

Synthesis of conjugated dienes from vinyl epoxides, vinyl acetonides and 2,5-dihydrofurans *via* zirconocene-mediated deoxygenation

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The zirconocene-mediated reaction of vinyl epoxides, vinyl acetonides and 2,5-dihydrofurans proceeds *via* deoxygenation, yielding conjugated dienes.

During the last two decades organozirconium compounds have attracted a great deal of attention, along with organotitanium compounds, and their synthetic importance has been demonstrated in carbon-carbon bond forming reactions including cyclization and carbonylation.¹ Recently, the reactions of zirconacycles have been extensively studied.² β -Fragmentation reactions of zirconacyclopropanes, generated from the zirconocene-mediated reaction of allyl ethers and related allylic compounds, proved to be synthetically useful.³ We were originally interested in the possibility of observing the previously unknown [4 + 2] retrocycloaddition of oxazirconacyclohexenes, comparable to the retro-Diels-Alder reaction,⁴ as shown in Scheme 1, and studied zirconocene-mediated deoxygenation reactions with vinyl epoxides and vinyl acetonides. Deoxygenation of epoxides by metallocenes⁵ and titanium(III)-mediated deoxygenation of vinyl epoxides⁶ have been previously reported.

When vinyl epoxide **1** was treated with dibutylzirconocene in THF at room temperature for 4 h, deoxygenation occurred smoothly, yielding the diene **5** in 84% yield. We have found that the deoxygenation of vinyl epoxides was completely stereospecific and stereoselective, and the *E*- and *Z*-geometry of the conjugated dienes depended on the stereochemistry of the vinyl epoxides. Reaction of *cis*-epoxide with dibutylzirconocene in THF afforded *Z*-diene (Table 1, entry 1), whereas zirconocene-

mediated reaction of *trans*-epoxide afforded *E*-diene (entry 2). In the case of a trisubstituted vinyl epoxide (entry 5), the diene was also obtained in high yield, although zirconocene cannot normally form an alkene-zirconocene complex.⁷ The stereochemical outcome obtained in this study seems to rule out the [4 + 2] retrocycloaddition pathway because *cis*- and *trans*-epoxide should give the same oxazirconacyclohexene intermediate. The reaction may proceed *via* allyl zirconocene **4**,⁸ although the retention of geometry from the epoxide is difficult to rationalize. Further studies are needed to clarify the mechanism.

We also studied the zirconocene-mediated reaction of vinyl acetonides. As shown in Scheme 2, the reaction may proceed through β -fragmentation of zirconacyclopropane **7** and the subsequent formation of allyl zirconocene **4** along with the loss of acetone. As predicted, when vinyl acetonide **6** was treated with dibutylzirconocene in THF at room temperature for 6 h, conjugated diene **5** was isolated in 83% yield. Further examples are shown in Table 1. The reaction proceeded cleanly and was normally complete within 6 h at room temperature. *cis*-Vinyl acetonide (entries 8 and 9) afforded *Z*-diene, whereas *trans*-vinyl acetonides (entries 10 and 11) yielded *E*-dienes, indicating that the reaction was also stereospecific and stereoselective. The disubstituted vinyl acetonide (entry 13) did not react with zirconocene to form the alkene-zirconocene complex due to steric effects.⁷

We next turned our attention to the deoxygenation of 2,5-dihydrofurans. This approach involves β -fragmentation of zirconacyclopropane intermediate **9** and subsequent deoxygenation

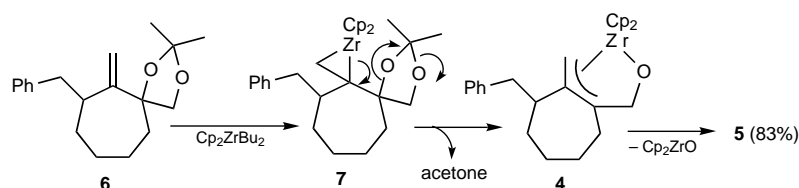
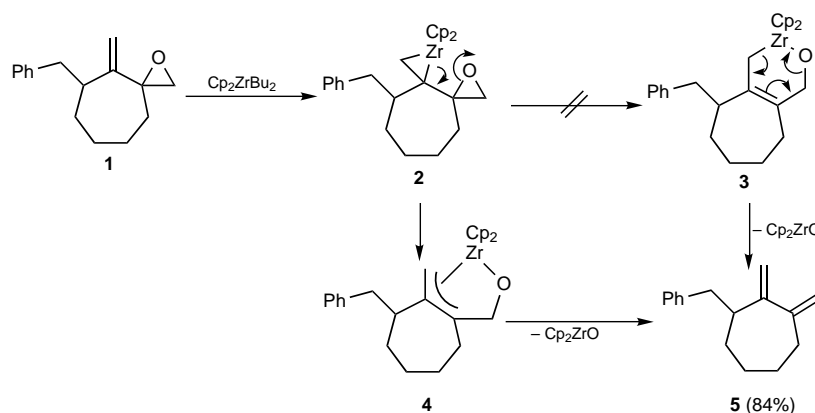
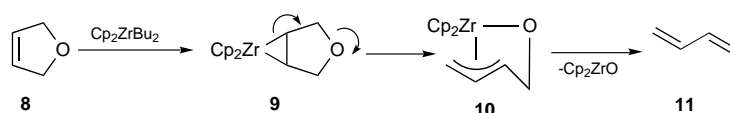


Table 1 Synthesis of conjugated dienes^a

Entry	Substrate	Product	Yield (%) ^b	Entry	Substrate	Product	Yield (%) ^b
1			60				
2			66	10	R = CH ₂ CH ₂ Ph		71
				11	R = CH ₂ OCH ₂ Ph		81
3			89	12	R = H		80
4	n = 2, R = (CH ₂) ₇ CH ₃		83	13	R = CH ₃		0
5			93	14 ^c	R = CH ₂ CH ₂ Ph, R' = H		64
	R = CH ₂ CH ₂ Ph			15 ^c	R = R' = CH ₂ CH ₂ Ph		56
6	n = 1, R = CH ₂ CH ₂ Ph		92	16 ^c			72
7	n = 2, R = (CH ₂) ₇ CH ₃		84	17 ^c			0
8			68	18			82
9	R = CH ₂ OCH ₂ Ph		73				

^a The reaction was carried out in THF at room temperature for 5–6 h. ^b The yield refers to the isolated yield. ^c The reaction was carried out at 50 °C for 6 h.

**Scheme 3**

ation to afford diene **11** as shown in Scheme 3. The reaction proceeded very slowly at room temperature and required gentle heating at 50 °C for 6 h. 2,5-Dihydrofuran (entries 14 and 15) and 7-oxabicyclo[2.2.1]hept-2-ene (entry 16) derivatives worked well. The sterically hindered 3,4-disubstituted dihydrofuran (entry 17) failed to undergo deoxygenation. Furthermore, it is noteworthy that a 2,5-dihydrothiophene derivative (entry 18) underwent desulfurization at room temperature to yield a conjugated diene, indicating that desulfurization is faster than deoxygenation.

Experimental

General procedure for the preparation of conjugated dienes

To a solution of dibutylzirconocene, prepared *in situ* by reaction of zirconocene dichloride (94 mg, 0.32 mmol) in THF (2 cm³) with butyllithium (2.3 mol dm⁻³ solution in hexane; 0.28 cm³, 2 equiv) at -78 °C for 1 h, was added a solution of 5-benzyl-4-methylene-1-oxaspiro[2.6]nonane **1** (55 mg, 0.24 mmol) in THF (2 cm³) at -78 °C, and the temperature was raised to ambient temperature. After stirring for 4 h, the reac-

tion mixture was quenched with 10% HCl (10 cm³) and extracted with diethyl ether (3 × 10 cm³). The combined organic layer was washed with water (10 cm³) and brine (10 cm³), dried over MgSO₄ and concentrated under reduced pressure. The residue was purified by silica gel column chromatography to give 1-benzyl-2,3-dimethylenecycloheptane (43 mg, 84%) as a colourless oil; $\nu_{\max}(\text{CHCl}_3)/\text{cm}^{-1}$ 3026, 2924, 2852, 1603, 1495, 1453, 894, 747 and 699; $\delta_{\text{H}}(300 \text{ MHz}; \text{CDCl}_3)$ 1.31–1.73 (6 H, m), 2.39–2.48 (2 H, m), 2.55 (1 H, m), 2.60 (1 H, m), 2.85 (1 H, m), 4.71 (1 H, m), 4.74 (1 H, m), 4.94 (1 H, dd, J 1.2, 1.2[†]), 5.06 (1 H, d, J 1.9) and 7.14–7.28 (5 H, m); $\delta_{\text{C}}(50 \text{ MHz}; \text{CDCl}_3)$ 28.02 (s), 28.42 (s), 35.13 (s), 35.81 (s), 40.44 (s), 45.71 (t), 110.52 (s), 110.61 (s), 125.68 (t), 128.08 (t), 129.11 (t), 141.29 (q), 152.43 (q) and 155.80 (q) (HRMS: found, 212.1570. C₁₆H₂₀ requires M , 212.1565).

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[†] J Values given in Hz.

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