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Refractive Indices of Maltose Solutions

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The refractive indices of maltose hydrate solutions have been determined at 20° and at 25° C. Equations relating the refractive index to the percentage concentration of sugar have been prepared from the observed data by the method of averages. A table, giving the refractive indices of maltose solutions at 1-percent intervals over a range of 1 to 65 percent of maltose hydrate at both 20° and 25° C, is included.

I. Introduction

The disaccharide, maltose, has found extensive use in the food industry. Starch is converted into "soluble starch" by mild acid treatment, and this in turn is hydrolized to a mixture of maltose and dextrins by the enzymes of barley flour. Much of the maltose is not further purified but is used as a constituent of this mixture. Upon hydrolysis, maltose yields two glucose units, which are joined in the maltose molecule to form a 4-D-glucose D-glucoside. In the present investigation refractive index measurements have been made of aqueous maltose solutions at 20° and at 25° C. It is believed that these values will be of use in estimating the quantity of maltose present in solutions of the pure sugar, as well as in those containing maltose along with other sugars.

II. Purification of Maltose Hydrate

Maltose crystallizes from aqueous solution and from aqueous alcohol solution as maltose·H_2O. Considerable care is required to remove the last traces of dextrins. The preparation of the pure sugar by crystallization from alcohol, from acetic acid [1] and by deacetylation of the acetate [2] have been discussed in the literature.

The sugar used in this investigation was prepared by three recrystallizations of maltose from aqueous solution at approximately 5° C. The starting product was the chemically pure maltose of Pfanstiehl and of Eastman Kodak Co. The sugar was dissolved in water and the solution filtered through carbon, evaporated under reduced pressure, and crystallized in an ice bath with constant stirring. After the first crystallizations the carbon was omitted. The crystals were dried at room temperature, and finally at 50° C. They gave a very clear solution, were ash free, and had a specific rotation of +130.5 (water, C=4.73). This crystallization from water solution gives lower yields than when alcohol is used but has the advantage that small amounts of dextrose or dextrins remain in solution.

[1] T. S. Harding, Sugar **25,** 350 (1923).

[2] G. Zemplén, Ber. deut. chem. **59,** 1258 (1926); Ber. Ges. **60,** 2 1555 (1927); G. Zemplén and E. Pacsu, Ber. deut. chem. **62,** 1613 (1929); W. A. Mitchell, J. Am. Chem. Soc. **63,** 3534 (1941).

The maltose used for the refractive index determinations was found to contain 0.14 percent of moisture in excess of the theoretical 5.00 percent for maltose hydrate. This moisture content was determined by a procedure used previously in this laboratory by R. F. Jackson, who found that carefully prepared maltose hydrate dried at room temperature and finally at 50° C contained 5.13 percent of moisture rather than the theoretical 5.00 percent. He dried maltose to constant weight in a vacuum over P_2O_5. The initial drying temperature of 64° C was slowly increased to 105° C. In order to be assured that the loss of weight, in excess of 5.0 percent, was not due to decomposition, a sample of the sugar hydrate was allowed to come to equilibrium in an atmosphere whose vapor pressure was that of pure maltose hydrate. This vapor pressure was maintained by means of a mixture containing equal amounts of maltose hydrate and partially dehydrated maltose hydrate. A relatively small sample of the sugar hydrate after standing 255 hours at 56° C in this environment reached a constant weight and had lost 0.13 percent of its weight.

Tables 1 and 2 record data obtained by R. F. Jackson.

TABLE 1. *Drying of maltose hydrate in vacuum over* P_2O_5

Sample 1: 1.16355 g, moisture 5.14%				Sample 2: 1.1093 g, moisture 5.12%			
Temperature	Time	Loss	Total loss	Temperature	Time	Loss	Total loss
°C	hr	mg	mg	°C	hr	mg	mg
76	26	42.1	42.1	76	26	44.1	44.1
76	19	2.3	44.4	76	19	2.1	46.1
100	3	2.0	46.4	100	3	1.6	47.8
100	7	1.8	48.2	100	7	1.4	49.2
100	3	0.3	48.5	100	3	0.5	49.7
100	3.5	.6	49.1	100	3.5	.6	50.3
105	4	2.2	51.1	110	3	3.8	54.1
105	8	2.5	53.6	110	2.2	1.9	56.0
105	8.2	1.7	55.3	110	2	0.4	56.4
105	6.4	1.3	56.6	110	2	.3	56.7
105	10.3	1.8	58.4	110	4	0	56.8
105	6.8	0.4	58.8				
105	7.2	.5	59.3	Total	74.7		
105	6	.25	59.5				
105	4	.15	59.7				
105	4.5	.1	59.8				
105	4	0	59.8				
Total	130.9						

TABLE 2. *Maltose hydrate sample in atmosphere having vapor pressure of maltose.H_2O*

Temperature	Time	Loss	Total loss
°C	hr	mg	mg
36	40	0.65	0.65
56	40	.3	.95
56	40	.1	1.05
56	45	.2	1.25
54	45	−.1	1.15
55	45	0	1.15
Total	255	9.13%	

III. Measurements and Discussion of Results

The refractive index measurements were made on solutions whose concentrations varied from approximately 1 to 65 percent of maltose hydrate. All measurements were made under carefully controlled temperature conditions. Observations over the entire range of concentration were made on a Bausch & Lomb precision refractometer, and at the lower concentrations, a Zeiss dipping refractometer was used. These instruments were calibrated at this Bureau. A measurement of the refractive index of water [3] was made before and after that of each maltose solution, and proper corrections were applied. The value used was the average of four or five readings on a given solution. The maximum difference on a given solution never exceeded 0.00002 in refractive index. Each solution stood at least 4 hours to allow the maltose to reach equilibrium.[4]

Sixteen observations were made at 20°C and eight observations at 25°C. Equations relating the refractive index to the percentage concentration of sugar hydrate (p) were calculated by the method of averages from the observed data. Equations 1 and 2 express this relationship.

$$n_D^{20} = 1.33299 + 1.38914 \times 10^{-3} p + 4.7602 \times 10^{-6} p^2 + 2.0933 \times 10^{-8} p^3 - 6.124 \times 10^{-11} p^4 \quad (1)$$

$$n_D^{25} = 1.33250 + 1.38275 \times 10^{-3} p + 3.9303 \times 10^{-6} p^2 + 5.2527 \times 10^{-8} p^3 - 3.4994 \times 10^{-10} p^4 \quad (2)$$

Tables 3 and 4 contain the observed data, along with the calculated values. At 20°C the average deviation of the calculated values from those observed amounts to ±0.000024, whereas at 25°C the corresponding average deviation is ±0.000049. At both temperatures the deviations at the higher concentrations are greater than in the lower range. This may be attributed to the increased difficulty in the preparation and the handling of the solutions of higher concentration. The refractive indices in table 5 were calculated by means of eq 1 and 2. The temperature coefficient of maltose solutions appears to be very similar to that of sucrose solutions in this temperature range. The apparent decrease in temperature effect above 44-percent concentration is small and may be a result of experimental error. It is of the same order of magnitude as the deviation of the observed values from the calculated values. At 21°C a saturated maltose solution contains 46.4 percent of sugar; thus the solutions with concentration above 46.4 percent are supersaturated and are more subject to error due to shifting of the equilibrium products. It appears that a temperature coefficient of 0.00016 would be within the experimental error of the data for the concentration range above 23 percent.

TABLE 3. *Refractive indices of maltose solutions at 20° C*

Percentage of maltose hydrate	n_D^{20} (observed)	n_D^{20} (calculated) [a]	Observed−calculated
1.563	1.33518	1.33517	+0.00001
5.015	1.34008	1.34008	.00000
7.003	1.34294	1.34296	−.00002
12.929	1.35180	1.35179	+.00001
14.410	1.35404	1.35406	−.00002
20.512	1.36362	1.36366	−.00004
25.586	1.37200	1.37197	+.00003
25.197	1.37135	1.37132	+.00003
31.034	1.38126	1.38125	+.00001
36.666	1.39128	1.39124	+.00004
40.995	1.39918	1.39921	−.00003
44.801	1.40640	1.40641	−.00001
50.713	1.41807	1.41800	+.00007
55.537	1.42781	1.42782	−.00001
59.798	1.43674	1.43677	−.00003
65.529	1.44920	1.44922	−.00002
Average deviation ±0.000024			

[a] Equation 1 was used in obtaining calculated values.

TABLE 4. *Refractive indices of maltose solutions at 25° C*

Percentage of maltose hydrate	n_D^{25} (observed)	n_D^{25} (calculated) [a]	Observed−calculated
3.312	1.33709	1.33712	−0.00003
10.180	1.34707	1.34703	+.00004
12.530	1.35051	1.35054	−.00003
25.530	1.37026	1.37023	+.00003
39.837	1.39633	1.39626	+.00007
40.405	1.39725	1.39732	−.00007
50.992	1.41777	1.41783	+.00006
65.551	1.44842	1.44836	−.00006
Average deviation ±0.000049			

[a] Equation 2 was used in obtaining calculated values.

TABLE 5. *Refractive indices of maltose hydrate solutions at 20° and 25° C*

Percent	n_D^{20}	n_D^{25}	Δn	$\Delta n/\Delta t$
1	1.33438	1.33389	0.00049	0.00010
2	1.33579	1.33528	.00051	.00010
3	1.33720	1.33668	.00052	.00010
4	1.33862	1.33810	.00052	.00010
5	1.34006	1.33952	.00054	.00011
6	1.34150	1.34095	.00055	.00011
7	1.34295	1.34239	.00056	.00011
8	1.34442	1.34384	.00058	.00012
9	1.34589	1.34530	.00059	.00012
10	1.34738	1.34677	.00061	.00012
11	1.34887	1.34825	.00062	.00012
12	1.35039	1.34974	.00065	.00013
13	1.35190	1.35124	.00066	.00013
14	1.35343	1.35276	.00067	.00013
15	1.35497	1.35428	.00069	.00014

[3] L. W. Tilton and J. K. Taylor, J. Research NBS **20,** 419 (1938).
[4] H. S. Isbell and W. W. Pigman, J. Research NBS **18,** 183 (1937) RP969.

TABLE 5. *Refractive indices of maltose hydrate solutions at 20° and 25° C*—Continued

Percent	n_D^{20}	n_D^{25}	Δn	$\Delta n/\Delta t$
16	1.35652	1.35582	0.00070	0.00014
17	1.35808	1.35737	.00071	.00014
18	1.35965	1.35893	.00072	.00014
19	1.36124	1.36051	.00073	.00015
20	1.36283	1.36209	.00074	.00015
21	1.36444	1.36369	.00075	.00015
22	1.36606	1.36530	.00076	.00015
23	1.36770	1.36692	.00078	.00016
24	1.36934	1.36856	.00078	.00016
25	1.37100	1.37021	.00079	.00016
26	1.37267	1.37187	.00080	.00016
27	1.37435	1.37355	.00080	.00016
28	1.37604	1.37524	.00080	.00016
29	1.37775	1.37694	.00081	.00016
30	1.37946	1.37865	.00081	.00016
31	1.38120	1.38038	.00082	.00016
32	1.38294	1.38213	.00082	.00016
33	1.38470	1.38388	.00082	.00016
34	1.38647	1.38565	.00081	.00016
35	1.38825	1.38744	.00081	.00016
36	1.39004	1.38924	.00080	.00016
37	1.39185	1.39105	.00080	.00016
38	1.39367	1.39287	.00080	.00016
39	1.39551	1.39471	.00080	.00016
40	1.39735	1.39656	.00079	.00016
41	1.39922	1.39843	.00079	.00016
42	1.40109	1.40031	.00078	.00016
43	1.40298	1.40221	.00077	.00016
44	1.40488	1.40411	.00077	.00015
45	1.40680	1.40603	.00077	.00015
46	1.40873	1.40797	.00076	.00015
47	1.41067	1.40992	.00075	.00015
48	1.41263	1.41188	.00075	.00015
49	1.41460	1.41385	.00075	.00015
50	1.41658	1.41584	.00074	.00015
51	1.41858	1.41784	.00074	.00015
52	1.42059	1.41986	.00073	.00015
53	1.42262	1.42189	.00073	.00015
54	1.42466	1.42392	.00074	.00015
55	1.42672	1.42598	.00074	.00015
56	1.42878	1.42804	.00074	.00015
57	1.43087	1.43012	.00075	.00015
58	1.43296	1.43221	.00075	.00015
59	1.43508	1.43431	.00077	.00015
60	1.43720	1.43643	.00077	.00015
61	1.43934	1.43855	.00079	.00016
62	1.44150	1.44069	.00081	.00016
63	1.44367	1.44283	.00084	.00017
64	1.44585	1.44499	.00086	.00017
65	1.44805	1.44716	.00089	.00018

Results of work by F. W. Zerban and J. Martin, now in press (J. Assoc. Off. Agr. Chem.) on the refractive indices of maltose solutions at 20°C is in good agreement with the results obtained in this investigation. Previous work may be summarized as follows. Tolman and Smith [5] reported the refractive indices of maltose solutions of relatively low concentrations. In their discussion they state that the sugars were dried at 70°C under a diminished pressure of about 27 in.; no other comment is made as to the preparation of the sugar. The following refractive indices are those reported by these authors along with values obtained from table 5 of this investigation.

Percentage of maltose	n_D^{20} (T and S)	n_D^{20} (McD)
1.00	1.3343	1.3344
2.07	1.3357	1.3359
5.07	1.3402	1.3402
10.07	1.3477	1.3475
15.12	1.3555	1.3552
20.17	1.3637	1.3631

Pulvermacher [6] determined the refractive indices of maltose solutions whose concentrations varied from 1.16 to 19.40 percent of anhydrous sugar at 25°C. His results are reported to the fourth place, and the values are all higher by one in the third place than the results here presented. As the results reported in the same article by Pulvermacher are higher for glucose than the accepted values, it appears that perhaps some discrepancy persisted throughout his measurements.

WASHINGTON, October 23, 1950.

[5] L. M. Tolman and W. B. Smith, J. Am. Chem. Soc. **28**, 1476 (1906).
[6] G. Pulvermacher, Z. anorg. chem. **113**, 141 (1920).