College Physics I
Lab 10: Buoyancy

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Buoyant forces

The buoyant force upward on a submerged object due to the fluid in which the object is submerged is equal to the weight of the fluid displaced by the submerged object:

$$\begin{aligned} F_{\mathsf{b}} &= m_{\mathsf{fluid}}\, g, \\ m_{\mathsf{fluid}} &= \rho V, \\ &\Rightarrow F_{\mathsf{b}} = \rho V g. \end{aligned} \tag{1}$$

where ρ is the density of the fluid, V is the volume that is submerged), g is acceleration due to gravity.

We can use this to design a simple method of measuring the density of a liquid. We find the buoyant force on an object when it is totally submerged in a fluid. If we carefully measure the volume of the object beforehand, then we can find the density of the fluid from our measurements:

$$\rho = \frac{F_{\mathsf{b}}}{Vg}. \tag{2}$$

Can we measure F_{b} directly? If you try to weigh an object while it is under water, you will find it weighs less than if it were in air. That is because when you weigh a submerged object, you are actually measuring the weight minus the buoyant force. If you do this with a mass scale, then the apparent mass, m_{apparent}, will be less than the actual mass, m_{actual}. So we will measure the apparent mass of the object when it is submerged in the fluid using the mass scale—there is a special attachment that allows you to do this. The difference between the apparent mass and the actual mass will be due to the buoyant force on the object. That is:

$$F_{\mathsf{b}} = m_{\mathsf{actual}}\,g - m_{\mathsf{apparent}}\,g = (m_{\mathsf{actual}} - m_{\mathsf{apparent}})g. \tag{3}$$

Combining Equations (2) and (3):

$$\rho = \frac{(m_{\mathsf{actual}} - m_{\mathsf{apparent}})g}{Vg} = \frac{m_{\mathsf{actual}} - m_{\mathsf{apparent}}}{V}. \tag{4}$$

Assuming that the submerged object is a rectangular solid of height h, width w, and length l:

$$\rho = \frac{m_{\mathsf{actual}} - m_{\mathsf{apparent}}}{hwl}. \tag{5}$$

The densities of various liquids are not our interest here. The object is to get additional experience doing careful lab work, that you experience for yourself how the buoyant force varies with the kind of liquid used, and that you see how an application of Newton's Laws to the buoyant force on an object can be used as the basis for a measurement of something else; in this case, the density of a fluid. This is common in physics: a deeper understanding of how the universe works provides a new way to do some practical thing.

Part 1: Initial measurements

For a cube, measure m_{actual} with a balance scale, and measure w, h and l with calipers. I will show you how to use the scale on the calipers.

Note that the calipers are marked in mm. Remember that 1 mm = 0.001 m = 10^{-3} m. Convert your measurements to standard units (kg and m) before doing any further analyses. Masses must be measured especially precisely—see the note in part 3.

To hand in for part 1

Measured values for m_{actual}, h, w, and l.

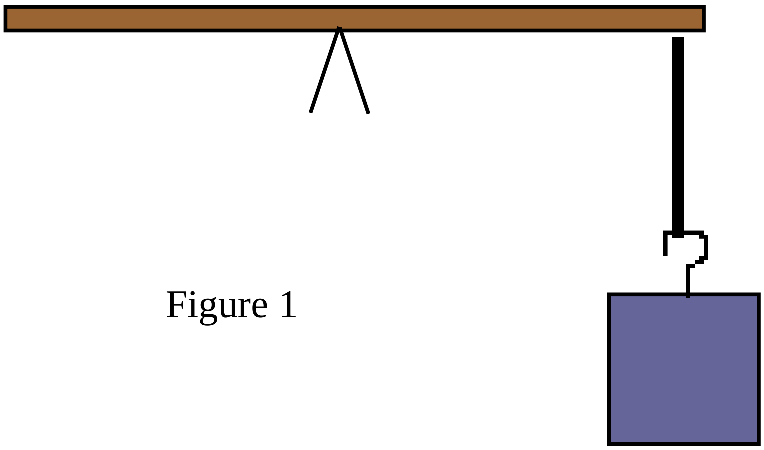

Figure 1

Part 2: Measuring m_{apparent} when immersed in various fluids

For the fluids provided, directly measure the apparent mass of the cube when it is submerged in a beaker of each fluid. See Figure 2; I will show you how to do this using the balance. Be sure to thoroughly wash and dry the beaker and the object each time you change to a different fluid.

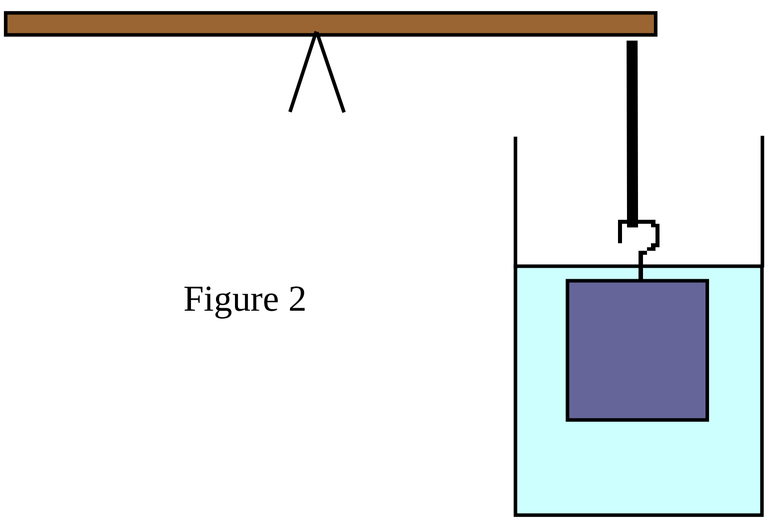

Figure 2

To hand in for part 2

Value of m_{apparent} for each fluid.

Part 3: Calculate the density for each fluid

Using the data gathered in parts 1 and 2, and using Equation (5), calculate the density of each of the fluids tested. Compare your resulting values with any accepted values you can find. (It's up to you how to find these.) Also look at results obtained by others in the lab. Discuss any discrepancies amongst yourselves with me.

Note: Since m_{actual} and m_{apparent} may be very close to each other, and you need to use their difference in your calculation, you must be especially precise in measuring m_{actual} and m_{apparent}. Ask me if the reason for this is not clear.

To hand in for part 3

- The value of ρ for each fluid,
- Quantitative comparisons of each value with accepted values, if available, and qualitative comparisons with results from other groups.