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FERRATE (VI) ION, A NOVEL OXIDIZING AGENT[1]

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Oxidation of a primary or secondary alcohol to the corresponding aldehyde or ketone with reagents[3] such as chromium(VI) in sulfuric acid or pyridine[4], specially prepared manganese dioxide in pentane[5], aluminum isopropoxide in acetone[6], or lead tetraacetate in pyridine[7] has received considerable attention in recent years. Certain problems have been associated with oxidation procedures in general; i.e., failure of the reagent to be specific or selective often leads to oxidation of the aldehyde product to the corresponding acid as well as to reaction with unsaturated linkages in the molecule and subsequent degradation of the substrate. Furthermore, the presence of a strong acid as catalyst can give rise to reaction of the formed aldehydic function with the substrate alcohol to yield a hemi-acetal which is readily oxidized to an ester, a major side-reaction for chromium(VI) oxidations in sulfuric acid. The presence of a strong base catalyst is again undesirable in that isomerization and/or condensation can occur with more active molecules, for example, in the Oppenauer oxidation reaction. Another requirement for several oxidation procedures is that a high reflux temperature is necessary for oxidation to proceed, a factor which often leads to complicating side-reactions.

This communication reports our findings that potassium ferrate(VI) K_2FeO_4[8], is a selective oxidizing agent at room temperature in water and mixed solvents. Primary alcohols and amines and secondary alcohols are converted rapidly to the corresponding aldehydes or ketones. Unsaturation in the molecule as well as aldehyde, tertiary alcohol and tertiary amine functional groups are resistant to oxidation under the conditions employed.

The oxidizing ability of ferrate(VI) on organic substrates has not been investigated to a significant extent. Becarud[9], in an investigation of the properties of ferrate(VI) salts, reported that no specific organic reaction was found for this oxidizing agent. Zhdanov and

Pustovarova[10], however, using a 200 per cent excess of 0.1M alkaline solution of potassium ferrate(VI), converted methyl, ethyl, and propyl alcohols to the aldehydes in yields of less than twenty per cent. They also found that the secondary alcohols, isopropyl alcohol and cyclohexanol, could be converted to the ketones in low yields. However, only benzoic acid (45 per cent) was identified from the oxidation of benzyl alcohol, a result contrary to that reported herein.

A series of alcohols and amines were oxidized in the present study and these are listed in Table I along with their corresponding products, yield data, and approximate time for complete reaction. In all cases, the reactions were carried out at room temperature in water at an initial pH of approximately 11.5 since ferrate(VI) reacts slowly in neutral solution and is very unstable in acidic media. The yield of product was not affected by initial solubility of the substrate molecule, in fact, the best yields were obtained for heterogeneous reactions where base catalyzed condensation reactions could not occur to a significant extent. The reaction medium acts as an indicator as it turns from deep purple to colourless with the formation of the brown precipitate, $Fe(OH)_3$, when all the oxidant has been reduced. The final pH of the reaction solution was approximately 13.5. Oxidation gave only the aldehyde or ketone with the only isolatable by-product[11] being the unreacted starting material. Double bonds were not oxidized under the conditions employed as styrene and cyclohexene were recovered quantitatively from the reaction mixture and cinnamyl alcohol produced only cinnamaldehyde. Furthermore, tertiary alcohols and tertiary amines were also unreactive as t-butanol and N,N-dimethylbenzylamine did not decolorize a purple ferrate(VI) solution.

A typical procedure is as follows: K_2FeO_4, 0.002 mole, was added to the alcohol or amine, 0.003 mole, in 10 ml of water and the resulting solution or mixture was shaken vigorously until the purple colour of the ferrate(VI) disappeared (1 minute to 90 minutes). The basic reaction mixture was extracted with either diethylether or benzene. The combined organic extracts were dried and the solvent removed under reduced pressure to yield the crude product. The product was purified and the percentage yield determined by gas-liquid chromatography and N.M.R. analysis. The aqueous layer was acidified and examined for acidic products.

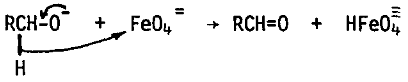
The oxidation reaction is qualitatively dependent on both the concentrations of ferrate(VI) ion and substrate with the slower reactions appearing to have an inhibition period. It is catalyzed by base and water is essential since the process did not proceed in dry dimethylsulfoxide, diglyme, or dioxane although addition of water to these solvents caused reaction in

Table I[12]

Reactant	Product	Approximate Yield(%)	Time for Complete Reaction (min)
Ethanol	Acetaldehyde	20-30	45
n-Heptanol	n-Heptaldehyde	30	70
Benzyl alcohol	Benzaldehyde	80	4
1-Phenylethanol	Acetophenone	90	18
2-Phenylethanol	α-Phenylacetaldehyde	20	6
Cyclohexanol	Cyclohexanone	20-30	90
Cinnamyl alcohol	Cinnamaldehyde	75	7
Benzyl amine	Benzaldehyde	70	1
1-Methylbenzylamine	Acetophenone	70	4

the mixed solvents. The following reaction pathway similar to that suggested by Stewart[13] for permanganate oxidations of alcohols in basic solutions, may account for the results obtained;

$$RCH_2OH + OH^- \rightleftarrows RCH_2O^- + H_2O \qquad |1|$$



$$RCH\text{-}O^- + FeO_4^{=} \rightarrow RCH{=}O + HFeO_4^{\equiv} \qquad |2|$$

$$FeO_4^{=} + HFeO_4^{\equiv} + OH^- \rightarrow H_2O + 2FeO_4^{\equiv} \qquad |3|$$

$$FeO_4^{\equiv} + RCH_2O^- \rightarrow HFeO_4^{\equiv} + RCHO \qquad |4|$$

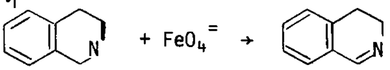
$$HFeO_4^{\equiv} + 3H_2O \rightarrow Fe(OH)_3\downarrow + 4OH^- \qquad |5|$$

The alkoxide ion generated in equation 1 reacts with ferrate (VI) to produce aldehyde and $HFeO_4^{\equiv}$ by hydrid ion transfer (eq. 2). The $HFeO_4^{\equiv}$ ion combines with ferrate (VI) and hydroxide to produce $FeO_4^{\equiv}$ (eq. 3) which reacts with alkoxide to form aldehyde and $HFeO_4^{\equiv}$ (eq. 4). $HFeO_4^{\equiv}$ is hydrated by solvent water to give ferric hydroxide and hydroxide ion (eq. 5). The overall reaction results in a net production of base. This is consistent with the inhibition period observed for the less reactive substrates.

The intermediate for the amine oxidations could possibly be an imine which is rapidly hydrolyzed by water to produce the carbonyl function, eq. |6|.

$$RCH=NH \; + \; H_2O \rightarrow RCH+O \; + \; NH \qquad |6|$$

This is supported by the fact that 1,2,3,4-tetrahydro-isoquinoline when oxidized produced 3, 4-dihydro-isoquinoline in high yield, a compound expected to be resistant to hydrolysis, as the major product, eq. | 7.|



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We believe that this oxidation prodedure is very useful because of its specificity, mild conditions and speed of reaction. We are currently investigating the kinetics, scope, mechanism and optimum synthetic conditions of this novel oxidation reaction.

References

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