$$

which says that the pressure in a stationary incompressible fluid increases in proportion to depth.

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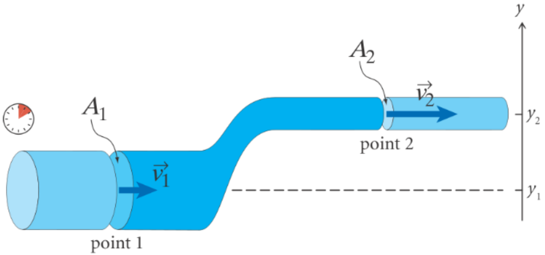
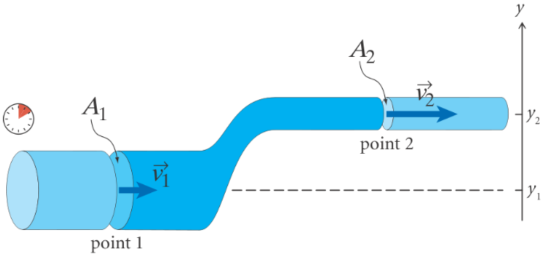
We just saw in the insect-in-pipe example that pressure seems to increase when flow speed is slower, and pressure seems to decrease when flow speed is faster.

We can use "Bernoulli's equation" to make sense of both of these facts, by considering **conservation of mechanical energy** for an incompressible fluid.



Consider the mechanical energy of a little chunk of fluid flowing through a pipe, from point 1 to point 2.

If $v_2 > v_1$, what form of mechanical energy has increased?



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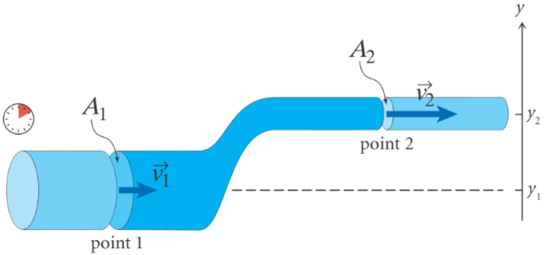

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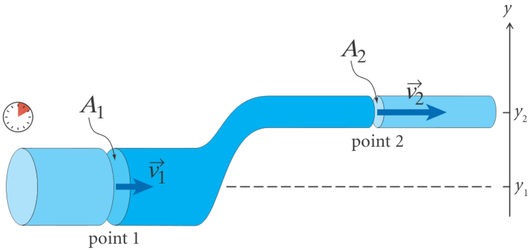
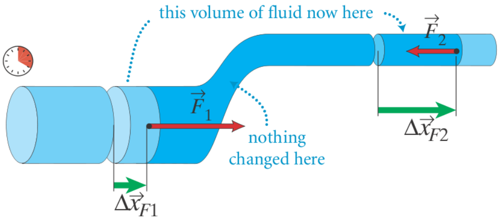
If $v_2 > v_1$, what form of mechanical energy has increased?

If $y_2 > y_1$, what form of mechanical energy has increased?

Suppose the combined kinetic + potential energy of this chunk of fluid has increased from point 1 to point 2. So some external agent has done work to provide this energy.

Work is force times displacement. What force (per unit area) could perform this work on that chunk of fluid?





$$(P_1A_1)(v_1\Delta t) - (P_2A_2)(v_2\Delta t) = \frac{1}{2}m(v_2^2 - v_1^2) + mg(y_2 - y_1)$$

$$(P_1 - P_2)(\text{Volume}) = (P_1 - P_2)\frac{m}{\rho} = \frac{1}{2}m(v_2^2 - v_1^2) + mg(y_2 - y_1)$$

Pressure in a fluid depends both on depth and on speed. To analyze this, we consider mechanical energy of the fluid.

Notice PV has units of energy, and of course work has units of energy. (Work = force × displacement.)

$$(\text{pressure})(\text{volume}) = \left(\frac{\text{force}}{\text{area}}\right)(\text{area} \times \text{length}) = (\text{force})(\text{length})$$

If a difference in pressure causes a volume of fluid to be displaced, that pressure difference is doing work on the fluid, thus changing the fluid's energy.

In the absence of friction (a.k.a. "viscosity,"), we expect mechanical energy to add up. So we set the work done (due to the pressure difference) equal to the change in mechanical energy: $(\text{work}) = \Delta\,(\text{energy})$.

$$(P_1 - P_2)V = \frac{1}{2}m(v_2^2 - v_1^2) + mg(y_2 - y_1)$$

$$(P_1 - P_2)V = \frac{1}{2}m(v_2^2 - v_1^2) + mg(y_2 - y_1)$$

rearranging terms, we get

$$P_1 V + \frac{1}{2}mv_1^2 + mgy_1 = P_2 V + \frac{1}{2}mv_2^2 + mgy_2$$

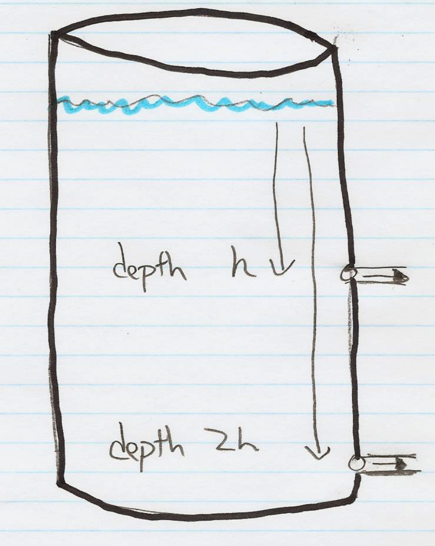
If we divide all terms by volume, we get *Bernoulli's equation:*

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

or in this more compact form:

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

Strictly speaking, Bernoulli's equation only works if the fluid is incompressible, if the flow is steady and non-turbulent, and if there is no dissipation of energy by friction. But it's handy for estimation even in cases where it is not strictly valid.



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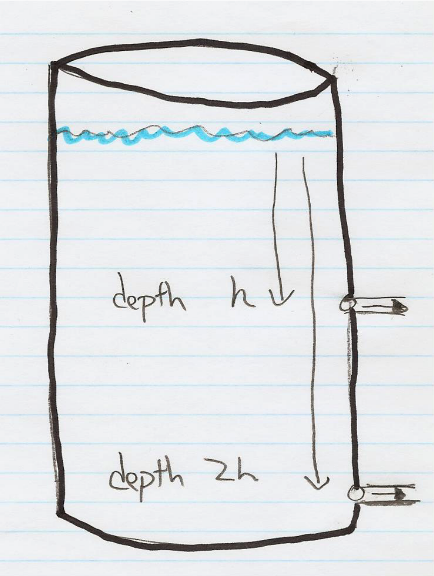


A large, water-filled cylinder has two horizontal spigots. Spigot 1 is at depth h, and spigot 2 is at depth $2h$. If I neglect the small downward motion of the top surface of the water, what I can I say about the horizontal velocity v_x of the water emerging from each spigot?

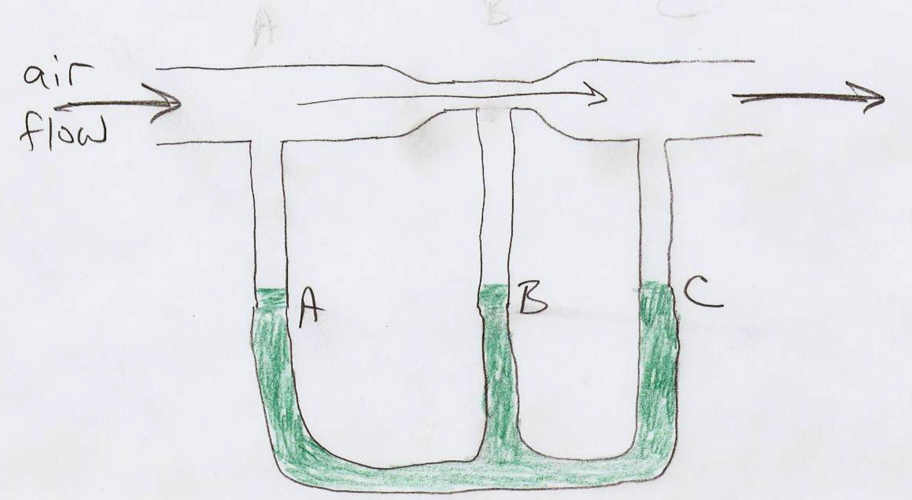
(A) $v_{2x} = \frac{1}{2} v_{1x}$

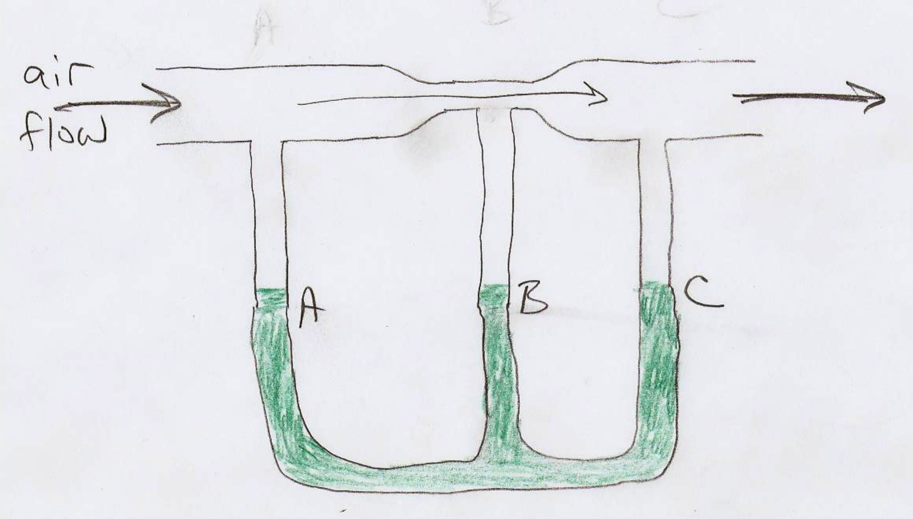
(B) $v_{2x} = \sqrt{2} v_{1x}$

(C) $v_{2x} = v_{1x}$

(D) $v_{2x} = 2 v_{1x}$

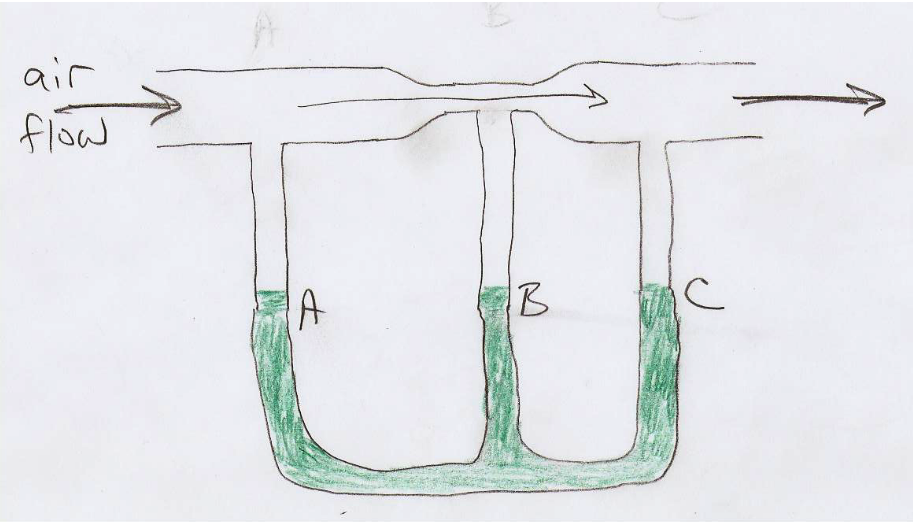
This experiment combines the "equation of continuity" with Bernoulli's equation. When I open the valve, compressed air will flow from left to right through the horizontal tube. The tube is wide on the left and right, but narrow in the middle. Where is the speed largest? Where is the pressure lowest? How will height of the green liquid respond to changes in pressure in the horizontal tube?





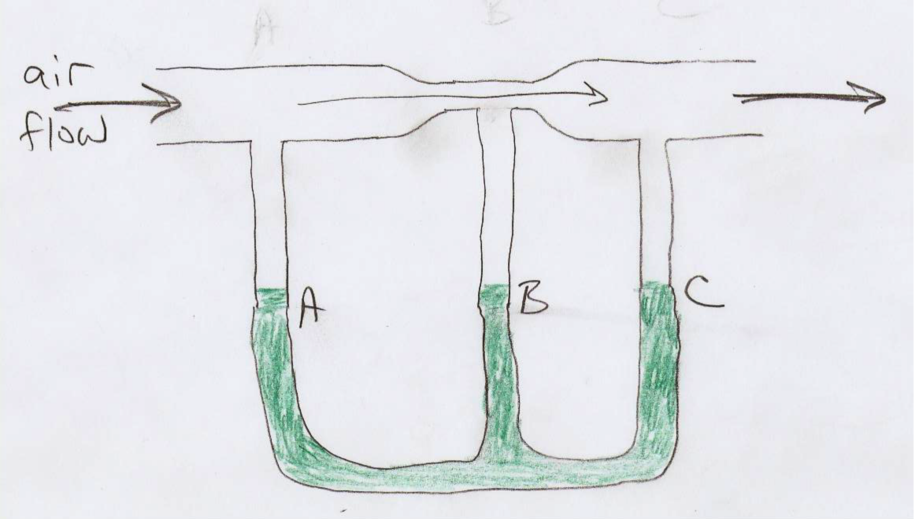
Once I turn on the air flow, the horizontal speed of the flowing air will be

(A) fastest above tube B
(B) slowest above tube B
(C) the same above all tubes



Once I turn on the air flow, the air pressure above the green liquid will be

(A) lowest in tube B
(B) highest in tube B
(C) the same in all tubes



Once I turn on the air flow, the height of the green liquid will be

(A) lowest in tube B

(B) highest in tube B

(C) the same in all tubes

What gauge pressure in the water mains is necessary if a firehose is to spray water to a height of 10 meters? (Use $g = 10\ \mathrm{m/s^2}$ and ignore all friction or other dissipative effects.)

(a) $10^3\ \mathrm{N/m^2}$ (b) $10^4\ \mathrm{N/m^2}$ (c) $10^5\ \mathrm{N/m^2}$ (d) $10^6\ \mathrm{N/m^2}$

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How many atmospheres is this?

If the "gauge pressure" is 1 atm, what is the absolute pressure?

What is the speed at which water flows from a faucet if the pressure head is 20 meters? (In other words the height of the nearby water tower is 20 meters above the height of the faucet.) Neglect all friction or other dissipative effects. Use $g = 10 \text{ m/s}^2$.

(a) 5 m/s (b) 10 m/s (c) 14 m/s (d) 20 m/s

What is the volume rate of flow of water from a 2 cm-diameter faucet if the pressure head is 20 meters? (In other words the height of the nearby water tower is 20 meters above the height of the faucet.) Neglect all friction or other dissipative effects. Use $g = 10\ \mathrm{m/s^2}$. Use $\pi \approx 3$.

(a) $6\ \mathrm{cm^3/s}$ (b) $0.6\ \mathrm{L/s}$ (c) $6\ \mathrm{L/s}$ (d) $6\ \mathrm{m^3/s}$

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This seems unrealistically fast, even though a 20 meter (2 atm) pressure head is not unrealistic. What are we neglecting?!

If the wind blows horizontally at speed $v = 10\ \mathrm{m/s}$ over a house (that's about 22 mph), what is the net force on a flat roof of area $A = 100\ \mathrm{m}^2$ (that's about 1100 sqft)? For the density of air, use $\rho = 1.3\ \mathrm{kg/m^3}$.

recap

pressure: $P = F/A$. $1 \text{ Pa} = 1 \text{ N/m}^2$. $1 \text{ atm} = 101323 \text{ Pa} = 760 \text{ mm-Hg}$.

Pascal's principle: if an external pressure is applied to a confined fluid, the pressure at every point within the fluid increases by that amount.

Archimedes' principle: the buoyant force on an object immersed (or partially immersed) in a fluid equals the weight of the fluid displaced by that object.

Equation of continuity: $\rho_1 A_1 v_1 = \rho_2 A_2 v_2$

Bernoulli's equation (neglects viscosity, assumes constant density):

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

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