

Short Communication**Solute Potentials of Sucrose Solutions¹**

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Three basic sources exist (4, 9, 10, 13, 14) from which data may be obtained for calculating the solute potential (ψ_s) of sucrose solutions. Authorities usually cited (1-3, 8, 17-19) by plant physiologists obtained their values directly or indirectly from Morse (9, 10).

If agreement among the sources were excellent, there would be no problem. Unfortunately discrepancies occur (Table I), with differences ranging from 0.20 to 0.74 bars and from 8.0 to 2.8%.

The data of Morse, obtained by measuring hydrostatic pressure developed in a rigid osmometer, offer the practical advantage of covering the range from 0 to 80 C in 5 or 10 degree increments. Atmospheres are easily converted to bars, but the concentration range to 1.0 molal may not always be adequate. One minor difficulty is that Morse (9, p. 116) used 339.6 ($H = 1$) rather than 342.3 as the molecular weight of sucrose. This produces an 0.8% error. Only one of the reference table authors, Garner (3), corrected for it.

Although the data of Robinson and Stokes (13, 14), obtained isopiesticly, extend the concentration range to 6.0 molal, they are limited to one temperature, 25 C. This isopiestic method involved vapor pressure equilibrium being reached by the contents of cups open into common evacuated space with gravimetric determination of concentrations and should not be confused with isopiestic thermocouple psychrometry. Freezing point depression data (4) leave the possibility of improper temperature correction. The limitation to one temperature and the question of the effects of temperature present another problem. Morse (9) reported unusual effects of temperature, especially between 25 and 30 C, where his data show a discontinuity. Instead of continuing its steady decrease with rising temperature, ψ_s increases at low sucrose concentrations and plateaus or decreases much less rapidly at moderate to high concentrations.

This paper presents the results of a careful consideration of available data and additional data generated from a vapor pressure osmometer in an attempt to resolve these problems.

MATERIALS AND METHODS

Because the osmotic coefficient (ϕ) appears to be the most satisfactory unit with which to work, it will be used in the balance of this paper. The relation between ψ_s and ϕ is indicated by this equation (ref. 14, p. 205):

$$\psi_s = -RTvm\phi M_w/1000\bar{V}_w \quad (1)$$

where ψ_s is in bars; R is the gas constant (83.143 bars cm³

degree⁻¹ mole⁻¹); T is the Kelvin temperature; v is the number of particles per molecule of solute; m is the molality; M_w is the molecular weight of water; and \bar{V}_w is the partial molal volume of water.

For sucrose, v is unity and M_w/\bar{V}_w is nearly the same as the density of water (D_w) (5). The latter was verified by using data (20) in method II (ref. 7, p. 206) and utilizing this equation,

$$\bar{V}_w = (V_t - M_s \bar{V}_s)/M_w \quad (2)$$

where V_t is total volume and M_s and \bar{V}_s are molecular weight and partial molal volume of solute. Therefore, equation 1 simplifies to

$$\psi_s \approx -10^{-3}RTD_w m\phi \quad (3)$$

The data of Morse (9, p. 184) were corrected for molecular weight, converted to bars, and then to values of ϕ by use of equation 3.

Published isopiestic concentrations of KCl and sucrose, ranging from 0.183 to 1.099 molal sucrose (11, 12, 15) and ϕ values for KCl (14) were used to calculate ϕ values for sucrose so the reproducibility of this method could be checked. Two values were rejected as obviously far out of line. The other 42 values were subjected to regression analysis.

The freezing point depression data (4) were converted to ϕ values using this equation (16),

$$\phi = \theta/(1.86 - 0.001\theta) vm \quad (4)$$

where θ is the freezing point depression.

A 302B vapor pressure osmometer with a 18575A variable temperature controller (Hewlett-Packard) was used to compare, successively, equimolal concentrations of sucrose and mannitol in the concentration range of greatest percentage disparity between isopiestic and hydrostatic methods. Reagent grade sucrose and mannitol were used without further purification or drying. Vapor pressure osmometry is not isopiestic, measuring vapor pressure differences between solution and solvent as imbalance in a bridge circuit containing thermistor beads wet with drops of solution and solvent in a solvent-saturated atmosphere. Mannitol ϕ values at 0 C were calculated from freezing point depressions (4) and equation 4. For 0.1, 0.2, 0.4, and 0.5 molal they are 0.9995, 1.0015, 1.0032, and 1.0036, respectively. Because they are so close to unity, in agreement with Morse (9, p. 207), no significant error should have entered when they were multiplied by the ratio of sucrose to mannitol instrument readings to obtain ϕ values for sucrose. The 28 values obtained were also subjected to regression analysis.

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Table I. Sucrose Solution Solute Potentials at 25 C Calculated from Three Sources

The values were obtained by conversion of published data by methods indicated in the text to ψ_s in bars.

Source	Molal Concn of Sucrose									
	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
	ψ_s , bars									
H.P. ¹	-2.69	-5.26	-7.90	-10.52	-13.22	-15.96	-18.82	-21.71	-24.65	-27.63
I. ²	-2.49	-5.03	-7.59	-10.21	-12.87	-15.57	-18.34	-21.12	-24.00	-26.89
F.P.D. ³	-2.50	-5.05	-7.65	-10.31	-13.03	-15.79	-18.62	-21.49	-24.43	-27.41

¹ H.P.: hydrostatic pressure from Morse (9, 10).² I: isopiestic from Robinson and Stokes (13, 14).³ F.P.D.: freezing point depression from Hall and Sherrill (4).Table II. Sucrose Solution Osmotic Coefficients (ϕ) as Determined by Four Methods

Molal Concn	Methods and Temperatures (C)										
	Isopiestic ¹	Hydrostatic Pressure					Freezing Point Depression ¹	Vapor Pressure Osmometry ¹			
		25	0	20	25	30		40	0	20	25
0.1	1.008	1.107	1.087	1.088	1.007	1.012	1.011	1.019	1.011	1.020	1.000
0.2	1.017	1.062	1.063	1.064	1.026	1.021	1.022	1.009	1.013	1.016	1.031
0.3	1.024	1.062	1.064	1.065	1.037	1.032	1.032				
0.4	1.033	1.062	1.064	1.064	1.047	1.048	1.043	1.036	1.044	1.034	1.036
0.5	1.041	1.070	1.070	1.070	1.056	1.056	1.054	1.059	1.045	1.043	1.049
0.6	1.050	1.078	1.077	1.076	1.066	1.064	1.065				
0.7	1.060	1.085	1.087	1.088	1.076	1.069	1.076				
0.8	1.068	1.095	1.097	1.098	1.087	1.078	1.087				
0.9	1.079	1.105	1.106	1.108	1.095	1.087	1.098				
1.0	1.088	1.117	1.118	1.118	1.108	1.095	1.109				

¹ Regression analyses of the isopiestic and freezing point depression values listed and of the 28 determinations from which the listed values for vapor pressure osmometry were obtained provided the following: isopiestic, $\phi = (0.998 \pm 0.001) + (0.089 \pm 0.001) m$, $R = 0.999$; freezing point depression, $\phi = (1.000 \pm 0.000) + (0.109 \pm 0.000) m$, $R = 1.000$; vapor pressure osmometry, $\phi = (1.001 \pm 0.004) + (0.091 \pm 0.011) m$, $R = 0.858$.

RESULTS AND DISCUSSION

The ϕ values obtained by four methods and regression line equations for the data from three of these are given in Table II.

That the isopiestic method is capable of great precision and reproducibility is shown by the regression line equation and correlation coefficient (R) yielded by analysis of the 42 values from the three sources previously cited.

$$\phi = (0.998 \pm 0.001) + (0.089 \pm 0.002)m; \quad R = 0.993 \quad (5)$$

Equation 5 bears elegant testimony to the reliability of this technique, and it has the same intercept and slope as the equation for the tabular values (Table II). The reduced variation and higher R value of the latter no doubt reflect the smoothing that produced them.

The minimal variation and maximal R value of the regression line equation for the freezing point depression data (Table II) must have resulted from the smoothing of original data for presentation (4). In fact, I interpolated freezing point depressions and inserted ϕ values for sucrose concentrations of 0.3, 0.6, 0.8, and 0.9 molal.

The raw data of Morse (9) indicate the hydrostatic pressure method gave extremely precise and reproducible data.

Comparatively, vapor pressure osmometry data are not as good. What is important, however, is that they are good enough

to support strongly the isopiestic and freezing point depression data and to help cast strong doubt on the high ϕ values for low concentrations of sucrose at and below 25 C. Both the latter and the vapor pressure osmometry data help deny the existence of a discontinuity between 25 and 30 C. In addition, the almost complete absence of a temperature effect on ϕ values between 0 and 25 C also argues against the sudden appearance of the large change reported. Finally, NaCl, for which the data for temperatures between 0 and 40 C have been reviewed and treated carefully not long ago (6), exhibits no discontinuity between 25 and 30 C or any other interval.

The ϕ values for NaCl increase slightly from 0 to 25 C (6). The vapor pressure osmometry data are sufficiently scattered to obscure possible changes in ϕ for sucrose between 20 and 40 C, but comparison of freezing point depression and isopiastically determined ϕ values for sucrose indicate a slight decrease between 0 and 25 C (Table II). Because the latter show percentage differences increasing with concentration to a maximum of 1.9% at 1 molal, straight line interpolation between 0 and 25 C and extrapolation to 40 C should provide ϕ values accurate to within 1% throughout that temperature range for concentrations of sucrose to 1 molal. Use of such ϕ values in equation 3 should provide equally accurate ψ_s values. Additional investigation of temperature effects would be valuable.

It is not easy to depreciate the painstakingly achieved and

beautiful data of Morse and coworkers (9, 10); however, all other available evidence indicates this should be done.

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