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. An object’s true weight in vacuo, \( W_v \), is related to its weight in air, \( W_a \), by the equation

\[
W_v = W_a \times \left[ 1 + \left( \frac{1}{D_o} - \frac{1}{D_w} \right) \times 0.0012 \right] \quad \text{(A9.1)}
\]

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 °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 °C the density of water is 0.997 05 g/cm\(^3\).

Solution

Using equation A9.1 the water’s true weight is

\[
W_v = 9.9736 \times \left( 1 + \left( \frac{1}{0.99705} - \frac{1}{8.40} \right) \times 0.0012 \right) = 9.9842
\]

and the actual volume of water dispensed by the pipet is

\[
\frac{9.9842}{0.99705} = 10.014 \text{ cm}^3 = 10.014 \text{ mL}
\]

If we ignore the buoyancy correction, then we report the pipet’s volume as

\[
\frac{9.9736}{0.99705} = 10.003 \text{ cm}^3 = 10.003 \text{ mL}
\]

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


Contributors

David Harvey (DePauw University)