Workshop Tutorials for Introductory Physics

Solutions to PI3: **Fluid Flow**

A. Review of Basic Ideas:

Fluid flow

By definition, a fluid is a substance which can **flow**. As over 70% of the earth's surface is covered with **water**, and the **air** above is also a fluid, it is important to understand how fluids flow.
Fluids will flow from a region of **high** pressure to one of **lower** pressure. This is how we breathe.

When we inhale, we increase the volume of our chest. This **decreases** the pressure in our lungs, and air flows in. To exhale we allow the chest to collapse back to its smaller volume, which **increases** the pressure inside the lungs. This causes the air to flow out again.

When a fluid flows steadily along a pipe, the **volume** rate of flow must be constant along the pipe. This means that if you measure the volume passing through one section of a pipe, as long as there are no holes in the pipe and the fluid is **incompressible**, the same volume will flow through any other section of the pipe in a given time. This is true even if the pipe gets wider or narrower. In a narrow section the fluid will flow faster, and it will flow more slowly in a wide section.

This is very important in the lungs. The total blood flow going up the pulmonary arteries from the **heart** to the lungs must be the same as the flow through the capillaries, around the lungs, and back down the pulmonary veins to the heart to be pumped out to the body. In between, millions of tiny **capillaries** each take a tiny flow of blood, and all together give a large flow.

A useful way of visualizing the flow of fluids is with streamlines. A streamline is the path of a particle of the fluid. The velocity of the particle is always **tangent** to the streamlines. We can trace streamlines in air by adding a little smoke to the air, or in fluids by adding a few drops of dye.

Flow rate also depends on **viscosity**. Viscosity is a measure of the **friction** between molecules in the fluid, the more friction, the slower it will flow. If there were no frictional forces between the molecules, fish couldn't **swim**, and **birds** couldn't fly.

Discussion question:

If water had zero viscosity it would not be possible to row, the water would move but not provide any resistance to the oar, and hence you couldn't push a boat along. Birds also rely on viscosity to be able to fly, by pushing the air with their wings. Birds would still be able to glide, but not fly if there was no viscosity.

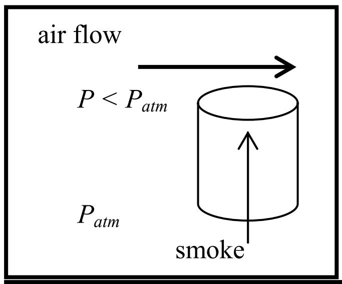
B. Activity Questions:

1. Hot honey

The mass and volume of the honey change very little when it is heated. However the viscosity changes a lot, the honey goes from flowing very slowly, to very quickly as its viscosity decreases.

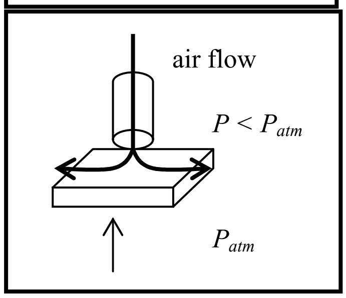
2. Chimney effect .

The air rushing past the top of the chimney has lower pressure than the air in the chimney. There is a net upward force on the air and foam balls in the chimney, and the air and the balls rise. This effect is also used by burrowing animals to ventilate their burrows



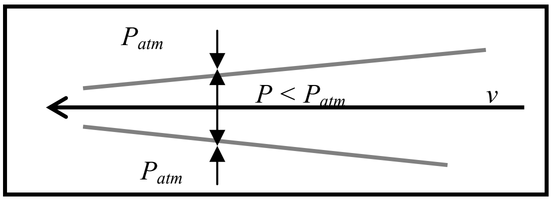
3. Blowing and lifting

As air rushes through the narrow gap it speeds up and the pressure drops. There is atmospheric pressure under the polystyrene so the pressure difference results in a force up, equal and opposite to the weight of the polystyrene.



4. Two sheets of paper

There is reduced pressure between the sheets of paper and they move inwards. Other examples are passing vehicles and the lower end of a shower curtain curling towards the water.



C. Qualitative Questions:

1. Viscosity and density are different.

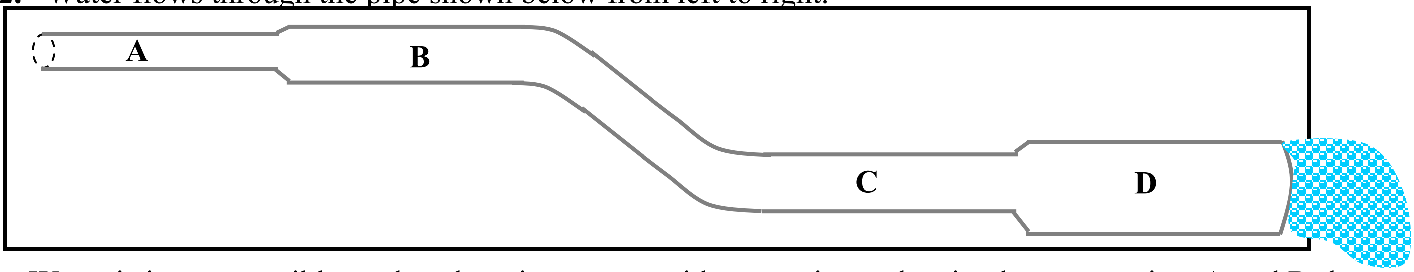
a. Viscosity is a measure of how easily a fluid flows, the less easily it flows, the greater the viscosity. Viscosity depends on the frictional forces of the fluids. Density is mass per unit volume, the greater the mass of a given volume, the greater the density.

b. Mercury liquid has high density and low viscosity, it is dense but flows easily.

c. Thickened cream has low density and high viscosity.

d. Spiders move by pumping fluid into and out of their legs, so when it gets colder the fluid becomes more viscous and it is harder for them to pump it in and out and they move slowly.

2. Water flows through the pipe shown below from left to right.



a. Water is incompressible, and as there is no water either entering or leaving between points A and D the volume flow rate must be same at all points, just as current must be the same at all points along an arm of an electrical circuit. This is called the principle of continuity- $A \times v$ = constant.

b. As the water flows from **A** to **B** the area increases, hence to maintain continuity v must decrease, therefore $v_A > v_B$. As the water then flows downhill to point **C** it will gain energy, however the area has not changed so we know, because of continuity, that the velocity has not changed, $v_B = v_C$. When the water flows from **C** to **D** the area increases again, so the velocity will decrease again, $v_C > v_D$. The ranking is therefore $v_A > v_B = v_C > v_D$.

c. When the water flows from **A** to **B** there is no change in gravitational potential energy, however the velocity has decreased which means that the kinetic energy of the water has decreased. By conservation of energy we know that if kinetic energy decreases, some other form of energy must increase. If we look at Bernoulli's equation, $\rho gh + \frac{1}{2}\rho v^2 + P$ = constant, (which is a statement of conservation of energy density), we can see that the pressure must have increased, $P_B > P_A$. When the water flows downhill from **B** to **C** it loses gravitational potential energy, but the velocity and hence kinetic energy does not change. The pressure must again increase in going from **B** to **C**, $P_C > P_B$. Finally, as the water flows from **C** to **D** the velocity decreases again and the pressure must once more increase, $P_D > P_C$. So the final pressure ranking will be $P_A < P_B < P_C < P_D$

D. Quantitative Question:

Smoking causes inflammation of the bronchioles. Air is flowing down a normal section of a bronchiole with a diameter of 1 mm at a velocity of 0.5 m.s^{-1}.

a. Part of the bronchiole is narrowed due to inflammation, and has a diameter of only 0.7 mm. We can use continuity to find the flow rate in this region: $A_1v_1 = A_2v_2$.

$v_2 = A_1v_1 / A_2 = \pi r_1^{\,2} \times v_1 / \pi r_2^{\,2} = \pi(\frac{1}{2} \times 1.0 \times 10^{-3}\text{ m})^2 \times 0.5\text{ m.s}^{-1} / \pi(\frac{1}{2} \times 0.7 \times 10^{-3}\text{ m})^2 = 1.0\text{ m.s}^{-1}$.

b. If the air moves past the surfaces much faster then the oxygen spends less time in contact with the gas exchange surfaces and is less likely to be absorbed, decreasing the oxygen supply to the body. To compensate for this the lungs and heart have to work harder to get more oxygen and move it around more effectively.