ELECTRON TRANSFER ACTIVATION. HYDROPEROXIDE INTERMEDIATES IN A NOVEL AND SELECTIVE PROCEDURE FOR BENZYLIC OXIDATIONS.
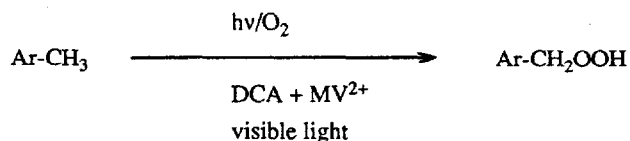
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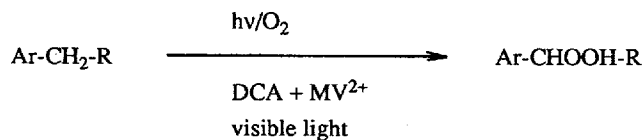10 rue Vauquelin - 75231 PARIS Cedex 05.

Abstract : A selective and mild photochemical procedure for benzylic oxidations with 9,10-dicyanoanthracene (DCA), an usual electron acceptor, in the presence of methyl viologen (MV^{2+}), an electron relay, has been developed. Methyl and methylene groups are oxidized in good to excellent yields to the corresponding hydroperoxides.

Hydroperoxides are important intermediates in autoxidation and in organic synthesis for which they represent useful forms of "mono-oxygen donating" reagents for oxidative transformations.

For their preparation, the most attractive oxidant, from the point of view of cost, is molecular oxygen. Thus, alkyl hydroperoxides can be produced in high selectivity *via* autoxidation of tertiary aliphatic hydrocarbons or alkylaromatic hydrocarbons. Unfortunately, for the latter group, autoxidation suffers from one basic disadvantage: oxidizability[1] decreases *significantly in the order tertiary > secondary > primary benzylic C-H bonds*[2]. Thus, with primary alkylaromatics, the rate of chain-termination is so high that it is not possible to achieve a *high selectivity in hydroperoxide at reasonable rates of reaction*.

We report a selective and mild photochemical procedure for benzylic oxidations based on a photoinduced electron transfer reaction using 9,10-dicyanoanthracene (DCA), an usual electron acceptor, in the presence of methyl viologen (MV^{2+}), an electron relay. Benzylic methyl and methylene groups are selectively oxidized in good to excellent yields (57-100 %) to the corresponding hydroperoxides which can be isolated as such.

$$Ar\text{-}CH_3 \xrightarrow[\substack{DCA + MV^{2+} \\ \text{visible light}}]{hv/O_2} Ar\text{-}CH_2OOH$$

$$\text{Ar-CH}_2\text{-R} \xrightarrow[\substack{\text{DCA + MV}^{2+} \\ \text{visible light}}]{\text{h}\nu/\text{O}_2} \text{Ar-CHOOH-R}$$

Typical procedure. The irradiation of an acetonitrile-methanol (9-1) solution (50 ml) of aromatic compound (3 mmol) in the presence of catalytic amounts of DCA (0.02 mmol) and MV^{2+} (0.02 mmol) is carried out with a 500 W high-pressure mercury lamp through a U.V. cut-off glass filter ($\lambda \geq 420$ nm) at 20°C under oxygen bubbling. The progress of the photoreaction is followed by t.l.c. and h.p.l.c. After consumption of the substrate, the solvent is removed and the residue analyzed on the basis of the ^{1}H NMR data. The oxygenated products are isolated by flash column chromatography on silica gel[3].

Table 1 summarizes the results obtained with various aromatic hydrocarbons. With polymethyl substrates, only one methyl group was oxidized in these conditions, and in the naphthalene series oxidation occurs selectively on a methyl group in the α position.

Table 1 - DCA, MV^{2+}-sensitized photooxidation of various alkylaromatic compounds.

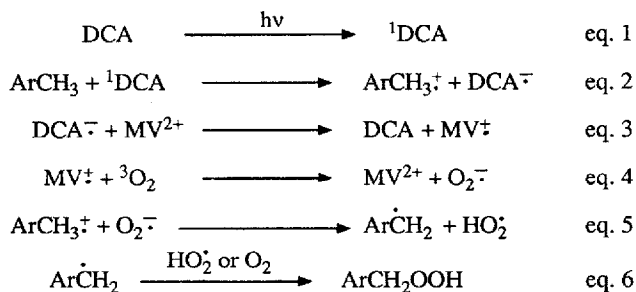| Substrate		Yield^a (%)			Reaction time (h)
a, $ArCH_3$		**b,**$ArCH_2(\alpha)OOH$	**c,**$ArCH(\alpha)O$	**d,**$ArC(\alpha)OOH$	
1-Methylnaphtalene	**1a**	**1b**[4] 93	6	traces	3
1,2-Dimethylnaphthalene	**2a**	**2b**[5] 93	7	traces	1.5
1,3-Dimethylnaphthalene	**3a**	**3b**[6] 88	11	traces	3
1,4-Dimethylnaphthalene	**4a**^{b}	**4b**[7] 70	20	2	3.5
1,2,3,4-Tetramethylnaphthalene	**5a**^{c}	**5b**[8] 57	5	2	3
1,2,3,4,5-Tetramethylbenzene	**6a**	**6b**[9] 100	-	-	2
Hexamethylbenzene	**7a**	**7b**[10] 77	15	7	4
a, Ar-CH$_2$-R					
Ethylbenzene	**8a**	**8b** 100	-	-	1.5
Tetralin	**9a**	**9b** 100	-	-	2
1-Ethylnaphthalene	**10a**	**10b**[11] 100	-	-	2

a. *Evaluated from ^{1}H NMR data* ; b. *1,4-endoperoxide (6 %) was concurrently obtained* ; c. *Similarly, the 1,4-endoperoxide (32 %) was also obtained.*

Competitive formation of singlet oxygen adducts, which predominate in these series when DCA is used

alone as was shown before[12], remains low, though not completely suppressed, in the present conditions. For instance with the more reactive $^1O_2$-acceptors **4a** or **5a** only minor amounts of the corresponding 1,4-endoperoxides are also formed and could be recovered.

To explain the preceeding results, a sequence of electron transfer steps as shown in Scheme 1 are postulated.

In acetonitrile, all the substrates quench DCA fluorescence at diffusion controlled rates[12] and the radical cation $ArCH_3^{\ddot{+}}$ generated by electron transfer from a substrate to ^1DCA (eq. 2) is the key intermediate of photooxidation. From the respective reduction potentials of ground state oxygen and methyl viologen $(E(O_2/O_2^{\bar{\cdot}})$ $= -0.78$ V^{13}, $E(MV^{2+}/MV^{\ddot{+}}) = -0.45$ $V^{14})$ it is probable that the anion radical $DCA^{\bar{\cdot}}$ $(E(DCA/DCA^{\bar{\cdot}}) = -0.89$ $V^{13})$ transfers afterwards an electron preferentially to methyl viologen (eq. 3). This step should reduce simultaneously the rate of back electron transfer to the radical cation $ArCH_3^{\ddot{+}}$ and may be the origin of the stepping down of $^1O_2$ production[12,15]. Subsequently the reduced form of methyl viologen would be reoxidized rapidly by ground state oxygen producing the superoxide anion $O_2^{\bar{\cdot}}$ (eq. 4).

$$DCA \xrightarrow{h\nu} {}^1DCA \qquad \text{eq. 1}$$

$$ArCH_3 + {}^1DCA \longrightarrow ArCH_3^{\ddot{+}} + DCA^{\bar{\cdot}} \qquad \text{eq. 2}$$

$$DCA^{\bar{\cdot}} + MV^{2+} \longrightarrow DCA + MV^{\ddot{+}} \qquad \text{eq. 3}$$

$$MV^{\ddot{+}} + {}^3O_2 \longrightarrow MV^{2+} + O_2^{\bar{\cdot}} \qquad \text{eq. 4}$$

$$ArCH_3^{\ddot{+}} + O_2^{\bar{\cdot}} \longrightarrow Ar\dot{C}H_2 + HO_2^{\dot{}} \qquad \text{eq. 5}$$

$$Ar\dot{C}H_2 \xrightarrow{HO_2^{\dot{}} \text{ or } O_2} ArCH_2OOH \qquad \text{eq. 6}$$

Scheme 1

Finally, deprotonation of the alkylaromatic radical cation, possibly by superoxide anion (eq. 5)[16], should lead to the neutral radical which then gives the hydroperoxide either by cage-recombination with the radical $HO_2^{\dot{}}$ or by the classical free-radical chain autoxidation as postulated by preceding authors in related electron-transfer photooxidations[16,17].

A distinction between these two terminal possibilities is difficult although it could be remarked that contrary to most classical initiated autoxidations of alkylaromatics the percentages of aldehyde and acid remain very low in our conditions. This can be taken as indicating a different mechanism.

REFERENCES AND NOTES

1. For a discussion of oxidizability see R.A. Sheldon and J.K. Kochi, *Metal-Catalyzed Oxidations of Organic Compounds*, Academic Press, New-York (1981).
2. J.A. Howard, *Adv. Free-Radical Chem.*, **4**, 49 (1972).
3. Solvents were distilled prior to use. Reaction products were isolated from preparative reactions by flash chromatography on silica gel (230-400 mesh). Elution with pentane-CH_2Cl_2 (1:1 to 0:1) gave hydroperoxide compounds. Cristalline hydroperoxides were recristallized from ether.

4. **1b.** M$^+$ 174 (5 %, C$_{11}$H$_{10}$O$_2$), 156, 141, 128 ; IR (CHCl$_3$, cm^{-1}) 3380 (OH) ; ^{1}H NMR (CDCl$_3$, δ) 5.43 (2H, s, CH$_2$OOH), 7.85 (7H, m, H arom.), 8.16 (1H, s, broad, D$_2$O exchangeable OOH).

5. **2b.** M$^+$ 188 (6 %, C$_{12}$H$_{12}$O$_2$), 170, 155, 141, 128, 115 ; IR, 3380 (OH) ; ^{1}H NMR, 2.55 (3H, s, CH$_3$-C$_2$) ; 5.50 (2H, s, CH$_2$OOH) ; 7.73 (6H, m, H arom.), 8.16 (1H, s, broad, D$_2$O exchangeable OOH).

6. **3b.** M$^+$ 188 (8 %, C$_{12}$H$_{12}$O$_2$), 170, 155, 141, 128, 115 ; IR, 3390 (OH) ; ^{1}H NMR, 2.48 (3H, s, CH$_3$-C$_3$), 5.41 (2H, s, CH$_2$OOH) , 7.73 (6H, m, H arom.), 8.06 (1H, s broad, D$_2$O exchangeable OOH).

7. **4b.** M$^+$ 188 (5 %, C$_{12}$H$_{12}$O$_2$), 170, 155, 141, 128, 115 ; IR, 3380 (OH) ; ^{1}H NMR, 2.66 (3H, s, CH$_3$-C$_4$), 5.40 (2H, s, CH$_2$OOH), 7.70 (6H, m, H arom.), 8.06 (1H, s broad, D$_2$O exchangeable OOH).

8. **5b.** m.p. 86 °C ; M$^+$ 216 (16 %, C$_{14}$H$_{16}$O$_2$), 198, 183, 171, 155, 141, 128, 115 ; IR, 3385 (OH) ; ^{1}H NMR, 2.40 (3H, s, CH$_3$), 2.50 (3H, s, CH$_3$), 2.63 (3H, s, CH$_3$), 5.56 (2H, s, CH$_2$OOH), 7.4 (2H, m, H arom.), 8.06 (2H, m, H arom.), 8.56 (1H, s, broad, D$_2$O exchangeable OOH).

9. **6b.** m.p. 44 °C ; M$^+$ 166 (13 %, C$_{10}$H$_{14}$O$_2$), 148, 147, 133, 119 ; IR, 3390 (OH) ; ^{1}H NMR, 2.05 (6H, s, CH$_3$-C$_4$,C$_5$), 2.31 (3H, s, CH$_3$-C$_2$), 4.98 (2H, s, CH$_2$OOH), 6.96 (1H, s, H$_3$), 7.08 (1H, s, H$_6$), 7.85 (1H, s, D$_2$O exchangeable OOH).

10. **7b.** m.p. 116 °C ; M$^+$ 194 (6 %, C$_{12}$H$_{18}$O$_2$), 176, 175, 161, 160, 145, 133, 115 ; IR, 3390 (OH) ; ^{1}H NMR, 2.21 (9H, s, CH$_3$-C$_3$,C$_4$,C$_5$), 2.31 (6H, s, CH$_3$-C$_2$,C$_6$), 5.18 (2H, s, CH$_2$OOH), 8.00 (1H, s broad, D$_2$O exchangeable OOH).

11. **10b.** M$^+$ 188 (12 %, C$_{12}$H$_{12}$O$_2$), 170 ; IR, 3385 (OH) ; ^{1}H NMR , 1.56 (3H, d (J = 6 Hz), CH$_3$), 5.78 (1H, q (J = 6 Hz), CH), 7.56 (6H, m, H arom.), 8.00 (1H, m, H$_8$), 8.20 (1H, s broad, D$_2$O exchangeable OOH).

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