



Fig. 12-1

Equipment

Dial-O-Gram balance
Wood cylinder
2 Metal cylinders
String

Graduated cylinder
Pipette
Vernier caliper
Rod & Clamp
Overflow container

Experiment 12

Archimedes' Principle

Advance Reading: Halliday, Resnick and Walker - Chapter 14, Section 14-7

Objective: The objective of this lab is to measure the buoyant force on a variety of objects.

Theory: Archimedes' principle states that a body wholly or partially submerged in a fluid is buoyed up by a force equal in magnitude to the weight of the fluid displaced by the body. It is important to remember that fluid includes *liquids and gases*. This force is given by:

$$F_B = \rho Vg \quad (\text{Eq 1})$$

where ρ (rho) is the density of the fluid, V is the volume of fluid displaced and g is acceleration due to gravity. It is the buoyant force that keeps ships afloat and hot air balloons floating in air.

In this experiment, the buoyant force will be measured three ways and the results compared. The first method is by the *measurement of force*. This method involves weighing an object first in air, then in water, and using the difference in weight as the buoyant force. Though the object's mass does not change, its apparent weight will change when measured while immersed in a fluid that is denser than air.

The second method is the *displaced volume* method. The volume of fluid displaced by the object is measured and its weight calculated. The weight of the water displaced is equal to the buoyant force exerted on the object, by Archimedes' Principle.

The third method is by the *buoyant force equation* method. By measuring the dimensions of the object and calculating the volume, one can determine the buoyant force (by using Eq-1) of an that would be exerted on the object when it is submerged in a fluid of known density ρ .

Please note that for the third method, the volumes of interest are different for objects that float and objects that sink.

Procedure

Part 1: Force Measurement method- Weight

1. Measure the mass of one of the metal cylinders in air and calculate its weight. Label this weight in air F_A . Suspend the object by a string tied to the pan of the Dial-O-Gram balance. Partially fill the overflow can with water, then completely submerge the cylinder. Do not allow the cylinder to touch the sides of the container. Measure its "mass" while it is submerged. Calculate its weight in water, F_w . The difference between the objects weight in air and its weight in water is the buoyant force on the object, or

$$F_B = F_A - F_w \quad (\text{Eq 2})$$

2. Repeat the above procedure and calculate the average.
3. Repeat Step 1 for the other metal cylinder.
4. Repeat the above procedure and calculate the average.

Part 2: The Displacement Method - Volume

5. Partially fill the graduated cylinder with water. Use the pipette to fine tune the meniscus level (i.e., fill to where the meniscus level is not between markings). Record this initial volume, V_i .
6. Gently immerse one of the metal cylinders into the water. Record the new water level, V_f ; calculate the change in volume. This is the volume of displaced water. Calculate the weight of displaced water, F_B , using Eq 1 ($\rho_{\text{water}} = 1000 \text{ kg/m}^3$).
7. Compare the values obtained for buoyant force.
8. Repeat Steps 5 - 7 for the other metal cylinder.

Part 3: Buoyant force equation method

9. Measure the height and diameter of each cylinder; calculate the volumes. Using these volumes, the acceleration of gravity g and the density of water, calculate the respective buoyant forces using Eq-1.
10. Compare these values to the corresponding values obtained previously.
11. Calculate the density of each object. Compare to accepted values.

Part 4: Finding the buoyant force for an object that floats.

12. Measure the mass and volume of the wood cylinder.
13. Partially fill and fine tune the graduated cylinder with water. Record V_i .
14. Gently immerse the wood cylinder into the water. Record V_f and calculate ΔV . This is the volume of displaced fluid. Calculate the weight of the displaced water. Compare this buoyant force to the weight of the wood cylinder. Are they the same?
15. Draw a free-body diagram for this system. Calculate the density of the wood.

Questions:

1. If air is a fluid, why do we not include the buoyant force caused by the displacement of air by the objects in this experiment? Explain your answer carefully. (Hint: $\rho_{\text{water}} = 1000 \text{ kg/m}^3$, $\rho_{\text{air}} = 1.21 \text{ kg/m}^3$)
2. Which weighs more? (Justify your answer by drawing a force diagram for each case.)
 - a. A tub filled to the brim with water.
 - b. A tub filled to the brim with water, with a boat floating in it.
 - c. They weigh the same.
3. A 1000 cm^3 gold brick ($\rho = 19.3 \text{ g/cm}^3$, so $m = 19.3 \text{ kg}$) and a 1000 cm^3 aluminum brick ($\rho = 2.7 \text{ g/cm}^3$, so $m = 2.7 \text{ kg}$) are immersed in water. Which brick experiences the greater buoyant force? Justify your answer.
4. How can a ship made of steel ($\rho_{\text{steel}} = 7.88 \text{ g/cm}^3$) float in water?
5. Explain how a hot air balloon flies.
6. Calculate the buoyant force that would be exerted on the wood cylinder if you held it under water. How much force must you exert?