

[CONTRIBUTION FROM THE CHEMICAL LABORATORIES OF COLUMBIA UNIVERSITY]

The Formation of Cyclic Acetals from Aldehydes or Ketones and Alkylene Oxides

BY MARSTON TAYLOR BOGERT AND RICHARD O. ROBLIN, JR.¹

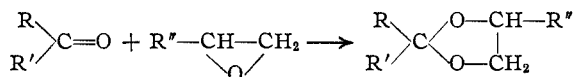
Introduction

Cyclic acetals have been the subject of numerous investigations,² and in every case their formation has involved the use of a polyhydroxy compound. Wurtz,³ in preparing ethylidene glycol, $\text{CH}_3-\text{CH} \begin{array}{l} \diagup \text{O}-\text{CH}_2 \\ \diagdown \text{O}-\text{CH}_2 \end{array}$, attempted

a direct condensation of ethylene oxide and acetaldehyde, but reported only negative results. Later, Lochert⁴ confirmed this observation of Wurtz. He was unable to obtain a reaction between propylene oxide and acetaldehyde. More recently⁵ negative results have also been reported in the case of benzyl ethylene oxide, when 40% sulfuric acid was used as a catalyst.

When dioxane is prepared from ethylene oxide in the presence of a catalyst, some cyclic acetal is formed.⁶ It has been suggested that the acetal formation involved a rearrangement of ethylene oxide to acetaldehyde, which then reacted with more ethylene oxide to form ethylidene glycol. While up to the present time there has been no direct experimental basis for the second step in this hypothesis, it has been generally accepted, and has even crept into textbooks as a reaction of ethylene oxide.⁷

During a study of the properties of ethylene oxides in this Laboratory, it was discovered that these compounds react with aldehydes and ketones in the presence of metallic chlorides. The resulting compounds are cyclic acetals, the formation of which may be typified as follows



In so far as we have been able to determine, this is the first time that the reaction of ethylene oxides with aldehydes or ketones has been carried out successfully.

Since the reaction does not take place in the absence of a catalyst, any hypothetical mechanism must take cognizance of this fact. It is well

(1) This research could not have been carried out but for the generous assistance of Mr. G. A. Pfeiffer, President, Richard Hudnut, New York, N. Y., the donor of the fellowship held by the junior author; and of Dr. George O. Curme, Jr., Vice President, Carbide & Carbon Chemicals Corporation, New York, N. Y., who very kindly supplied the requisite alkylene oxides.—M. T. B. and R. O. R., Jr.

(2) (a) Fischer, *Ber.*, **27**, 1524 (1894); (b) **28**, 1979 (1895); (c) Fischer and Pfähler, *ibid.*, **53**, 1606 (1920); (d) Irvine, *J. Chem. Soc.*, **103**, 575 (1913); (e) **107**, 337 (1915); (f) Hibbert and co-workers *THIS JOURNAL*, **45**, 734; (g) 3108 (1923), *et seq.*; (h) *Can. J. Research*, **2**, 35; (i) 131; (j) 214 (1930).

(3) Wurtz, *Ann.*, **120**, 328 (1861).

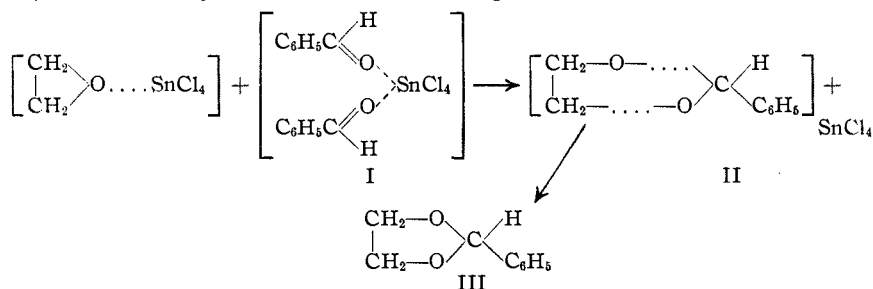
(4) Lochert, *Ann. chim. phys.*, [6], **16**, 56 (1889).

(5) Read, Lathrop and Chandler, *THIS JOURNAL*, **49**, 3116 (1927).

(6) Faworski, *J. Russ. Phys.-Chem. Soc.*, **38**, 741 (1906); *Chem. Zentr.*, **78**, I, 15 (1907).

(7) Richter-Anschütz, "Chemie der Kohlenstoffverbindungen," 1928, 12th ed., Vol. I, pp. 402-403.

established that stannic chloride forms addition compounds with ethers and carbonyl compounds.⁸ The addition of stannic chloride to benzaldehyde, for example, causes the precipitation of a solid complex, which gradually dissolves as ethylene oxide is introduced. This may be due to the formation of a soluble addition compound between ethylene oxide and stannic chloride, which, in turn, interacts either with free benzaldehyde, or the benzaldehyde-stannic chloride complex, I, as follows



As will be seen in II, this involves the simultaneous opening of the three membered oxide ring and the two membered carbonyl ring. If these two unstable systems combine, the cyclic acetal III will be formed. The benzaldehyde is written in the form of its stannic chloride complex rather than in the free form, because this solid complex does not disappear until the reaction is practically complete.

The course of the reaction, in the case of benzaldehyde, may be followed by observing the color changes which take place. As ethylene oxide is added the liquid becomes red in color. The red color gradually deepens until, near the end of the reaction, a green fluorescence appears. When the reaction is complete the solution is a clear green. If this green solution is allowed to stand in the presence of sunlight, it fades to a pale yellow, but it persists indefinitely in the absence of light. The red color was shown to be due to the benzaldehyde-stannic chloride complex in solution, while the green color could be produced by the addition of stannic chloride to the pure cyclic acetal. The low yield may be accounted for, in part, by this cyclic acetal complex, which removes stannic chloride from the reaction. When acetophenone or methyl hexyl ketone is used, the solution becomes orange, and this color persists during the reaction. Here, too, the color is sensitive to sunlight. No color appears when heptaldehyde is used.

Experimental

Since a trace of water is detrimental to the reaction, the starting materials were thoroughly dried. In the case of ethylene oxide this was accomplished by passing the gas over soda lime, as recommended in "Organic Syntheses."⁹ The propylene oxide and other starting materials were purified by two fractional distillations.

(8) Pfeiffer, *Ann.*, **376**, 285 (1910); (b) **412**, 253 (1916); (c) *Ber.*, **44**, 2653 (1911); (d) *Z. anorg. Chem.*, **87**, 335 (1914); (e) Weinland, "Komplex-Verbindungen," Stuttgart, 1919, p. 236.

(9) "Organic Syntheses," John Wiley and Sons, New York, 1926, Vol. VI, p. 54.

Preparation of Cyclic Acetals

After a number of experiments, the following conditions were selected as giving the best results: 0.2 mole of the aldehyde or ketone was cooled in an ice-bath to 5°, and 0.01 mole of anhydrous stannic chloride added slowly from a graduated pipet. A complex formed which in the case of benzaldehyde and acetophenone was a white solid; 0.25 mole of the oxide was then added gradually with occasional shaking. The temperature was maintained between 40–50° throughout the addition, which generally required about eighty minutes. The clear solution¹⁰ was allowed to cool to room temperature, and an equal volume of benzene added, the mixture washed with three 10-cc. portions of 10% sodium hydroxide to remove the stannic chloride, and then with three 10-cc. portions of water. The resulting benzene solution was dried over anhydrous sodium sulfate, the benzene removed on a steam-bath, and the product fractionated; yield, 25–35%.

Attempts to increase the yields were unsuccessful because of two opposing factors. The amount of cyclic acetal formed was shown to be directly proportional to the amount of stannic chloride used, and also to the temperature of the reaction. However, these factors bore a similar relation to the formation of a high boiling material, probably a polymer. Thus, the use of larger relative amounts of stannic chloride resulted in the recovery of less of the original carbonyl compound, but a larger amount of the "polymer" was formed; so that the yield of cyclic acetal had not been increased and may even have been decreased. The same was true of the temperature; high temperatures favored the reaction, but also favored "polymerization." The procedure described above represents the optimum conditions possible in the face of these opposing factors. The use of solvents such as ether, benzene or carbon tetrachloride did not give an appreciable increase in the yield. Benzene was found to be the best solvent, while ether actually inhibited the reaction.

Under the same experimental conditions the following catalysts produced only a trace of the desired product: $\text{SnCl}_4 \cdot 4\text{H}_2\text{O}$, ZnCl_2 , FeCl_3 , SbCl_3 , AlCl_3 .¹¹ CaCl_2 , NH_4Cl , HCl , H_2SO_4 and POCl_3 gave no appreciable reaction.

Formation of the "Polymer" and Reversibility of the Reaction.—The formation of the high boiling material seriously decreased the yield, and an attempt was made to determine its constitution. If the residue consists of polymerized acetal it should be possible to obtain a quantitative hydrolysis to the original aldehyde or ketone and the corresponding glycol. The residue resulting from the reaction of benzaldehyde and ethylene oxide was, therefore, heated at 150° and 20 mm. for three hours to remove as much of the lower boiling material as possible. Ten grams of the resulting residue was refluxed with dilute hydrochloric acid for one-half hour. This treatment resulted in the formation of only a trace of benzaldehyde. The remainder of the material was recovered unchanged. Since, under the same conditions, benzylidene glycol is hydrolyzed quantitatively to benzaldehyde and ethylene glycol, it would appear that the high boiling residue is not a polymer of the cyclic acetal. An attempt to distil the high boiling "polymer" at 20 mm. pressure produced a slow decomposition. Benzaldehyde was the only definite compound which could be isolated from the resulting distillate.

The reaction was shown to be non-reversible by the following experiment: 10 g. of pure benzylidene glycol was heated in a distilling flask with 0.7 g. of anhydrous stannic chloride at 50° for one hour. The receiver was immersed in solid carbon dioxide, but no ethylene oxide was liberated, and the original material was recovered unchanged.

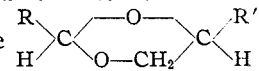
(10) In the case of acetophenone and ethylene oxide, the ketal separated as a crystalline solid. By cooling to -5° practically all of the material separated from the reaction mixture. It was dissolved in ether, washed and dried in the usual manner, and purified by fractional distillation *in vacuo*.

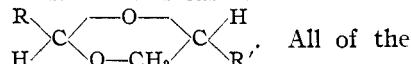
(11) Because of the tendency of this salt to resinify the carbonyl compound only 0.003 mole could be used.

The following cyclic acetals and ketals were prepared by the procedure described above.

Compound (1,3-dioxolane)	B. p., (corr.), °C.	Yield, %	Analyses			
			Calcd.		Found	
			C	H	C	H
2-Phenyl- ^{12a} (benzylidene glycol)	225	35
4-Methyl-2-phenyl-	118 (23 mm.)	30	73.1	7.3	72.9	7.5
2-Hexyl- ^{12b,13}	200	25
4-Methyl-2-hexyl-	102.5-103.5 (23 mm.)	22	69.7	11.6	69.6	11.7
2-Methyl-2-hexyl-	97 (23 mm.)	25	69.7	11.6	68.9	11.9
2,4-Dimethyl-2-hexyl-	102 (23 mm.)	30	70.9	12.0	70.5	12.2
2-Methyl-2-phenyl- ¹⁴	103.5-104.5 (23 mm.)	28	73.1	7.3	73.1	7.3
2,4-Dimethyl-2-phenyl-	105 (23 mm.)	32	74.1	7.9	73.8	7.9

2-Phenyl-1,3-dioxolane and 2-hexyl-1,3-dioxolane were identified by their boiling points, and by comparison with the same compounds prepared from ethylene glycol. In every case the compounds were readily hydrolyzed by dilute acid to the corresponding aldehyde or ketone.

Hibbert¹⁵ has shown that compounds of the type  are capable of existing in two isomeric forms. These isomers are accounted for by the different relative positions of the groups R and R', and may be considered as *cis* and *trans* isomers. In this case the *trans* form

would be represented by the formula . All of the compounds in this paper, which were prepared from propylene oxide, should show this type of isomerism, in addition to optical isomerism. Since none of these compounds were solids, no method could be devised for separating the isomers.

While the preparation of cyclic acetals from ethylene or substituted ethylene glycols is quite satisfactory in most cases, the cyclic ketals are prepared only with difficulty and in very small yields.¹⁶ Thus, by the use of ethylene glycol in the presence of 40% sulfuric acid, the authors were unable to prepare even a trace of the cyclic ketal of acetophenone.¹⁷ Although the method described in this paper is not entirely satisfactory, it furnishes a simple approach to cyclic ketals which are difficult or impossible to make by the usual method.

The polysubstituted ethylene oxides in which more than one hydrogen is replaced have not been studied. However, it may be anticipated that these compounds will react in an analogous manner, at least in the case of

(12) (a) Hibbert and Timm, *THIS JOURNAL*, **46**, 1283 (1924); (b) Dworzak and Herrmann, *Monatsh.*, **52**, 83 (1929).

(13) Lochert, *Ann. chim. phys.*, [6] **16**, 26 (1889).

(14) Crystallized from ether in large flat plates, m. p. 62° (corr.), soluble in alcohol, toluene, carbon tetrachloride, petroleum ether, acetone and glacial acetic acid; insoluble in water.

(15) Hibbert and Carter, *THIS JOURNAL*, **50**, 3376 (1928).

(16) (a) Böeseken and Hermans, *Rec. trav. chim.*, **42**, 1104 (1923); (b) Dworzak and Herrmann, *Monatsh.*, **52**, 83-106 (1929).

(17) Cf. Fröschl and Heuberger, *Monatsh.*, **59**, 289 (1932).

the simpler derivatives. An investigation of the higher membered oxides such as trimethylene oxide and tetrahydrofuran was not undertaken, since the lesser reactivity of these compounds made it seem doubtful that an appreciable reaction would take place.

Summary

Ethylene oxides react with aldehydes and ketones in the presence of metallic chlorides to form cyclic acetals, in yields varying from 25 to 35%

By this method six new acetals and ketals were prepared, some of which would be difficult or impossible to make by the use of a glycol.

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The Measurement of Oxidation-Reduction Potentials in Glacial Acetic Acid Solutions

BY J. B. CONANT AND B. F. CHOW

It was shown eight years ago¹ that the ion of a halochromic salt and a free radical such as triphenylmethyl form a mobile oxidation-reduction system whose potential can be measured in a non-aqueous medium. The lack of adequate information about the properties of acids and bases in such non-aqueous media prevented a detailed quantitative study of the problem at that time. A study of glacial acetic acid solutions was undertaken therefore, and has now reached a point where it is possible to return to the study of oxidation-reduction potentials in this and similar non-aqueous media. In this paper we shall present the results of the study of certain dyes and quinones of the type which has been studied extensively in water; in a later paper we shall consider the rather unique system composed of a free radical and a halochromic salt.

The measurements were all made using glacial acetic acid as the solvent. The hydrogen-ion activity was kept constant in each experiment by means of suitable "buffers," which in most instances consisted of an organic base partially neutralized with sulfuric acid. The ionic strength was constant at 0.2 in all the buffers, and where necessary a neutral salt was added to bring the value of the ionic strength to 0.2. The exact composition of the buffers is given in Table I together with the $(P_H)^{HAc}$ values determined by means of a chloranil electrode as previously described in papers from this Laboratory.

The Acidity Scale in Acetic Acid

A few words are necessary in regard to the significance of the $(P_H)^{HAc}$ values. Since the first work from this Laboratory on glacial acetic acid,

(1) Conant, Small and Taylor, *THIS JOURNAL*, **47**, 1959 (1925).