8.4.3 *Density of sucrose solutions*

The density of sucrose solutions is generally used in sugar technology and in the sugar trade to measure the concentration of dissolved substances. Since the non-sucrose impurities present in technical sugar solutions affect the density in the same way as sucrose, density can be used as an approximate method for determination of dry substance content. The density tables for sucrose have existed for nearly one century (Plato, 1900) and are still used as reference marks in brewery. ICUMSA recommended in its 16th session (1978) that density should be determined at 20°C related to water at 4°C (weight corrected to vacuum) by means by hydrometers or pycnometers, the latter giving more accurate results.

Following the recommendations adopted by ICUMSA in 1982, new measurements of density were performed by Wagenbreth *et al.* (1988) using Kell's (1975) relation of determination of water density ϱ_w (kg/m^3) when temperature t (°C) is varied:

$$\varrho_w = (999.83952 + 16.952577 \times t - 7.9905127 \times 10^{-3} \times t^2 - 46.241757 \times 10^{-6} \times t^3 + 105.84601 \times 10^{-9} \times t^4 - 281.03006 \times 10^{-12} \times t^5) / (1 + 16.887236 \times 10^{-3} \times t)$$

A polynomial including ϱ_w giving the density ϱ of sucrose solutions as a function of mass concentration c (g sucrose % g of solution) at 20°C and temperature t (°C) was adopted by ICUMSA (1990) to replace Plato's table:

$$\varrho = \varrho_w + a_1c^2 + a_3c^3 + (b_1c + b_2c^2 + b_3c^3) \times (t - 20) + (c_1c + c_2c^2 + c_3c^3) \times (t - 20)^2 + (d_1c + d_2c^2) \times (t - 20)^3 + e_1c(t - 20)^4$$

Coefficients:

$a_1 = 385.850\,74$	$b_1 = -0.459244$	$c_1 = 6.0198 \times 10^{-3}$
$a_2 = -13.034\,35$	$b_2 = 7.5699 \times 10^{-2}$	$c_2 = -1.3008 \times 10^{-3}$
$a_3 = -3.666\,3$	$b_3 = 6.2667 \times 10^{-2}$	$c_3 = -4.907 \times 10^{-4}$
$d_1 = -5.110 \times 10^{-5}$	$e_1 = 1.986 \times 10^{-7}$	
$d_2 = 1.580 \times 10^{-5}$		

The values of density derived from this polynomial are listed in Table 8.9 with ϱ in kg/m^3, c in g sucrose % g of solution and t in °C.

8.4.4 *Density and apparent specific volume*

Theoretically the density (or mass per unit volume) represents the packing characteristics of solute molecules among water molecules, which depends on the molecular structure of both. Moreover, since water is 'structured',

Table 8.9 Density ϱ (kg m^{-3}) of aqueous sucrose solution as a function of the mass fraction w (%) and temperature (°C) (from ICUMSA, 1990)

	Temperature (°C)							
w (%)	10	20	30	40	50	60	70	80
5	999.70	998.20	995.64	992.21	988.03	983.19	977.78	971.76
5	1019.56	1017.79	1015.03	1011.44	1007.14	1002.20	996.70	990.65
10	1040.15	1038.10	1035.13	1031.38	1026.97	1021.93	1016.34	1010.23
15	1061.48	1059.15	1055.97	1052.06	1047.51	1042.39	1036.72	1030.56
20	1083.58	1080.97	1077.58	1073.50	1068.83	1063.60	1057.85	1061.63
25	1106.47	1103.59	1099.98	1095.74	1090.94	1085.61	1079.78	1073.50
30	1130.19	1127.03	1123.20	1118.80	1113.86	1108.44	1102.54	1096.21
35	1154.76	1151.33	1147.28	1142.71	1137.65	1132.13	1126.16	1119.79
40	1180.22	1176.51	1172.25	1167.52	1162.33	1158.71	1150.88	1144.27
45	1206.58	1202.01	1198.16	1193.25	1187.94	1182.23	1176.14	1169.70
50	1233.87	1220.64	1224.98	1219.93	1214.50	1208.70	1202.56	1196.11
55	1262.11	1257.64	1252.79	1247.59	1242.05	1236.18	1220.99	1223.53
60	1291.31	1286.61	1281.59	1276.25	1270.61	1264.67	1258.45	1251.99
65	1321.46	1316.56	1311.38	1305.93	1300.21	1294.21	1287.96	1281.52
70	1352.55	1347.49	1342.16	1336.63	1330.84	1324.80	1318.55	1312.13
75	1384.58	1379.36	1373.98	1366.36	1362.52	1356.46	1350.21	1343.83
80	1417.50	1412.20	1406.70	1401.10	1395.2	1389.2	1383.0	1376.60
85	1451.30	1445.90	1440.50	1434.80	1429.00	1422.90	1416.80	1410.60

the interaction between solute and solvent is extremely complex. Electrostrictive forces counterbalance displacement of water molecules so that water molecules, in general, have good packing characteristics. In other words, sugars dissolved in water show higher densities (up to 1.5 g/cm^3) than many other organic compounds. Sucrose is no exception to this rule and, in fact, sucrose has a slightly higher density than many other sugars which emphasizes its good compatibility with water structure. The interaction between sucrose and water, giving rise to the solute–solvent effects, is largely due to hydrogen bonds. These have a lifetime of about 10^{-9} s and occur at specific loci in the sucrose molecule. Generally equatorial hydroxyl groups are more easily hydrated than axial hydroxyl groups but such effects are modified by the interplay between the hydroxyl groups of the sucrose molecule itself, i.e. intramolecular hydrogen bonding.

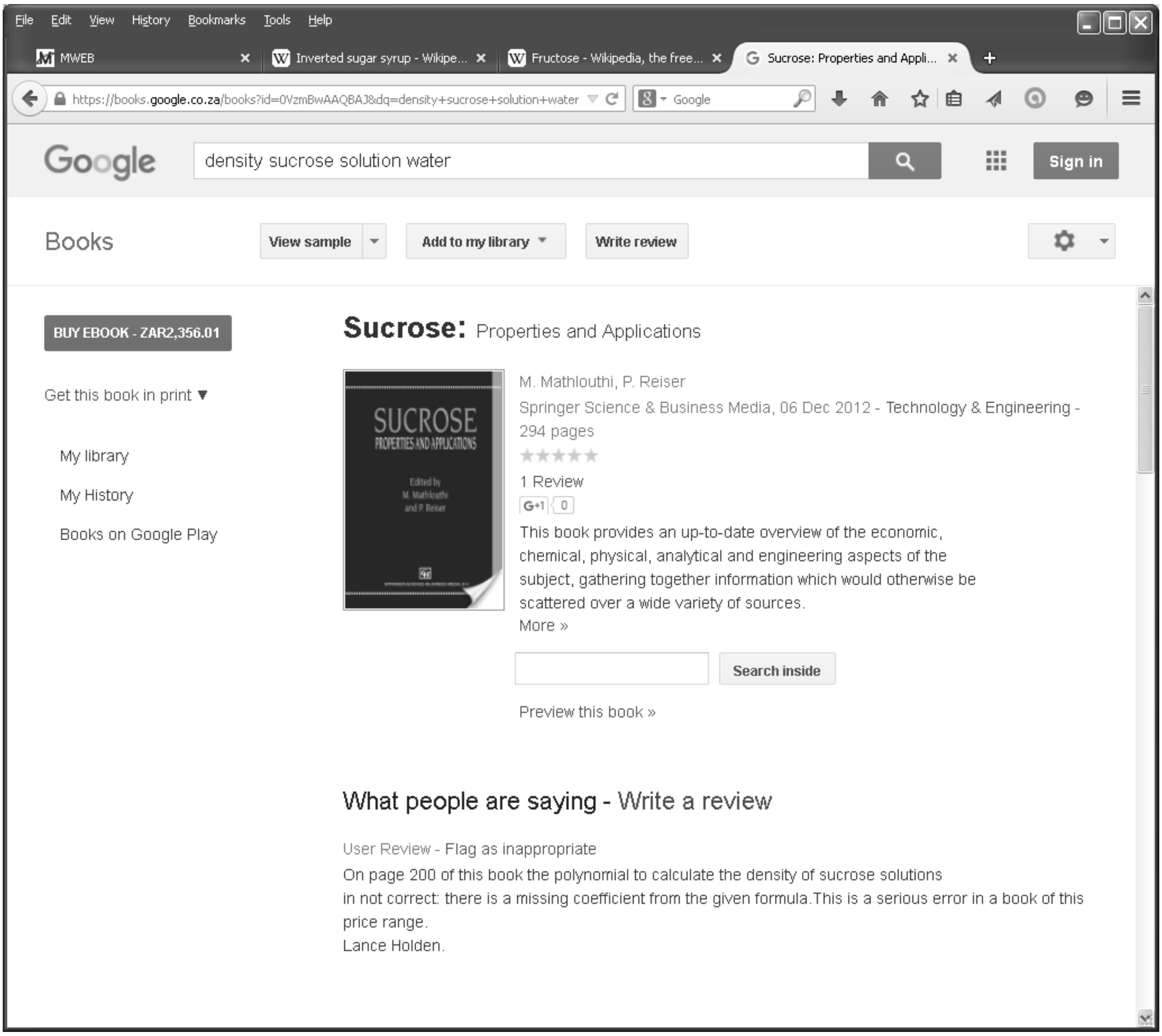
Apparent molar volume $\phi(V_2^0)$ of the sugar can be calculated using the density of solution and that of water:

$$\phi(V_2^0) = M \times \left(\frac{1}{\varrho_1} - \frac{w_1}{\varrho_2} \right) / w_2$$

with ϱ_1 density of solution, ϱ_2 density of water, w_1 mass fraction of water, w_2 mass fraction of solute and M molecular weight of solute. The partial molar volume is apparent molar volume at infinite dilution. The corresponding specific volumes are obtained by dividing molar volumes by molecular weight of the solute. These offer the advantage of comparing the characteristics of substances on a mass basis. The apparent molar volumes of dissaccharides are about twice those of monosaccharides and trisaccharides about thrice, etc. . . . However, the apparent specific volumes of most sugars are all within 0.60–0.63 cm^3/g. Increase in temperature causes a corresponding increase in apparent specific volume which is presumably related to a diminution in the overall number of hydrogen bonds. Apparent molar volumes (AMV in cm^3/mol) are good experimental indicators of the effective size of sugar molecules (see Table 8.10). Of particular importance in taste chemoreception is the apparent specific volume (ASV in cm^3/g) which is a measure of the packing ability of a particular form of solute conformation in water (Shamil *et al.*, 1987). This parameter was useful to discriminate basic tastes. Sweet substances generally fit into the range 0.51–0.71 cm^3/g and sucrose, the optimum sweetener, is situated in the center of the sweet range (0.61 cm^3/g).

8.4.5 *Refractive index*

Like densimetry, refractometry is a rapid method for determining total solids in aqueous sucrose solutions. The principle of the method is recalled in chapter 7 (in this book). The 20th Session of ICUMSA (1990) officially adopted formulae and tables recommended in the 17th Session (1978) which give the Refractive Index *in vacuo* for aqueous sucrose solutions with concentrations ranging from 0 to 85% at temperatures between 15 and 30°C, and wavelengths from 546.1 to 589.3 nm.



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On page 200 of this book the polynomial to calculate the density of sucrose solutions in not correct: there is a missing coefficient from the given formula.This is a serious error in a book of this price range.

Lance Holden.