# 1 Objective

- To understand buoyancy by exploring the buoyant force on various objects wholly and partially submerged in fluids.

# 2 Introduction

Archimedes' principle states that the buoyant force on an object is equal to the weight of the fluid it displaces. If the density of the fluid is $\rho_f$ and the volume of fluid displaced is $V$ then the weight of the displaced fluid is $\rho_f V g$ and the magnitude of the buoyant force is

$$F_B = \rho_f V g \tag{1}$$

The direction of the force is upwards.
The **apparent weight** of an object is its weight in vacuum (or nearly equivalently for our purposes, air) minus the buoyant force on it.

$$W_{apparent} = Mg - F_B \tag{2}$$

Where $M$ is the mass of the object, $g$ is acceleration due to gravity, and $F_B$ is the buoyant force. As you can see by Equation 1, the buoyant force on an object is proportional to the density of the fluid in which it is immersed. This is why you feel much lighter in water than in air.

In this lab we will use a *PhET* simulation, created at the University of Colorado at Boulder, to observe the effects of buoyant forces. Click **here** to get started with the simulation.

# 3 Procedure

## 3.1 Wooden cube in water

In this section you will predict, then measure, the proportion of a wooden cube ($\rho_{wood} = 0.40\, {}^{kg}/_{L}$) that is submerged in water ($\rho_w = 1.00\, {}^{kg}/_{L}$) when in equilibrium. Specifically you will find the volume of the block that is submerged ($V_{sub}$) divided by the total volume of the block ($V_{obj}$).

1. By summing forces on the wooden block and using equation 1 for the buoyant force, determine the proportion of the block that is submerged (${}^{V_{sub}}/_{V_{obj}}$) when in equilibrium. Record this value on your paper (you will upload it in the last question on the Canvas assignment).

2. Verify the value found in step 1 using the PhET simulation:

   (a) Click **here** to access the simulation if you don't already have it open.
   (b) Click the *Buoyancy Playground* tab at the top of the page.
   (c) Click the *one block* option at the top right.
   (d) From the dropdown menu next to *material*, choose *wood*.
   (e) At the bottom of the page, set the density of the fluid to that of water, $1.00\, {}^{kg}/_{L}$.
   (f) Place the block in the water and note the increase in the water level. The difference in volumes displayed next to the tank is the equal to the volume of the submerged portion of the block. It is helpful but not necessary to set the volume of the block to $1.00\, L$ for this part.
   (g) If the value found using the simulation differs from that found in step (1) you may need to correct your calculation.

3. Answer questions 1 and 2 on the Canvas assignment.

### 3.2 Determine the density of a block of unknown material (fully submerged)

In this section you will determine the density of an unknown material using only values that you can directly measure (not the values given in the box at the top left of the page)

1. Set the density of the fluid in the tank to that of water, $1.00\,{}^{kg}/_{L}$
2. In the top left corner of the buoyancy playground page, choose *My Block*.
3. Adjust the mass and volume of your block until it has an arbitrary density **greater than** $1.00\,{}^{kg}/_{L}$
4. Measure and record the weight of the block in air ($Mg$) and the apparent weight of the block in water ($W_{apparent}$).
5. By noting the increase in volume of the tank, measure and record the volume of your block.
6. Using only the values that you measured and the known density of water, calculate the density of your block, $\rho_{obj}$, in two ways:
   (a) From the weight measurement, determine the mass of the block then divide the mass by the measured volume.
   (b) Using equation 2 above, and noting that $Mg = \rho_{obj} V_{obj} g$, solve for $\rho_{obj}$.
7. Compare with the theoretical density value displayed in the box at the top left (all three values should be identical).

### 3.3 Determine the density of a block of unknown material (partially submerged)

1. Repeat steps 1–3 from section 3.2 but this time choose the fluid to have the density of honey, $\rho_{honey} = 1.42\,{}^{kg}/_{L}$, and set the density of your block to a value **less than** $1.42\,{}^{kg}/_{L}$.
2. Measure and record the weight of the block in air ($Mg$).
3. Measure the volume of the submerged portion of the block, then, drag the block completely under the surface to measure its entire volume.
4. By summing the forces on the block and setting them equal to zero (equilibrium condition), derive an expression for the density of the block in terms of measured quantities and $\rho_{honey}$. (This portion will somewhat resemble what you did in step 1 of section 3.1)
5. Calculate the density of your block and compare with the theoretical density value displayed in the box at the top left (they should be identical).

### 3.4 Two blocks: brick and styrofoam

1. Answer question 3 on the Canvas assignment. You may use the PhET simulation (click *two blocks* in the top right corner) to check if your answer is correct.