

College Physics I

Lab 7: Buoyancy

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Buoyant forces

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

$$\begin{aligned} F_b &= m_{\text{fluid}} g, \\ m_{\text{fluid}} &= \rho V, \\ \Rightarrow F_b &= \rho V g. \end{aligned} \tag{1}$$

ρ is the density of the fluid, V is the volume of the object (assuming it is completely submerged), g is acceleration due to gravity. This model for buoyant forces is called Archimedes' Principle.¹

We can use Archimedes' Principle to design a simple method of measuring the density of a liquid. The basic idea is that 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:

$$\rho = \frac{F_b}{Vg}. \tag{2}$$

¹We discussed, or will discuss, the derivation of this principle in class, and it is discussed in your textbook. It is important that you understand not just how to use formulas, but where they come from—how they can be derived from more basic ideas.

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:

$$F_b = m_{\text{actual}}g - m_{\text{apparent}}g = (m_{\text{actual}} - m_{\text{apparent}})g. \quad (3)$$

Combining Equations (2) and (3):

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

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

$$\rho = \frac{m_{\text{actual}} - m_{\text{apparent}}}{hwl}. \quad (5)$$

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. A more up-to-date example of this is the application of quantum mechanics and lasers to more precisely measure the passage of time. Those precise measurements of time, in turn, are what allow us to use the Global Positioning System—a system which locates you anywhere on earth to within about a meter, using satellites and light signals.

Activity 1: Initial measurements

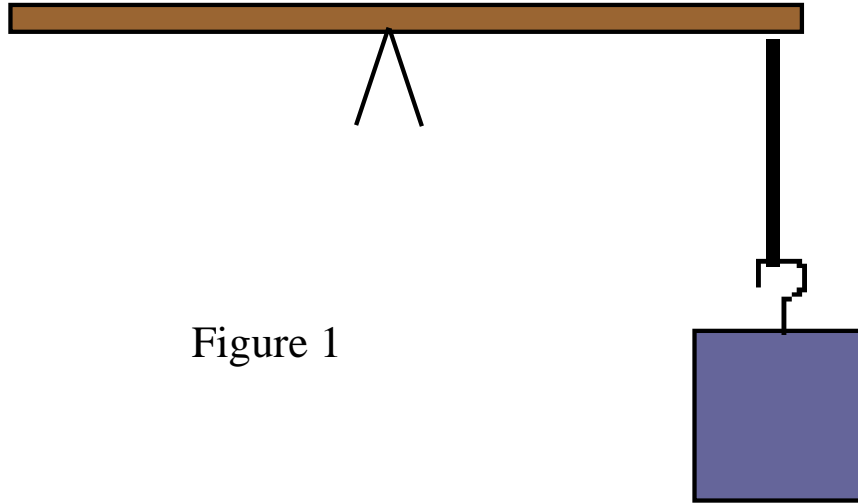


Figure 1

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 $1 \text{ mm} = 0.001 \text{ m} = 10^{-3} \text{ m}$. Convert your measurements to standard units (kg and m) before doing any further analyses. Masses must be measured especially precisely—see the note in activity 3.

To hand in for activity 1

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

Activity 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.

ACTIVITY 3: CALCULATE THE DENSITY FOR EACH FLUID

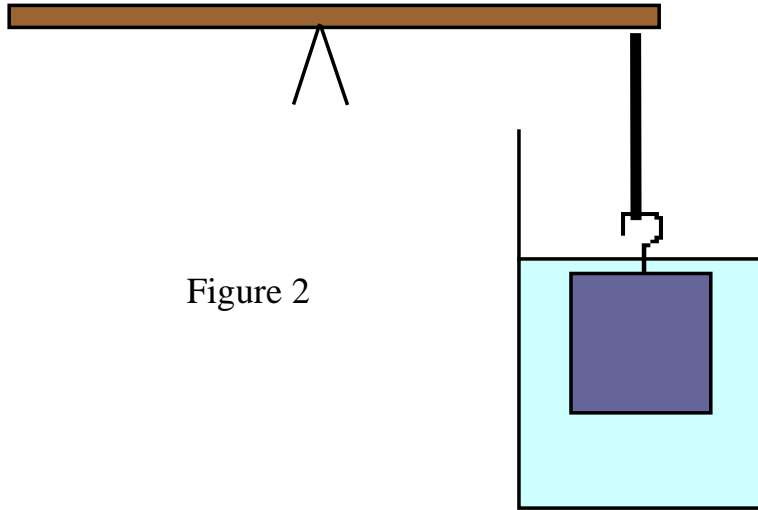


Figure 2

To hand in for activity 2

Value of m_{apparent} for each fluid.

Activity 3: Calculate the density for each fluid

Using the data gathered in activities 1 and 2, and using Equation (5), calculate the density of each of the fluids tested. Compare your resulting values with any accepted values given, and with 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 activity 3

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