Calibrating a balance does not eliminate all sources of determinate error in the signal. Because of the buoyancy of air, an object always weighs less in air than it does in a vacuum. If there is a difference between the object’s density and the density of the weights used to calibrate the balance, then we can make a correction for buoyancy.\(^1\) An object’s true weight in vacuo, \((W_v)\), is related to its weight in air, \((W_a)\), by the equation
\[
W_v = W_a \times \left[1 + \left(\dfrac{1}{D_o} - \dfrac{1}{D_w}\right) \times 0.0012\right]
\tag{A9.1}
\]
where \(D_o\) is the object’s density, \(D_w\) is the density of the calibration weight, and 0.0012 is the density of air under normal laboratory conditions (all densities are in units of \(g/cm^3\)). The greater the difference between \(D_o\) and \(D_w\) the more serious the error in the object’s measured weight.

The buoyancy correction for a solid is small, and frequently ignored. It may be significant, however, for low density liquids and gases. This is particularly important when calibrating glassware. For example, we can calibrate a volumetric pipet by carefully filling the pipet with water to its calibration mark, dispensing the water into a tared beaker, and determining the water’s mass. After correcting for the buoyancy of air, we use the water’s density to calculate the volume dispensed by the pipet.

Example

A 10-mL volumetric pipet was calibrated following the procedure just outlined, using a balance calibrated with brass weights having a density of 8.40 \(g/cm^3\). At 25 \(^o\)C the pipet dispensed 9.9736 \(g\) of water. What is the actual volume dispensed by the pipet and what is the determinate error in this volume if we ignore the buoyancy correction? At 25 \(^o\)C the density of water is 0.997 05 \(g/cm^3\).

Solution

Using equation A9.1 the water’s true weight is
\[
W_v = 9.9736 \times \left[1 + \left(\dfrac{1}{0.99705} - \dfrac{1}{8.40}\right) \times 0.0012\right] = 9.9842\]
and the actual volume of water dispensed by the pipet is
\[
\dfrac{9.9842 \times 0.99705}{8.40} = 10.014\ \\text{cm}^3 = 10.014\ \\text{mL}
\]

If we ignore the buoyancy correction, then we report the pipet’s volume as
\[
\dfrac{9.9736 \times 0.99705}{8.40} = 10.003\ \\text{cm}^3 = 10.003\ \\text{mL}
\]
introducing a negative determinate error of -0.11%.

Problems

The following problems will help you in considering the effect of buoyancy on the measurement of mass.
1. In calibrating a 10-mL pipet a measured volume of water was transferred to a tared flask and weighed, yielding a mass of 9.9814 grams. (a) Calculate, with and without correcting for buoyancy, the volume of water delivered by the pipet. Assume that the density of water is 0.99707 g/cm$^3$ and that the density of the weights is 8.40 g/cm$^3$. (b) What are the absolute and relative errors introduced by failing to account for the effect of buoyancy? Is this a significant source of determinate error for the calibration of a pipet? Explain.

2. Repeat the questions in problem 1 for the case where a mass of 0.2500 g is measured for a solid that has a density of 2.50 g/cm$^3$.

3. Is the failure to correct for buoyancy a constant or proportional source of determinate error?

4. What is the minimum density of a substance necessary to keep the buoyancy correction to less than 0.01% when using brass calibration weights with a density of 8.40 g/cm$^3$?

References


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