

Photoinduced Heterolysis of the Carbon-Oxygen Bond in Bichromophoric 1-Arylmethoxy-2-pyridones

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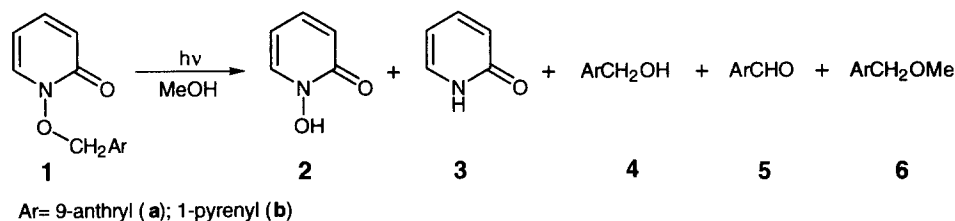
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Abstract: Irradiation of the title compound having a 9-anthryl (**1a**) or a 1-pyrenyl group (**1b**) in methanol was found to give the heterolytic C-O bond cleavage products: 1-hydroxy-2-pyridone and arylmethyl methyl ether, (which predominate for the reaction of **1a**), along with 2-pyridone, aryl-substituted methanol and aryl aldehyde derived from the homolysis of the N-O bond (that mainly occurs in the photolysis of **1b**). Spectroscopic analysis of the ground-state and excited singlet-state behavior of **1** revealed that a non-emissive intramolecular exciplex (whose formation rate is much faster in **1a** than in **1b**) plays a key role in inducing the C-O bond heterolysis.

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Photochemical control of the homolytic *versus* heterolytic bond-cleavage pathway has been the subject of extensive research efforts²⁻⁶ because of its potential application to developing protecting groups of biological molecules^{2,3} as well as photoinitiators with high efficiency and selectivity.⁴ In the course of our systematic study toward the characterization of the excited-state behavior of cyclic hydroxamic acid derivatives, we found that bichromophoric 1-benzyloxy-2-pyridone in the excited singlet state undergoes the homolytic N-O bond cleavage giving benzaldehyde and 2-pyridone as major products along with a minor amount of benzyl alcohol.⁷ It was also shown that the reaction proceeds mainly through a folded conformation and not a stretched one,⁸ allowing us to expect that replacement of the phenyl group in a benzyloxy pyridone molecule by the anthryl or the pyrenyl would markedly enhance interaction between the two chromophores in the excited singlet state affecting the bond-fission process of these *O*-substituted cyclic hydroxamic acids. Thus, we designed and synthesized 1-(9-anthryl)methoxy-2-pyridone (**1a**)⁹ and 1-(1-pyrenyl)methoxy-2-pyridone (**1b**)⁹ in order to explore the possibility of photochemical control of heterolytic *versus* homolytic bond scission in these two bichromophoric compounds.



Scheme 1

On irradiation of a nitrogen-purged methanol solution of **1a** (1.0×10^{-3} mol dm⁻³) with light of wavelengths longer than 340 nm (from a 450 W high-pressure Hg lamp) at room temperature, there appeared four new HPLC signals with retention times of 4.5 (1-hydroxy-2-pyridone **2** and 2-pyridone **3**), 9.5 [9-(hydroxymethyl)anthracene **4a**], 21.9 (9-formylanthracene **5a**) and 28.5 min [9-(methoxymethyl)anthracene **6a**] in addition to that of the starting **1a** (13.5 min; mobile phase: 60 vol. % MeCN-H₂O) (Scheme 1). Because

the unexpected product **6a** as well as a substantial overlap of HPLC signals for **2** and **3** had been observed, we attempted to isolate these products and succeeded in obtaining **6a**¹⁰ in 30% yield (conversion: 50%) along with a mixture of **2** and **3** whose ¹H NMR spectrum was compatible with that of the mixture of authentic **2** and **3**. As demonstrated in Fig. 1, the compositions of **2** (major) and **3** (minor) are comparable to those of the ether **6a** and the alcohol **4a** plus the aldehyde **5a** at each irradiation time, respectively (¹H NMR analysis). Since arylmethyl carbonium ions readily react with methanol giving the corresponding arylmethyl methyl ethers,⁵ this observation suggests that the ether **6a** is derived from the heterolytic C–O bond cleavage in **1a** but not from the homolytic N–O bond scission that should be responsible for the appearance of **3**, **4a** and **5a**.⁷

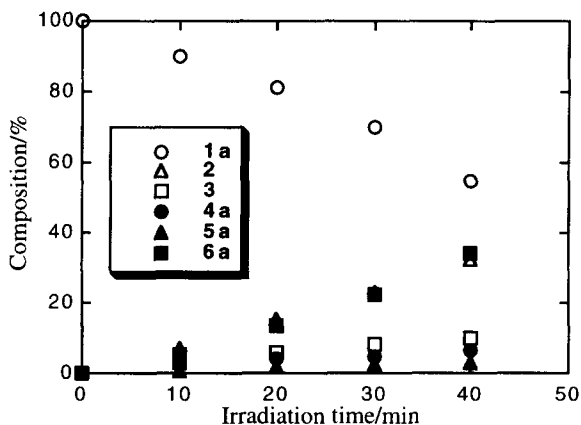


Figure 1. Relation between irradiation time and composition of each compound in methanol.

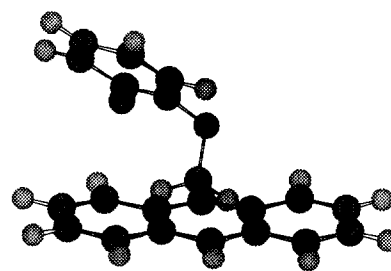
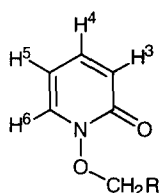


Figure 2. Energy-minimized conformation of **1a**.

Table 1. Chemical shifts (δ) of the pyridone-ring protons for 1-substituted methoxy-2-pyridones in CDCl₃ at room temperature



R	H ³	H ⁴	H ⁵	H ⁶
Methyl	6.66	7.33	6.15	7.55
9-Anthryl	6.71	7.17	5.72	6.92
1-Pyrenyl	6.72	7.18	5.67	6.87

On the other hand, irradiation of **1b** (5.0×10^{-4} mol dm⁻³) in methanol under the same reaction conditions as those used for **1a** afforded **2** (composition: 5.0%), **3** (19.4%), **4b** (3.0%), **5b** (17.3%) and **6b** (4.1%) at 24.4% conversion of the starting **1b** (¹H NMR analysis). Evidently, the introduction of a 1-pyrenyl group instead of a 9-anthryl renders the heterolytic C–O bond cleavage minor pathway. The large difference in composition for the ion-derived products between **1a** and **1b** may argue against a mechanism involving initial homolysis of the C–O bond, followed by electron transfer since the oxidation potential of the 1-pyrenylmethyl radical is deemed to be comparable to that of the 9-anthrylmethyl.^{5,6} In order to probe the interesting substituent effects on the product distribution, we analyzed the ground-state conformation by means of ¹H NMR spectroscopy as well as MM2 calculations. An examination of Table 1 reveals that the replacement of the ethyl substituent in 1-ethoxy-2-pyridone by the 9-anthrylmethyl or the 1-pyrenylmethyl results in a relatively large upfield shift of the pyridone-ring protons H⁵ and H⁶. Taking into account that this upfield shift is due to aromatic ring-current effects,⁸ we are led to propose a folded conformation (shown in Fig. 2) which is supported by MM2 calculations. It is, thus, expected that there is perceivable interaction between the pyridone and aromatic rings in the ground and excited singlet states.

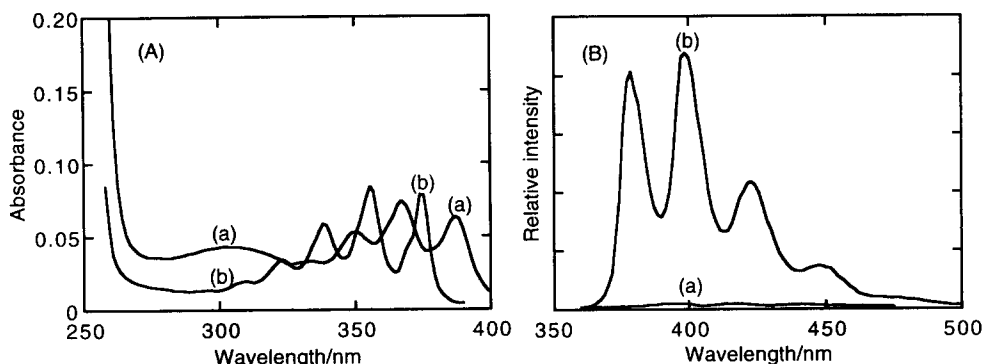
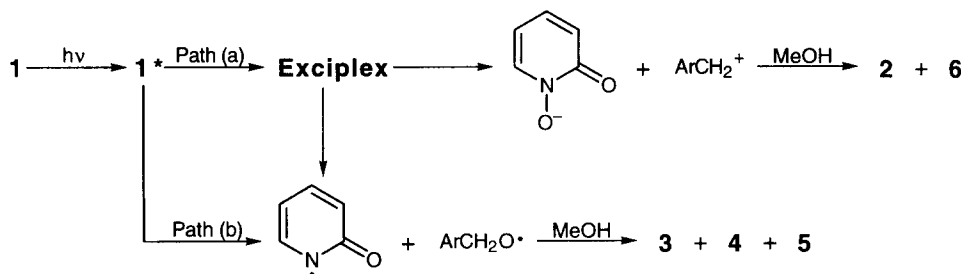


Figure 3. UV absorption (A) and fluorescence (B; $\lambda_{\text{ex}} = 342$ nm) spectra of **1a** (curve a; 0.7×10^{-5} mol dm^{-3}) and anthracene (curve b; 1.0×10^{-5} mol dm^{-3}) in methanol at room temperature.

As typically shown in Fig. 3, the first absorption band (that results from the anthracene ring of **1a**) was red-shifted by 12 nm with broadening of each vibrational structure as compared to that of the reference compound, anthracene (the first singlet excitation energy, $E_S = 319$ kJ mol^{-1} ; the first triplet excitation energy, $E_T = 178$ kJ mol^{-1})¹¹ (Fig. 3A), whereas we observed intramolecular fluorescence quenching of the anthracene chromophore by the pyridone having excitation energies of 343 (E_S)⁷ and 268 kJ mol^{-1} (E_T)⁷ (Fig. 3B). Similar absorption and emission behavior was observed also for **1b** and its reference, pyrene ($E_S = 321$ kJ mol^{-1} ; $E_T = 202$ kJ mol^{-1})¹¹. The finding of endothermic energy transfer from the anthracene or pyrene moiety (that is selectively excited) to the pyridone in **1** strongly suggests the involvement of a non-emissive exciplex with some charge-transfer character as a precursor of the heterolytic C–O bond cleavage products **2** and **6**.¹² The suggestion described above is substantiated also by the observation of intramolecular charge-transfer deactivation of the 9-anthryl chromophore by the propiophenone moiety in ω -(9-anthryl)propiophenones.¹³ The fluorescence lifetimes of the reference compounds (anthracene: 4.5 ns; pyrene: 40 ns) and the area ratio of their emission bands to those of **1a** and **1b** enabled estimation of the rate constant for exciplex formation as 4×10^9 s⁻¹ (**1a**) and 8×10^7 s⁻¹ (**1b**).¹⁴



Scheme 2

If we could adopt an intramolecular exciplex in which the aromatic and pyridone rings serve as electron donor and acceptor, respectively, quantum yields for the formation of **4** ($\phi_{4a} = 0.013 \pm 0.002$; $\phi_{4b} = 0.012 \pm 0.001$), **5** ($\phi_{5a} = 0.008 \pm 0.001$; $\phi_{5b} = 0.068 \pm 0.003$) and **6** ($\phi_{6a} = 0.045 \pm 0.002$; $\phi_{6b} = 0.016 \pm 0.001$) in methanol ($[\mathbf{1a}] = 1.0 \times 10^{-3}$; $[\mathbf{1b}] = 0.5 \times 10^{-3}$ mol dm^{-3}) indicate the assumed exciplex intermediate not to have such high reactivity.¹⁵ In addition to these quantum yields, the rate constants shown above make it highly reasonable to propose Scheme 2 in which path (a) predominates for the reaction of **1a** whereas the photolysis of **1b** proceeds mainly through path (b) giving the aldehyde **5b** as the main product. Hydrogen-bonding solvation of the amide carbonyl oxygen in **1** is considered to play some role in promoting the heterolytic C–O bond fission.⁸

In conclusion, we have demonstrated here that bichromophoric 1-arylmethoxy-2-pyridones having strong ability to form an exciplex undergo novel photo-induced heterolytic cleavage of the C–O bond in competition with the homolysis of the N–O bond.

References and Notes

1. Present address: Institute of Advanced Material Study, Kyushu University, Kasuga-Koen, Kasuga, Fukuoka 816-0811, Japan.
2. Binkley, R. W.; Flechtner, T. W. in *Synthetic Organic Photochemistry*, Horspool, W. M., Ed.; Plenum Press: New York, 1984, pp. 375–423.
3. Shi, Y.; Corrie, J. E. T.; Wan, P. *J. Org. Chem.* **1997**, *62*, 8278–8279 and references cited therein.
4. MacDonald, S. A.; Willson, C. G.; Fréchet, J. M. J. *Acc. Chem. Res.* **1994**, *27*, 151–158; Pirrung, M. C.; Huang, C.-Y. *Tetrahedron Lett.* **1995**, *36*, 5883–5884; Cameron, J. F.; Willson, C. G.; Fréchet, J. M. J. *J. Am. Chem. Soc.* **1996**, *118*, 12925–12937.
5. Pincock, J. A. *Acc. Chem. Res.* **1997**, *30*, 43–49; Nevill, S. M.; Pincock, J. A. *Can. J. Chem.* **1997**, *75*, 232–247.
6. Dreyer, J.; Peters, K. S. *J. Phys. Chem.* **1996**, *100*, 15156–15161 and references cited therein; Dreyer, J.; Lipson, M.; Peters, K. S. *J. Phys. Chem.* **1996**, *100*, 15162–15164.
7. Sakurai, T.; Takeda, Y.; Inoue, H. *Nippon Kagaku Kaishi*, **1984**, 1–7. It is very likely that the dramatic difference in product distribution between 1-benzyloxy-2-pyridone (**1c**) and **1a** is due to the selective excitation of the pyridone ring in the former (313 nm light irradiation) and the anthracene ring in the latter (366 nm light irradiation). The finding that the photolysis of **1a** (2.5×10^{-4} mol dm⁻³) in methanol with 313 nm light increases the composition of (**4a** + **5a**) relative to **6a** by a factor of 2.2 at 19.0% conversion implies that the N–O bond cleavage in the excited singlet-state **1a** and **1c** takes place by different mechanisms.
8. Sakurai, T.; Obana, T.; Inagaki, T.; Inoue, H. *J. Chem. Soc., Perkin Trans. 2*, **1989**, 535–538; Sakurai, T.; Murakata, Y.; Inoue, H. *J. Chem. Soc., Perkin Trans. 2*, **1990**, 499–503.
9. Data for **1a**: mp 174–175°C. IR (KBr): 1660 cm⁻¹. ¹H NMR (500 MHz, CDCl₃) δ 5.72 (ddd, 1H, *J* = 1.8, 6.7, 7.0 Hz), 6.39 (s, 2H), 6.71 (dd, 1H, *J* = 1.8, 9.2 Hz), 6.92 (dd, 1H, *J* = 1.8, 7.0 Hz), 7.17 (ddd, 1H, *J* = 1.8, 6.7, 9.2 Hz), 7.47–8.53 (m, 9H). Anal. Calcd (Found) for C₂₀H₁₅NO₂: C, 79.72 (79.44); H, 5.02 (4.89); N, 4.65% (4.57%).
Data for **1b**: mp 114–115°C. IR (KBr): 1650 cm⁻¹. ¹H NMR (500 MHz, CDCl₃) δ 5.67 (ddd, 1H, *J* = 1.8, 6.7, 6.7 Hz), 6.04 (s, 2H), 6.72 (dd, 1H, *J* = 1.8, 9.2 Hz), 6.87 (dd, 1H, *J* = 1.8, 6.7 Hz), 7.18 (ddd, 1H, *J* = 1.8, 6.7, 9.2 Hz), 7.90–8.67 (m, 9H). Anal. Calcd (Found) for C₂₂H₁₅NO₂: C, 81.21 (81.13); H, 4.65 (4.67); N, 4.30% (4.18%).
10. Data for **6a**: mp 87.5–89°C. IR (KBr): 1190 cm⁻¹. ¹H NMR (500 MHz, CDCl₃) δ 3.55 (s, 3H), 5.44 (s, 2H), 7.47 (dd, 2H, *J* = 6.4, 8.5 Hz), 7.55 (dd, 2H, *J* = 6.4, 8.5 Hz), 8.02 (d, 2H, *J* = 8.5 Hz), 8.39 (d, 2H, *J* = 8.5 Hz), 8.47 (s, 1H). Physical and spectroscopic properties of this isolated product agreed with those of an authentic sample independently prepared from the reaction between 9-(chloromethyl)anthracene and sodium methoxide in methanol.
11. Murov, S. L.; Carmichael, I.; Hug, G. L. *Handbook of Photochemistry*, 2nd Edn.; Marcel Dekker: New York, 1993, pp. 4–53.
12. Exciplex fluorescence was not observed in methanol and cyclohexane, whereas the fluorescence of the anthracene chromophore in **1a** was quenched to a much greater extent in the former solvent than in the latter. The occurrence of intermolecular fluorescence quenching of anthracene (1.0×10^{-5} mol dm⁻³) by 1-hydroxy-2-pyridone (0.10 mol dm⁻³) having the quenching constant of 40 dm³ mol⁻¹ is consistent with the assumption of an intramolecular exciplex.
13. Burgdorff, C.; Löhmansröben, H.-G.; Sander, T. *J. Chem. Soc., Faraday Trans.*, **1996**, *92*, 3043–3049.
14. The rate constant (k_{ex}) of exciplex-forming process was estimated by using the equation: $k_{ex} = \tau_f^{-1}[(A_r/A_f) - 1]$, where τ_f is the fluorescence lifetime of the reference compound and A_r/A_f is the area ratio of the fluorescence band for a given reference to that for **1**.
15. Quantum yields were determined at low conversions (10–15%) of the starting **1** according to the method of Hatchard and Parker which employs a potassium trioxalatoferate(III) actinometer (Hatchard, C. G.; Parker, C. A. *Proc. R. Soc. London, Ser. A* **1956**, *235*, 518–536). All the quantum yields are an average of more than five determinations. Filter combination to isolate 366 nm light has been described previously (Sakurai, T.; Sukegawa, H.; Inoue, H. *Bull. Chem. Soc. Jpn.*, **1985**, *58*, 2875–2881). The quantum yield for appearance of each product is subject to, if any, only a small concentration effect in the range of $2.5\text{--}25 \times 10^{-4}$ (**1a**) or $2.0\text{--}10 \times 10^{-4}$ mol dm⁻³ (**1b**).