I. Before you come to lab:

1. Read this handout and the supplemental.
2. Review the second half of lecture 7 on drag forces. It's been a while since we dealt with these concepts, so you'll want to have them fresh in your mind for this lab.

II. Learning Objectives

1. Learn how fluids such as blood exert a pressure that varies with height
2. Understand the motion of objects in fluids and how it depends on viscosity and density.

III. Materials

- Digital video camera and props, including ruler and red cardboard for backdrop
- 25 mL graduated cylinder filled with corn syrup
- 600 mL beaker for hot water
- Forceps
- Box containing spheres of different materials, all with 1/16'' radius
- Lab jack
- Blood pressure sensor

The blood pressure sensor consists of an inflatable cuff with connects to a pressure sensor, which is the small box that connects to the computer and interfaces with Logger Pro.

IV. Warm up

For this warm up, it will probably be easier (for you and for the grader) to write down your derivations on paper and include pictures here, instead of typing the derivations directly.

A uniform sphere of radius r and density ρ is submerged in a fluid whose density is ρ_{fluid}. The object begins to sink under the influence of gravity. **Draw a free-body diagram of the sphere.** Do not ignore the interactions between the fluid and the sphere. *Hint*: you should have three forces.

FBD:

After a while, the sphere will reach terminal velocity, v_{term}. When moving at terminal velocity, the acceleration of the sphere is zero. **Derive an expression for the density of the sphere as a function of v_{term}, assuming the dominant drag force is pressure drag.** The formula for pressure drag is $\frac{1}{2} c_D A \rho_{\text{fluid}} v^2$, where A is the cross-sectional area of the object. *Hint*: Think FANCLAN!

ρ (assuming pressure drag):

Derive an expression for the density of the sphere as a function of v_{term}, assuming the dominant drag force is viscous drag. The formula for viscous drag for spheres, known as Stokes Law, is $6\pi\eta rv$.

ρ (assuming viscous drag):

Assume you repeat the experiment several times for spheres with the same radius but different densities, all sinking in the fluid, and determine the terminal velocity of each sphere. (The density of the sphere is known, as is the common radius.) You then construct a plot of density vs. terminal velocity. **How could you determine if the dominant drag force was pressure drag or viscous drag?**

A:

V. Procedure

Tell us who you are (names, pictures, and emails, please)

A:

Part 1: Blood pressure

In this part of the lab, you will measure your own blood pressure at your upper arm using the blood pressure sensor and think a little bit about how the sensor works.

NOTE: If you do not feel comfortable performing any portion of the lab, feel free to borrow a friend's data for the portion in question.

IMPORTANT SAFETY WARNING: Before you begin taking data, make sure that you know how to release the pressure in the cuff (by pressing on the valve). If the pressure in the cuff gets high enough to be painful to the patient, release it immediately. For most people, it will not be painful to reach a pressure of 170 or 180 mmHg (though it is mildly uncomfortable; after all, the idea is to cut off blood flow to the arm temporarily).

Instructions on how to use the pressure sensor are included in the supplemental. Make sure you understand them well before continuing.

Estimate the volume of air in the cuff when it is wrapped around the patient's arm and inflated. The cuff is 14 cm wide. *Hint*: you will have to estimate your arm's radius and how thick the cuff is when it is fully inflated. You can use a piece of string to measure the circumference of both your arm and the cuff.

Volume =

Take the blood pressure of one of your lab mates ("Not-Patient 1") while he/she is sitting down on a high chair, with his/her arm resting on the table. **What is the not-patient's systolic and diastolic blood pressure (in mmHg)?**

Systolic =

Diastolic =

The air in the cuff obeys Boyle's Law (PV = constant) during the time when it is wrapped around your arm. Assume that the total volume (volume of arm + volume of cuff) is constant, such that the increase in volume of the brachial artery during each pulse is equal to the amount by which the air in the cuff decreases. Using your data, **estimate by how much the volume of your arm changes during each heartbeat.** *Hint*: If the changes in P and V are small, the Boyle's Law can be written as: $\Delta P/P = -\Delta V/V$.

A:

Attach the blood pressure cuff to another lab mate's ("Not-Patient 2") arm, and measure the not-patient's blood pressure. **What are the not-patient's systolic and diastolic blood pressures (in mmHg)?**

Systolic =

Diastolic =

Retake Not-Patient 2's blood pressure with his/her arm resting on a lab jack. **What is the height of the center of the cuff in this position compared to when Not-Patient 2's arm was resting on the table?**

Height =

What are the not-patient's systolic and diastolic blood pressures in this case?

Systolic =

Diastolic =

By how much do these values differ compared to the previous values? Why do they differ?
A:

Based on the height difference, **calculate how much the blood pressure in your arm should differ by in the two configurations. How does this compare to your measurement?**
A:

Part 2: Terminal Velocity
In this part of the lab, you will drop small spheres into a viscous fluid (corn syrup, which will be familiar to all of you from the previous lab) and use video analysis techniques you learned in previous labs to determine the terminal velocity of each sphere. You will use the Logger Pro file called **"Lab6.cmbl"**, which is already set up to do this experiment, for data capture and analysis. You will fill out the table below with the measured terminal speed of the falling spheres. **Instructions on how to run this experiment are found in the supplemental.**

Using a pair of forceps, pick the white **Teflon** sphere and hold it in the corn syrup about an inch below the surface. Start recording, release the sphere, and remove the forceps from the fluid. Use video analysis techniques to obtain a **graph of the sphere's *y*-position vs. time**, and include a copy below.
Graph:

Is there a time when the sphere is accelerating? If so, when? If not, how do you know?
A:

Determine the terminal velocity of the sphere, with uncertainty. Write down the terminal velocity on the table below and on page 5 of the Logger Pro file.

Repeat the same procedure of each sphere. Note that each sphere has its own page on the Logger Pro file for you to use. There are several key differences to note each time:

- When setting the Video Analysis Options, change "Capture File Name Starts With" to the name of the material for each sphere you drop.
- Likewise, when setting the Data Set Options after you do each analysis, change the data set name to the name of the material. That makes it much easier to keep track of which data set corresponds to which sphere.
- You don't have to paste the graph and answer questions about it for each sphere. Just record the terminal velocity in the table below and on page 5 of the Logger Pro file.

Material	Density (kg/m^3)	Terminal velocity (m/s)	Uncertainty in terminal velocity (m/s)
Teflon	2198		
Titanium	4514		
Steel	7814		
Tungsten Carbide	15060		

After your table on page 5 is filled up, create a **graph of density vs. terminal velocity**. Paste a copy of it here:
Graph:

How can you determine which type of drag force dominates (pressure drag or viscous drag) from a plot of density vs. terminal velocity?
A:

Does the shape of your graph correspond to the dominant drag force being pressure drag or viscous drag?
A:

Fit the appropriate equations to your data, and write down the parameters below (with uncertainty):
A:

Use the expression you derived in the warm up, and your fit above, to **determine the density of corn syrup (with uncertainty).**
Density of corn syrup =

How does this compare with other known densities (such as water, air, the materials of the spheres)?
A:

By pouring corn syrup into a graduated cylinder on a precise balance, we directly measured its density to be 1.36 ± 0.01 grams per mL. **Does your measurement agree with this value?** (*Hint*: How does one answer scientific claims such as this?)
A:

Use the expression you derived in the warm up, and your fit above, to **determine the viscosity of corn syrup (with uncertainty).** The manufacturer reports that the **diameter** of the spheres is 125 ± 2 mils (1 mil is a thousandth of an inch) – which correspond to 3.18 ± 0.05 millimeters.
Viscosity of corn syrup =

How does this compare with other known viscosities? (The viscosity of water is about 10^{-3} Pa•s, canola oil is about 10^{-1} Pa•s, motor oil is 1 Pa•s, honey is 10 Pa•s, and various types of lava have viscosities of about 100 Pa•s and up.)
A:

Nylon has a density of 1060 kg/m^3. From your fit, predict the terminal velocity of a nylon sphere of the same size (1/8'' diameter) submerged in corn syrup.
Terminal velocity =

Does your answer make sense? Perform the experiment to convince yourself.
A:

Based on your calculated density and viscosity, **estimate the largest Reynolds number of the different spheres dropping. Is it small enough that viscous drag is a good assumption?**
Re =
A:

VI. Conclusion

What is the most important thing you learned today?
A: