conditions and deposited on the cool walls of the outlet tube which was later cut off and weighed. Any unreacted water was condensed along with the generated hydrogen halide in a trap of the fractionating line at liquid nitrogen temperatures and, after separation from the hydrogen halide at Dry Ice temperature, was weighed. *n*-Butane was then added to the reaction tube and the run was made in the usual manner.[1]

In those experiments in which *n*-butane was isomerized in the presence of aluminum halide and water, all the reagents were added and the vessel was then slowly warmed to reaction temperature without the intermediate step of reacting the aluminum halide and water and pumping off the generated hydrogen halide.

The apparatus and procedure used in preparing deuteroxy-aluminum bromide and in determining the deuterium content of the water of combustion of the product in the deuterium transfer experiments will be described in a subsequent paper.[3]

Summary

The effect of water upon aluminum bromide and aluminum chloride, employing high-vacuum technique, has been studied.

The amount of hydrogen halide produced by the action of water upon aluminum halide depends upon the molal ratio of water to aluminum halide used.

The isomerization of *n*-butane in the presence of catalysts, produced by the action of water on aluminum halide and freed of non-combined hydrogen halide, has been studied.

The isomerization of *n*-butane in the presence of aluminum bromide or aluminum chloride and water has been investigated.

A mechanism of isomerization of alkanes using a catalyst produced by the action of water on aluminum halide is suggested.

CHICAGO, ILLINOIS RECEIVED FEBRUARY 7, 1946

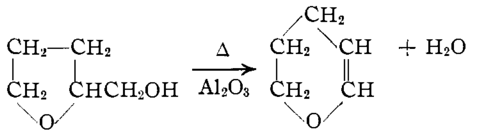
[CONTRIBUTION FROM THE NORTHERN REGIONAL RESEARCH LABORATORY[1]]

Preparation of Dihydropyran, δ-Hydroxyvaleraldehyde and 1,5-Pentanediol from Tetrahydrofurfuryl Alcohol

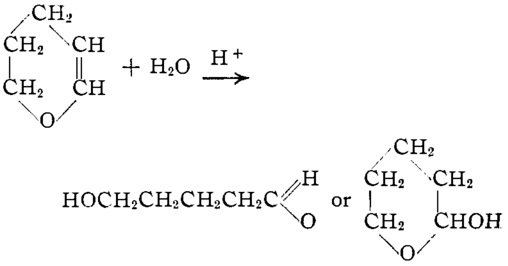
BY L. E. SCHNIEPP AND H. H. GELLER

Furfural and its hydrogenation derivatives present many interesting possibilities as starting materials for the preparation of four-, five-, six- and seven-carbon difunctional compounds. Investigations of these possibilities have resulted in the development of an improved method for the synthesis of 1,5-pentanediol. This method, previously investigated by Paul,[2,3] consists in catalytically converting tetrahydrofurfuryl alcohol to dihydropyran, hydrolysis of the latter to δ-hydroxyvaleraldehyde, and hydrogenation of the aldehyde to the diol. This procedure has an advantage over the hydrogenolysis method of Connor and Adkins,[4] which produces a mixture of the 1,2- and 1,5-pentanediols, in that the 1,5-diol is the sole product.

Substantial improvements in the yields of dihydropyran and δ-hydroxyvaleraldehyde over those previously reported[3,5,6] have been accomplished by thorough investigation of the reaction conditions. The catalytic conversion of tetrahydrofurfuryl alcohol over activated alumina has been increased from 65 to 70%[3,4] up to 85 to 90% and the hydrolysis of dihydropyran to δ-hydroxyvaleraldehyde from 38[3] to 78%. The hydrogenation of δ-hydroxyvaleraldehyde to 1,5-pentanediol proceeds almost quantitatively over copper chromite. By a combination of the best conditions for this three-step process, a 70% yield of 1,5-pentanediol from tetrahydrofurfuryl alcohol has been obtained. These reaction may be illustrated by the equations



(1)



(2)

$$HOCH_2CH_2CH_2CH_2CHO \xrightarrow[CuCr_2O_4]{H_2} HOCH_2CH_2CH_2CH_2CH_2OH \quad (3)$$

A study of the catalytic conversion of tetrahydrofurfuryl alcohol to dihydropyran showed that the main factor in limiting yields and production rates was the highly exothermic reaction which occurred when the alcohol vapors came in contact with the alumina catalyst at temperatures above 300°. The extent of this heat rise was dependent upon the size of the catalyst bed and the feed rate. For example, a feed rate of 5 g./min. to a tube containing 500 cc. of catalyst heated to

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(1) One of the laboratories of the Bureau of Agricultural and Industrial Chemistry, Agricultural Research Administration, U. S. Department of Agriculture. Article not copyrighted.

(2) R. Paul, *Bull. soc. chim.*, [4] **53**, 1489–1495 (1933).

(3) R. Paul, *ibid.*, [5] **1**, 971–980 (1934).

(4) Connor and Adkins, THIS JOURNAL, **53**, 1091 (1931).

(5) C. H. Kline and J. Turkevich, *ibid.*, **67**, 498 (1945).

(6) R. L. Sawyer and D. W. Andrus, "Organic Syntheses," **23**, 25 (1943).

350° caused the temperature to rise to 525°. Under these conditions carbonization and inactivation of the catalyst resulted. It was found that this exothermic reaction occurred when fresh activated alumina came in contact with dihydropyran vapors and that treatment of a catalyst with dihydropyran under controlled conditions produced a stabilized catalyst which gave high yields, high production rates, and was active over a long period of time when used for the dehydration of tetrahydrofurfuryl alcohol.

Catalyst conditioning was accomplished by two different procedures. The better of these methods consisted in passing dihydropyran vapors over the alumina catalyst, which had been heated to 100–125°, at such a rate that the catalyst temperature did not exceed 180°. The second method consisted in passing tetrahydrofurfuryl alcohol vapors through the alumina catalyst at temperatures of 200–225°. In this temperature range dihydropyran was formed in amounts so small that a temperature rise was barely perceptible. This second method produced an equally satisfactory catalyst but required considerably more time than the dihydropyran method. In both cases ivory-gray catalysts free of carbonaceous deposits were produced. Four grades of commercial activated alumina behaved similarly under these conditions and all yielded stable catalysts capable of producing dihydropyran in 85 to 90% yields at rates up to 3 g./min. per 100 cc. of catalyst.

The hydrolysis of dihyropyran to δ-hydroxyvaleraldehyde was accomplished by refluxing with four volumes of 0.02 *N* hydrochloric acid for one hour, followed by neutralization of the acid and distillation of the reaction mixture. Prolonged heating of the reaction mixture or failure to carefully neutralize the acid prior to distillation resulted in poorer yields due to polymerization. Spectrographic analysis of the distilled reaction product showed that this aldehyde exists chiefly in the form of its cyclic hemi-acetal, 2-hydroxytetrahydropyran.

The hydrogenation of δ-hydroxyvaleraldehyde over copper chromite catalysts proceeded smoothly in alcohol solution to give an excellent yield of easily isolated 1,5-pentanediol.

Experimental

Dehydration Apparatus.—The catalyst chamber consisted of a 2-inch Pyrex glass tube 40 inches long. This tube was mounted vertically in a 36-inch electrically-heated furnace. The tube was packed with a 3-inch layer of porcelain Raschig rings at the bottom, then the catalyst, followed by porcelain rings to within 12 inches of the top. This top layer of rings served as a vaporizing and preheating section. Catalysts varying in volume from 100 to 1000 cc. were used in this investigation. Temperatures were taken by means of a thermocouple inserted into a glass thermocouple-well extending down the center of the catalyst tube. This thermocouple was connected to an indicating potentiometer which controlled the heat input to the furnace.

A liquid feed-line was attached to the top of the catalyst tube and the feed rate controlled by adjustments of a bellows-type, constant-feed pump. The bottom of the catalyst tube was connected to a condenser and receiver system which was vented through a wet-test meter for measurement of the volume of non-condensable gases.

Catalysts.—Several grades of activated alumina were evaluated with regard to activity. Only slight differences were noted and all gave 85 to 90% yields of dihydropyran under optimum operating conditions. Alorco Grade F-1, 8–14 mesh, was used in most of the work reported here. This catalyst gave best results at 375°, whereas optimum yields were obtained at slightly lower temperatures with some of the other catalysts.

Catalyst Conditioning.—The catalyst tube was charged with 200 cc. of Alorco Grade F-1, 8–14 mesh, activated alumina and the catalyst bed heated to 100°. Dihydropyran was fed into the top of the tube at a uniform rate of 2 g. per minute. When the dihydropyran vapors reached the catalyst, the temperature at the top of the bed rose rapidly to 180°. As the feed continued this zone of temperature rise gradually worked down through the bed and was followed by keeping the thermocouple at the point of highest temperature. After about fifteen minutes this hot zone had progressed completely through the catalyst, and the catalyst temperature began to fall. Approximately 5 g. of the dihydropyran was lost by consumption and holdup in this operation. After treatment the catalyst had changed from the original white to a grayish-ivory color. The conditioned catalyst was heated to 375° and the feed of tetrahydrofurfuryl alcohol started. No further heat rise occurred.

The same grade of activated alumina was also conditioned by heating to 200–225° and passing in tetrahydrofurfuryl alcohol at a rate of 2 g. per minute. A slight heat rise occurred on contact of the vapors with the catalyst. Conditioning of the entire catalyst required eighty minutes after which the catalyst temperature was raised to 375° and the tetrahydrofurfuryl alcohol feed increased to the desired operating rate. No further exothermic reaction on the catalyst occurred.

Dihydropyran.—The catalyst tube containing the dihydropyran-conditioned catalyst was heated to 375° and tetrahydrofurfuryl alcohol pumped from a graduate into the top of the tube at various rates to determine the optimum feed-rate conditions. The vapors from the bottom of the tube were condensed in a water-cooled condenser and collected in a receiving flask. The volume of non-condensable gases was measured by a wet-test meter connected to the condensate receiver. When the system was operating in equilibrium, *i. e.*, liquid condensate was being collected at approximately the same rate at which the alcohol was being fed, the receiver was changed and the feed-graduate reading was recorded. Conditions were then held constant for a sufficiently long period to give reliable data and then the receiver was again changed and the graduate reading again recorded. Yield and recovery data were thus obtained for the period between readings. Operating in this manner 406.0 g. (3.98 moles) of tetrahydrofurfuryl alcohol was fed to a catalyst tube containing 200 cc. of conditioned activated alumina at a rate of 5 g. per minute. At the conclusion of the run, which required eighty-one minutes, the liquid condensate weighed 401.5 g. This material consisted of two layers; the upper light-brown water-insoluble layer weighed 328.5 g. and the lower aqueous layer weighed 73.0 g. The upper layer was separated and distilled through a glass-helices packed column equipped with a variable reflux distilling head. The first portions of the distillate separated into two layers on condensation and the water layer was removed while the non-aqueous layer was returned to the column as reflux. In this manner practically all of the dissolved water was removed from the still charge. The distillate temperature rose from 70 to 83° during this period. A small fraction of material boiling at 83–85° was then collected. The main fraction boiling at 85–86° was very high purity dihydropyran. From the 328.5 g. of crude product the following fractions were obtained: water, 2 g.; dihydropyran containing 0.3% water, 6.1 g.; pure dihydropyran, 291 g. (3.46 moles); residue, 29 g. The yield of dry, distilled dihydropyran,

b. r. 85–86°, was 87% of the theoretical. Total yield including that containing traces of water was 88.7%.

The distillation residues consisted of a mixture of high-boiling by-products. Very little unreacted tetrahydrofurfuryl alcohol could be isolated. Small amounts of δ-hydroxyvaleraldehyde were present and the remaining components probably were reaction products of dihydropyran with 2-hydroxytetrahydropyran and with tetrahydrofurfuryl alcohol. Since these materials decompose on heating above 100°,[3] it was not possible to isolate them in pure form.

Various temperature and feed-rate conditions were investigated to establish the limitations and optimum conditions for this procedure. Although the dehydration of tetrahydrofurfuryl alcohol over activated alumina takes place to some extent at temperatures as low as 200°, the best yields and conversion efficiencies are obtained in the range of 350 to 375° at feed rates of 2.0–3.0 g. per minute per 100 cc. of catalyst. Feed rates above 3 g. per minute or temperatures of 400° or over gave lower yields. For example, yields of 88–90% of the theoretical were consistently obtained at 2.0–2.5 g. per minute at both 350 and 375° whereas 3.1 g. per minute gave 86% yields in both cases. The maximum yield at 400° was 85.3%.

Catalyst life under optimum operating conditions was found to be excellent. In at least one instance 60 moles of tetrahydrofurfuryl alcohol was dehydrated over a 100 cc. volume of catalyst before any noticeable decrease in activity occurred.

δ-Hydroxyvaleraldehyde.—Dihydropyran, 100 g. (1.19 moles), and 400 cc. of 0.2 N hydrochloric acid were mixed and heated to boiling. After refluxing for forty minutes the water-insoluble layer disappeared. Refluxing was continued for another twenty minutes after which the acid was neutralized by addition of 0.4 N sodium hydroxide to a faint phenolphthalein alkalinity. The reaction mixture was then distilled under reduced pressure. Eighty grams of δ-hydroxyvaleraldehyde, b. r. 54–55° (3 mm.); n^{25}_{D} 1.4514, d^{25}_{4} 1.0537, was obtained.

The water distillate contained an additional 15 g. increasing the total yield to 95 g. or 78.2%. Since this portion of the product was difficult to isolate, the aqueous distillates were usually used for subsequent hydrolyses in which cases the 95-g. yields were obtained directly on distillation. Absorption spectrum analysis ($E^{1\%}_{1\,\text{cm.}}$ 2900 Å. = 0.059) showed this material to exist as 95% 2-hydroxytetrahydropyran and 5% as δ-hydroxyvaleraldehyde. The product was completely miscible with water and the same equilibrium mixture was found to exist in the aqueous solutions.

1,5-Pentanediol.—δ-Hydroxyvaleraldehyde, 102 g. (1 mole), was dissolved in 400 cc. of ethyl alcohol and the solution mixed with 5 g. of copper chromite in a hydrogenation bomb. The hydrogenation was conducted at 150° under 2000 pounds per square inch pressure and was complete in ten to fifteen minutes. The catalyst was removed by centrifugation and the alcoholic solution of the product fractionated under reduced pressure. A yield of 100 g., 96.2% of the theoretical was obtained; b. r. 118–119 (3 mm.); n^{26}_{D} 1.4480; d^{26}_{4} 0.989. No by-products were formed in this operation. The over-all yield of 1,5-pentanediol from tetrahydrofurfuryl alcohol was 70%.

Attempts were also made to prepare 1,5-pentanediol without the intermediate isolation of the hydroxyvaleraldehyde. Dihydropyran, 100 g., was hydrolyzed with 0.02 N hydrochloric acid as described above and the neutralized reaction mixture was charged into the hydrogenation bomb with 10 g. of copper chromite. The hydrogenation was conducted at 200° under 2000 pounds per square inch pressure. The reaction mixture was centrifuged to remove the catalyst and the aqueous mixture distilled. Yields of 75 to 77 g., 60–62% of the theoretical, were obtained.

Summary

A three-step method for the conversion of tetrahydrofurfuryl alcohol to 1,5-pentanediol in 70% yield is described.

1. Dihydropyran was prepared in 85 to 90% yield by catalytic dehydration of tetrahydrofurfuryl alcohol over a preconditioned alumina catalyst.

2. Hydrolysis of dihydropyran to δ-hydroxyvaleraldehyde was accomplished in 78% yield.

3. Catalytic hydrogenation of δ-hydroxyvaleraldehyde to 1,5-pentanediol was practically quantitative.

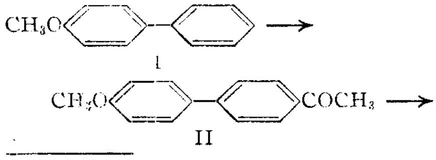
PEORIA, ILLINOIS RECEIVED MARCH 29, 1946

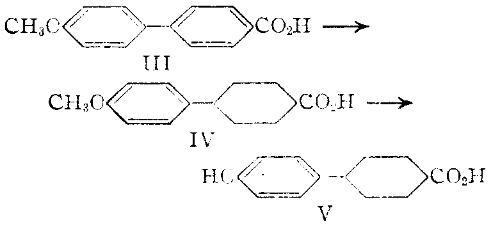
[CONTRIBUTION FROM THE LABORATORY OF ORGANIC CHEMISTRY OF THE UNIVERSITY OF WISCONSIN]

4-(*p*-Hydroxyphenyl)-cyclohexanecarboxylic Acid and Derivatives

BY WILLIAM S. JOHNSON, C. DAVID GUTSCHE AND ROBERT D. OFFENHAUER[1]

In a previous communication[2] we described a synthesis of 4-(*p*-hydroxyphenyl)-cyclohexanecarboxylic acid, V, and the preparation of several derivatives which may be considered structural models of estrone. In the present paper an improved synthesis of V is described, together with the preparation of four dialkylaminoalkyl esters (VI through IX) which are interesting as possible spasmolytic substances.





The new synthesis of V is outlined in the accompanying flow sheet. 4-(*p*-Methoxyphenyl)-acetophenone, II, was prepared in 62% yield *via* the Friedel–Crafts acetylation of *p*-methoxybiphenyl, I, according to the method of Fieser and Bradsher,[3] Oxidation of II with sodium hypobromite gave 4-(*p*-methoxyphenyl)-benzoic acid, III in 91% yield. Successful selective reduction of

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[1] Present address: Allied Chemical and Dye Corporation, Central Research Laboratory, Morristown, N. J.

[2] Johnson and Offenhauer, THIS JOURNAL, **67**, 1045 (1945).

[3] Fieser and Bradsher, *ibid.*, **58**, 1738 (1936).