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PHOTOOXIDATION OF *p*-METHYLBENZYL ALCOHOL BY OXYGEN, CATALYZED BY FLAVIN ANALOGUES (3-METHYL-10-PHENYLISOALLOXAZINE AND 3-METHYL-10-PHENYL-5-DEAZAISOALLOXAZINE) IN THE PRESENCE OF Mg^{2+} ION

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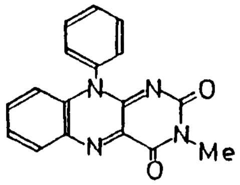
Flavin analogues (3-methyl-10-phenylisoalloxazine and 3-methyl-10-phenyl-5-deazaisoalloxazine) catalyze the photooxidation of *p*-methylbenzyl alcohol by oxygen in the presence of Mg^{2+} ion in acetonitrile to yield *p*-methylbenzaldehyde and hydrogen peroxide under irradiation of the visible light of $\lambda > 360$ nm.

Biomimetic dehydrogenation reactions using flavin analogues as catalysts have merited considerable interest in relation with flavoenzyme-catalyzed dehydrogenation reactions.1-3) Oxidizable substrates under mild conditions have, however, been limited to rather strong reductants such as alcoholate anions because of the much lower oxidizing ability of flavin analogues than that of protein-bound flavins of flavoenzymes. On the other hand, photochemical activation of flavin analogues can be expected to improve the oxidizing ability of flavin analogues singnificantly. Indeed, photoreduction of flavin analogues by a variety of substrates such as amino acids, carboxylic acids, amines, and NADH, or intramolecularly, by ribityl side chain of the flavin has been known for many years.4,5) However, no photocatalytic conversion of neutral alcohols to aldehydes using simple flavin analogues as catalysts to mimic the flavoenzyme-catalyzed oxidation of alcohols has so far been reported,6) since the oxidizing ability of the excited states of flavin analogues may be still insufficient to oxidize neutral alcohols faster than photodegradation of flavin analogues.

We wish to report herein the first successful catalytic oxidation of *p*-methylbenzyl alcohol by oxygen using flavin analogue - Mg^{2+} ion complexes as catalysts which have much stronger oxidizing abilities than free flavin analogues



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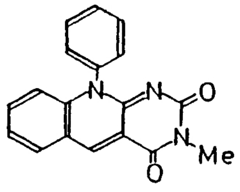

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in acetonitrile (MeCN) under irradiation of the visible light of λ > 360 nm.

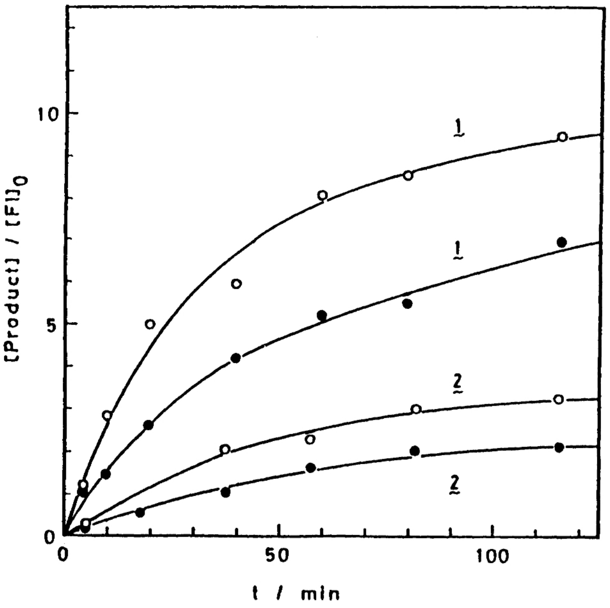


Fig. 1. Yields of products [p-MeC_6H_4-CHO (○) and H_2O_2 (●)] based on the initial amount of 1 (1.9×10^{-4} mol dm^{-3}) or 2 (1.2×10^{-4} mol dm^{-3}) *vs*. irradiation time for the photooxidation of p-$MeC_6H_4CH_2OH$ (4.9×10^{-2} mol dm^{-3}) or 1.0×10^{-1} mol dm^{-3}) by O_2 in the presence of Mg^{2+} ion (1.0×10^{-1} mol dm^{-3}) in MeCN at 298 K.

Flavin analogues (3-methyl-10-phenylisoalloxazine: 1, 3-methyl-10-phenyl-5-deazaisoalloxazine: 2) were prepared according to the literatures.[7] Irradiation of an oxygen saturated MeCN solution containing 1, p-$MeC_6H_4CH_2OH$, and $Mg(ClO_4)_2$ with visible light from a Xenon lamp through a filter cutting off below 360 nm results in the formation of p-MeC_6H_4CHO and H_2O_2 as shown in Fig. 1. The amount of p-MeC_6H_4CHO was determined by the UV spectrum of the diluted MeCN solution (x 100) of the product mixture (λ_{max} = 255 nm, $\varepsilon = 1.60 \times 10^5$ mol^{-1} dm^2), and the amount of H_2O_2 was determined by the visible spectrum of I_3^- (λ_{max} = 364 nm, $\varepsilon = 2.50 \times 10^5$ mol^{-1} dm^2) which was formed by treating the diluted MeCN solution (x 100) of the product mixture with excess amounts of NaI.[8] Yields of p-MeC_6H_4CHO based on the initial amount of 1 exceed 1000% after 150 min, demonstrating an efficient recycling of 1 in the photooxidation of p-$MeC_6H_4CH_2OH$, although the rate of formation of p-MeC_6H_4CHO decreases gradually with increasing the irradiation time (Fig. 1) probably because of concomitant photodegradation of 1. When a 5-deazaflavin 2 is used as a photocatalyst instead of a flavin 1, yields of p-MeC_6H_4CHO based on the initial amount of 2 exceed 300% after 2 h, but yields of H_2O_2 as well as p-MeC_6H_4CHO become lower than those in the case of 1, indicating a low efficiency of 2 in the photooxidation. The amount of H_2O_2 formed by the photooxidation of p-$MeC_6H_4CH_2OH$ by oxygen is smaller than that of p-MeC_6H_4CHO because of the photodecomposition of H_2O_2. Indeed, H_2O_2 was found to decompose partially under irradiation of the visible light of λ > 360 nm in the presence of 1 or 2. It should be emphasized that p-MeC_6H_4CHO has hardly been formed in the absence of Mg^{2+} ion under otherwise the same conditions as those in Fig. 1, and no thermal reaction of p-$MeC_6H_4CH_2OH$ with 1 or 2 has occurred in the absence or presence of Mg^{2+} ion in MeCN at 298 K.

When 1 is allowed to react with p-$MeC_6H_4CH_2OH$ under degassed conditions by irradiation of the absorption band of 1 in the presence of 0.10 mol dm^{-3} Mg^{2+} ion (λ_{max} = 424 nm), the absorbance at 424 nm decreases with increasing the irradiation time as shown in Fig. 2. Upon introducing oxygen to the resulting solution, 1 is regenerated in about a 90% yield as shown by the broken line in Fig. 2. In the absence of Mg^{2+} ion, however, the original spectrum of 1 has little changed in contrast with the facile photochemical reaction of 1 with p-$MeC_6H_4CH_2OH$ in the presence of Mg^{2+} ion.

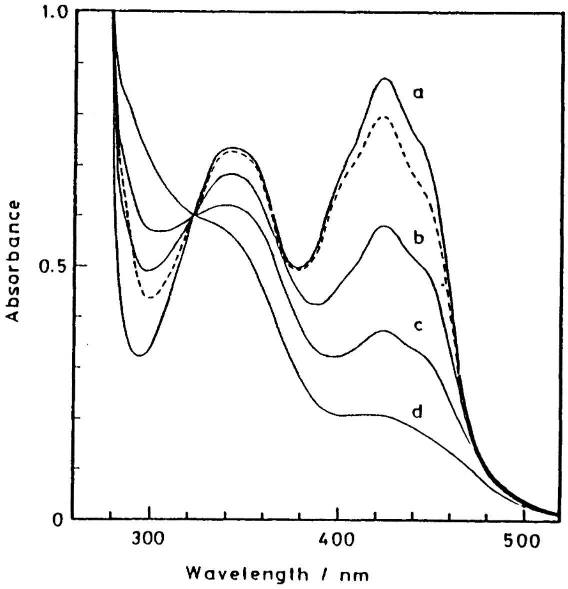


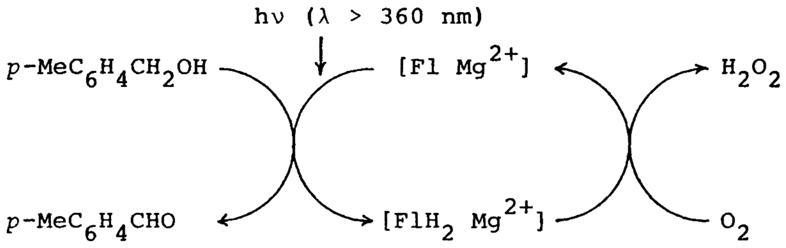
Fig. 2. Electronic spectra observed in the photochemical reaction of 1 (1.9×10^{-4} mol dm^{-3}) with p-MeC_6H_4-CH_2OH (1.2×10^{-1} mol dm^{-3}) in the presence of Mg^{2+} ion (1.0×10^{-1} mol dm^{-3}) in MeCN under degassed conditions; irradiation time: (a) 0 min, (b) 2 min, (c) 4 min, (d) 22 min. The broken line spectrum is observed upon introducing oxygen to the solution after irradiation of the visible light of λ > 360 nm for 22 min.

It has previously been reported that Mg^{2+} ion forms 1 : 1 complexes with 1 and 2; the formation constants of $K = 1.7 \times 10^2$ and 1.1×10^3 mol^{-1} dm^3, respectively, in MeCN at 298 K (Eq. 1).[9] At the Mg^{2+} concentration (0.10 mol dm^{-3})

$$\mathrm{Fl} + \mathrm{Mg}^{2+} \overset{K}{\rightleftharpoons} [\mathrm{Fl\ Mg}^{2+}] \qquad (1)$$

used in this study, therefore, most flavin or 5-deazaflavin molecules form the 1 : 1 complex with Mg^{2+} ion. Thus, the oxidizing ability of the excited state of 1 as well as 2 may be enhanced by the complex formation with Mg^{2+} ion.[9]

In conclusion, the present study has shown that the excited state of a flavin analogue - Mg^{2+} ion complex, $[\mathrm{Fl\ Mg}^{2+}]^*$, is able to oxidize p-$MeC_6H_4CH_2OH$ to p-MeC_6H_4CHO efficiently, resulting in the formation of a reduced flavin analogue (FlH_2) which is oxidized by oxygen to yield H_2O_2, regenerating Fl as shown below.



The detailed study on the mechanism of this photocatalytic reaction is now in progress.

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