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AN ALTERNATE METHOD TO DETERMINE DENSITY OF SOLIDS ACCORDING TO ARCHIMEDES' PRINCIPLE

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To measure density of a solid object, according to Archimedes' principle, hanging pan balance or toploading balance with density measurement kit are used. In the conventional method, weight of water displaced is calculated in terms of weight of the object hanged in water. We report a new and easier method to determine the density of a solid object based on same principle by using a toploading balance, but without any density measurement kit. In the new approach, weight of water displaced is measured directly on the balance. The proposed method is simpler, quicker and accurate.

Keywords: *Archimedes density, Toploading balance, Density measurements*

1. Introduction

Density is an important physical property of a substance. It is defined as mass per unit volume. The method of density determination depends on the physical state and nature of a substance being investigated e.g. solid, liquid or gas? If it is solid, is it a single piece or collection of many particles like powder? If it is a single piece (present work), what is its shape regular or irregular? Is it porous? And what level of precision is required ?

For a regularly shaped object, one can calculate volume from its geometrical dimensions. For irregularly shaped bodies, one dips the object in water in a graduated container and determines the volume of water displaced by the body, or it is determined in terms of mass of water displaced.

A well established method to determine the density (ρ) of a solid, based on Archimedes' principle, is known to us since the time of great scientist Archimedes (287-212 BC). Archimedes explored the method according to the type of balance available at that time i.e. hanging balance.

With the advent of digital electronics, the old instruments are being quickly replaced by the more advanced instruments. So is the case with the balances. Spring balances and hanging pan balances have been replaced by digital toploading balances for routine weighing purposes. Now-a-days being almost obsolete, hanging pan balances are quite difficult to be found in a well established laboratory. These types of balances are found in laboratories where density measurements are a routine work. In a laboratory where hanging pan balance is not available, to carry out density experiments one needs an extra density measurement kit to make the toploading balance equivalent to the hanging pan balance [1-2]. This equivalency of two types of balances is adopted for the already known conventional method, given by Archimedes.

In the present communication, an alternate method has been proposed based upon the same principle but without the help of any extra density measuring kit, in which the easily available toploading balance is employed directly (Fig. 1). The experimental setup is simple, quick, easy and accurate in performance.

2. Experimental

The general procedure to determine the density of an object according to alternate method is: Note down the room temperature, density of water (ρ_w), and dry weight of a non-porous heavy object in air (m_O). Place a 2/3 water filled beaker on toploading balance and tare its weight to zero. Hang the object, tied with a thin thread, to an isolated stand

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placed near balance (or just keep the thread in your own hand), and dip the object slowly in water without touching the walls of the beaker till the object is fully submerged in water. Note down the reading on balance (m_W), and calculate the density of object (ρ_o) using following formula:

$$\rho_0 = \frac{m_0 \times \rho_w}{m_w} \quad (1)$$

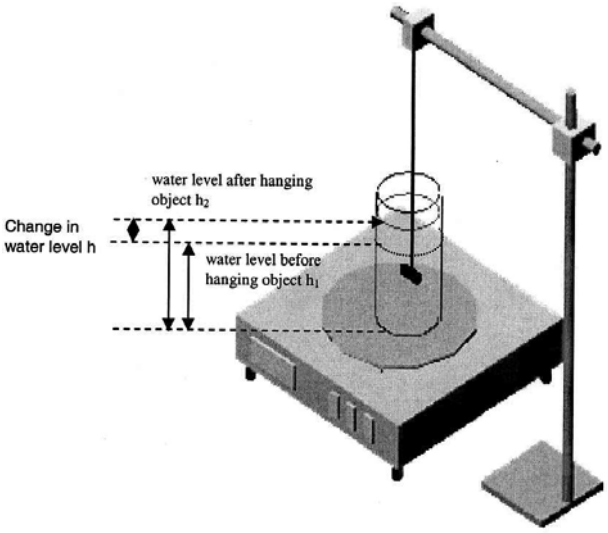

Figure 1. Setup of proposed 'Alternate' method on toploading balance, for density measurements of solid objects heavier than water.

There are some additional/modified steps to carry out density experiments for lighter or rigid porous objects. For density measurements, the object of interest should be fully dipped in water. Therefore, a heavy object (sinker) is used with lighter body to keep it fully dipped in water. In this type of experiment, tie the sinker with object of interest in series with a thread. While hanging the object in water, first lower down the thread so much that the sinker is in water and the lighter object is in air (Fig. 2a). Note the weight on balance (m_{HW}). Then, further lower down the thread and dip both bodies in water (Fig. 2b). Again note down the weight value displayed (m_{HLW}) on balance, and calculate the density according to the formula given below.

$$\rho_0 = \frac{m_0 \times \rho_w}{(m_{HLW} - m_{HW})} \quad (2)$$

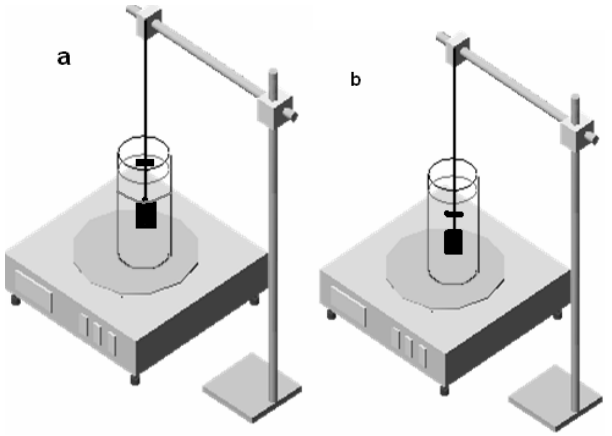

Figure 2. Setup of proposed 'Alternate' method on toploading balance, for density measurements of solid objects lighter than water. (a) only heavy object is dipped, (b) both heavy and lighter objects are dipped.

Similarly to determine the apparent density of a porous object, it is necessary to keep the entrance of hanging medium into the pores of object [3]. In this study, the object is soaked first in water to fill the pores with water (or in some cases one has to boil the object in water to desorb the adsorbed gases). Afterwards, blot the extra water with a tissue paper and hang the soaked object in water on balance. Note the displayed reading on balance (m_{wA}). The density is calculated using the following formula:

$$\rho_0 = \frac{m_0 \times \rho_w}{m_{WA}} \quad (3)$$

3. Discussion

By definition density (ρ_o) is mass per unit volume (m/v). Now for density calculations, determination of dry mass of an object is no problem. The problem is in determination of volume of an irregular shaped body. Archimedes had taken this volume as buoyancy in terms of object mass lost as a difference of weight of object in air and weight of object in water. In the new setup, volume of object equivalent to volume of water displaced can be read directly on the toploading balance in terms of mass of water displaced.

Table 1. Density of solid objects calculated according to conventional- and 'Alternate' method

Items	Density (26°C) according to method:		Difference	%relative difference (RD)* in results of conventional and alternate methods
	Conventional	Alternate		
Al (cylinder) of known dimensions	2.6837	2.668	0.0157	+ 0.585
Steel disc	7.8144	7.7865	0.0279	+ 0.357
Gold piece (impure)	13.8825	13.8869	- 0.0044	- 0.032
Silver	10.511	10.522	- 0.011	- 0.105
Cork	0.2060	0.2065	- 0.0005	- 0.243
Porous stone	1.853	1.856	- 0.003	- 0.162

$$* \ \%RD = \frac{\rho_{conventional} - \rho_{alternate}}{\rho_{conventional}}$$

Weight of water is acting downward and pressure exerted on the bottom of beaker (on balance) is given by

$P = hg\rho$

$F/A = hg\rho$

$mg/A = hg\rho$

$m/A = h\rho$

$m = Ah\rho$

$m = v\ \rho$

or

$m_1 = v_1\ \rho$ (before hanging the object)

and

$m_2 = v_2\ \rho$ (after hanging the object)

Taking the difference of two situations

$(m_2 - m_1) = (v_2 - v_1)\ \rho$

or

$$\Delta m = \Delta v \rho \qquad (4)$$

It is this Δm of water for its Δv because of submerging of object in water, which is read directly on toploading balance.

'Alternate' method proved accurate equally in evaluating densities of non-porous objects heavier or lighter than water and rigid porous objects. Porous object requires more discussion, because for such objects, two types of densities are defined: Apparent density and true density. True density of porous object is obtained when the volume measured excludes the pores within the sample. Apparent (bulk) density of porous object is obtained when the pore spaces within the object are included in volume measurement, and it is defined as total mass per unit of total volume. Apparent density is not an intrinsic property of a material. Some of the factors that affect this type of density are the fill rates, size of the particle and its pores and the material with which the pores are filled. Apparent density can give information about object's porosity, which is calculated by using the formula

% Porosity = [1-(apparent density / actual density)] x 100

In case of true density, when the dried object is hanged in water placed on balance, water will enter into the pores, this point needs a little bit more explanation, but briefly behind the density calculations, the idea is same as given in Eq. 4. Data for some objects is given in Table 1. Both methods produce same results within relative difference of ± 0.59% (Actual difference of values ±0.03). Alternate method is not only easy and accurate, but also cost effective and time saving. Therefore, to determine the density of a solid object, alternate method could be easily adopted and perform in any laboratory.

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