Protonated Pteridine and Flavin Analogues acting as Efficient and Substrate-selective Photocatalysts in the Oxidation of Benzyl Alcohol Derivatives by Oxygen

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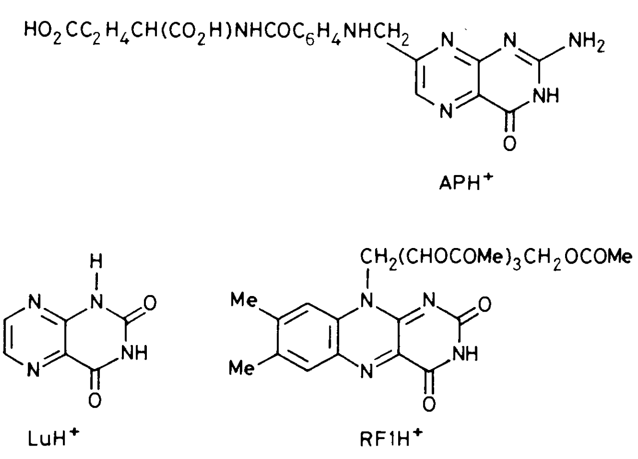
Protonated aminopterin, lumazine, and riboflavin-tetra-acetate efficiently catalyse the substrate-selective photo-oxidation of benzyl alcohol derivatives by oxygen in the presence of perchloric acid in acetonitrile at 298 K.

Flavin coenzymes which contain a tricylic isoalloxazine ring as well as pterin coenzymes such as folic acid (pteroylglutamic acid) and biopterin which contain a dicyclic pteridine ring (a part of the skeleton of flavins) are known to play versatile roles in biological redox reactions.[1] Both flavins and pteridine analogues can absorb visible light and thus, flavin photochemistry has been the subject of intense research for a long time.[2] In contrast with flavin photochemistry, little is known of the excited-state chemistry of pteridine analogues.[3] In addition, pteridine analogues as well as flavins are known to undergo photo-degradation and thus, cannot be used as efficient photocatalysts by themselves.[4,5] We have previously reported that flavin analogues can be used as photocatalysts for the oxidation of *p*-methylbenzyl alcohol when they are complexed with metal ions.[6] In this study, we report that protonated pteridine derivatives, aminopterin (4-aminofolic acid) and lumazine (pteridine-2,4-diol), as well as a protonated flavin analogue (riboflavin-tetra-acetate) can be used as much more efficient and more stable photocatalysts for the substrate-selective oxidation of benzyl alcohol derivatives with oxygen than the flavin–metal ion complex. Thus, the present study provides a unique opportunity to compare the photo-catalytic activity of pteridine analogues of biologically important redox coenzymes, folic acid and biopterin, with that of a structurally related flavin coenzyme analogue.

No appreciable photo-oxidation of benzyl alcohol by oxygen occurred when aminopterin (AP), lumazine (Lu), or riboflavin-tetra-acetate (RFl) was used as a photocatalyst in the absence of acid in acetonitrile (MeCN). When perchloric acid was added to this system, the flavin and pteridine derivatives were protonated ($\lambda_{max.}$ 334, 350, and 392 nm for APH^+, LuH^+, and $RFlH^+$, respectively).[7—9] Each protonated species ($catH^+$) acted as an efficient photocatalyst for the oxidation of benzyl alcohol derivatives ($X\text{-}C_6H_4CH_2OH$) with oxygen [equation (1)] when the photochemical reactions were carried out using a xenon lamp with a filter transmitting light of 220 nm < λ < 440 nm. The formation of $X\text{-}C_6H_4CHO$ was identified by ^1H n.m.r. and electronic spectra, and that of hydrogen peroxide was confirmed by titration with iodide ion as described elsewhere.[6] No appreciable photo-degradation of the catalysts was observed during the photocatalytic oxidation in the presence of $HClO_4$ in MeCN.

$$X\text{-}C_6H_4CH_2OH + O_2 \xrightarrow[catH^+]{h\nu} X\text{-}C_6H_4CHO + H_2O_2 \quad (1)$$

The quantum yields (φ) of the photocatalytic oxidation were determined using a ferrioxalate actinometer with the difference in light absorption between the catalyst and the actinometer appropriately accounted for according to the literature.[10] The φ value increased with increase in the $HClO_4$ concentration to reach a constant value ($>1.0 \times 10^{-2}$ mol dm^{-3}) when all photocatalyst molecules are protonated. The φ values at a constant $X\text{-}C_6H_4CH_2OH$ concentration (2.9×10^{-2} mol dm^{-3}) as well as the limiting quantum yields ϕ_∞ in the presence of $HClO_4$ (1.4×10^{-2} mol dm^{-3}) are listed in Table 1. The φ value (0.30) for $RFlH^+$ at 2.9×10^{-2} mol dm^{-3} $p\text{-}MeC_5H_4CH_2CH_2OH$ is 13-fold larger than the reported φ value for a flavin–Mg^{2+} complex.[6] Such large φ values are obtained for each photocatalyst when the substituents (X) are moderately electron-donating or electron-withdrawing (X = *o*-Br, *p*-Cl, H, *p*-Me, *p*-Pr^i). Thus, protonated flavin and pteridine analogues act as much more efficient and more stable photocatalysts than the flavin–metal ion complex reported previously.[6] However, no appreciable photo-oxidation of $X\text{-}C_6H_4CH_2OH$ by oxygen was observed with strongly electron-donating (X = *p*-OH, *p*-MeO) or -withdrawing (X = *p*-NO_2) substituents. Such substrate selectivities and the magnitude of quantum yields are similar among the photocatalysts irrespective of them being dicyclic pteridine analogues (APH^+ and LuH^+) or a tricyclic flavin ($RFlH^+$) as shown in Table 1. The similar photo-catalytic activities may be ascribed to the cancellation of the difference in the ground state oxidizing ability, which is in the order $RFlH^+ > LuH^+ > PH^+$,[8] by that in the excitation energy, which is in the opposite order $RFlH^+ < LuH^+ < PH^+$.



Scheme 1

$$2RFlH^+ + X\text{-}C_6H_4CH_2OH \xrightarrow{h\nu} 2RFlH_2^{+\bullet} + X\text{-}C_6H_4CHO \quad (2)$$

In the absence of oxygen, $RFlH^+$ can be reduced by $X\text{-}C_6H_4CH_2OH$ by irradiation of the absorption band due to $RFlH^+$ (λ_{max} 392 nm) to yield the dihydroflavin radical cation $RFlH_2^{+\bullet}$ (λ_{max} 416 nm) and $X\text{-}C_6H_4CHO$, equation (2).[11] The limiting quantum yields ϕ_∞ for the formation of $RFlH_2^{+\bullet}$ were determined and the ϕ_∞ values are also listed in Table 1. The ϕ_∞ values in the absence of oxygen agree well with those of the $RFlH^+$-catalysed photo-oxidation of $X\text{-}C_6H_4CH_2OH$ by oxygen (Table 1). Such an agreement of the ϕ_∞ values in the absence and in the presence of oxygen was also confirmed in the case of LuH^+ (Table 1). In addition, the reduced flavin and pteridine analogues are known to be readily oxidized to yield hydrogen peroxide.[8,12] Thus, the photocatalytic oxidation of $X\text{-}C_6H_4CH_2OH$ by oxygen may proceed *via* the photo-reduction of the catalyst ($catH_3^+$), followed by the

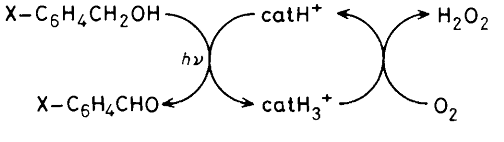


Table 1. Quantum yields (φ) of photocatalytic oxidation of benzyl alcohol derivatives ($X\text{-}C_6H_4CH_2OH$) with oxygen, catalysed by APH^+, LuH^+, and $RFlH^+$ in the presence of $HClO_4$ (1.4×10^{-2} mol dm^{-3}) in MeCN at 298 K.

$X\text{-}C_6H_4CH_2OH$	(APH^+)	(LuH^+)		($RFlH^+$)		
X	ϕ^a	ϕ^a	ϕ_∞^b	ϕ^a	$\phi_\infty^{b,c}$	
p-NO_2	d	d	d	d	e	(0.18)
o-Br	0.084	0.020	0.10	0.089	0.17	(0.17)
p-Cl	0.16	0.088	0.17	0.22	0.28	(0.28)
H	0.15	0.17	0.38[f]	0.094	0.23	(0.25)
p-Me	0.13	0.18	0.30	0.21	0.29	(0.30)
p-Pr^i	0.17	0.18	0.23	0.19	0.28	(0.31)
p-MeO	0.020	d	d	d	e	(0.0016)
p-HO	d	d	d	d	d	d

[a] [$X\text{-}C_6H_4CH_2OH$] 2.9×10^{-2} mol dm^{-3}. [b] Limiting quantum yields (ϕ_∞) were obtained from the intercepts of the linear plots between ϕ^{-1} and $[X\text{-}C_6H_4CH_2OH]^{-1}$. [c] The values in parentheses are those for the formation of $RFlH_2^{+\bullet}$ in the absence of oxygen. [d] Value $< 1 \times 10^{-3}$. [e] Value could not be determined accurately. [f] The ϕ_∞ value in the absence of oxygen is 0.40.

thermal oxidation of the reduced catalyst ($catH_3^+$) by oxygen to yield H_2O_2, accompanied by the regeneration of $catH^+$, as shown in Scheme 1.

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