Oxidation of Furfural.—After several experiments with temperature and time and dilution as the variables, the following conditions seemed to give the best yields in this oxidation.

In a round-bottomed liter flask which was equipped with a mechanical stirrer, dropping funnel and reflux condenser, were placed 100 g. of furfural, 100 g. of potassium dichromate and 10 g. of water. The flask was then heated to 100° on a steam-bath and, dropwise, there was added a mixture of 200 g. of sulfuric acid and 100 g. of water during thirty to forty-five minutes. The heat of reaction was such that the steam-bath was removed after a short time. When complete, the reaction mixture was cooled and nearly neutralized with sodium hydroxide. Then it was completely neutralized with sodium carbonate. The chromium hydroxide which was filtered off weighed 56 g. after drying. The filtrate was made acid with sulfuric acid and the dark brown precipitate of furoic acid was collected upon a filter. The filtrate was concentrated for more furoic acid. In all, 105 g. of crude material was formed. It was dissolved in the minimum amount of hot water, filtered from any insoluble matter, and the filtrate cooled. Eighty-seven grams (dry) of white furoic acid separated; yield, 75% The crystals melted at 131.5°.

Summary

A method is given for the oxidation of furfural to furoic acid by potassium dichromate and sulfuric acid. Improved directions are recorded for the preparation of furfuryl alcohol and furoic acid from furfural by the Cannizzaro reaction. Manganous furoate trihydrate is described.

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Sucrose and Other Disaccharides. Sir James Irvine's "Correction"

BY H. C. CARRINGTON, W. N. HAWORTH AND E. L. HIRST

In a recent paper which deals with the properties of 2,3,6-trimethylglucose and their bearing on the chemistry of the di- andpoly saccharides, Irvine and McGlynn[1] revert to a theme which was initiated and decided by one of us, but in their treatment of the subject they again dispense with the isolation of crystalline reference substances. They describe 2,3,6-trimethyl-γ-gluconolactone as a liquid with an initial rotation, $[\alpha]_D$ $+80.5°$ or 90.5° (both values being given), observed in a mixture of alcohol and water of unspecified composition. As shown in our experimental section the pure lactone is a crystalline substance, m. p. 29–30°, with the initial rotation $[\alpha]_D$ $+55°$ in water, alcohol or mixtures of the two solvents. We have characterized it as a γ-lactone by measuring its rate of mutarotation in water (which Irvine and McGlynn omitted to attempt), by preparing from it the crystalline phenylhydrazide of 2,3,6-trimethylgluconic

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[1] Irvine and McGlynn, THIS JOURNAL, **54**, 356 (1932).

acid and by converting it by methylation into tetramethyl-γ-gluconolactone (characterized by the crystalline phenylhydrazide). It is prepared from 2,3,6-trimethylglucose which undergoes oxidative degradation to *d*-dimethoxysuccinic acid recognized as the crystalline methylamide.

This trimethyl-γ-gluconolactone is obtainable by oxidation of 2,3,6-trimethylglucose both in the presence of hydrobromic acid and when the reaction is carried out in the presence of calcium carbonate. Under the latter conditions Irvine and McGlynn claim categorically that the oxidation product does not pass through the stage of the calcium salt. On frequent occasions we have made use of this procedure to obtain the calcium salt of the aldose sugar acids. So far from our criticism[2] of his experimental methods being, as he asserts, pointless we now publish experimental observations which show (a) that when the oxidation is conducted for eight hours at 0° at least 66% of the product is in the form of the calcium salt, (b) that an aqueous solution of the more stable γ-lactone of 2,3,6-trimethylgluconic acid reacts during five hours to the extent of 40% with calcium carbonate at 0°, (c) that the hydrolysis of the γ-lactone to acid is greatly accelerated by hydrobromic acid.

The position is therefore that Irvine and McGlynn have completely misconceived the nature of the γ-lactone, and on the basis of a sirupy product which bears no relation in properties to the pure substance it is claimed to be, they suggest that previous, but unspecified, results have a doubtful validity. Moreover, under the experimental conditions adopted by these authors, any lactone (γ or δ) formed by direct oxidation of the sugar must either hydrolyze to a mixture of acid and the two lactones or must be converted largely into the calcium salt. In these circumstances their experimental results can provide no sanction for any conclusions concerning the direct oxidation of 2,3,6-trimethylglucose to either the γ- or δ-lactone. Results have now been obtained by Isbell and Hudson's method[3] which suggest that in a buffered solution direct oxidation to the δ-lactone occurs but, on keeping, this changes in water to the equilibrium of γ- and δ-lactone and free acid or salt. We are unable to see in what manner Irvine and McGlynn's oxidation experiments, coupled with a confirmation of earlier work by others on 2,3,6-trimethyl-γ-methylglucoside, can be used to substantiate the claim that "much further work and the application of new methods are alike necessary before definite constitutions can be assigned to the disaccharides and polysaccharides which are convertible into 2,3,6-trimethylglucose." Further work and new methods can only be welcomed but these authors overlook the fact that the actual terms they use in referring to five- and six-atom ring forms of 2,3,6-trimethylglucose are based on our original determination of the structure of γ- and normal sugars. As one of us has pointed out, new methods of

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(2) Hirst, THIS JOURNAL, **54**, 2559 (1932).

(3) Isbell and Hudson, *J. Bur. Standards*, **8**, 327 (1932).

attack were developed six years ago and definite constitutions have been assigned by these means to maltose, lactose, cellobiose, melibiose, 4-glucosidomannose and 4-galactosidomannose. In his recent letter[4] Sir James Irvine admits knowledge of these results but gives no reason for his omission to mention them and to state his objection either to the methods or to the formulas assigned.

Heptamethylsucrose.—In the isolation of tetramethyl-γ-fructose as a residue from methylated sucrose a partly methylated product was employed in which the whole of the hydroxyl groups of the fructose component were protected while the hydroxyl groups in the glucose portion were only partly methylated. On hydrolysis this led to the separation of a distillate consisting essentially of the desired fructose portion of sucrose, and the procedure was improved in subsequent papers.[5]

In the first paper dealing with the isolation of tetramethyl-γ-fructose,[6] the partly methylated sucrose, described as heptamethylsucrose, was considered to be a homogeneous substance but this view was corrected in a later paper,[7] wherein it was stated that heptamethylsucrose gives rise to "a mixture of trimethylglucoses and tetramethyl-γ-fructose," since we isolated both 2,3,6- and 2,4,6-trimethylglucoses from the glucose residues.

Sir James Irvine in his criticism[8] seems to be unaware of these facts since he occupies much space in attacking the earlier view of the homogeneity of heptamethylsucrose. His further statement that he was unable to obtain by fractional distillation a product which "consists essentially of heptamethylsucrose" can be dismissed briefly. He claims that it is impossible to isolate a product containing less than 30% of the octamethylsucrose and a compensating quantity of hexamethyl and lower methylated sucroses. Over a large and extended series of preparations of this material, and by repeated fractional distillation controlled by refractive indices of the fractions, we have experienced no difficulty in obtaining a product which is "essentially heptamethylsucrose" containing less than 2% of the octamethyl derivative. The yield of the desired product is subject to the original statement on such methylation processes, namely, that "the success of the operation is governed to a remarkable degree by the conditions of the experiment."[9] A specific warning against the use of octamethylsucrose is given in the paper by Avery, Haworth and Hirst.[5]

In the past nine years during which we have revised the constitutional formulas of all sugars we have repeatedly stated that no structure is acceptable unless it is based on the isolation of well-recognized crystalline substances. Despite the dangers involved in the non-observance of this

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(4) Irvine, THIS JOURNAL, **54**, 2567 (1932).

(5) Avery, Haworth and Hirst, *J. Chem. Soc.*, 2308 (1927).

(6) Haworth, *ibid.*, **117**, 206 (1920).

(7) Haworth and Sedgwick, *ibid.*, 2574 (1926).

(8) Irvine, THIS JOURNAL, **54**, 1486 (1932).

(9) Haworth, *J. Chem. Soc.*, **107**, 9 (1915).

rule, Sir James Irvine persists in advancing conjectural formulas of sirupy products, and in this paper now under review he claims to have recognized a 2,3,5-trimethylglucose as a partly methylated hydrolysis product of methylated sucrose, and on this basis seeks to maintain "the disquieting possibility that methylation is accompanied to some extent by a change in the position of the internal oxygen ring in a sugar."

In the present case he has neglected to take into account the application of partition coefficients, since he claims that tetra- and tri-substituted methylglucoses, each of which is soluble in chloroform, can be extracted by this solvent from aqueous solution by methods which allow of a "sharp separation" in that all the tri-substituted sugar remains in the water while the tetra- is extracted by chloroform. We have long known the contrary to be true. But in order to test the special case involved in this claim we have prepared 2,3-dimethylmethylglucoside which Sir James Irvine definitely identified in his product (owing to incomplete fractionation of his methylated sucrose), and we have shown that, after eight extractions from an 8% aqueous solution, more than 80% is taken up by the chloroform. This glucose derivative he has characterized by the conversion of its 6-*p*-toluenesulfonyl derivative into the 6-iodo compound. The supposed 2,3,5-trimethylglucose (obtained through the γ-methylglucoside) he also claims to have recognized by treating a residual mixture of 5 g. of a trimethyl-γ-methylglucoside-*p*-toluene sulfonate with sodium iodide in acetone, heating the product in acetonitrile solution with silver nitrate and weighing the silver iodide formed. By this means he calculates that the mixture contained 14% of a 6-*p*-toluenesulfonyl derivative (equal to 0.35 g. of the free sugar from 100 g. methylated sucrose). Inasmuch as the trimethylmethylglucosides were extracted by chloroform from water they must have contained some 2,3-dimethylmethylglucosides, and it is clear that the latter would also give a 6-*p*-toluenesulfonyl derivative which must react with sodium iodide. An amount of 0.35 g. of dimethylmethylglucoside, forming part of 17 g. of a sirupy mixture of "trimethylmethylglucosides" would not be revealed by C and H and OMe estimations (no analyses are quoted). The evidence therefore for the presence of 2,3,5-trimethylglucose (which alternatively he considers as possibly 1,3,4-trimethylfructose) is unacceptable. It is on this experimental basis that Sir James Irvine seeks to establish a claim that "the case now presented opens up grave possibilities" of the insecurity of carbohydrate formulas which we have established.

Experimental

2,3,6-Trimethyl-γ-gluconolactone.—Bromine (10 cc.) was added slowly to a solution of 2,3,6-trimethylglucose, m. p. 121°, (7 g.) in water (30 cc.) maintained at 35°. After twenty-four hours the excess of bromine was removed by aeration and the solution was extracted with chloroform. Removal of the chloroform under diminished pressure left a yellow sirup which on distillation gave 2,3,6-trimethyl-γ-gluconolactone

(6.1 g.) as a colorless sirup which rapidly crystallized. Recrystallization from ether–light petroleum at −10° gave needles, m. p. 29–30°, b. p. about 130° (0.05 mm.), $n_{\mathrm{D}}^{16^\circ}$ 1.4625 (superfused solid), $[\alpha]_{\mathrm{D}}^{18}$ +55° in water, *c* 2.4; +56° in alcohol, *c* 0.5; +55° in 50% aqueous alcohol, *c* 0.4. 0.3193 g. of substance required 14.7 cc. of *N*/10 NaOH. Calcd. 14.5 cc. (Found: C, 49.0; H, 7.6; OMe, 41.2. $C_9H_{16}O_6$ requires C, 49.1; H, 7.3; OMe, 42.3%).

Under the conditions given by Irvine and McGlynn (eight hours at 0°) the oxidation is incomplete. The mixture (yield 50%) of sugar and lactone so obtained reduced Fehling's solution vigorously and when kept crystallized partially giving 2,3,6-trimethyl-γ-gluconolactone, m. p. 28°, identical with the material described above (yield 25%).

The rate of mutarotation of the 2,3,6-trimethyl-γ-gluconolactone in aqueous solution was similar to that of tetramethyl γ-gluconolactone: $[\alpha]_{\mathrm{D}}^{18^\circ}$ +55° initial value in water, *c* 2.4; 53° (12 hrs.); 52° (24 hrs.); 49° (60 hrs.); 46° (100 hrs.); 42° (200 hrs.); 40° (250 hrs.); 37° (500 hrs.); 37.5° (700 hrs.). After 700 hours the rotation fell extremely slowly. The rate of mutarotation was greatly accelerated by hydrobromic acid: $[\alpha]_{\mathrm{D}}^{19^\circ}$ +55°, initial value in *N* aqueous HBr, *c* 0.5; 54° (3 min.); 52° (15 min.); 48° (30 min.); 44° (1 hr.); 42° (3 hrs.); 40° (5 hrs.); 34° (48 hrs.).

The rotation of the acid in water was $[\alpha]_{\mathrm{D}}^{20^\circ}$ +28° initial value, *c* 1.4 (calcd. as lactone); 30° (15 min.); 31° (45 min.); 32° (90 min.); 32.5° (200 min.; constant value, observed for 70 hrs.). The proportions of δ-lactone, γ-lactone and acid at equilibrium cannot be calculated from these figures, but the proportion of acid must be at least 85% since, as shown below, the δ-lactone has a rotation higher than 55°.

The phenylhydrazide of 2,3,6-trimethylgluconic acid was prepared by heating on the water-bath a mixture of the lactone with a slight excess of phenylhydrazine. After ten minutes the mixture solidified. The excess of phenylhydrazine was removed by washing with benzene and the product was recrystallized from ethyl acetate, giving colorless needles, m. p. 145°, yield 90%. (Found: C, 55.0; H, 7.4; N, 8.8; OMe, 28.2. $C_{15}H_{24}O_6N_2$ requires C, 54.9; H, 7.3; N, 8.6; OMe, 28.4%).

On methylation with methyl iodide and silver oxide 2,3,6-trimethyl-γ-gluconolactone gave 2,3,5,6-tetramethyl-γ-gluconolactone recognized as the corresponding crystalline phenylhydrazide, m. p. 136°, alone or when mixed with an authentic sample.

Oxidation of 2,3,6-Trimethylglucose in the presence of Calcium Carbonate.—When the oxidation of 2,3,6-trimethylglucose was carried out at 0° in the presence of calcium carbonate most of the product passed through the stage of the calcium salt (contrast Irvine).[4] 2,3,6-Trimethylglucose (1 g.) was oxidized for eight hours at 0° by bromine in the presence of calcium carbonate. The bromine was removed by aeration and the excess of calcium carbonate by filtration. Aliquot parts of the filtrate were analyzed for halogen and calcium. (Found: total calcium in solution, 0.250 g. Calcium equivalent to bromide ion in solution 0.186 g.). The excess calcium (0.064 g.) which existed as the calcium salt of an organic acid was equivalent to 0.77 g. of 2,3,6-trimethylgluconic acid; *i. e.*, 66% of the theoretically possible quantity occurs as the calcium salt. Control experiments showed that this method of analysis is not vitiated by errors due to the formation of calcium bicarbonate. When 2.5 cc. of 0.135 *N* hydrobromic acid was added slowly over a period of one hour to a mixture of calcium carbonate and water at 0° the calcium in the filtered solution was found to be exactly equivalent to the added hydrobromic acid. The solution therefore contained no bicarbonate.

Again, when a solution of 2,3,6-trimethyl-γ-gluconolactone (0.150 g.) in water (10 cc.) was kept in contact with calcium carbonate at 0° for five hours the filtered solution contained 0.0054 g. of calcium (determined by precipitation as the oxalate and estimated volumetrically with permanganate). This is equivalent to the transformation of 0.059 g. of trimethyl-γ-gluconolactone into the calcium salt. The stable γ-lactone is converted into the calcium salt to the extent of 40% under these mild conditions.

Oxidation by Isbell and Hudson's Method.—When 2,3,6-trimethylglucose was oxidized in a buffered solution in accordance with Isbell and Hudson's procedure[9] the following observations were made: $[\alpha]^{20^\circ}_D$ +60° in a solution (24 cc.) containing sodium acetate (3.75 g.), glacial acetic acid (0.25 cc.), trimethylglucose (2.5 g.). Five minutes after the addition of bromine (0.75 cc.) the $[\alpha]_D$ was +73°; 70° (10 min.); 63° (20 min.); 55° (45 min.); 53° (60 min.); 49° (90 min.); 43° (300 min.). After eleven minutes a sample of the solution was removed, and the bromine eliminated by shaking with olive oil. The solution then had $[\alpha]^{20^\circ}_D$ +49° (50 min. after commencement of oxidation); 48° (90 min.); 46° (300 min.). At eleven minutes it was found that the oxidation was complete to the extent of 50%. Since the rotation of the γ-lactone is +55°, the above figures indicate that under these conditions preferential formation of the δ-lactone takes place.

Lactonization of 2,3,6-Trimethylgluconic Acid.—The conditions governing the lactonization of 2,3,6-trimethylgluconic acid were complex. The pure γ-lactone was obtained invariably (a) by evaporating to a sirup an aqueous solution of the free acid containing a trace of mineral acid, (b) by evaporating a chloroform extract of an aqueous solution of the free acid to which some mineral acid had been added a short time previous to the extraction. Mixtures containing some δ-lactone in addition to γ-lactone were obtainable (a) by evaporating to a sirup of an aqueous solution of the γ-lactone which had been kept at 100° for four hours, (b) from a chloroform extract of an aqueous solution of the free acid made immediately after liberation of the acid from a salt. Method (b) was uncertain in its results and sometimes gave pure γ-lactone, particularly when the aqueous solution contained mineral acid. A typical experiment (method (a)) gave a mixture of lactones which had $[\alpha]^{17^\circ}_D$ +61° initial value in water, *c* 0.4; 49° (3 hrs.); 49° (5 hrs.); 46° (17 hrs.); 41° (100 hrs.). The initial rapid fall in rotation followed by a slow fall is characteristic of a mixture of γ- and δ-lactones. Since the equilibrium rotation is +35° and that of the γ-lactone +55°, an approximate value for the rotation of the δ-lactone can be calculated (+90°). The mixture with $[\alpha]_D$ +61° would therefore contain about 20% of the δ-lactone.

WITH C. W. LONG

Oxidation of 2,3,6-Trimethylglucose by Nitric Acid.—Crystalline 2,3,6-trimethylglucose (5 g.) was heated on the water-bath (95°) for seven hours with nitric acid (40 cc., *d* 1.42). The acid was removed by distillation under diminished pressure, water being added from time to time. The sirupy product was boiled for six hours with 2% methyl alcoholic hydrogen chloride. The acid was removed by addition of silver carbonate and after removal of the solvent the esterified oxidation product was distilled giving 2.6 g., b. p. about 80° (0.05 mm.), n^{17}_D 1.4355, $[\alpha]^{17}_D$ +80° in water (*c* 1.7). This consisted almost entirely of methyl *d*-dimethoxysuccinate, as was proved by its conversion into the corresponding amide (yield 80%), m. p. 280° decomp., $[\alpha]^{17}_D$ +95° in water (*c* 0.4) and methylamide, m. p. 207–208°. A mixed melting point with an authentic sample of the methylamide prepared by Haworth and Jones[10] showed no depression. [Found (methylamide): C, 47.0; H, 7.9; N, 13.7. Calcd. for $C_8H_{16}O_4N_2$: C, 47.0; H, 7.85; N, 13.7%.] The yield of methyl *d*-dimethoxysuccinate was 80% of the theoretical.

Extraction of 2,3-Dimethyl-α-methylglucoside from Water by Chloroform.—A 4% aqueous solution of crystalline dimethyl-α-methylglucoside[11] was shaken with an equal volume of chloroform. On evaporation of the dried chloroform solution 4% of the original dimethyl-α-methylglucoside was recovered. Three successive extractions with an equal volume of chloroform removed 10% of the material in the aqueous solution. When a stronger aqueous solution (8%) was extracted thoroughly with chloro-

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(10) Haworth and Jones, *J. Chem. Soc.*, 2349 (1927).

(11) Irvine and Scott, *ibid.*, **103**, 582 (1913).

form 85% of the 2,3-dimethylmethylglucoside was obtained in the chloroform extract. The solubility of the glucoside in chloroform is so marked that we have found extraction by chloroform of an aqueous solution (8–10% concentration) of the crude material a useful method of purification. (These experiments were carried out by Dr. A. C. Waine.)

Summary

The oxidation of 2,3,6-trimethylglucose under various conditions has been studied, with results contrary to the conclusions of Irvine and McGlynn. 2,3,6-Trimethyl-γ-gluconolactone is a crystalline substance the properties of which diverge widely from those ascribed to this lactone by the above authors. It is shown that dimethylmethylglucoside is readily extracted from aqueous solution by chloroform. The bearing of these results on the critical views of Irvine concerning the chemistry of sucrose and other disaccharides is discussed.

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The Preparation of Some Higher Aliphatic Sulfonic Acids

BY C. R. NOLLER AND J. J. GORDON

The work of Reychler[1a] and of McBain and his associates[1b] has shown that cetyl sulfonic acid has unique properties for the investigation of soap solutions, but it has the disadvantage that it is not very soluble in water at temperatures below 50°. Sulfonic acids giving colloidal aqueous solutions but having a lower molecular weight should be more satisfactory but none appear to have been described between C_8 and C_{16}. Accordingly the straight chain aliphatic sulfonic acids containing from nine to fourteen carbon atoms have been prepared in quantity and in a pure state and we wish to report on their preparation at the present time. The work on the physical properties of their solutions will be reported by others at a future date.

The general methods available for preparing aliphatic sulfonic acids in quantity are few in number and in general unsatisfactory. Attempts to prepare esters of sulfonic acids from ethyl chlorosulfonate and alkylmagnesium halides by Mr. Poe Liang in this Laboratory were not successful, nor did the direct oxidation of the disulfides lead to satisfactory results. The method used in the present work has been the nitric acid oxidation of the lead mercaptide, a procedure first described by Williams.[2] In all cases the starting material was the corresponding alcohol.

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(1) (a) Reychler, *Bull. soc. chim. Belg.*, **27**, 110, 217, 300 (1913); (b) Norris, *J. Chem. Soc.*, **121**, 2161 (1922); McBain and Williams, *Colloid Symposium Annual*, **7**, 105 (1929).

(2) Williams, Ph.D. Thesis, Stanford University, 1929. See forthcoming article by McBain and Williams, THIS JOURNAL (1933).