# Novel Radical Couplings in the Photoreduction of Xanthenoid Dyes with Tribenzylamine

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The photoreduction of the eosin analogue (1; R = H) by tribenzylamine under anaerobic conditions is found to produce a high yield of the cross-coupled product (3; R = H) which readily reoxidises to the starting dye. The formation of (3; R = H), which is considered to take place in the initial solvent cage, has implications for earlier kinetic studies on the photoreduction of related dyes.

The effectiveness of the photocatalysed initiation of vinyl monomer polymerisation[1] by eosin Y (1; R = CO_2^- Na^+)–tertiary amine mixtures depends on the concentrations of amine and eosin derived radicals generated and the efficiency of these species as initiators for chain growth. In photostudies on the fate of the dye, when styrene polymerisation was carried out in dilute benzene solution under anaerobic conditions with tribenzyl-amine as the tertiary amine,[2] it was noticed that two major leuco forms were produced in approximately equal quantities and that these both regenerated eosin Y under aerobic conditions. By working with the more tractable eosin Y analogue, 6-hydroxy-9-phenyl-2,4,5,7-tetrabromo-3H-xanthen-3-one (1; R = H), which showed similar photochemical characteristics, we have been able to establish that the corresponding leuco analogues are the expected dihydro derivative of (2; R = H) (>52% yield) and the unexpected cross-coupled product from the amine and the dye (3; R = H) (>39% yield). Reports of significant yields of cross coupling products when tertiary amines act as the reducing agents in the photoreduction of ketones appear to be confined to a limited number of intra-molecular examples involving phenyl ketones[3] and the photo-reduction of benzophenone with diazabicyclo[2.2.2]octane.[4] As far as we are aware the formation of (3; R = H) constitutes the first authenticated example of such cross-coupling in the photo-bleaching of triarylmethane dyes.


(1)

(2)

(3)
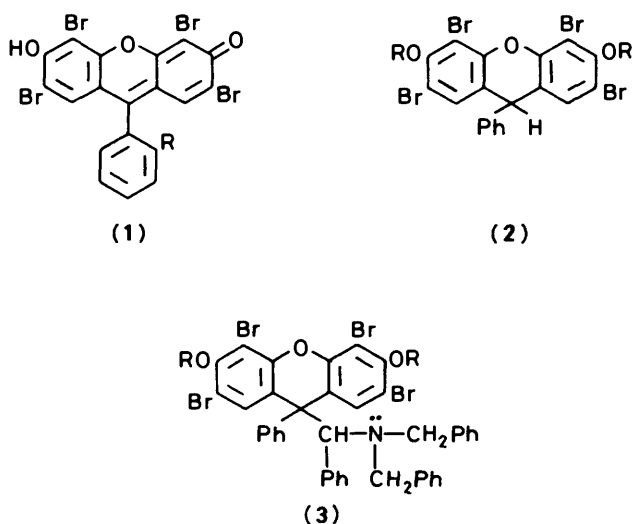
The two major leuco compounds were revealed by two-dimensional t.l.c. of the phenolic products formed when benzene solutions of either eosin Y or the less polar analogue (1; R = H) were irradiated. Styrene had no detectable influence on their formations and was omitted in all but the initial experiments.

After chromatography of the products on the silica gel plates in one direction, the leuco compounds were allowed to reoxidise before development in the second direction was carried out to identify the regenerated dyes. This reoxidation was slower in the dark and effectively absent in vacuo. Comparable chromato-graphic studies with authentic samples of the corresponding dihydro dye indicated that this was the more polar leuco product in each case. Minor colourless products from the irradiation experiments, which reverted to the starting dyes, were also detected on chromatographing the authentic dihydro dyes. These are regarded as the 9-hydroperoxy and 9-hydroxy intermediates formed on aerial oxidation of the dihydro compounds.[5]

In order to characterise fully the leuco products a dilute solution of the tetrabromoxanthene derivative (1; R = H) (0.45 mmol l^{-1}) and tribenzylamine (66 mmol l^{-1}) was irradiated in degassed benzene with light from a halogen 150 W lamp for 3 h, over which period the solution became virtually colourless. The alkali-soluble products were isolated, purified by h.p.l.c., and methylated with diazomethane to prevent reoxidation. The identity of the dimethyl ether (2; R = Me), m.p. 210 °C, from the dihydro product, was established by direct comparison with an authentic sample prepared by reduction ($NaBH_4$) of the dye followed by methylation. Elemental analysis and mass spectro-scopy of the methylated product clearly indicated that the second leuco compound was formed from the coupling of radicals derived from both the dye and tertiary amine. In parti-cular, the mass spectrum showed a high abundance of a tetra-bromo fragment with m/z centred at 631 and abundant ions at m/z 211 and 196 which were also observed in the spectrum of tribenzylamine. The linkage between C-9 of the xanthene nucleus and a benzylic carbon of the amine residue followed from the ^1H n.m.r. spectrum which showed two methoxy methyls (δ 3.82 and 3.93) and two isolated aromatic protons (δ 6.64 and 6.66) in prochiral environments.[6] Two coupled signals (δ 2.85 and 3.54, J_{gem} 13.6 Hz) for four benzylic protons and a methine singlet (δ 4.75) were also in accord with structure (3; R = Me). The characteristic signal (δ 5.15) shown by the 9-H in the dimethyl ether (2; R = Me) was absent.

The photo-oxidation of tertiary amines by aryl ketones or quinonoid dyes involves the initial transfer of one lone pair electron from the amine nitrogen to the triplet state of the photosensitised species followed by further rapid migration to the newly created oxygen radical centre of a proton from carbon α to the nitrogen.[7] Spin inversion and cross coupling within the initial solvent cage is not normally regarded as a subsequent process of significance in intermolecular cases but enamines are frequently formed from the radical products of triethyl and higher tertiary amines[8] and it seems probable that this further hydrogen loss may well take place within the initial solvent cage. In studies on light-induced hydrogen transfer from alcohols to aryl ketones, cross-coupling within the initial solvent cage has

been proposed as the major subsequent step,[9] although this interpretation has recently been challenged.[10] The high degree of cross-coupling observed in this study is probably associated with radicals confined to the initial solvent cage, for outside this cage the resulting amine radical (4), from the initial hydrogen transfer, would be expected to stabilise rapidly to the delocalised radical (5) and subsequently lose hydrogen to give *N*-benzyl-2,3-dihydro-1-phenylisoindole (6).

$$PhC\overset{\cdot}{H}\overset{\cdot\cdot}{N}(CH_2Ph)_2$$

(4)

(5)　　　　(6)
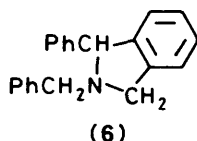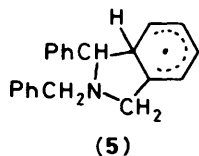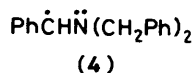
Presumably (1; R = H) is regenerated by fragmentation of a phenoxyl radical formed by aerial oxidation of the phenolate anion from (3; R = H) and is accompanied by the regeneration of the amine radical (4). The ease of this conversion, together with the ease of formation of (3; R = H), underlines the need for care in interpreting the spectral changes associated with the photoreduction of triarylmethane dyes. Such changes have been monitored in many kinetic studies, and often have been assumed to relate solely to the formation and reoxidation of the corresponding dihydro species.[11]

Experimental

[1]H N.m.r. spectra were determined in $CDCl_3$ solutions with a JEOL PFT 100 instrument using $SiMe_4$ as an internal reference. Mass spectra were run on a Micromass 16F instrument and u.v.–vis. spectra were measured on a Perkin Elmer Model 402 spectrometer.

Nitrogen (B.O.C. White Spot) was passed through concentrated H_2SO_4 before use. Benzene and dioxane were purified by distillation from $LiAlH_4$ under nitrogen and stored under nitrogen in the dark. Diazomethane was generated in anhydrous ether from *N*-methyl-*N*-nitrosotoluene-*p*-sulphonamide (Aldrich).

2,4,5,7-Tetrabromo-6-hydroxy-9-phenyl-3H-*xanthen-3-one* (1; R = H).—6-Hydroxy-9-phenyl-3*H*-xanthen-3-one[12] (5.0 g, 17.3 mmol) was dissolved in ethanol–2% H_2O (500 cm³) containing KOH (1.52 g, 27 mmol) by stirring for 2 h at 50 °C. A small amount of solid was removed by filtration. Potassium acetate (8.7 g) was added to the stirred solution followed by bromine (4.2 cm³, 81 mmol) dropwise over a period of 10 min. After 1 h the precipitated solids were isolated, rigorously washed with water, and dried *in vacuo* at 80 °C to give the crude product (8.6 g, 14.2 mmol). Soxhlet extraction ($MeCO_2H$) yielded, after drying at 155 °C under high vacuum, the chromatographically pure *tetrabromo derivative* as fine red microcrystals m.p. >355 °C (Found: C, 38.0; H. 1.4; Br, 51.8. $C_{19}H_8Br_4O_3$ requires C, 37.8; H, 1.3; Br, 52.9%); $\lambda_{max.}$ (EtOH + 1 drop 2M-NaOH) 254, 310, 341infl and 516 nm ($\varepsilon_{max.}$ 3.40 × 10⁴, 1.79 × 10⁴, 8.50 × 10³, and 4.82 × 10⁴ respectively).

2,4,5,7-Tetrabromo-3,6-dimethoxy-9-phenyl-9H-xanthene (2; R = Me).—A stirred suspension of 2,4,5,7-tetrabromo-6-hydroxy-9-phenyl-9*H*-xanthene (0.5 g, 0.825 mmol) was reduced at room temperature with $NaBH_4$ (3.0 g) in ethanol

(700 cm³) and 0.5M-aqueous NaOH (200 cm³) over a period of 4 h to give a clear solution of the product. The bulk of the ethanol was evaporated and the residual aqueous solution acidified prior to extraction with ether (4 × 50 cm³). The dried ($MgSO_4$) ethereal solution was reduced to 80 cm³, diluted with methanol (60 cm³), and treated under nitrogen with an excess of CH_2N_2 in ether at 4 °C in the dark for 13 h. Orange solids obtained after the removal of the excess CH_2N_2 and solvents were dissolved in hot ethyl acetate, filtered from insoluble methylene polymeric material, and repeatedly crystallised from small volumes of ethyl acetate and finally from $CHCl_3$ to give the *dimethoxyxanthene* as large, pale yellow prisms, m.p. 210 °C (Found: C, 39.9; H, 2.2%; $C_{21}H_{14}Br_4O_3$ requires C, 39.8; H, 2.2%); $\lambda_{max.}$(EtOH) 272 (ε 1.51 × 10⁴) and 302sh nm (ε 3.57 × 10⁻³); δ 3.89 (6 H, s, 2 × OMe), 5.15 (1 H, s, 9-H), 6.60 (2 H, s, 1 and 8-H), and 7.07—7.35 (5 H, m, Ph).

Irradiation Study.—A suspension of 2,4,5,7-tetrabromo-6-hydroxy-9-phenyl-3*H*-xanthen-3-one (40 mg, 66 µmol) was dissolved in anhydrous benzene (150 cm³) by stirring for 20 h. Tribenzylamine (3 g, 10 mmol) was added and the solution was deoxygenated over 1.5 h by a nitrogen gas flow. Throughout this initial stage the solution was shielded from light. Irradiation for 3 h with concentrated and filtered (H_2O) light from a 150 W halogen lamp completely reduced the dye. The solution was concentrated under reduced pressure to 50 cm³ and extracted with 1M-NaOH (2 × 60 cm³). The extracts were combined, rapidly washed with benzene, acidified to pH 2 with dilute hydrochloric acid and back extracted into ether (3 × 40 cm³). After drying ($MgSO_4$) and evaporation, the ethereal solution gave the crude products (55 mg).

T.l.c. on 20 × 20 cm silica gel $60F_{254}$ plates (Merck) (C_6H_6:$MeCO_2Et$:$MeCO_2H$, 35:5:1) separated the phenolic products into two main components, R_F values 0.71 and 0.78, which after 1 h in air and diffuse daylight were converted into the original dye; a transformation confirmed by subsequently spotting the plates with authentic dye and developing at right angles.

The phenolic products from two irradiation experiments were combined and the two principal components separated in MeOH–H_2O (4:1) by h.p.l.c. using multiple injections on a 10 cm Walters Bondapack C_{18} analytical column. The more mobile component (R_F 0.71 on t.l.c.) was methylated in ether–methanol under nitrogen with an excess of CH_2N_2, as described above, and the product was purified by h.p.l.c. [THF–H_2O (7:3)] to give 2,4,5,7-tetrabromo-3,6-dimethoxy-9-phenylxanthene (43.2 mg, 69 µmol), m.p. 210 °C, indistinguishable in physical properties from the authentic material prepared above.

The less mobile component (R_F 0.78 on t.l.c.) was methylated and purified in a similar manner to give the *amine* (3; R = Me) (47.7 mg, 52 µmol). The h.p.l.c. purification was repeated to obtain analytically pure material (colourless prisms, $MeCO_2Et$), m.p. 179—181 °C (Found: C, 55.2; H. 3.7; Br, 32.9; N, 1.5. $C_{42}H_{33}Br_4NO_3$ requires C, 54.9; H, 3.6; Br, 34.8; N, 1.5%); $\lambda_{max.}$(EtOH) 270 (ε 1.62 × 10⁻⁴) and 300sh nm (ε 3.11 × 10⁻³); the [1]H n.m.r. data is discussed in the text.

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