ketone, it is advisable to wash the ether solution with 5% sodium bicarbonate solution in order to remove benzoic acid formed during the condensation.

In the experiment with propiophenone, the reaction mixture was poured onto ice and hydrochloric acid and the mixture was extracted with ether. Since benzoylpropiophenone is insoluble in cold alkali, the ether phase was washed with cold 10% sodium hydroxide until free from phenol, then with water, dried over Drierite, and the solvent distilled. The β-diketone was isolated from the residue (containing a red oil) either by the addition of ligroin (30–60°) followed by recrystallization of the precipitated crystals from ethanol, or by direct recrystallization from ethanol. In the latter method the ethanol solution was decanted from the red oil and chilled.

The yields of β-diketones and other data, using Methods A and B are given in Table I. Aqueous-alcoholic ferric chloride was used for the enol tests.

Reactions with Methyl Benzoate.—The reaction of 0.2 mole of cyclohexanone with 0.4 mole each of methyl benzoate and sodium amide (Method A, in which excess ester is used)[2] was carried out in the usual manner and the reaction mixture worked up by the first procedure described above. The residue, obtained on distillation of the solvent from the dried ether solution, was recrystallized from dilute ethanol, yielding 18.7 g. (47%) of benzoylcyclohexanone, m. p. 88–89°. From the ether phase, obtained on decomposing the reaction mixture with water, there was recovered 24 g. (0.18 mole) of methyl benzoate, b. p. 94–97° (25 mm.), and 7.7 g. of material b. p. 90–180° (6 mm.), which was assumed to be a mixture of aldol condensation products. From the bicarbonate wash there was obtained on acidification 8.0 g. of benzoic acid, m. p. 120–121°. This corresponds to 15% of the methyl benzoate charged.

From the reaction of 0.5 mole each of cyclohexanone and sodium amide with 0.25 mole of methyl benzoate (Method B), there was isolated only a 22% yield of benzoylcyclohexanone, along with 12.0 g. (0.1 mole) of benzoic acid and 19.0 g. (0.1 mole calculated as the dimer) of a product, b. p. 100–210° (9 mm.), which apparently resulted from aldol condensations.

With cyclopentanone (0.15 mole), methyl benzoate (0.3 mole), and sodium amide (0.3 mole) there was obtained 8.3 g. (21%) of α-benzoyl-α′-cyclopentylidenecyclopentanone, yellow needles from ethanol, m. p. 99.5° (not benzoylcyclopentanone, m. p. 45°).[6]

Anal. Calcd. for $C_{17}H_{18}O_2$: C, 80.31; H, 7.14. Found: C, 80.73; H, 7.39.

The product gave a light green copper salt and an immediate brown enol test. The diketone was cleaved by suspending it in cold sodium hydroxide, followed by rapid steam distillation. The distillate contained a small amount of α-cyclopentylidenecyclopentanone, which was extracted with ether and the extract dried over Drierite. After removal of the ether the remaining oil was converted to an oxime, m. p. 123–124°.[14] The residue from the steam distillation, on acidification, yielded benzoic acid, m. p. 120–121°, and a small amount of an unidentified acid.

Summary

1. The anions of cyclohexanone and certain other methylene ketones, prepared by means of sodium amide, are benzoylated in much better yields with phenyl benzoate than with ethyl benzoate.

2. The anion of cyclohexanone is benzoylated in better yield with methyl benzoate than with the ethyl ester. With cyclopentanone, self-condensation occurs followed by benzoylation.

3. The parallelism between the reactivities of esters in the Claisen acylation of a ketone anion and the rates of alkaline hydrolysis of the esters is pointed out.

DURHAM, N. C. RECEIVED JUNE 2, 1947

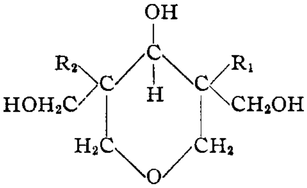
[CONTRIBUTION FROM THE CHEMICAL LABORATORY, GENERAL MILLS, INC.]

The Condensation of Formaldehyde with Lower Aliphatic Ketones. Allylation as a Means of Structure Proof[1]

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

The separation of pentaerythritol and dipentaerythritol in a technical mixture has been achieved in this Laboratory by distillation of their allyl ethers. The determination of the physical constants, in particular the iodine number, of the allyl ethers established a basis for the identification of the parent compounds, whereas the amount of each fraction in the distillate served as a roughly quantitative measure of the composition of the original mixture. These observations have led to a procedure for the separation of pure compounds from the sirupy reaction products resulting from the condensation of excess formaldehyde with lower aliphatic ketones. Thus allylation and subsequent distillation has made possible the establishment of the structures of the chief constituents, and the postulation of possible structures of the minor constituents.

Apel and Tollens[1a,b] reported that acetone condenses with excess formaldehyde to yield an "anhydroenneaheptitol," which Mannich and Brose[2] later identified as tetrahydro-3,3,5,5-*tetrakis*-(hydroxymethyl)-4-pyranol, Ia. Although these investigators employed long periods of reaction, the present work has shown that at slightly elevated temperatures the reaction proceeds in a few hours. The resulting sirupy reaction product was converted by the action of allyl bromide in the



Ia, $R_1 = R_2 = CH_2OH$
Ib, $R_1 = CH_2OH$, $R_2 = CH_3$
Ic, $R_1 = R_2 = CH_3$

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[1] Paper No. 78, 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] M. Apel and B. Tollens, *Ber.*, **27**, 1087 (1894); (b) M. Apel and B. Tollens, *Ann.*, **289**, 46 (1895).

[2] C. Mannich and W. Brose, *Ber.*, **55**, 3155 (1922).

presence of 50% aqueous alkali[3] to a partially allylated product, after which complete allylation was accomplished by the action of sodium and allyl bromide. Distillation of the completely allylated mixture gave not only the allyl ether of the pentahydric anhydroenneaheptitol, Ia, but also the allyl ether of a lower condensation product which had escaped detection in previous investigations. This lower boiling product gave no test for a ketone group, and although the analytical data were only in partial agreement because the small amount of low boiling fraction precluded complete fractionation, the iodine number checked well for the theoretical value for a triallyl ether of a trihydroxypentane. Indeed, the iodine number excluded all other possible relatively low boiling allyl ethers of acetone–formaldehyde condensation products. Although lower condensation products of acetone and formaldehyde have previously been described,[4] none has been found in which the carbonyl group is reduced unless at the same time complete hydroxymethylation occurred. Although such a reduction is possible, it is also possible that the carbonyl group was reduced by the action of sodium during the completion of the allylation, for copious quantities of hydrogen were evolved. As will become apparent later, a similar type of reduction appears to have taken place in the case of a lower condensation product of methyl ethyl ketone and formaldehyde. Thus a possible structure for this low-boiling fraction is the triallyl ether of 2-hydroxymethyl-1,3-butanediol. Credence is lent to this postulation by the fact that only unsymmetrical *bis*-hydroxymethylation products have been reported.[4c]

The analytical data for the higher boiling material, with the exception of the iodine number which in numerous preparations was consistently ten units high, agreed well with those required by the pentaallyl ether of tetrahydro-3,3,5,5-*tetrakis*-(hydroxymethyl)-4-pyranol. The high iodine value appears to be characteristic of this type of compound regardless of the procedures employed for determination of iodine number. Thus the allyl ethers of tetrahydro-3,3,5-*tris*-(hydroxymethyl)-5-methyl-4-pyranol, Ib, and tetrahydro-3,5-*bis*-(hydroxymethyl)-3,5-dimethyl-4-pyranol, Ic, also showed high iodine values.

Cleavage of the allyl ether of Ia by action of hydriodic acid yielded tetrahydro-3,3,5,5-*tetrakis*-(hydroxymethyl)-4-pyranol which was identified by means of its diisopropylidene derivative.[2]

Although numerous investigators[4a,5] have condensed methyl ethyl ketone with formaldehyde and have obtained *mono*- and *bis*-hydroxymethyl derivatives, no higher condensation product has ever been reported. However, such a material probably existed in the reaction mixtures, although its isolation was precluded because the substance could not be distilled, nor could it be converted into crystalline derivatives. These difficulties are avoided by complete allylation of the condensation product, for the mixture of allyl ethers can be separated readily into two fractions by distillation. No ketone group was present in the small amount of lower boiling fraction whose iodine number, per cent. hydroxyl, molecular weight, and elementary analyses indicated that it consisted of a 50% mixture of the di- and triallyl ethers of a trihydroxy-hexane. This is possibly 2-methyl-2-hydroxymethyl-1,3-butanediol since only unsymmetrical *bis*-hydroxymethylation has been reported.[5] Again the carbonyl group was reduced, either during hydroxymethylation or during the completion of the allylation.

The main fraction of the above allylated mixture was shown by physical data to be the tetraallyl ether of tetrahydro-3,3,5-*tris*-(hydroxymethyl)-5-methyl-4-pyranol, Ib. During microhydrogenation of the allyl ether,[6] 4.3 moles of hydrogen were absorbed per mole of compound. This result cannot be regarded as a test for purity of the compound because of the possibility of hydrogenolysis of the ether linkages. Fission of the allyl ether with hydriodic acid yielded an oil which could not be crystallized and which did not yield solid derivatives. Since two asymmetric carbon atoms are present in this compound, this lack of crystallization is not surprising.

Although the interaction of diethyl ketone with formaldehyde has likewise been shown previously to yield lower condensation products,[4a,5b] as in the case of methyl ethyl ketone the fully hydroxymethylated product has not previously been isolated. From the allylation of the reaction product of diethyl ketone with excess formaldehyde there resulted a readily distillable material whose physical constants showed it to be the triallyl ether of tetrahydro-3,5-*bis*-(hydroxymethyl)-3,5-dimethyl-4-pyranol, Ic. The forerun from the allylation product did not yield fractions of constant refractive index.

Further insight into the composition of the ketone–formaldehyde condensation products was furnished by comparison of the hydroxyl content determined experimentally and the hydroxyl content calculated for a mixture whose composition was suggested by the distillation data of the allyl ethers. For the acetone–formaldehyde product the distillation data indicated that the low and high boiling products were present in a molar ratio of approximately 1:5.1. A mixture of this composition would have a hydroxyl content of 34.4% as compared to the experimentally determined

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(3) P. L. Nichols, Jr., and E. Yanovsky, This Journal, **67**, 46 (1945).

(4) (a) G. T. Morgan and E. L. Holmes, *J. Chem. Soc.*, 2667 (1932); (b) H. Gault and L. A. Germann, *Compt. rend.*, **197**, 620 (1933); (c) J. Y. Johnson, British Patent 381,686.

(5) (a) Bayer and Co., German Patent 223,207; (b) J. Decombe, *Compt. rend.*, **203**, 1077 (1936); (c) G. Morgan and C. F. Griffith, *J. Chem. Soc.*, 841 (1937); (d) N. M. Tilichenko, *J. Gen. Chem.* (*U. S. S. R.*), **10**, 718 (1940); (e) N. V. de Bataafsche Petroleum Maatschappy, British Patent 521,068.

(6) The authors wish to express their thanks to Professor Robert H. Baker of Northwestern University who kindly carried out the microhydrogenation experiments.

value of 29.2% for the original condensation product. This discrepancy can be explained by the presence of high molecular weight ethers formed by intercondensation of the polyhydroxy compounds. These compounds would be comparable to the di- and polypentaerythritols which result during the acetaldehyde–formaldehyde condensation. The large amount of undistillable residue from the distillation of the allyl ethers in this case substantiates this postulation. Of course a portion of this residue resulted from the unavoidable polymerization of the allyl ethers during distillation.

In the case of the methyl ethyl ketone condensation product, there was little discrepancy between the experimentally determined hydroxyl content (31.5%) and the hydroxyl content (32.0%) of a theoretical mixture of the two products at a ratio indicated by the data for the distillation of their allyl ethers. This would suggest that only a small amount of intercondensation took place during the condensation reaction with formaldehyde in contrast to the larger amount in the acetone reaction. This is also suggested by an appreciably smaller residue from the distillation of the corresponding allyl ethers. Similar postulations in the case of the diethyl ketone condensation product were not possible since a relatively pure compound from the low boiling fraction could not be obtained. However, the relatively small amount of residue (10.7%) remaining after distillation of the allyl ethers suggests that little if any intercondensation took place.

Experimental

The Condensation of Acetone and Formaldehyde.—Calcium hydroxide (148 g., 2 moles) was added with stirring to a mixture of acetone (292 cc., 4 moles) and paraformaldehyde (970 g., 32.3 moles) in water (3.5 liters).[7] In some cases it was necessary to initiate the reaction by slight external heating but, once started, the exothermic reaction was controlled so that the temperature did not exceed 55°, and the temperature was maintained at this point for two hours. Sulfuric acid (25%, 706 g., 1.8 moles) was added with stirring to the cooled and filtered solution. Thereafter, hydrated oxalic acid (25.2 g., 0.2 mole) was added as a concentrated aqueous solution. Filtration yielded a faintly yellow solution which was evaporated under reduced pressure at 60–70°. The residue was extracted with dry methanol (600 cc.) and the extract was filtered and evaporated under reduced pressure. The light yellow sirup weighed 800 g. and possessed a hydroxyl content of 29.2%.[8,9]

Allylation of the Condensation Products of Acetone and Formaldehyde.—The above condensation product (300 g., 5.3 equivalents of OH) was mixed with aqueous sodium hydroxide (50%, 928 g., 11.6 moles) in small portions with stirring and external cooling. This mixture was then heated to 73° and allyl bromide (1280 g., 10.6 moles) was added with stirring over a period of seven hours. After two hours more of stirring and heating, the mixture was cooled, and the upper organic layer was separated. The aqueous layer was extracted with ether, and the extract was combined with the organic layer after which both were washed with water and dried over sodium sulfate. The solvent was removed and there was obtained 331 g. (72.3% yield on basis of 75% allylation of the hydroxyl groups) of product. Upon distillation under reduced pressure (2 mm.) in an atmosphere of carbon dioxide, there resulted a distillate (209 g.) boiling at 70–180° (2 mm.) and a gelled residue (122 g.), the ratio of distillate to residue being 63.2:36.8. The distillate had an iodine number of 276.7 and a hydroxyl content of 3.6%.

To complete the allylation, sodium (31 g., 1.35 moles) was added slowly (three hours) at 105° in small portions and with stirring to the above material (205 g.). The reaction mixture was allowed to stand overnight and then more allyl bromide (200 g., 1.65 moles) was added at 85° with stirring over a period of forty-five minutes. The deep blue reaction mixture was heated at 85° and stirred for three hours longer after which it was cooled and excess sodium was removed by addition of alcohol. The product, obtained by the usual procedure of ether extraction, was fractionated through a 16-inch heated Vigreux column. From a curve obtained by plotting refractive indices against weight of distillate, it was apparent that the distillate consisted of two products. The low boiling fraction (23.0 g.) on refractionation yielded a product (10.7 g.) boiling at 111–116° (2 mm.) which had a $n^{25}\text{D}$ of 1.4618 and a d^{25} of 0.9564. No positive test with 2,4-dinitrophenylhydrazine could be obtained. This material is possibly the impure triallyl ether of 2-hydroxymethyl-1,3-butanediol.

Anal.[10] Calcd. for $C_{14}H_{24}O_3$: C, 69.96; H, 10.07; iodine number, 316.7; mol. wt., 240.3. Found: C, 69.03; H, 10.82; iodine number, 312.5, 313.9; mol. wt., 282, 252.

The main product (88.9 g.) distilled at 175–178° (3 mm.) and fractions collected at intervals showed a constant $n^{25}\text{D}$ of 1.4733 and a d^{25} of 0.9993. The higher boiling material was the pentaallyl ether of tetrahydro-3,3,5,5-*tetrakis*-(hydroxymethyl)-4-pyranol. After removal of the lower boiling product the heating element on the column failed, thus interrupting the distillation. This caused excessive polymerization which vitiated the yield of the higher boiling product. However, previous runs indicated that the weight ratio of low to high boiling products in the distillate was 10:90.

Anal. Calcd. for $C_{24}H_{38}O_6$: C, 68.22; H, 9.06; iodine number, 301.0; mol. wt., 422.5; mol. ref., 118.37. Found: C, 67.89; H, 8.85; iodine number, 310.7, 312.1; mol. wt., 409.0, 411.0; mol. ref. 118.60.

Iodine Numbers.—Several methods for determination of the iodine numbers of these allyl ethers were examined. Freshly distilled tetraallyl ether of tetrahydro-3,3,5-*tris*-(hydroxymethyl)-5-methyl-4-pyranol was used as a reference compound. The Rosenmund method[11] and the rapid Wijs method[12] yielded results which were consistently sixteen to nineteen units high, even when the latter method was applied with specially prepared anhydrous reagents and with special care during the analysis to eliminate moisture. Titration[13] with bromine gave values which were eight to twelve units high regardless of whether the reaction time was one, two or five hours. The Kaufmann procedure[14] yielded results which were very low. These anomalous results were noted in the analyses of all of the allyl ethers of the pyranol derivatives, whereas correct results were obtained for all of the other allyl ethers prepared in this Laboratory.

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[7] Later experiments showed that half this quantity of water was adequate.

[8] The procedure indicated for isolating the methyl ethyl ketone-formaldehyde condensation product was also applicable here and is probably preferable. Ammonium carbonate was not an adequate precipitant for the catalyst.

[9] The authors are grateful to Mr. Harold Boyd and to Mrs. Eileen Smith for determining hydroxyl and iodine values.

[10] Analyses were performed either on freshly distilled samples or on samples which were stored in sealed tubes under nitrogen.

[11] K. W. Rosenmund and W. Kuhnhenn, *Z. Nahr. Genussm.*, **46**, 154 (1923).

[12] H. D. Hoffman and C. E. Green, *Oil & Soap*, **16**, 236 (1939).

[13] G. D'Alelio, "A Laboratory Manual of Plastics and Synthetic Resins," John Wiley and Sons, Inc., New York, N. Y., 1943, p. 124.

[14] H. P. Kaufmann and L. Hartweg, *Ber.*, **70B**, 2554 (1937).

Such compounds as *n*-butyl ether, 2-chloroethyl ether, dioxane, and the diisopropylidene derivative of tetrahydro-3,3,5,5-*tetrakis*-(hydroxymethyl)-4-pyranol were shown to possess zero iodine numbers, indicating that oxonium salt formation was probably not the cause of the high values.

Fission of the Pentaallyl Ether of Tetrahydro-3,3,5,5-*tetrakis*-(hydroxymethyl)-4-pyranol.—A mixture of the pentaallyl ether (5 g.) and hydriodic acid (55%, 15.6 g., 10% excess) was refluxed for three hours. The mixture was diluted with water and extracted with ether until the aqueous layer was colorless. Evaporation of the aqueous phase under reduced pressure yielded a dark sirup which did not crystallize even when seeded with a crystal of tetrahydro-3,3,5,5-*tetrakis*-(hydroxymethyl)-4-pyranol. The dark oil was dissolved in acetone (15 cc.) and sulfuric acid (2 drops) was added. Crystals of the diisopropylidene derivative of tetrahydro-3,3,5,5-*tetrakis*-(hydroxymethyl)-4-pyranol deposited immediately. The mixture was placed in the refrigerator overnight, and the product was then removed and washed with ether. Crystallization from ethanol (95%) yielded white platelets which melted at 225° (uncor., lit. 229°[2]) and which did not depress the melting point of an authentic sample.

The Condensation of Methyl Ethyl Ketone and Formaldehyde.—Methyl ethyl ketone (288 g., 360 cc., 4 moles) and paraformaldehyde (780 g., 26 moles) were condensed in water (3 liters) by the addition of calcium hydroxide (148 g., 2 moles). The temperature was maintained at 50–55° for two hours. The filtered solution was made barely acid with dilute acetic acid, and was evaporated under reduced pressure. The residue was extracted with dry methanol (1000 cc.) and filtered. Evaporation of the filtrate under reduced pressure yielded 742.8 g. of a colorless sirup with a hydroxyl content of 31.5%.

Attempts to prepare crystalline esters of this product, such as the acetate and the benzoate, led only to intractable oils. Likewise the benzylidene and the isopropylidene derivatives were liquids. Distillation of the product or of its sirupy acetate was unsuccessful since the distillate amounted only to a small percentage of the product.

Allylation of the Condensation Products of Methyl Ethyl Ketone and Formaldehyde.—The preliminary allylation of the above product was carried out as described previously, employing the above sirup (250 g., 4.6 equivalents of OH), aqueous sodium hydroxide (50%, 840 g., 10.5 moles), and allyl bromide (1200 g., 9.9 moles). The time required for addition of the allyl bromide was six hours. There resulted 302 g. (77.8% yield on the basis of 75% allylation of the hydroxyl groups) of product which gave 237 g. of distillate boiling at 95–170° (2 mm.) and 65 g. of viscous residue, the weight ratio of distillate to residue being 78.5:21.5.

The complete allylation of 180 g. of the above distillate was accomplished according to the procedure outlined previously (14 g., 0.61 mole of metallic sodium and 112 g., 0.92 mole of allyl bromide). Fractionation of the product through a 16-inch heated Vigreux column yielded 151 g. of distillate which consisted of 15% of low boiling product and 85% of high boiling product, which is a molar ratio of 1:3.94, and 5 g. of residue. Of the distillate 22 g. distilled at 78–81° (1.3 mm.) and had a $n^{25}\text{D}$ of 1.4517 and a d^{25} of 0.9311. This product did not react with ketone reagents and its analytical data indicate that it consists of a 50% mixture of the di- and triallyl ethers of a trihydroxyhexane of empirical formula, $C_{13.5}H_{24}O_3$.

Anal. Calcd. for $C_{13.5}H_{24}O_3$: C, 69.20; H, 10.32; iodine number, 271.0; hydroxyl 3.63; mol. wt., 234.3. Found: C, 68.54; H, 10.10; iodine number, 271.5; hydroxyl, 3.00; mol. wt., 219.2, 224.6.

From the main fraction which consisted of 120.0 g. there was obtained an analytical sample which had a $n^{25}\text{D}$ of 1.4683 and a d^{25} of 0.9760. This product, which was the tetraallyl ether of tetrahydro-3,3,5-*tris*-(hydroxymethyl)-5-methyl-4-pyranol, distilled at 150° (1.3 mm.).

Anal. Calcd. for $C_{21}H_{34}O_5$: C, 68.82; H, 9.35; iodine number, 277.2; mol. wt., 366.5; mol. ref., 103.34. Found: C, 68.97; H, 9.74; iodine number, 294.8, 294.5; mol. wt., 362.0; mol. ref., 103.72.

The fission of the tetraallyl ether with hydriodic acid was attempted according to the above outlined procedure but the product was an intractable oil.

Bromination of the tetraallyl ether under ordinary conditions led to a copious evolution of hydrogen bromide, and far more bromine was absorbed than was theoretically required by the unsaturation. Bromination in carbon tetrachloride under strictly anhydrous conditions led to absorption of the theoretical amount of bromine without evolution of hydrogen bromide. The product was an oil which fumed in moist air and which could not be crystallized.

Hydroxylation with peracetic acid according to the procedure of Scanlan and Swern[15] likewise did not yield crystalline material.

The Condensation of Diethyl Ketone and Formaldehyde.—The procedure was similar to that described for the condensation of acetone and formaldehyde (86 g., 1 mole of diethyl ketone; 165 g., 5.5 moles of paraformaldehyde; 1000 cc. water; 37 g., 0.5 mole of calcium hydroxide). Since the exothermic reaction in this case was less pronounced than in the preceding reactions, external heating was necessary in order to maintain the reaction mixture at 55° for two hours. The cooled and filtered solution was treated with sulfuric acid (25%, 0.45 mole) and oxalic acid (6.3 g., 0.05 mole) dissolved in a small amount of water. The mixture was filtered and the colorless filtrate was evaporated under reduced pressure. The residue was extracted with absolute ethanol and the extract when evaporated yielded 200 g. of a colorless sirup which had a hydroxyl content of 30%.

Allylation of the Condensation Products of Diethyl Ketone and Formaldehyde.—Allylation of the above product was effected as described previously (200 g. of condensation product, 3.5 equivalents of OH; 670 g., 8.37 moles of 50% aqueous sodium hydroxide; 960 g., 687 cc., 7.9 moles of allyl bromide; time, four and one-half hours). There resulted 212.9 g. (70% yield on basis of 75% allylation of the hydroxyl groups) of product of which 190 g. distilled at 74–160° (1 mm.) and which had an iodine number of 223.4. The residue weighed 22.9 g. Thus the weight ratio of distillate to residue was 89.3:10.7.

Completion of the allylation was likewise accomplished as previously indicated (175 g. of the partially allylated product; 18.4 g., 0.80 mole of sodium; and 117 g., 84 cc., 0.97 mole of allyl bromide). There resulted 160 g. of product which on fractionation through a 16-inch heated Vigreux column yielded 140 g. of distillate. Of the distillate, 106.5 g. had a constant $n^{25}\text{D}$ of 1.4638 and a d^{25} of 0.9583, and distilled at 128–30° (1 mm.) (156° at 5 mm.). This product was shown by analytical data to be the triallyl ether of tetrahydro-3,5-*bis*-(hydroxymethyl)-3,5-dimethyl-4-pyranol. Although the forerun was refractionated, it distilled over a range of 70–110° (1 mm.) and a pure compound could not be isolated.

Anal. Calcd. for $C_{18}H_{30}O_4$: C, 69.64; H, 9.74; iodine number, 245.8; mol. wt., 310.4; mol. ref., 88.31. Found: C, 69.54; H, 10.02; iodine number, 265.4, 266.4; mol. wt., 306.8, 319.2; mol. ref., 89.37.

Summary

1. Allylation followed by fractional distillation is a valuable procedure for the analysis and identification of mixtures of polyhydric alcohols which result from the condensation of ketones with formaldehyde.

2. Condensation of methyl ethyl ketone and excess formaldehyde yields chiefly tetrahydro-3,3,5-*tris*-(hydroxymethyl)-5-methyl-4-pyranol, as well as a small amount of a lower condensation product which after allylation is probably the

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[15] J. T. Scanlan and D. Swern, This Journal, 62, 2305 (1940).

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-

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(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).