

# 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 given in Table 1.

**Table 1** Tolerances for various physical parameters.

Variable	Uncertainty in computed air density	
	± 0.1%	± 1.0%
Relative humidity (%)	± 11.3%	—
Air temperature (°C)	± 0.29 K	± 2.9 K
Air pressure (kPa)	± 0.10 kPa	± 1.0 kPa

- Barometer accurate to ± 0.05 kPa,
- Thermometer accurate to ± 0.1°C,
- 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  $0.0012 \text{ g cm}^{-3}$  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  $8.4 \text{ g cm}^{-3}$ , the more recent one on the use of stainless steel weights adjusted to a density<sup>1</sup> of  $8.0 \text{ g cm}^{-3}$ .

### 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  $\text{g cm}^{-3}$  can be computed from measurements of pressure, temperature, and relative humidity (Jones, 1978):

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

where

- $p$  = air pressure (kPa),
- $U$  = relative humidity (%),
- $t$  = temperature ( $^{\circ}\text{C}$ ),
- $e_s$  = saturation vapor pressure (kPa),

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

### 4.2 Computation of mass from weight

The mass,  $m$ , of a sample of weight,  $w$ , and density,  $\rho(\text{sample})$ , is computed from the expression

<sup>1</sup> Strictly, these densities apply only at  $20^{\circ}\text{C}$ . 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.

$$m = w \left( \frac{1 - \rho(\text{air})/\rho(\text{weights})}{1 - \rho(\text{air})/\rho(\text{sample})} \right) \quad (3)$$

(see Annexe for the derivation).

## 5. Example calculation

The following data were used for this calculation<sup>2</sup>:

weight of sample,  $w = 100.00000$  g,  
density of sample,  $\rho(\text{sample}) = 1.0000$  g cm<sup>-3</sup>.

Weighing conditions:

$p = 101.325$  kPa (1 atm),  
 $U = 30.0\%$ ,  
 $t = 20.00^\circ\text{C}$ ,  
 $\rho(\text{weights}) = 8.0000$  g cm<sup>-3</sup>.

### 5.1 Computation of air density

$e_s = 2.338$  kPa,  
 $\rho(\text{air}) = 0.0012013$  g cm<sup>-3</sup>.

### 5.2 Computation of mass

$m = 100.10524$  g.

## 6. Bibliography

- 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. *J. Res. Natl. Bureau Stand.* **83**: 419–428.
- Schoonover, R.M. and Jones, F.E. 1981. Air buoyancy correction in high-accuracy weighing on analytical balances. *Anal. Chem.* **53**: 900–902.
- Taylor, J.K. and Oppermann, H.V. 1986. Handbook for the quality assurance of metrological measurements. National Bureau of Standards Handbook 145.
- Woodward, C. and Redman, H.N. 1973. High-precision Titrimetry. The Society for Analytical Chemistry, London, 63 pp.

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<sup>2</sup> The seemingly excessive number of decimal places is provided here so that users of this procedure can check their computation scheme.

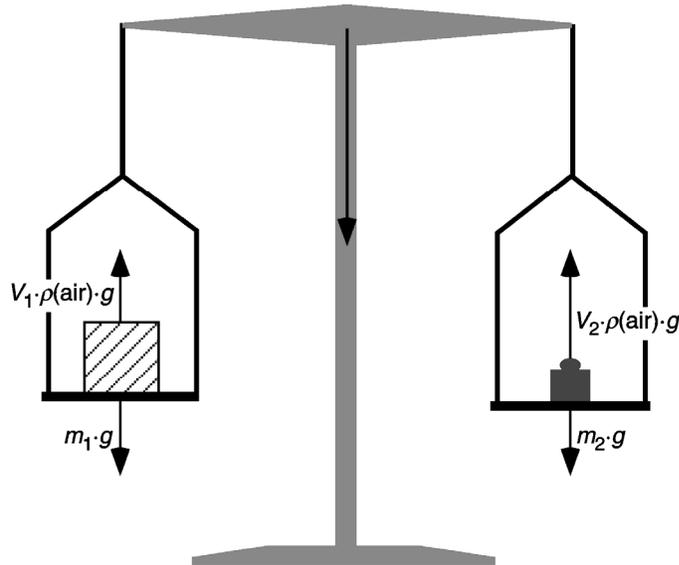
## Annexe

### 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:

$$m_1g - V_1\rho(\text{air})g = m_2g - V_2\rho(\text{air})g \quad (4)$$

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  $m_1$ .



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

As

$$V = m/\rho, \quad (5)$$

we can rewrite equation (4) as

$$m_1 - m_1\rho(\text{air})/\rho_1 = m_2 - m_2\rho(\text{air})/\rho_2. \quad (6)$$

This equation can be rearranged to obtain the expression

$$m_1 = m_2 \frac{1 - \rho(\text{air})/\rho_2}{1 - \rho(\text{air})/\rho_1}. \quad (7)$$

Equation (7) is the basis of the expression used for air buoyancy correction (Schoonover and Jones, 1981; Taylor and Oppermann, 1986):

$$m = w \frac{1 - \rho(\text{air})/\rho(\text{weights})}{1 - \rho(\text{air})/\rho(\text{sample})} \quad (8)$$

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

Equation (6) can also be rearranged to give

$$m_1 = m_2 + m_2 \rho(\text{air}) \left( \frac{m_1}{m_2} \frac{1}{\rho_1} - \frac{1}{\rho_2} \right). \quad (9)$$

As  $m_1 \approx m_2$ , equation (9) is almost identical to the commonly quoted expression for buoyancy correction,

$$m = w + w \rho(\text{air}) \left[ \frac{1}{\rho(\text{sample})} - \frac{1}{\rho(\text{weights})} \right] \quad (10)$$

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