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REDUCTION OF ALDEHYDES AND KETONES TO ALCOHOLS WITH HYDROUS ZIRCONIUM OXIDE AND 2-PROPANOL

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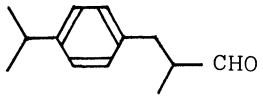
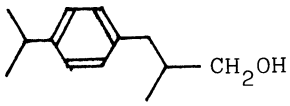
Reduction of aldehydes and ketones with 2-propanol was found to proceed efficiently in the presence of hydrous zirconium oxide. The reaction is performed simply and the products are easily isolated in the pure state by filtering off the hydrous zirconium oxide, followed by evaporation of solvents.

It is well known that ketones and aldehydes can be reduced satisfactorily by the use of metal alkoxides and alcohols (Meerwein-Ponndorf-Verley reduction). Aluminum alkoxide (especially isopropoxide) has been found to be the best reagent. It has the advantage of being a much weaker condensing agent than other metal alkoxides and of being soluble in both alcohols and hydrocarbons. It induces a more rapid reaction, side reactions are reduced, and the yield of product is improved.[1] Disadvantage in the reaction is the need of strong acidic treatment to neutralize alkoxide salt as well as tedious other workups.

In this paper, we describe an alternative to aluminum isopropoxide, namely, the use of hydrous zirconium oxide. The hydrous zirconium oxide was employed in the form of hard granules. It was translucent polymer, and amorphous to X-ray diffraction. The surface area was 300 to 400 m^2g^{-1}.[2] It was stable at room temperature in air for 7 years, and it could be used anytime for the reduction. It was removed easily from a reaction mixture and could be used for another reaction. The hydrous zirconium oxide was prepared by the slow addition of an aqueous solution of sodium hydroxide (1 mol/l) to an aqueous solution of zirconium oxychloride ($ZrOCl_2 \cdot 8H_2O$) (200 g of solid in 10 l deionized water) at room temperature. Constant gentle stirring was maintained and the addition was continued until the pH of the resulting solution increased to a constant value of 6.80. The solution was allowed to stand for a period of 48 h at room temperature. The resulting product was filtered and washed free from chloride ions. The gel was spread over a glass plate and dried in air at room temperature for 10 h and then at 80 °C for 2 h. Fifty four grams of the oxide was obtained as granules.

A typical procedure of the reduction is as follows. In a 100 ml round bottomed flask equipped with a reflux condenser are placed 10 g of hydrous zirconium oxide (8-14 mesh), 911 mg (5 mmol) of benzophenone, 10 ml of 2-propanol, and 142 mg (1 mmol) of n-decane as an internal standard. The contents were heated under gentle reflux. The amounts of benzophenone and its reduction product were

Table 1. Reduction of Aldehydes and Ketones with Hydrous Zirconium Oxide and 2-Propanol[a)]

	Aldehyde & Ketone	Reaction time / h	Product	Yield[b)] / %
1	2-Methylbutanal	1	2-Methylbutanol	100
2	Hexanal	1	1-Hexanol	83
3	Decanal	1.5	1-Decanol	72
4	Benzaldehyde	1	Benzyl alcohol	43
5	Cyclamen aldehyde 	5		100 (100[c)])
6	Butanal	1	1-Butanol	80
7	2-Methylpropanal	1	2-Methylpropan-1-ol	100
8	Cyclohexanone	2	Cyclohexanol	98
9	2-Methylcyclohexanone	2	2-Methylcyclohexanol	100[e)]
10	Acetophenone	12	1-Phenylethanol	100
11	Propiophenone	10	1-Phenylpropan-1-ol	100
12	Benzophenone	10	Benzhydrol	100 (96[c)])
13	1,4-Benzoquinone	1	Hydroquinone	100 (98[c)])
14	2-Decanone	5	2-Decanol	100
15	3-Decanone	30	3-Decanol	100
16	2-Pentanone	10	2-Pentanol	100
17	Camphor	30	Borneol and Isoborneol	21[d,e)]

a) Reaction conditions : aldehyde or ketone (5 mmol), hydrous zirconium oxide (10 g), in 10 ml of 2-propanol under reflux

b) Determined by GLC using n-decane as an internal standard

c) Isolated yield

d) 79% of camphor was recovered
e) A mixture of two epimeric alcohols (1 : 1)

determined by GLC using a calibration obtained with authentic mixtures. After ten-hour heating, the content were cooled and filtered. The hydrous zirconium oxide was washed with ether. After rotary evaporation of the solvents, 885 mg (96%) of the alcohol was obtained as colorless needles.

The results of the procedure using aldehydes and ketones are shown in Table 1.

Several aspects of the reactions 1-17 (Table 1) merit discussion. The rates of the reduction of aldehydes are faster than that of ketones (with an exception of reaction 13). The reduction of hindered ketones and aldehydes are subjected to some steric effect. Reaction 5 shows that it took much time to complete the reduction of aldehyde with bulky groups, although simple aldehydes were reduced within 1 h. Reaction 17 shows that complete reduction of camphor was not obtained within 30 h. Reactions 14 and 15 indicate that a less hindered carbonyl group in ketone could be reduced preferentially. These suggest that controlled experiments might make possible to reduce ketone and/or aldehyde groups selectively. In the case of straight-chain aldehydes, some side-reactions were observed by GLC and the yields of the reduction products are somewhat low (reactions 2,3, and 6). However, a methyl group attached to the α-position to a formyl group seems to inhibit the side-reactions (reactions 1,5, and 7). Reduction of ketones does not accompany the side-reactions (reactions 8-17). Reaction 4 shows that the reaction is rapid, but the yield of benzyl alcohol is low (43%). A certain amount of condensed products with benzyl alcohol was observed by GLC. Two epimeric alcohols (1 : 1) were given by the reduction of 2-methylcyclohexanone or camphor. It is unknown in those examples (reactions 9 and 17) whether the selectivity depends on a result of the kinetic control or on that of the thermodynamic control.[3] The replacement of 2-propanol by ethanol did not have advantage. In the case of the reduction of cyclohexanone, 20-30% of the ketone gave condensed products not only between two molecules of the ketone but also between the ketone and acetaldehyde.

Recovered hydrous zirconium oxide could be used again. After completion of the reduction of 2-methylbutanal, the oxide was removed by filtration, washed with 2-propanol, dipped in hot water (80 °C) for 2 h and dried at 80 °C for 5 h. Some part of the oxide was broken up. A little amount of pulverized oxide was floated on the hot water and can be removed easily by decantation. The recovery of the oxide was 98%. The oxide was subjected to the reduction of cyclohexanone. The ketone was completely reduced after two-hour reaction. Advantages of this method are (1) stability of the oxide which can be stored at room temperature in air and used anytime; (2) easy product isolation; (3) possibility of repeated usage of the oxide.

We are now interested in the selectivity[4,5] for carbonyl reduction and the compatibility with many types of functional groups.

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