Archimedes' Principle

Aims

1. Determination of the specific gravity of a solid ρ_s.
2. Determination of the specific gravity of a liquid ρ_L.

Intended Learning Outcomes

By the end of the experiment, the student should be able to:

1. Explain Archimedes' principle
2. Apply Archimedes' principle to a body that is completely immersed in water and some other liquids.
3. Set up an experiment to determine the specific gravity for both a solid and a liquid.

Apparatus

Digital sensitive balance – Cubes of side length 1 cm made from different metals – Different liquids.

Theory

Materials are characterized by their densities ρ, which can be defined as the mass of the body divided by its volume.

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

The MKS unit for the density is kg/m^3. An alternative CGS unit is g/cm^3.

The Specific Gravity SG (or the relative density) of a material is defined as

$$Specific\ Gravity = \frac{Density\ of\ Material}{Density\ of\ water}$$

or

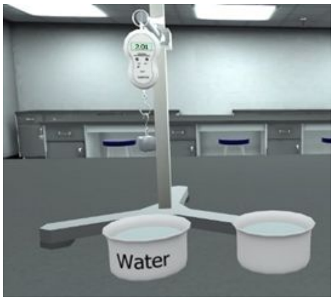
$$SG = \frac{\rho}{\rho_w}$$

Also, since the density of water in CGS is 1 g/cm^3, the specific gravity of a material is numerically equal to the density of the material if we use the CGS system. However, SG is a **dimensionless quantity**.

Archimedes' principle states that "When a body is completely or partially immersed in a fluid (liquid or a gas), it is acted upon by an upward force called "Upthrust or buoyant" that is equal to the weight of the displaced fluid by the body. Also, the volume of the immersed body equals the volume of the displaced liquid".

(a) Determination of the Density of the Solid

If we hung an object (metallic cube) using a thread to a digital balance, the reading of the balance is equal to the mass of the cube while being hung in air *m*. Then weigh it again while being completely immersed in water results in m_w, which is less than the mass in the air because of the buoyant force F_w exerted by the water on the body.



$$\begin{aligned} F_w &= W - W_w \\ &= m\,g - m_w\,g \\ &= \rho_s V_s\, g - \rho_w V_w\, g \quad . \end{aligned}$$

where ρ_s and ρ_w are the densities of the solid cube and water, respectively, while V_s and V_w are the volumes of the solid and the displaced liquid when the body is completely immersed in water, respectively. However, the buoyant force is equal to the weight of displaced water and the volume of displaced liquid is equal to the volume of the immersed body. That is, $V_w = V_s$.

Therefore, the ratio between the weight of the cube in air and the buoyant force is:

$$\frac{W}{F_w} = \frac{\rho_s V_s\, g}{\rho_w V_w\, g} = \frac{\rho_s V_s\, g}{\rho_w V_s\, g} = \frac{\rho_s}{\rho_w} = (SG)_s$$

$$(SG)_s = \frac{W}{F_w} = \frac{W}{W - W_w}$$

Or simply, since $W = m\,g$

$$(SG)_s = \frac{m}{m - m_w}$$

(b) Determination of the Specific Gravity of a Liquid

To determine the SG of a liquid, we weigh the object once more while it's completely immersed in the liquid m_L. The buoyant force in this case F_L is equal to the weight of the displaced liquid. As in part (a),

$$\begin{aligned} F_L &= W - W_L \\ &= m\,g - m_L g \\ &= \rho_s V_s\, g - \rho_L V_L\, g \end{aligned}$$

But, $V_L = V_w = V_s$. Therefore,

$$\frac{F_L}{F_w} = \frac{m_L\, g}{m_w\, g} = \frac{\rho_L V_L\, g}{\rho_w V_w\, g} = \frac{\rho_L}{\rho_w} = (SG)_L$$

Therefore,

$$(SG)_L = \frac{F_L}{F_w} = \frac{W - W_L}{W - W_w}$$

Or simply

$$(SG)_L = \frac{m - m_L}{m - m_w}$$

Procedure

1. From the drop list, choose one liquid (other than water) to determine its specific gravity.
2. The mass of body m in air is shown on the balance screen.
3. Click the **Record** button to record this value.
4. Immerse the body inside the beaker full of water and find the mass of the body m_w.
5. Click the **switch liquids** button to bring the beaker with the liquid beneath the body.
6. Immerse the body inside the beaker full of the liquid.
7. Click the **Record** button to record this value m_L.
8. The experiment has been completed, and an Excel sheet that contains the recorded data will be downloaded.

Data Analysis

1. Calculate the specific gravity of the solid body's material using the relation:

$$(SG)_s = \frac{m}{m - m_w}$$

2. Calculate the specific gravity of the liquid using the relation:

$$(SG)_L = \frac{m - m_L}{m - m_w}$$

Useful Information

Solid	Density (g/cm^3)
Copper	8.92
Aluminum	2.7
Steel	7.87
Tungsten	19.4

Liquid	Density (g/cm^3)
Alcohol	0.806
Glycerine	1.26
Chloroform	1.48