Friedel–Crafts alkylation of indoles with nitroolefins in the presence of β-cyclodextrin in water under neutral conditions

Vydyula Pavan Kumar, Regati Sridhar, Boga Srinivas, Mendu Narender, and Kakulapati Rama Rao

Abstract: Various indolyl nitroalkanes were prepared by the reaction of indoles with nitroolefins in the presence of β-cyclodextrin in water under neutral conditions. β-Cyclodextrin can be recovered and re-used several times without loss of activity.

Key words: β-cyclodextrin, nitroolefins, indoles, neutral conditions, water.

Résumé : On a préparé divers nitroalcanes d'indolyle par réaction d'indoles avec des nitrooléfines, en présence de cyclodextrine, dans des conditions aqueuses neutres. On peut récupérer la β-cyclodextrine et la réutiliser un certain nombre de fois sans perte d'activité.

Mots-clés : β-cyclodextrine, nitrooléfines, indoles, conditions neutres, eau.

[Traduit par la Rédaction]

Introduction

Indoles are present in many biologically active and naturally occurring compounds (1) and are also important intermediates for the synthesis of drugs and pharmaceuticals (2). Many indole alkaloids were synthesized utilizing the increased nucleophilic reactivity of the 3-position of the indole ring (3). The addition of indoles to electron-deficient alkenes, which in many respects is considered as Friedel–Crafts reaction (4), is a reaction of considerable synthetic utility, and the adducts resulting from the reaction are key intermediates for the synthesis of many biologically active compounds (5). However, the synthesis of 3-substituted indoles in the classical methodologies utilized indolylgrignard reagent (6), whereas the later reports involved either acid or base catalysts (7). These methods suffer from various disadvantages, such as drastic reaction conditions, longer reaction times, lower yields, and undesirable side products due to polymerization (8). Thus, there is a need to develop mild and environmentally benign Friedel–Crafts synthesis of these high value 3-substitued indoles in water under neutral conditions with a recyclable catalyst. The use of aqueous medium as solvent under neutral conditions reduces the harmful effects of organic solvents and also precludes the use of either acid or base. This becomes further sophisticated if these reactions can be performed under supramolecular catalysis. Though there are reports in aqueous media with Lewis-acid catalysts (9), there are no reports under neutral conditions in water. The fundamental problem in performing these reactions in water is that many organic substrates are hydrophobic and are insoluble in water. Therefore, we made an attempt at the Friedel–Crafts synthesis of 3-substituted indoles in water through supramolecular catalysis using β-cyclodextrin (β-CD) under neutral conditions.

The choice towards cyclodextrins was dictated by the fact that many interactions are dominated by hydrogen bonding in organocatalysis. Recently, metal-free hydrogen-bonding based catalysts have been put on a rational basis (10). Hydrogen-bonding motif is becoming a powerful tool in organocatalysis for the activation of carbonyl groups and related compounds through weak hydrogen-bond interactions (11). It is well-known that substituents of aromatic rings capable of hydrogen bonding can bind the OH groups of the cyclodextrin edges (12). Cyclodextrins, which are cyclic oligosaccharides, exert micro-environmental effects leading to selective reactions (13). They catalyze reactions by supramolecular catalysis through noncovalent bonding as seen in enzymes. Complexation depends on the size, shape, and hydrophobicity of the guest molecules. These attractive features of cyclodextrins and our earlier expertise in the biomimetic modeling of chemical reactions (14) prompted us to examine their utility in Friedel–Crafts reaction of indoles with nitroolefins.

Results and discussion

In general, the reactions were carried out by the in situ formation of the β-CD complex of the indole in water followed by the addition of nitroolefin and stirring for 1–3 h at 50 °C to give the corresponding products (Scheme 1). Alkylated indoles were formed as single products with high

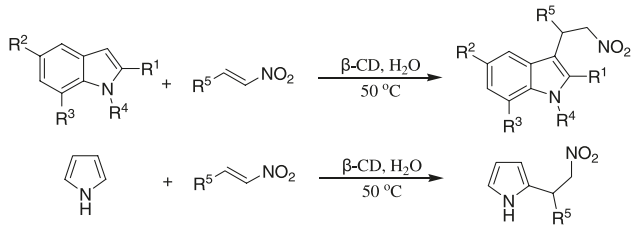
Received 18 February 2008. Accepted 21 May 2008. Published on the NRC Research Press Web site at canjchem.nrc.ca on 5 August 2008.

V. Pavan Kumar, R. Sridhar, B. Srinivas, M. Narender, and K. Rama Rao.[1] Organic Chemistry Division-I, Indian Institute of Chemical Technology, Uppal Road, Hyderabad 500–007 India.

[1]Corresponding author (e-mail: drkrrao@yahoo.com).

 doi:10.1139/V08-118

Scheme 1.



degree of conversion (Table 1). This methodology is also compatible with various substituted indoles and nitroolefines. Several examples illustrating this simple and practical methodology are summarized in Table 1. All the products were characterized by ^{1}H NMR, IR, mass spectroscopy, and elemental analysis. No asymmetric induction was observed in these reactions. The catalyst β-CD can be easily recovered and re-used. To see the further application of this reaction, it was also extended to pyrrole heterocycle (Table 1, entries 17 and 18).

The reaction also occurs at room temperature, but longer reaction times (48 h) are required and the isolated yields of products obtained are also low (1%–15%). All compounds listed in Table 1 failed to react with nitroolefins in water at 50 °C without the presence of β-cyclodextrin. Use of a catalytic amount of β-CD (0.1 mmol per mole of the substrate) at 50 °C had no impact on the reaction. These experiments indicate the substantial role of cyclodextrin. However, the reaction did not proceed when substituents such as bromo and nitro were present in the 5-position of indole ring, whereas the presence of other functionalities improved the reaction, which explains the important role of electron density on heterocycle. It is observed that the reaction did not proceed with alkyl substituted nitroolefins such as ((*E*)-2-nitrovinyl)cyclohexane and (*E*)-1-nitrobut-1-ene. The importance of this methodology can be seen in the case of 5-hydroxy indole (Table 1, entries 9 and 10), which reacts with nitroolefins in very good yields, whereas the reported methodologies utilize either acidic or basic catalysts leading to low yields even after prolonged reaction times because of the interaction of the indolyl hydroxyl group with the catalyst (4*d*, 7*f*).

Inclusion complexes of indole with β-cyclodextrin have been studied by Galian et al. (15). In this model, it was proposed that the indole is included in the β-cyclodextrin cavity in such a way that the pyrrole moiety of indole ring is directed towards primary face of β-cyclodextrin and a hydrogen bonding formed between indolic proton and oxygen of the primary hydroxyl (C_6–O) of β-cyclodextrin. This hydrogen bonding enhances the nucleophilicity of indole. Under the present reaction conditions of supramolecular catalysis, this type of positioning of indole in the cyclodextrin cavity facilitates the complexation of nitroolefin from the primary side, which can be activated by hydrogen bonding with C_6–OH of cyclodextrin for further reaction with indole. This is depicted in Fig. 1. However, in the case of *N*-substituted indoles (Table 1, substrates **1g** and **1h**), longer reaction times are required, since the hydrogen bonding is not possible in these cases. This clearly explains the importance of the presence of free indolic NH group.

The evidence for this mechanistic approach (Fig. 1) was deduced from ^{1}H NMR spectroscopy. The studies were carried out with indole (**1a**) and 2-((*E*)-2-nitrovinyl)furan (**2b**) as representative examples. NMR spectroscopy is one of the most important techniques used for the characterization of inclusion complexes. The formation of an inclusion complex results in the shift changes in the resonances of the host cyclodextrin and the guest protons (16). A comparison of the ^{1}H NMR spectra (D_2O) of β-CD, β-CD : indole complex, and freeze-dried reaction mixture of β-CD : indole complex with the nitroolefin **2b** at 1 h were studied. It is observed from Fig. 2 that there is an upfield shift of H_3 (0.03 ppm) and H_5 (0.05 ppm) protons of cyclodextrin in the β-CD : indole complex as compared with β-CD, indicating the formation of an inclusion complex of indole with β-CD from the secondary side of cyclodextrin. It is further observed from the spectra of the reaction mixture of β-CD : indole complex with the nitroolefin **2b** at 1 h that there is also an upfield shift of H_6 proton by 0.06 ppm. This indicates the complexation of the nitroolefin **2b** from the primary side of cyclodextrin for the reaction to proceed (Fig. 2). This clearly demonstrates that the nitroolefin is elegantly set for the addition reaction with the indole in the hydrophobic microenvironment of β-cyclodextrin cavity.

Thus, we have demonstrated for the first time an operationally simple and efficient aqueous phase Friedel–Crafts synthesis of indolyl nitroalkanes and pyrrolyl nitroalkanes by using β-cyclodextrin under neutral conditions. β-Cyclodextrin, apart from being nontoxic is also considered metabolically safe (17). In contrast with the existing methodologies using many acidic and basic catalysts, this method is very simple, high-yielding, and environment-friendly. Further potential applications of this reaction are under study.

Experimental

General

Melting points were recorded on a Buchi R-535 apparatus and are uncorrected. IR spectra were recorded on a PerkinElmer FTIR 240-c spectrometer using KBr optics. ^{1}H NMR spectra were recorded on Gemini-200 spectrometer in DMSO using TMS as internal standard. Mass spectra were recorded on an Agilent 1200 spectrometer. Starting materials were obtained commercially from Aldrich, Lancaster and were used without purification.

General procedure for the synthesis of indolyl nitroalkanes and pyrrolyl nitroalkanes

β-CD (1 mmol) was dissolved in water (20 mL) by warming to 50 °C until a clear solution was formed. Then, indole/pyrrole (1 mmol) dissolved in methanol (0.5 mL) was added dropwise, followed by nitroolefin (1 mmol), and the mixture was stirred at 50 °C until the reaction was complete (as monitored by TLC) (Table 1). The mixture was extracted with ethyl acetate, and the extract was filtered. The organic layer was dried over anhyd. Na_2SO_4, the solvent was removed under reduced pressure, and the resulting product was further purified by column chromatography. The aqueous layer was cooled to 5 °C to recover β-CD by filtration.

Table 1. Freidel–Crafts reaction of indoles and pyrrole with nitroolefins in the presence of β-CD in water at 50 °C.

Entry	Substrate	R^1	R^2	R^3	R^4	Nitroolefin	R^5	Product[a]	Time (h)	Yield[b] (%)
1	**1a**	H	H	H	H	**2a**	Ph	**3a**[c]	3.0	88
2	**1a**	H	H	H	H	**2b**	2–Furyl	**3b**[c]	3.2	86
3	**1b**	Me	H	H	H	**2a**	Ph	**3c**[c]	2.1	92
4	**1b**	Me	H	H	H	**2b**	2-Furyl	**3d**[d]	2.4	93
5	**1c**	Ph	H	H	H	**2a**	Ph	**3e**[d]	2.5	90
6	**1c**	Ph	H	H	H	**2b**	2-Furyl	**3f**	3.0	89
7	**1d**	COOH	H	H	H	**2a**	Ph	**3g**	2.4	85
8	**1d**	COOH	H	H	H	**2b**	2-Furyl	**3h**	2.5	86
9	**1e**	H	OH	H	H	**2a**	Ph	**3i**[d]	3.4	91
10	**1e**	H	OH	H	H	**2b**	2-Furyl	**3j**	3.5	90
11	**1f**	H	H	Et	H	**2a**	Ph	**3k**	2.2	93
12	**1f**	H	H	Et	H	**2b**	2-Furyl	**3l**	2.4	94
13	**1g**	H	H	H	Me	**2a**	Ph	**3m**[c]	5.3	82
14	**1g**	H	H	H	Me	**2b**	2-Furyl	**3n**[c]	5.5	84
15	**1h**	H	H	H	Bn	**2a**	Ph	**3o**[e]	6.2	81
16	**1h**	H	H	H	Bn	**2b**	2-Furyl	**3p**[e]	6.3	80
17	Pyrrole	—	—	—	—	**2a**	Ph	**3q**[c]	3.3	89
18	Pyrrole	—	—	—	—	**2b**	2-Furyl	**3r**[c]	3.4	92

[a]All the products were characterized by ^{1}H NMR, IR, and mass spectroscopy.
[b]Isolated yields after purification.
[c]Ref. 7*g*.
[d]Ref. 9*b*.
[e]Ref. 7*h*.

Fig. 1.

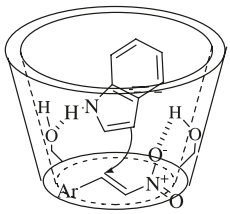
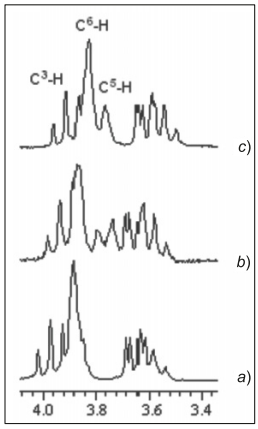


Fig. 2. ^{1}H NMR spectra of (*a*) β-CD, (*b*) β-CD : indole complex, and (*c*) reaction mixture after 1 h. The spectra were obtained in D_2O at 25 °C.



Characterization data for new compounds

*3-(1-(Furan-2-yl)-2-nitroethyl)-2-phenyl-1*H*-indole (3f)*

Light yellow solid; mp 125–127 °C. IR: 3429, 3057, 2924, 1456 cm^{-1}. ^{1}H NMR ($CDCl_3$, 300 MHz) δ: 8.13 (s, 1H), 7.59–7.04 (m, 10H), 6.35–6.27 (m, 1H), 6.14 (d, 1H, *J* = 3.21 Hz), 5.35 (t, 1H, *J* = 7.74 Hz), 5.22 (dd, 1H, *J* = 12.46, 7.55 Hz), 4.93 (dd, 1H, *J* = 12.46, 7.93 Hz). ^{13}C NMR ($CDCl_3$, 75 MHz) δ: 152.58, 142.16, 136.98, 135.97, 131.90, 129.08, 128.73, 126.72, 122.59, 120.25, 119.82, 111.32, 110.46, 107.37, 107.31, 77.12, 35.48. ESI-MS *m*/*z*: 333 (M + 1). Anal. calcd. for $C_{20}H_{16}N_2O_3$: C, 72.28; H, 4.85; N, 8.43. Found: C, 72.02; H, 4.98; N, 8.56.

*3-(2-Nitro-1-phenylethyl)-1*H*-indole-2-carboxylic acid (3g)*

White solid; mp 198–200 °C. IR: 3367, 2961, 1556 cm^{-1}. ^{1}H NMR ($CDCl_3$ + DMSO-d_6, 200 MHz) δ: 11.15 (s, 1H), 7.53–7.07 (m, 8H), 6.96 (t, 1H, *J* = 7.32 Hz), 6.08 (t, 1H, *J* = 8.05 Hz), 5.47–5.12 (m, 2H). ^{13}C NMR ($CDCl_3$ + DMSO-d_6, 75 MHz) δ: 168.43, 156.72, 146.14, 141.83, 132.52, 130.65, 128.31, 125.64, 122.84, 122.31, 121.74, 121.43, 120.58, 80.74, 41.27. EI-MS *m*/*z*: 310 (M^+). Anal. calcd. for $C_{17}H_{14}N_2O_4$: C, 65.80; H, 4.55; N, 9.03. Found: C, 66.04; H, 4.43; N, 9.12.

*3-(1-(Furan-2-yl)-2-nitroethyl)-1*H*-indole-2-carboxylic acid (3h)*

Brown solid; mp 201–203 °C. IR: 3506, 2972, 1574 cm^{-1}. ^{1}H NMR ($CDCl_3$ + DMSO-d_6, 200MHz) δ: 11.44 (b s, 1H), 7.65–6.84 (m, 5H), 6.39–6.06 (m, 3H), 5.27 (dd, 1H, *J* = 12.50, 8.59 Hz), 5.02 (dd, 1H, *J* = 13.28, 7.03 Hz). ^{13}C NMR ($CDCl_3$ + DMSO-d_6, 75 MHz) δ: 168.16, 157.41, 146.52, 141.19, 130.93, 129.84, 129.67, 125.66, 125.10, 121.53, 117.76, 115.38, 111.79, 81.81, 39.48. ESI-MS *m*/*z*: 301 (M + 1). Anal. calcd. for $C_{15}H_{12}N_2O_5$: C, 60.0; H, 4.03; N, 9.33. Found: C, 60.23; H, 4.11; N, 9.24.

3-(1-(Furan-2-yl)-2-nitroethyl)-1*H*-indol-5-ol (3j)

Oil. IR: 3419, 1550 cm^{-1}. ^1H NMR ($CDCl_3$, 200MHz) δ: 10.18 (s, 1H), 7.21–6.95 (m, 2H), 6.88–6.80 (m, 1H), 6.76–6.59 (m, 2H), 6.32–6.22 (m, 1H), 6.13 (d, 1H, *J* = 2.94 Hz), 5.16–4.78 (m, 3H). ^{13}C NMR ($CDCl_3$, 75 MHz) δ: 150.62, 141.04, 131.04, 126.19, 123.40, 113.62, 112.27, 112.0, 110.18, 109.47, 106.87, 102.43, 77.23, 35.57. ESI-MS *m/z*: 273 (M + 1). Anal. calcd. for $C_{14}H_{12}N_2O_4$: C, 61.76; H, 4.44; N, 10.29. Found: C, 61.51; H, 4.57; N, 10.17.

7-Ethyl-3-(2-nitro-1-phenylethyl)-1*H*-indole (3k)

Oil. IR: 3422, 3058, 2965, 1550 cm^{-1}. ^1H NMR ($CDCl_3$, 200 MHz) δ: 7.94 (b s, 1H), 7.41–7.17 (m, 6H), 7.06–6.87 (m, 3H), 5.25–4.77 (m, 3H), 2.83 (q, 2H, *J* = 7.39 Hz), 1.35 (t, 3H, *J* = 7.39 Hz). ^{13}C NMR ($CDCl_3$, 75 MHz) δ: 139.23, 135.36, 128.86, 127.74, 127.48, 126.77, 125.83, 121.23, 121.14, 120.23, 116.60, 114.83, 79.49, 41.63, 23.84. 13.68. ESI-MS *m/z*: 295 (M + 1). Anal. calcd. for $C_{18}H_{18}N_2O_2$: C, 73.45; H, 6.16; N, 9.52. Found: C, 73.68; H, 6.29; N, 9.40.

7-Ethyl-3-(1-(furan-2-yl)-2-nitroethyl)-1*H*-indole (3l)

Oil. IR: 3417, 3018, 2929, 1552 cm^{-1}. ^1H NMR ($CDCl_3$, 300 MHz) δ: 7.98 (b s, 1H), 7.39–7.31 (m, 2H), 7.08–6.95 (m, 3H), 6.29–6.24 (m, 1H), 6.13–6.09 (m, 1H), 5.19 (t, 1H, *J* = 7.74 Hz), 4.99 (dd, 1H, *J* = 12.46, 7.93 Hz), 4.86 (dd, 1H, *J* = 12.46, 7.36 Hz), 2.81 (q, 2H, *J* = 7.74 Hz), 1.35 (t, 3H, *J* = 7.74 Hz). ^{13}C NMR ($CDCl_3$, 75 MHz) δ: 142.23, 140.56, 132.41, 129.71, 128.52, 123.47, 121.20, 120.43, 117.61, 116.46, 112.23, 107.36, 77.84, 35.81, 22.70, 13.73. ESI-MS *m/z*: 285 (M + 1). Anal. calcd. for $C_{16}H_{16}N_2O_3$: C, 67.59; H, 5.67; N, 9.85. Found: C, 67.82; H, 5.78; N, 9.72.

Acknowledgement

We thank Council of Scientific & Industrial Research (CSIR), New Delhi, India, for fellowships to VPK, RS, BS, and MN.

References

1. (*a*) R.J. Sunberg. The chemistry of indoles. Academic Press, New York. 1969. p. 113; (*b*) L.G. Thomas. *In* Heterocyclic chemistry. 3rd Ed. Vol. 11. Longman. England. 1997. Parts 1, 2, and 5.
2. (*a*) A. Kleeman, J. Engel, B. Kutscher, and D. Reichert. Pharmaceutical substances. 4th Ed. Thieme, New York. 2001; (*b*) J.F. Austin and D.W.C. MacMillan. J. Am. Chem. Soc. **124**, 1172 (2002).
3. (*a*) R.A. Moore, C. Cheuk, X.Q.G. Yang, G.M.L. Patterson, R. Bonjoukalian, T.A. Smitka, J.S. Mynderse, R.S. Foster, N.D. Jones, J.K. Skiartzendruber, and J.B. Deeter. J. Org. Chem. **52**, 1036 (1987); (*b*) R.L. Garnick, S.B. Levery, and P.W. Le Quesne. J. Org. Chem. **43**, 1226 (1978); (*c*) R.E. Moore, C. Cheuk, and G.M.L. Patterson. J. Am. Chem. Soc. **106**, 6456 (1984).
4. (*a*) M. Bandini, A. Melloni, S. Tommasi, and A. Umani-Ronchi. Synlett, 1199 (2005); (*b*) M. Bandini, M. Fagioli, and A. Umani-Ronchi. Adv. Synth. Catal. **346**, 545 (2004); (*c*) Z.-P. Zhan and K. Lang. Synlett, 1551 (2005); (*d*) G. Bartoli, M. Bosco, S. Giuli, A. Giuliani, L. Lucarelli, E. Marcantoni, L. Sambri, and E. Torregiani. J. Org. Chem. **70**, 1941 (2005); (*e*) G. Bartoli, M. Bartolacci, M. Bosco, G. Foglia, A. Giuliani, E. Marcantoni, L. Sambri, and E. Torregiani. J. Org. Chem. **68**, 4594 (2003).
5. (*a*) H. Harada, Y. Hirokawa, K. Suzuki, Y. Hiyama, M. Oue, H. Kawashima, H. Kato, N. Yoshida, Y. Furutani, and S. Kato. Chem. Pharm. Bull. **53**, 184 (2005); (*b*) E.D. Cox, H. Diaz-Arauzo, Q. Huang, M.S. Reddy, C. Ma, B. Harris, R. McKernan, P. Skolnick, and J.M. Cook. J. Med. Chem. **41**, 2537 (1998).
6. W.E. Noland, G.M. Christensen, G.L. Sauer, and G.G.S. Dutton, J. Am. Chem. Soc. **77**, 456 (1955).
7. (*a*) T. Koike, M. Hagiwara, N. Takeuchi, and S. Tobinaga. Heterocycles, **45**, 1271 (1997); (*b*) S. Mahboobi, W. Wiegrebe, and A. Popp. J. Nat. Prod. **62**, 577 (1999); (*c*) T. Koike, N. Takeuchi, M. Hagiwara, K. Yamazaki, and S. Tobinaga. Heterocycles, **51**, 1271 (1999); (*d*) M. Bandini, M. Fagioli, and A.U. Ronchi. Adv. Synth. Catal. **346**, 545 (2004); (*e*) C. Lin, J. Hsu, M.N.V. Sastry, H. Fang, Z. Tu, J.-T. Liu, and Y.C. Fa. Tetrahedron, **61**, 11751 (2005); (*f*) R. Ballini, R.R. Clemente, A. Palmieri, and M. Petrini. Adv. Synth. Catal. **348**, 191 (2006); (*g*) L.-T. An, J.-P. Zou, L.-L. Zhang, and Y. Zhang. Tetrahedron Lett., **48**, 4297 (2007); (*h*) G. Srihari, M. Nagaraju, and M. M. Murthy. Synth. Commun. **38**, 100 (2008).
8. (*a*) M. Chakrabarty, R. Basak, and N. Ghosh. Tetrahedron Lett. **41**, 8331 (2001); (*b*) I. Komoto and S. Kobayashi. Org. Lett. **4**, 1115 (2002).
9. (*a*) K. Manabe, N. Aoyama, and S. Kobayashi. Adv. Synth. Catal. **343**, 174 (2001); (*b*) M. Bandini, P. Melchiorre, A. Melloni, and A. Umani-Ronchi. Synthesis, 1110 (2002); (*c*) M. Bandini, P.G. Cozzi, M. Giacomini, P. Melchiorre, S. Selva, and A. Umani-Ronchi. J. Org. Chem. **67**, 3700 (2002); (*d*) H. Firouzabadi, N. Iranpoor, and F. Nowrouzi. Chem. Commun. 789 (2005); (*e*) N. Azizi, F. Arynasab, and M. R. Saidi. Org. Biomol. Chem. **4**, 4275 (2006); (*f*) R.S. Kumar and P.T. Perumal. J. Heterocycl. Chem. **43**, 1383 (2006); (*g*) Y. Gu, C. Ogawa, and S. Kobayashi. Org. Lett. **9**, 175 (2007).
10. (*a*) P.R. Schreiner and A. Wittkopp. Org. Lett. **4**, 217 (2002); (*b*) A. Wittkopp and P. Schreiner. Chem. Eur. J. **9**, 407 (2003); (*c*) P.R. Schreiner. Chem. Soc. Rev. **32**, 289 (2003); (*d*) P.M. Pihko. Angew. Chem., Int. Ed. **43**, 2062 (2004); (*e*) C.S. Wilcox, E.-I. Kim, D. Romano. L.H. Kuo, A.L. Burt, and D.P. Curran. Tetrahedron, **51**, 621 (1995).
11. R.P. Herrera, V. Sgarzani, L. Bernardi, and A. Ricci. Angew. Chem., Int. Ed. **44**, 6576 (2005).
12. (*a*) G.G. Gaitano, P.R. Sainz-Rozas, J.R. Isasi, M. Sanchez, and G. Tardajos. J. Phys. Chem. **108A**, 392 (2004); (*b*) A. Sytnik and C.D. Valle. J. Phys. Chem. **99**, 13028 (1995); (*c*) T. Stalin and N. Rajendiran. J. Photochem. Photobiol. A, **182**, 137 (2006); (*d*) B. Manunza, S. Deiana, M. Pintora, and C. Gessa. J. Mol. Graphics Mod. **15**, 79 (1997).
13. (*a*) V.B. Sheshanath and V.B. Sidhanath. Mini-Rev. Org. Chem. **4**, 231 (2007); (*b*) K. Liu, D. Haeussinger, and W.-D. Woggon. Synlett, **14**, 2298 (2007); (*c*) V. Ramamoorthy, C. Meenakshi, S. Muthusubramanian, and S. Sivasubramanian. J. Inclusion Phenom. Macrocyclic Chem. **36**, 425 (2000).
14. (*a*) M. Narender, M.S. Reddy, V. Pavan Kumar, V.P. Reddy, Y.V.D. Nageswar, and K.R. Rao. J. Org. Chem. **72**, 1849 (2007); (*b*) K. Surendra, N.S. Krishnaveni, A. Mahesh, and K.R. Rao. J. Org. Chem. **71**, 2532 (2006); (*c*) N.S. Krishnaveni, K. Surendra, and K.R. Rao. Chem. Commun. 669 (2005); (*d*) K. Surendra, N.S. Krishnaveni, M.A. Reddy, Y.V.D. Nageswar, and K.R. Rao. J. Org. Chem. **68**, 2058 (2003).
15. R.E. Galian and A.V. Veglia. J. Photochem. Photobiol. A, **187**, 356 (2007).

16. (*a*) S.-Y. Jia, Y.-Q. Hao, L.-N. Li, K. Chen, Y. Wu, J. Liu, L. Wu, and Y.-H. Ding. Chem. Lett. **34**, 1248 (2005); (*b*) H.J. Schneider, F. Hacket, V. Rudiger, and H. Ikeda. Chem. Rev. **98**, 1755 (1998); (*c*) P.V. Demarco and A.L. Thakkar. J. Chem. Soc. Chem. Commun. 2 (1970); (*d*) H. Yamamura, Y. Yamada, R. Miyagi, K. Kano, S. Araki, and M. Kawai. J. Inclusion Phenom. Macrocyclic Chem. **45**, 211 (2003).
17. K. Uekama, F. Hirayama, and T. Irie. Chem. Rev. **98**, 2045 (1998).