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A STEREOCHEMICAL PROBE OF THE FATE OF CARBON RADICALS OXIDIZED BY METALS

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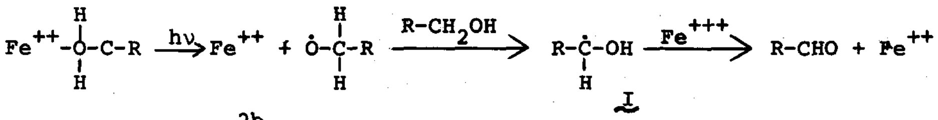
There have been numerous studies on the photoreduction of iron complexes which proceed generally by electron transfer to the metal from a ligand.[1] Peculiar among these are reports of the photodissociation of iron(III)-alcohol complexes which are reported to produce alkoxy radicals and eventual alcohol oxidation *via* Scheme I.[2] Support for this scheme comes from the observation of radicals[2b] such as I in the esr and the isolation of carbonyl products. There has appeared as yet no direct evidence for an alkoxy radical and in particular no report of a most typical alkoxy radical reaction, γ-hydrogen abstraction.

Scheme I



$$\mathrm{Fe^{++}\text{-}\overset{H}{\underset{H}{O}}\text{-}C\text{-}R \xrightarrow{h\nu} Fe^{++} + \dot{O}\text{-}\overset{H}{\underset{H}{C}}\text{-}R \xrightarrow{R\text{-}CH_2OH} R\text{-}\underset{H}{\dot{C}}\text{-}OH \xrightarrow{Fe^{+++}} R\text{-}CHO + Fe^{++}}$$

Photolysis of an acetonitrile solution of 2-cyclohexylethanol (1) in the presence of anhydrous ferric perchlorate[3] with a Hanovia 450-watt lamp through a Pyrex filter led to complete reduction of iron(III) to iron(II) after 4 hr (quantum yield ~0.1). Concentration of the reaction mixture and analysis of the products after distillation afforded cyclohexyl acetaldehyde (2) and *cis* and *trans*-perhydrobenzofuran (3 and 4)[4] (Table I, Scheme II).

The first-order interpretation of these results is that an alkoxy radical (5), initially formed upon photodissociation of an iron(III)-2-cyclohexyl ethanol complex [1 → Fe(III)], undergoes intramolecular γ-hydrogen abstraction in a manner analogous to the family of Barton-type reactions.[5]

Scheme II

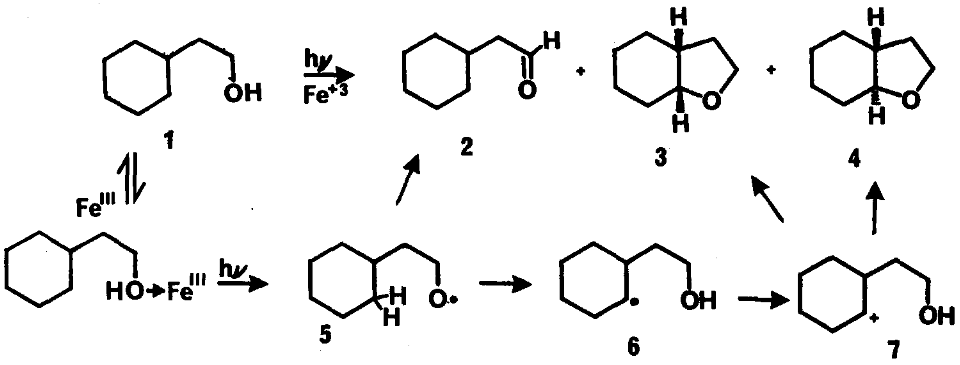


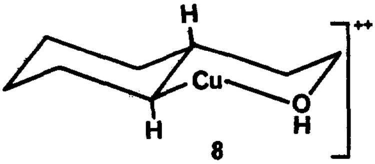
Table I

Reaction Conditions	Yield (%)			
	2	3	4	3/4
a) 9.25 g $Fe(ClO_4)_3$ + 1.28 g 1, hν 4 hr	16^e	4	17	0.24
b) 3.25 g LTA, 1.0 g 1, reflux 8 hr	35	27	7	3.9
c) As in b with 1.5 g $Cu^{++}(BF_4)_2$	7	5.5	25	0.22
d) As in b with 1.5 g $Fe^{+++}(ClO_4)_3$	19	23	11.5	2.0
e) Increased to 64% with $Fe^{+++}(ClO_4)_3 \cdot 6H_2O$. Cf. Ref. 12.				

At this stage of detail the mechanism outlined in Scheme II is identical to currently prevailing ideas regarding the mechanism of cyclic ether formation by the lead tetraacetate oxidation of alcohols.[6] However, treatment of 1 with lead tetraacetate in refluxing benzene-acetonitrile mixtures produces a profound difference in the stereochemistry of the ether products (3/4 = 3.9). Accordingly, there must be a divergent fate of the organic radical 6 depending on the nature of the metal oxidant. Significantly, the LTA oxidation favors the more stable *cis*-isomer 3,[4,6e] while the strained *trans*-isomer (4) is equally predominant in the iron photoreduction.

Both iron and lead would be expected *a priori* to involve electron transfer oxidation but a convenient explanation for the marked difference in *cis*/*trans* ratios of cyclic ether formation would be a change in the mechanism of radical oxidation by one of the two metals.[7,8,9] To probe this possibility, we have observed the distribution of ether products in the LTA oxidation of 1 as a function of added transition metal. Added ferric perchlorate caused a small but distinct increase in the amount of 4 and added cupric fluoroborate led to predominant formation of the *trans*-isomer 4 in analogy to the iron(III) photoreduction result (Table I).

Since cupric ion is known to be an extremely efficient oxidant of organic radicals, we conclude that the intermediate carbon radical (6) produced from the LTA oxidation of 1 is intercepted by copper(II) and to a lesser extent by iron(III) and that copper(II) oxidation and iron(III) oxidation of 6 produces predominantly *trans* stereochemistry. The proposed intermediacy of alkylcopper intermediates provides a satisfying explanation for the observed stereochemical preferences. Models indicate the need to considerably distort carbonium ion 7 in order to produce 4. Accordingly, we propose that electron transfer oxidation of 6 by lead leads to 7 which cyclizes to give predominantly the less strained *cis*-ether 3. In contrast, if oxidation of 6 by copper(II) leads to an alkylcopper and if, in acetonitrile, the hydroxyl group is also a ligand of copper, two stereochemically distinct bicyclic alkylcopper intermediates (8 and 9) are possible.



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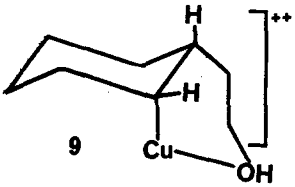

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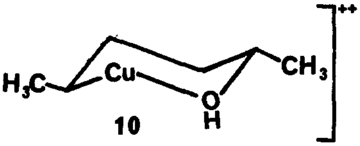

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Most rudiments of conformational analysis would predict that 8 would be lower in energy than 9. Oxidative substitution of 8 with retention of configuration at the copper-bound carbon would of necessity afford the less stable *trans*-ether (4).[10] By analogy, 6 may be oxidized by iron(III) in acetonitrile *via* a similar process.

Also significant in these oxidative cyclizations is the lack of olefinic products expected for oxidative elimination of complexes such as 8. Indeed, the Fe^{++}/Cu^{++} promoted decomposition of 2-hexylhydroperoxide in acetonitrile has been reported to yield equal amounts of elimination and substitution products (olefin and ether).[11] This difference would be well accounted for by the conformational rigidity of complex 8 if oxidative elimination has geometrical structures since the methyl protons in 10 are free to adopt any preferred conformation. These factors are under current study.[12]

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References and Notes

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(3) Ferric perchlorate, "Reagent, Non Yellow" was obtained from the G. Frederick Smith Co., Columbus, Ohio, and was used as received. 2-Cyclohexyl ethanol was prepared by the treatment of cyclohexylacetic acid with lithium aluminum hydride.

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(9) For a cogent review see J. K. Kochi, Ref. 5, Ch. 11.

(10) More formally, this process may be regarded as a solvent-assisted heterolysis of the copper-carbon bond and subsequent displacement of the solvent molecule by the pendant hydroxyl. Alternatively, the process may be regarded as an "internal" oxidative displacement, *cf.* Ref. 9, p. 610, a similar suggestion,insertion of a neighboring ligand,has been proposed by C. Walling, C. M. El'taliawi, and R. A. Johnson, *J. Amer. Chem. Soc.*, **96**, 133 (1974).

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