Experiment 11. Archimedes' Principle

An application of Archimedes' principle - a piece of iron sinks while a steel cup of the same weight floats on water.

Objective:

(a) To determine the specific gravity of a liquid by using a hydrometer.

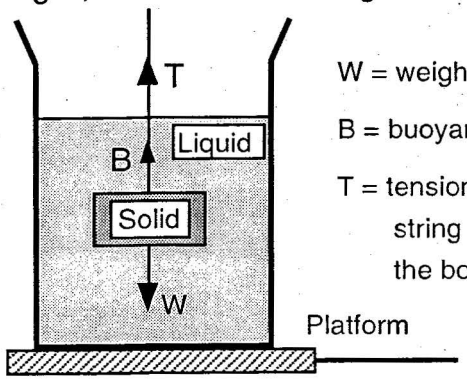
(b) the specific gravity of a solid heavier than water, the specific gravity of a liquid and the specific gravity of a solid lighter than water by applying Archimedes' principle.

Apparatus:

A balance, a solid heavier than water, a wooden cylinder, a hydrometer, alcohol and distilled water

Theory:

According to Archimedes' principle, when a body is immersed in a fluid (Fig. 1), either wholly or partially, the fluid exerts a buoyant force B on it. This buoyant force is equal to the weight of the fluid displaced by the body. Thus the apparent weight of the body is less than its actual weight, the loss of weight being equal to the buoyant force.



W = weight of the body

B = buoyant force

T = tension in the string supporting the body

Fig. 1

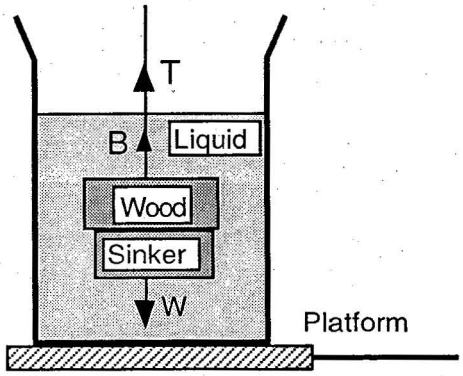


Fig. 2

Consider the following problem:

Weight of the body in air (actual weight of the body), $w = 600$ gm-wt

Volume of the body, $V = 80\ cm^3$

Density of the liquid, $\rho = 1.2\ gm/cm^3$

Volume of the liquid displaced = volume of the body $V_\ell = 80\ cm^3$

Weight of the liquid displaced, $w_\ell = V_\ell \times \rho = 96$ gm-wt

Buoyant force, $B = 96$ gm-wt

Apparent weight of the body, $w_a = 600 - 96$ gm-wt

$= 504$ gm-wt

Note that the apparent loss of weight of the body is equal to the buoyant force of the fluid acting on the body, which, in turn, is equal to

the weight of the fluid displaced by the body. Thus,
the buoyant force = apparent loss of weight,
or, $B = w - w_a = w_\ell$ = weight of fluid displaced (1)
Remember, if the body is completely immersed in the fluid, the weight of the fluid displaced by it is equal to the weight of the fluid whose volume is the same as the volume of the body.
Archimedes' principle provides a convenient method of determining specific gravities of substances.

(a) Principle of a hydrometer:

A hydrometer is an instrument for determining the specific gravities of liquids. When a hydrometer is floating in equilibrium in any liquid, the buoyant force (the weight of the liquid displaced by it) is equal to the weight of the hydrometer. Let
Weight of the hydrometer = 600 gm-wt
Volume of the hydrometer under water = 600/1 = 600 cm^3
(when floating in water of density 1 gm/cm^3)
Volume of the hydrometer under the liquid = 600/1.2 = 500 cm^3
(when floating in a liquid of density 1.2 gm/cm^3)
Thus the volume of the hydrometer under a liquid depends on the density of the liquid. In general, hydrometers are calibrated so that the specific gravities can be read off directly.

(b) Specific gravity of a solid heavier than water:

Specific gravity (sp. gr.) is defined as

$$\text{sp. gr.} = \frac{\rho}{\rho_\ell}, \text{ where } \rho = \text{density of the substance}$$

and ρ_ℓ = density of water at 4 °C

$$\text{or sp. gr.} = \frac{M/V}{M_\ell/V_\ell}, \text{ where } M = \text{mass of the body, } V = \text{volume of the body,}$$

M_ℓ = mass of water, and V_ℓ = volume of water.

Now if volume of water (V_ℓ) is made equal to the volume of the body (V),

$$\text{sp. gr.} = \frac{M}{M_\ell} = \frac{Mg}{M_\ell g} = \frac{W}{W_\ell},$$

where W = weight of the body, and
W_ℓ = weight of water whose volume is equal to the volume of the bod
According to Eq. (1), $W_\ell = W - W_a$, where W_a = apparent weight of the body. Thus

$$\text{sp. gr.} = \frac{W}{W_\ell} = \frac{W}{W - W_a} \qquad (2)$$

(c) Specific gravity of a liquid:

Let W = weight of a solid in air

W_b = apparent weight of the solid completely immersed in a liquid, and

W_a = apparent weight of the solid completely immersed in water.

Thus, by Eq. (1),

$W - W_b$ = weight of the liquid whose volume equals the volume of the solid

and $W - W_a$ = weight of water whose volume equals the volume of the solid.

Therefore, specific gravity of the liquid is given by

$$\text{sp. gr.} = \frac{W - W_b}{W - W_a} \qquad (3)$$

(d) Specific gravity of a solid lighter than water:

To determine the sp. gr. of a solid lighter than water, a sinker is used to immerse the solid completely in water. In this case, the denominator of Eq. (2) can be written as

$W - W_a = W + W_s - (W_s + W_a)$, where W_s is the weight of the sinker in water.

In this experiment, the solid used in part (b) is used as a sinker.

Procedure:

(a) Sp. gr. of alcohol by using a hydrometer:

1. Find the least count of the hydrometer.
2. Carefully float the hydrometer in the alcohol filled in the cylindrical jar and read the specific gravity of the liquid.

(b) Sp. gr. of the solid:

3. Find the least count of the balance and measure the weight of the metal cylinder in air.
4. Find the apparent weight of the metal cylinder by immersing it completely in water.

(c) Sp. gr. of alcohol:

5. Find the apparent weight of the metal cylinder [used in part (b)] by completely immersing it in alcohol.

(d) Sp. gr. of wood:

6. Weigh the wooden cylinder in air.
7. Tie the wooden cylinder and metal cylinder together and suspend them in water as shown in Fig. 2. Thus find the total apparent weight of the wooden cylinder and metal cylinder when they are completely immersed in water.

Use gm-wt as the unit of weight in this experiment.

York College of The City University of New York

Physics I Name:

Experiment No. 11: Pre-Lab Questionnaire

1. Calculate the specific gravity of liquid from the following data:
   Mass of a metal cylinder in air = 56.8 gm
   Apparent mass of the metal cylinder in water = 50.3 gm
   Apparent mass of the metal cylinder in liquid = 48.7 gm

2. Determine the specific gravity of the wooden cylinder from the following data: (The metal cylinder of question 1 was used as the sinker.)
   Mass of a wooden cylinder in air = 6.9 gm
   Apparent mass of the metal cylinder and wooden cylinder in water = 45.8 gm

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Experiment No. 11

Name: Marks:

Partner: Remarks:

Section:

Date Submitted:

Title:

Objective:

Theory/Formulas:

Data Sheet

(a) Sp. gr. of alcohol by using a hydrometer:

Least count of the hydrometer =

Specific gravity of alcohol =

(b) Sp. gr. of a metal cylinder:

Least count of the balance =

Weight of the metal cylinder in air =

Apparent weight of the metal cylinder in water =

(c) Sp. gr. of alcohol:

Apparent weight of the metal cylinder in alcohol

(d) Sp. gr. of wooden cylinder:

Weight of the wooden cylinder in air =

Total weight of both, wooden cylinder and metal cylinder,

in water =

Calculations:

Show substitutions in all calculations.

(a) Percent error in the experimental value of the alcohol =

(b) Apparent loss of weight of the metal cylinder in water =

Buoyant force on the metal cylinder in water =

Weight of water whose volume equals the volume of the metal cylinder

=

Sp. gr. of the metal =

Percent error in the sp. gr. of the metal =

(c) Weight of alcohol whose volume equals the volume of the metal

cylinder =

Weight of water whose volume equals the volume the metal cylinder =

Sp. gr. of alcohol =

Percent error in the experimental value of the alcohol =

(d) Apparent loss of weight of the wooden cylinder in water =

Sp. gr. of wooden cylinder =

Experiment No. 11: Questions

1. State Archimedes' principle.

2. Explain the working principle of a hydrometer.

3. Why is the apparent loss of weight of the wooden cylinder larger than its weight in air?

4. Draw a neat diagram showing the forces acting on a solid immersed in a fluid.