

of the decomposition being the yellow, crystalline compounds dehydro-rotenone and rotenonone.

3. Similar changes are undergone by dihydrorotenone and isorotenone in pyridine solution, analogous compounds no doubt being formed.

4. Dry, crystalline rotenone undergoes no change on long standing.

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## STUDIES ON LEVULINIC ACID. I. ITS PREPARATION FROM CARBOHYDRATES BY DIGESTION WITH HYDROCHLORIC ACID UNDER PRESSURE<sup>1</sup>

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Priority of discovery of the fact that dilute mineral acids acting upon hexoses or any carbohydrate yielding them on hydrolysis cause the formation, among other substances, of levulinic acid must be accorded to Mulder<sup>2</sup> in that the compound which he isolated from such a reaction mixture and described as glucinic acid was later found by Grote and Tollens<sup>3,4</sup> to be identical with the substance which they obtained from inulin under similar conditions.<sup>4</sup> It is to the latter investigators that the common name for this keto acid is due.

The traditional equation for the formation of this acid



by no means represents a complete picture. Subsidiary reactions take place to such an extent that the best yields<sup>5</sup> of levulinic acid which have been reported as a direct result of studied attempts so to guide the course of this reaction that a greater conversion of carbohydrate might be rapidly

<sup>1</sup> This paper, and others already published by R. W. Thomas on the general theme of the sugars as chemical raw materials [THIS JOURNAL, 52, 2028, 3010 (1930)], forms part of a thesis presented to the Graduate Faculty of the University of Wisconsin in partial fulfilment of the requirements for the degree of Doctor of Philosophy, June, 1931.

<sup>2</sup> Mulder, *J. prakt. Chem.*, 21, 219 (1840).

<sup>3</sup> Grote and Tollens, *Ber.*, 7, 1375 (1874).

<sup>4</sup> Mulder's discovery has been many times verified. Since his day the following carbohydrates have been made to yield this acid: starch [Grote and Tollens, *Ber.*, 7, 1379 (1874)]; dextrose, levulose [Grote, Kehrer and Tollens, *Ann.*, 206, 228 (1881)]; lactose [Rodewald and Tollens, *ibid.*, 206, 231 (1881)]; galactose [Kent and Tollens, *ibid.*, 227, 228 (1885)]; raffinose [Rischbiet and Tollens, *ibid.*, 232, 193 (1886)]; sorbose [Wehmer and Tollens, *ibid.*, 243, 320 (1888)]; Smith and Tollens, *Ber.*, 33, 1286 (1900); and mannose [Fischer and Hirschberger, *ibid.*, 22, 370 (1889)].

<sup>5</sup> (a) McKenzie, "Organic Syntheses," John Wiley and Sons, Inc., New York, 1929, Vol. IX, p. 50; (b) Sah and Ma, THIS JOURNAL, 52, 4880 (1930).

and conveniently brought about are approximately 23% of the theoretical when sugars serve as raw material, starch yielding lesser amounts. Berthelot and André,<sup>6</sup> in studying the decomposition of dextrose by phosphoric acid, and Ost and Brodtkorb,<sup>7</sup> in following the action of dilute sulfuric acid upon this sugar at temperatures up to 145°, in a sense pointed out a way for the development of an improved procedure for the preparation of levulinic acid. This fact has apparently been overlooked until now although it is true that the statement<sup>5b</sup> has been recently made, without supporting data, that the action will proceed rapidly if the temperature of the solution be raised to 110°.

The best current practice for preparing levulinic acid consists in digesting sucrose or dextrose with dilute hydrochloric acid (1 + 4)<sup>5a</sup> or (1 + 1)<sup>5b</sup> for ten to forty-eight hours on a boiling water-bath, filtering off the humus material, either fractionating the filtrate<sup>5a,b</sup> or concentrating it and finally extracting the acid with a suitable solvent. An alternative procedure<sup>5a</sup> is to evaporate the reaction mixture to dryness before extracting the acid. These methods, however, are uneconomical in that they are time-consuming and productive of even at best but comparatively low yields, and for this reason were not well suited for the preparation of levulinic acid in the quantity needed for carrying out an investigation under way<sup>8</sup> in this Laboratory on sucrose as a chemical raw material. The hope that a study of the effect of altering the acid concentration and time and temperature of digestion might lead to improvements in the technique of preparing this acid, to the end that the process would be shortened and the yields increased, was realized in so far as the latter have been increased by approximately 100% over those obtainable by heretofore existing methods. How these objectives have been reached is herein communicated.

### Experimental

**Materials.**—Commercially pure (99.85%) sucrose, levulose (moisture, 3.1%,  $[\alpha]_D^{25} - 79.0^\circ$ ), dextrose (moisture, 6.9%,  $[\alpha]_D^{25} + 49.5^\circ$ ), and ordinary domestic corn starch were used in this study.

**Procedure.**—The carbohydrate in question was treated with dilute hydrochloric acid in a two-liter beaker, the whole transferred to a four-liter copper autoclave containing water and digested for varying periods of time and at various temperatures as indicated in the accompanying tables. The reaction mixture<sup>9</sup> was then evaporated to dry-

<sup>6</sup> Berthelot and André [*Compt. rend.*, **123**, 567 (1896)] heated dextrose and phosphoric acid in sealed tubes kept at 100° for 168 and 648 hours, respectively. On measuring quantitatively the products of reaction they found 37.10% of levulinic acid in the first case and 39.88% in the second.

<sup>7</sup> Ost and Brodtkorb, *Chem.-Ztg.*, **35**, 1126 (1911).

<sup>8</sup> Schuette and co-workers, *THIS JOURNAL*, **48**, 3163 (1926); **52**, 2028, 3010 (1930).

<sup>9</sup> It was found that ether removed practically nothing from the humus material formed in the reaction and, since its presence gave to the dried residue a porous character which proved an aid to extraction, it was not filtered off.

ness on a steam-bath and the levulinic acid extracted from it with diethyl ether. The latter operation required approximately forty-eight hours when carried out in a continuous extractor. After recovery of the ether the residual oily liquid was distilled, the fraction boiling at 120–130° (4.5 mm.), collected and redistilled. The final product boiled at 106–108° (2 mm.),  $n^{40}$  1.4342, average deviation for all runs being +0.0004. This latter value, which is new, was obtained on a product twice recrystallized and one which did not turn yellow after liquefaction and standing in the light for several years. It was used as a criterion of purity for each batch of levulinic acid made.

All yields recorded herein represent the mean of duplicate runs. They were found to be easily reproducible within two to three per cent.

### Results and Discussion

Table I shows the effect of the temperature of digestion on the amount of sucrose converted to levulinic acid. The advantage of carrying out this reaction at high temperatures is clearly shown, the yields steadily increasing to 162°, which was the maximum obtainable with the apparatus available for this study. If per cent. yield is plotted against temperature, a curve is obtained which, although rising, begins to flatten out at the higher temperatures, thus indicating that above 162° there would result a relatively smaller increase in yield per degree rise in temperature.

TABLE I  
EFFECT OF TEMPERATURE OF DIGESTION ON CONVERSION OF SUCROSE TO LEVULINIC ACID

Sucrose, g.	HCl, (1 + 5) cc.	Digestion data			Levulinic acid	
		Time, hrs.	Temp., °C.	Pressure, atm.	Yield g.	%
250	600	1	120	2.0	30.5	10.2
250	600	1	130	3.6	53.6	31.5
250	600	1	145	4.3	58.2	34.3
250	600	1	162	7.0	72.5	42.7

In Table II are set down the data pertinent to the effect that time of digestion was found to exert upon the amounts of sucrose, dextrose, levulose and starch converted to levulinic acid. It appears that equilibrium is practically reached in one hour at a temperature of 162°, longer periods of digestion producing no appreciably larger yields. The same holds true at a temperature of 145°.

Continuing the digestion of levulose, dextrose or starch with hydrochloric acid for periods longer than one hour actually resulted in decreased yields of levulinic acid, the effect decreasing in the order named. These results were not entirely unexpected, however, because of the sensitiveness of the hexose sugars to heat and continued action of the mineral acid.

That the yields of levulinic acid depend to some extent upon the concentration of the hydrochloric acid used is shown in Table III, in which the data as recorded were obtained by using always the same volume of acid solution (600 cc.), its strength being so adjusted as to give the value indicated in the second column. Hydrochloric acid diluted in the proportion

TABLE II  
EFFECT OF TIME OF DIGESTION ON CONVERSION OF SUCROSE, DEXTROSE, LEVULOSE AND STARCH TO LEVULINIC ACID

Carbo- hydrate, g.	HCl (1 + 5), cc.	Digestion data			Levulinic acid	
		Time, hrs.	Temp., °C.	Pressure, atm.	g.	Yield %
Sucrose						
250	600	1	162	7.0	72.5	42.7
250	600	2	162	7.0	73.6	43.4
250	600	5	162	7.0	72.7	42.9
250	600	1	145	4.3	58.2	34.3
250	600	2	145	4.3	61.5	36.2
250	600	5	145	4.3	55.0	32.4
Dextrose						
250	600	1	162	7.0	61.0	37.8
250	600	2	162	7.0	53.0	32.9
Levulose						
200	480	1	162	7.0	50.2	39.0
200	480	2	162	7.0	37.5	29.1
Starch						
250	600	1	162	7.0	65.4	36.5
250	600	2	162	7.0	60.2	33.6

of one volume to five of water (6.5%) is of ample strength, a greater concentration being not only unnecessary but undesirable in that it was found to complicate the purification of the final product.

TABLE III  
EFFECT OF CONCENTRATION OF HYDROCHLORIC ACID UPON CONVERSION OF SUCROSE TO LEVULINIC ACID

Sucrose, g.	Concentration of HCl, %	Digestion data			Levulinic acid	
		Time, hrs.	Temp., °C.	Pressure, atm.	g.	Yield %
250	3.5	1	162	7.0	59.0	34.8
250	6.5	1	162	7.0	72.0	42.4
250	10.7	1	162	7.0	70.0	41.3
250	4.2	1	145	4.3	62.0	36.5
250	6.5	1	145	4.3	60.0	35.4
250	10.7	1	145	4.3	63.0	37.1

Not much further need be said about these data except that they clearly show that a readjustment of the experimental conditions heretofore recommended is desirable not only because, by the use of high temperatures, economies as to time and materials are effected but also that the course of the fundamental reaction involved in the preparation of levulinic acid from hexoses is hereby directed away from its empirical feature to a closer approach to stoichiometrical conditions. The large increase in yields of acid so obtained points to these conclusions.

In the light of the information gained by this study the following pro-

cedure appears to warrant recommendation as a modified practical method for preparing levulinic acid.

Dissolve sucrose in dilute hydrochloric acid solution (1 + 5) in the proportion of 250 g. (0.73 mole) to 600 cc. of acid. Heat the mixture, contained in a beaker, for one hour in an autoclave after the temperature has reached 162°. If the beaker be surrounded by water, which is a very necessary condition here, the total pressure will rise to approximately seven atmospheres at this temperature. Break up the cake of humus material which has formed in the reaction mixture and transfer the whole to an evaporating dish, taking it to dryness on a steam-bath. Extract the dry residue with diethyl ether until the levulinic acid is completely removed. Drive off the ether by distillation at atmospheric pressure and then fractionally distil the residual oily liquid *in vacuo*, collecting for redistillation (106–108°, 2 mm.) that fraction boiling at 120–130° (4.5 mm.); yield, 42%.

Equally satisfactory yields may be obtained by filtering the reaction mixture, washing the humus material well with water and fractionally distilling the combined filtrates. While this latter procedure materially shortens the process, it has a disadvantage in that a tarry residue is left in the distillation flask which is very difficult to remove. Proceeding according to this modification, levulinic acid may be prepared in yields exceeding 40% in a period of five to six hours.

If a product of high degree of purity is desired, the acid may be crystallized in an ice-bath. To that end stir the liquefied acid to induce the formation of small crystals, remove them from the mother liquor by centrifugal force, and wash the crystalline mass several times with small portions of cold diethyl ether, which is in turn removed by centrifuging. Remove the last trace of ether by evaporation at room temperature and reclaim the acid in the washings by distillation. A product prepared in this way ( $n^{40}_D$ , 1.4342) may be kept in the liquid state without the appearance of the slightly yellow tint that is characteristic of the fractionally distilled acid.

### Summary

As the result of a study of the action of dilute hydrochloric acid on certain carbohydrates, during the course of which the three variables concentration of acid, time and temperature of digestion were altered, there has been developed a modification of existing procedures for preparing levulinic acid to the end that a larger conversion of carbohydrate to this acid is now possible than by heretofore existing methods. The recommended procedure is to digest sucrose under pressure for one hour with dilute hydrochloric acid at 162° in the presence of water vapor. Details of a method leading to the preparation of a very pure product are given.