degassing occurs. As most substances have a decomposition point not far above this, an optimum temperature must be discovered. The pressure should be lowered gradually with the oil pump and, when its full capacity is reached, pumping should progress for about five minutes before the mercury pumps are started, the temperature being raised gradually until the substance is about 10 to 20° below the boiling point as the mercury pumps take hold. The temperature is then raised until distillation commences. If no decomposition appears to be taking place, the temperature may be raised until a steady distillation occurs.

Pressures as low as 10^{-5} mm. were obtained if a liquid nitrogen trap was used and if the temperature of the distillation flask was held reasonably low. Most of the compounds studied, however, do not require such low pressures. With many of the propionates, good results were obtained if the pressures were 0.01 mm. Some distilled even up to 0.1 mm., whereas others required pressures below 0.001 mm. Usually the latter pressure could be reached when the cold trap was at −78° but it could always be reached without difficulty when cooled by liquid nitrogen.

With pressures below 0.05 mm., as read on the gage, the bath temperatures around the distillation flask do not correlate well with the pressure. If a mixture is being distilled it is usually necessary to maintain a higher bath temperature than if the corresponding pure substance was being distilled. The place to make a cut, therefore, must be decided from the character of the distillate, particularly its color and viscosity, and the rate of distillation. In separating monosaccharide and disaccharide derivatives, for example, the distillate becomes darker as the disaccharide starts to distil. Receivers are changed when the distillate ceases to drop freely and starts to string. The approximate time to take a cut can be told by the stopping of distillation at a given pot temperature if the pressure remains constant.

It is possible to distil as complex a compound as raffinose hendecapropionate in the apparatus shown in Fig. 1, but the molecular still of Fig. 2 makes this operation easier to perform. The molecular still is attached directly to the cold trap (Fig. 1) by means of the standard taper joint. The design of this type of molecular still was suggested to one of us by Dr. K. C. D. Hickman.

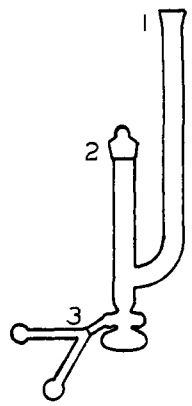

Fig. 2.—1, Standard taper 24/40; 2, standard taper 29/42; 3, standard taper 14/35.

Summary

An apparatus is described and the procedure outlined for the distillation of propionates of mono-, di- and trisaccharides.

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[CONTRIBUTION FROM THE CHEMICAL LABORATORY OF NORTHWESTERN UNIVERSITY]

Propionyl Derivatives of Sugars

BY CHARLES D. HURD AND K. M. GORDON[1]

Only one propionyl derivative of a monosaccharide is reported in the literature and there are none for di- or trisaccharides. α-D-Glucose pentapropionate was reported by Hess and Messmer[2] to be a colorless sirup boiling at 205° (2 mm.).

Sixteen new propionates have been prepared in the present investigation. The carbohydrates from which these were derived may be grouped as follows: two pentoses, one methylpentose, two aldohexoses, two ketohexoses, eight disaccharides, one trisaccharide. All were completely propionylated, the general method being to leave a mixture of the sugar, propionic anhydride and dry pyridine at room temperature for several days. A summary of data concerning these compounds is given in Table I.

Most of these propionates were purified by distillation at low pressures. No decomposition was apparent when appropriate conditions were maintained. Propionates of the monosaccharides and disaccharides distilled at pressures of 0.07–0.001 mm., when the bath temperature was 160–280°. The propionates from sorbose or fructose were less stable than the others, hence lower bath temperatures were used for them, namely, 160 to

TABLE I

PROPIONATES OF MONO-, DI- AND TRISACCHARIDES

	M. p., °C.	$[\alpha]^{20}D$	Anal., % Found	C_2H_5CO Calcd.
L-Rhamnose tetrapropionate	Sirup	−43	58.3	58.8
L-Arabinose tetrapropionate	80	116	60.6	61.0
D-Xylose tetrapropionate	42–43	43	61.1	61.0
D-Fructose pentapropionate	Sirup	24	62.2	62.0
D-Mannose pentapropionate	Sirup	24	62.5	62.0
D-Galactose pentapropionate	Sirup	54	62.0	62.0
L-Sorbose pentapropionate	Sirup	−17	62.1	62.0
Maltose octapropionate	144	55	57.7	57.7
Cellobiose octapropionate	170	8.0	57.7	57.7
Lactose octapropionate	Sirup	32	57.1	57.7
Sucrose octapropionate	45–46	53	57.6	57.7
Gentiobiose octapropionate	151–152	− 3.3	58.6	57.7
Trehalose octapropionate	52–53	144	57.5	57.7
Melibiose octapropionate	Sirup	92		
Neolactose octapropionate	Sirup	−4.5		
Raffinose hendecapropionate	Sirup	95	55.8	56.0

(1) Holder of Pabst Research Fellowship, 1938–1941.

(2) Hess and Messmer, *Ber.*, **54**, 511 (1921).

200°. Temperatures up to 300° did not seem to cause pyrolysis of the others but it was found that decomposition did set in at 325° (bath temp.). This temperature, as would be expected, is somewhat below that required for vapor phase pyrolysis of simple esters. *i*-Propyl acetate decomposes[3] to the extent of 19% in 3.9 sec. at 430°, and *t*-butyl acetate decomposes 2.7% in 2.6 sec. at 360°.

Although special distillation equipment was constructed for these propionates, the fact that they may be distilled without decomposition is quite significant. Even raffinose hendecapropionate, $C_{61}H_{75}O_{27}$, distilled smoothly, if proper precautions were taken.

It was mentioned previously[4] that propionates of carbohydrates distil more readily than acetates. It was established in this work, however, that maltose octaacetate can be made to distil. The conditions found were a pressure of 0.0005 mm. and a bath temperature of 260°. The distillate was a glassy material so viscous that it would not flow into the collecting tube.

More than passing mention should be given to the fact that maltose octapropionate is so readily crystalline. In work with sugar mixtures containing maltose, which will be reported in later papers, it was established that the propionate is not only the best derivative of maltose but frequently is the only derivative which can be made to crystallize from the mixture in question.

Experimental Part

Materials.—Most of the sugars used were obtained from commercial sources, but small samples of gentiobiose, melibiose and neolactose were generously furnished by H. S. Isbell and M. L. Wolfrom.

Propionylation of Sugars. General Procedure.—A mixture of the sugar, propionic anhydride and dry pyridine was set aside for three to seven days at room temperature, during which period complete solution of the sugar took place. Theoretically, each mole of pentose or methylpentose calls for 4 moles of propionic anhydride. Each mole of hexose similarly requires 5 moles of the anhydride; each disaccharide, 8 moles; and each trisaccharide, 11 moles. A 1.3-fold excess of propionic anhydride was used and it was found that no better yields were obtained when a 1.7-fold excess was taken. For each mole of propionic anhydride there was used 1.9 moles of pyridine. Yields of the products ranged from 70 to 90%, after purification by the method outlined below.

To work up the reaction it was poured into about six volumes of ice water with stirring for two hours and left overnight. If crystallization occurred at this stage, as it did with maltose octapropionate, the crystals were filtered off, washed with water, and dried. Good solvents for crystallization were 95% ethyl alcohol or *i*-propyl alcohol, pentane serving as a rinse liquid. If the propionate did not crystallize during treatment with water it was ether extracted and the extract was washed with four molar hydrochloric acid solution, dilute sodium carbonate solution, and water. The solution was dried with anhydrous sodium carbonate, the solvent removed, and the residual propionic ester purified further either by recrystallization or distillation at low pressures. The propionates of maltose, cellobiose, gentiobiose and xylose crystallized particularly easily. Those from arabinose, sucrose and trehalose crystallized easily if seeded with previously prepared crystals, otherwise considerable time was required for the onset of crystallization. In these cases also it was found that crystallization could be encouraged by dissolving the substance in *i*-propyl alcohol and cooling the solution to temperatures between −20 and −80°.

The propionates were distilled by the method outlined in the previous paper.[4] These conditions were used for the propionates listed in Table I (bath temperatures, pressure on McLeod gage): rhamnose 210°, 0.07 mm.; arabinose 200°, 0.001; fructose 160°, 0.001; mannose 230°, 0.02; galactose 210°, 0.008; sorbose 185°, 0.003; maltose 275°, 0.004; sucrose 270°, 0.03. Glucose pentapropionate, prepared similarly, distilled smoothly at 0.001 mm. and a bath temperature of 200°. The raffinose hendecapropionate was synthesized by R. W. Liggett, who found that it distilled smoothly with a clear yellow color from the molecular still, Fig. 2 of previous paper,[4] when the bath temperature was 250–275° and the pressure was between 10^{-4} and 10^{-5} mm. Distillation was possible also at 300° in the apparatus of Fig. 1.

Analyses.—The analysis of the propionic esters reported in Table I was by the method of Kunz and Hudson.[5] This method, which was developed for acetates, was found to apply satisfactorily for propionates. Best results were obtained when fairly large samples (about 0.6 g.) were taken. Essentially, the method involves dissolving the substance in 50 cc. of acetone at 0°, adding an excess of 0.1 *N* alkali and back-titrating after six hours with 0.1 *N* sulfuric acid. A slight blank correction was applied (usually about 0.1 cc. of the alkali).

Specific rotations, listed in Table I, were determined in a 1-dm. tube. For these measurements about 0.8 g. of the substance was dissolved in 10 cc. of chloroform, except with the rarer sugars when 0.3 g. was used.

Distillation of Maltose Octaacetate.—This material was prepared by the usual procedure with maltose hydrate, acetic anhydride, and pyridine at 0°. It melted at 154–156°.

The substance was found to be distillable but with much less ease than the corresponding propionate. The acetate started to distil when the bath temperature was 260° and the pressure about 0.0005 mm. The distillate was much more viscous than that from raffinose hendecapropionate and could not be induced to run into the pigs. This glassy material was dissolved in *i*-propyl alcohol, from which needle-shaped crystals, m. p. 155–156°, deposited on cooling.

(3) Hurd and Blunck, THIS JOURNAL, **60**, 2419 (1938).

(4) Hurd, Liggett and Gordon, *ibid.*, **63**, 2656 (1941).

(5) Kunz and Hudson, *ibid.*, **48**, 1982 (1926).

Maltose Octapropionate.—The synthesis with propionic anhydride and pyridine at 20° has been given. Two modifications of this reaction were carried out. One involved a higher temperature and the other used sodium propionate instead of pyridine.

A mixture of 0.5 g. of maltose hydrate, 10 cc. of propionic anhydride and 10 cc. of pyridine was heated at 100° for thirty minutes, then poured into water, ether extracted, and the extract washed with water. The yield of product, m. p. 130–136°, was 0.53 g. or 48%. After one crystallization from alcohol it melted at 140–142°.

Two and a half grams of maltose, 2.5 g. of sodium propionate, and 75 cc. of propionic anhydride were kept at 100° for thirty minutes. There was obtained 0.76 g. of the crystalline propionate, m. p. 140–141°, and 3.3 g. of an oil which resisted efforts at crystallization.

An oil was obtained also when 1.6 g. of the crystalline maltose octapropionate was heated with 25 cc. of propionic anhydride and 0.5 g. of fused zinc chloride, and then thrown into water. Repeated washings with water did not induce crystallization. This method was used by Hudson and Johnson[6] to effect the conversion of β-maltose octaacetate into the crystalline α-isomer.

Summary

Sixteen new propionates of sugars have been synthesized. Some of these are crystalline, and all are distillable when low-pressure methods are employed, even raffinose hendecapropionate. Conditions were found also for the distillation of maltose octaacetate at 0.0005 mm., but acetates of the sugars distil much less readily than the propionates. Maltose octapropionate is an exceptionally good crystalline derivative of maltose.

(6) Hudson and Johnson, THIS JOURNAL, **37**, 1276 (1915).

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Analytical Separation of Sugars by Distillation of their Propionates

BY CHARLES D. HURD AND R. W. LIGGETT[1]

The fact that propionates of sugars are easily prepared and distillable[2] suggested their possible usefulness in the analysis of sugar mixtures. The present work shows that analytical separation of mono-, di- and trisaccharides is possible and is relatively simple to carry out.

Another method recently developed[3] for this type of analysis, and in fact the only method otherwise recorded, involves an indirect methylation procedure requiring several steps, followed by vacuum distillation of the methylated product. The first step in the methylation procedure was acetylation.

Propionylation is the first and only step involved in the present procedure. Since this is strictly comparable with the acetylation of the previous procedure, it is evident that the present method is much simpler from the standpoint of steps involved. It possesses other advantages as well.

Both methods involve distillation at low pressures as the step wherein separation occurs, with subsequent weighing of the distilled fractions to obtain the analytical data. Large enough samples must be taken in both methods to absorb the error that would arise if the cut into fractions was not taken at precisely the right points. One must allow a drop or two leeway in taking the distillation cuts.

In the methylation procedure, 25 g. of the sugar mixture was taken for analysis, from which about 10–12 g. of methylated derivatives was obtained for the distillation step. In the present procedure, only 15–20 g. of mixture is taken for analysis with the consequent formation of about 35–40 g. of sugar propionates for distillation. Thrice the quantity of substance in this analytical step naturally makes for greater accuracy, other things being equal, and it is gratifying to note that the accuracy of this method does seem to be higher. No correction curve is used for the propionates, in contrast to the corrections which were necessary for the methylation procedure.

The methylation method fails with mixtures containing fructose. This limitation is not encountered in the analyses *via* propionates. The combined fructose–glucose portion is analyzed satisfactorily if a small correction factor is introduced to care for the slight decomposition of the fructose pentapropionate which occurs during its distillation.

The glucose and fructose fractions are not collected together but the fructose fraction is collected first. This separation is not clear cut be-

(1) Corn Products Research Fellow, 1939–1941.

(2) Hurd and Gordon, THIS JOURNAL, **63**, 2657 (1941).

(3) Hurd and Cantor, *ibid.*, **60**, 2677 (1938).