Archimedes' Principle (Balance)

Buoyancy is the ability of a fluid to sustain a body floating in it or to diminish the apparent weight of a body submerged in it. Archimedes' principle states that this apparent reduction in weight is equal to the weight of the fluid displaced. It is the purpose of this experiment to study Archimedes' principle and its application to the determination of density and specific gravity. In particular, the specific gravities of a solid heavier than water, a solid lighter than water, and a liquid other than water will be measured.

THEORY

The density of a body is defined as its mass per unit volume. It is usually expressed in grams per cubic centimeter.* The specific gravity of a body is the ratio of its density to the density of water at the same temperature. Since for a given location the weight of a body is taken as a measure of its mass, the specific gravity may be taken as the ratio of the weight of a given volume of a substance to the weight of an equal volume of water. Because the mass of 1 cm³ of water at 4°C is 1 g, the specific gravity of a body at this temperature is also numerically equal to its density in grams per cubic centimeter.

If a body is totally immersed in a fluid, the volume of fluid displaced must be equal to the volume of the body, because if the body weren't there, its volume would be occupied by the fluid. Moreover, the hydrostatic pressure on the bottom of the body is greater than that on the top because hydrostatic pressure rises as depth increases. The situation is illustrated in Fig. 1, which shows a beaker of fluid with an object (which we have made rectangular in the interest of simplicity) submerged in it. Let us begin by imagining an area of 1 cm² on the bottom of the beaker as shown at the right in Fig. 1. The dotted lines indicate that we may think of this 1-cm² patch as supporting a column of fluid 1 cm² in cross section extending up to the surface a distance d above it, the depth of fluid being d cm. Thus a volume 1 x d cm³ and hence a weight of \( \rho gd \) dynes of the fluid sitting on that 1 cm² of the bottom. Here \( \rho \) is the fluid's density and \( g \) is the acceleration of gravity in centimeters per second squared. Hence the pressure sustained by the bottom of the beaker is \( \rho gd \) dynes of fluid on every square centimeter, or \( \rho gd \) dynes/cm². Note that this is the gauge pressure. The absolute pressure must include the pressure due to the atmosphere on the fluid surface—we could imagine the dotted lines in Fig. 1 going up on top of the top of the atmosphere and indicating a column of air 1 cm² in cross section sitting on top of the column of liquid. Since atmospheric pressure does not affect the present experiment we will not consider it further.

Turning now to the immersed solid, we note that it has height \( h \), its bottom end being at depth \( h_2 \) and its top end at depth \( h_1 \) where \( h_2 - h_1 = h \). The considerations of the last paragraph show that the pressure at any depth \( d \) in a fluid of density \( \rho \) is \( \rho gd \); hence the pressure on the bottom of the body is \( \rho gh_2 \) and the force exerted on the bottom, which will be an upward force, is \( \rho gh_2 A \), where \( A \) is the body's cross sectional area as shown in Fig. 1. Similarly, the downward force on the body's top surface is \( \rho gh_1 A \), so that there is a net upward or so-called buoyant force \( \rho g A ( h_2 - h_1 ) = \rho g Ah \). But \( Ah \) is just the body's volume \( V \), so that the buoyant force may be written as simply \( \rho g V \). Then, since \( \rho \) is the fluid's density, \( \rho g V \) is identical with the weight of the displaced fluid. This result, namely that the buoyant force (which, being an upward force, gives rise to an apparent loss of weight of the submerged body) is equal to the weight of the displaced fluid, is known as Archimedes' principle.

The specific gravity of a solid heavier than water may be easily determined by the application of this principle. The body is weighed in air; then it is weighed in water, that is, suspended by a thread from the arm of a balance so as to be completely submerged (see Fig. 2). The loss of weight in water is \( W - W_i \), where \( W \) is the weight in air and \( W_i \) is the weight in water. But the loss of weight in water is equal to the weight of the water displaced, or the weight of an equal volume of water. Thus, the specific gravity \( S \) will be

*The CGS (centimeter-gram-second) system will be used in this experiment as it is both more usual and more convenient for this work.
where $M$ is the body's mass in air and $M_1$ its apparent mass in water.

The specific gravity of a liquid may be found by measuring the loss of weight of a convenient solid body when immersed in that liquid and the loss of weight when immersed in water. The procedure is as follows: A heavy body is weighed in air; this weight is called $W$. Then it is weighed in water; this weight is called $W_1$. Finally, it is weighed in the liquid whose specific gravity is to be determined; this weight is called $W_2$. The specific gravity of the liquid will then be

\[
S = \frac{W}{W - W_2} = \frac{M - M_2}{M - M_1}
\]

since this expression represents the weight of a certain volume of the liquid divided by the weight of an equal volume of water. Here $W - W_1$ is the loss of weight in water, and $W - W_2$ is the loss of weight in the given liquid.

In order to find the specific gravity of a solid lighter than water, it is necessary to employ an auxiliary body, or sinker, of sufficient weight and density to hold the other body completely submerged. The specific gravity of a solid lighter than water, as obtained by the sinker method, is given by

\[
S = \frac{W_1 - W}{W} = \frac{M}{M_1 - M_2}
\]

where $W$ is the weight of the solid in air; $W_1$ is the weight of the solid and the sinker, with the sinker alone immersed; and $W_2$ is the weight when both solids are immersed in water.

The hydrometer is an instrument designed to indicate the specific gravity of a liquid by the depth to which it sinks in the liquid. To measure the specific gravity of a liquid by means of a hydrometer, it is only necessary to let the hydrometer float in the liquid and to read the specific gravity directly on the calibrated scale. The reading is taken, if possible, by placing the eye below the liquid surface and seeing where this surface cuts the hydrometer scale.

**Procedure**

1. Make sure the following is set up
   - Balance is on the stand
   - String is attached to the under side of balance
2. Find the mass of the empty catch bucket (the small container). Change mass to weight.
3. Find the mass of the metal mass and change to weight.
4. Attach the mass to the string attached to the balance.
5. Fill the can with the pour spout to the spout.
6. Center can under the balance and the catch bucket under the spout.
7. Place the metal in the can and catch the runoff. (Center so the metal doesn’t touch the side of the can.)
8. Find the mass of the metal in the water. Change to weight in the water (\(F_{\text{gwater}}\)) and record.
9. Subtract the the \(F_{\text{gwater}}\) weight in water from the \(F_{\text{gair}}\) (weight in air). This is the calculated buoyancy \(F_b\).
10. Remove the metal mass and string from the balance.
11. Find the mass of the catch bucket and water. Change to weight.
12. Subtract the weight of the catch bucket from the weight of the water and catch bucket. This is the experimental buoyancy.
13. Calculate the percent error using the buoyancy from step 9 as the calculated buoyancy and the buoyancy from step 12 as the experimental buoyancy. % error = experimental – calculated/calculated*100.

**Find the Density of a block of metal**

14. Find the mass of the metal in air. Change to weight (\(F_{\text{gair}}\)). Record.
15. Find the mass of the empty catch bucket. Change to weight.
16. Fill the can with the pour spout to the spout.
17. Attach the metal to the string and attach to the balance
18. Center can under the balance and the catch bucket under the spout.
19. Place the metal in the can and catch the runoff.
20. Center so the metal doesn’t touch the side of the can.
21. Find the mass of the metal in the water. Change to weight in the water (\(F_{\text{gwater}}\))
22. Subtract the the \(F_{\text{gwater}}\) weight in water from the \(F_{\text{gair}}\) (weight in air). This is the buoyancy \(F_b\).
23. Calculate the density of the metal. \(F_g \text{ in air}/F_b = \rho_{\text{object}}/\rho_{\text{water}}\).
24. The density of water is 1000kg/m\(^3\)
25. Look up the density of your metal from the chart.
26. Calculate the percent error. Experimental – from chart/from chart*100
27. Choose a second metal. And repeat the procedure.
28. Complete lab report. You must include Name, procedure, data, discussion, and conclusion.

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<thead>
<tr>
<th>Metal in air</th>
<th>Metal in water</th>
<th>Catch bucket</th>
<th>Catch bucket + water</th>
<th>Wt of water</th>
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<tbody>
<tr>
<td>Mass (g)</td>
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<td>Mass (kg)</td>
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<td>Weight (N)</td>
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<table>
<thead>
<tr>
<th>Calculated buoyancy</th>
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<tr>
<td>Experimental buoyancy</td>
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<tr>
<td>Percent error</td>
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<tr>
<td>Density of metal</td>
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