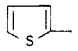
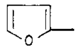
Table I. Preparation of 1-Aryl-2-silyl-2-diazoethanones 3 and 1-Aryl-2-siloxyalkynes 4 (1 → 3 → 4)

			3[a,b]			4[a,c]		
diazo compd 1, Ar =	R_3SiOTf 2, R_3Si =		yield, %	$\nu(C{=}N_2)$,[d] cm^{-1}		yield,[e] %	bp,[f] °C/torr	$\nu(C{\equiv}C)$,[d] cm^{-1}
1a, Ph	$SiEt_3$	**3aA**	87	2065	**4aA**	[g]		2258
	$SiMe_2$-*t*-Bu				**4aB**	70	150/0.006	2265
	Si-*i*-Pr_3				**4aC**	61	130/0.07	2260
1b, C_6H_4-4-CH_3	Si-*i*-Pr_3				**4bC**	56	120/0.05	2258
1c, C_6H_4-4-OCH_3	$SiEt_3$	**3cA**	58	2063	**4cA**	[h]		2260
	$SiMe_2$-*t*-Bu				**4cB**	53	145/0.005	2265
	Si-*i*-Pr_3	**3cC**	62	2060	**4cC**	65	175/0.45	2260
1d, C_6H_4-4-Br	Si-*i*-Pr_3				**4dC**	62	150/0.05	2260
1e, C_6H_4-3-Cl	Si-*i*-Pr_3				**4eC**	60	130/0.01	2260
	$SiMe_2$-*t*-Bu				**4fB**	68	160/0.005	2255
	Si-*i*-Pr_3	**3fC**	39[h]	2060	**4fC**	71	150/0.01	2260
	Si-*i*-Pr_3				**4gC**	69	140/0.01	2261

[a] All isolated compounds except for the unstable alkynes **4aA** and **4cA** gave satisfactory elemental analyses. [b] Isolated by column chromatography (Merck Lobar column, LiChroprep Si60, eluent $CHCl_3$). [c] Compounds **4** are colorless to yellow oils. [d] IR spectrum from film, except for **3fC** (KBr pellet). [e] Yield refers to **1**. [f] Oven temperature for Kugelrohr distillation. [g] Only crude product obtained. [h] Yellow powder, mp 37 °C (from pentane).

much lower than normally found for the β-keto silane → siloxyalkene rearrangement,[10] probably due to the more polar $C{=}O$ bond in the diazo ketone. The rearrangement leads to a diazoethene **6**. This elusive species has been postulated as an intermediate in other reactions[11] but was never isolated or trapped. It is assumed that **6** either reacts to **4** in a concerted fashion or that spontaneous loss of N_2 from **6** creates vinylidenecarbene **7**.[11b] Such species can be trapped if the migrating tendency of the β-substituents is low.[12] The presence of a β-aryl group (bearing no strongly electron-withdrawing substituents) prevents such trapping completely. In line with these known facts, thermolysis of **3cC** in the presence of cyclohexene gave only rearrangement product **4cC** but no [2 + 1]-cycloaddition product arising from a vinylidene carbene.

Another pathway would be thermal decomposition of **3** to give keto carbene **8** which then rearranges to **4** via vinylidene carbene **7** or ketene **5**. At least the latter route could be excluded. Silyl ketenes **5a,b** which were obtained by unsensitized irradiation of **3aA**, **3fC**[13] do not rearrange to a siloxyacetylene up to 164 °C (mesitylene, 3 h). The formation of a silyl ketene on photolysis of **3** is not in itself a proof of a carbene intermediate, since it is well-known that on direct photolysis of a diazo carbonyl compound, Wolff rearrangement can occur directly from the excited singlet state of the diazo compound.[14] On the other hand, the thermal stability of many α-diazo carbonyl compounds and of silyl diazo acetates does not lend support to the "thermal" decomposition **3** → **8** at room temperature. The detailed mechanistic aspects of the transformation **3** → **4** as well as the chemistry of siloxyalkynes are under active investigation.

Acknowledgment. This work was supported by the Deutsche Forschungsgemeinschaft.

Registry No. **1a**, 3282-32-4; **1b**, 17263-64-8; **1c**, 6832-17-3; **1d**, 4203-30-9; **1e**, 7023-78-1; **1f**, 72676-21-2; **1g**, 21443-46-9; **2a**, 79271-56-0; **2b**, 69739-34-0; **2c**, 80522-42-5; **3aA**, 96845-66-8; **3cA**, 96845-67-9; **3cC**, 96845-68-0; **3fC**, 96845-69-1; **4aA**, 96845-70-4; **4aB**, 96845-71-5; **4aC**, 96845-72-6; **4bC**, 96845-73-7; **4cA**, 96845-74-8; **4cB**, 96845-75-9; **4cC**, 96845-76-0; **4dC**, 96845-77-1; **4eC**, 96845-78-2; **4fB**, 96845-79-3; **4fC**, 96845-80-6; **4gC**, 96845-81-7; **5a**, 96845-82-8; **5b**, 96845-83-9.

Gerhard Maas,* Ralf Brückmann
Fachbereich Chemie
Universität Kaiserslautern
D-6750 Kaiserslautern
West Germany

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(10) Neat ω-(trimethylsilyl)acetophenone rearranges quantitatively to the siloxystyrene only after 36 h at 150 °C: Brook, A. G.; MacRae, D. M.; Limburg, W. W. *J. Am. Chem. Soc.* **1967**, *89*, 5493.

(11) (a) Colvin, E. W.; Hamill, B. J. *J. Chem. Soc., Perkin Trans. 1* **1977**, 869. (b) Gilbert, J. C.; Weerasooriya, U. *J. Org. Chem.* **1982**, *47*, 1837 and references cited therein. (c) Fox, D. P.; Bjork, J. A.; Stang, P. J. *J. Org. Chem.* **1983**, *48*, 3994.

(12) (a) Stang, P. J. *Acc. Chem. Res.* **1982**, *15*, 348; *Chem. Rev.* **1978**, *78*, 384. (b) Gilbert, J. C.; Weerasooriya, U.; Giamalva, D. *Tetrahedron Lett.* **1979**, 4619. (c) Gilbert, J. C.; Weerasooriya, U. *J. Org. Chem.* **1983**, *48*, 448.

(13) Irradiation of **3aA** (λ > 280 nm, 2 mmol in 90 mL of anhydrous benzene, 1.5 h) gave **5a** (37% yield after column chromatography): IR (neat) $\nu(C{=}C{=}O)$ 2080 cm^{-1}. Irradiation of **3fC** as before gave **5b** (94% yield; Kugelrohr distillation at 140 °C/0.25 torr); IR (neat) $\nu(C{=}C{=}O)$ 2085 cm^{-1}).

(14) (a) Ando, W. In "The Chemistry of Diazonium and Diazo Groups"; Patai, S., Ed.; Wiley: New York, 1978; Vol. I, p 467. (b) Meier, H.; Zeller, K.-P. *Angew. Chem., Int. Ed. Engl.* **1975**, *14*, 32.

Catalytic "Homo-Reformatsky" Reaction. Ambident Chemical Reactivities of the Zinc Homoenolate of Propionate

Summary: Zinc halide catalyzed reaction of 1-alkoxy-1-siloxycyclopropane with carbonyl compounds gives 4-siloxy esters, while a related reaction with acid chlorides produces either 4-keto esters or (acyloxy)cyclopropanes.

Sir: Generation of nucleophilic metal homoenolates from siloxycyclopropanes[1-3] is an emerging new methodology for organic synthesis. We have previously demonstrated the feasibility of such an approach by the reactions of titanium[1] (**1**) and zinc[2] (**2**) homoenolates of alkyl propionates

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(1) (a) Nakamura, E.; Kuwajima, I. *J. Am. Chem. Soc.* **1977**, *99*, 7360; (b) **1983**, *105*, 651; (c) **1985**, *107*, 2138.

(2) (a) Nakamura, E.; Kuwajima, I. *J. Am. Chem. Soc.* **1984**, *106*, 3368; *Org. Synth.*, a procedure checked for publication. (b) Nakamura, E.; Shimada, J.-i.; Kuwajima, I. *Organometallics* **1985**, *4*, 641.

(3) (a) Review: Murai, S.; Ryu, I.; Sonoda, N. *J. Organomet. Chem.* **1983**, *250*, 121. (b) Ryu, I.; Matsumoto, K.; Ando, M.; Murai, S.; Sonoda, N. *Tetrahedron Lett.* **1980**, *21*, 4283. (c) Ryu, I.; Ando, M.; Ogawa, A.; Murai, S.; Sonoda, N. *J. Am. Chem. Soc.* **1983**, *105*, 7192. (d) Giese, B.; Horler, H.; Zwick, W. *Tetrahedron Lett.* **1982**, *23*, 931.

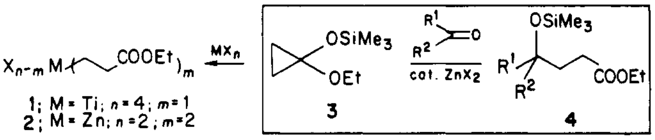
0022-3263/85/1950-2802$01.50/0

Table I. ZnX_2-Catalyzed "Homo-Reformatsky" Reaction[a]

carbonyl compd	% yield[b]	
	ZnI_2	$ZnCl_2$
benzaldehyde	89	84
cinnamaldehyde	84	94
crotonaldehyde	72	54 (77)
piperonal	95	91
p-nitrobenzaldehyde	84	c
heptanal	44 (50)	51 (74)
acetophenone	77	0
benzaldehyde dimethyl acetal	91	0

[a] The reactions were performed with 1.1–1.2 equiv of the cyclopropane 3. [b] The values in parentheses refer to the yield determined by quantitative NMR determination. [c] Not examined.

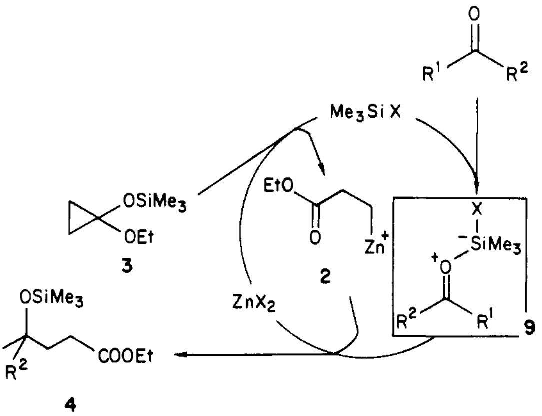
with carbonyl compounds. The nature of these reactions is such that a stoichiometric amount of the homoenolate must be prepared from the cyclopropane **3** and a metal halide prior to the reaction.[1,2a] Although such stoichiometric reactions do not pose any practical problem on laboratory-scale applications, direct catalytic coupling of the cyclopropane **3** and an electrophile is by all means aesthetically more pleasing. To this end, we examined the reactivities of the zinc homoenolate **2** to develop an efficient synthetic route to 4-siloxy esters **4** through ZnX_2-catalyzed coupling of **3** with aldehydes or ketones. In addition to this catalytic "homo-Reformatsky" reaction, the intriguing ambident reactivities of the homoenolate **2** toward acid chlorides is also described.



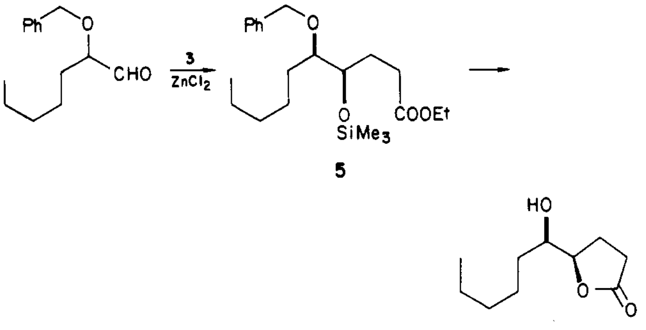
The synthesis of the 4-siloxy esters has been achieved with remarkable ease by treating a mixture of **3** (slight excess) and the carbonyl compounds with just 0.3–2 mol % of ZnI_2 in CH_2Cl_2 at room temperature. The reaction applies well to both milligram- and multigram-scale reactions.[4] While a variety of aldehydes serve as the substrate of this reaction, producing the desired 4-siloxy esters, ketones generally give complex mixtures. Acetophenone, being an exception, cleanly give the siloxy ester as a single product. Interestingly, benzaldehyde acetal also takes part in the reaction. The coupling reaction can also be effected by $ZnCl_2$ (30–50 mol %). This catalyst, although ineffective for the reaction with ketones and acetals (the substrates were recovered unchanged), is the preferred catalyst for the reaction with aliphatic aldehydes. The product from these reactions, siloxy ester **4**, is a valuable precursor of 4-hydroxy esters (aqueous acetic acid in THF), γ-lactones (*p*-toluenesulfonic acid), and 4-keto esters (cromic acid oxidation) (Table I).

A high level of chelation-controlled 1,2-asymmetric induction[5] has been observed in the reaction with a 2-alkoxyaldehyde (93% selectivity for **5**).[6] The titanium homoenolate **1** showed lower selectivity (79%). Stereoselective construction of hydroxy lactonic systems such as

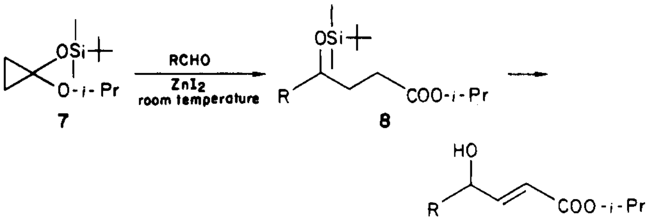
Scheme I



6 has potential utilities in the synthesis of polyether antibiotics.



Alkylidenation of silyl ketene acetals[7] provides a versatile route to the structurally complex derivatives of **3**. (*tert*-Butyldimethylsiloxy)cyclopropanes such as **7** assumes importance in such a context, since the starting *tert*-butyldimethylsilyl ketene acetals[8] are much more stable than the hydrolytically labile trimethylsilyl analogues. To our satisfaction, ZnI_2 (but not $ZnCl_2$) catalyzes the reaction of the prototypal **7** (**8**: R = Ph, 86%). 4-Hydroxy-2-alkenoates, a ubiquitous partial structure found among a variety of natural products, e.g., cytochalasins, are readily prepared from **8**.[9]



A mechanistic rationale based on various supporting evidence[10] is shown in Scheme I. The fact that Me_3SiCl

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(4) A typical procedure: To dry ZnI_2 (94 mg, 0.3 mmol) under nitrogen was added at 20 °C a mixture of 1-ethoxy-1-(trimethylsiloxy)cyclopropane (20.9 g, 0.12 mol) and benzaldehyde (10.6 g, 0.1 mol) in 60 mL of methylene chloride. After 4 h, dry pyridine (0.05 mL, 0.06 mmol) was added. The crude product was distilled under reduced pressure to obtain 24.7 g (88%) of the adduct: bp 122–125 °C (2.3 mmHg).

(5) Cf. Morrison, J. D.; Mosher, H. S.; "Asymmetric Organic Reactions"; Prentice Hall: New Jersey, 1973.

(6) An authentic sample of **6** was prepared by OsO_4 oxidation of ethyl oct-4-enoate.

(7) (a) A series of the cyclopropane derivatives have been prepared by methylenation with CH_2I_2/Et_2Zn: Unpublished results by the authors. (b) For a recent independent effort, see: Rousseaux, G.; Slowgui, N. *Tetrahedron Lett.* **1983**, *24*, 1251.

(8) Cf. Ireland, R. E.; Mueller, R. H.; Willard, A. K. *J. Am. Chem. Soc.* **1976**, *98*, 2868.

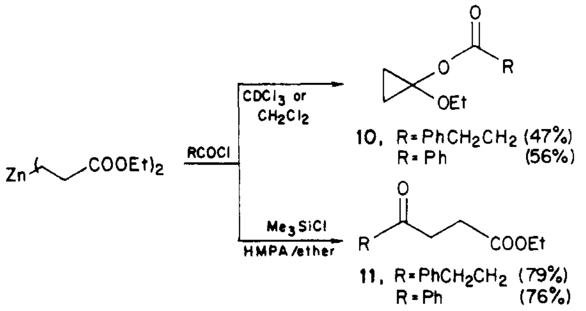
(9) Cf. Stork, G.; Nakamura, E. *J. Am. Chem. Soc.* **1983**, *105*, 5510.

(10) (a) Crucial evidence (notably for X = Cl) against the (more straightforward and usual) addition/silylation mechanism is the following: (1) Inertness of the purified zinc homoenolate **2** toward benzaldehyde and acetophenone in various solvents;[2b] (2) kinetic origin of this lack of addition; (3) sluggishness of the reaction of Me_3SiCl with the preformed zinc alkoxide of a 4-hydroxy ester, a supposed precursor to the 4-siloxy ester. (b) The mechanism involving direct interaction between the cyclopropane **3** and an aldehyde/Lewis acid complex has been precluded by various lines of evidence, inter alia, the inability of common Lewis acids other than $TiCl_4$ and ZnX_2 to effect the addition reaction.

vastly accelerates the reaction of the homoenolate **2** with aldehydes in halomethane (note that $ZnCl_2$ is ineffective) provides a vital support for our proposal which involves activation of the carbonyl group by Me_3SiCl (cf. **9**).[11] The higher Lewis acidity of Me_3SiI,[12] as compared with Me_3SiCl, explains the wider tolerance of the electrophiles (vide supra) in the ZnI_2-catalyzed reaction.

Since the catalytic reaction with acid chlorides tended to give complex results, stoichiometric conditions were examined. To our surprise, the purified homoenolate **2** in $CDCl_3$ reacted with acid chlorides *exclusively on oxygen* to produce the 1-(acyloxy)cyclopropanes **10** in good yield. The characteristic NMR signals of the cyclopropane protons[13] were diagnostic for identification of these structurally interesting products.

In more polar (and basic) solvents (e.g., in ether) consumption of the reactants almost stopped; with 2 equiv of HMPA, however, the reaction again proceeded as fast as in $CDCl_3$ but now *gave only a C-acylated product.* Thus, under the optimized conditions with 2 equiv each of Me_3SiCl and HMPA in ether, keto esters **11** were obtained in 70–80% yield.[14]



After more than 20 years since the recognition of the homoenolate chemistry[15a] the nature of the homoenolate anion still remains rather obscure.[15b] The condition-dependent C/O-dichotomy of the homoenolate reported above is, therefore, of great heuristic value, showing that homoenolate does show typical ambident reactivities related to the one widely found for enolates.

Acknowledgment. We thank Toray Silicone for the generous supply of Me_3SiCl and the Ministry of Education, Culture, and Science for the financial support.

Registry No. 3, 27374-25-0; 4 (R^1 = H, R^2 = Ph), 87768-37-4; 4 (R^1 = H, R^2 = PhCH=CH), 96790-96-4; 4 (R^1 = H, R^2 = CH_3CH=CH), 96759-95-4; 4 (R^1 = H, R^2 = benzodioxol-5-yl), 96759-96-5; 4 (R^1 = H, R^2 = p-$NO_2C_6H_4$), 96759-97-6; 4 (R^1 = H, R^2 = $CH_3(CH_2)_5$), 96759-98-7; 4 (R^1 = CH_3, R^2 = Ph), 96790-97-5; 5, 96760-00-8; 7, 96760-01-9; 8 (R = Ph), 96760-02-0; 10 (R = $Ph(CH_2)_2$), 96760-03-1; 10 (R = Ph), 91496-66-1; 11 (R = $Ph(CH_2)_2$), 90147-73-2; 11 (R = Ph), 6270-17-3; PhCHO, 100-52-7; PhCH=CHCHO, 104-55-2; CH_3CH=CHCHO, 4170-30-3; p-$NO_2C_6H_4CHO$, 555-16-8; $CH_3(CH_2)_5CHO$, 111-71-7; $PhC(O)CH_3$, 98-86-2; $PhCH(OMe)_2$, 1125-88-8; ZnI_2, 10139-47-6; $ZnCl_2$, 7646-85-7; $PhCH_2OCH(CHO)(CH_2)_4CH_3$, 96759-99-8; $Zn((CH_2)_2C(O)OEt)_2$, 90147-62-9; $Ph(CH_2)_2C(O)Cl$, 645-45-4; PhC(O)Cl, 98-88-4; piperonal, 120-57-0.

Hiroji Oshino, Eiichi Nakamura,* Isao Kuwajima*
Department of Chemistry
Tokyo Institute of Technology
Meguro, Tokyo 152, Japan

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[11] For recent proposals of a related role of Me_3SiCl, see: ref 2a; RajanBabu, T. V. *J. Org. Chem.* **1984**, *49*, 2083.

[12] Cf. Sakurai, H.; Sasaki, K.; Hosomi, A. *Tetrahedron Lett.* **1981**, *22*, 745.

[13] 1-Ethoxy-1-(benzoyloxy)cyclopropane: IR (neat) 1750 (vs), 1600 (w); ^1H NMR (CCl_4) 0.75–1.0 (m, 4 H, cyclopropane), 1.05 (t, J = 7 Hz, 3 H), 2.3–3.65 (m, 2 H), 2.65–3.0 (m, 2 H), 3.44 (q, J = 7 Hz, 2 H), 6.93 (s, 5 H).

[14] Performing the reaction in the presence of Cu^+ (ref 2a) is preferred for synthetic purposes as it is faster, giving cleaner products.

[15] (a) Nickon, A.; Lambert, J. L. *J. Am. Chem. Soc.* **1962**, *84*, 4604. (b) Review: Werstiuk, N. H. *Tetrahedron* **1983**, *39*, 205.

[16] Spectral studies indicated that **2** does not change its structure in all solvents used for the chemical reactions. Discussion of the origin of the C/O-dichotomy will be deferred to the full report.

Opposite High Diastereoselectivity in the Carbonyl Addition of Organolithium and Grignard Reagents to 3-Acylisoxazolines

Summary: The reactions of organolithium and Grignard reagents with 3-acyl-4,5-disubstituted-isoxazolines to produce tertiary alcohols show high but opposite diastereoselectivity; competitive pathways involving attack on s-trans and metal-chelated s-cis conformations of the O=CC=N system are proposed.

Sir: Carbonyl addition of organometallic compounds is one of the two or three most extensively used reactions for organic synthesis. Stereochemical aspects have been exhaustively studied and have been instrumental in the development of Cram's rule[1] (open-chain, cyclic, and dipolar models) and Prelog's rule.[2] It is generally perceived that organolithium and Grignard reagents add by similar mechanisms,[3] although it is also recognized that stereoselectivity can differ significantly.[1,4-5] In a few instances high metal-dependent selectivity for opposite faces has been documented.[6] The degree of metal chelation is a well-recognized powerful factor in determining the stereochemical outcome for addition where α- or β-heteroatoms are present.[7]

Carbonyl addition to the 3-acylisoxazolines[8] **1a** and **3a**

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[1] For a recent review, see: Eliel, E. L. In "Asymmetric Synthesis"; Morrison, J. D., Ed.; Academic Press: New York, 1983; Vol 2; pp 125–55.

[2] For a review, see: Fiaud, J. C. In "Stereochemistry, Fundamentals and Methods"; Kagan, H. B., Ed.; Georg Thieme: Stuttgart, 1977; Vol. 3; pp 20–49.

[3] Both SET and polar mechanisms appear to be involved: Liotta, D.; Saindane, M.; Waykole, L. *J. Am. Chem. Soc.* **1983**, *105*, 2922. Ashby, E. C.; Bowers, J. R., Jr. *J. Am. Chem. Soc.* **1981**, *103*, 2242 and references cited therein. Ashby, E. C. *Pure Appl. Chem.* **1980**, *52*, 545. See also: Smith, J. G.; Irwin, D. C. *J. Am. Chem. Soc.* **1980**, *102*, 2757.

[4] For three recent examples involving 1,2-asymmetric induction, see: (a) Still, W. C.; McDonald, J. H., III. *Tetrahedron Lett.* **1980**, *21*, 1031. (b) Eliel, E. L.; Morris-Natsche, S. *J. Am. Chem. Soc.* **1984**, *106*, 2937. (c) Mead, K.; Macdonald, T. L. *J. Org. Chem.* **1985**, *50*, 422.

[5] For examples involving long-range asymmetric induction, see: (a) Still, W. C.; Schneider, J. A. *Tetrahedron Lett.* **1980**, *21*, 1035 [β-alkoxy aldehydes]. (b) Lutomski, K. A.; Meyers, A. I. In "Asymmetric Synthesis"; Morrison, J. D., Ed.; Academic Press: New York, 1984; Vol 3; pp 213–74 (pp 241, 47) [2-ketooxazolines and 2-acylphenyloxazolines]. (c) Whitesell, J. K.; Bhattacharya, A.; Henke, K. *J. Chem. Soc., Chem. Commun.* **1982**, 988 [α-keto esters]. (d) Fouquey, C.; Jaques, J.; Angiolini, L.; Tramontini, M. *Tetrahedron* **1974**, *30*, 2801 [β-amino ketones].

[6] We are aware of only four examples: (a) Beloeil, J.-C.; Bertranne, M.; Fetizon, M.; Prange, T. *J. Chem. Soc., Chem. Commun.* **1981**, 363 [LiC≡CH and BrMgC≡CMgBr]. (b) Stocker, J. H. *J. Am. Chem. Soc.* **1966**, *88*, 2878 [PhMgBr and PhLi]. See also: Stocker, J. H. *J. Org. Chem.* **1964**, *29*, 3593. (c) Mukaiyama, T.; Soai, K.; Sato, T.; Shimizu, H.; Suzuki, K. *J. Am. Chem. Soc.* **1979**, *101*, 1455 [chiral pyrrolidine complexes of R_2Mg and RLi]. (d) Miljković, M.; Gligorijević, M.; Satoh, T.; Miljković, D. *J. Org. Chem.* **1974**, *39*, 1379 [MeMgI and MeLi].

[7] For a discussion, see: (a) ref 4b and 4c. (b) Morrison, J. D.; Mosher, H. S. "Asymmetric Organic Reactions"; Prentice-Hall: Englewood Cliffs, NJ, 1971; pp 100–108.

[8] 3-Acylisoxazolines are conveniently prepared from alkenes and α-nitro ketones under acidic conditions: Wade, P. A.; Amin, N. V.; Yen, H.-K.; Price, D. T.; Huhn, G. F. *J. Org. Chem.* **1984**, *49*, 4595.