

Regioselective Photo-oxygenation of 2-Aryl-4,5,6,7-tetrahydroindoles: Preparation and Reactions of 2-Aryl-7a-hydroperoxy-4,5,6,7,7a-pentahydroindolenines

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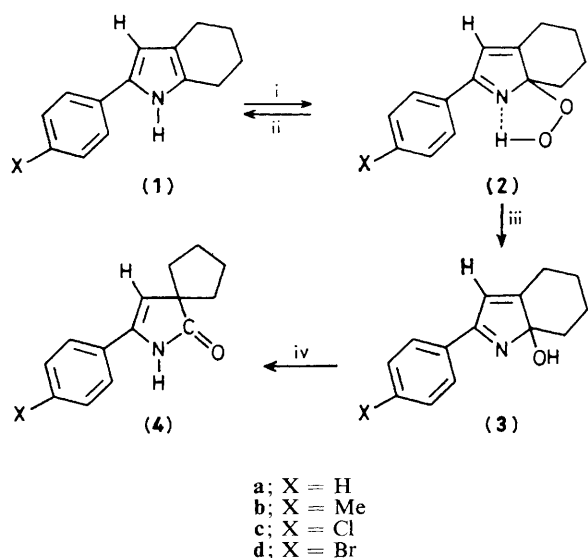
Dye-sensitized photo-oxygenation of 2-aryl-4,5,6,7-tetrahydroindoles quantitatively afforded 2-aryl-7a-hydroperoxy-4,5,6,7,7a-pentahydroindolenines, which were converted into the corresponding hydroxy-indolenines and spiro- γ -lactams in excellent yields.

Dye-sensitized photo-oxygenation of pyrroles has been widely investigated during the last 2 decades.¹⁻⁷ However, in this photoreaction, a variety of oxidation products or complex mixtures were generally produced in a non-selective manner except in the cases of poly-phenyl- and poly-*t*-butyl-substituted pyrroles.^{6,7} We now report the regioselective photo-oxygenation of bicyclic pyrroles such as 2-aryl-4,5,6,7-tetrahydroindoles (**1a—d**) to give stable hydroperoxy compounds (**2a—d**) at room temperature.

Irradiation of methanolic solutions of (**1a—d**) containing methylene blue as sensitizer under a continuous stream of

oxygen gas with a 300 W halogen lamp for 20—30 min regioselectively gave 2-aryl-7a-hydroperoxy-4,5,6,7,7a-pentahydroindolenines (**2a—d**) in quantitative yield (Scheme 1).† No solvent-incorporated product was detected *via* its endoperoxide even at low temperature (≤ -50 °C).

† After evaporation of methanol below 30 °C, the residue was dissolved in benzene-hexane(1:1). Insoluble methylene blue was filtered off and evaporation of the solvent below 30 °C gave the hydroperoxide as a colourless solid in a practically pure state.



Scheme 1. i, *hν*-methylene blue, O₂, MeOH; ii, NaBH₄, MeOH; iii, PPh₃ or Me₂S; iv, heat or KOBu^t-DMF.

For the formation of (2a), tetraphenylporphyrin was also effective as a sensitizer. However, a complex mixture was obtained when rose bengal or Ru(bpy)₃²⁺ (bpy = bipyridine) was used. It was also found that MeCN, CH₂Cl₂, and C₆H₆ can be used as solvents. The oxidation of (1a) by NaOCl-H₂O₂ in an aqueous methanolic solution afforded the hydroperoxide (2a) in the dark. The formation of (2a) in the methylene blue-sensitized photoreaction was quenched by 1,4-diazabicyclo-[2.2.2]octane or β-carotene efficiently. These results clearly suggest that ¹O₂ is an active species for the photo-oxidation.

The structures of (2a-d) were assigned from their ele-

mental analyses and spectral properties,† and also from chemical transformations including the positive peroxide test.

The hydroperoxides (2a-d) were stable at room temperature (≤35 °C) for at least 10 days. The reduction of (2a-d) with PPh₃ in Et₂O or Me₂S in MeOH gave 2-aryl-7a-hydroxy-4,5,6,7,7a-pentahydroindolenines (3a-d) in quantitative yields.‡ In contrast, the reduction of (2a) with NaBH₄ in MeOH afforded the starting pyrrole (1a) in a quantitative yield. The other unusual observation was that the spiro-γ-lactams (4a-d) are obtained in excellent yields (80–90%) via 1,5-sigmatropic rearrangement on pyrolysis of (3a-d) at 180 °C for 3 min under an argon atmosphere or on treatment with KOBu^t in *N,N*-dimethylformamide at –30 °C for 1 h.‡

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† Compound (2a): m.p. 126–128 °C (decomp.); u.v. λ_{max}(MeOH) 252 nm (ε 14 000); i.r. ν_{max}(KBr) 3040, 2840–2740 (OOH ··· N), 1640 (C=N), and 1600 cm⁻¹; *m/z* 213 (*M*⁺–16); ¹H n.m.r. δ(CDCl₃) 8.80–3.05(8H, m, CH₂), 6.40(1H, s, CH=C), 7.00–7.60 (5H, m, Ph), and 12.00(1H, br., OOH). Compound (3a): m.p. 154–155 °C (decomp.); u.v. λ_{max}(MeOH) 252 nm (ε 17 200); i.r. ν_{max}(KBr) 3080(OH), 1635 (C=N) cm⁻¹; *m/z* 213(*M*⁺); the ¹H n.m.r. spectrum of (3a) was not obtained owing to its insolubility in CDCl₃ and (CD₃)₂SO. Compound (4a): m.p. 181–182 °C; i.r. ν_{max}(KBr) 3140(NH), 1680(C=O) cm⁻¹; *m/z* 213(*M*⁺); ¹H n.m.r. δ(CDCl₃) 1.40–2.10(8H, m, CH₂), 5.65(1H, d, *J* 2 Hz, CH=C), 7.20–7.60(5H, m, Ph), 9.45(1H, br., NH); ¹³C n.m.r. δ(CDCl₃) 26.1(t), 36.5(t), 57.4(s), 111.6(d), 124.7(d), 128.6(d), 128.8(d), 130.3(s), 138.0(s), and 187.0(s) p.p.m. All new compounds gave satisfactory elemental analyses.