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# On the Mechanism of Alcoholysis of Allylic and Benzylic Alcohols and of Epoxides in the Presence of Ceric Ammonium Nitrate

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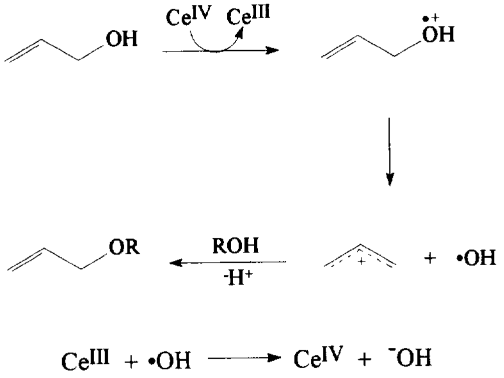
*Key words:* Alcoholysis, Allylic and Benzylic Alcohols, Cerium IV.

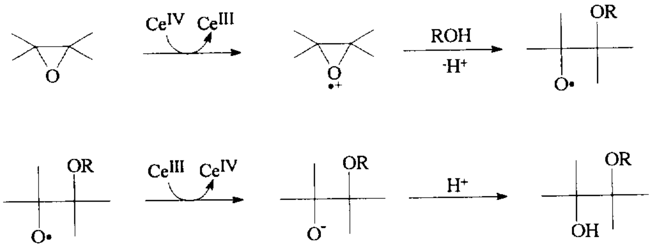
**Abstract** : The methanolysis of allylic alcohols, benzylic tertiary alcohols and epoxides in the presence of a catalytic amount of ceric ammonium nitrate (CAN) is shown to be catalysed by protons generated from the oxidation of methanol. This reaction is also catalysed by Lewis acids.

## Introduction

Recently, Iranpoor *et al.* (1, 2) reported that ceric ammonium nitrate (CAN) acted as an effective catalyst for the alcoholysis of allylic alcohols and benzylic tertiary alcohols (1) and for the alcoholysis of epoxides (2). They proposed a mechanism involving first the oxidation of the alcohol (Scheme 1) or the epoxide (Scheme 2) to a radical cation then the heterolytic cleavage of the C-O bond to a carbocation and a hydroxyl or an alcoxyl radical which is reduced by Ce (III) with the regeneration of Ce (IV); the carbocation subsequently reacts with the alcohol to give an ether. The formation of polyacrylamide when the alcoholyses were performed in the presence of acrylamide was taken as evidence for the formation of the hydroxyl or alcoxyl radical intermediates. Using ferric chloride or 2,3-dichloro-5,6-dicyano-p-benzoquinone (DDQ) as catalysts, Iranpoor et *al.* (3, 4) obtained similar results as those obtained with CAN.



**Scheme 1**



**Scheme 2**

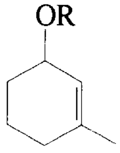
In this paper, we report that methanolysis of allylic alcohols, benzylic tertiary alcohols and epoxides, carried out in the presence of a catalytic amount of sulfuric acid, gives exactly the same results (yields and reaction time) as the methanolysis performed in the presence of a catalytic amount of CAN under identical conditions of temperature and concentration. We also show that the Lewis acid catalysed methanolysis of the same substrates gives comparable yields.

## Results and discussion

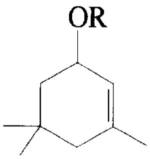
The results of a comparison of the methanolysis of triphenylmethanol (1), 3-methyl-2-cyclohexen-1-ol (2), 3,5,5-trimethyl-2-cyclohexen-1-ol (3) and 1-chloro-2,3-epoxypropane (4) in the presence of CAN and in

$Ph_3COR$

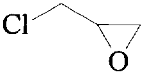
1, R = H
5, R = Me



2, R = H
6, R = Me



3, R = H
7, R = Me



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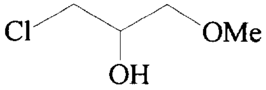

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the presence of sulfuric acid under identical experimental conditions are recorded in Table 1. In entries 1, 8 and 18, the reaction conditions were the same as those used by Iranpoor et *al.* (1, 2) and the yields obtained for ethers 5, 6 and 8 were the same, within the experimental errors, as those reported. Thus, we were able to reproduce exactly the results published by Iranpoor et *al.* (1, 2). One may note that with benzylic alcohol 1, the yield of ether 5 was essentially the same using a 0.05 molar equivalent of CAN as compared to a 0.2 molar equivalent used by the Iranian authors (compare entries 1 and 2). The most striking feature of Table 1 is that the yields of ethers were exactly the same wether sulfuric acid (0.05 or 0.2 molar equivalent with alcohols 1, 2 and 3; 0.4 molar equivalent with epoxide 4) or CAN was used as a catalyst (compare entries 1 to 4, 8 to 10, 14 to 16 and 18 to 19). This strongly suggests that methanolysis in the presence of CAN is catalysed by protons generated by oxidation of the solvent which is present in large excess with respect to the substrate (alcohol or epoxide). Indeed, when the molar fraction of Ce (IV) was monitored by potentiometric titration (Table 2), it was found not only that it continuously decreased during the methanolysis to reach zero after 4.5 hours, so the reaction is not catalytic with respect to Ce (IV), but that the rate of disappearance of Ce (IV) was the same in the absence and in the presence of an allylic alcohol. Further confirmation of the reaction of CAN with methanol came from trapping of the formaldehyde formed with 5, 5-dimethyl-1, 3-cyclohexanedione in the absence and in the presence of the organic substrate. No α,β-unsaturated ketone resulting from the oxidation of 2 and 3 by CAN was detected.

Iranpoor et *al.* (1, 2) used the formation of polyacrylamide when the CAN catalysed methanolysis of 2 and of 4 was carried out in the presence of an excess of acrylamide as evidence for the radical mechanisms of Scheme 1 and Scheme 2. We found that the polymerization of acrylamide was initiated under the CAN catalysed methanolysis conditions *wether alcohol 2 was present or not*. Since polymerization of acrylamide was observed in the absence of any organic substrate, such polymerization cannot be taken as evidence for the mechanisms proposed by Iranpoor et *al.* (1, 2) (Schemes 1 and 2). The polymerization of acrylamide is most probably initiated by the addition to acrylamide of the hydroxymethylene radical generated in the oxidation of methanol.

Table 1. Methanolysis of Alcohols 1-3 (0.075 M) and Epoxide 4 (0.075 M) in the Presence of CAN, $H_2SO_4$, $AlCl_3$, $CuSO_4$ and $CeCl_3$

| Entry | Substrate | Cat. (molar frac.) | Reaction time (hr) | Reaction temp.[a] | Product | % Yield | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | GLC | isolated | Lit. |
| 1 | 1 | CAN (0.2) | 4.5 | r. t. | 5 | 97 | 88 | 97[b] |
| 2 | | CAN (0.05) | 4.5 | r. t. | | 92 | 90 | - |
| 3 | | $H_2SO_4$ (0.2) | 4.5 | r. t. | | 97 | 93 | - |
| 4 | | $H_2SO_4$ (0.05) | 4.5 | r. t. | | 97 | 93 | - |
| 5 | | $AlCl_3$ (0.2) | 4.5 | r. t. | | 95 | 89 | - |
| 6 | | $CuSO_4$ (0.2) | 24 | refl. t. | | 97 | 91 | - |
| 7 | | $CeCl_3$ (0.2) | 192 | refl. t. | | 97 | 92 | - |
| 8 | 2 | CAN (0.2) | 0.25 | r. t. | 6 | 94 | 93 | 93[b] |
| 9 | | $H_2SO_4$ (0.2) | 0.25 | r. t. | | 94 | 86 | - |
| 10 | | $H_2SO_4$ (0.05) | 0.25 | r. t. | | 93 | 80 | - |
| 11 | | $AlCl_3$ (0.2) | 0.50 | r. t. | | 96 | 80 | - |
| 12 | | $CuSO_4$ (0.2) | 15.5 | refl. t. | | 93 | 83 | - |
| 13 | | $CeCl_3$ (0.2) | 24 | refl. t. | | 93 | 93 | - |
| 14 | 3 | CAN (0.2) | 0.5 | r. t. | 7 | 97 | 87 | - |
| 15 | | $H_2SO_4$ (0.2) | 0.5 | r. t. | | 99 | 90 | - |
| 16 | | $H_2SO_4$ (0.05) | 0.5 | r. t. | | 94 | 88 | - |
| 17 | | $AlCl_3$ (0.2) | 3.5 | r. t. | | 96 | 89 | - |
| 18 | 4 | CAN (0.4) | 0.50 | refl. t. | 8 | 96 | 95 | 91[c] |
| 19 | | $H_2SO_4$ (0.4) | 0.50 | refl. t. | | 95 | 94 | - |

[a] R.t. : room temperature (20-23 °C); refl.t. : refluxing temperature (65 °C).
[b] Taken from ref. 1.
[c] Taken from ref. 2.

As can be seen in Table 1 (entries 5 to 7, 11 to 13, and 17), the yields of methanolysis of alcohols 1, 2 and 3 catalysed by Lewis acids were as high (93-96 %) as those obtained by proton catalysis (CAN or sulfuric acid, 92-99 %, entries 1 to 4, 8 to 10, 14 to 16). Cupric sulfate (entries 6 and 12) and cerous chloride (entries 7 and 13) required refluxing methanol and the methanolysis took between 15 to 192 hours depending on the substrate. Aluminium trichloride (entries 5, 11 and 17) is more efficient since methanolysis was carried out at room temperature and took between 0.5 to 4.5 hours depending on the substrate. Protons appear slightly more efficient than aluminium trichloride on the basis of the shorter reaction times required for methanolysis of alcohols 2 and 3 in the presence of sulfuric acid or CAN.

Table 2. Variation of the Molar Fraction of Ce $^{IV}$ in Methanol at Room Temperature in the Absence and in the Presence of a Substrate

| Entry | Solution | Residual molar fraction of Ce $^{IV}$ [a] (%) | | | |
|---|---|---|---|---|---|
| | | Time (hours) | | | |
| | | 0.25 | 0.5 | 1 | 4.5 |
| 1 | MeOH + Ce $^{IV}$ + 1 | 74-78 | 58-74 | 52-54 | 0 |
| 2 | MeOH + Ce $^{IV}$ + 3 | 68-70 | --- | 58-61 | 0 |
| 3 | MeOH + Ce $^{IV}$ | 78-80 | 68-74 | 45-65 | 0 |

[a] Range of values obtained from 2-3 experiments determined by potentiometric titration.

In conclusion, we have shown that the methanolysis of allylic alcohols, benzylic tertiary alcohols and epoxides carried out in the presence of CAN is catalysed by protons generated from the oxidation of methanol. The mechanisms proposed by Iranpoor et *al.* (1, 2) (Schemes 1 and 2) are therefore not valid.

## Experimental

Alcohols 1, 2 and 3 and epoxide 4 were purchased from Aldrich. Infrared spectra were recorded in chloroform on a 1600 FTIR Perkin Elmer spectrometer and $^1$H NMR spectra were taken in deuterochloroform on a 300 MHz Bruker BFX-5 apparatus. The gaz liquid chromatography (GLC) analyses were performed on a Hewlett Packard (HP) 5710A chromatograph equipped with a flame ionization detector and an HP 3390A integrator, using a DB-5 fused capillary column 30 m long.

### *General procedure for the methanolyses*

Methanolysis of alcohols 1, 2 and 3 and of epoxide 4 was performed in anhydrous methanol (dried over Mg turnings) as described by Iranpoor (1, 2) and the progress of the reaction was monitored by GLC. The products obtained after extraction with ether and removal of the organic solvent under reduced pressure were pure according to GLC analysis and spectroscopic data. The ethers 5, 6, 7 and 8 were identified by comparison of their infrared and $^1$H NMR data with the literature data (ref. 1 for 5 and 6; ref. 5 for 7 and ref. 2 for 8).

### *Polymerization of acrylamide*

- In methanol only

To a 5 mL solution of methanol containing 1.42 g (20 mmol) of acrylamide, 219 mg of CAN (0.4 mmol) was added. After 3 hours, a white precipitate was formed and filtered. Polyacrylamide was characterized by differential scanning calorimetry (DSC). T.G. : 179.4 °C (Litt. : 165 °C (6)).

- In the presence of alcohol **2**

The reaction was carried out as above in the presence of 119 mL (1mmol) of alcohol **2** and polyacrylamide was also formed and characterized.

*Determination of the $Ce^{IV}$ concentration*

- In the absence of substrate

To a 5 mL solution of methanol, 219 mg of CAN (0.4 mmol) were added. Depending on the progress of the reaction, aliquots of 1 to 5 mL were poured into a 5 % sulfuric acid solution (150 mL). The residual concentration of $Ce^{IV}$ was determined by potentiometric titration using a previously standardised solution ($6 \cdot 10^{-3}$ M) of ferrous ammonium sulfate in $H_2SO_4$ 5 %. The reference electrode was a saturated calomel electrode (SCE) purchased from Sargent Welch and the working electrode was a 1 mm diameter platinum wire.

- In the presence of alcohol **1** or **3**

The same procedure as above was followed except that 1 mmol of alcohol **1** or **3** was added.

*Reaction with 5, 5-dimethyl-1, 3-cyclohexanedione*

- In methanol only

In a 100 mL round bottom flask containing 329 mg of CAN (0.6 mmol), 40 mL of anhydrous methanol were added. After 4.5 hours, the temperature of the mixture was decreased to - 40 °C and 25 mL of water containing 210 mg of 5, 5-dimethyl-1, 3-cyclohexanedione (1.5 mmol) were added. After extraction with ether and removal of the organic solvent under reduced pressure, the formation of methylene bis-dimedone was shown by GC-MS and thin layer chromatography and by comparison with an authentic sample obtained from the reaction of a formaldehyde solution (Fisher Scientific) with 5, 5 dimethyl 1, 3-cyclohexanedione ( m. p. = 188 °C; litt.(7) = 188 °C).

- In the presence of alcohol **1**

The reaction was carried out as above in the presence of 781 mg of alcohol **1** (3 mmol) and the formation of methylene bis-dimedone was shown as above.

Acknowledgements

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