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Determination of Lactose Alone and in the Presence of Sucrose by the Method of Munson and Walker

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The existence of uncertainties in the tables employed in the determination of lactose, alone and in the presence of sucrose, by the method of Munson and Walker has led to the redetermination of the reducing-sugar values from which these tables were calculated. The original tables were based on the weights of cuprous oxide corresponding to various weights of lactose, and in the present paper all values are referred to the weights of copper determined electrolytically. Data showing the magnitude of the contamination of the cuprous oxide under the conditions prevailing in the method are given. The table of Straughn and Given for mixtures of lactose and sucrose in the ratio of 1:12 is shown to be in error. From the redetermined values an extensive table of the copper values for lactose and for two ratios of lactose and sucrose has been computed.

I. Introduction

The estimation of lactose is of considerable importance to the dairy industry, to other processors of food, and to the State and Federal Governments. The interest of the latter is indicated by the fact that the determination of lactose is listed in the Book of Methods of the Association of Official Agricultural Chemists.

This paper is a report of the results obtained by the redetermination of the copper values of lactose and two of its mixtures with sucrose by the unified method of Munson and Walker. This method, published in 1906 [1],[1] has found wide acceptance because of its simplicity and reproducibility of results. However, the original tables are based on the weight of cuprous oxide obtained rather than on the procedure of the direct determination of metallic copper or of other accepted methods. In addition, there exists evidence that there are other errors in these tables.

The original Munson and Walker table consisted of weights of dextrose, invert sugar, and two mixtures of invert sugar and sucrose corresponding to various weights of cuprous oxide. In 1907 Walker [2] extended the applicability of the method to include both lactose and maltose. Subsequently, an error in the calculation of the lactose table was discovered, and a corrected table was published [3] in 1912. In this same year Given published [4] a book of methods of sugar analysis in which he stated that a question had arisen as to the composition of the lactose prepared by Walker. He further stated that "Mr. M. N. Straughn of the Sugar Laboratory, Bureau of Chemistry, U. S. Dept. of Agric. has prepared a pure sugar and made the determinations for a new table for lactose, and with the assistance of the author has made the calculations for that table and, in addition, the determinations and calculations for a table for a mixture of 1 part lactose and 4 parts sucrose for use on condensed milks, and for 1 part lactose and 12 parts sucrose for use on milk chocolates. In all cases the work was done on lactose of the formula $5(C_{12}H_{22}O_{11})+2(H_2O)$, and calculated to the hydrated form $C_{12}H_{22}O_{11}+H_2O$." As far as can be ascertained, this direct quotation from Givens' book is the only record of this work extant. No statement was made as to the method of preparing the lactose, no analytical data were given, nor did the author state the method of determining copper, which, presumably, was weighed as Cu_2O in the manner followed by Munson and Walker. As

[1] Figures in brackets indicate the literature references at the end of this paper.

this table for lactose and its mixtures with sucrose is official with the Association of Official Agricultural Chemists, it seemed desirable to carry out a complete redetermination on the basis of the copper values rather than on the basis of weights of cuprous oxide.

II. Preparation of Lactose

Walker prepared his sample of lactose by pouring a hot aqueous solution of the recrystallized sugar into alcohol, with constant stirring. The fine crystals that separated were first dried in air and then over anhydrous calcium chloride. From a moisture determination according to the method of Brown, Morris, and Millar [5] on the dried purified sample, Walker concluded that the composition of his preparation was $C_{12}H_{22}O_{11}\cdot\frac{1}{2}H_2O$. This conclusion was further supported by a determination of carbon and hydrogen. He reported the specific rotation of his material to be 52.93°, but did not specify the concentration, temperature, or wavelength. Von Lippman [6] states that lactose prepared in the manner described above has the composition $5C_{12}H_{22}O_{11}\cdot 2H_2O$. Quisumbing and Thomas [7] prepared lactose by adding equal volumes of alcohol and ether to a cold aqueous solution of sugar. They report moisture (loss at 125° to 130°) 5.22 percent, ash 0.03 percent and $[\alpha]_D^{25}=52.90°$. Lane and Eynon [8] prepared lactose by recrystallizing a pure commercial sample twice from water and found the specific rotation to be 52.5°. Bertrand [9] recrystallized lactose five times from an aqueous solution and found $[\alpha]_D^{19}=54.5°$. He declared the sample to be $C_{12}H_{22}O_{11}\cdot H_2O$. Schmoeger [10] showed that the specific rotation of lactose hydrate for c=2.372 to 41.536 was independent of the concentration and from a mean of 70 determinations found that $[\alpha]_D^{20}=52.53°$. This value was confirmed by Deniges and Bonvans [11] as well as by Parcus and Tollens [12] and it is the value reported in NBS Circular C440. On the contrary, Bacharach [13] determined the value 52.42°, which agrees with the value given by Grossman and Bloch [14]. Hudson [15] has demonstrated that lactose prepared by precipitating with alcohol is not a definite compound, but that it is a mechanical mixture of the hydrated and anhydrous forms. Given and Walker state that their analytical work was done on lactose having a known formula, and that the results were calculated to $C_{12}H_{22}O_{11}\cdot H_2O$. Quisumbling and Thomas made no statement as to the composition of their preparation. They gave its physical constants, apparently regarded it as the monohydrate, and reported their analytical results on that basis. However, from the work of Hudson it seems possible that the differences in the specific rotation values of these various preparations were due to differences in the amount of water of hydration.

The lactose used in this work was prepared from U. S. P. lactose. A hot 50-percent solution was treated with vegetable char and filtered. Aluminum hydroxide was then added, the solution filtered, and the filtrate was crystallized while in motion. This material was then twice recrystallized under the following conditions. A 50-percent solution was made by heating to 80° C. The temperature was maintained around this point to prevent the formation of β-lactose, which is stable above 93° C. The solution was crystallized in motion while cooling it to room temperature. The mother liquor was separated from the crystals by means of a centrifuge, and the crystals were washed with water at 5° C and dried at room temperature. The lower part of a desiccator was filled with a large portion of the dried material, and a working sample of the lactose was stored over it. The desiccator was kept in a room at 20° C. At the same time, a small weighed sample of the lactose was placed in the desiccator and kept exposed to its atmosphere. This sample has remained at constant weight over a period of months. Analysis showed the preparation to contain: moisture,[2] 5.05 percent; ash, 0.003 percent; and $[\alpha]_D^{20}$ (c=6.9779)=52.54°. These data indicate that the material is lactose monohydrate, $C_{12}H_{22}O_{11}\cdot H_2O$.

III. Contamination of Cuprous Oxide

It has long been known that Cu_2O, produced by the action of impure solutions of reducing sugar, such as sugar-house products, is contaminated with organic and inorganic impurities. It is not so generally appreciated, however, that Cu_2O, formed by the reducing action of solutions of pure sugars, is contaminated with organic impurities, for the

[2] McDonald and Turcotte [16] have recently completed an extensive study of α-lactose hydrate, in which they determined the loss of weight in vacuo at 80°, 120°, and 130° C. The curves show that this hydrate contains 5 percent of water of hydration. However, they observed a slight variation in the total loss of weight and in the discoloration of the sample with change in time and temperature.

statement is commonly found in the literature that copper should be weighed as Cu_2O only when pure sugars are involved. Before Munson and Walker [1] expressed the results of their work in terms of the weight of Cu_2O, the senior author [17] made a series of determinations on solutions of an unidentified reducing sugar in which series the copper was determined electrolytically and as Cu_2O. He obtained differences between the two sets that varied between -1.2 and $+1.8$ mg. A surprising thing about these differences is the fact that in a series of 29 copper determinations, the results from the electrolytic set were higher than those weighed as Cu_2O in 18 determinations, three sets giving identical weights. Munson states that a portion of the differences can be attributed to the loss of weight of the Gooch crucibles caused by the solvent action of Soxhlet's reagent on the asbestos. No details of the work are given and it may be surmised that, during the electrolysis, the current density may have been such that the deposit of copper was oxidized. Munson concluded from this work, however, that copper could be determined as Cu_2O when solutions of pure sugar were used.

Shortly after the publication of Munson and Walker's work, Zerban and Naquin [18], using a solution of invert sugar and the Munson and Walker method, compared the copper values calculated from the weights of Cu_2O and CuO with the corresponding values determined by Low's volumetric iodide method. The results from the CuO and volumetric sets were practically identical but were 2 mg lower than those from Cu_2O. This difference they attributed to incomplete drying of the Cu_2O. They used the Monroe crucible [19] and thus missed the visual evidence of the contamination of the Cu_2O by organic decomposition products, which is readily observed in a porcelain crucible when the Cu_2O is treated with nitric acid.

When the reducing sugar values of the Munson and Walker method were redetermined by the author [20] and compared with the original ones, it was noted that differences existed between the two sets of data that were greater than any that could be attributed to probable experimental error. Jackson and McDonald [21] made a comprehensive study of these differences and showed that the amount of contamination of the Cu_2O was almost exactly equal to the differences between the copper values of Munson and Walker and the newly determined ones. They also emphasized that the copper that is reduced should not be determined by weighing it as cuprous oxide. It seemed desirable to investigate the extent of the contamination of the cuprous oxide when lactose and mixtures of lactose and sucrose are evaluated.

Determinations of various concentrations of lactose and its mixtures with sucrose were made by weighing the copper as Cu_2O, then dissolving it in nitric acid and determining the copper electrolytically. The data in table 1 are the differences between the value of the copper calculated from the weight of Cu_2O and the value of the copper determined electrolytically. In all cases, the value of the electrolytic copper is the smaller and, as is to be expected, the differences increase with increasing concentrations of sugar. This effect is much less pronounced with lactose, however, than with its sucrose mixtures.

TABLE 1. *Contamination of cuprous oxide*

Weight of lactose·H_2O	Lactose·H_2O	Lactose·H_2O and sucrose	
		1 lactose 4 sucrose	1 lactose 12 sucrose
mg	*mg of* Cu	*mg of* Cu	*mg of* Cu
60	---------	---------	0.2
100	---------	0.1	.5
140	---------	.7	---------
150	---------	---------	2.1
200	0.1	1.3	3.3
240	---------	1.9	---------
250	.4	---------	4.9
300	.6	2.8	---------
305	---------	---------	7.5
340	---------	3.8	9.1
350	.8	---------	---------

IV. Analytical Procedure

The basic conditions of the determination as given by Munson and Walker were followed. The Soxhlet reagent contained 34.639 g of $CuSO_4.5H_2O$ in 500 ml and 173 g of potassium sodium tartrate ($KNaC_4H_4O_6.4H_2O$) and 50 g of sodium hydroxide in 500 ml. The sucrose used was National Bureau of Standards Standard Sample 17. The preparation and properties of the lactose used have been given in detail above. All solutions were measured at 20° C.

In the original method, the solution was heated over a gas flame, but in this work electrical heating was substituted. The heater was of such a type that the solution in the beaker was practically surrounded by the heating element and the current was controlled by means of a constant-voltage regulator and a variable ratio transformer. The solution could be brought to boiling in the required time within ±5 sec.

The determinations were made as follows: 50 ml of the solution containing lactose was transferred to a 400-ml beaker containing 50 ml of the mixed Soxhlet reagent. The solution was heated to the boiling point in 4 min and then allowed to boil 2 min longer. The cuprous oxide was transferred immediately to a Gooch crucible and washed with water at 60° C. It was then dissolved by adding 5 ml of 1:1 nitric acid, and the crucible was quickly covered. Before the addition of the acid a small quantity of water was added to the crucible to minimize the ebullition of nitric oxides. The copper nitrate and washing were received in a 250-ml beaker to which 10 ml of the 1:1 nitric acid and about 5 g of ammonium sulfate had been added. Sufficient water was added to cover the cylindrical platinum-gauze electrodes, the total volume of electrolyte being about 180 ml. The electrolysis was conducted overnight at room temperature and at an approximate current density of 0.10 amp/dm^2. Upon completion of the deposition, the electrolyte was replaced by distilled water before the circuit was broken. The copper was washed with alcohol, dried 15 min at 100° C, cooled in a desiccator, and then weighed. All deposits were bright and showed no evidence of oxidation.[3]

The copper values given in table 2 are the average of four aliquots from one solution of a given concentration. Sugar concentrations above and below those employed in good analytical procedure were included in order to establish the direction of the curve for the whole range of concentrations and particularly in the region where the concentration of copper in the reacting mixture becomes diminishingly small.

V. Calculation of Results and Sugar Tables

An examination of the experimental data shown in table 2 shows that a modified equation for the rectangular hyperbola will fit the data satisfactorily. The equation

$$(a+x)(b-y)=c+d(y_1-y)^{-1} \qquad (1)$$

is formed by adding the term $(d(y_1-y)^{-1}$ to the equation for the rectangular hyperbola and was developed by J. B. Saunders of this Bureau in connection with previous work of the author [20]. In this equation, x equals milligrams of sugar and y equals milligrams of copper. As the concentration of sugar increases, the curve bends more and more away from the copper ordinate, and the added term allows the curve to approach the limiting value of copper in the reagent, y_1=440.9 mg, asymptotically. The applicability of the Munson and Walker method is questionable for concentrations of sugar corresponding to values of copper greater than approximately 395 mg, and it probably would be more desirable to limit the maximum sugar concentration of determinations within a range of about 200 to 250 mg in 50 ml.

From the average result of each series of determinations as shown in table 2, the constants of eq 1 were calculated and adjusted by the method of averages, and the values of the adjusted constants are given in table 3.

TABLE 2. *Experimental data*

Weight of lactose.H_2O taken	Weight of Cu found		
	Lactose.H_2O	Lactose.H_2O and sucrose	
		1 lactose 4 sucrose	1 lactose 12 sucrose
mg	*mg*	*mg*	*mg*
10	12.6	--------	--------
20	25.8	26.5	28.2
40	52.5	52.9	57.0
60	78.2	79.9	85.2
80	104.3	106.8	112.9
100	129.6	133.2	140.3
120	156.4	160.0	167.9
140	182.4	185.5	194.5
160	207.8	211.9	220.9
180	232.7	237.7	247.4
200	259.5	263.6	274.5
220	285.2	289.8	300.8
240	309.9	315.8	326.9
260	335.9	342.5	352.8
280	361.0	366.7	377.7
300	385.2	391.5	403.5
320	409.8	416.4	428.3
340	435.4	439.3	439.3
360	439.6	439.8	439.7

[3] In determining the copper values upon which to base the table, the electrolytic method of estimating copper was selected because of its extreme accuracy. In the routine analysis of products containing lactose, any of the conventional methods of determining copper may be used.

Table 3. *Values of equation constants*

Constants	Lactose. H_2O	Lactose. H_2O and sucrose mixtures	
		1 lactose 4 sucrose	1 lactose 12 sucrose
a	16, 922. 8	11, 123. 61	5, 504. 99
b	22, 207. 2	14, 979. 37	7, 812. 13
c	375, 810, 000	166, 628, 790	43, 001, 550
d	492, 005	246, 657	176, 400

Solving eq 1 for x it becomes

$$x=\frac{c+d(y_1-y)^{-1}}{b-y}-a, \tag{2}$$

where x equals milligrams of sugar, y equals milligrams of copper and y_1 equals 440.9, the amount of copper in milligrams in 50 ml of the alkaline tartrate copper reagent. The number of significant figures retained in the parameters was found sufficient to eliminate any significant computational errors in table 7.

Table 4 shows the differences between the experimental values and those computed from eq 2. For the whole range of experimental points in the determination of lactose and of its mixtures with sucrose, the mean differences are fairly small. However, considering the practical working range of the method not to exceed 280 mg of sugar, the differences between the experimental and computed values become 0.2 mg each for the three sets of determinations.

In table 5 are shown the differences in terms of milligrams of copper between the tables of Walker and those of Straughn and Given and the data in table 7. The comparisons are made for various increments of lactose, as shown in column 1. The data of Straughn and Given are from table 78 of NBS Circular C440, which had been calculated to copper from the original values reported in weights of Cu_2O. They were then corrected for the organic impurities in the Cu_2O by means of a graph constructed from data in table 1. For lactose and its mixture with sucrose in the ratio of 1:4, the differences between the various sets are moderate, but the differences given in column 5 are greater than could reasonably be attributed to differences caused by experimental errors. As shown in column 5, the difference for the concentration of 40 mg of lactose is about the same as the others, but as the sugar concentration increases the differences become correspondingly larger. Since there is no record of the work of Straughn and Given other than their table of copper and

Table 4. *Differences between the experimental and computed values*

Lactose .H_2O			Sucrose and lactose .H_2O					
			1 lactose; 4 sucrose			1 lactose; 12 sucrose		
Weight taken	Weight calculated	Weight calculated minus weight taken	Weight taken	Weight calculated	Weight calculated minus weight taken	Weight taken	Weight calculated	Weight calculated minus weight taken
mg	*mg*	*mg*	*mg*	*mg*	*mg*	*mg*	*mg*	*mg*
20	19. 8	−0. 2	20	20. 0	0	20	19. 5	−0. 5
40	40. 2	. 2	40	39. 7	−0. 3	40	40. 0	0
60	59. 9	−. 1	60	60. 0	0	60	60. 2	0. 2
80	80. 0	0	80	80. 2	0. 2	80	80. 3	. 3
100	99. 5	−. 5	100	100. 1	. 1	100	100. 2	. 2
120	120. 2	. 2	120	120. 4	. 4	120	120. 5	. 5
140	140. 3	. 3	140	139. 8	−. 2	140	140. 1	. 1
160	160. 0	0	160	160. 0	0	160	159. 8	−. 2
180	179. 4	−. 6	180	179. 7	−0. 3	180	179. 6	−. 4
200	200. 3	. 3	200	199. 6	−. 4	200	200. 1	. 1
220	220. 4	. 4	220	219. 8	−. 2	220	220. 1	. 1
240	239. 7	−. 3	240	240. 0	0	240	240. 1	. 1
260	260. 2	. 2	260	260. 7	0. 7	260	260. 1	. 1
280	280. 0	0	280	279. 7	−. 3	280	279. 5	−. 5
300	299. 2	−. 8	300	299. 2	−. 8	300	299. 9	−. 1
320	319. 0	−1. 0	320	319. 0	−1. 0	320	320. 7	. 7
340	342. 6	2. 6	340	343. 0	3. 0	340	342. 4	2. 4
Mean	--------	0. 5	--------	--------	0. 5	--------	--------	0. 4

sugar equivalents, any explanation of the cause of these differences must be speculative. However, if their lactose is considered to be anhydrous and their concentrations calculated to the hydrate, the differences between the copper values of the recalculated concentrations and those in table 7 are much smaller and are given in column 6. They are on the order of the other differences shown in this table. It can only be surmised that, due to some inadvertence, the Straughn and Given copper equivalents for the mixture of lactose and sucrose in the ratio of 1:12 are those for the anhydrous form instead of those for lactose monohydrate.

TABLE 5. *Differences between the various lactose tables*

Weight lactose $.H_2O$	Copper values				
	Lactose $.H_2O$		Sucrose and lactose $.H_2O$		
	Walker minus Hammond	Straughn-Given minus Hammond	1 lactose 4 sucrose (Straughn-Given minus Hammond)	1 lactose 12 sucrose (Straughn-Given minus Hammond)	1 lactose 12 sucrose (Straughn-Given (corrected) minus Hammond)[a]
mg	*mg*	*mg*	*mg*	*mg*	*mg*
40	2.8	2.1	2.7	2.3	--------
60	2.4	2.0	2.7	4.3	−0.1
80	1.8	1.9	2.8	6.1	.3
100	1.4	1.7	2.6	7.9	.7
120	1.0	1.7	2.4	9.4	.9
140	0.5	1.5	2.1	10.9	1.0
160	0	1.5	1.9	12.2	1.0
180	−0.5	1.3	1.8	13.4	0.8
200	−1.0	1.2	1.3	14.3	.7
220	−1.7	0.9	1.0	15.3	.3
240	−2.3	.9	0.6	15.9	−.1
260	−2.7	.5	.3	16.5	−.9
280	−3.3	.4	−.2	17.1	−1.1
300	−3.8	.4	−.7	17.7	−1.7
320	−3.8	.7	−.6	--------	−1.2

[a] This column shows the differences between the values of Straughn and Given and those of table 7 when it is assumed that their lactose is anhydrous and when calculated to hydrate.

Table 7 was calculated by means of eq 2. It shows the sugar values of lactose hydrate and two of its mixtures with sucrose for weights of copper from 10 to 435 mg in intervals of 1 mg. For lactose the slope of the curve changes so slowly that, for the first 300 points, linear interpolations could be made between values calculated from eq 2 at 50-point intervals. Between 300 and 375 mg, the calculated intervals were 25 points apart, and from 375 mg each point was calculated. For the 1:4 ratio the first 200 points were linearly interpolated at calculated intervals of 50 mg; from 200 to 375 mg of copper each tenth point was calculated and thence each point. For the 1:12 mixture each tenth point between 100 and 375 mg was calculated, as well as each individual point after 375 mg.

VI. General Discussion

Since there is no stoichiometrical relation between the reacting compounds in a determination of reducing sugar by the use of Soxhlet's reagent, it follows that all such determinations must be empirical. In order to utilize these reactions as a quantitative analytical method, it is necessary that all procedures and conditions be standardized and to observe rigidly all such conditions of the method when making a determination. Then, in order to be able to interpret the results, it is required that certain data accompany the method. They are usually given in the form of a table, such as table 7. In its present form this table has a limited use. Although the Straughn-Given table was published in 1912, no proposal was made to widen its use until 1930 when White [22] published a graph constructed from the data in this table. In 1932 Fitelson [23] also published a graph based on that of White's to which he added an additional curve and extrapolated all the curves to include the 16:1 ratio of sucrose to lactose, and since 1935 this chart has been included in the Methods of Analysis of the Association of Official Agricultural Chemists. Following the present procedure, the author has already completed some work of extending the ratios of sucrose to lactose in convenient intervals from 2:1 to 20:1, inclusive, so as to secure more extended data from which to construct a chart or table for correcting determinations of lactose in mixtures with sucrose for the presence of the sucrose. It is expected that this work will be completed and published in the near future.

TABLE 6. *Comparison with results of Hammond*

	Milligrams of lactose taken							
	20	40	50	100	150	200	260	300
	Milligrams of copper found							
Hammond	25.8	52.5	------	129.6	------	259.5	335.9	385.2
Brewster	25.7	52.6	65.5	130.4	194.8	259.4	335.4	386.2
Computed from table 7	26.1	52.3	65.3	130.3	194.7	259.1	335.8	386.3

TABLE 7. *Table for calculating lactose hydrate and its mixtures with sucrose*

Copper	Lactose . H_2O	Lactose . H_2O and sucrose	
		1 lactose 4 sucrose	1 lactose 12 sucrose
mg	*mg*	*mg*	*mg*
10	7.7	7.7	6.6
11	8.5	8.5	7.3
12	9.3	9.2	8.0
13	10.0	10.0	8.7
14	10.8	10.7	9.4
15	11.5	11.5	10.1
16	12.3	12.2	10.8
17	13.1	12.9	11.5
18	13.8	13.7	12.2
19	14.6	14.4	12.9
20	15.4	15.2	13.6
21	16.1	15.9	14.4
22	16.9	16.7	15.1
23	17.7	17.4	15.8
24	18.4	18.2	16.5
25	19.2	18.9	17.2
26	19.9	19.7	17.9
27	20.7	20.4	18.6
28	21.5	21.1	19.3
29	22.2	21.9	20.0
30	23.0	22.6	20.7
31	23.8	23.4	21.4
32	24.5	24.1	22.2
33	25.3	24.9	22.9
34	26.1	25.6	23.6
35	26.8	26.4	24.3
36	27.6	27.1	25.0
37	28.4	27.9	25.7
38	29.1	28.6	26.4
39	29.9	29.4	27.1
40	30.6	30.1	27.8
41	31.4	30.8	28.6
42	32.2	31.6	29.3
43	32.9	32.3	30.0
44	33.7	33.1	30.7
45	34.5	33.8	31.4
46	35.2	34.6	32.1
47	36.0	35.3	32.8
48	36.8	36.1	33.5
49	37.5	36.8	34.3
50	38.3	37.6	35.0
51	39.1	38.3	35.7
52	39.8	39.1	36.4
53	40.6	39.8	37.1
54	41.4	40.6	37.8
55	42.1	41.3	38.5
56	42.9	42.1	39.3
57	43.7	42.8	40.0
58	44.4	43.6	40.7
59	45.2	44.3	41.4
60	46.0	45.1	42.1
61	46.7	45.8	42.8
62	47.5	46.5	43.6
63	48.3	47.3	44.3
64	49.0	48.0	45.0

TABLE 7. *Table for calculating lactose hydrate and its mixtures with sucrose*—Continued

Copper	Lactose . H_2O	Lactose . H_3O and sucrose	
		1 lactose 4 sucrose	1 lactose 12 sucrose
mg	*mg*	*mg*	*mg*
65	49.8	48.8	45.7
66	50.6	49.5	46.4
67	51.3	50.3	47.1
68	52.1	51.0	47.9
69	52.9	51.8	48.6
70	53.6	52.5	49.3
71	54.4	53.3	50.0
72	55.2	54.0	50.7
73	55.9	54.8	51.4
74	56.7	55.5	52.2
75	57.5	56.3	52.9
76	58.2	57.0	53.6
77	59.0	57.8	54.3
78	59.8	58.5	55.0
79	60.5	59.3	55.7
80	61.3	60.0	56.5
81	62.1	60.8	57.2
82	62.8	61.6	57.9
83	63.6	62.3	58.6
84	64.4	63.1	59.3
85	65.1	63.8	60.1
86	65.9	64.6	60.8
87	66.7	65.3	61.5
88	67.4	66.1	62.2
89	68.2	66.8	62.9
90	69.0	67.6	63.7
91	69.7	68.3	64.4
92	70.5	69.1	65.1
93	71.3	69.8	65.8
94	72.1	70.6	66.5
95	72.8	71.3	67.3
96	73.6	72.1	68.0
97	74.4	72.8	68.7
98	75.1	73.6	69.4
99	75.9	74.3	70.2
100	76.7	75.1	70.9
101	77.4	75.8	71.6
102	78.2	76.6	72.3
103	79.0	77.3	73.1
104	79.7	78.1	73.8
105	80.5	78.8	74.5
106	81.3	79.6	75.2
107	82.1	80.4	76.0
108	82.8	81.1	76.7
109	83.6	81.9	77.4
110	84.4	82.6	78.1
111	85.1	83.4	78.9
112	85.9	84.1	79.6
113	86.7	84.9	80.3
114	87.4	85.6	81.0
115	88.2	86.4	81.8
116	89.0	87.1	82.5
117	89.8	87.9	83.2
118	90.5	88.6	84.0
119	91.3	89.4	84.7

TABLE 7. *Table for calculating lactose hydrate and its mixtures with sucrose*—Continued

Copper	Lactose.H_2O	Lactose.H_2O and sucrose	
		1 lactose 4 sucrose	1 lactose 12 sucrose
mg	*mg*	*mg*	*mg*
120	92.1	90.2	85.4
121	92.8	90.9	86.1
122	93.6	91.7	86.9
123	94.4	92.4	87.6
124	95.2	93.2	88.3
125	95.9	93.9	89.0
126	96.7	94.7	89.8
127	97.5	95.5	90.5
128	98.2	96.2	91.2
129	99.0	97.0	92.0
130	99.8	97.7	92.7
131	100.6	98.5	93.4
132	101.3	99.2	94.1
133	102.1	100.0	94.9
134	102.9	100.7	95.6
135	103.6	101.5	96.3
136	104.4	102.3	97.1
137	105.2	103.0	97.8
138	106.0	103.8	98.5
139	106.7	104.5	99.3
140	107.5	105.3	100.0
141	108.3	106.0	100.7
142	109.0	106.8	101.4
143	109.8	107.5	102.2
144	110.6	108.3	102.9
145	111.4	109.1	103.6
146	112.1	109.8	104.4
147	112.9	110.6	105.1
148	113.7	111.3	105.8
149	114.4	112.1	106.6
150	115.2	112.8	107.3
151	116.0	113.6	108.0
152	116.8	114.4	108.8
153	117.5	115.1	109.5
154	118.3	115.9	110.2
155	119.1	116.6	111.0
156	119.9	117.4	111.7
157	120.6	118.2	112.4
158	121.4	118.9	113.2
159	122.2	119.7	113.9
160	122.9	120.4	114.6
161	123.7	121.2	115.4
162	124.5	121.9	116.1
163	125.3	122.7	116.8
164	126.0	123.5	117.6
165	126.8	124.2	118.3
166	127.6	125.0	119.1
167	128.4	125.7	119.8
168	129.1	126.5	120.5
169	129.9	127.3	121.3
170	130.7	128.0	122.0
171	131.5	128.8	122.7
172	132.2	129.5	123.5
173	133.0	130.3	124.2
174	133.8	131.1	124.9

TABLE 7. *Table for calculating lactose hydrate and its mixtures with sucrose*—Continued

Copper	Lactose.H_2O	Lactose.H_2O and sucrose	
		1 lactose 4 sucrose	1 lactose 12 sucrose
mg	*mg*	*mg*	*mg*
175	134.6	131.8	125.7
176	135.3	132.6	126.4
177	136.1	133.4	127.2
178	136.9	134.1	127.9
179	137.7	134.9	128.6
180	138.4	135.6	129.4
181	139.2	136.4	130.1
182	140.0	137.2	130.8
183	140.8	137.9	131.6
184	141.5	138.7	132.3
185	142.3	139.4	133.1
186	143.1	140.2	133.8
187	143.9	141.0	134.5
188	144.6	141.7	135.3
189	145.4	142.5	136.0
190	146.2	143.3	136.8
191	147.0	144.0	137.5
192	147.7	144.8	138.2
193	148.5	145.5	139.0
194	149.3	146.3	139.7
195	150.1	147.1	140.5
196	150.8	147.8	141.2
197	151.6	148.6	142.0
198	152.4	149.3	142.7
199	153.2	150.1	143.4
200	153.9	150.9	144.2
201	154.7	151.6	144.9
202	155.5	152.4	145.7
203	156.3	153.2	146.4
204	157.0	153.9	147.1
205	157.8	154.7	147.9
206	158.6	155.5	148.6
207	159.4	156.2	149.4
208	160.2	157.0	150.1
209	160.9	157.7	150.9
210	161.7	158.5	151.6
211	162.5	159.3	152.4
212	163.3	160.0	153.1
213	164.0	160.8	153.8
214	164.8	161.6	154.6
215	165.6	162.3	155.3
216	166.4	163.1	156.1
217	167.1	163.9	156.8
218	167.9	164.6	157.6
219	168.7	165.4	158.3
220	169.5	166.2	159.1
221	170.3	166.9	159.8
222	171.0	167.7	160.6
223	171.8	168.5	161.3
224	172.6	169.2	162.1
225	173.4	170.0	162.8
226	174.2	170.8	163.6
227	174.9	171.5	164.3
228	175.7	172.3	165.1
229	176.5	173.1	165.8

TABLE 7. *Table for calculating lactose hydrate and its mixtures with sucrose*—Continued

Copper	Lactose.H_2O	Lactose.H_2O and sucrose	
		1 lactose 4 sucrose	1 lactose 12 sucrose
mg	*mg*	*mg*	*mg*
230	177.3	173.8	166.5
231	178.1	174.6	167.3
232	178.8	175.3	168.0
233	179.6	176.1	168.8
234	180.4	176.9	169.5
235	181.2	177.6	170.3
236	181.9	178.4	171.0
237	182.7	179.2	171.8
238	183.5	180.0	172.5
239	184.3	180.7	173.3
240	185.1	181.5	174.0
241	185.8	182.3	174.8
242	186.6	183.0	175.5
243	187.4	183.8	176.3
244	188.2	184.6	177.0
245	189.0	185.3	177.8
246	189.7	186.1	178.5
247	190.5	186.9	179.3
248	191.3	187.6	180.1
249	192.1	188.4	180.8
250	192.9	189.2	181.6
251	193.6	189.9	182.3
252	194.4	190.7	183.1
253	195.2	191.5	183.8
254	196.0	192.2	184.6
255	196.8	193.0	185.3
256	197.5	193.8	186.1
257	198.3	194.6	186.8
258	199.1	195.3	187.6
259	199.9	196.1	188.3
260	200.7	196.9	189.1
261	201.4	197.6	189.8
262	202.2	198.4	190.6
263	203.0	199.2	191.4
264	203.8	199.9	192.1
265	204.6	200.7	192.9
266	205.3	201.5	193.6
267	206.1	202.2	194.4
268	206.9	203.0	195.1
269	207.7	203.8	195.9
270	208.5	204.6	196.7
271	209.2	205.3	197.4
272	210.0	206.1	198.2
273	210.8	206.9	198.9
274	211.6	207.6	199.7
275	212.4	208.4	200.4
276	213.2	209.2	201.2
277	214.0	210.0	202.0
278	214.7	210.7	202.7
279	215.5	211.5	203.5
280	216.3	212.3	204.2
281	217.1	213.0	205.0
282	217.9	213.8	205.7
283	218.7	214.6	206.5
284	219.4	215.4	207.3

TABLE 7. *Table for calculating lactose hydrate and its mixtures with sucrose*—Continued

Copper	Lactose.H_2O	Lactose.H_2O and sucrose	
		1 lactose 4 sucrose	1 lactose 12 sucrose
mg	*mg*	*mg*	*mg*
285	220.2	216.1	208.0
286	221.0	216.9	208.8
287	221.8	217.7	209.5
288	222.6	218.4	210.3
289	223.3	219.2	211.1
290	224.1	220.0	211.8
291	224.9	220.8	212.6
292	225.7	221.5	213.4
293	226.5	222.3	214.1
294	227.3	223.1	214.9
295	228.0	223.9	215.6
296	228.8	224.6	216.4
297	229.6	225.4	217.2
298	230.4	226.2	217.9
299	231.2	227.0	218.7
300	232.0	227.7	219.5
301	232.7	228.5	220.2
302	233.5	229.3	221.0
303	234.3	230.1	221.7
304	235.1	230.8	222.5
305	235.9	231.6	223.3
306	236.7	232.4	224.0
307	237.4	233.1	224.8
308	238.2	233.9	225.6
309	239.0	234.7	226.3
310	239.8	235.5	227.1
311	240.6	236.3	227.9
312	241.4	237.0	228.6
313	242.2	237.8	229.4
314	243.0	238.6	230.2
315	243.7	239.4	230.9
316	244.5	240.1	231.7
317	245.3	240.9	232.5
318	246.1	241.7	233.2
319	246.9	242.5	234.0
320	247.7	243.2	234.8
321	248.5	244.0	235.5
322	249.2	244.8	236.3
323	250.0	245.6	237.1
324	250.8	246.3	237.8
325	251.6	247.1	238.6
326	252.4	247.9	239.4
327	253.2	248.7	240.1
328	253.9	249.5	240.9
329	254.7	250.2	241.7
330	255.5	251.0	242.4
331	256.3	251.8	243.2
332	257.1	252.6	244.0
333	257.9	253.3	244.8
334	258.7	254.1	245.5
335	259.4	254.9	246.3
336	260.2	255.7	247.1
337	261.0	256.5	247.8
338	261.8	257.2	248.6
339	262.6	258.0	249.4

TABLE 7. *Table for calculating lactose hydrate and its mixtures with sucrose*—Continued

Copper	Lactose H_3O	Lactose H_3O and sucrose	
		1 lactose 4 sucrose	a lactose 12 sucrose
mg	*mg*	*mg*	*mg*
340	263. 4	258. 8	250. 2
341	264. 2	259. 6	250. 9
342	265. 0	260. 4	251. 7
343	265. 8	261. 1	252. 5
344	266. 6	261. 9	253. 3
345	267. 4	262. 7	254. 0
346	268. 1	263. 5	254. 8
347	268. 9	264. 2	255. 6
348	269. 7	265. 0	256. 4
349	270. 5	265. 8	257. 1
350	271. 3	266. 6	257. 9
351	272. 1	267. 4	258. 7
352	272. 9	268. 2	259. 4
353	273. 7	268. 9	260. 2
354	274. 4	269. 7	261. 0
355	275. 2	270. 5	261. 8
356	276. 0	271. 3	262. 6
357	276. 8	272. 1	263. 3
358	277. 6	272. 8	264. 1
359	278. 4	273. 6	264. 9
360	279. 2	274. 4	265. 7
361	280. 0	275. 2	266. 4
362	280. 8	276. 0	267. 2
363	281. 6	276. 8	268. 0
364	282. 4	277. 5	268. 8
365	283. 2	278. 3	269. 6
366	284. 0	279. 1	270. 3
367	284. 8	279. 9	271. 1
368	285. 6	280. 7	271. 9
369	286. 3	281. 5	272. 7
370	287. 1	282. 2	273. 5
371	287. 9	283. 0	274. 2
372	288. 7	283. 8	275. 0
373	289. 5	284. 6	275. 8
374	290. 3	285. 4	276. 6
375	291. 1	286. 2	277. 4
376	291. 9	286. 9	278. 2
377	292. 7	287. 7	278. 9
378	293. 5	288. 5	279. 7
379	294. 3	289. 3	280. 5
380	295. 0	290. 1	281. 3
381	295. 8	290. 9	282. 1
382	296. 6	291. 7	282. 9
383	297. 4	292. 4	283. 6
384	298. 2	293. 2	284. 4
385	299. 0	294. 0	285. 2
386	299. 8	294. 8	286. 0
387	300. 6	295. 6	286. 8
388	301. 4	296. 4	287. 6
389	302. 2	297. 2	288. 4

TABLE 7. *Table for calculating lactose hydrate and its mixtures with sucrose*—Continued

Copper	Lactose H_3O	Lactose H_3O and sucrose	
		1 lactose 4 sucrose	a lactose 12 sucrose
mg	*mg*	*mg*	*mg*
390	303. 0	298. 0	289. 2
391	303. 8	298. 8	290. 0
392	304. 6	299. 5	290. 7
393	305. 4	300. 3	291. 5
394	306. 2	301. 1	292. 3
395	307. 0	301. 9	293. 1
396	307. 8	302. 7	293. 9
397	308. 6	303. 5	294. 7
398	309. 4	304. 3	295. 5
399	310. 2	305. 1	296. 3
400	311. 0	305. 9	297. 1
401	311. 8	306. 7	297. 9
402	312. 6	307. 5	298. 7
403	313. 4	308. 3	299. 5
404	314. 2	309. 1	300. 3
405	315. 0	309. 9	301. 1
406	315. 9	310. 7	301. 9
407	316. 7	311. 5	302. 7
408	317. 5	312. 3	303. 5
409	318. 3	313. 1	304. 3
410	319. 1	313. 9	305. 1
411	319. 9	314. 7	305. 9
412	320. 7	315. 5	306. 7
413	321. 6	316. 3	307. 6
414	322. 4	317. 1	308. 4
415	323. 2	317. 9	309. 2
416	324. 0	318. 7	310. 0
417	324. 9	319. 5	310. 8
418	325. 7	320. 3	311. 7
419	326. 5	321. 2	312. 5
420	327. 4	322. 0	313. 4
421	328. 2	322. 8	314. 2
422	329. 1	323. 6	315. 0
423	329. 9	324. 5	315. 9
424	330. 8	325. 3	316. 8
425	331. 7	326. 2	317. 6
426	332. 6	327. 0	318. 5
427	333. 5	327. 9	319. 4
428	334. 4	328. 8	320. 4
429	335. 3	329. 7	321. 3
430	336. 3	330. 6	322. 3
431	337. 3	331. 5	323. 3
432	338. 3	332. 5	324. 4
433	339. 4	333. 5	325. 5
434	340. 7	334. 6	326. 7
435	342. 0	335. 8	328. 1

Since there was a controversy over the composition of the lactose prepared by Walker, and since the author has discovered the Straughn-Given table for the lactose-sucrose ratio of 1:12 to be in error, it was felt that the results reported in this paper should not depend solely on the work of one individual. So the author has determined the reducing value of the lactose used by McDonald and Turcotte [16] in their work on the density and refractive index of lactose solutions and found it to be identical with that of his preparation. J. F. Brewster of this Bureau also prepared a sample of pure lactose and found its reducing power to be the same as that of McDonald and Turcotte and that of the author. In addition, he kindly checked several values in the experimental data given in table 2. His results are shown in table 6 and are self-explanatory.

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