Viscosity

by

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Theory

Viscosity is a measure of a fluid's resistance to relative motion within the fluid. Highly viscous fluids do not readily flow. The viscosity of a fluid usually varies with temperature. For a fluid flowing through a pipe in laminar flow, viscosity is one of the factors determining the volume flow rate.

Poiseuille's law:

$$Q = \frac{\pi \Delta \mathrm{P} \mathrm{r}^4}{8\eta L}$$

Volume flow rate = π * (pressure difference) * (pipe radius)^4 / [8 * viscosity * (pipe length)]

It is often important to know the viscosity of a fluid. A viscosimeter is the instrument used to measure viscosity. The study of the viscosity of substances is known as rheology.

Example:

> In order to keep the pistons moving smoothly in the cylinders of the internal combustion engine in a car, a thin film of motor oil between the piston rings and the cylinder wall acts as a lubricant. The oil must be able to keep the piston moving smoothly, when the engine first starts up and is still cold and when the engine reaches its high operating temperature. One way of measuring an oil's ability to lubricate is to measure its viscosity.

In this session you will determine the viscosity of different brands of "Volumizing Shampoo" using Stokes' law. You will use a fluid column as a viscometer and measure the rate of descent of a steel sphere, as it falls under the influence of gravity through the fluid, after the sphere has reached terminal velocity.

George Gabriel Stokes, an Irish-born mathematician, worked most of his professional life describing fluid properties. **Stokes' law** gives the force required to move a sphere through a viscous fluid at a specific velocity, as long as the flow around the sphere is laminar and the Reynolds number is low (Reynolds number < 1).
Stokes' Law is written as

$$F = 6\pi\eta r v$$

Here r is the radius of the sphere, v the speed and η the viscosity.

Apparatus

- Shampoo bottle with metal sphere and linear scale
- Magnet
- Webcam

Open a Microsoft Excel spreadsheet to keep a log of your experimental procedures, results and discussions. This log will form the basis of your lab report. Address the points highlighted in blue. Answer all questions.

Exercise 1

- Lay your hands on the table in front of you and locate a bulging vein. Slowly raise your hand until it is well above your head while constantly watching that vein. What happens? What height above your shoulders do you first notice a change? Describe your observations.
  Slowly lower your hand while still watching the vein. Repeat the process. Do you have an explanation for your observations?

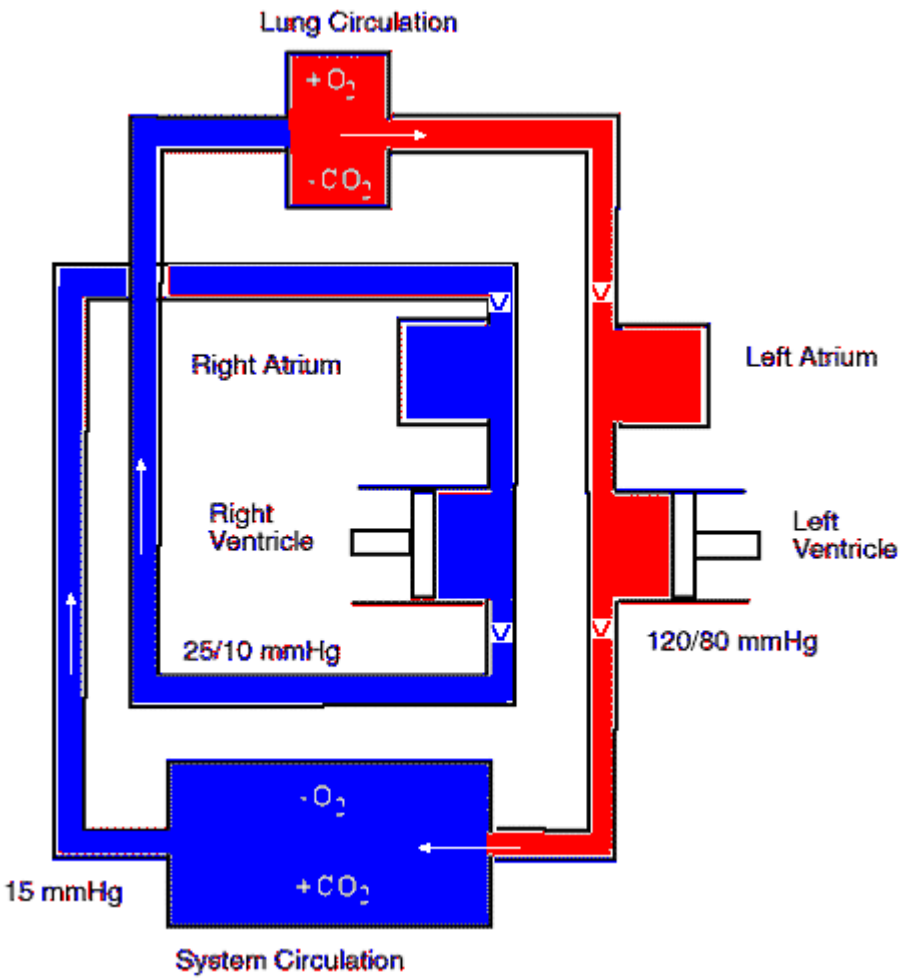
- Lay two thick books about 10 cm apart. Place a sheet of paper on the books so that it bridges the gap between them. Try to blow the paper off the books by blowing underneath it. Describe what happens. Do you have an explanation for your observations?

- Hold two sheets of paper vertically about 5 cm apart. Blow the sheets apart by blowing hard between them. Describe what happens. Do you have an explanation for your observations?

Record your observations and explanations in your log.

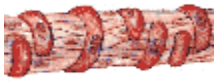
Exercise 2

Blood is a viscous fluid circulating through the human body. The circulatory system is a closed-loop system with two pumps. One-way valves keep the flow unidirectional. A sketch is shown below. The unit of pressure in the sketch is mmHg. (1 atm = 760 mmHg)



During heavy exercise, the blood's volume flow rate is 5-10 times higher than when the body is at rest. Discuss different possible ways that a body can accomplish this?

- Is increasing blood pressure 5 - 10 times higher a viable option? What percentage increase in blood pressure is reasonable? Explain!
- Is decreasing the length of your blood vessels a viable option? Explain!
- The arterioles (small arteries) are surrounded by circular muscles.

  In order to increase the blood flow rate by a factor of 5, what percentage increase in the radius of a blood vessel is needed? (This is called vasodilatation.)
- Arteries in the human body can be constricted when plaque builds up on the inside walls. How does this affect the blood flow rate through this artery? Is it possible for the body to keep the flow rate constant? Explain!

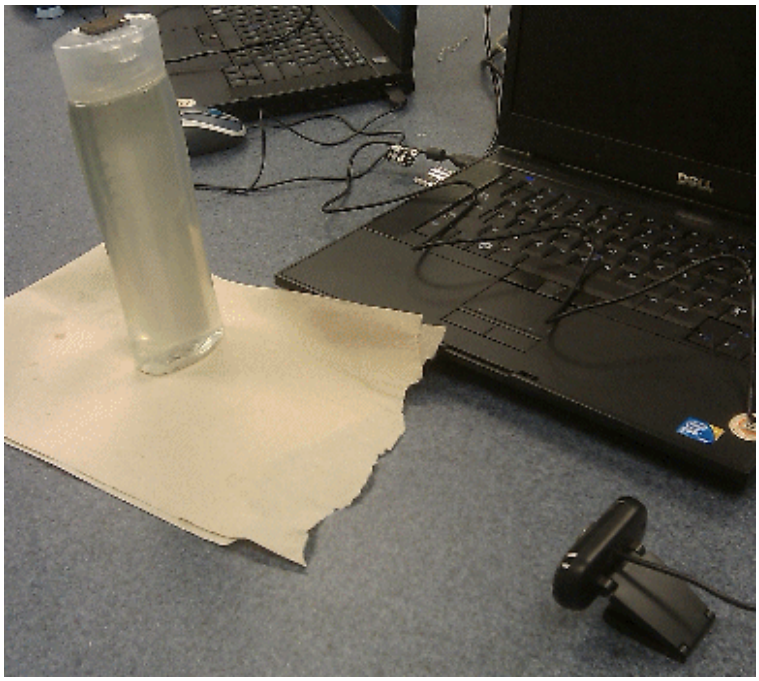
Record your explanations in your log.

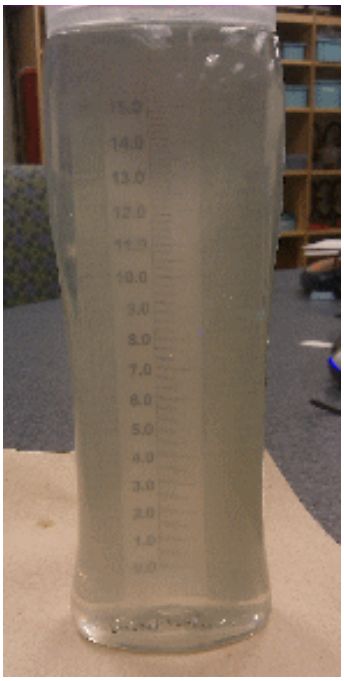
Experiment 1

Students will work as a group on this experiment. All groups will compare their results and predictions.

Measure the rate of descent of a steel sphere, as it falls under the influence of gravity through the shampoo.

- Start with the steel sphere held near the middle of the lid of the shampoo bottle by the magnet. Make sure all the bubbles have risen and the fluid is quiet.
- Connect a webcam to one computer.
- Start Movie Maker.
- Choose "Webcam video".
- Position the camera so it has a good view of the shampoo bottle and the scale.



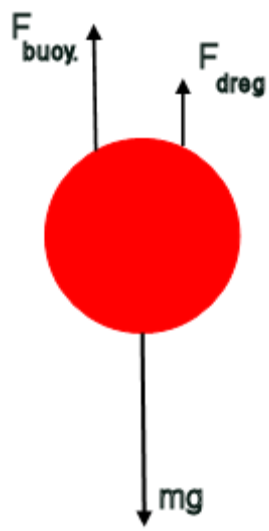


- Remove the magnet and wait for the ball to drop. Make sure it does not contact the wall of the bottle.
- When the ball has fallen ~2 cm start capturing.
- Stop capturing when the ball reaches the bottom of the bottle. Save your movie.
- Review your movie on the timeline. You can pause it at any frame. Pause the video when the sphere is in front of the scale at 12 cm, 11 cm, ..., 2 cm, and enter these times into the Excel spreadsheet.

position (cm)	time (s)
12	
11	
10	
9	
8	
7	
6	
5	
4	
3	
2	

- Plot position (vertical axis) versus time (horizontal axis). Verify that the plot resembles a straight line. This verifies that the sphere moves with constant, terminal velocity. Find the speed of the sphere by adding a linear trendline. The magnitude of the slope of this trendline is the speed (positive number) of the sphere.

Data Analysis:



The forces acting on the sphere are gravity, the buoyant force, and the viscous drag force given by Stokes' law. A free body diagram is shown on the left. Since the sphere moves with constant velocity, the net force is zero.

$$F_{\text{drag}} + F_{\text{buoyant}} = mg$$
$$6\pi\eta r_{\text{sphere}} v + \rho_{\text{fluid}} V_{\text{sphere}} g = \rho_{\text{sphere}} V_{\text{sphere}} g$$
$$6\pi\eta r_{\text{sphere}} v + \tfrac{4}{3}\pi\rho_{\text{fluid}} \left(r_{\text{sphere}}\right)^3 g = \tfrac{4}{3}\pi\rho_{\text{sphere}} \left(r_{\text{sphere}}\right)^3 g$$
$$\eta = \frac{2\left(\rho_{\text{sphere}} - \rho_{\text{fluid}}\right)\left(r_{\text{sphere}}\right)^2 g}{9v}$$

The density of the "Volumizing Shampoo" is very close to that of water, ρ_{fluid} = 1.03 g/cm^3.

The density of the stainless steel ball is 7.866 g/cm^3, and its diameter is 1/4 inch = 0.635 cm.

- Calculate the viscosity η of the shampoo using your measured velocity in units of poise = g/(cm-s). Use the densities in units of g/cm^3, the speed in units of cm/s, the radius of the sphere in units of cm and g = 981 cm/s^2.
  (1 Pa-s = 1 kg/(m s) = 10 g/(cm-s) = 10 poise)

- Calculate the Reynolds number

$$R = \frac{2\rho_{\text{fluid}} r_{\text{sphere}} v}{\eta}$$

  It is a dimensionless number. Check that the Reynolds number is less than 1, so that we are in the regime where Stokes' law is valid.
- Compare your value for η with the value obtained by the other groups. Do the values agree?
- The table below lists typical viscosities of some viscous fluids at room temperature. Does your value for the viscosity of the shampoo seem reasonable? Discuss.

fluid	viscosity (Pa-s)
honey	2 - 10
molasses	5 - 10
ketchup	50 - 100
chocolate syrup	10 - 25

- Predict the terminal velocity of a sphere made of the same material but with diameter of 3/8 inch in the same fluid. One group should measure it.

Record your results and conclusions in your log.

References

[1]http://labman.phys.utk.edu/phys221core/Studio%20sessions/Studio%20Session%209.html