Archimedes' Principle

Objectives

In this lab you will

- use Excel to plot mass and volume data for water to obtain its density.
- use Archimedes' Principle to measure the densities of Lucite, lead, and wood.
- measure weight using the Vernier Force Sensor.
- plot your data and analyze it using the Vernier Logger Pro™ software.

Equipment

Vernier Force Sensor, Vernier LabPro™ system (includes computer and Logger Pro™), graduated cylinder, solid Lucite cylinder, lead sinker, wooden block, support bracket (clamped to a small stand), clamps, plastic beaker, scale, and string.

Theory

The density ρ (Greek letter *rho*) of any material is defined as

$$\rho = \frac{m}{V}$$ **Equation 1**

where m is the mass of a sample of the material and V is its volume. By varying the size of the sample you will obtain different masses m_1, m_2, … corresponding to different volumes V_1, V_2, … When you plot your mass data along the y axis and your volume along the x axis, you will find that the points tend to follow a straight line of slope equal to the density since $m = \rho V$ from Equation 1, *i.e*. the equation has the form $y = ax + b$.

Another method of measuring density involves fully immersing the sample in a fluid, such as water. The sample experiences an upward buoyant force; as a result, it appears to weigh *less* according a standard scale (see Figure 1).

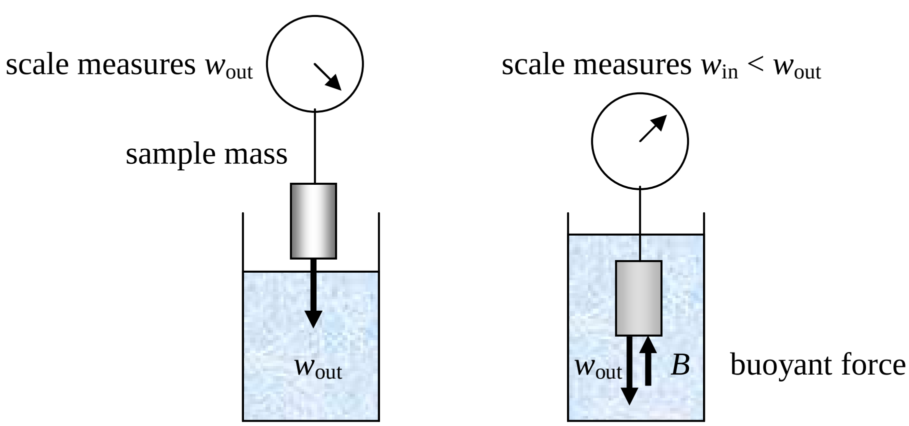


Figure 1

Let w_{out} denote the weight measured when the sample is *outside* of the fluid (*i.e.* its true weight) and let w_{in} denote the weight measured when the sample is *inside* the fluid (*i.e.* itse apparent weight). Then the magnitude of the buoyant force B is simply the difference between these two weight measurements:

$$B = w_{\text{out}} - w_{\text{in}} \qquad \textbf{Equation 2}$$

According to Archimedes' Principle the buoyant force also equals the weight of displaced fluid, or $B = w_{\text{f}}$. Use Equation 1 to express $w_{\text{out}} = \rho Vg$ and $w_{\text{f}} = \rho_{\text{f}}Vg$ so that $w_{\text{out}}/w_{\text{f}} = \rho/\rho_{\text{f}}$. With Equation 2 we can write the ratio $w_{\text{out}}/w_{\text{f}}$ as $w_{\text{out}}/(w_{\text{out}} - w_{\text{in}})$. Therefore, $\rho/\rho_{\text{f}} = w_{\text{out}}/(w_{\text{out}} - w_{\text{in}})$, or

$$\rho = \frac{\rho_f w_{out}}{w_{out} - w_{in}} \qquad \textbf{Equation 3}$$

Procedure

I. Determining the Density of Water

1) Use the scale to measure the mass of the graduated cylinder. Record its mass (in grams) on your data sheet.

2) Fill the cylinder with 100 mL of water and measure the total mass. Repeat for 200, 300, 400, and 500 mL of water. Subtract the mass of the graduated cylinder from each value and record your results on your data sheet.

3) Open Excel and plot your data (see the Theory section). Add a trendline and compute the slope which equals the density of water ρ_{water} in g/cm^3. (Note that 1 cm^3 = 1 mL.) You will use this value of ρ_{water} in Part II. Print your graph.

II. Determining the Densities of Lucite, Lead, and Wood

1) Screw down a clamp to the support bracket then fasten the handle of the force sensor to the clamp. Make sure to select the ±10 N setting on the sensor. Now hang the Lucite cylinder by a string from the sensor's hook. Adjust the clamp until the string is completely vertical (see Photos 1 and 2).

2) Connect the force sensor to the LabPro interface and then open Logger Pro on your computer. A Force-Time plot should appear; delete any other plots that are shown. Click the Collect ▷ button to test the quality of your data. Make sure that your data is collected for no more than 2 seconds (see Graph 1). Also check that the collection rate is is at least 30 data/sec.

3) Click the Collect ▷ button to measure the weight of the Lucite cylinder outside of the water. You should obtain a flat line for your Force-Time plot. A significant amount of jitter in your data implies that the sensor and/or the Lucite is vibrating. Re-adjust your set-up and try again. Use the R button to find the *y* intercept and record its value on your data sheet.

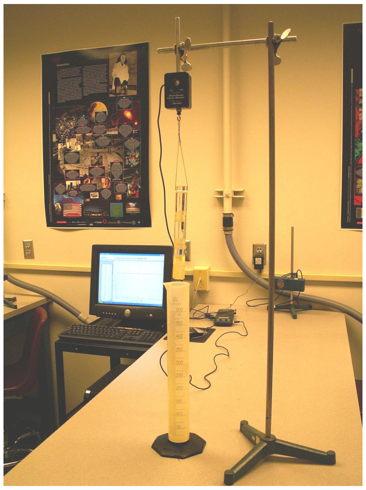


Photo 1

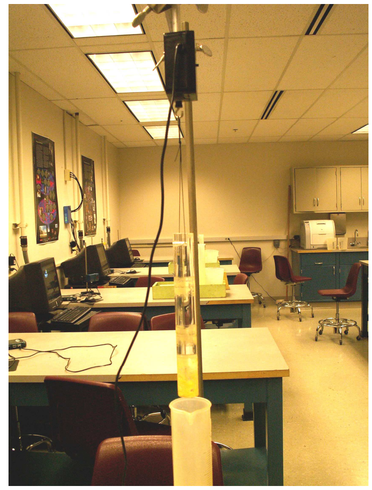


Photo 2

4) Fill your graduated cylinder with 350 mL of water and then lower the Lucite into it. Make sure that the Lucite is fully submerged. Repeat Step 3. Use Equation 3 to calculate the density in g/cm^3 and the percent error.

5) Replace the Lucite cylinder with the lead sinker and repeat Steps 2 – 4.

*   *   *   *   *

The procedure must be slightly modified in order to measure the density of the wooden block because it floats in water.
6) Replace the lead sinker with the wooden block and repeat only Steps 2 and 3. Record its weight as w^{wd-out}.

7) Now attach the lead sinker with a piece of string to the bottom of the wooden block (see Photo 3). Fill at least half of the plastic beaker with water and then lower the block and sinker until the sinker only is fully submerged. Repeat Steps 2 and 3 (see Photo 4). Record the weight in this case as w_{Pb-in}^{wd-out}.

8) Now lower the block + sinker until both objects are fully submerged. Repeat Step 3. Record the weight in this case as w_{Pb-in}^{wd-in}. Complete the rest of the calculations.

Each student is required to submit a completed data sheet in order to receive full credit. Your lab group needs to submit only one Mass-Volume graph. This graph is to be stapled to the data sheet of one of your lab partners – Each lab partner does not need to submit his/her own graph.

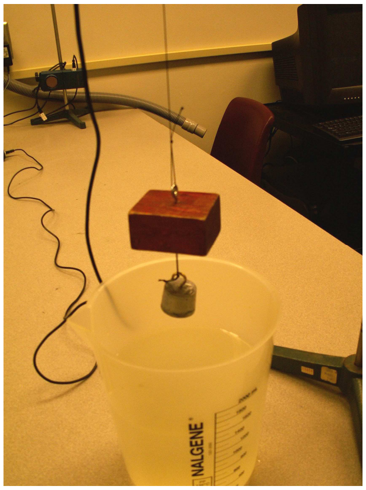


Photo 3

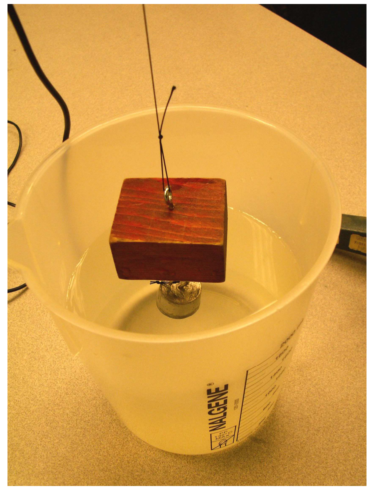
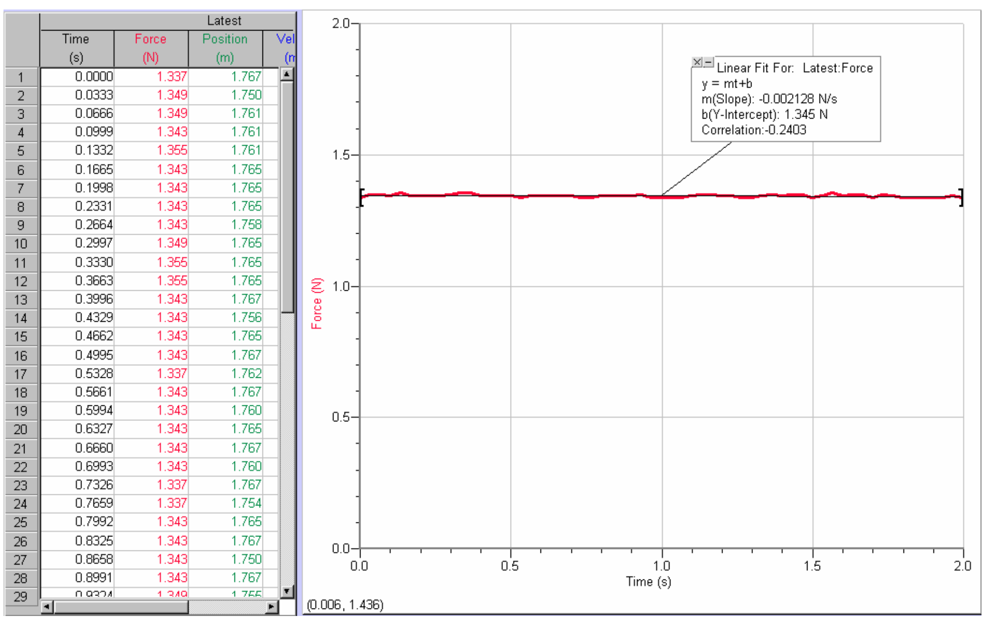


Photo 4



	Latest			
	Time (s)	Force (N)	Position (m)	Vel (m
1	0.0000	1.337	1.767	
2	0.0333	1.349	1.750	
3	0.0666	1.349	1.761	
4	0.0999	1.343	1.761	
5	0.1332	1.355	1.761	
6	0.1665	1.343	1.765	
7	0.1998	1.343	1.765	
8	0.2331	1.343	1.765	
9	0.2664	1.343	1.758	
10	0.2997	1.349	1.765	
11	0.3330	1.355	1.765	
12	0.3663	1.355	1.765	
13	0.3996	1.343	1.767	
14	0.4329	1.343	1.756	
15	0.4662	1.343	1.765	
16	0.4995	1.343	1.767	
17	0.5328	1.337	1.762	
18	0.5661	1.343	1.767	
19	0.5994	1.343	1.760	
20	0.6327	1.343	1.765	
21	0.6660	1.343	1.767	
22	0.6993	1.343	1.760	
23	0.7326	1.337	1.767	
24	0.7659	1.337	1.754	
25	0.7992	1.343	1.765	
26	0.8325	1.343	1.767	
27	0.8658	1.343	1.750	
28	0.8991	1.343	1.767	
29	0.9324	1.349	1.765	

Graph 1

Data Sheet – Archimedes' Principle

Name ____ Date ______________

Partners' Names ____

I. Determining the Density of Water

Mass of graduated cylinder (w/o water) = ___________________________ grams

Volume [mL]	100	200	300	400	500
Mass [g]					

Measured density of water (slope of Excel trendline) = ________________ g/cm^3

Accepted density of water = 1.00 g/cm^3

Percent error = $\frac{|Acc - Meas|}{Acc} \times 100 =$ ___________________ %

II. Determining the Densities of Lucite, Lead, and Wood

Accepted density of Lucite = 1.19 g/cm^3

Accepted density of lead = 11.3 g/cm^3

Material	Weight Out w_{out} [N]	Weight In w_{in} [N]	Density ρ [g/cm^3]	% error
Lucite				
Lead				

Weight of wood alone out of water $w^{wd\text{-}out}$ = _________________ N

Weight of wood and sinker, sinker in w_{Pb-in}^{wd-out} = _________________ N

Weight of wood and sinker, both in w_{Pb-in}^{wd-in} = _________________ N

Use Equation 3 (modified): $\rho = \frac{\rho_{water} w^{wd-out}}{w_{Pb-in}^{wd-out} - w_{Pb-in}^{wd-in}} =$ _____________ g/cm^3