

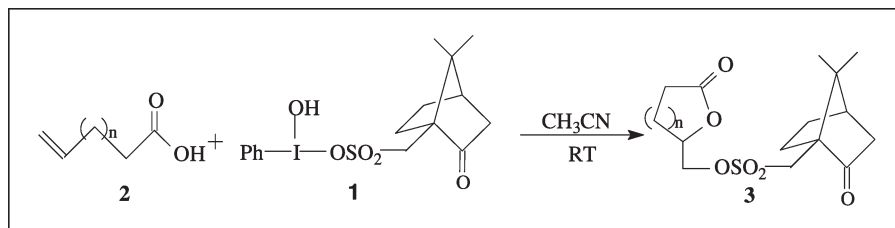
Min Zhu,<sup>a\*</sup> Na-Bo Sun,<sup>a</sup> He Li,<sup>a</sup> and Jie Yan<sup>b</sup><sup>a</sup>College of Biological and Environmental Sciences, Zhejiang Shuren University, Hangzhou, Zhejiang 310015, People's Republic of China<sup>b</sup>College of Chemical Engineering and Materials Sciences, Zhejiang University of Technology, Hangzhou, Zhejiang 310032, People's Republic of China

\*E-mail: hzzm60@163.com

Received September 3, 2009

DOI 10.1002/jhet.337

Published online 4 March 2010 in Wiley InterScience (www.interscience.wiley.com).



The novel reaction of [hydroxyl (((+)-10-camphorsulfonyl)oxy)iodo]benzene (**1**) with alkenoic acids was reported. When **1** reacted with various 4-pentenoic acids in CH<sub>3</sub>CN, camphorsulfonylactons were obtained in excellent yields in short times, some had two diastereoisomers, whereas **1** reacted with 5-hexenoic acid, giving middle yield of camphorsulfonylacton; however, 3-butenic and *trans*-3-hexenoic acids reacted with **1** slowly in CH<sub>2</sub>Cl<sub>2</sub>, only unsaturated lactones were provided.

*J. Heterocyclic Chem.*, **47**, 436 (2010).

## INTRODUCTION

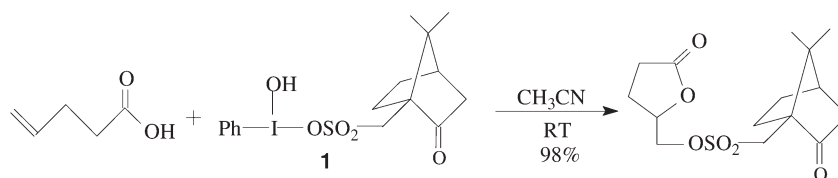
Lactonizations have been studied extensively, and this type of transformation serves as an important key reaction in a variety of syntheses [1]. Among them, halolactonization and phenylselenolactonization are general used methods [2]. Recently, organic hypervalent iodine reagents have found broad application in organic chemistry and frequently used in synthesis due to their chemical properties and reactivity are similar to those of Hg (II), Tl (III), and Pb (IV), but without the toxic and environmental problems of these heavy metal congeners [3]. Koser and coworkers first reported the tosyloxylactonization of alkenoic acids with the hypervalent iodine reagent, [hydroxyl(tosyloxy)iodo]benzene (HTIB, Koser's reagent), which mechanism was different with halolactonization and phenylselenolactonization and received much attention [4]. The ability of HTIB to introduce the tosylate ligand into alkenoic acids prompted us to investigate the camphorsulfonyloxylactonization of alkenoic acids with the analogous reagent, [hydroxyl (((+)-10-camphorsulfonyl)oxy)iodo]benzene (**1**) [5], a stable and incorporating a chiral ligand hypervalent iodine reagent. Here, we would like to report a novel and convenient camphorsulfonyloxylactonization of alkenoic acids, a series of new 5-camphorsulfonyloxy-4-pentanolactones and 6-camphorsulfonyloxy-5-hexanolactone were synthesized.

Initially, we prepared [hydroxyl (((+)-10-camphorsulfonyl)oxy)iodo]benzene (**1**) according to the literature procedure [5]. Then, we investigated the reaction of 4-

pentenoic acid with **1**, we found that when the equal equivalent of both them were mixed and stirred in CH<sub>3</sub>CN at room temperature, the reaction was carried out fluently and finished in 0.5 h, the novel compound of 5-camphorsulfonyloxy-4-pentanolactone was obtained in nearly quantitative (Scheme 1). Prompted by the good result, a series of experiments were performed on the reaction of 4-pentenoic acid with **1** in order to determine the suitable reaction conditions, and CH<sub>3</sub>CN and CH<sub>2</sub>Cl<sub>2</sub> were found to be the most preferred solvents. Finally, the reaction of a series of alkenoic acids (**2**) with **1** in CH<sub>3</sub>CN or CH<sub>2</sub>Cl<sub>2</sub> at room temperature were investigated, several new camphorsulfonylactons (**3**) were provided (Scheme 2), the good results are summarized in Table 1.

It is shown from Table 1 that 4-pentenoic acid (**2a**), 2-methyl-4-pentenoic acid (**2b**), 3-methyl-4-pentenoic acid (**2c**) and 2, 2-dimethyl-4-pentenoic acid (**2d**) all reacted with **1** fast, and gave the corresponding 5-camphorsulfonyloxy-4-pentanolactones, respectively, in excellent yields (entries **1–4**); Similar treatment of 5-hexenoic acid needed longer time compared with 4-pentenoic acid and provided 6-camphorsulfonyloxy-5-hexanolactone (**3e**) in middle yield (entry **5**), which meant that five-membered lactone ring was formed easier than six-membered lactone ring in the camphorsulfonyloxylactonization of alkenoic acids. We also checked the reaction of 6-heptenoic acid with **1**, found that after 48 h it had not been completed and the desired seven-membered lactone ring was obtained in poor yield. When 3-butenic and *trans*-3-hexenoic acids were treated with **1**

Scheme 1



in same reaction conditions, the reaction was somewhat difficult to carry out in  $\text{CH}_3\text{CN}$  and slowly; then using  $\text{CH}_2\text{Cl}_2$  in place of  $\text{CH}_3\text{CN}$ , we found that after 24 h the reaction was finished. However, the products were not the desired camphorsulfonylactons, two unsaturated lactones were found (entries **6** and **7**). It was revealed by  $^1\text{H-NMR}$  technique that the desired 3-sulfonyloxy-4-butanolactones were first formed, but then transformed into the unsaturated lactones during workup procedure by elimination. 2-Cyclopenteneacetic acid reacted with **1** also fluently, but gave another unsaturated lactone (entry **8**), which agreed with Koser and coworkers report [4].

Koser et al. in 1988 reported another lactonization using the similar hypervalent iodine reagent, [hydroxyl ((bis(phenyloxy)phosphoryl)oxy)iodo]benzene, and they found that when 2-methyl-4-pentenoic acid was treated with the hypervalent iodine reagent, the products were a mixture of diastereomers, with a ratio varied from 1.2 to 1.4:1 [6]. Because of [hydroxyl (((+)-10-camphorsulfonyl)oxy)iodo]benzene is a chiral hypervalent iodine reagent, the lactonization of it may be stereoselectivity, and some evidence was obtained by examination of the  $^1\text{H-NMR}$  spectrum of camphorsulfonylactons: when 2-methyl-4-pentenoic acid (**2b**) and 3-methyl-4-pentenoic acid (**2c**) were treated with **1** at room temperature, the provided products were mixtures of diastereomers, the ratios of them were 3.1:1 and 2.3:1, respectively. Then, we checked the effect of temperature on the stereoselectivity of **2b** and found that the camphorsulfonylactonization got diastereomers with higher ratio at lower of temperature; The reaction was investigated at room temperature,  $-20^\circ\text{C}$  and  $-50^\circ\text{C}$ , respectively, the ratios of diastereomers varied from 3.1, 4.0 to 4.8:1. However, except **2b** and **2c**, other alkenoic acids were not observed having the stereoselectivity in the camphorsul-

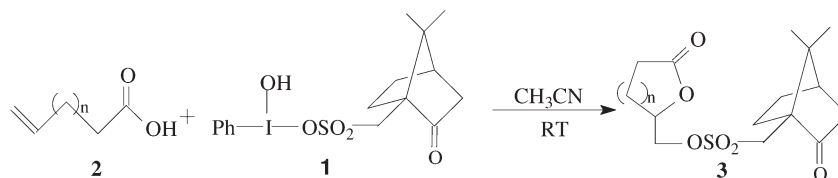
fonylactonization at room temperature. Solvents also had small effect on the stereoselectivity, we found that  $\text{CH}_3\text{CN}$  was better than  $\text{CH}_2\text{Cl}_2$  to get high diastereomers ratio for **2b** in the reaction.

[Hydroxyl (((+)-10-camphorsulfonyl)oxy)iodo]benzene was made from (diacetoxyiodo)benzene and (+)-10-camphorsulfonic acid in  $\text{CH}_3\text{CN}$ . To extend the scope of camphorsulfonylactonization, find simpler and more convenient camphorsulfonylactonization, the “one-pot” reaction was investigated; when equal equivalent of (diacetoxyiodo)benzene, (+)-10-camphorsulfonic acid and 4-pentenoic acid were mixed in  $\text{CH}_3\text{CN}$  at room temperature and stirred the mixture, we found that the reaction was completed in 0.5 h, giving the desired **3a** in 95% of yield. When [bis(trifluoroacetoxy)iodo]benzene was used in place of (diacetoxyiodo)benzene, the same result was obtained in 94% of yield. Therefore, the simpler and more convenient “one-pot” camphorsulfonylactonization was found (Scheme 3). Further investigation of the reaction will be reported later.

The plausible mechanism is similar to the literature procedure [4], which included the electrophilic addition of hypervalent iodine reagent **1** on the alkene, then an intramolecular nucleophilic displacement was happened, followed by another nucleophilic displacement to give the camphorsulfonylactone (Scheme 4).

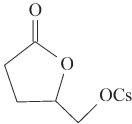
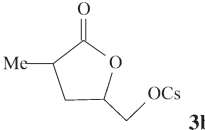
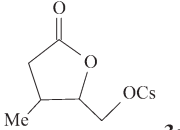
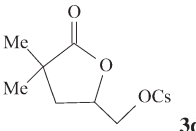
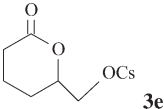
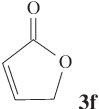
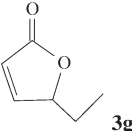
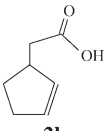
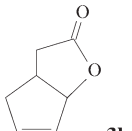
In conclusion, we have successfully developed a novel and convenient reaction of [hydroxyl-(((+)-10-camphorsulfonyl)oxy)iodo]benzene with alkenoic acids, several new 5-camphorsulfonyloxy-4-pentanolactones in excellent yields and 6-camphorsulfonyloxy-5-hexanolactone in middle yield were prepared. The camphorsulfonylactonization has some advantages, such as, mild reaction conditions, simple procedure, and good yields. Furthermore, the scope of hypervalent iodine reagents in organic synthesis could be extended.

Scheme 2



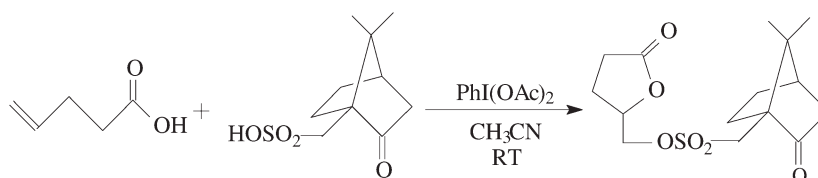
**Table 1**

The result of the camphorsulfonylactonization of alkenoic acids.

| Entry | Alkenoic acids (2)                                                                               | Camphorsulfonyloxylactones (3) <sup>a</sup>                                                      | Time (h) | Yield (%) <sup>b</sup> |
|-------|--------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------|----------|------------------------|
| 1     | $\text{CH}_2=\text{CH}(\text{CH}_2)_2\text{CO}_2\text{H}$<br><b>2a</b>                           | <br><b>3a</b>   | 0.5      | 98                     |
| 2     | $\text{CH}_2=\text{CHCH}(\text{Me})\text{CHCO}_2\text{H}$<br><b>2b</b>                           | <br><b>3b</b>   | 0.5      | 95                     |
| 3     | $\text{CH}_2=\text{CHCH}(\text{Me})\text{CH}_2\text{CO}_2\text{H}$<br><b>2c</b>                  | <br><b>3c</b>   | 0.5      | 93                     |
| 4     | $\text{CH}_2=\text{CHCH}(\text{Me})_2\text{CO}_2\text{H}$<br><b>2d</b>                           | <br><b>3d</b>  | 1.0      | 95                     |
| 5     | $\text{CH}_2=\text{CH}(\text{CH}_2)_3\text{CO}_2\text{H}$<br><b>2e</b>                           | <br><b>3e</b> | 2.5      | 63                     |
| 6     | $\text{CH}_2=\text{CHCH}_2\text{CO}_2\text{H}$<br><b>2f</b>                                      | <br><b>3f</b> | 24       | 52 <sup>c</sup>        |
| 7     | $\text{CH}_3\text{CH}_2\text{CH}=\text{CHCH}_2\text{CO}_2\text{H}$<br><b>2g</b>                  | <br><b>3g</b> | 24       | 41 <sup>c</sup>        |
| 8     | <br><b>2h</b> | <br><b>3h</b> | 1.0      | 81                     |

<sup>a</sup> Cs, (+)-10-camphorylsulfonyl.<sup>b</sup> Isolated yield.<sup>c</sup>  $\text{CH}_2\text{Cl}_2$  was used as solvent.

Scheme 3



## EXPERIMENTAL

**General procedure for the iodination of terminal alkynes.** To  $\text{CH}_3\text{CN}$  or  $\text{CH}_2\text{Cl}_2$  (2 mL), alkenoic acid **2** (0.3 mmol), [hydroxyl (((+)-10-camphorsulfonyl)oxy)iodo]benzene **1** (0.3 mmol) were added. The mixture was stirred at room temperature for 0.5–24 h (shown in Table 1) and then separated on a silica gel plate using (3:1, hexane–ethyl acetate) as eluant to give camphorsulfonyloxylactone **3** in good to excellent yields.

**3a:** Oil.  $^1\text{H-NMR}$  (500 MHz,  $\text{CDCl}_3$ ): 4.82–4.79 (m, 1H), 4.51 (ddd,  $J = 22.0, 11.5, 3.0$  Hz, 1H), 4.37 (ddd,  $J = 21.5, 11.0, 4.5$  Hz, 1H), 3.62 (dd,  $J = 15.5, 6.0$  Hz, 1H), 3.08 (dd,  $J = 15.0, 4.0$  Hz, 1H), 2.69–2.52 (m, 2H), 2.43–2.37 (m, 3H), 2.20–2.02 (m, 3H), 1.97 (d,  $J = 17.5$  Hz, 1H), 1.75–1.65 (m, 1H), 1.51–1.45 (m, 1H), 1.10 (s, 3H), 0.88 (s, 3H).  $^{13}\text{C-NMR}$  (125 MHz,  $\text{CDCl}_3$ ): 214.2, 176.1, 76.7 (d,  $J = 7.5$  Hz), 70.1, 69.9, 57.8 (d,  $J = 2.5$  Hz), 48.1, 47.2, 42.6 (d,  $J = 2.5$  Hz), 42.4 (d,  $J = 1.3$  Hz), 27.9, 26.8, 24.8 (d,  $J = 7.5$  Hz), 23.3 (d,  $J = 8.8$  Hz), 19.5 (t,  $J = 2.5$  Hz). IR (film):  $\nu = 2963, 1781, 1746, 1456, 1418, 1360, 1282, 1167, 1070, 962\text{ cm}^{-1}$ . MS (EI,  $m/z$ , %): 330 ( $\text{M}^+$ , 100). HRMS:  $\text{C}_{15}\text{H}_{22}\text{O}_6\text{S}$  calcd.: 330.1137, found: 330.1125.

**3b:** Oil.  $^1\text{H-NMR}$  (500 MHz,  $\text{CDCl}_3$ ): 4.79–4.72 (**3b<sub>1</sub>**) and 4.68–4.62 (**3b<sub>2</sub>**) (m, 1H), 4.51 (ddd,  $J = 19.0, 11.5, 3.0$  Hz, 1H), 4.37–4.31 (m, 1H), 3.66–3.59 (m, 1H), 3.09–3.03 (m, 1H), 2.83–2.78 (**3b<sub>1</sub>**) and 2.77–2.70 (**3b<sub>2</sub>**) (m, 1H), 2.56–2.49 (m, 1H), 2.46–2.37 (m, 2H), 2.16–2.13 (m, 1H), 2.10–2.03 (m, 1H), 1.97 (d,  $J = 18.0$  Hz, 1H), 1.79–1.68 (m, 2H), 1.50–1.44 (m, 1H), 1.31 (d,  $J = 5.5$  Hz, **3b<sub>1</sub>**) and 1.30 (d,  $J = 6.0$  Hz, **3b<sub>2</sub>**) (d, 3H), 1.10 (**3b<sub>1</sub>**) and 1.09 (**3b<sub>2</sub>**) (s, 3H), 0.89 (**3b<sub>1</sub>**) and 0.88 (**3b<sub>2</sub>**) (s, 3H).  $^{13}\text{C-NMR}$  (125 MHz,  $\text{CDCl}_3$ ): 214.4, 214.3, 179.2, 178.3, 74.9, 74.5 (d,  $J = 7.5$  Hz), 70.5, 70.4, 69.7, 69.4, 57.9 (d,  $J = 3.8$  Hz), 48.2 (d,  $J = 3.8$  Hz), 47.4, 47.3 (d,  $J = 6.3$  Hz), 42.7, 42.5 (d,  $J = 2.5$  Hz), 35.2, 33.7, 32.2 (d,  $J = 8.8$  Hz), 31.6 (d,  $J = 6.3$  Hz), 26.9, 24.9 (t,  $J = 3.8$  Hz), 19.6 (d,  $J = 5.0$  Hz), 16.1, 15.1 (d,  $J = 3.8$  Hz). IR (film):  $\nu = 2966, 1775, 1747, 1456, 1360, 1286, 1168, 1069,$

972, 931  $\text{cm}^{-1}$ . MS (EI,  $m/z$ , %): 344 ( $\text{M}^+$ , 100). HRMS:  $\text{C}_{16}\text{H}_{24}\text{O}_6\text{S}$  calcd.: 344.1294, found: 344.1289.

**3c:** Oil.  $^1\text{H-NMR}$  (500 MHz,  $\text{CDCl}_3$ ): 4.75–4.30 (m, 3H), 3.63 (dd,  $J = 15.0, 4.5$  Hz, 1H), 3.07 (dd,  $J = 15.5, 4.0$  Hz, 1H), 2.85–2.78 (m, 1H), 2.72–2.66 (**3c<sub>1</sub>**) and 2.56–2.49 (**3c<sub>2</sub>**) (m, 1H), 2.45–2.22 (m, 3H), 2.15–2.13 (m, 1H), 2.11–2.02 (m, 1H), 1.97 (d,  $J = 18.5$  Hz, 1H), 1.75–1.65 (m, 1H), 1.51–1.44 (m, 1H), 1.23 (dd,  $J = 6.5, 3.0$  Hz, **3c<sub>1</sub>**) and 1.17 (d,  $J = 7.5$  Hz, **3c<sub>2</sub>**) (3H), 1.10 (s, 3H), 0.88 (s, 3H).  $^{13}\text{C-NMR}$  (125 MHz,  $\text{CDCl}_3$ ): 214.3, 175.7 (d,  $J = 2.5$  Hz), 175.4, 83.3 (d,  $J = 2.5$  Hz), 79.2 (d,  $J = 5.0$  Hz), 68.8, 68.6, 68.2, 68.0, 57.9 (d,  $J = 3.8$  Hz), 48.2, 47.4 (d,  $J = 3.8$  Hz), 47.2 (d,  $J = 2.5$  Hz), 42.7 (d,  $J = 3.8$  Hz), 42.5 (d,  $J = 2.5$  Hz), 36.4 (d,  $J = 3.8$  Hz), 36.2, 31.9, 31.8, 31.7, 26.9, 24.9 (d,  $J = 2.5$  Hz), 24.8, 19.6 (d,  $J = 3.8$  Hz), 18.0, 13.5. IR (film):  $\nu = 2965, 1785, 1747, 1456, 1418, 1361, 1283, 1214, 1166, 1054, 975, 933\text{ cm}^{-1}$ . MS (EI,  $m/z$ , %): 344 ( $\text{M}^+$ , 100). HRMS:  $\text{C}_{16}\text{H}_{24}\text{O}_6\text{S}$  calcd.: 344.1294, found: 344.1277.

**3d:** Oil.  $^1\text{H-NMR}$  (500 MHz,  $\text{CDCl}_3$ ): 4.73–4.69 (m, 1H), 4.51 (ddd,  $J = 20.0, 11.5, 3.5$  Hz, 1H), 4.33 (ddd,  $J = 19.5, 11.5, 5.5$  Hz, 1H), 3.63 (dd,  $J = 15.5, 8.0$  Hz, 1H), 3.08 (d,  $J = 15.0$  Hz, 1H), 2.45–2.37 (m, 2H), 2.20–2.13 (m, 2H), 2.10–2.01 (m, 1H), 1.99–1.95 (m, 2H), 1.75–1.67 (m, 1H), 1.51–1.45 (m, 1H), 1.32 (s, 3H), 1.30 (s, 3H), 1.10 (s, 3H), 0.89 (s, 3H).  $^{13}\text{C-NMR}$  (125 MHz,  $\text{CDCl}_3$ ): 214.3 (d,  $J = 8.8$  Hz), 180.8, 73.6 (d,  $J = 3.8$  Hz), 69.9, 69.6, 57.9, 48.2, 47.4 (d,  $J = 10.0$  Hz), 42.7, 42.5 (d,  $J = 2.5$  Hz), 40.0 (d,  $J = 2.5$  Hz), 38.4 (d,  $J = 7.5$  Hz), 26.9, 24.9 (d,  $J = 3.8$  Hz), 24.8 (d,  $J = 3.8$  Hz), 24.7 (d,  $J = 2.5$  Hz), 19.6. IR (film):  $\nu = 2967, 1775, 1747, 1457, 1361, 1280, 1207, 1169, 1130, 1067, 983, 926\text{ cm}^{-1}$ . MS (EI,  $m/z$ , %): 358 ( $\text{M}^+$ , 100). HRMS:  $\text{C}_{17}\text{H}_{26}\text{O}_6\text{S}$  calcd.: 358.1451, found: 358.1441.

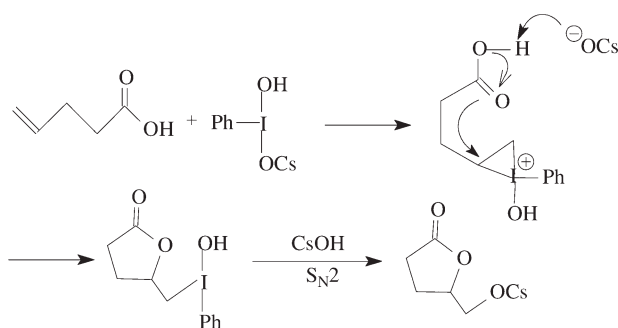
**3e:** Oil.  $^1\text{H-NMR}$  (500 MHz,  $\text{CDCl}_3$ ): 4.65–4.55 (m, 1H), 4.45–4.34 (m, 2H), 3.64 (dd,  $J = 15.0, 8.5$  Hz, 1H), 3.09 (d,  $J = 15.0$  Hz, 1H), 2.65–2.60 (m, 1H), 2.52–2.35 (m, 3H), 2.15–1.85 (m, 6H), 1.80–1.70 (m, 2H), 1.51–1.42 (m, 1H), 1.10 (s, 3H), 0.89 (s, 3H).  $^{13}\text{C-NMR}$  (125 MHz,  $\text{CDCl}_3$ ): 214.4, 170.1, 70.4, 70.2, 57.9, 48.2 (d,  $J = 2.5$  Hz), 47.4 (d,  $J = 2.5$  Hz), 42.7 (d,  $J = 3.8$  Hz), 42.5, 29.5, 26.9, 24.9 (d,  $J = 11.3$  Hz), 23.9 (d,  $J = 6.3$  Hz), 19.6, 18.2. IR (KBr):  $\nu = 2961, 1744, 1456, 1360, 1240, 1169, 1081, 1054, 963\text{ cm}^{-1}$ . MS (EI,  $m/z$ , %): 344 ( $\text{M}^+$ , 100). HRMS:  $\text{C}_{16}\text{H}_{24}\text{O}_6\text{S}$  calcd.: 344.1294, found: 344.1288.

**Acknowledgments.** Financial support from the Natural Science Foundation of China (Project 20672100) is greatly appreciated.

## REFERENCES AND NOTES

- [1] (a) Dowle, M. D.; Davies, D. I. *Chem Soc Rev* 1979, 8, 171; (b) Harding, K. E.; Tiner, T. H. In *Comprehensive Organic Synthesis*; Trost, B. M., Fleming, I., Eds.; Pergamon Press: Oxford, 1991; Vol. 4, p 363; (c) Rousseau, G.; Robin, S. *Tetrahedron* 1998, 54, 13681.

Scheme 4



- [2] (a) Bartlett, P. A.; Meyerson, J. *J Am Chem Soc* 1978, 100, 3950; (b) Haas, J.; Piguel, S.; Wirth, T. *Org Lett* 2002, 4, 297; (c) Nicolaou, K. C.; Seitz, S. P.; Sipio, W. J.; Blount, J. F. *J Am Chem Soc* 1979, 101, 3884.
- [3] (a) Varvoglis, A. *Tetrahedron* 1997, 53, 1179; (b) Stang, P. J.; Zhdankin, V. V. *Chem Rev* 1996, 96, 1123; (c) Zhdankin, V. V.; Stang, P. J. *Chem Rev* 2002, 102, 2523; (d) Wirth, T.; Hirt, U. H. *Synthesis* 1999, 1271; (e) Kirschning, A. *Eur J Org Chem* 1998, 11, 2267; (f) Ochiai, M. *J Organomet Chem* 2000, 611, 494; (g) Okuyama, T. *Acc Chem Res* 2002, 35, 12; (h) Zhdankin, V. V.; Stang, P. J. *Tetrahedron* 1998, 54, 10927; (i) Grushin, V. V. *Chem Soc Rev* 2000, 29, 315.
- [4] Shah, M.; Taschner, M. J.; Koser, G. F.; Rach, N. L. *Tetrahedron Lett* 1986, 27, 4557.
- [5] Hatzigrigoriou, E.; Varvoglis, A.; Bakola-Christianopoulou, M. *J Org Chem* 1990, 55, 315.
- [6] Koser, G. F.; Lodaya, J. S.; Ray, D. G., III; Kokil, P. B. *J Am Chem Soc* 1988, 110, 2987.