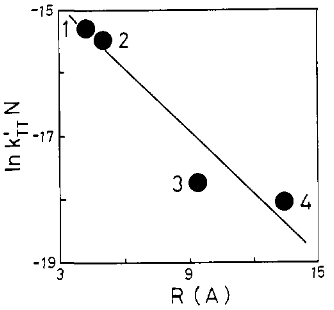

**Figure 2.** Correlation between intermolecular Pt–Pt distance between two $Pt_2$ units and $k_{TT}'$ for $X_4[Pt_2(P_2O_5H_2)_4]$; X = $Na^+$ (1), $K^+$ (2), $Et_4N^+$ (3), and $(n\text{-}Bu)_4N^+$ (4). The magnitude of $N$ was estimated from the known value of the $K^+$ salt.[8b] The increment or decrement of the ion radius depending on the countercation was adjusted on the intermolecular Pt–Pt distance.

the smaller the $k_{TT}$ value. We believe that this is a reflection of interatomic distance between two $Pt_2$ units.

To gain further insight into the mechanism, we apply the Dexter mechanism to the present systems.[13] The hopping rate constant from molecule 1 to one of the nearest neighbors ($W_1$) is given by eq 3, where $R$, $L$, $H_0$, and $\int f(\nu)\epsilon(\nu)\,d\nu$ are the intermolecular Pt–Pt

$$W_1 = \frac{4\pi^2(H_0)^2\exp(-2R/L)}{h}\;\frac{\int f(\nu)\epsilon(\nu)\,d\nu}{\int f(\nu)\,d\nu\int \epsilon(\nu)\,d\nu} \qquad (3)$$

distance between two $Pt_2$ units along the $z$ axis, the effective average Bohr radius of orbitals related to energy transfer, the preexponential factor, and the spectrum overlap integral between the phosphorescence and the singlet–triplet absorption, respectively. The exponential part in eq 3 is proportional to the exchange integral between initial and final states. On the assumption that the exchange integral is calculated according to the Wolfsberg–Helmholz formula,[14] the relevant orbitals are confined to $5d_{z^2}$ and $6p_z$, which are related to the lowest excited state. Consequently, a meaningful value of $W_1$ is conceivable only for the interaction among $Pt_2$ units along the $z$ axis. The resident time of a triplet exciton on molecule 1 ($\tau_1$) is given by eq 4, since there are two nearest neighbors in these systems. In the case of one-dimensional

$$\tau_1^{-1} = 2W_1 \qquad (4)$$

energy migration over evenly distributed molecules ($N$ molecules per unit length), the proportional relationship is concluded to be eq 5, where the number of nearest neighbors is 2.[15] Since only

$$k_{TT} \propto 2/\tau_1 N \qquad (5)$$

$R$ and $N$ are affected by the countercation, eq 6 is derived from eq 3–5, expressing the effect of the countercation on the relative T–T annihilation constant $k_{TT}'$. Using the values of $R$ and $N$

$$\ln k_{TT}'N = \text{constant} - 2R/L \qquad (6)$$

estimated by the CPK model,[16] we obtained a reasonable linear plot as shown in Figure 2. The slope gives $L$ = 6 Å. This large value in comparison with those in the usual organic systems[17a] is attributed to a much larger spatial distribution of $6p_z$ and $5d_{z^2}$ orbitals relative to $2p\pi$ orbitals. Furthermore, the present Pt–Pt interaction is a $\sigma$-type interaction and stronger than a $\pi$-type interaction in organic compounds.[17b]

We have demonstrated that the probability of oriented triplet energy migration can be controlled by simple chemical modification. For the design of well-oriented energy migration, the use of triplet-state interaction requiring orbital overlap would be more suitable than singlet energy migration governed by long-range electrostatic interaction.

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(14) Whangbo, M.-H.; Hoffmann, R. *J. Am. Chem. Soc.* **1978**, *100*, 6093.

(15) (a) Suna, A. *Phys. Rev. B* **1970**, *1*, 1716. (b) Jortner, J.; Rice, S. A.; Katz, J. L.; Choi, S.-I. *J. Chem. Phys.* **1965**, *42*, 309.

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(17) (a) Hasson, S.; Lustig, H.; Rubin, M. B.; Speiser, S. *J. Phys. Chem.* **1984**, *88*, 6367. (b) Albright, T. A.; Burdett, J. K.; Whangbo, M.-H. *Orbital Interaction in Chemistry*; Wiley: New York, 1985.

(18) (a) Market, J. T.; Clements, D. P.; Corson, M. R. *Chem. Phys. Lett.* **1983**, *97*, 175. (b) It was not possible to obtain a single exponential decay profile for the well-grown crystals even with the lowest excitation density in the present experiment. Therefore, $k_P$ was not experimentally obtainable and a calculated value was used. The adopted value agrees closely with the value for the amorphous sample in which T–T annihilation does not participate (~4 μs).

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# Novel Strategy of Using a $C_2$ Symmetric Chiral Diether in the Enantioselective Conjugate Addition of an Organolithium to an $\alpha,\beta$-Unsaturated Aldimine[†]

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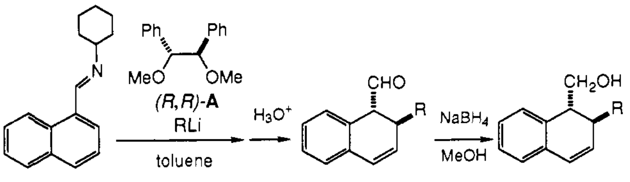
*Received July 5, 1989*

Enantioselective conjugate addition of organometallics to $\alpha,\beta$-unsaturated carbonyl compounds has been a challenge in synthetic organic chemistry.[1,2] It is most important, at the present time, to propose a rational strategy for designing a chiral ligand. We report herein a prototype of enantioselective conjugate addition of an organolithium to an achiral $\alpha,\beta$-unsaturated aldimine based on the novel strategy of using a $C_2$ symmetric chiral diether as a stereocontrol catalyst. The procedure is exemplified by the reaction of butyllithium with 1-naphthaldehyde cyclohexylimine **1** in the presence of (*R*,*R*)-1,2-diphenylethane-1,2-diol dimethyl ether A.



**1** **2** (1*R*,2*S*)-**3**

A solution of butyllithium (1.3 equiv) in hexane was added to a mixture of aldimine **1**[3] and (*R*,*R*)-A[4] (1.4 equiv) in toluene at −78 °C, and the whole was stirred at −78 °C for 6 h and then treated with acetate buffer (pH 4.5) for 12 h. The usual workup afforded 2-butyl-1,2-dihydronaphthalene-1-carbaldehyde **2**, which was then reduced with $NaBH_4$ in MeOH to afford, after silica gel column chromatography (hexane–AcOEt, 10:1), the corresponding 1*R*,2*S* alcohol **3** (R = Bu) of 91% ee ($[\alpha]^{22}_D$ +406° (*c* 1.14, $CHCl_3$))[5] in 80% overall yield.[6] The absolute configuration and % ee were determined by optical rotation[5] and by HPLC analysis using a chiral column (Waters Opti-Pak TA, XC, or PC, hexane–*i*-PrOH, 9:1). The diether A was recovered quantitatively for reuse without any loss of optical purity. It is important to note

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[†] We dedicate this paper to the memory of the late Professor John K. Stille.

(1) Review of the asymmetric conjugate addition reaction: Tomioka, K.; Koga, K. In *Asymmetric Synthesis*; Morrison, J. D., Ed.; Academic Press: New York, 1983; Vol. 2, Part A, Chapter 7.

(2) Recently reported enantioselective conjugate addition reactions of organometallics: Corey, E. J.; Naef, R.; Hannon, F. J. *J. Am. Chem. Soc.* **1986**, *108*, 7114. Villacorta, G. M.; Rao, C. P.; Lippard, S. J. *Ibid.* **1988**, *110*, 3175. Soai, K.; Yokoyama, S.; Hayasaka, T.; Ebihara, K. *J. Org. Chem.* **1988**, *53*, 4148. Takasu, M.; Wakabayashi, H.; Furuta, K.; Yamamoto, H. *Tetrahedron Lett.* **1988**, *29*, 6943.

(3) Comins, D. L.; Brown, J. D. *J. Org. Chem.* **1984**, *49*, 1078.

(4) Prepared by methylation of the corresponding diol obtained according to the reported procedure[11] (NaH, $Me_2SO_4$–THF, 82%, mp 99–100 °C, $[\alpha]^{25}_D$ −14.1° (*c* 1.39, $CHCl_3$)).

(5) Meyers, A. I.; Roth, G. P.; Hoyer, D.; Barner, B. A.; Laucher, D. *J. Am. Chem. Soc.* **1988**, *110*, 4611.

(6) The compounds described herein gave satisfactory analytical and spectroscopic data.

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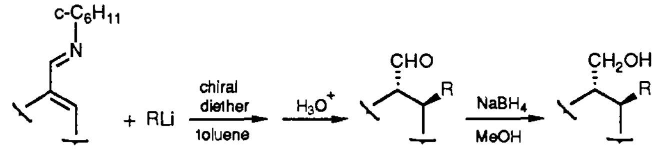
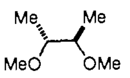
**Table I.** Enantioselective Conjugate Addition by the Mediation of a Chiral Diether[a]



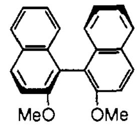
| entry | imine | RLi[b] | chiral diether[c] | temp, °C | time, h | product[d] | ee,[d] % | yield,[e] % |
|---|---|---|---|---|---|---|---|---|
| 1 | **1** | Bu | (*R*,*R*)-A | −78 | 6 | (1*R*,2*S*)-**3**[f] | 91 | 80 |
| 2 | **1** | Bu | (*R*,*R*)-B | −78 | 2 | (1*R*,2*S*)-**3**[f] | 53 | 92 |
| 3 | **1** | Bu | (*S*)-C | −78 | 8 | (1*R*,2*S*)-**3**[f] | 6 | 46 |
| 4 | **1** | Bu | (*S*,*S*)-D | −78 | 4 | (1*S*,2*R*)-**3**[f] | 11 | 26 |
| 5 | **1** | Ph | (*R*,*R*)-A | −45 | 13 | (1*R*,2*S*)-**3**[f] | 94 | 82 |
| 6 | **1** | Ph | (*S*,*S*)-B | −45 | 13 | (1*S*,2*R*)-**3**[f] | 90 | 68 |
| 7 | **4** | Ph | (*R*,*R*)-A | −45 | 7 | (1*S*,2*S*)-**5**[g] | 96 | 61 |
| 8 | **4** | Ph | (*S*,*S*)-B | −45 | 5 | (1*R*,2*R*)-**5**[g] | 80 | 69 |
| 9 | **6** | Ph | (*R*,*R*)-A | −45 | 3 | (1*S*,2*S*)-**7**[g] | 98 | 59 |
| 10 | **6** | Ph | (*S*,*S*)-B | −45 | 4 | (1*R*,2*R*)-**7**[g] | 90 | 76 |
| 11 | **8** | Ph | (*R*,*R*)-A | −78 | 4 | (*S*)-**9**[h] | >99 | 58 |
| 12 | **8** | Ph | (*S*,*S*)-B | −78 | 3 | (*R*)-**9**[h] | 93 | 45 |
| 13 | **10** | Bu | (*R*,*R*)-A | −78 | 1 | (*R*)-**9**[h] | 82 | 40 |
| 14 | **11** | Ph | (*R*,*R*)-A | −78 | 3 | (*S*)-**12**[h] | >99 | 48 |
| 15 | **11** | Ph | (*S*,*S*)-B | −78 | 1 | (*R*)-**12**[h] | 94 | 42 |

[a] Reaction procedure is exemplified in the text. In entry 4, ether was use as a solvent. [b] BuLi in hexane; PhLi in cyclohexane–ether (7:3), 1.3–2.2 equiv of RLi was used. [c] Amount of chiral diether used was 1.4–2.4 equiv. [d] Absolute configuration was determined by optical rotation; ee was determined by HPLC analysis using a chiral column (Waters Opti-Pak TA (runs 1–6, 11–13), XC (runs 7, 8), and PC (runs 9, 10, 14, 15), hexane–*i*-PrOH, 9:1). [e] Overall yield purified by silica gel column chromatography. Imine **1** was recovered (44% for run 3 and 65% for run 4). The 1,2-addition product was obtained as a byproduct in 10–25% yield for runs 11–15. [f] See ref 5. [g] Hashimoto, S.; Kogen, H.; Tomioka, K.; Koga, K. *Tetrahedron Lett.* **1979**, 3009. [h] Tomioka, K.; Suenaga, T.; Koga, K. *Tetrahedron Lett.* **1986**, *27*, 369. The corresponding ester was reduced to the alcohol with $LiAlH_4$ (Paquette, L. A.; Gilday, J. P. *J. Org. Chem.* **1988**, *53*, 4972).

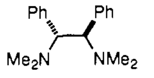
that the reaction did not proceed smoothly in the absence of the chiral diether A in toluene. Therefore it is apparent that a chiral diether A not only promotes the reaction but also controls the reaction stereochemistry.



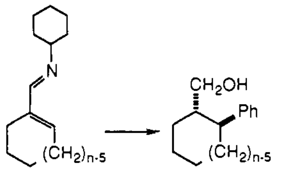
(*R*,*R*)-**B**



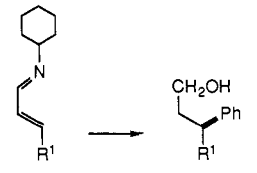
(*S*)-**C**



(*R*,*R*)-**D**



**4** n = 6
**6** n = 5
(1*S*,2*S*)-**5** n = 6
**7** n = 5



**8** $R^1$ = Bu
**10** $R^1$ = Ph
**11** $R^1$ = Me
(*S*)-**9** $R^1$ = Bu
**12** $R^1$ = Me

Diether A was also effective in the enantioselective conjugate addition reaction of organolithium reagents to other cyclic and acyclic $\alpha,\beta$-unsaturated aldimines (**4**, **6**, **8**, **10**, and **11**). As shown in Table I (entries 1, 5, 7, 9, 11, 13, and 14), conjugate addition products (**3**, **5**, **7**, **9**, and **12**) were obtained in high enantiomeric excess. It is noteworthy that nearly optically pure (*S*)-**9** and (*S*)-**12** were produced from **8** and **11**, respectively (entries 11 and 14).

Dimethyl ether B[7] derived from butane-2,3-diol was also effective in asymmetric induction. As shown in entries 6, 8, 10, 12, and 15, cyclic and acyclic $\alpha,\beta$-unsaturated aldimines were converted to the corresponding addition products in over 80% ee. However, the ee decreased to 53% in the reaction of butyllithium with **1** (entry 2). Diether A generally exhibited higher efficiency than B.

It was disappointing to find that ether C[8] derived from binaphthol was the worst stereocontrol catalyst studied so far (entry 3). It is also important to note that diamine D,[9] although this amine maintains a diphenylethane unit as in A, induced only 11% enantioface differentiation (entry 4).

The absolute configuration of the alcohol produced in the reaction mediated by chiral diethers A and B is predictable on the basis of the stereochemical model of the intermediate complex (**13** (shown by the example of reaction of **11** in the presence of (*R*,*R*)-A) (entry 14)). It is quite reasonable to assume that the organolithium forms a five-membered chelated complex with diether A. In the chelation, four substituents of A would take an all-trans arrangement due to steric factors. It is most important to note that two methyl groups on the ether oxygen atoms occupy the opposite face of the plane of five-membered chelation.[10] The lone pair of the nitrogen atom of aldimine coordinates to the fourth coordination site of lithium to satisfy its tetravalency, leading to favorable complex **13** and unfavorable complex **14**. The N-cyclohexyl bond would be syn to the Li–O1 bond in the complex **13**. Then intracomplex migration of the R group of the organolithium to the $sp^2$ carbon of the aldimine from the bottom face affords the conjugate addition product with the configuration observed. Alternative complex **14**, with the N–cyclohexyl bond syn to the Li–O2 bond, is not probable on the basis of steric considerations.

The higher efficiency exhibited by A and B over C and D is rationalized by the presence of two dimethyl groups on the oxygen atoms in a desired arrangement. More efficient fixation of trans geometry in A than in B is attributed to higher asymmetric induction exhibited by chiral diether A rather than B.

The $C_2$ symmetric chiral diethers (A and B) in both enantiomeric forms are readily available from the corresponding commercial diols. A variety of $C_2$ symmetric diols are also available in quantity and in high optical purity by employing the

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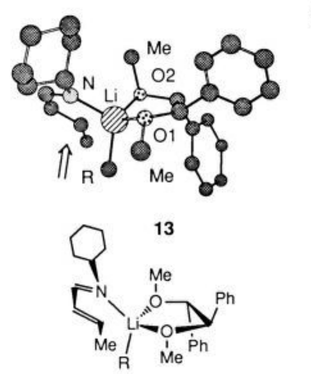
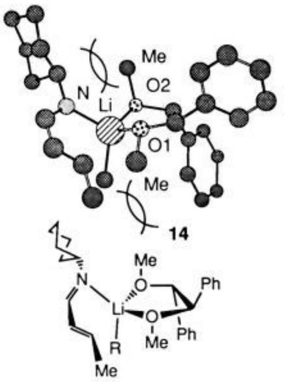
(10) Geometry around ether oxygen in lithium–ether complexes has been reported. Review: Seebach, D. *Angew. Chem., Int. Ed. Engl.* **1988**, *27*, 1624. Leading references: Becker, G.; Birkhahn, M.; Massa, W.; Uhl, W. *Angew. Chem., Int. Ed. Engl.* **1980**, *19*, 741. Amstutz, R.; Schweizer, W. B.; Seebach, D.; Dunitz, J. D. *Helv. Chim. Acta* **1981**, *64*, 2617. Hope, H.; Power, P. P. *J. Am. Chem. Soc.* **1983**, *105*, 5320. Wanat, R. A.; Collum, D. B.; Van Duyne, G.; Clardy, J.; DePue, R. T. *Ibid.* **1986**, *108*, 3415. Williard, P. G.; Hintze, M. J. *Ibid.* **1987**, *109*, 5539.



**13**



**14**

asymmetric dihydroxylation of olefins recently developed.[11] We believe that the simple strategy of using a diether of a $C_2$ symmetric chiral diol as a stereocontrol catalyst provides a basis for further development of asymmetric reactions.[12]

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[11] Tomioka, K.; Nakajima, M.; Koga, K. *J. Am. Chem. Soc.* **1987**, *109*, 6213. Lohray, B. B.; Kalantar, T. H.; Kim, B. M.; Park, C. Y.; Shibata, T.; Wai, J. S. M.; Sharpless, K. B. *Tetrahedron Lett.* **1989**, *30*, 2041.

[12] We are grateful to the Japan Foundation for Optically Active Compounds and the Hoansha Foundation and for a Grant-in-Aid for Scientific Research, Ministry of Education, Science and Culture, Japan (No. 01571143), for partial financial support.

## Transition-Metal-Mediated Thiosulfinate Ester Synthesis

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Unlike sulfur dioxide ($SO_2$), the coordination and organic reaction chemistry of disulfur monoxide ($S_2O$) has received little attention. A handful of transition-metal $S_2O$ complexes have been synthesized via oxidation of the corresponding disulfur ($S_2$) complexes.[1] A few Diels–Alder reactions of simple dienes with $S_2O$ have also been reported.[2] However, there were no reports of direct $S_2O$ complex synthesis prior to our initial work.[3]

In order to undertake a detailed study of the chemistry of $S_2O$ or $S_2O$ complexes, a reliable source of $S_2O$ or an $S_2O$ equivalent was needed. Previously reported procedures for $S_2O$ generation suitable for use in synthetic studies yielded mixtures of $S_2O$, $SO_2$, and SO.[2,4] We recently published a synthesis of 4,5-diphenyl-3,6-dihydro-1,2-dithiin 1-oxide (**2**) which liberates $S_2O$ via a transition-metal-assisted retro-Diels–Alder reaction.[3,5] Here we report further on the unusual reactivity of **2** and its utilization in the synthesis of cyclic thiosulfinate esters.

**Scheme I**

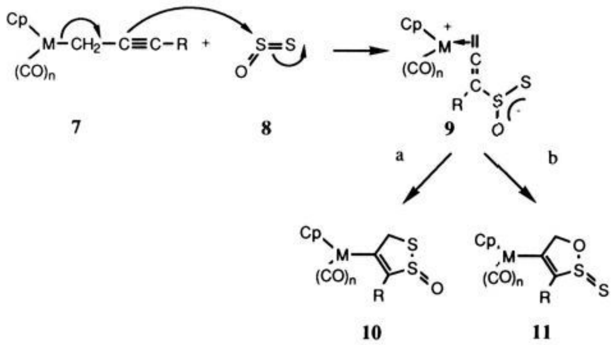
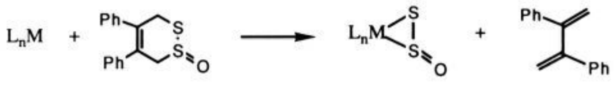


**Table I.** Cyclizations of 2-Alkynyl Complexes **12**

| | M | *n* | *m* | R | yield, % |
|---|---|---|---|---|---|
| **13a** | Fe | 5 | 2 | $CH_3$ | 74 |
| **13b** | Fe | 5 | 2 | Ph | 81 |
| **13c** | Fe | 0 | 2 | $CH_3$ | 71 |
| **13d** | Fe | 0 | 2 | Ph | 72 |
| **13e** | Mo | 0 | 3 | $CH_3$ | $45^a$ |
| **13f** | Mo | 0 | 3 | Ph | $43^a$ |

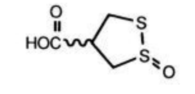
[a] Greater than 90% based on recovered starting material.



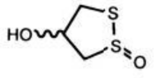
**1** **2** **3** **4**

$L_nM = Ir(diphos)_2^+Cl^-$, $CpMn(CO)_2(thf)$

Thiosulfinate esters have shown biological activity as antibacterials,[6] antifungals,[6] antivirals,[7] plant growth regulators,[8] platelet aggregation inhibitors,[9] and tumor growth inhibitors.[10] Compounds containing this functional group have practical applications as alkene autoxidation inhibitors[11] and radioprotective agents.[12] Thiosulfinate esters of particular synthetic interest to us were analogues of the asparagusic acid *S*-oxides (**5**) (potent plant growth regulators)[8] and the brugeriols (**6**) (isolated from mangroves).[13] One possible route to compounds of this general type would be a (3 + 2) cycloaddition reaction between transition-metal 2-alkynyl complexes (**7**) and $S_2O$ (**8**) (Scheme I). These complexes (**7**) have been shown to react in this manner with a variety of other small organic electrophiles.[14] If cyclization



**5**



**6**

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