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# OXIDATION OF ALCOHOLS AND ALDEHYDES

IN KOH - DIMETHOXYETHANE - O2 SYSTEMS

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In previous works we used the KOH-dimethoxyethane(DME)-18-crown-6 (18-c-6) ether system for the oxidation by oxygen of a series of alkyl aromatic compounds to the corresponding acids. Obviously the intermediate compounds in this process should be aldehydes and alcohols. However, analysis of reaction mixtures during the course of these reactions revealed the absence of any substantial quantities of alcohols and aldehydes, which indicates their quite rapid conversion to acids. Inasmuch as the oxidation of aldehydes and alcohols by oxygen in a basic medium is a virtually unexplored process we investigated the oxidation of benzaldehyde and some of its derivatives in the KOH-DME system, and also that of benzyl alcohol and a number of other alcohols.

It seems that aromatic aldehydes are readily oxidized by oxygen in KOH-DME systems at 20°C, forming the corresponding acids in nearly quantitative yields (Table 1). In the absence of base the oxidation of benzaldehyde does not take place to any great extent in a reaction run lasting 48 h. As seen from Table 1 benzaldehyde with either electron-donor or electron-acceptor substituents is rapidly and smoothly oxidized. The stoichiometry of the absorption of  $O_2$  is 0.7 mole of  $O_2$  for each mole of ArCHO.

It is known that transformations of carbonyl compounds in basic media involve the addition of the base to the carbonyl group as the first step, in which case it leads to the formation of adducts A and A' (Scheme 1). It would be predicted that adducts A and A' in solution are capable of forming ion pairs B and B' in limited steady-state concentrations., Then the function of the oxidizing agent is reduced to acceptance of hydride ions from these ion pairs. However direct attack of the oxidizing agent on the hydride of the tetrahedral intermediates A and A' is not excluded. In principle the oxidizing agent maybe both the aromatic aldehyde itself (paths a, a') and the oxygen (paths b, b')



In the first instance we are dealing with the well-known Cannizzaro reaction. In order to establish the reaction rates for a and b we carried out the reaction of benzaldehyde and also its  $p-NO_2$ - and  $p-CH_3O$ - derivatives with KOH and DME in an Ar atmosphere. It appeared that the reaction with PhCHO was 50% complete in 2 min and 98% complete in 5 min. With p-nitrobenzaldehyde the reaction was complete after 2-3 min, whereas with anisaldehyde the reaction was 80% complete in 5 min but required 40-60 min to go all the way to completion. There-

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TABLE 1. Oxidation of Aromatic Aldehydes in KOH-DME-O<sub>2</sub> Systems at 20°C

x in XC₀H₄CHO	Reaction time, h	Yield of XC <sub>6</sub> H <sub>4</sub> COOH, %
H m-NO <sub>2</sub> p-NO <sub>2</sub> p-MeO p-Br	3-3,5   4   4   4   4   4	100 92-96 94-96 95-97 93-96

TABLE 2. Oxidation of Alcohols in KOH-DME- $O_2$ Systems at 20°C

Alcohol	Reaction time, h	Yield of acid
$\begin{array}{l} C_{6}H_{5}CH_{2}OH \\ p-MeOC_{6}H_{4}CH_{2}OH \\ p-NO_{2}C_{6}H_{4}CH_{2}OH \\ p-NO_{2}C_{6}H_{4}CH_{2}OH + p-NO_{2}C_{6}H_{4}CHO \ (1:1) \\ p-NO_{2}C_{6}H_{4}CH_{2}OH + p-NO_{2}C_{6}H_{4}CHO \ (1:2) \\ Me_{3}CCH_{2}OH \\ Ph_{2}CHOH \end{array}$	$ \begin{array}{c ccccccccccccccccccccccccccccccccccc$	100 96 60 75 95 8085 9095 <b>*</b>

\* Reaction product, benzophenone.



Fig. 1. Oxidation of benzyl alcohol by oxygen in dimethoxyethane containing hydroxides of alkali metals: KOH (1), NaOH (2), LiOH (3); PhCH<sub>2</sub>OH = 0.333 M.

Fig. 2. Oxidation by oxygen of the ethylates of potassium (1), sodium (2), and lithium (3) in dimethoxyethane, [EtOM] = 1 M, \* is the point at which the KOH was added.

Fig. 3. Influences of the concentration of benzyl alcohol on its oxidation rate by oxygen in the KOH-DME system. [PhCH<sub>2</sub>OH] = 1.0 (1), 0.5 (2), and 0.25 M (3).

fore the oxidation of benzaldehydes under these conditions includes a rapid Cannizzaro reaction and subsequent rather slow oxidation of the benzylic alcohols by the oxygen. However partial direct oxidation of the benzaldehydes by oxygen (paths b and b') is not excluded.

We carried out the oxidation of benzylic alcohols and also neopentyl alcohol in this same KOH-DME system (Table 2). All of the alcohols studied with the exception of  $p-NO_2C_6H_4CH_2OH$  are oxidized to acids in nearly quantitative yields. One oxidation product is benzophenone.

It is well known that alcoholate ions derived from primary and secondary alcohols are reducing agents capable of yielding hydride ions to suitable acceptors such as ketones, aldehydes and nitroso compounds [1]. It is believed that on dehydrogenation of primary aliphatic and aromatic-aliphatic alcohols to acids by heating with strong bases in aqueous solutions at 200-300°C (Dumas-Stass reaction [2]) the water acts as the hydride ion

acceptor [3]. An alcohol molecule can serve as a similar kind of hydride ion acceptor at 200-225°C [4, 5]. It is natural that carrying out the two subsequent reactions requires rigorous conditions. Using a stronger hydride ion acceptor, oxygen, and an aprotic medium allows oxidation of alcohols to be accomplished under mild conditions,



Oxidation of an alcohol by the action of oxygen, by analogy with Scheme 1, can take place with participation of ion pair B as an intermediate (Scheme 2).\* Oxygen, reacting with alcoholate A or ion pair B converts an alcohol into an aldehyde (or a ketone in the case of  $Ph_2CHOH$ ). The aldehyde, as previously indicated, disproportionates with formation of the corresponding acid and alcohol



As evident from Table 2 oxidation of p-nitrobenzyl alcohol leads to the formation p-nitrobenzoic acid with a yield of only 60%. Along with the acid a substantial amount of tar is formed which is probably a mixture of products of partial reduction of the nitro group by reaction with a base. However on adding  $p-NO_2C_6H_4CHO$ , (which is apparently a much stronger hydrideion acceptor than the nitro group) to the reaction mixture, the yield of acid goes up to almost quantitative.

An important peculiarity of the oxidation of alcohols found in this study is the dependence of their oxidation rate on the nature of the base. On going from KOH to LiOH, i.e., with a decrease in the cation group, the oxidation rate drops sharply (Fig. 1). This fact is linked both with the decreased strength of the base and with the decreased ability of the alcoholate to oxidize by increasing the degree of association of the metallic cation with oxygen in the order K < Na $\leq$  Li [6-8]. The same order of cation activities is observed in the intramolecular hydride reductions of carbonyl compounds by alcoholates [9-11]. We found that the oxidation of benzyl alcohol in a basic medium goes more rapidly in the presence of KOH than NaOH. However on oxidation of the aforementioned benzylates it appears that the rates of oxidation of Na and K benzylates are approximately equal and very high (absorption of half of the maximum quantity of oxygen occurs within 5 min). This signifies that the base influences the reaction rate also, by means of a step involving alcoholate formation. However, lithium alcoholate is oxidized much more slowly. In the DME  $-O_2$  system we carried out the oxidation of methyl and ethyl alcohols and the corresponding alcoholates. It appears that the oxidation rate drops in the series Ph<sub>2</sub>CHOH > PhCH<sub>2</sub>OH > EtOH > MeOH. Of course the oxidation rate of alcohols depends on many factors: the ease of conversion to the alcoholate (which is determined by the acidity of the alcohol [12, 13]), the basicity of the alcoholate ion, the association of the ion pair [6-8] etc. Because ethanol and methanol oxidize more slowly the effect of the nature of the opposite ion is stronger here than with benzyl alcohol. Thus the oxidation of potas-

<sup>\*</sup> It should be noted that alternate mechanisms for oxidation of benzylic alcohols in the presence of bases, including the intermediate formation of the ArCHOH carbanion or the dianion  $ArCHO^-$ , are improbable since oxidation of PhCH<sub>2</sub>Cl in this system reaches only 20% after 24 h and probably via the stage of hydrolysis of the chloride to PhCH<sub>2</sub>OH.

sium ethylate and methylate take place at substantially different rates (Fig. 2). The same situation is observed on addition of 18-c-6 ether. Its effect was practically imperceptible on the rapidly oxidized benzyl alcohol but very substantial on the oxidation of methanol.

The oxidation of alcohols in KOH-DME systems is greatly inhibited by the addition of hydroxyl-containing solvents. Thus oxidation of benzyl alcohol is completely suppressed in the presence of 5% (by volume) of water. (The reaction does not start, at least within a 15-hperiod.) In this case only the Cannizzaro reaction was observed with aldehydes although its rate is also greatly reduced. After 3 h the reaction is only 15-20% complete (equivalent amounts of PhCH<sub>2</sub>OH and PhCOOH are present in the reaction mixture). Benzyl alcohol also has an inhibiting action in that on increasing its concentration in the DME solution the oxidation rate is decreased (Fig. 3).

The inhibiting action of hydroxyl-containing solvents is evidently linked with the decreased basicity of both the KOH and the potassium benzylate as a result of hydrogen bond formation. The inhibiting action of water could also be caused by shifting the following equilibrium reaction to the left

### $ROH + KOH \Rightarrow ROK + H_2O$

As was evident in the example of the reaction of  $p-NO_2C_6H_4CH_2O^-K^+$  with  $p-NO_2C_6H_4CHO$ , the alcoholate under these conditions is capable of acting as a hydride donor with respect to the nitrobenzaldehyde. Under these same conditions alcoholate ions reduce other carbonyl compounds, as for example, benzophenone. The reaction of Ph<sub>2</sub>CO with KOH in a 10:1 DME<sup>-</sup>ethanol mixture for 5-6 h at 20°C leads to the formation of benzhydrol in 75% yield. As noted above the scheme of reduction by the action of alcoholates includes elimination of hydride ions. In the instances of tertiary alcoholates  $R_3CO^-$  evidently elimination of carbanions can occur, whereby the ease of splitting off of R<sup>-</sup> should correspond to the stability of the carbanion formed. We have shown that the dimethyl(trichloromethyl)carbinol in DME splits in the presence of KOH with elimination of the CCl<sub>3</sub> anion, which was indicated by the detection of dichlorcarbene in the reaction carried out in the presence of cyclohexene. Indeed also potassium tris(p-nitrophenyl) carbinolate forms p-nitrophenol in the presence of oxygen which is evidence for the elimination of the p-NO<sub>2</sub>C<sub>6</sub>H<sub>4</sub><sup>-</sup> carbanion [14].

In conclusion it should be noted that the proposed  $KOH-DME-O_2$  system makes it possible to carry out the oxidation of benzaldehydes and benzylic alcohols under mild conditions and with quantitative yields of the corresponding acids or ketones. This relates to the mechanism of oxidation of alcoholates by the action of oxygen as well as the reaction of reduction of carbonyl compounds by the action of alcoholates, in which two possible mechanisms may be considered, the ionic [9-11] and the free radical [15, 16]. Because we do not have any basis for assumptions about the free radical character of the basic stages of these reactions, the acceptance of the hydride ion by the oxygen or the carbonyl compound, we are inclined toward the ionic mechanism. It should also be noted that in the scheme which we proposed no steps were included involving the participation of inorganic peroxides (which by their nature tend to produce free radicals) in the oxidation process.

#### EXPERIMENTAL

Analysis of the reaction mixtures and the reaction products was carried out by a GLC method on the LKhM-8MD chromatograph on columns of 1-2-m length, 3-mm diameter, carrier gas (nitrogen) at a rate of 20 ml/min, temperature interval used 120-200°C, flame ionization detector. Packing used: 10% E-301 on Khezasorb AWGMDS; 7% 1,3-bis(3-phenoxy)benzene (5Ph4É) on 545 Celite AWGMDS.

The synthesis of p-methoxybenzyl alcohol was carried out by a method analogous to that described in [17]. Commercially available KOH and NaOH were used in all oxidation and reduction reactions. The base was stored in a dry container and pulverized before each experiment. The DME was purified by a twofold distillation from KOH, distilled twice from Na, and preliminary to the experiment, from LiAlH<sub>4</sub>. The oxidation was carried out in a 25-50-ml two-necked flask provided with stopcocks. One of the stopcocks was connected to a gas burette filled with oxygen. Mixing was accomplished by means of a magnetic stirrer.

<u>General Method of Oxidation of Alcohols and Aldehydes.</u> A mixture of DME and KOH was purged several times with oxygen, then the calculated quantity of alcohol or aldehyde was added. After the absorption of oxygen ceased, the mixture was diluted with water and traces of neutral products extracted with an appropriate solvent. The organic layer was evaporated on a rotary evaporator, the aqueous layer acidified with HCl, and the acidic products extracted or filtered off. The average concentration of alcohols and aldehydes in the solution ranged from 0.125-0.5 M. About a tenfold excess of base was used.

Carrying Out the Cannizzaro Reaction in KOH-DME Systems. A mixture of aldehyde, KOH and DME was stirred in an Ar atmosphere. The aldehyde concentrations were 0.333 M. Samples were taken every minute (in

the case of  $p-MeOC_6H_4CHO$  the first five samples were taken every minute then after 10, 20, 40, and 60 min). The samples were diluted with water, the neutral products extracted with ether, the aqueous layer acidified, and the acids extracted with ether. The acids were analyzed in the form of methyl esters. The yields of products were nearly quantitative.

Oxidation of the Alcoholates. The oxidation and isolation of products were carried out according to methods previously described. The synthesis of potassium alcoholates was carried out by dissolving metallic potassium in a solution of an equivalent quantity of alcohol in benzene. The benzene was distilled off and DME added. Sodium ethylate and methylate were obtained directly by dissolving metallic sodium in ethanol and methanol, and PhCH<sub>2</sub>ONa by heating the sodium with a solution of benzyl alcohol in benzene. Lithium benzylate was obtained by adding an equivalent quantity of BuLi to a solution of benzyl alcohol in ether with cooling. The resulting mixture was warmed to about 20°C, stirred 30 min, the solvent was distilled off, and DME added. The average concentration of alcoholate was 0.5 M.

Reduction of Benzophenone in KOH-DME Systems. A mixture of 0.5 g  $Ph_2CO$ , 1 ml ethanol, 3 g KOH, and 10 ml DME was stirred 3 h in Ar. The solvent was distilled off and the mixture added to 30 ml of water and acid added to neutrality. The precipitate formed was filtered off and dried. Yield of benzhydrol 75%, mp 65-67 (from hexane).

Splitting of Dimethyl(trichloromethyl)carbinol. A mixture of 0.9 g of the alcohol, 0.5 ml cyclohexene, 2 g KOH in 10 ml DME was stirred 6 h in Ar. The solvent was distilled off, the mixture diluted with water and the neutral products extracted with ether. From the GLC analysis data the dichlorocarbene assay was 0.05 g (10% of the theoretical).

#### CONCLUSIONS

1. The method presented for oxidation of aromatic aldehydes and alcohols by oxygen in KOH-DME systems makes it possible to obtain carboxylic acids in high yields under mild conditions.

2. The rate of oxidation of alcoholates varies greatly according to the nature of the accompanying action and decreases in the order:  $K^+ > Na^+ > L^+$ .

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