SOP 21

Applying air buoyancy corrections

1. Scope and field of application

The effect of air buoyancy is, if uncorrected, frequently the largest source of error in mass measurements. This procedure provides equations to be used to correct for the buoyant effect of air. An air buoyancy correction should be made in all high accuracy mass determinations.

2. Principle

The upthrust due to air buoyancy acts both on the sample being weighed and on the counter-balancing weights. If these are of different densities and hence of different volumes, it will be necessary to allow for the resulting difference in air buoyancy to obtain an accurate determination of mass.

3. Requirements

3.1 Knowledge of the air density at the time of weighing.

For the most accurate measurements, the air density is computed from a knowledge of pressure, temperature and relative humidity. Tolerances for the various measurements are:

	Uncertainty in computed air density	
Variable	± 0.1%	± 1.0%
Relative humidity	± 11.3%	. . .
Air Temperature	± 0.29 °C	± 2.9 °C
Air pressure	± 0.10 kPa	± 1.0 kPa

3.1.1 Barometer accurate to ± 0.05 kPa

3.1.2 Thermometer accurate to ± 0.1 °C

3.1.3 Hygrometer accurate to 10%

An error of 1% in air density results in an error of approximately 1 part in 10^5 in the mass corrected for air buoyancy. Although meteorological variability can result in variations of up to 3% in air density, the change of pressure (and hence of air density) with altitude can be much more significant. For measurements of moderate accuracy, made at sea level and at normal laboratory temperatures, an air density of 0.0012 $g \cdot cm^{-3}$ is often adequate.

3.2 Knowledge of the apparent mass scale used to calibrate the balance

There are two apparent mass scales in common use. The older one is based on the use of brass weights adjusted to a density of 8.4 $g \cdot cm^{-3}$, the more recent one on the use of stainless steel weights adjusted to a density of 8.0 $g \cdot cm^{-3}$ (Note 1).

3.3 Knowledge of the density of the sample

The density of the sample being weighed is needed for this calculation.

4. Procedure

4.1 Computation of air density

The density of air in $g \cdot cm^{-3}$ can be computed from measurements of pressure, temperature and relative humidity (Jones, 1978):

$$\rho(\text{air}) = \frac{3.4848(p - 0.0037960 U \cdot e_S)}{273.15 + t} \times 10^{-3} \qquad (1)$$

where

- p – air pressure (kPa),
- U – relative humidity (%),
- t – temperature (°C),
- e_s – saturation vapor pressure (kPa):

$$e_s = 1.7526 \times 10^8 \exp(-5315.56 / (t + 273.15)) \,. \qquad (2)$$

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1 Strictly, these densities apply only at 20 °C. The conversion factor from the "apparent mass" obtained by using these values to "true" mass is defined by the expression

$$Q = \frac{\rho(\text{weights})(D_{20} - 0.0012)}{D_{20}(\rho(\text{weights}) - 0.0012)}$$

where D_{20} is the apparent mass scale to which the weights are adjusted. This factor may be considered as unity for most purposes.

4.2 Computation of mass from weight

The mass m of a sample of weight w and density ρ(sample) is computed from the expression—see Annexe for derivation:

$$m = w\frac{1-\rho(\text{air})/\rho(\text{weights})}{1-\rho(\text{air})/\rho(\text{sample})} \ . \qquad (3)$$

5. Example computations

The following data were used for this calculation (Note 2):

weight of sample, $w = 100.00000$ g ,
density of sample, $\rho(\text{sample}) = 1.0000\ \text{g·cm}^{-3}$,
weighing conditions:

p = 101.325 kPa (1 atm) ,
U = 30.0% ,
t = 20.00 °C ,
ρ (weights) = 8.0000 g·cm^{-3} .

5.1 Computation of air density

$$e_\text{s} = 2.338\ \text{kPa} ,$$
$$\rho(\text{air}) = 0.0012013\ \text{g·cm}^{-3} .$$

5.2 Computation of mass

$$m = 100.10524\ \text{g} .$$

References

Dean J. A. (1985) *Lange's handbook of chemistry*, McGraw-Hill Book Company, New York, 1792 pp.

Jones F. E. (1978) The air density equation and the transfer of the mass unit. *Journal of Research of the National Bureau of Standards*, **83**, 419–428.

Schoonover R. M. & F. E. Jones (1981) Air buoyancy correction in high-accuracy weighing on analytical balances. *Analytical Chemistry* **53**, 900–902.

Taylor J. K. & H. V. Oppermann (1986) Handbook for the quality assurance of metrological measurements. National Bureau of Standards Handbook 145.

Woodward C. & H. N. Redman (1973) *High-precision titrimetry*, The Society for Analytical Chemistry, London, 63 pp.

[2] The seemingly excessive number of decimal places is provided here so that users of this procedure can check their computation scheme.

Annexe

Derivation of the expression for buoyancy correction

An expression for the buoyancy correction can be derived from a consideration of the forces shown in Figure 1. Although the majority of balances nowadays are single-pan, the principles remain the same, the difference being that the forces are compared sequentially using a force sensor rather than simultaneously using a lever. At balance, the opposing forces are equal:

$$m_1 g - V_1 \rho(\text{air}) g = m_2 g - V_2 \rho(\text{air}) g , \qquad \text{(A.1)}$$

where g is the acceleration due to gravity and $\rho(\text{air})$ is the density of the air at the temperature, pressure and humidity of the weighing operation. Note that m_2 is the “weight” of a sample whose true mass is m_1.

As

$$V = m / \rho , \qquad \text{(A.2)}$$

we can rewrite (A.1) as

$$m_1 - m_1 \rho(\text{air}) / \rho_1 = m_2 - m_2 \rho(\text{air}) / \rho_2 . \qquad \text{(A.3)}$$

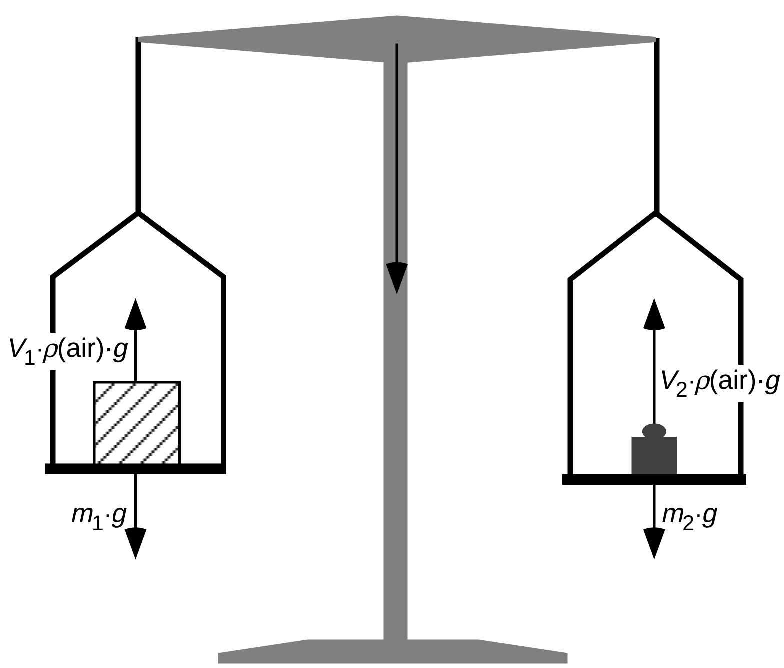

Figure 1. Forces on sample (1) and weights (2) when weighing in air.

This equation can be rearranged to obtain the expression:

$$m_1 = m_2 \frac{1 - \rho(\text{air})/\rho_2}{1 - \rho(\text{air})/\rho_1} . \qquad \text{(A.4)}$$

Equation (A.4) is the basis of the expression used for air buoyancy correction (Schoonover, 1981; Taylor & Oppermann, 1986):

$$m = w \frac{1 - \rho(\text{air})/\rho(\text{weights})}{1 - \rho(\text{air})/\rho(\text{sample})} , \qquad \text{(A.5)}$$

where w is the “weight” of the sample in air and m is the true mass.

Equation (A.3) can also be rearranged to give

$$m_1 = m_2 + m_2 \rho(\text{air}) \left(\frac{m_1}{m_2} \frac{1}{\rho_1} - \frac{1}{\rho_2} \right) . \qquad \text{(A.6)}$$

As $m_1 \approx m_2$, equation (A.6) is almost identical to the commonly quoted expression for buoyancy correction:

$$m = w + w \rho(\text{air}) \left(\frac{1}{\rho(\text{sample})} - \frac{1}{\rho(\text{weights})} \right) \qquad \text{(A.7)}$$

(Woodward & Redman, 1973; Dean, 1985). An approximate value of $\rho(\text{air})$ (0.0012 $g \cdot cm^{-3}$) is often used with this expression; this is appropriate to measurements of moderate accuracy made at sea level pressures and at normal laboratory temperatures.