

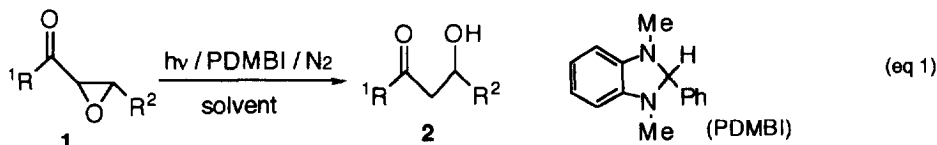
Photoinduced Electron Transfer Reactions of α , β -Epoxy Ketones with 2-Phenyl-N,N-dimethylbenzimidazoline (PDMBI): Significant Water Effect on the Reaction Pathway

Eietsu Hasegawa,* Teru Kato, Takashi Kitazume, Kazuhiro Yanagi, Kazuya Hasegawa, and Takaaki Horaguchi

Department of Chemistry, Faculty of Science, Niigata University, Ikarashi, Niigata, 950-21, Japan

Abstract: Irradiation of aryl substituted epoxy ketones with 2-phenyl-N,N-dimethylbenzimidazoline in aqueous tetrahydrofuran or aqueous benzene produced the corresponding aldols in good to excellent yields. Changing the amount of water added significantly influenced the product distribution.
 Copyright © 1996 Elsevier Science Ltd

Since selective transformation of α , β -epoxy ketones to β -hydroxy ketones (aldols) is recognized as a synthetically important process, various methods have been developed to achieve this objective.¹ Among them are the methods conducted under electron transfer conditions in which generation of a ketyl radical species of epoxy ketones is involved. The photoinduced electron transfer (PET) process is also known to be a useful way to generate ketyl radicals.² Thus, Cossy and coworkers have reported that irradiation of epoxy ketones with triethylamine produced the corresponding aldols in moderate to good yields.³ However, we have found that the major isolable products were β -diketones rather than aldols on the irradiation of certain aromatic epoxy ketones, such as chalcone epoxides, with triethylamine.^{4a} Apparently, there have been no generally acceptable electron donors for this photochemical transformation, particularly for aryl substrates. Based on our mechanistic studies,⁴ we simply considered that compounds possessing both good electron-donating and hydrogen-donating properties should be promising candidates. Thus, 2-phenyl-N,N-dimethylbenzimidazoline (PDMBI)^{5,6} became attractive to us. Here, we first report that photoreactions of α , β -epoxy ketones with PDMBI in aqueous tetrahydrofuran or aqueous benzene produced β -hydroxy ketones in good yields (eq 1).⁷



When 1,3-diphenyl-2,3-epoxypropanone (**1a**) was irradiated in the presence of PDMBI in dry tetrahydrofuran, the desired 1,3-diphenyl-3-hydroxypropanone (**2a**) was found to be a minor component of the reaction mixture. Other products were 1,3-diphenylpropanone (**3a**), the major product, and a small amount of benzaldehyde (**4a**). After several attempts to find the best solvent systems, we have finally found that addition of water dramatically increased the yield of **2a**.⁸ Other interesting observations were that 1) polar solvents such as acetonitrile and methanol were not effective even in the presence of water, 2) aqueous benzene operated quite well just as tetrahydrofuran did. These preliminary observations prompted us to look at the reaction profile influenced by changing the amount of water added. The results are shown in Figure 1 (the yields are based on the conversion of **1a**). As mentioned above, **3a** was usually the major product for the reactions in

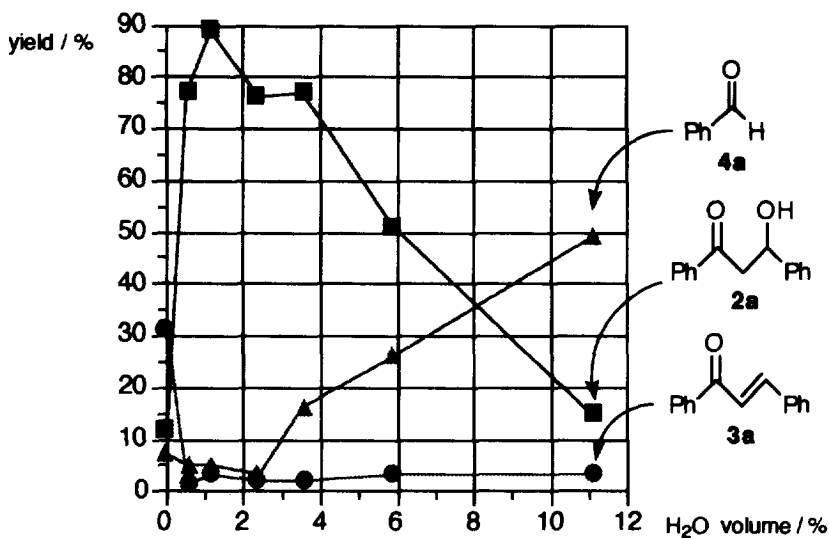


Figure 1. Effect of H₂O amount on the photoreaction of **1a** with PDMBI in THF

dry tetrahydrofuran.⁹ As the amount of water was increased to about 1% of the solution volume, the yield of **2a** dramatically increased to become greater than 85%. At the range of more than 2% of water content, the yield of **2a** gradually decreased and that of **4a** increased to a similar extent¹⁰ while the yield of **3a** was kept at less than 5%.

Next, we conducted photoreactions of other epoxy ketones **1b**, **1c**, **1d**, and **1e** with PDMBI in both aqueous tetrahydrofuran and aqueous benzene to determine the generality and the limitations of this photochemical method. As presented in Table 1, irradiation of aryl substituted epoxy ketones **1a-1d** with PDMBI produced the corresponding aldols in good to excellent yields. On the other hand, no formation of

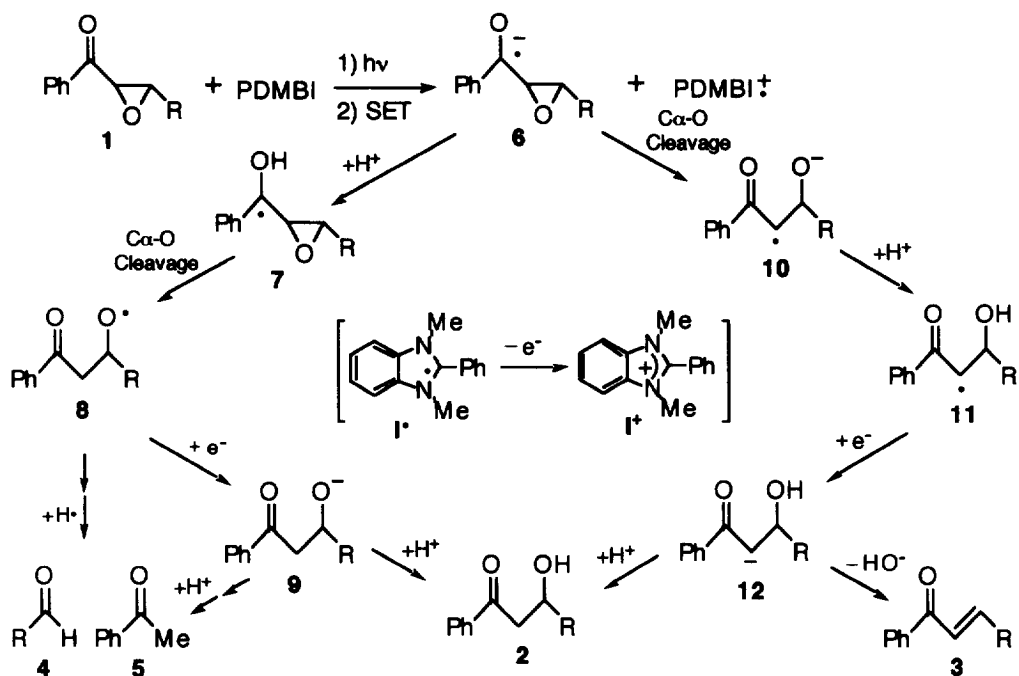
Table 1. Photoreactions of epoxy ketones **1** with PDMBI in aqueous tetrahydrofuran and aqueous benzene^{a)}

Entry	1	R ¹	R ²	aq Solvent	Conv / %	2 / % ^{b)}
1	1a	Ph	Ph	THF	100	89
2	1a	Ph	Ph	Benzene	100	85
3	1b	Ph	H	THF	97	74 (76)
4	1b	Ph	H	Benzene	100	84
5	1c	Ph	<i>i</i> -Pr	THF	81	55 (68)
6	1c	Ph	<i>i</i> -Pr	Benzene	97	74 (76)
7	1d	Ph	<i>n</i> -Pr	THF	93	68 (73)
8	1d	Ph	<i>n</i> -Pr	Benzene	97	67 (69)
9	1e	Me	Ph	THF	34	0
10	1e	Me	Ph	Benzene	13	0

a) Conditions: 500 W Xe-Hg lamp (Pyrex); 1 h; N₂; **1** (0.40 mmol), PDMBI (1.5 equiv), solvent (8 ml), H₂O (0.1 ml).

b) Isolated yields by column chromatography (yields based on the conversion of **1**).

aldol **2e** was observed in the photoreaction of acetyl substituted epoxy ketone **1e** with PDMBI. Under the irradiation conditions, acetyl chromophore less efficiently absorbs the incident light ($\lambda > 280$ nm) that could account for the lower reactivity of **1e**.



Based on the results obtained and our related studies,^{11,4} the reaction mechanism depicted in Scheme 1 is proposed. The photoexcited state of **1** is considered to be efficiently quenched by PDMBI.¹¹ The formed anion radical **6** would abstract the proton from PDMBI^{•+} or undergo epoxy ring-opening. The ketyl radical **7** undergoes α -O bond cleavage to give the oxy radical **8** that is subsequently reduced by **I[•]** to the anion **9**. The anion **9** easily undergoes retro-aldol fragmentation to produce aldehyde **4** and ketone **5**. On the other hand, the opened anion radical **10** abstracts the proton from PDMBI^{•+} to give the β -keto radical **11** that is reduced by **I[•]** to the anion **12**. The anion **12** is expected to easily give the enone **3**. Therefore, effective protonation of the anions **9** and **12** would give the aldol **2** in good yields. In any case, two electrons and two protons are required to convert **1** to **2**. Since PDMBI donates two electrons and one proton,⁶ additional proton sources have to be added into the reaction solutions. Apparently, water acts as an effective proton donor in the above reaction systems. However, increasing the amount of water should also change the medium polarity. A highly polar medium prefers a free ion radical species rather than ion radical pairs.² In the former case, effective proton and electron transfers do not occur between the intermediates in Scheme 1 and PDMBI derived radicals (PDMBI^{•+} and **I[•]**). Particularly, a large amount of water may be able to protonate **6** to give **7** and finally **8** that undergoes radical retro-aldol fragmentation¹¹ since subsequent electron transfer from **I[•]** would not be effective.

In summary, we have found that 2-phenyl-N,N-dimethylbenzimidazoline is an effective amine to photochemically convert aryl substituted epoxy ketones to aldols. Since various imidazoline derivatives could be designed and synthesized from readily available starting materials,⁵ such compounds are expected to be useful reductants for various PET processes. This methodology is currently under investigation in our laboratory.

Acknowledgments: This work was supported by a Grant-in-Aid for Scientific Research (No. 07640713) from the Ministry of Education, Science, and Culture of Japan. The grants from the Japan Association of Chemistry and the Uchida Energy Science Promotion Foundation are also acknowledged. We are grateful to Professor Masaki Kamata (Faculty of Education, Niigata University) for his assistance in measurement of redox potentials.

References and Notes

- a) Robinson, C. H.; Henderson, R. *J. Org. Chem.*, **1972**, *37*, 565-568. b) Weile, G. R.; McMorris, T. C. *J. Org. Chem.*, **1978**, *43*, 3942-3946. c) Shapiro, E. L.; Gentles, M. J.; Kabasakalian, P.; Magatti, A. *J. Org. Chem.*, **1981**, *46*, 5017-5019. d) Osuka, A.; Takaoka, K.; Suzuki, H. *Chem. Lett.*, **1984**, 271-272. e) McChesney, J. D.; Thompson, T. N. *J. Org. Chem.*, **1985**, *50*, 3473-3481. f) Molander, G. A.; Hahn, G. *J. Org. Chem.*, **1986**, *51*, 2596-2599. g) Miyashita, M.; Suzuki, T.; Yoshikoshi, A. *Tetrahedron Lett.*, **1987**, *28*, 4293-4296. h) Inokuchi, T.; Kusumoto, M.; Torii, S. *J. Org. Chem.*, **1990**, *55*, 1548-1553. i) Hasegawa, E.; Ishiyama, K.; Kato, T.; Horaguchi, T.; Shimizu, T.; Tanaka, S.; Yamashita, Y. *J. Org. Chem.*, **1992**, *57*, 5352-5359. j) Engman, L.; Stern, D. *J. Org. Chem.*, **1994**, *59*, 5179-5183.
- a) *Photoinduced Electron Transfer, Part C*, Fox, M. A. and Chanon, M., Eds. Elsevier, Amsterdam, 1988. b) Yoon, U. C.; Mariano, P. S.; Givens, R. S.; Atwater III, B. W. In *Advances in Electron Transfer Chemistry*; Mariano, P. S., Ed.; JAI Press: Greenwich, 1994; Vol. 4; pp 117-205 and references cited therein.
- a) Cossy, J.; Bouzide, A.; Ibbi, S.; Aclinou, P. *Tetrahedron* **1991**, *47*, 7775-7782. b) Authors reported that 42% of **2a** was obtained at 88% conversion of **1a** without any formation of dibenzoylmethane.^{3a}
- a) Hasegawa, E.; Ishiyama, K.; Horaguchi, T.; Shimizu, T. *J. Org. Chem.*, **1991**, *56*, 1631-1635. b) Hasegawa, E.; Ishiyama, K.; Horaguchi, T.; Shimizu, T. *Tetrahedron Lett.*, **1991**, *32*, 2029-2032.
- a) Chikashita, H.; Itoh, K. *Bull. Chem. Soc. Jp.*, **1986**, *59*, 1747-1752. b) Chikashita, H.; Ide, H.; Itoh, K. *J. Org. Chem.*, **1986**, *51*, 5400-5405.
- a) Chen, J. J.; Tanner, D. D. *J. Org. Chem.*, **1988**, *53*, 3897-3900. b) Tanner, D. D.; Chen, J. J. *J. Org. Chem.*, **1989**, *54*, 3842-3846. c) Tanner, D. D.; Chen, J. J.; Chen, L.; Luelo, L. *J. Am. Chem. Soc.*, **1991**, *113*, 8074-8081. d) Tanner, D. D.; Chen, J. J. *J. Org. Chem.*, **1992**, *57*, 662-666. e) Tanner, D. D.; Chen, J. J.; Luelo, C.; Peters, P. M. *J. Am. Chem. Soc.*, **1992**, *114*, 713-717.
- Epoxy ketones **1**, hydroxy ketones **2**, and enones **3** were fully characterized by their spectral data.^{1a,4} Since isolation of volatile benzaldehyde **4a** was difficult, its yield was determined by ¹H-NMR analysis of the crude reaction mixture. Although isolation and characterization of the oxidized products from PDMBI have not been completed yet, among the compounds detected was N-methyl-N-(2-N'-methylamino)benzamide, a ring-opened form of 2-hydroxy-PDMBI, that is probably formed through the reaction of imidazolium ion and hydroxy ion (see Scheme 1).
- We similarly conducted photoreactions of **1a** with other commonly used amines for PET reactions² and found that neither triethylamine nor tributylamine was effective to obtain **2a** in high yields.
- Using dry tetrahydrofuran (distilled from Na-benzophenone) for the reactions, we found that the yields of **2a** irregularly changed on several entries. Lower yields of **2a** appeared to result from the greater formation of **3a**. We think that such tricky results indicate that accidental contamination of water (moisture) would influence the product distribution and this could not be easily avoided in the usual preparative experiments.
- Since **4a** seems to be the retro-aldol fragmentation product from the β-hydroxy carbonyls, the other fragment, acetophenone, should exist in the reaction mixture. This was confirmed by ¹H-NMR analysis of the concentrated photolysate. Qualitatively, the amount of acetophenone changed in a similar way to that of **4a** upon changing the amount of water added.
- PDMBI was found to be a highly electron donating amine: the oxidation potential was measured as +0.32 V (E_p^{ox} vs SCE; 100 mV/s). Therefore, electron transfer from PDMBI to the excited triplet state of **1a** would be highly exothermic since the reduction potential of **1** was reported as -1.70 V (E_p^{red} vs SCE; 100 mV/s)^{4a} and the triplet energy of **1a** is estimated as 71 kcal/mol.^{11b} b) Dewar, D. J.; Sutherland, R. G. *J. Chem. Soc., Perkin Trans 2*, **1977**, 1522-1526.

(Received in Japan 26 June 1996; revised 8 August 1996; accepted 12 August 1996)