Glassware Calibration Guidelines
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Adapted from National Bureau of Standards Document 74-461

The purpose of calibrating glassware is to determine the volume of liquid that the glassware actually holds, as opposed to the advertised or stated volume. The volume of water contained in glassware is derived from the mass, using density as a conversion factor.

The indicated mass of the water (M_I) is easy to calculate, by subtracting the weight of an empty *dry* flask (M_{EF}) from the weight of the full flask (M_{FF}), as measured using an analytical balance.

$$M_I = M_{FF} - M_{EF} \qquad \text{Eq. 1}$$

However, depending on the level of accuracy desired, a series of adjustments should be made to correct this value. The true mass of the water and the expansion of glass due to temperature can be accounted for as follows.

Adjustment #1 - Buoyancy

The buoyancy adjustment corrects the mass indicated by the balance in cases where the object being weighed does not have the same density as the material used to calibrate the balance. Balances measure weight through comparison to a calibration weight, typically a metal. The apparent mass of both the water and the calibration weight are affected by the air in which they're sitting. The air produces a buoyancy force counteracting the downward force applied by both the balance weights and the unknown water mass. An electronic balance works by comparison of these two forces.

$$M_W \left[1 - \frac{\rho_A}{\rho_W}\right] = M_I \left[1 - \frac{\rho_A}{\rho_B}\right] \qquad \text{Eq. 2}$$

Here, M_w refers to the corrected mass of water, M_I is the mass as indicated by the balance, ρ is the typical symbol for density, B represents the calibration weights, and A stands for air. Typical analytical balances use counterweights with a density of 7.78 g/cm^3. Eq 2 rearranges to yield:

$$M_W = M_I \left[1 - \frac{\rho_A}{\rho_B}\right] \left[\frac{\rho_W}{\rho_W - \rho_A}\right] \qquad \text{Eq. 3}$$

To obtain the volume of water, divide the mass M_W by the density of water for the temperature at which the measurements were made ρ_W:

$$V_T = M_I \left[\frac{1}{\rho_W - \rho_A}\right] \left[1 - \frac{\rho_A}{\rho_B}\right] \qquad \text{Eq. 4}$$

This volume, V_T, is the volume dispensed or contained by the piece of glassware, for the temperature at which the measurements were made. A final correction is required to account for expansion or contraction of the glass with temperature if a comparison of the volume of the device to the volume specified for 20 °C is desired.

The density of water and air can often be found in tables if the temperature and pressure are known. If necessary, the following equations, where T is the temperature in °C and B is the pressure in mm Hg, can be used to determine density.

$$\rho_A = \frac{0.464554B - 40(0.00252T - 0.020582)}{1000(T + 273.16)} \quad \text{Eq. 5}$$

$$\rho_W = \left[1 - \frac{(T - 3.9863)^2}{508929.2} \times \frac{T + 288.9414}{T + 68.12963}\right](0.999973) \quad \text{Eq. 6}$$

Note that these equations yield densities with units of g/cm^3. When weighing an analyte other than water, a similar adjustment can be made, replacing ρ_W with the density of the new material.

Adjustment #2 - Glass Expansion/Contraction

The above calculations result in the volume contained in the flask at the test temperature. Standard glass calibration yields the volume contained at 20°C. The expansion of the glassware should also be accounted for when highly accurate results are needed. This adjustment, *K*, is material dependent, calculated using

$$K = 1 - \alpha(T - 20) \quad \text{Eq. 7}$$

where α is the temperature coefficient of cubical expansion (because the glass expands in three dimensions) and *T* is the test temperature in °C. The majority of laboratory glassware is borosilicate, for which α = 0.000010/°C. Note that a larger α value or a temperature that differs greatly from 20 °C will result in a larger K value. By accounting for glass expansion, the volume at 20°C (V_{20}) can be calculated.

$$V_{20} = M_I \left[\frac{1}{\rho_W - \rho_A}\right]\left[1 - \frac{\rho_A}{\rho_B}\right][1 - \alpha(T - 20)] \quad \text{Eq. 8}$$

The slightly condensed version isolates the contribution of each adjustment.

$$V_{20} = M_I \left[\frac{1}{\rho_W - \rho_A}\right]\left[1 - \frac{\rho_A}{\rho_B}\right][K] \quad \text{Eq. 9}$$

Sample Glassware Calibration Problem

Note: for these problems it is useful to carry through more significant digits than is needed in the final answer.

After carefully cleaning and drying a 100 mL volumetric flask, you measure its weight to be 68.22 g. You fill the flask with water until the bottom of the meniscus is even with the “full” line, at which point the weight is 167.61 g. Two more replicates yield full flask weights of 167.73 g and 167.81 g. Before moving on, you dutifully measure the temperature of the water to be 24.6 °C and the barometric pressure to be 750 mmHg.

1. What is the indicated weight of the water (M_I) in each of the three trials? Based on the conversion 1 g water = 1 mL water, what would you calculate the volume of your flask to be without any adjustments? What is the average of these measurements?

2. The density of the built-in weights in your analytical balance is 7.78 g/cm^3; density tables for air and water are attached. What is the value of the buoyancy adjustment for this set of measuremnts, $\left[\frac{1}{\rho_W - \rho_A}\right]\left[1 - \frac{\rho_A}{\rho_B}\right]$?

3. You’re using borosilicate glass, for which the temperature coefficient of cubical expansion (α) is 0.000010 /°C. What is the glass expansion adjustment, K?

4. Taking into account all of these adjustments, what volume does this flask hold at 20°C in each of the three trials? What is the average?

5. What is the precision (relative standard deviation) of these measurements?

6. Using the average, unadjusted volume found in Problem 1, determine what you would find the final volume to be in each case if you ignored one of the adjustments? (i.e. ignore the buoyancy correction and incorporate only Q and K)

7. What are the absolute and relative errors associated with each of these measurements?

8. Which adjustment has the greatest effect? The least effect?

9. What adjustments might you feel safe ignoring? Justify your answer and mention circumstances in which you would not ignore the adjustment(s).

Water and air density tables (given in g/cm3) (source: NBS 74-461)

T	0.0°C	0.1°C	0.2°C	0.3°C	0.4°C	0.5°C	0.6°C	0.7°C	0.8°C	0.9°C
.0	.999840	.999846	.999853	.999859	.999865	.999871	.999877	.999883	.999888	.999893
1.0	.999899	.999903	.999908	.999913	.999917	.999921	.999925	.999929	.999933	.999937
2.0	.999940	.999943	.999946	.999949	.999952	.999954	.999956	.999958	.999961	.999963
3.0	.999964	.999966	.999967	.999968	.999969	.999970	.999971	.999971	.999972	.999972
4.0	.999972	.999972	.999972	.999971	.999971	.999970	.999969	.999968	.999967	.999965
5.0	.999964	.999962	.999960	.999958	.999956	.999954	.999951	.999949	.999946	.999943
6.0	.999940	.999937	.999933	.999930	.999926	.999922	.999918	.999914	.999910	.999906
7.0	.999901	.999896	.999892	.999887	.999881	.999876	.999871	.999865	.999860	.999854
8.0	.999848	.999842	.999835	.999829	.999822	.999816	.999809	.999802	.999795	.999787
9.0	.999780	.999773	.999765	.999757	.999749	.999741	.999733	.999725	.999716	.999707
10.0	.999700	.999690	.999681	.999672	.999662	.999652	.999643	.999634	.999624	.999614
11.0	.999604	.999594	.999583	.999573	.999562	.999552	.999541	.999530	.999519	.999507
12.0	.999496	.999485	.999473	.999461	.999449	.999437	.999425	.999413	.999401	.999388
13.0	.999376	.999363	.999350	.999337	.999324	.999311	.999297	.999284	.999270	.999256
14.0	.999243	.999229	.999215	.999200	.999186	.999172	.999157	.999142	.999128	.999113
15.0	.999098	.999083	.999067	.999052	.999036	.999021	.999005	.998989	.998973	.998957
16.0	.998941	.998925	.998908	.998892	.998875	.998858	.998841	.998824	.998807	.998790
17.0	.998773	.998755	.998738	.998720	.998702	.998684	.998666	.998648	.998630	.998612
18.0	.998593	.998575	.998556	.998537	.998519	.998500	.998480	.998461	.998442	.998422
19.0	.998403	.998383	.998364	.998344	.998324	.998304	.998284	.998263	.998243	.998222
20.0	.998202	.998181	.998160	.998139	.998118	.998097	.998076	.998055	.998033	.998012
21.0	.997990	.997968	.997947	.997925	.997903	.997881	.997858	.997836	.997814	.997791
22.0	.997768	.997746	.997723	.997700	.997677	.997654	.997630	.997607	.997584	.997560
23.0	.997536	.997513	.997489	.997465	.997441	.997417	.997392	.997368	.997344	.997319
24.0	.997294	.997270	.997245	.997220	.997195	.997170	.997145	.997119	.997094	.997068
25.0	.997043	.997017	.996991	.996966	.996940	.996913	.996887	.996861	.996835	.996808
26.0	.996782	.996755	.996728	.996702	.996675	.996648	.996621	.996593	.996566	.996539
27.0	.996511	.996484	.996456	.996428	.996401	.996373	.996345	.996316	.996288	.996260
28.0	.996232	.996203	.996175	.996146	.996117	.996088	.996060	.996031	.996001	.995972
29.0	.995943	.995914	.995884	.995855	.995825	.995795	.995765	.995736	.995706	.995676
30.0	.995645	.995615	.995585	.995554	.995524	.995493	.995463	.995432	.995401	.995370
31.0	.995339	.995308	.995277	.995246	.995214	.995183	.995151	.995120	.995088	.995056
32.0	.995024	.994992	.994960	.994928	.994896	.994864	.994831	.994799	.994766	.994734
33.0	.994701	.994668	.994635	.994602	.994569	.994536	.994503	.994470	.994436	.994403
34.0	.994369	.994336	.994302	.994268	.994234	.994201	.994167	.994132	.994098	.994064
35.0	.994030	.993995	.993961	.993926	.993891	.993857	.993822	.993787	.993752	.993717
36.0	.993682	.993647	.993611	.993576	.993541	.993505	.993469	.993434	.993398	.993362
37.0	.993326	.993290	.993254	.993218	.993182	.993146	.993109	.993073	.993036	.993000
38.0	.992963	.992926	.992889	.992852	.992815	.992778	.992741	.992704	.992667	.992629
39.0	.992592	.992554	.992517	.992479	.992442	.992404	.992366	.992328	.992290	.992252

TABLE 2: Density of Air Free Water in g/cm 3 as a Function of the Celsius Temperature Scale, Based on the Work by H. Wagenbreth and W. Blanke, PTB-Mitteilungen 6-71.

TABLE 1B.

This table provides values of air density calculated from temperature, barometric pressure and assumed relative humidity of 40%. Errors in V_{20} which result from use of this table are insignificant.

TABLE 1B

BAROMETRIC PRESSURE (MM OF HG)	16 °C	18 °C	20 °C	22 °C	24 °C	26 °C	28 °C
600	0.00096	0.00095	0.00095	0.00094	0.00093	0.00093	0.00092
605	0.00097	0.00096	0.00095	0.00095	0.00094	0.00093	0.00093
610	0.00098	0.00097	0.00096	0.00096	0.00095	0.00094	0.00093
615	0.00098	0.00098	0.00097	0.00096	0.00096	0.00095	0.00094
620	0.00099	0.00099	0.00098	0.00097	0.00096	0.00096	0.00095
625	0.00100	0.00099	0.00099	0.00098	0.00097	0.00096	0.00096
630	0.00101	0.00100	0.00099	0.00099	0.00098	0.00097	0.00097
635	0.00102	0.00101	0.00100	0.00099	0.00099	0.00098	0.00097
640	0.00102	0.00102	0.00101	0.00100	0.00100	0.00099	0.00098
645	0.00103	0.00103	0.00102	0.00101	0.00100	0.00100	0.00099
650	0.00104	0.00103	0.00103	0.00102	0.00101	0.00100	0.00100
655	0.00105	0.00104	0.00103	0.00103	0.00102	0.00101	0.00100
660	0.00106	0.00105	0.00104	0.00103	0.00103	0.00102	0.00101
665	0.00106	0.00106	0.00105	0.00104	0.00103	0.00103	0.00102
670	0.00107	0.00107	0.00106	0.00105	0.00104	0.00103	0.00103
675	0.00108	0.00107	0.00107	0.00106	0.00105	0.00104	0.00103
680	0.00109	0.00108	0.00107	0.00107	0.00106	0.00105	0.00104
685	0.00110	0.00109	0.00108	0.00107	0.00107	0.00106	0.00105
690	0.00110	0.00110	0.00109	0.00108	0.00107	0.00107	0.00106
695	0.00111	0.00110	0.00110	0.00109	0.00108	0.00107	0.00107
700	0.00112	0.00111	0.00110	0.00110	0.00109	0.00108	0.00107
705	0.00113	0.00112	0.00111	0.00110	0.00110	0.00109	0.00108
710	0.00114	0.00113	0.00112	0.00111	0.00110	0.00110	0.00109
715	0.00115	0.00114	0.00113	0.00112	0.00111	0.00110	0.00110
720	0.00115	0.00114	0.00114	0.00113	0.00112	0.00111	0.00110
725	0.00116	0.00115	0.00114	0.00114	0.00113	0.00112	0.00111
730	0.00117	0.00116	0.00115	0.00114	0.00114	0.00113	0.00112
735	0.00118	0.00117	0.00116	0.00115	0.00114	0.00114	0.00113
740	0.00119	0.00118	0.00117	0.00116	0.00115	0.00114	0.00113
745	0.00119	0.00118	0.00118	0.00117	0.00116	0.00115	0.00114
750	0.00120	0.00119	0.00118	0.00118	0.00117	0.00116	0.00115
755	0.00121	0.00120	0.00119	0.00118	0.00118	0.00117	0.00116
760	0.00122	0.00121	0.00120	0.00119	0.00118	0.00117	0.00117
765	0.00123	0.00122	0.00121	0.00120	0.00119	0.00118	0.00117
770	0.00123	0.00122	0.00122	0.00121	0.00120	0.00119	0.00118
775	0.00124	0.00123	0.00122	0.00122	0.00121	0.00120	0.00119
780	0.00125	0.00124	0.00123	0.00122	0.00121	0.00121	0.00120
785	0.00126	0.00125	0.00124	0.00123	0.00122	0.00121	0.00120
790	0.00127	0.00126	0.00125	0.00124	0.00123	0.00122	0.00121
795	0.00127	0.00126	0.00126	0.00125	0.00124	0.00123	0.00122