(I) The Optical Rotation and Cryoscopic Behaviour of Sugars dissolved in (a) Formamide, (b) Water; and (II) The Sublimation of Sugars.

Thesis for the degree of D.Sc.

by

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PART I.

Theoretical.

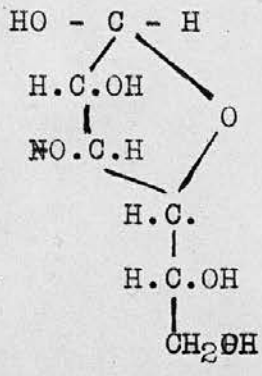
In 1816 Seebeck observed the effect of a sugar solution upon polarized light, and in 1817 Biot (Mém., 1817, ii, 41) determined the "Specific Rotation" of sugars, and at the same time introduced the term "optical saccharimetry" for the method of estimation of a sugar from its optical rotation.

In 1846, Dubrunfaut (Ann. Chim. Phys., 1846, XVIII, 99) observed that the specific rotation of a freshly prepared aqueous solution of crystalline glucose decreased from an initial value of about $+110^{\circ}$ to become constant at $+52^{\circ}$. The initial value being nearly twice the final value, he called the phenomenon "bi-rotation". Later discoveries proved the term unsuitable in the case of other substances where a similar change of rotation took place, the initial and final values being rarely in the proportion of 2:1, and so the term "multi-rotation" came into use. A better term, "muta rotation", which was introduced by Lowry (Chem. Soc. J. 1899, LXXV, 212) in 1899, is now in general use and indicates the change in rotation of a solution from its initial to its constant value at the same temperature. Mutarotation is a characteristic property of the sugars which display reducing properties, and of many optically active substances which occur in tautomeric or isodynamic forms.

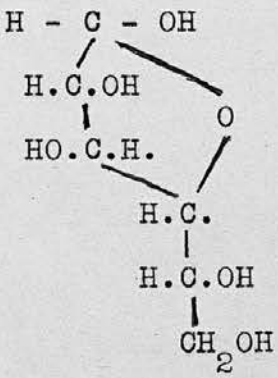
Many theories have been proposed to explain the change/

change of rotation in the case of the sugars. Some of these have had to be laid aside owing to the isolation of distinct modifications of the same sugar. Thus two forms of glucose are now definitely known, the one showing an initial rotation, $(\alpha)_D^{20} = +110^\circ$, the other $(\alpha)_D^{20} = +20^\circ$, and both becoming constant with $(\alpha)_D^{20} = +52.5^\circ$. The former is the ordinary glucose, which was known to Saussure (Bulletin de Pharm. 1814, VI, 502); the latter was discovered by Tanret (Bull. Soc. Chim., 1896 (111) 15, 195). In 1899, Lowry advanced the view that the mutarotation of glucose is caused by a balanced reaction between the highest and lowest rotating forms of the sugar, a view expressed by the equation α-glucose $\rightleftharpoons$ β-glucose.

In 1895, Lippmann suggested that the lactonic formula (or γ-oxidic constitution) predicts two possible forms of the sugar on account of the asymmetry of the end carbon atom, the two structures for d-glucose, for example, being:-



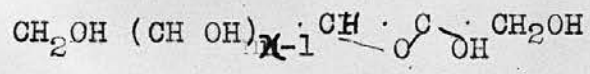
and



This suggestion, after a slight modification by Simon (Compt. rend., 1901, 132, 487), was made more probable by/

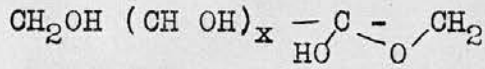
by Armstrong's discovery that the α- and β- forms of methyl-glucoside are hydrolyzed by enzymes to give methyl-alcohol and the α- and β- forms of glucose respectively. This suggestion received further support in 1909 when Hudson (Jour. Amer. Ch. Soc. 1909, XXXI, 66) showed that certain numerical relations, which can only be explained by the assumption of such lactonic structures for the two forms of the sugar, hold all through the sugar group.

Recently, however, Nef (Ann. 403, p.204, 1914) has reached the conclusion that the various crystalline forms of the simple sugars, including also malt and milk sugars are to be represented either by a corresponding ketose or aldose structure (or at times by a corresponding ketose or aldose monohydrate structure analogous to chloral hydrate) or by a monomolecular α-lactone formula,



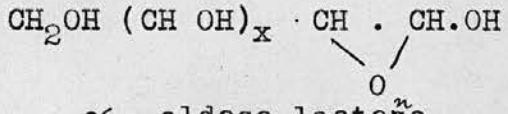
2, 3 - α - ketose-lactone.

or



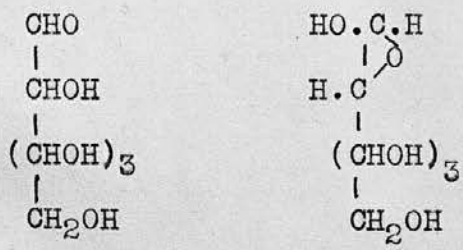
1,2 - α - ketose-lactone.

and



α - aldose lactone.

Thus for d - glucose, the forms are,



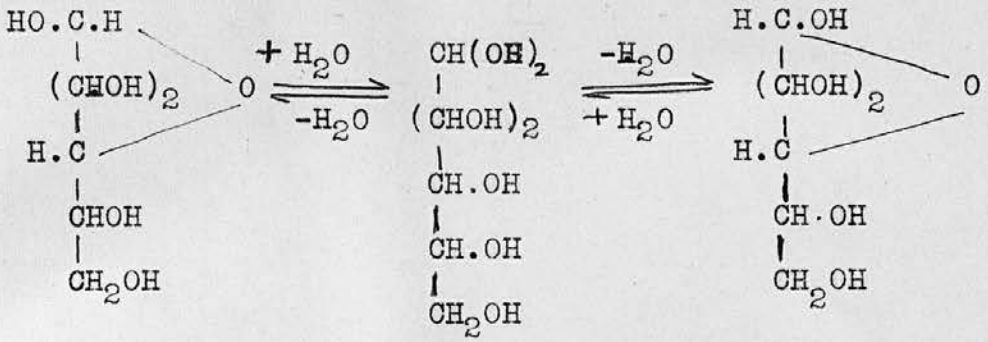
β α

The/

The form commonly known as α - d - glucose is represented by the α - lactone formula, while the form known as β - d - glucose is supposed to be a mixture of 80% of aldehyde sugar and 20% of α - d - glucose, the pure β- form being supposed to be laevorotatory. But the view of Nef that the β- modification of d- glucose when isolated by Tanret's method usually consists of mixed crystals of which theoretically a limitless number are possible seems to me rather irreconcilable with the recent method of preparation of β - d - glucose by Behrend (Ann. 377, 1910, 220) in which it comes out as a pyridine compound, the β- form thus obtained having the same initial specific rotation as that obtained by the method of Tanret. Fischer (Ber., 1914, XLVII, 1980) has dealt so effectively with Nef's ideas that it is unnecessary to produce any further argument to show that, whatever may be the cause of the isomerism of α- and β- methyl-glucosides, it is independent of the nature of the oxidic linking, which must be the same in each compound; and the same view might be extended to the α- and β- forms of glucose and those of other sugars as well.

Of the theories advanced to explain the mechanism of the change from the α- to the β- modification, only one or two need be mentioned. The first, that of Lowry (Chem. Soc. J., 1903, LXXXIII, 1314), supposes the γ-oxidic ring to break up with formation of aldehydrol or/

or aldehydehydrate, thus,



The addition and splitting off of water taking place, so that both the modifications may be formed.

The second, that of E. F. Armstrong, (Chem. Soc. J. 1903, LXXXIII, 1305), supposes the γ-oxidic ring to remain unbroken, but that water becomes attached to the γ-oxidic oxygen and thereafter is separated in different ways, giving the α- and β- forms respectively. The formation of an oxonium compound is possible but problematical, in the case of the sugars (cf. Mackenzie, Sugars, pp. 128-131).

Both the hypotheses assume the presence of water in the solution, and indeed the majority of the measurements of the mutarotation of sugars has been carried out in aqueous solution. Methyl and ethyl alcohols and acetone were not available as solvents owing to the very small solubility of most of the sugars in these liquids. Using mixtures of the alcohol or of acetone with water as solvent, the rate of mutarotation was diminished, an argument in support of the theory that the mutarotation was dependent on the presence of hydroxyl groups (Trey, Zeitsch. phys. chem., 1903, XLVI, 620). Perhaps the/

the strongest argument in favour of this theory is the fact that the presence of traces of caustic alkali or ammonia causes extremely rapid mutarotation, the rotation becoming constant almost immediately (Lowry, loc. cit.).

On the other hand, the non-electrolytic nature of aqueous solutions of sugars would appear to oppose the hydroxyl theory. Further, the fact that mutarotation takes place in non-hydroxylic solvents such as pyridine is remarkable. Pyridine appears to have been first used by Behrend and Roth (Annalen, 1904, 331, 359) as a solvent for glucose. They found an initial rotation $(\alpha)_D = +138.88^\circ$, which became constant after twenty-four hours with $(\alpha)_D = +70.89^\circ$. Subsequently they showed the formation of an addition compound of glucose with pyridine, $C_6H_{12}O_6 \cdot C_5H_5N$, which decomposed on heating or on standing over sulphuric acid (Ann., 1910, 377, 220).

Similar measurements with a solution of galactose in pyridine were made by Heikel (Annalen, 1904, 338, 71). Subsequently Grossmann and Bloch (Zeitsch. Ver. Deut. Zuckerind., 1912, 62, 19) made comparison of the mutarotations of xylose, rhamnose, galactose, glucose, fructose, sucrose, lactose, maltose and raffinose in aqueous, pyridine, and formic acid solutions respectively. They found that mutarotation took place more slowly in pyridine than in water solution, but in the same direction. On the other hand, the direction of mutarotation in formic acid is the reverse of that in water solution, and/

and mutarotation is shown by non-reducing sugars such as sucrose and raffinose, which do not exhibit the phenomenon in water or pyridine solution. Grossmann and Bloch suppose that in formic acid solution the higher sugars are hydrolyzed and converted into formates of the simpler sugars. It seems probable that this would take place in the case of all the sugars, and consequently the changes of rotation be due not to isodynamic change but to the production of these formates.

According to van't Hoff, the velocity of transformation of a substance in different solvents is connected with the solubility of the substance in these media, and evidence in support of such a relationship has been recently obtained by Dimroth (Ann., 1910, 377, 131). In the case cited (1 - phenyl - 5 - oxytriazole - carbonic acid - ester) the velocity of transformation seems to decrease with increase in solubility of one of its forms. In the case of the sugars, however, the velocity seems to decrease with decrease in solubility. Such a relationship, if true, would clearly militate against the supporters of the hydroxylic theory who seem to find defence in the diminished rate of mutarotation with mixtures of water and alcohol or acetone. The work on the subject is so far rather meagre to express any definite opinion on such a relationship.

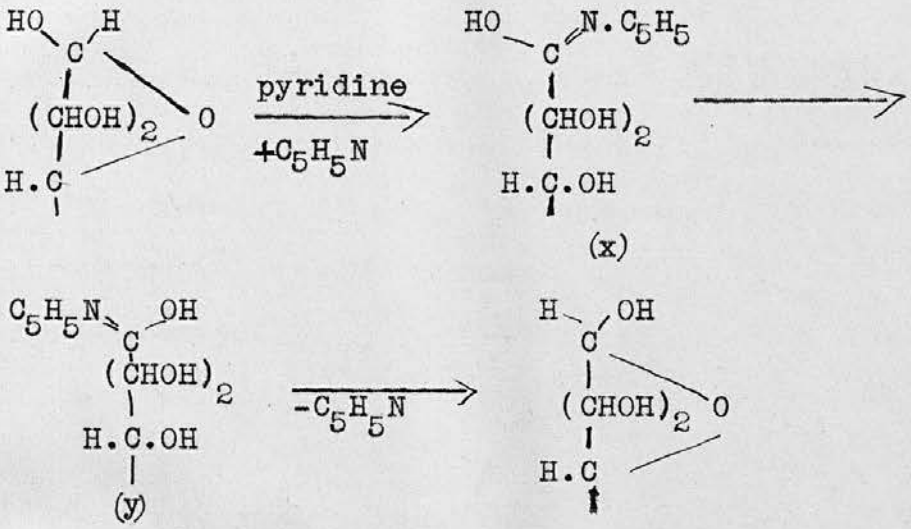
The experiments with pyridine as solvent suggest that the hydration theory of the mechanism of mutarotation is/

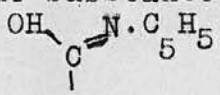
is untenable. If similar results were obtainable with other non-aqueous solvents, some new theory must be forthcoming. The cryoscopic measurements of Walden on the molecular weight of starch, using formamide as solvent, were extended to the sugars, most of which are sufficiently soluble in formamide to allow of measurements of molecular weight and of specific rotation. As it was of importance to know that each sugar dissolved in formamide in the monomolecular state, the molecular weight was determined by the cryoscopic method, and the data obtained proved this to be the case. Apparently no such determinations of molecular weights were made by the above-mentioned investigators of mutarotation in pyridine and formic acid solution; and though there is no reason to suspect that the molecular weights in pyridine solution are abnormal, there is much reason to expect that in formic acid solution complicated changes take place, and that the data obtainable from cryoscopic or ebullioscopic measurements would give evidence of such changes.

The constitutional formula for formamide is generally assumed to be $H - \overset{O}{\overset{\|}{C}} - NH_2$, but it might be argued that ithad the iminohydrin structure, $H - C\begin{matrix}\diagup OH \\ \diagdown\!\!= NH\end{matrix}$, which offers the OH group for the transformation. While in dilute formamide solution the presence of the imino-modification is possible, it is extremely improbable that this modification is present in the pure substance of very low conductivity such as was used in the following experiments.

The/

The transformation appears to me to be controlled by the solvent - whatever it is. Possibly a very unstable addition compound (as is evidenced by the pyridine compound with β- glucose) is formed with the solvent and the change brought about in some such way as the following:-



(x) and (y) represent the same substance at different stages of rotation of the group  round the axis joining the central carbon atom with the adjacent CH.OH Group. By the elimination of the pyridine molecule, the α- or the β- form may be produced as indicated. The atoms N or O - or some other polyvalent ones (with their latent valencies) of the solvents might easily be supposed to furnish the connecting link with the sugars.

The results obtained prove conclusively that mutarotation takes place in non-aqueous solutions of sugars with a velocity comparable with, though not so great as, that in aqueous solutions. This is seen most readily on inspection of the curves, though it must be/

be noted that the curves in the case of pyridine solutions as given by Grossmann and Bloch are for red light and not for the sodium flame. The velocity of mutarotation for the two kinds of light does not apparently differ to any great extent, so that for comparison the curves for red light have only to be moved parallel to themselves (G. and B., loc. cit.). That the mutarotation in formamide solution is of the nature of a reversible isodynamic change is evidenced by the fair agreement of the values of K for the α and β forms in the cases where the temperature could be regulated.

PART I.

EXPERIMENTAL.

Formamide.

The formamide used was supplied by C.A.F.Kahlbaum and was purified by careful fractional distillation under diminished pressure. The dehydration by means of anhydrous sodium sulphate previous to distillation under diminished pressure, as recommended by Walden (Zeitsch. phys. Chem., 1903, XLVI, 145), was not found to offer any advantage over direct distillation. Formamide distils at 99-100° under 11 mm. pressure, using a fine capillary air inlet. Walden mentions the melting-point as $+2.1^{\circ}$ and the conductivity $x_{25} = 4.7 \times 10^{-5}$, and our experiments confirm these numbers, our data being, melting-point $+ 2.1^{\circ}$ and $x_{25} = 3.2 \times 10^{-5}$.

The cryoscopic constant used - 38.5 - was that of Bruni and Trovanelli (Gazz. chim., 1904, 343, 350).

Water.

The distilled water of the laboratory was used.

Cryoscopic Apparatus.

The ordinary Beckmann freezing-point apparatus was used, the thermometer being graduated in 0.02° and read with the help of a lens, so that the limit of error in reading was approximately 0.01°. To prevent access of moist air, dry air was bubbled through the side tube, escaping through the small glass tube in which the stirrer moved.

The/

The Polarimeter.

The polarimeter was a Landolt-Lippich triple-field instrument, graduated in 0.01°, supplied by Schmidt & Haensch. A sodium flame produced by a Meker burner heating fused sodium chloride contained in a circular platinum gutter was the source of light. In the first experiments unjacketed tubes were used and the atmospheric temperature of the dark chamber kept as constant as possible. For comparison the rotations at a series of different temperatures were made, using a tube enclosed in an asbestos-covered box filled with water, which could be heated or cooled as required. The tubes and other vessels with which the solutions came in contact had been washed repeatedly with distilled water before use to remove alkali from the surface of the glass.

In later experiments a jacketed 2-dcm. tube provided with a thermometer immersed in the solution was used.

The Sugars.

Some of the sugars used in the following experiments were obtained from C.A.F.Kahlbaum. Further purification of such forms as were obtainable in sufficient quantities was effected by crystallisation from aqueous or aqueous-alcoholic solutions. Dr. Mackenzie kindly supplied some sugars given to him by Professor Irvine and Mr. Ford. The measurement of the specific rotation of these optically active forms is practically the only method of testing their purity. In such cases as that

of/

of lactose, where well-defined crystals of each modification are obtainable, the specific-gravity determination affords valuable confirmation. The melting points of sugars are so indefinite as to be of little value, generally speaking.

Some difficulty was at first experienced in dehydrating sugars owing to their decomposition on long-continued heating at 105° or even lower. Eventually a drying apparatus arranged in the following manner was found to give good results. The finely divided sugar was placed in a copper-foil boat about 5 in. long by ½ in. deep and ½ in. broad, and the boat inserted into a tube B, which is sealed on to a drying tube A, filled with phosphorus pentoxide and having an air inlet regulated by a screw clip. The other end of B is provided with a rubber stopper, through which passes the end of a second drying tube C, which leads to a mercury pump by means of which a pressure of from 1 to 2 mm. could be maintained for hours. As a rule the tube B was kept at ordinary room temperature for one or two hours, and then gradually heated by means of a steam jacket to near 100° until constant weight was attained. In this manner most of the adherent moisture and some hydrate water were expelled at room temperature and the remainder at the higher temperature without decomposition.

Preparation of Sugar Solutions.

The sugar, after drying to constant weight, was again/

again finely powdered - this being done in a large desiccating case provided with openings for the hands - weighed in a tube, and emptied into a dry 10-c.c. or 25-c.c. glass-stoppered flask, and the solvent added and the whole vigorously shaken till solution was complete. In some cases the solution had to be filtered to remove particles of fibre, which caused opacity of the solution. The first measurements of the rotation were made as soon as solution was complete, the time being taken from the instant when the sugar came in contact with the solvent.

β-l-Arabinose.

The arabinose was dried at 105° till of constant weight. It was perfectly colourless, and melted at 151°(uncor.).

Cryoscopic measurements gave the following data:-

Solvent.	Concentrations per 100 grams of solvent.	Mol. weight found.	Mol. weight calculated, $C_5H_{10}O_5$.
Water	1.23	148.4	150
"	2.28	149.0	"
Formamide	0.39	153.0	"
"	0.77	144.7	"
"	0.66	158.5	"
"	1.22	155.7	"

The polarimetric results were as follows:-

Solvent	Water		Water		Formamide.	
Graph	X				+	
Concentration grams in 100 c.c.solution.	2.606		4.512		2.3984	
	Time. hr. min.	$(\alpha)^{12}_D$.	Time hr. min.	$(\alpha)^{13}_D$.	Time hr. min.	$(\alpha)^{13}_D$.
	6½	+172.68°	9	+167.98°	10	+185.75°
	10	165.39	12½	158.80	16	184.49
	12	161.55	15	154.03	23	183.87
	19	150.99	18	149.38	26	183.04
	25	142.36	22	143.73	29	182.83
	33	134.69	27	137.85	33	181.58
	40	128.93	32	133.20	39	180.54
	54	121.26	39	127.66	46	179.08
	58	119.15	44	124.33	53	177.41
	1 19	113.01	50	121.12	1 1	175.53
	1 30	110.91	57	118.13	1 10	173.45
	1 50	108.98	1 5	115.02	1 26	170.32
	2 56	106.48	1 15	112.36	1 46	166.78
	3 13	105.91	1 28	110.04	2 4	163.03
	4 16	105.91	1. 31	109.70	2 34	158.65
	22 30	+105.91	1 46	107.93	3 0	155.31
			2 5	106.82	3 56	148.93
	K = 0.0134		3 7	105.82	4 41	143.64
	Calc.initial		4 30	105.82	5 16	140.30
	$(\alpha)^{12}_D$ = +186.8		5 15	105.82	6 3	136.34
	Extrapolated initial		24 0	+105.82	23 44	117.16
	$(\alpha)^{12}_D$ = +186°				25 16	117.16
					26 46	116.53
					30 16	116.53
					47 51	116.32
					52 46	116.32
					74 31	+116.32
					K = 0.00154.	
					Calc. initial	
					$(\alpha)^{13}_D$ = +189.5°	
					Extrapolated initial	
					$(\alpha)^{13}_D$ = +189°	

As will be seen from the graphs (figs. 1 and 2), the initial specific rotation obtained by extrapolation is about +186° for water, whereas the value obtained for it, using Levy's formula (Zeitsch. physikal, Chem., 1895, XVII, 301),

$$k = \frac{1}{t_2 - t_1} \log \frac{\beta_1 - \phi}{\beta_2 - \phi}$$

where/

where t_1 and t_2 are times from moment of solution till polarimetric readings were made, β_1 and β_2 are the actual polarimetric readings at times t_1 and t_2 and ϕ is the actual reading when constant, is $+186.9^\circ$ for concentration 2.606. In the formamide solution of concentration 2.3984 the extrapolated and calculated specific rotations are $+189^\circ$ and $+189.5^\circ$ respectively.

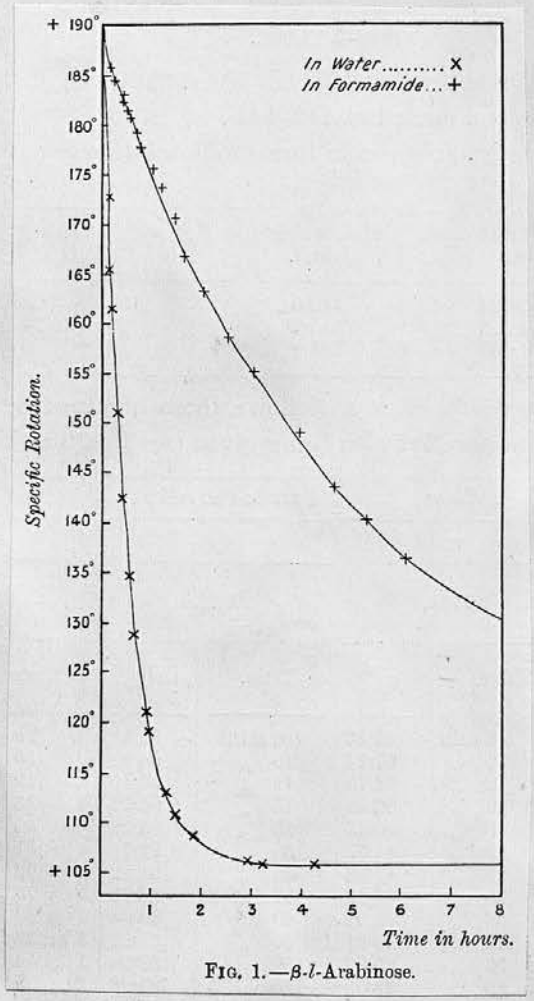


FIG. 1.—β-*l*-Arabinose.

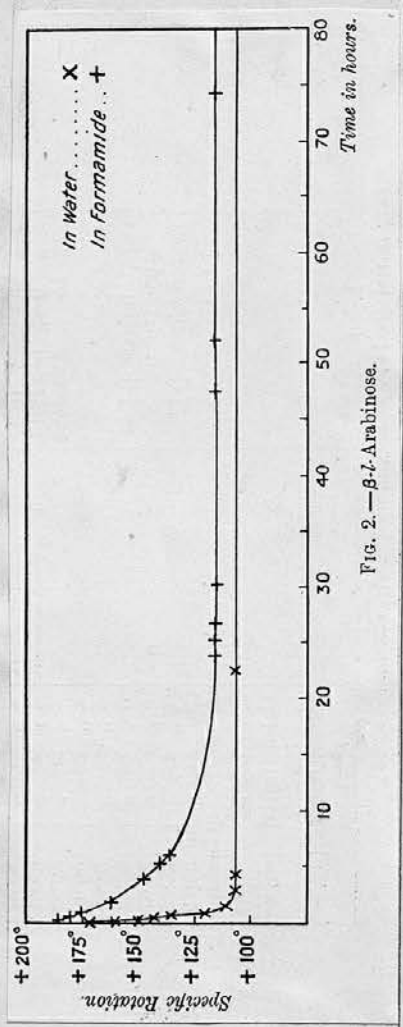


FIG. 2.—β-*l*-Arabinose.

l-XYLOSE.

Powdered xylose was dried at 105° till of constant weight. It showed a slight yellowish tint and melted at 142-144°.

The cryoscopic determinations in formamide solution gave the following figures.

Concentration per 100 grams solvent.	Mol. weight found.	Mol. weight calculated, $C_5H_{10}O_5$
0.624	140.5	150
1.205	145.8	"
1.698	145.2	"

The polarimetric results were as follows, those obtained by Grossmann and Bloch in pyridine solution also being given (see figs. 3 and 4):-

Solvent	Water		Pyridine G. and B.*		Formamide.	
Graph	X		⊕		+	
Concentration grams in 100 c.c.solution.	2.7184		1.28		4.0404	
	Time hr. min.	$(\alpha)^{20}_{D.}$	Time hr. min.	$(\alpha)^{20}_{red.}$	Time hr. min.	$(\alpha)^{20}_{D.}$
	8	+69.53°	8	+92.8°	11	+103.7°
	10	67.14	10	94.92	15	101.9
	12	62.73	12	96.10	19	99.6
	13	60.52	15	96.50	33	91.96
	18	50.23	20	95.32	40	89.48
	23	44.51	30	93.76	51	83.90
	25	41.02	40	91.82	62	79.58
	30	36.80	50	88.78	75	74.26
	36	32.01	60	86.34	87	70.29
	43	28.51	80	83.22	1 38	67.20
	53	25.02	100	82.04	1 54	61.63
	65	22.09	120	81.26	2 5	59.28
	85	20.82	1 day	53.13	2 26	54.57
	1 42	19.5	2 days	39.85	2 42	51.12
	1 55	19.5	4 "	+32.04	4 11	39.35
	2 9	+19.13	5 "	Constant	4 20	38.01
	4 15	Constant			4 29	36.88
					4 42	36.02
					4 59	34.90
					5 19	33.42
					5 35	32.67
					24 42	25.25
					47 34	+25.12 Constant.
	K = 0.0188 Calc. initial $(\alpha)^{20}_{D.}$ = +90.31° Extrapolated $(\alpha)^{20}_{D.}$ = +90°				K = 0.00306 Calc. initial $(\alpha)^{20}_{D.}$ = +109.39° Extrapolated $(\alpha)^{20}_{D.}$ = +109°	

*$(\alpha)^{20}_{D}$ initial = +117.39°, maximum 122.07°, constant +40.63°.

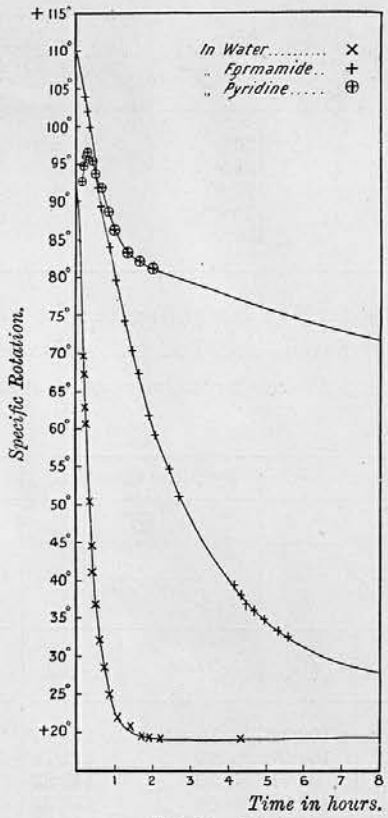


FIG. 3.—*l*-Xylose.

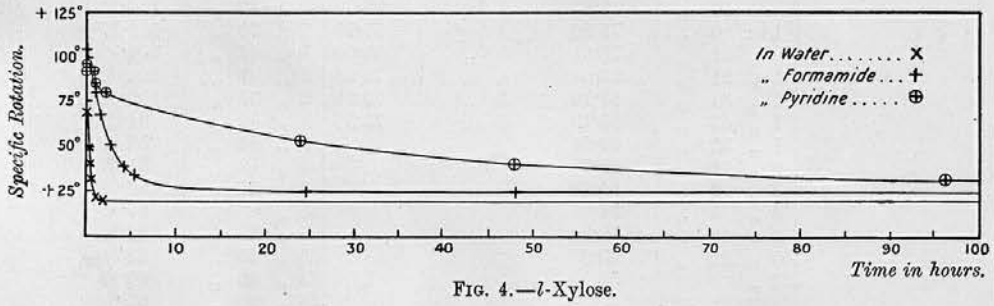


FIG. 4.—*l*-Xylose.

~~α~~-d-Glucose.

Glucose (Kahlbaum) was recrystallised three times from 90 per cent. alcohol solution. It was powdered and then dried at 105° till of constant weight.

Extremely accurate cryoscopic measurements of glucose in water having been made by several investigators (Loomis, Zeitsch. physikal. Chem., 1901, XXXVII, 407), it was not considered necessary to repeat them. The data obtained in formamide solution were:-

Concentration per 100 grams solvent.	Mol. weight found.	Mol. weight calculated for $C_6H_{12}O_6$
0.35	183.0	180.0
0.43	185.8	"
0.959	177.6	"
1.453	172.2	"
2.926	172.0	"

The polarimetric figures (cf. figs. 5 and 6) given for water solution correspond closely with those of Parcus and Tollens (Annalen, 1890, 257, 164). The figures of pyridine solution are those of Grossmann and Bloch (loc. cit.).

Solvent	Water		Pyridine G. and B.		Formamide.	
Graph	X		⊕		+	
Concentration) grams in 100 (c.c.solution.)	9.097		0.5625		2.5144	
	Time hr. min.	$(\alpha)^{20}_{D.}$	Time hr. min.	$(\alpha)^{20}_{red.}$	Time hr. min.	$(\alpha)^{20}_{D.}$
	7	+102.34°	10	+151.11°	17	+119.91°
	10	101.07	20	145.78	29	118.32
	14	98.31	30	142.23	37	116.93
	23	93.00	60	133.33	40	116.33
	30	88.75	120	127.11	41	114.94
	39	84.29	180	122.66	1 7	112.35
	50	79.83	1 day	97.77	1 17	110.76
	1 0	75.80	2 days	87.15	1 30	109.17
	1 11	72.61	3 "	80.00	1 44	106.98
	1 21	69.64	4 "	78.04	2 7	104.00
	1 31	67.10	5 "	75.56	2 37	100.62
	1 43	65.19	6 "	+75.56	3 50	94.06
	1 59	62.64			3 54	93.66
	2 12	60.73			4 13	91.67
	3 32	55.63			4 37	89.69
	4 3	54.78			5 0	87.88
	4 43	53.72			5 20	86.10
	5 25	53.08			5 48	83.90
	24 0	+52.23			23 46	60.85
					24 20	60.64
					24 46	60.24
					25 15	59.65
					71 15	57.27
					73 15	+57.27
	K = 0.00627				K = 0.001091	
	Calc. initial $(\alpha)^{20}_{D.}$ = + 108.5°				Calc. initial $(\alpha)^{20}_{D.}$ = 122.7°	
	Extrapolated $(\alpha)^{20}_{D.}$ = +108°				Initial $(\alpha)^{20}_{D}$ from curve = +122.5°.	

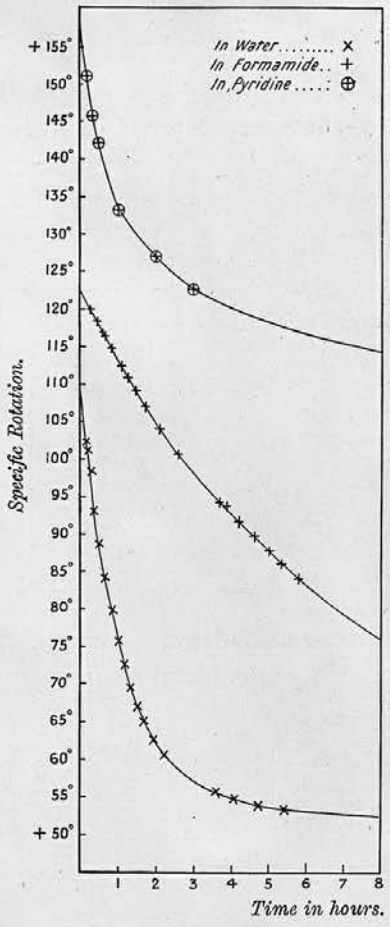


FIG. 5.—α-*d*-Glucose.

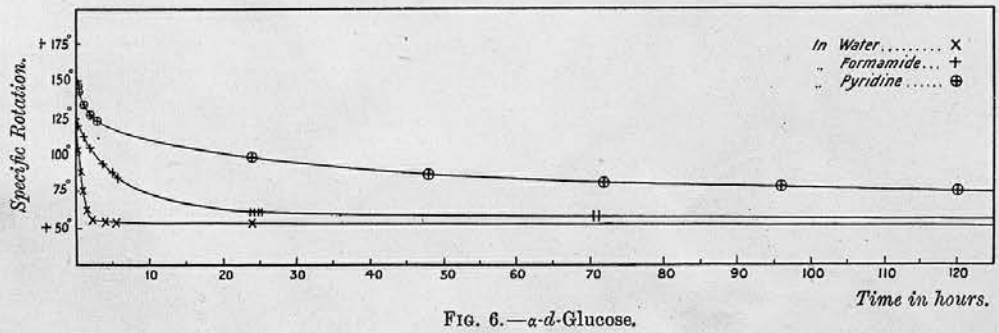


FIG. 6.—α-*d*-Glucose.

β-d-glucose.

10 grams of pure α-d-glucose were dissolved by boiling in 38 c.c. of freshly distilled (previously treated with KOH) pyridine (B.P. 114 - 115°C) and the solution filtered. The solution was cooled in ice water and on scratching the sides of the vessel crystals came out after about an hour. The solution was filtered off and the crystals washed with some pyridine and then with ether. On drying at 105°C to constant weight pure β-glucose in a very fine state of division was obtained. The yield was about 3.4 grams. The melting point of the substance was 146-148°C, and the sp. gr. at 13°C (determined by the method of flotation) - 1.547.

The cryoscopic measurements in water were not repeated. The figures in formamide solution were as follows:-

Concentration per 100 grams of solvent.	Mol. weight found.	Mol. weight calculated.
0.35	181.4	180
0.68	181.4	"
0.98	183.5	"

The/

The polarimetric figures (cf. figs. 7 and 8) were as follows:-

Solvent.	Water.		Formamide.	
Graph	⊗		⊕	
Concentration gms. in 100 c.c. solution.	2.3356		1.7148.	
	Time hr. min.	$(\alpha)_D^{20}$	Time hr. min.	$(\alpha)_D^{20}$
	8	+24.83°	10	+17.20°
	12	26.97	27	18.66
	18	28.47	45	20.41
	27	31.90	1 0	21.87
	32	33.39	1 19	23.33
	37	34.89	2 14	26.24
	42	36.61	2 42	27.99
	47	37.46	3 51	31.78
	53	38.96	4 30	33.82
	1 0	40.46	5 0	34.99
	1 49	46.67	5 36	36.45
	2 7	47.74	6 9	37.91
	2 55	50.09	24 34	48.11
	20 33	52.02	25 39	48.69
	48 0	+52.02	27.15	49.57
			29 0	51.03
			30 10	52.19
			47 45	54.23
			49 47	54.53
			53 6	55.69
			72 0	56.28
			14 days	+56.28
	K = 0.00690 Calc. initial $(\alpha)_D^{20}$ = +20.76° Extrapolated " = +20.90.		K = 0.000996 Calc. initial $(\alpha)_D^{20}$ = +15.74° Extrapolated " = +15.90°	

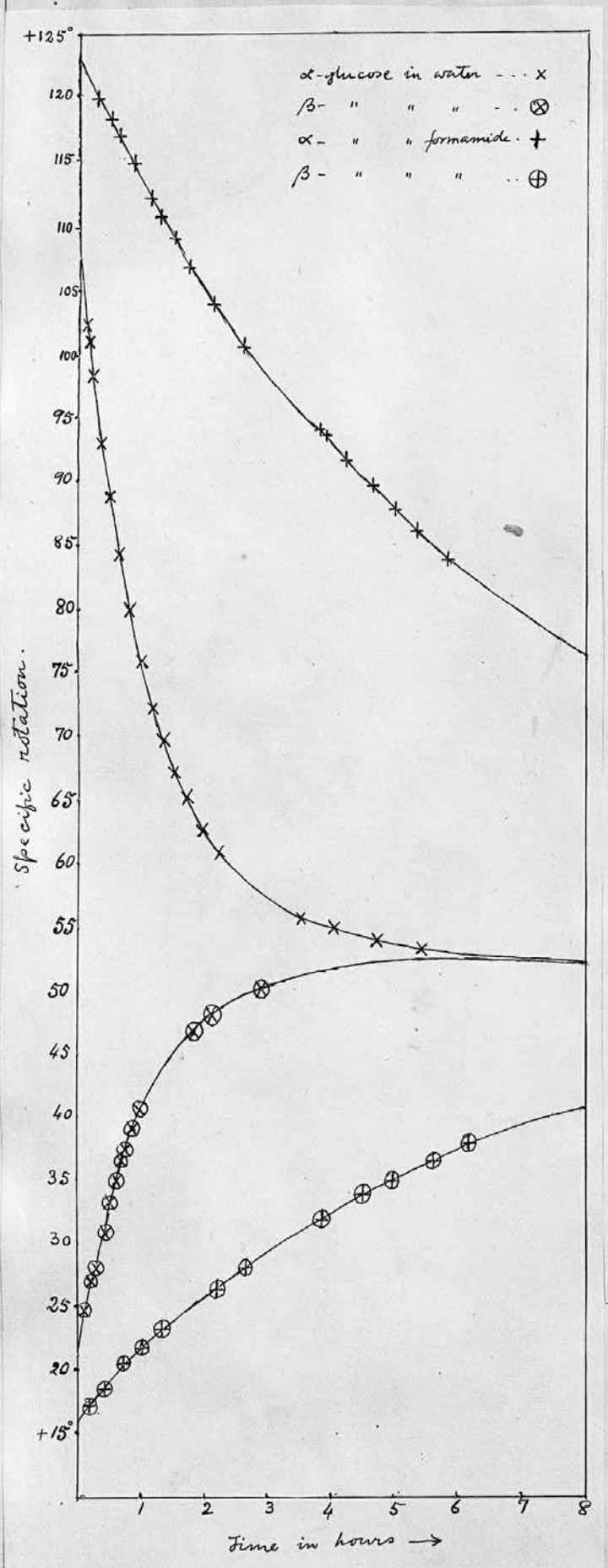


Fig. 7. α- and β- d- glucose

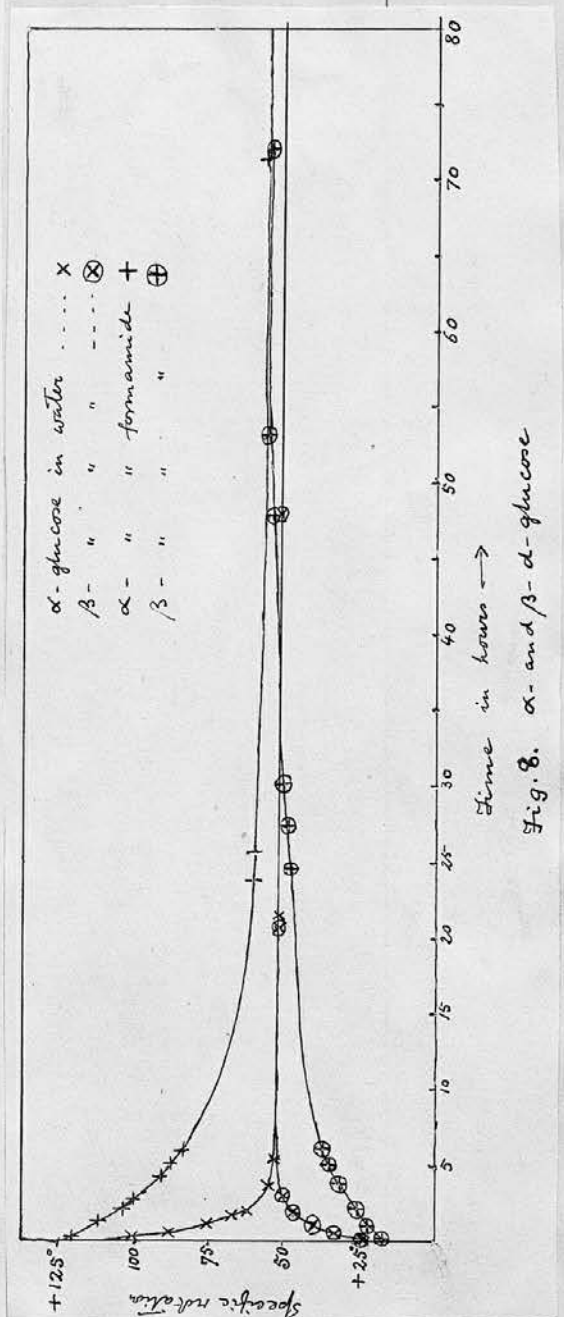


Fig. 8. α- and β- d- glucose

α-d-galactose.

The powdered galactose was dried in vacuo at 100° till of constant weight. It melted at 155-157° and dissolved in water forming a colourless solution.

The cryoscopic determinations in water and in formamide solutions gave the following figures:-

Solvent	Concentration per 100 grams solvent.	Mol. weight found.	Mol. weight calculated.
Water	1.01	171.4	180
"	2.07	179.5	"
Formamide	0.415	164.7	180
"	0.57	164.4	"
"	0.738	159.6	"
"	0.77	159.6	"
"	1.05	161.3	"

The galactose used for the polarimetric experiments was kindly sent by Professor Irvine. It had been re-crystallised from acetic acid and before use it was dried to constant weight in the drying apparatus.

The polarimetric results were as tabulated (cf. figs. 9 and 10) below:-

Solvent	Water		Pyridine G. and B.		Formamide	
Graph	X		⊙		+	
Concentration grams in 100 c.c.solution.	2.2460				1.7488	
	Time hr. min.	$(\alpha)^{20}_{D}$.	Time hr. min.	$(\alpha)^{20}_{Red.}$	Time hr. min.	$(\alpha)^{20}_{D}$.
	6	+131.57°	23	+120.98°	9	+152.96°
	10	127.78	30	112.34	12	151.25
	12	125.34	45	106.17	17	150.10
	15	122.22	60	102.47	22	148.96
	19	118.21	90	100.00	27	147.82
	25	113.09	120	97.50	34	145.53
	30	110.42	180	93.88	41	144.10
	35	106.86	240	91.31	52	140.96
	42	102.85	1 day	74.04	1 5	137.81
	48	99.78	2 days	55.53	1 15	136.09
	54	97.28	3 "	46.94	1 25	134.38
1	0	94.61	4 "	+ 46.94	1 35	132.66
1	7	92.61		Constant.	1 45	130.66
1	15	90.38			1 55	128.95
1	25	88.38			2 10	126.94
1	35	86.82			2 25	124.94
1	45	85.26			2 43	122.94
1	58	83.93			3 0	120.65
2	15	82.37			4 37	112.65
2	30	81.03			4 51	110.93
2	45	80.59			5 12	108.65
3	2	79.70			5 35	107.22
4	11	79.25			6 2	105.50
5	30	79.25			6 22	103.50
24	0	+ 79.25			23 42	89.20
					24 20	88.63
					26 32	87.77
					29 30	87.77
					48 0	+ 87.77
	K = 0.009601 Calc. initial $(\alpha)^{20}_{D}$ = +139.36° Extrapolated " = +139.50°				K = 0.001988 Calc. initial $(\alpha)^{20}_{D}$ = +155.25° Extrapolated " = + 155.0	

β-d-galactose.

I am indebted to Professor Irvine for kindly sending me directions from Professor Hudson for the preparation of β-galactose, which saved me a lot of time otherwise spent in following the method of Tanret.

The substance obtained was found to be partly mixed with α-galactose as shown by its initial specific rotation. The discrepancy in the values for K with those for a-galactose is possibly due to the impurity.

The polarimetric results (cf. figs. 9 and 10) were as follows:-

Solvent	Water		Formamide	
Graph	⊗		⊕	
Concentration grams in 100 c.c. solution.	1.8668		1.8064	
	Time hr. min.	$(\alpha)^{20}_{D}$.	Time hr. min.	$(\alpha)^{20}_{D}$.
	12	+60.53°	10	+63.39°
	18	62.14	22	64.22
	24	63.48	37	65.32
	34	65.35	50	66.43
	45	68.03	1 3	67.54
	55	70.44	1 18	68.64
	1 7	72.05	1 33	69.75
	1 22	73.65	1 50	71.13
	1 42	75.00	2 5	71.97
	2 2	76.33	2 25	73.07
	2 27	77.14	2 53	74.18
	3 0	77.94	4 15	76.39
	4 20	79.01	4 50	77.06
	5 15	+79.01°	5 20	77.78
		Constant	6 5	78.88
			23 35	86.63
			29 0	87.19
			48 0	+87.19°
	K = 0.007222		K = 0.001573	
	Calc.initial $(\alpha)^{20}_{D}$ = +56.51°		Calc.initial $(\alpha)^{20}_{D}$ =+62.30°	
	Extrapolated " = +56.5°		Extrapolated " = +62.50°	

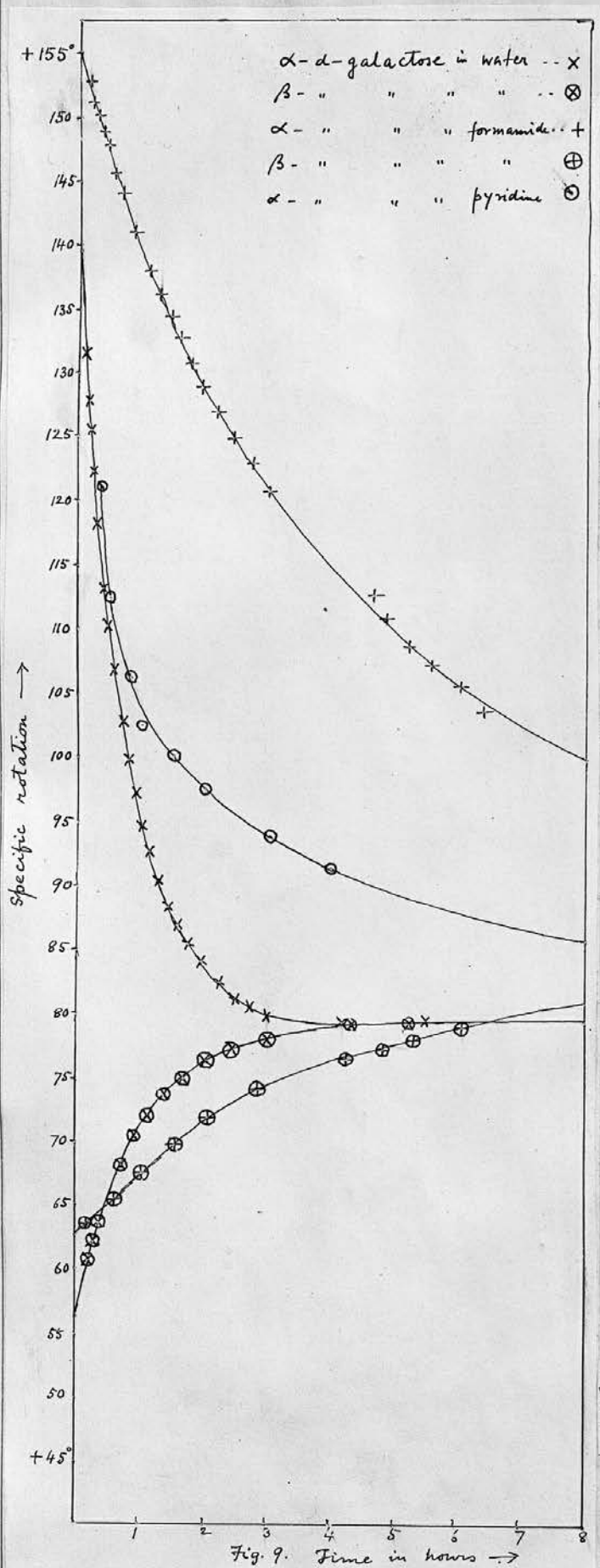

α-d-galactose in water --×
β- " " " " --⊗
α- " " " formamide--+
β- " " " " ⊕
α- " " " pyridine ⊙
Specific rotation →
+155°
150
145
140
135
130
125
120
115
110
105
100
95
90
85
80
75
70
65
60
55
50
+45°
1
2
3
4
5
6
7
8
Time in hours →

Fig. 9.

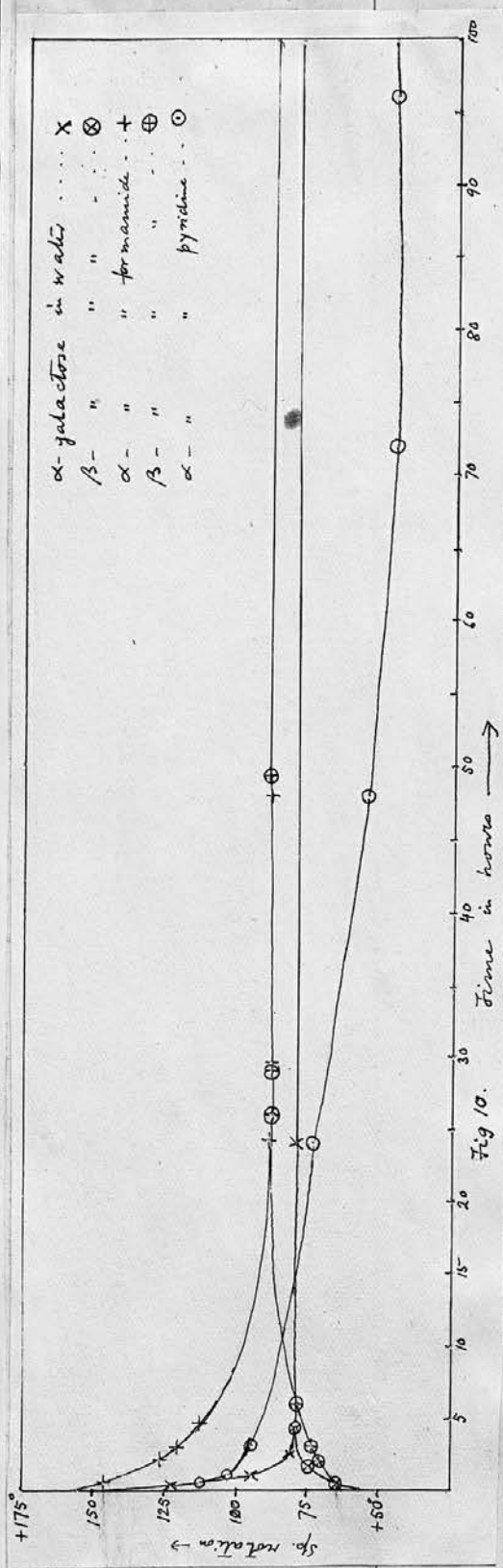

α-galactose in water ..... ×⊗
β- " " - - - -
α- " " formamide - - +⊕
β- " " " - - - -
α- " " pyridine - - ⊙
Sp. rotation →
+175°
150
125
100
75
+50°
5
10
15
20
30
40
50
60
70
80
90
100
Time in hours →

Fig 10.

d-Mannose.

The mannose was finely powdered and heated to 105° till of constant weight. It was perfectly colourless and melted at 129-132°.

The cryoscopic measurements, using formamide as solvent, were as follows:-

Concentration per 100 grams of solvent.	Mol. weight found.	Mol. weight calculated.
0.706	187.5	180.0
1.42	191.8	"
2.25	182.7	"

The following polarimetric results (cf. figs. 11 and 12) were obtained:-

Solvent	Water.		Formamide.	
Graph	X		+	
Concentration grams in 100 c.c.solution.	2.8128		2.0272.	
	Time hr. min.	$(\alpha)^{20}_{D}$.	Time hr. min.	$(\alpha)^{20}_{D}$.
	10	- 3.91°	7	- 25.16°
	22	+ 2.13	11	22.70
	28	+ 7.64	18	21.43
	32	10.84	24	20.22
	38	11.02	35	18.24
	71	13.83	45	15.30
	80	14.22	2 6	5.42
	93	14.22	2 12	2.46
	19 30	+ 14.40	2 33	1.72
	19 45	Constant	2 49	- 0.49
	20		3 0	+ 0.98
			3 13	+ 1.97
			3 32	2.95
			4 3	5.67
			21 52	+ 11.84
			23 0	Constant
	K = 0.0273		K = 0.000326	
	Calc.initial $(\alpha)^{20}_{D}$ = -19.9°		Calc.initial $(\alpha)^{20}_{D}$ = -26.9°	
	Extrapolated " = -20.0°		Extrapolated " = -26.0°	

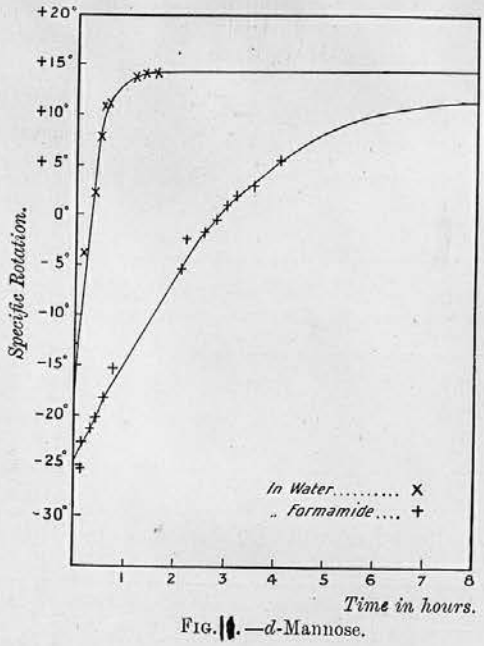


FIG. 11.—*d*-Mannose.

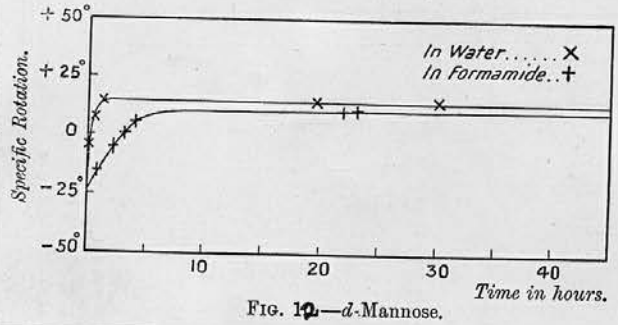


FIG. 12.—*d*-Mannose.

d-Fructose.

Powdered fructose was dried at room temperature in vacuo till of constant weight.

As in the case of glucose, it was not considered necessary to make cryoscopic measurements of fructose in water. The following figures were obtained in formamide solution:-

Concentration per 100 grams solvent.	Mol. weight found.	Mol. weight calculated for $C_6H_{12}O_6$
0.483	186	180
0.64	183.1	"
0.915	180.8	"
1.33	181.3	"
1.78	171.4	"

The polarimetric results (cf. figs. 13 and 14) are given in the following table, in which Grossmann and Bloch's/

Bloch's figures for mutarotation in pyridine solution are for red light. Their comparison between aqueous and pyridine solutions shows a much greater change in the latter than in the former solution. For water, $(\alpha)^{20}_{red}$ eight minutes after solution is - 85°, and when constant - 74°; whereas for pyridine, $(\alpha)^{20}_{red}$ fifteen minutes after solution is - 115°, and when constant - 25°.

Solvent	Water*		Pyridine G. and B.		Formamide.	
Graph	X		⊕		+	
Concentration grams in 100 c.c.solution.	9.9870.		0.9997.		2.2600	
	Time hr. min.	$(\alpha)^{20}_{D.}$	Time hr. min.	$(\alpha)^{20}_{red.}$	Time hr. min.	$(\alpha)^{20}_{D.}$
	6	-104.02°	15	-115.03°	17	-139.60°
	7	102.29	20	110.03	21	136.94
	7½	100.56	30	105.03	24	135.39
	8	98.84	45	101.03	29	133.62
	9	97.96	60	98.02	35	130.97
	10	97.44	90	93.02	45	127.65
	15	93.80	120	89.02	57	123.89
	20	92.76	150	85.02	1 7	121.45
	25	92.42	180	80.02	1 18	119.24
	35	92.09	240	72.02	1 29	117.25
	4¾ 0	92.09	22 0	25.0	1 40	115.93
	48 0	-92.09	48 0	-25.0	1 54	114.38
					2 3	113.49
					3 8	110.61
					3 42	109.51
					24 0	-109.51
					K = 0.00839	
					Calc.initial $(\alpha)^{20}_{D}$ = -151.76°	
					Extrapolated initial $(\alpha)^{20}_{D}$ = -151°.	

* Tollens and Parcus (Annalen, 1890, 257, 166.).

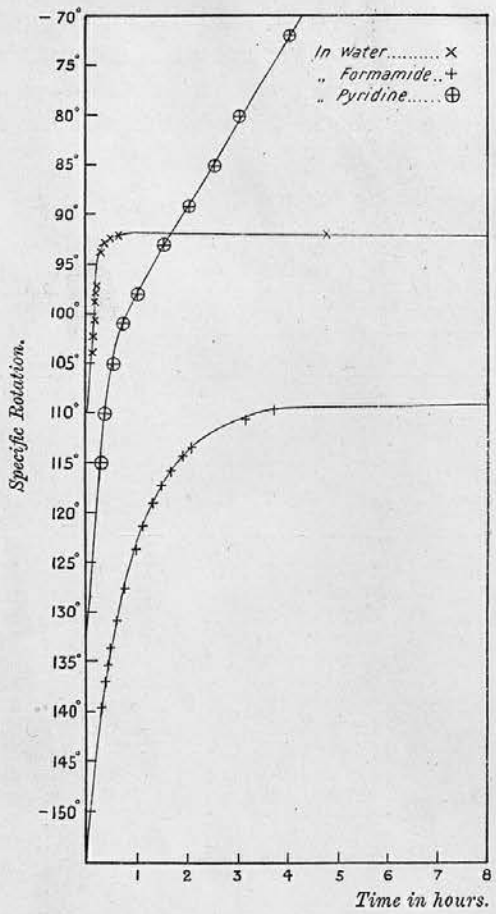


FIG. 13.—*d*-Fructose.

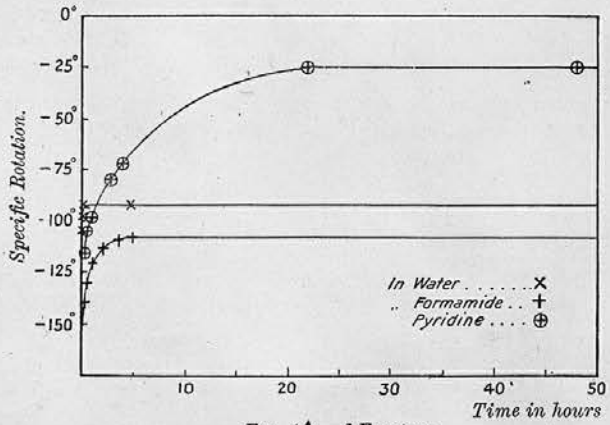


FIG. 14.—*d*-Fructose.

Maltose.

I am indebted to Mr. Ford of the Abbey and Holyrood breweries for kindly sending me a good sample of maltose. The sample was, according to his directions, recrystallised from alcohol. It was dried to constant weight before use, and it was found to be perfectly colourless and melted between 125-130°.

The cryoscopic measurements in water and formamide solutions gave the following values:-

Solvent.	Concentration per 100 grams solvent.	Mol. weight found.	Mol. weight calculated.
Water	0.45	341.8	342
"	0.56	333.0	"
Formamide	0.35	301.6	"
"	0.69	297.6	"

The slow rate of solution of maltose in formamide probably accounts for the low values obtained.

The polarimetric results (cf. figs. 15 and 16) were as tabulated. The values for pyridine solution are those of Grossmann and Bloch (for red light) and Schliephacke (Ann. 377, 164):-

Solvent	Water		Formamide		Pyridine G. & B.		Pyridine S.	
Graph	X		+		⊕		⊠	
Concentration grs. in 100 c.c.solution.	2.5188		2.1224				5.00	
	Time hr. min.	$(\alpha)^{20}_{D.}$	Time hr. min.	$(\alpha)^{20}_{D.}$	Time hr.min.	$(\alpha)^{20}_{red.}$	Time hr.min.	$(\alpha)^{20}_{D.}$
	9	+124.46°	12	+113.79°	15	+83.59	40	+97.7°
	12	124.86	23	114.73	20	85.93	13 40	105.4
	16	125.26	29	115.67	30	88.28	23 0	113.0
	25	126.65	1 0	117.32	45	89.84	42 0	117.0
	31	127.05	1 21	117.79	60	89.84	63 0	119.0
	39	127.84	1 42	118.73	120	90.66	85 0	120.1
	45	128.23	2 8	119.68	1 day	92.67	166 0	121.0
	53	129.03	2 35	121.09	3 days	95.31	214 0	121.8
1	1	129.83	4 25	123.21	4 "	96.87	14 days	122.2
1	9	130.42	5 20	124.62	5 "	97.66	Constant	+123.5
1	17	131.02	6 15	125.80	6 "	98.43		
1	28	131.61	23 45	130.28	8 "	98.43	K = 0.000210	
1	39	132.21	72 0	+130.28°	9 "	99.22	Calc. initial	
1	54	132.80			11 "	100.00	$(\alpha)^{20}_{D}$ = +97.2°	
2	9	133.40	K = 0.00163		12 "	100.00	Extrapolated "	
2	26	134.00	Calc.initial		15 "	+100.00	" = +97°	
2	43	134.20	$(\alpha)^{20}_{D}$ =					
3	0	134.60	+113.09°					
3	17	135.18	Extrapolated					
5	0	135.58	" "					
6	17	135.78	= +113.0					
24	5	136.18						
72	25	+136.18°						
K = 0.00503								
Calc. initial								
$(\alpha)^{20}_{D}$ = +123.20°								
Extrapolated "								
" = +123.0°								

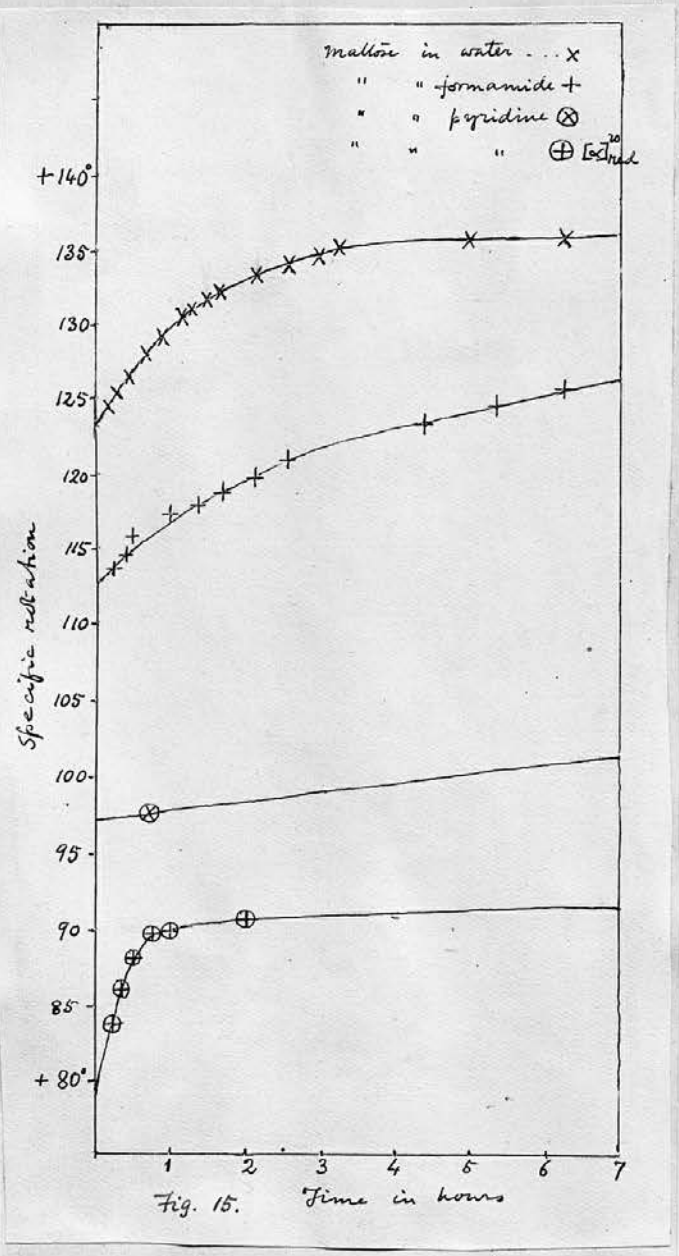


Fig. 15.

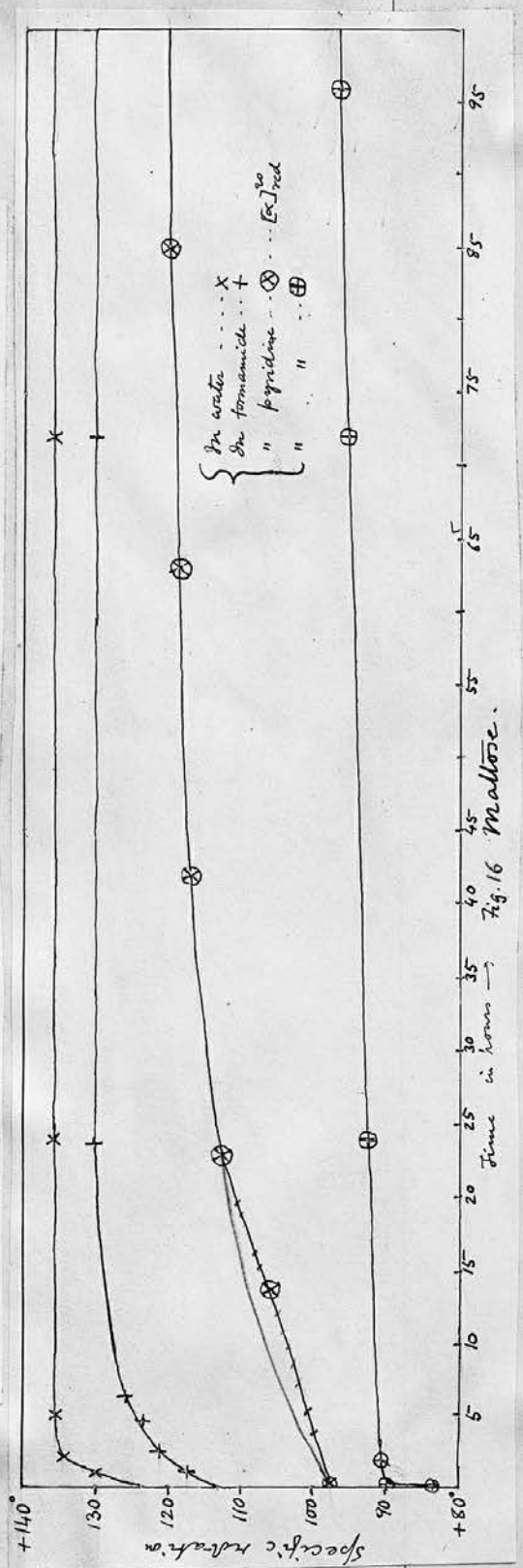


Fig. 16 Maltose.

α-Lactose.

This sugar was recrystallised twice from aqueous solution. Some difficulty was experienced in obtaining it in the anhydrous state, but this was overcome by means of the drying apparatus mentioned above. The temperature was ultimately raised to 130° before constant weight was obtained.

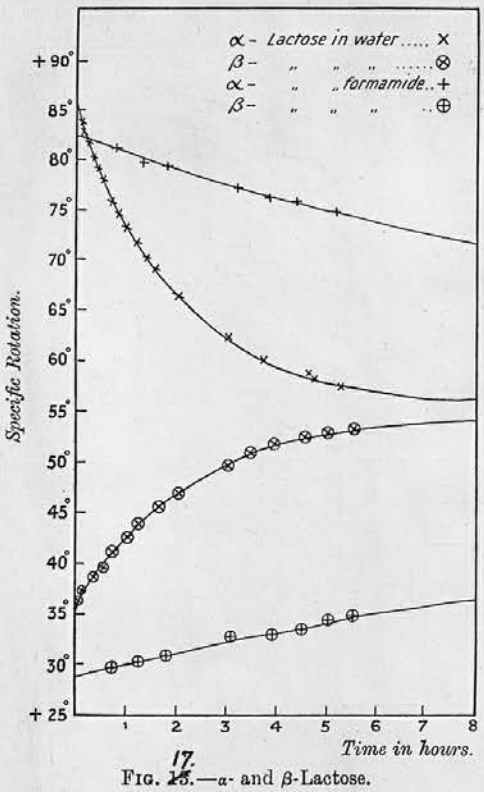
The cryoscopic measurement of α-lactose in aqueous solution was not repeated, having been done previously with great accuracy (Loomis, Zeitsch. physikal. Chem., 1901, XXXVII, 407). The slow rate of solution of lactose in formamide, owing to the formation of gummy masses, vitiated the results of some experiments. The following figures are typical of an experiment in which solution took place rapidly:-

Concentration per 100 grams solvent.	Mol. weight found.	Mol. weight calculated for $C_{12}H_{22}O_{11}$
1.783	326.8	342

The specific rotations as observed in water and in formamide solutions are given below (cf. figs. 17 and 18). Grossmann and Bloch state that lactose is only soluble in pyridine to the extent of about one per cent., and that they were unable to obtain exact readings, but found $(\alpha)^{20}_{red}$ initial = +20.52°, and constant = +31.5°; a reversal of the direction of the mutarotations in water and in formamide. The small initial value is probably due to incomplete solution of the lactose.

Solvent	Water.		Formamide.	
Graph	X		+	
Concentration grams in 100 c.c.solution.	2.3164		2.2756.	
	Time hr. min.	$(\alpha)_D^{14}$.	Time hr. min.	$(\alpha)_D^{15}$.
	7	+83.75°	48	+81.29°
	9	82.88	52	81.07
	14	81.80	1 22	79.97
	20	80.29	1 52	79.53
	27	79.22	3 15	77.34
	33	78.14	3 55	76.46
	36	77.70	4 28	76.02
	43	75.98	5 15	74.92
	52	74.68	22 24	61.74
	1 1	73.39	23 55	60.86
	1 12	71.87	25 55	59.98
	1 26	70.36	27 47	59.40
	1 36	69.29	28 30	58.44
	2 3	66.43	29 20	55.44
	3 5	62.38	46 20	54.05
	3 47	60.00	52 25	53.17
	4 42	58.71	3 days	51.85
	4 49	58.28	5 "	51.41
	5 20	57.41	7 "	+51.19
	24 29	+55.25 Constant		Constant
	K = 0.00378 Calc. initial $(\alpha)_D^{14}$ = +84.4°. Extrapolated initial $(\alpha)_D^{14}$ = +85°.		K = 0.000387 Calc. initial $(\alpha)_D^{15}$ = +82.39° Extrapolated initial $(\alpha)_D^{15}$ = +83°.	

$(\alpha)_D$ in water solution decreases 0.08° for each 1°C. rise in temperature from 10° to 25°; hence $(\alpha)_D^{20}$ constant = +54.77°.



17.
FIG. 15.—α- and β-Lactose.

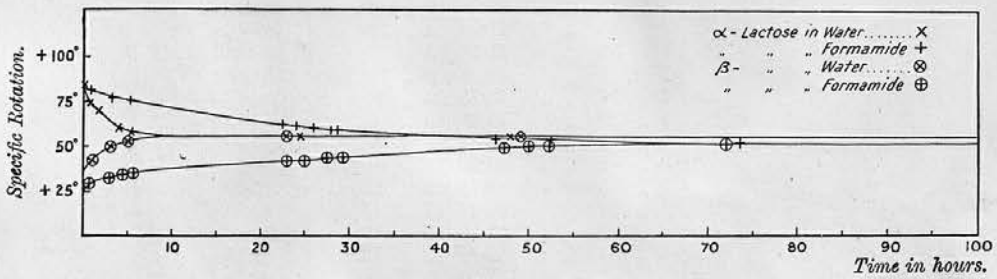


FIG. 18.—α- and β-Lactose.

β-Lactose.

This sugar was prepared by the method of Hudson (J. Amer. Chem. Soc., 1908, XXX, 960). The crushed crystals were found to have density 1.600 at 15°, whereas ordinary lactose, the α-form, has density 1.534.

The following molecular weights were found in aqueous solution:-

Concentration per 100 grams solvent.	Mol. weight found.	Mol. weight calculated for $C_{12}H_{22}O_{11}$
1.35	342.4	342
2.28	342.1	"
2.56	337.5	"
2.58	348.5	"
3.61	341.1	"
4.74	341.1	"
In formamide solution the numbers were:-		
1.235	324	342
2.46	327	"

The specific rotations (cf. figs. 17 and 18) are given in the following table:-

Solvent	Water.		Formamide.	
Graph	⊗		⊕	
Concentration grams in 100 c.c.solution.	2.752		1.8544	
	Time hr. min.	$(\alpha)_D^{17}$.	Time hr. min.	$(\alpha)_D^{17}$.
	4	+36.33°	45	+29.65°
	9	37.06	53	29.65
	11	37.24	1 15	30.19
	14	37.42	1 32	30.46
	23	38.51	1 49	30.73
	26	38.88	2 5	31.27
	34	39.42	3 7	32.62
	37	39.78	3 58	32.89
	45	41.06	4 33	33.43
	55	41.78	5 5	34.24
	1 5	42.58	5 33	34.78
	1 16	43.75	23 5	44.48
	1 39	45.60	25 7	44.75
	2 3	46.87	27 37	45.83
	3 2	49.60	28 42	46.37
	3 5	49.78	29 20	46.37
	3 31	50.87	47. 15	49.34
	4 0	51.59	50 10	49.88
	4 37	52.32	52 13	50.15
	5 5	52.87	3 days	50.69
	5 37	53.05	5 "	+51.22
	22 55	+55.23		Constant
		Constant		
	K = 0.00297		K = 0.00049	
	Calc.initial $(\alpha)_D^{17}$ = +35.97°		Calc.initial $(\alpha)_D^{17}$ = +29.11°	
	Extrapolated initial $(\alpha)_D^{17}$ = +36°		Extrapolated initial $(\alpha)_D^{17}$ = +29.5°.	

(Cf. figs. 17 and 18). $(\alpha)_D$ in water decreased 0.08° for each 1° rise in temperature from 10° to 25°; hence $(\alpha)_D^{20} = 54.99°$.

The corresponding values in formamide solution are 0.07°; +50.98°.

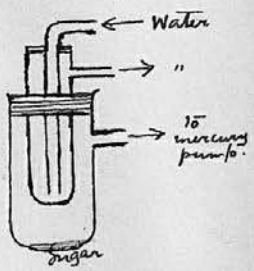
It will be observed that the equilibrium solution in both the water and the formamide solution is the same starting from either the α- or the β- modification of lactose.

PART II.

The Sublimation of sugars:-

A. Rhamnose (Isodulcite):-

While trying to dehydrate a sample of commercial (Kahlbaum's) rhamnose in the steam drying apparatus described above (p. 13.), it was observed that a sublimate was formed on the tube above the boat. This sublimate was found to be sweet to the taste and to char when heated. Suspecting it to be the original sugar, further attempts to sublime rhamnose were made using the apparatus figured at the side. The apparatus consisted of a vertical tube with side tube and a vertical water condenser. The side tube was connected with a mercury pump and the tube with the sugar in it was immersed in a paraffin bath the temperature being varied as desired. Sublimation took place below 105°C and the deposit on the bottom of the condenser formed a thin transparent layer. It was hygroscopic, reduced Fehling's solution and with phenyl-hydrazine gave an osazone.



The sample of rhamnose started with was found to be rather impure as shown by its specific rotation and the sublimation experiments could not be relied upon. Fresh quantities of purer Rhamnose (as shown later by the agreement in properties with those found in literature) were, however, soon placed at my disposal for/

for which I here express my gratitude to Professor Walker.

The melting point of the new rhamnose was 82-92°. Its $(\alpha)_D^{20}$ = +8.33. (Fischer and Piloty's (B. 23, 3102) value for the monohydrate, $(\alpha)_D^{20}$ = +8° to +9°.)

Combustion of the sample gave the values:-

%	Found	Calculated for the monohydrate $C_6H_{12}O_5 \cdot H_2O$.	$C_6H_{12}O_5$
C	39.38	39.55	43.90
H	7.71	7.69	7.33

It sublimed readily at about 115°C under 1-2mm. Pressure. The substance was hygroscopic and reduced Fehling's solution.

The literature of the subject would appear to show that with the single exception of glycolose, $CH_2OH.CHO$, which is described as "perceptibly volatile with water and alcohol vapour under diminished pressure, especially from a pure, concentrated solution" (Chemie der Zuckerarten - Lippmann, p.4), but which can hardly be called a typical sugar, no sugar has been observed to sublime.

The combustion of the sublimed substance gave the following figures:-

	Found.		Calculated.	
%	Expt.I (Kept over P_2O_5 in (vacuo for (2 days.	Expt.II (Kept over P_2O_5 in (vacuo for (7 days.	For $C_6H_{12}O_5 . \frac{1}{4}H_2O$	$C_6H_{12}O_5$
C	42.90	42.93	42.73	43.90
H	7.39	7.38	7.42	7.31

The substance thus appears to sublime in the anhydrous state/

state. The difference of the observed from the theoretical values for anhydrous substance can easily be accounted for by its hygroscopic nature, but it is rather curious to find the observed figures closely approaching those required for $C_6H_{12}O_5 \cdot \frac{1}{4} H_2O$.

The data for the combustion of the melted substance (a portion of which sublimed) before sublimation were as follows:-

%	Found	Calculated for $C_6H_{12}O_5$
C	43.75	43.90
H	7.26	7.31

Osazones were obtained from the sublimed substance and they melt under similar conditions with phenylhydrazine and acetic acid. The precipitates were washed repeatedly with water and dried in an oil bath at 90-105°C. The melting point of the osazone from the sublimed substance was 179-180°C, of that from the melt, 180-182°C, whereas the melting point of the osazone of rhamnose is stated in the literature to be 180°C. When observed under the microscope both the osazones were found to be needle-shaped and quite similar.

As the quantity of the sublimed sugar available for each experiment was rather small, the specific rotation had to be done in a decimetre tube of capillary bore having a capacity of about 1 c.c. In order to test the accuracy of the figures an exactly similar experiment was done with the commercial sample for which the figures with/

with the two-decimetre jacketed tube were known and the mutarotation values were found to be in close agreement. For the sublimed substance the following numbers were obtained:-

Found		Calculated for the anhydrous substance $C_6H_{12}O_5$
Expt. I	Expt. II	
conc. = 4.1266	conc. = 4.0000	conc. = 3.4208.
$(\alpha)_D^{12.5} = +9.21^\circ$	$(\alpha)_D^{12} = +9.00^\circ$	$(\alpha)_D^{20} = +9.24^\circ$

For melted substance (part of which sublimed) before sublimation:-

Expt. I.	Expt. II. Heated longer.
conc. = 2.932	conc. = 4.904
$(\alpha)_D^{11} = +5.80^\circ$	$(\alpha)_D^{12} = +3.65^\circ$

None showed any mutarotation, and it was possibly due to the production of the equilibrium form. The discrepancy in the values for the melt might be due to partial decomposition or some other change.

The identification of the sublimed substance with the original sugar is thus complete, the only differences being that it is obtained anhydrous and that it does not show any mutarotation.

B. Fructose:-

Its low melting point suggested its similarity with rhamnose and it has been observed to sublime at about 1-2 mm. pressure although much less rapidly. The work is being pursued and it is hoped that with a very good vacuum some of the other sugars will behave in a similar way.

In conclusion, I desire to express my heart-felt gratitude to Dr. J. E. Mackenzie, at whose suggestion the whole work was taken up and whose keen interest and kindly help, latterly in spite ofpressing military duties, have enabled me to carry it through.

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