Laboratory 11

Fluid Statics, Pressure, and Buoyant Forces

I. Introduction

In this exercise we will investigate some properties of non-moving fluids and the forces they exert on objects immersed in them. Two important physical properties associated with a fluid are its density ρ and the pressure it exerts P. The density ρ of a uniform substance is defined to be the ratio of its mass M to its volume V:

$$\rho \equiv \frac{M}{V} \ . \qquad [1]$$

In SI units, the density of air (at standard temperature and pressure) is 1.29 kg/m^3, the density of water is 1.000×10^3 kg/m^3, and the density of osmium (the densest element) is 22.61×10^3 kg/m^3.

Q1: What is the density of water in g/cm^3? Suppose we have 1 kg each of air, water, and osmium. How much volume does *each* occupy? If each is in the shape of a cube, how tall is the cube? In each case, give an example of a familiar object that is comparable to your cube's volume.

Any surface in contact with a fluid experiences a force; the fluid *pushes* on the surface in a direction perpendicular to the surface. The pressure P is defined as the ratio of the force F to the surface area A:

$$P \equiv \frac{F}{A} \ . \qquad [2]$$

In the SI system, the units of pressure are N/m^2, also known as *Pascals* (Pa). Since a large apple weighs about 1 N, to get some sense of how large 1 Pa is, you may imagine crushing an apple and spreading it over a 1 m × 1 m area. Frequently we use pounds per square inch (psi) as the units of pressure (a force of 1 lb = 4.455 N and a length of 1 inch = 0.0254 m).

Q2: How do you convert between psi and Pa? Air is a fluid, and we live under an ocean of air. The pressure of the air on us is one atmosphere, which is about 14.7 psi. With a reasonable estimate of the area of the top of your head, how many pounds of air is sitting on top of your head? Presuming you did the calculation correctly, why does this amount of air not crush you to death?

The pressure at any point in a stationary liquid (often called the *hydrostatic pressure*) comes from the weight of the liquid above that point, and this hydrostatic pressure points uniformly in all directions. It can be shown that at a depth h in a liquid of density ρ_{liquid}, the *gauge* pressure (as opposed to the *absolute* pressure), the amount by which the pressure exceeds normal atmospheric pressure, will be

$$P_{\text{gauge}} = \rho_{\text{liquid}} g h \ . \qquad [3]$$

The gauge pressure depends only on the depth, so all points in the liquid at the same depth below the surface will experience the same pressure. We have assumed that the liquid under consideration is *incompressible* so that its density does not change with pressure.

Any object totally or partially submerged in a liquid experiences a net upward force exerted on it by the liquid. This *buoyant* force arises from the hydrostatic pressure the liquid exerts at the bottom of the object being greater than the pressure at the top. *Archimedes's principle* states that the buoyant force equals the weight of the liquid the object displaces, or

$$F_{\text{buoyant}} = (\rho_{\text{liquid}} V_{\text{displaced}})g \ , \qquad [4]$$

where $V_{\text{displaced}}$ is the volume of the submerged portion of the object.

Q3: Suppose you are given the choice between two life preservers, the first a light one that is filled with Styrofoam and the second a very heavy one that is filled with osmium pellets, but both are identical in size. If you completely submerge these life preservers in water, upon which one will the buoyant force be larger?

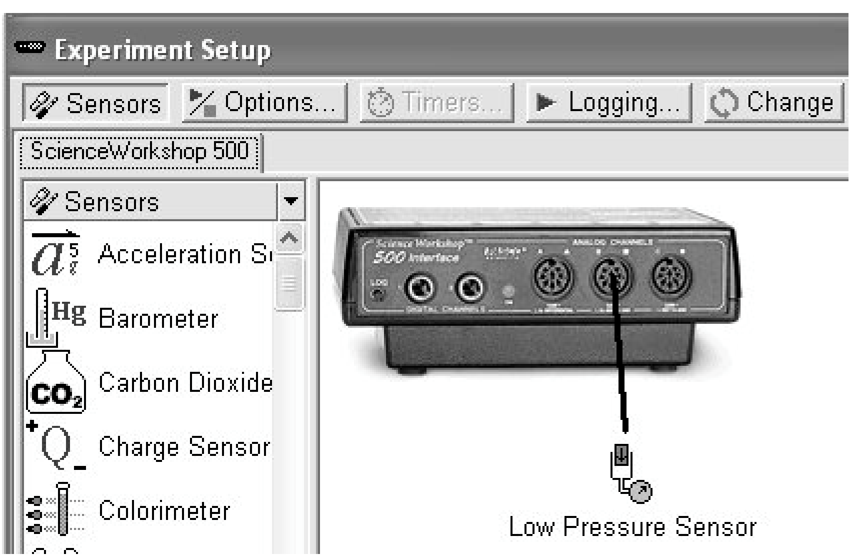
II. Hydrostatic Pressure as a Function of Depth

First we will measure the hydrostatic pressure P_{gauge} as a function depth h in water and test the validity of Eq. [3].

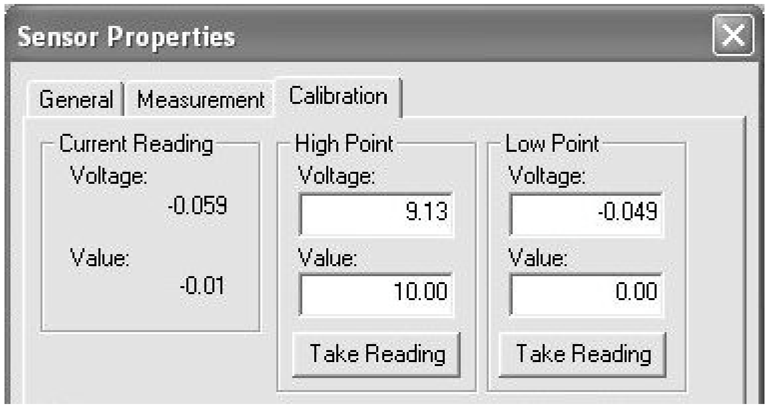
(1) Making sure that a pressure sensor is connected to Channel B of the computer interface, open the DataStudio file called "Pressure Sensor." Before using your pressure sensor, a "two-point" calibration must be performed. The "low point" is at the atmospheric pressure ($P_{\text{gauge}} = 0$) and the "high point" is at $P_{\text{gauge}} = 10.0$ kPa against a standard digital manometer (pressure meter).

(2) Click on the 

button. You should see the Experiment Setup window which indicates that your pressure sensor is connected to Channel B of the interface.



Now double-click on the "Low Pressure Sensor" icon, which should open the Sensor Properties window. Choose the Calibration tab.



With the tube of your pressure sensor open to atmospheric pressure, click on the 

button in the "Low Point" column. This calibrates the low point (the gauge pressure of atmosphere is zero).

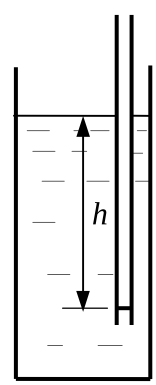
Now connect the tube of your pressure sensor to one of the ports of the pneumatic pump (the other port is connected to a digital pressure meter. Adjust the pump by turn its top knob until the digital meter reads 10.0 kPa. Click on the 

button in the "High Point" column to calibrate the high point. Click on OK and close the window. Disconnect your pressure sensor from the pump and it is ready for measurements.

(3) Click on the 

button to display pressure sensor readings. Insert the tube in water at 8 different depths and record the pressure readings. Dip a ruler in water and measure the depth *h*, which should be the difference between the water level in the jar and the water level inside the small plastic tube (not the lower end of the tube).

Depth *h* (m)	Pressure P_{gauge} (kPa)



(4) Using Microsoft Excel, plot P_{gauge} versus *h*, add a linear trendline, and display the equation on the graph.

Q4: Record the equation of the fit. What is the physical significance of the slope? Using the slope of the line, determine your experimental value for the density of water, compare it to the known value, and calculate a percent discrepancy.

III. Archimedes's principle

Now we want to verify Archimedes's principle (Eq. [4]) by measuring the buoyant forces on two objects, one that sinks in water and one that floats.

Q5: Measure the cylindrical PVC (poly vinyl chloride) block's mass (using a balance), its diameter, and its total height. Calculate its volume and its density.

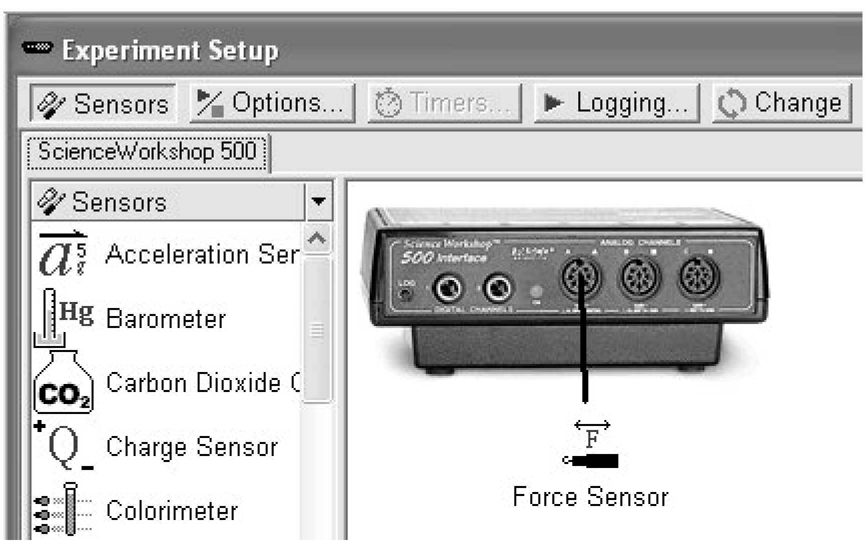
PVC block's mass (kg)	
PVC block's diameter (m)	
PVC block's total height (m)	
PVC block's total volume (m^3)	
PVC block's density (kg/m^3)	

Q6: Is the PVC block's density higher or lower than that of water? Do you expect it to sink in water or float on water?

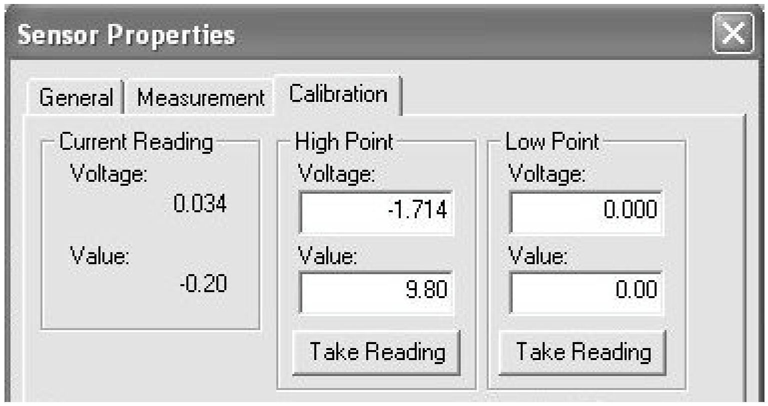
(1) Making sure that a force sensor is connected to Channel A of the computer interface, open the DataStudio file called "Force Sensor." Before using your force sensor, a "two-point" calibration must be performed. The "low point" is at F = 0 and the "high point" is at F = 9.80 N corresponding to the weight of a 1.00-kg mass.

(2) Click on the 

button. You should see the Experiment Setup window which indicates that your force sensor is connected to Channel A of the Interface.



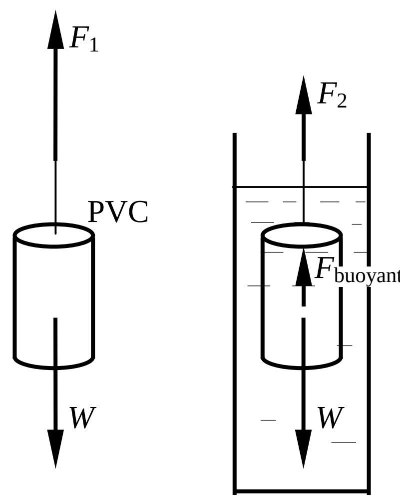
Now double-click on the "Force Sensor" icon, which should open the Sensor Properties window. Choose the Calibration tab.



With your sensor free of any force, click on Take Reading in the "Low Point" column. This calibrates the low point.

Attach a mass of exactly 1.00 kg to your force sensor. Click on Take Reading in the "High Point" column. This calibrates the high point. Click on OK and close the setup window. Take the mass off your force sensor and it is ready for measurements.

(3) We will now use the force sensor to directly measure the weight of a PVC rod and its apparent weight when submerged in water.



Q7: Attach the PVC block to the force sensor. Record the force sensor reading F_1. Do you think F_1 should be equal to its weight W? Why? Is your F_1 value consistent with its mass M measured earlier?

Q8: Measure the jar's inner diameter and mark the water level. Position the jar under the PVC block and raise the jar slowly until the block is completely submerged in water. Describe how the force sensor reading changes as the block is being submerged.

Q9: After the block is completely submerged, record the block's apparent weight in water (force sensor reading F_2). Also mark the new water level and record the difference between the two water levels.

PVC block's weight in air, F_1 (N)	
PVC block's apparent weight in water, F_2 (N)	
Difference between water levels (m)	
Inner diameter of jar (m)	

Q10: Why is the block's apparent weight smaller than its actual weight? (See the free-body diagrams on p.5.) What does the difference between F_1 and F_2 indicate? Record your experimental result for the buoyant force.

Experimental F_{buoyant} = ____________________.

Q11: Based on your measured water level difference and diameter of the jar, determine the volume of water being displaced by the block, and compare it with the total volume of the block found in **Q5.**

$V_{\text{displaced}}$ = ____________________.

Q12: Using Equation [4] and density of water, calculate a theoretical value for the buoyant force. How does the theoretical value compare with your experimental buoyant force in **Q10**?

Theoretical F_{buoyant} = _____________________.

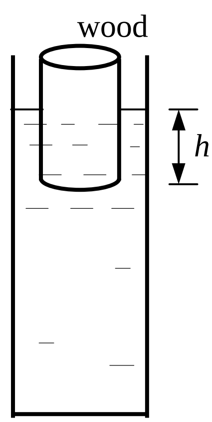
Percent discrepancy: _____________________.

(4) We will now experiment with a wooden block and investigate how it floats on water.

Q13: Measure the block's mass (using a balance), its diameter, and its total height. Calculate its total volume and its density.

Wooden block's mass (kg)	
Wooden block's diameter (m)	
Wooden block's total height (m)	
Wooden block's total volume (m^3)	
Wooden block's density (kg/m^3)	

Q14: Is the wooden block's density higher or lower than that of water? Do you expect it to sink in water or float on water?



(5) Place the wooden block in the water. It may tilt while floating. Gently use your fingers to keep it vertical without pushing it down or lifting it.

Q15: Dip a ruler in water and measure the depth h to which it submerges. Combine your h-value with the block's diameter to calculate the submerged volume of the wooden block.

Submerged volume of wooden block: ______________________.

Q16: Using Equation [4] and density of water, calculate the buoyant force. Using the mass value from **Q13**, calculate its weight. How does your buoyant force compare to the total weight of the wooden block. Why should the buoyant force be equal to the total weight of the block?

Buoyant force on wooden block F_{buoyant} = ________________.

Weight of wooden block W = ________________.

Percent discrepancy: __________________.

Q17: Consider the buoyant forces on a wooden block and a PVC block of the same size, both *completely* submerged. Which buoyant force is larger?

Q18: Given your answer to **Q17**, go back and reconsider your answer to **Q3**. Do you need to revise your answer? Perhaps this will help: Upon which life perserver, the Styrofoam or the osmium, is the bouyant force ineffective?

Challenge Questions

The relative densities of water, ice, and alcohol are 1.0, 0.9 and 0.8 respectively. Therefore, what can you say about a cocktail (a mixture of water and alcohol) in which the ice cubes lie at the bottom of the liquid?

Estimate the maximum weight of an object that a typical life preserver can keep afloat. Does the object's density matter?

Answer Sheet
Laboratory 11

Names: ________________________

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