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Experiment 1.08: Buoyancy

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I. EXPERIMENT 1.08: BUOYANCY

A. Abstract

Archimedes principle is used to determine the density of an unknown metal.

B. Formulas

$$\rho = \frac{m}{V} \tag{1}$$

$$B = \left(\rho_{\text{fluid}} V_{\text{displaced fluid}}\right) g \tag{2}$$

$$\frac{\rho_{\text{body}}}{\rho_{\text{fluid}}} = \frac{m}{m - m_{\text{in fluid}}}, \text{ submerged body} \tag{3}$$

$$m_{\text{from balance}} = \left(\frac{\Delta s_{\text{counter}}}{\Delta s}\right) m_{\text{counter}} \tag{4}$$

where on the last line $\Delta s_{\text{counter}}$ is the distance from the pivot to the counter weight in the mechanical balance, and Δs is the distance from the pivot to the hanging mass being measured. Equation (3) applies to a body suspended by a force $F = m_{\text{in fluid}} g$ in a fluid.

Metal	Density $[kg/m^3]$
Aluminum	2700
Titanium	4500
Iron	7870
Brass	8400
Copper	8960

C. Description and Background

Figure 1 shows the mechanical balance being used to mass the unknown metal object in water. The counter weight is adjusted to a position along the meter stick that leads to the horizontal equilibrium shown in the figure. By measuring the locations along the meter stick of the hanging metal object and the counter weight, the apparent mass of the metal object in the water, $m_{\text{in water}}$, can be determined. The same procedure can be used to determine the mass of the metal object in air, m.

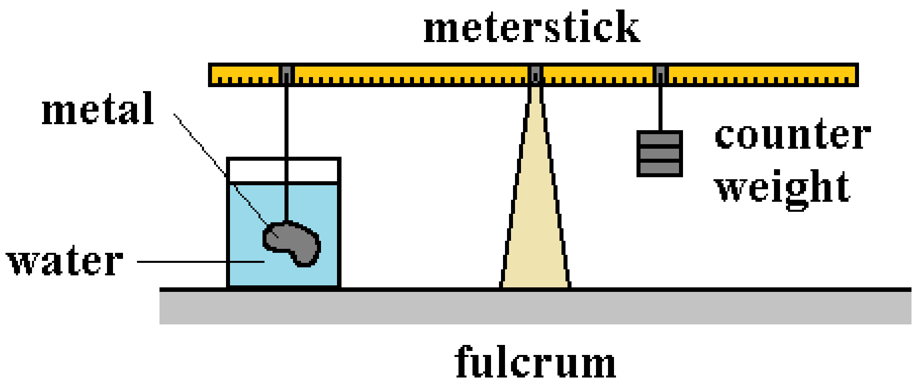

FIG. 1. Massing the metal while submerged in water.

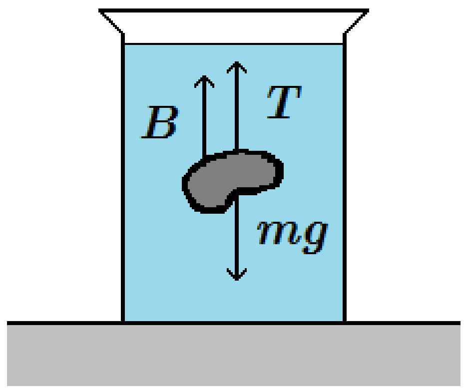

FIG. 2. Forces on submerged metal.

From Figure 2,

$$T = mg - B$$

But the tension is a measure of the apparent weight of the metal object in water, so

$$m_{\text{in water}}g = mg - B$$

Archimedes' Principle states that the buoyancy force is equal to the weight of displaced water, $B = \rho_{\text{water}} V_0 g$. The volume of the metal object can be expressed in terms of its mass and density, $V_0 = m/\rho_{\text{metal}}$. Putting these facts together yields Eq. (3). Using the accepted density of water, this equation allows the determination of the average density of the metal object and therefore its constitution using the table of densities provided above.

D. Procedure

1. In this experiment, try to measure all meterstick locations to half a millimeter precision.

2. Find the center of mass of the meter stick (s_{cm}), and place the support clamp and fulcrum at this point before using the mechanical balance. The body whose mass is being determined should always hang from the same position (s_0) along the meter stick; record this location. Equation (4) assumes the use of only a light string to suspend the mass. In the experiment, only the counter mass location is varied.

3. Use the mechanical balance to determine the mass of the unknown metal. Record the counter mass and its location ($m_{\text{counter}},\ s_{\text{counter}}$).

4. Repeat this procedure three times with different counter masses.

5. Use the mechanical balance to determine the apparent mass of the same metal in water.

6. Repeat this procedure three times with different counter masses.

E. Measurements

meter stick c.m., s_{cm} [cm]	
unknown mass location, s_0 [cm]	

Unknown mass in air:

Trial	m_{counter} [$gram$]	s_{counter} [cm]
1		
2		
3		

Unknown mass in water:

Trial	m_{counter} [$gram$]	s_{counter} [cm]
1		
2		
3		

F. Instructions

1. In each trial, calculate the mass of the metal in air, m [$gram$] using Eq. (4), where $\Delta s = |s_{\text{cm}} - s_0|$ and $\Delta s_{\text{counter}} = |s_{\text{cm}} - s_{\text{counter}}|$.

2. Use these calculations to determine an average and a standard error (SE) of the mass in air.

3. In each trial, calculate the mass of the metal in water, $m_{\text{in water}}$ [$gram$] using Eq. (4), where $\Delta s = |s_{\text{cm}} - s_0|$ and $\Delta s_{\text{counter}} = |s_{\text{cm}} - s_{\text{counter}}|$.

4. Use these calculations to determine an average and a standard error (SE) of the mass in water.

5. Based on the average masses, determine the density of the metal, ρ_{metal} [kg/m^3] using Eq. (3), where $\rho_{\text{fluid}} = 1000\ kg/m^3$.

6. Use the following error propagation equation to determine an uncertainty for the density calculated above

$$\delta\rho_{\text{metal}} = \rho_{\text{metal}} \left(\frac{m_{\text{in water}}}{m - m_{\text{in water}}} \right) \sqrt{\left(\frac{\delta m}{m} \right)^2 + \left(\frac{\delta m_{\text{in water}}}{m_{\text{in water}}} \right)^2}$$

7. Which metal from the table provided in the Formula section has a density closest to the metal density calculated above?

G. Calculations

	m [$gram$]	$m_{\text{in water}}$ [$gram$]
Trial 1		
Trial 2		
Trial 3		
$\bar{m}$ [$gram$]		
$\delta\bar{m}$ [$gram$]		

ρ_{metal} [kg/m^3]	
$\delta\rho_{\text{metal}}$ [kg/m^3]	
Metal Identity	