allyl ether of 2-methyl-2-hydroxymethyl-1,3-butanediol.

3. Diethyl ketone has been shown by the same procedure to condense with excess formaldehyde to yield tetrahydro-3,5-*bis*-(hydroxymethyl)-3,5-dimethyl-4-pyranol.

4. The condensation of acetone and excess formaldehyde was found by the allylation technique to yield chiefly tetrahydro-3,3,5,5-*tetrakis*-(hydroxymethyl)-4-pyranol. As with methyl ethyl ketone a small amount of a lower condensation product was isolated as an allyl ether which is possibly the triallyl ether of 2-hydroxymethyl-1,3-butanediol.

5. Evidence has been obtained for the formation of intercondensation products in these condensations. This tendency is greatest with acetone, considerably less with methyl ethyl ketone, and comparatively negligible with diethyl ketone.

MINNEAPOLIS, MINNESOTA   RECEIVED MAY 2, 1947

[CONTRIBUTION FROM THE CHEMICAL LABORATORY, GENERAL MILLS, INC.]

Polyglycerols. I. The Identification of Polyglycerol Mixtures by the Procedures of Allylation and Acetonation: Isolation of Pure Diglycerol[1]

BY HAROLD WITTCOFF, J. ROBERT ROACH AND SIDNEY E. MILLER

Polyglycerol mixtures are separated into their components by direct distillation only with difficulty. The allylation procedure for the separation and identification of two or more polyhydric alcohols described in a previous publication[1a] has now been applied to polyglycerol mixtures with the result that it has been possible to isolate the pure allyl ethers of the components contained therein.

The physical constants of the allyl ethers resulting from fractionation of the allylated product provide a means of identifying the components of the original polyglycerol mixtures. Likewise, the procedure serves as a semi-quantitative means for analysis. Thus from a polyglycerol mixture with a hydroxyl content of 39.1% there was obtained, after allylation and distillation, the triallyl ether of glycerol, the tetraallyl ether of diglycerol,[2] and the pentaallyl ether of triglycerol,[2] together with a small amount of undistillable residue.

As a means of obtaining pure glycerol, diglycerol, and triglycerol from a polyglycerol mixture the allyl ethers offer a disadvantage in that they are hydrolyzed to the parent compounds only with difficulty. Likewise, the higher allyl ethers are characterized by high boiling points. Although the separation has been achieved *via* the acetates, these likewise have high boiling points.[3] It was decided to prepare acetals of these mixtures, such as isopropylidene derivatives, in order to determine whether they could be separated by distillation. From pure derivatives obtained by such a procedure, the parent compounds could be regenerated easily. It was found that isopropylideneglycerol and diisopropylidenediglycerol could be removed readily by fractional distillation from an acetonated polyglycerol mixture. The residue consisted of isopropylidenediglycerol, the isopropylidene derivatives of triglycerol and a small amount of similar derivatives of higher polyglycerols. Accordingly, this residue was again subjected to acetonation after which more diisopropylidenediglycerol could be recovered by distillation. The higher boiling fraction from this second distillation consisted chiefly of diisopropylidenetriglycerol together with a small amount of the isopropylidene derivatives of higher polyglycerols. It was impossible to purify this fraction by distillation through a 16-inch Vigreux column.

Thus the acetonation procedure serves not only as a roughly quantitative estimation of the amounts of mono-, di- and higher polyglycerols of a polyglycerol mixture, but also provides a means of obtaining pure diisopropylidenediglycerol which on hydrolysis readily yields pure diglycerol. That the diglycerol was of linear structure and was not a branched molecule was shown by periodate oxidation in which exactly two moles of the reagent were required per mole of diglycerol.

Polyglycerols have been prepared previously by thermal condensation of glycerol[4] catalyzed by alkali. This method has been improved by employing azeotropic removal of the water of reaction, thus permitting an accurate estimation of the extent to which the condensation has proceeded. Still another method for preparing polyglycerols has been investigated, namely, the inter-

(1) Paper No. 76, Journal Series, Research Laboratories, General Mills, Inc. Presented at the 111th meeting of the American Chemical Society, Atlantic City, N. J., April 14-18, 1947.

(1a) J. Robert Roach, Harold Wittcoff and Sidney E. Miller, THIS JOURNAL, **69**, 2651 (1947).

(2) Although the terms diglycerol and triglycerol are unsystematic they are descriptive and will be used for the sake of convenience. The diglycerol referred to here is properly termed 4-oxa-1,2,6,7-heptatetrol or 2,3-dihydroxypropyl ether, while the triglycerol is 4,8-dioxa-1,2,6,10,11-hendecapentol or glycerol 1,3-*bis*-(2,3-dihydroxypropyl)-ether. The isopropylidenediglycerol referred to later is of course the mono-substituted diglycerol. We are indebted to Professor C. D. Hurd of Northwestern University for suggesting this nomenclature.

(3) H. J. Wright and R. N. DuPuis, THIS JOURNAL, **68**, 446 (1946).

(4) (a) P. I. Dmitriev and C. A. Dogadkina, *J. Applied Chem.* (U. S. S. R.), **14**, 110 (1941); C. A., **35**, 8146 (1941); (b) W. C. Calvert, British Patent 359,823; C. A., **27**, 312 (1933); (c) Henkel and Cie., G. m. b. H., British Patent 264,800; C. A., **22**, 244 (1928).

action of glycerol and glycerol α-mono-chloro-hydrin in the presence of concentrated alkali. This method gives products comparatively light in color and free from such compounds as acrolein which are present in samples prepared by thermal condensation.

Experimental

Preparation of Polyglycerol Mixture A.—Glycerol (92 g., 1 mole) was mixed with 50% aqueous sodium hydroxide (176 g., 2.2 moles), and after heating to 90° glycerol α-monochlorohydrin (222 g., 2 moles) was added dropwise over a period of eighty minutes with vigorous stirring. After five hours more of stirring and heating at 90° the mixture was diluted with ethanol, neutralized with concentrated hydrochloric acid, and filtered. The solvent was evaporated from the filtrate and the residue of salt and product which remained was again treated with absolute ethanol. This solution was filtered and the solvent evaporated from the filtrate. The extraction process was repeated once more, and then the product was heated under vacuum for several hours in order to remove the last traces of solvent. There resulted 215 g. (89% yield) of a reddish sirup with a hydroxyl content of 39.1%.[5]

Allylation of Polyglycerol Mixture A.—The above condensation product (200 g., 4.6 equivalents of hydroxyl ion), was treated with 50% sodium hydroxide solution (756 g., 9.45 moles) in small portions and with sufficient external cooling so that the temperature did not exceed 50°. This mixture was stirred and heated to 70–80°, and allyl bromide (1110 g., 9.17 moles) was added during a period of five hours. After five hours more the mixture was cooled and the upper organic layer was separated. The aqueous layer which had been treated with sufficient water to dissolve the sodium bromide was extracted with ether. This extract, combined with the organic layer, was washed with water and dried over sodium sulfate. The solvent was removed and the residue, which was distilled under reduced pressure (1–2 mm.) in an atmosphere of carbon dioxide, yielded a distillate (250 g., 74% yield on the basis of 75% allylation of the hydroxyl groups) boiling over a range of 45–190° (2 mm.), and a gelled residue (40 g., 12% yield). This residue undoubtedly consisted of a mixture of undistillable allyl ethers of higher polyglycerols as well as polymerized allyl ethers. The distillate had an iodine number of 281.5.

To complete the allylation, sodium (23 g., 1 mole) was added slowly (one and one-half hours) at 105–109° in small portions to the above material (225 g.) which was stirred vigorously. The reaction was continued at 105° for an additional four hours. The deep blue reaction mixture was cooled to 85° and allyl bromide (145 g., 1.2 moles) was added with stirring over a period of thirty minutes. Stirring and heating at 85° were continued for two hours whereupon the reaction mixture was cooled and the excess sodium destroyed with ethanol. The product (237 g., 69% yield) was obtained by the usual procedure of ether extraction.

Fractionation of Allylated Mixture and Analysis of Fractions.—A portion of the above product (225 g.) was fractionated through a 16-inch heated Vigreux column. There resulted 195 g. of distillate, collected in numerous fractions over a range of 68–187° (2 mm.), and 15 g. of non-distillable residue which polymerized violently at the end of the distillation.

When the refractive index of numerous fractions was plotted against the weight of the distillate, it was apparent that three distinct fractions were present. From the distillation data presented below the ratio of the allyl ethers of glycerol to diglycerol to triglycerol was 41.6:42.7:15.7. Numerous cuts of the first fraction (81 g.), which was O-triallylglycerol,[6] showed a constant n^{25}D of 1.4483, and a

d^{25} of 0.9269. It distilled at 68–70° (2 mm.) (mol. ref., 61.15; calcd. 61.34). The second fraction (83.3 g.) distilled at 140–144° (2 mm.) and consisted of O-tetraallyl-diglycerol and showed a constant n^{25}D of 1.4603 and a d^{25} of 0.9709.

Anal.[7] Calcd. for $C_{18}H_{30}O_5$: C, 66.23; H, 9.26; iodine number, 311.0; mol. wt., 326.42; mol. ref., 91.67. Found: C, 66.72; H, 8.56; iodine number, 308.5, 308.4; mol. wt., 331.8; mol. ref., 92.12.

The third fraction (30.7 g.) distilled at 182–187° (2 mm.) and consisted of O-pentaallyltriglycerol. It showed a constant n^{25}D of 1.4660 and a d^{25} of 0.9926.

Anal.[7] Calcd. for $C_{24}H_{40}O_7$: C, 65.42; H, 9.15; iodine number, 288.8; mol. wt., 440.56; mol. ref., 122.20. Found: C, 65.62; H, 9.45; iodine number, 284.9, 284.8; mol. wt., 428.2; mol. ref., 122.90.

Preparation of Polyglycerol Mixture B.—A mixture of glycerol (95%, 484.2 g., 5 moles), xylene (100 cc.) and sodium hydroxide (2.5 g. in 3 cc. of water) was heated and stirred in an apparatus equipped with an 18-inch helices-packed silvered column connected to a water trap of the Dean and Stark type.[8] The water in the reagents together with the water of reaction was removed azeotropically by the xylene and was collected in the water trap. Temperature control was maintained by regulating the amount of xylene in the flask.[9] Thus removal of the xylene through the water trap served to raise the temperature whereas addition of xylene through the condenser served to lower it. By this method the temperature was raised to 250° over a period of one hour and was maintained there for two hours more during which time 72 cc. of water had collected. All of the xylene was removed under reduced pressure to obtain a viscous mixture with a hydroxyl content of 40.0%.

Acetonation of Polyglycerol Mixture B.—To the above mixture (300 g.) was added a solution of hydrogen chloride (15 g.) in acetone (1500 cc.) and the reaction was stirred overnight with anhydrous sodium sulfate (300 g.) at room temperature. The initial slight temperature rise was controlled by external cooling. The solution was made slightly basic with alcoholic sodium hydroxide after which it was filtered and concentrated to yield 300 g. of product. Since the sodium sulfate was quite gummy, it was extracted with absolute methanol to obtain 30 g. of sirup which was set aside.

When the product was fractionally distilled through a 16-inch heated Vigreux column there resulted 141.9 g. of distillate and 141 g. of residue. A curve obtained by plotting refractive index against weight of the distillate indicated that the distillate consisted of two distinct fractions. The first (102.7 g.) was isopropylideneglycerol[10] (b. p. 47° (0.5 mm.); n^{25}D 1.4330). The second was di-isopropylidenediglycerol (39.2 g.). This compound formed an azeotrope with what was probably unreacted glycerol, for which reason the first few fractions were cloudy. For analysis the product was purified by distillation through a 12-inch monel metal helices-packed column. It had a boiling point of 88° (0.3 mm.), and 97° (1 mm.), a constant n^{25}D of 1.4371 and a d^{25} of 1.0530.

Anal. Calcd. for $C_{12}H_{22}O_5$: C, 58.51; H, 9.00; mol. ref., 61.43. Found: C, 58.34; H, 8.96; mol. ref., 61.29.

The residue from the distillation together with the 30 g. of material extracted from the sodium sulfate as described above was subjected to acetonation (1000 cc. acetone, 7.0 g. hydrogen chloride, 150 g. sodium sulfate) as before. The product (170 g.) was fractionally distilled as above to obtain 8.9 g. of isopropylideneglycerol and 32.6 g. of diisopropylidenediglycerol together with 82.3 g. of

(5) The authors express their thanks to Mr. Harold Boyd and to Mrs. Eileen Smith for the performance of the hydroxyl and the iodine number analyses.

(6) P. L. Nichols, Jr., and E. Yanovsky, THIS JOURNAL, **67**, 46 (1945).

(7) Analyses were usually performed immediately on freshly distilled samples. Otherwise the samples were stored in sealed tubes under nitrogen.

(8) E. W. Dean and D. D. Stark, *Ind. Eng. Chem.*, **12**, 486 (1920).

(9) K. A. Earhart and B. Rabin, U. S. Patent 2,308,498; *C. A.*, **37**, 3960 (1943).

(10) (a) E. Fischer, *Ber.*, **28**, 1167 (1895); (b) M. S. Newman and M. Renoll, THIS JOURNAL, **67**, 1621 (1945).

higher boiling material and 30.0 g. of undistillable residue. The high boiling material despite repeated fractional distillations did not yield fractions with constant refractive indices. Thus there was obtained in all 111.6 g. of isopropylideneglycerol and 71.8 g. of diisopropylidenediglycerol.

The higher boiling material was hydrolyzed as indicated in the next experiment to yield a polyhydric material whose hydroxyl content (32.1%) indicated that it was a mixture of triglycerol (hydroxyl content = 35.4%) with higher polyglycerols. These experiments show that 100 g. of polyglycerol (hydroxyl content = 40.0%) yields 88.5 g. of distillable isopropylidene derivatives and 10 g. of undistillable residue. Of the distillate 42% is isopropylideneglycerol, 27% is diisopropylidenediglycerol, and 31% consists of the isopropylidene derivatives of tri- and higher polyglycerols.

Diglycerol.—A solution of diisopropylidenediglycerol (71.0 g.), water (75 cc.), and concentrated hydrochloric acid (5 cc.) was heated on a steam-bath for a few minutes after which the volatile material was removed under reduced pressure. There resulted the theoretical quantity (48.0 g.) of previously characterized diglycerol[3] which distilled at 184° (0.28 mm.) and at 207° (1.2 mm.) and possessed a n^{20}D of 1.4885.

Periodate Oxidation of Diglycerol.—The periodate oxidation of the diglycerol was carried out at 24° using aqueous 0.05 M periodate (buffered, pH 4.2) prepared from trisodium paraperiodate and acetic acid.[11] In two

(11) (a) D. H. Graugaard, J. H. Michell and C. B. Purves, THIS JOURNAL, **61**, 1290 (1939); (b) O. A. Moe, S. E. Miller and M. H. Iwen, *ibid.*, **69**, 2621 (1947). The authors are indebted to Miss Marjorie Iwen for the performance of the oxidations.

experiments the diglycerol consumed 2.00 and 2.01 moles of oxidant per mole.

Summary

Allylation and subsequent distillation has provided a means for identifying, separating and estimating the amounts of the constituents of polyglycerol mixtures. These mixed polyglycerols were prepared by improved procedures.

Acetonation and subsequent distillation has provided an alternate means for the same process. This has an advantage in that isopropylidene derivatives are readily hydrolyzed to the parent compounds, and pure diglycerol can be obtained from a polyglycerol mixture by this procedure. A higher boiling fraction which could not be purified by fractional distillation consisted primarily of the isopropylidene derivatives of triglycerol together with a small amount of the isopropylidene derivatives of higher polyglycerols.

O-Tetraallyldiglycerol, O-pentaallyltriglycerol and diisopropylidenediglycerol are described.

The diglycerol obtained has been shown to be linear by periodate oxidation.

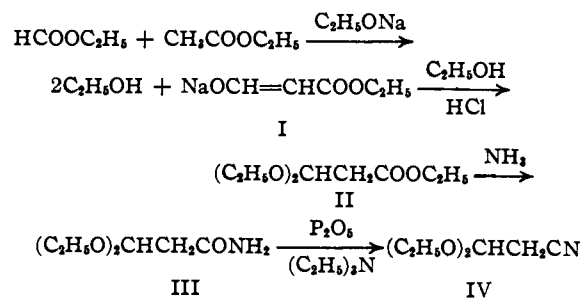[CONTRIBUTION FROM THE LABORATORY OF ORGANIC CHEMISTRY OF THE UNIVERSITY OF WISCONSIN]

The Preparation, Alcoholysis and Reduction of Cyanoacetaldehyde Diethylacetal. Malonaldehyde Tetraethylacetal

BY S. M. McELVAIN AND ROBERT L. CLARKE[1]

In the development of certain work in this Laboratory the orthoesters corresponding to cyanoacetaldehyde diethylacetal (IV) and malonaldehyde tetraethylacetal were desired. It therefore became necessary to prepare this cyanoacetal in sufficient quantity that further reactions utilizing it could be studied. The preparation of this cyanoacetal from the corresponding bromoacetal has been reported.[2] The procedure and results obtained by Uhle and Jacobs[2b] were duplicated in the present work, but this method did not seem suitable for our purposes, since the yield is low (14%) and the product requires long and careful fractionation for purification.[3] Consequently an

(1) Wisconsin Alumni Research Foundation Research Assistant, 1945-1946; Allied Chemical Company Fellow, 1946-1947.

(2) (a) Hartung and Adkins, THIS JOURNAL, **49**, 2517 (1927); (b) Uhle and Jacobs, *J. Org. Chem.*, **10**, 81 (1945); *cf.* Hartung and Adkins, THIS JOURNAL. **69**, 1535 (1947).

(3) Sice 67% of unchanged bromoacetal was recovered from this reaction after forty hours of heating the reactants in refluxing aqueous alcohol, the reaction time was doubled. The same yield of cyanoacetal and same recovery of starting material was obtained. Sodium iodide is used in this reaction, presumably to form the more reactive iodoacetal. That the iodoacetal is an intermediate in the reaction is shown by the fact that the same results were obtained when iodoacetal was used instead of the bromoacetal. Evolution of ammonia was noted throughout the course of the reaction, indicating that hydrolytic destruction of the cyanide ion proceeds at a greater rate than does the replacement of the halogen of the acetal.

alternative method of preparation of cyanoacetal was developed.

This method employed the following sequence of reactions

$$HCOOC_2H_5 + CH_2COOC_2H_5 \xrightarrow{C_2H_5ONa}$$

$$2C_2H_5OH + NaOCH=CHCOOC_2H_5 \xrightarrow[HCl]{C_2H_5OH}$$
$$\text{I}$$

$$(C_2H_5O)_2CHCH_2COOC_2H_5 \xrightarrow{NH_3}$$
$$\text{II}$$

$$(C_2H_5O)_2CHCH_2CONH_2 \xrightarrow[(C_2H_5)_3N]{P_2O_5} (C_2H_5O)_2CHCH_2CN$$
$$\text{III} \qquad\qquad\qquad\qquad \text{IV}$$

The lowest yields encountered were in the preparation of II and it is believed that these yields are a consequence of the quality of the sodium enolate (I). This enolate was prepared by the method of Cogan,[4] who reported that the salt obtained from the indicated ester condensation was composed of 63% of the enolate (I), 23% of the sodium enolate of acetoacetic ester, and 12% sodium formate. However, the salt obtained by Cogan's procedure in the present work appeared

(4) Cogan, *Bull. soc. chim.*, **8**, 128 (1941).