hypothesize that enantio-DNA in general recognizes complementary RNA specifically but not complementary DNA. It would be a characteristic feature of enantio-DNA, because natural DNA (and natural RNA) normally recognizes both complementary DNA and RNA.

Next we investigated the melting temperature (T_m) for interaction of L-dA$_6$ with polynucleotides (Figure 2).[10] The T_m profiles also demonstrated that L-dA$_6$ interacts with poly(U) but not with poly(dT). The T_m value of the L-dA$_6$/poly(U) complex was determined to be 32.5 °C under the experimental conditions used. The T_m values of D-dA$_6$/poly(U) and D-dA$_6$/poly(dT) complexes were determined to be 57 and 53 °C, respectively (in good coincidence with the reproted values). The higher T_m value of the D-dA$_6$/poly(U(dT)) complex than of the L-dA$_6$/poly(U) complex reflects the higher stability of the former than of the latter. Though the L-dA$_6$/poly(U) complex is less stable than the D-dA$_6$/poly(U) complex, L-dA$_6$ possesses the striking ability to distinguish RNA from DNA. Anderson et al. reported that L-(dUp)$_{17}$dU did not interact with poly(dA).[4] We predict that L-(dUp)$_{17}$dU should interact with poly(A) (RNA type).

Our results suggest that enantio-DNAs may have a characteristic ability to be RNA-specific antisense oligonucleotides. Such RNA-specific oligonucleotide analogues have not previously been reported to our knowledge. As a tool for biochemical research, enantio-DNAs would give a low background in various kinds of biological assays because of the RNA specificity, stability to nucleases, and nonnatural character. Investigations to study applications of enantio-DNAs having specific base sequences as biochemical tools and as chemotherapeutic agents are planned.

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(12) The values of the hypochromicity were in good accordance with the reported values. Cassani, G. R.; Bollum, F. J. *Biochemistry* **1969**, *8*, 3928.

Furanone Synthesis via an Electrophilic Capped Carbonyl Ylide

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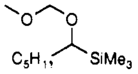
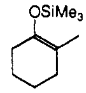
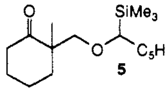
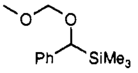
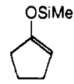
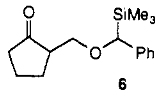
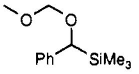
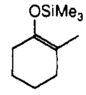
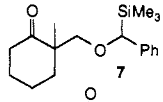
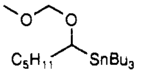
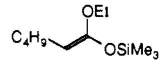
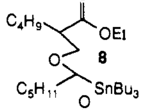
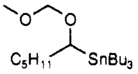
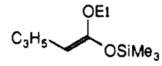
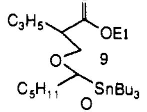
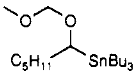
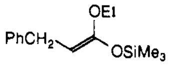
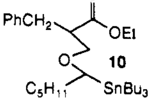
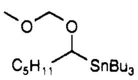
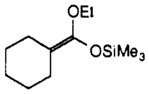
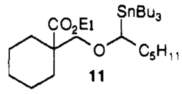
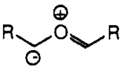
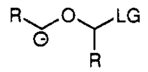
The synthesis of tetrahydrofurans (THFs) commonly proceeds via C–O bond formation, while the application of C–C bond forming reactions for this purpose is not common.[1] 1,3-Dipolar cycloaddition reactions[2] have provided nitrogen heterocycles via azomethine ylides; however, the extension of this approach to THF synthesis by carbonyl ylides has not been as successful. Carbonyl ylides may be generated by carbene additions to carbonyls,[3] by photolysis or thermolysis of oxiranes,[4] or by thermal decomposition of oxadiazolines.[5] Recently, Padwa and co-workers[6] have made considerable progress in the generation and reaction of stabilized carbonyl ylides; however, successful methods for nonstabilized ylides are still lacking. We have recently reported a new method for the regiospecific synthesis of THFs via a nucleophilic carbonyl ylide synthon,[7] and we report here our extension of this concept to the generation and reaction of an electrophilic carbonyl ylide synthon.

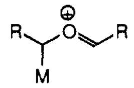
Table I. Directed Aldol Reactions of Mixed Acetals

Entry	Acetal	Nucleophile	Aldol Product	Yield,%[a] (Method)[b]
1			 5	99 (A)
2			 6	40 (A)
3			 7	48[c] (A) 79 (B)
4			 8	93 (C)
5			 9	83 (C)
6			 10	73 (C)
7			 11	73 (C)

[a] Isolated yields of analytically pure material. [b] Reaction conditions: A, 1.1 equiv of $TiCl_4$, CH_2Cl_2, −78 °C; B, 0.05 equiv of Me_3SiOTf, 0.05 equiv of 2,6-di-*tert*-butylpyridine, CH_2Cl_2, reflux; C, 0.9 equiv of $TiCl_4$, CH_2Cl_2, −78 °C. [c] Side products related to the formation of a benzyl cation intermediate reduced the yield. Method B provides an alternative procedure to A which results in improved yields of the aldol product; see entry 3.


non-stabilized
carbonyl ylide


nucleophilic
capped carbonyl
ylide
LG = leaving group


electrophilic
capped carbonyl
ylide
M = masked anion

We reasoned that the Mukaiyama reaction[8] could be applied to the electrophilic carbonyl ylide synthon problem provided that

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(1) For a recent review on the synthesis of THFs, see: Boivin, T. L. B. *Tetrahedron* **1987** *43*, 3309–3362. For recent examples of C–C bond forming reactions leading to THFs, see, inter alia: Broka, C. A.; Shen, T. *J. Am. Chem. Soc.* **1989**, *111*, 2981–2984. Feldman, K. S.; Fisher, T. E. *Tetrahedron* **1989**, *45*, 2969–2977. Middleton, D. S.; Simpkins, N. S.; Terrett, N. K. *Tetrahedron Lett.* **1988**, *29*, 1315–1318 and references therein.

(2) For a general discussion of synthetic, mechanistic, and theoretical aspects of dipolar cycloaddition reactions, see: *1,3-Dipolar Cycloaddition Chemistry*; Padwa, A., Ed.; Wiley-Interscience: New York 1984.

(3) (a) Houk, K. N.; Roudan, N. G.; Santiago, C.; Gallo, C. J.; Gandour, R. W.; Griffin, G. W. *J. Am. Chem. Soc.* **1980**, *102*, 1504–1512. (b) Huisgen, R.; DeMarch, P. *J. Am. Chem. Soc.* **1982**, *104*, 4953–4954. (c) DeMarch, P.; Huisgen, R. *J. Am. Chem. Soc.* **1982**, *104*, 4952. (d) L'Esperance, R. P.; Ford, T. M.; Jones, M. *J. Am. Chem. Soc.* **1988**, *110*, 209–213. (e) Padwa, A.; Carter, S. P.; Nimmesgern, H.; Stull, P. D. *J. Am. Chem. Soc.* **1988**, *110*, 2894–2900. (f) Soundararajan, N.; Jackson, J. E.; Platz, M. S.; Liu, M. T. H. *Tetrahedron Lett.* **1988**, *29*, 3419–3422.

(4) (a) Do-Minh, T.; Trozzolo, A. M.; Griffin, G. W. *J. Am. Chem. Soc.* **1970**, *92*, 1402. (b) Griffin, G. W. *Angew. Chem., Int. Ed. Engl.* **1971**, *10*, 537–585. (c) Huisgen, R. *Angew. Chem., Int. Ed. Engl.* **1977**, *17*, 572–585.

(5) (a) Bekhazi, M.; Warkentin, J. *J. Am. Chem. Soc.* **1981**, *103*, 2473–2474. (b) Bekhazi, M.; Warkentin, J. *J. Org. Chem.* **1982**, *47*, 4870–4873.

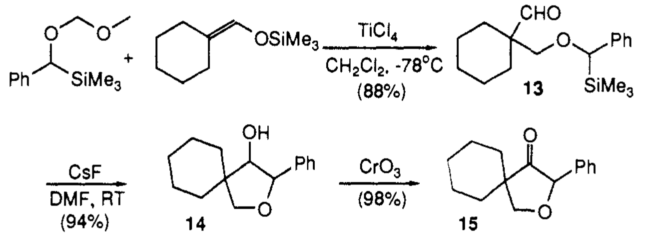
(6) For some recent examples from this research group, see the following references and earlier references cited therein: Dean, D. C.; Krumpe, K. E.; Padwa, A. *J. Chem. Soc., Chem. Commun.* **1989**, 921–922. Padwa, A.; Chinn, R. L.; Zhi, L. *Tetrahedron Lett.* **1989**, *30*, 1491–1494. Padwa, A.; Hertzog, D. L.; Chinn, R. L. *Tetrahedron Lett.* **1989**, *30*, 4077–4080. Padwa, A.; Hornbuckle, S. F.; Frypell, G. E.; Stull, P. D. *J. Org. Chem.* **1989**, *54*, 817–824.

(7) Linderman, R. J.; Godfrey, A. *J. Am. Chem. Soc.* **1988**, *110*, 6249–6251.

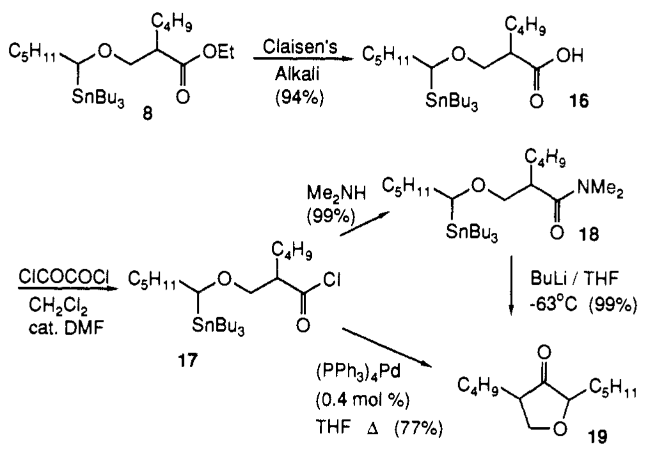
(8) Mukaiyama, T. *Org. React.* (*N.Y.*) **1982**, 203–326.

0002-7863/90/1512-7438$02.50/0

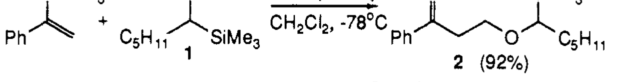
Scheme I

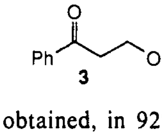


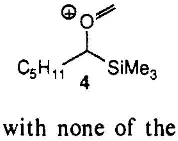
Scheme II



a masked carbanion could be incorporated in the oxonium species. Silicon and tin substituents are well precedented as precursors to nucleophilic carbon species;[9] however, α-alkoxy Sn- or Si-substituted acetals had not been investigated as oxonium ion precursors. Initial experiments served to ascertain the regioselectivity of Lewis acid catalyzed acetal cleavage of (α-alkoxyalkyl)trialkylsilane **1**. Only the silyl-substituted aldol product

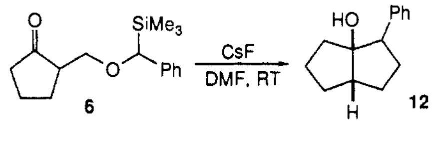






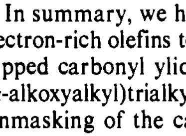
2 was obtained, in 92% yield, with none of the regioisomeric product **3** detected. The regioselective generation of oxonium ion **4** can be explained by steric arguments in that the Lewis acid preferentially forms a complex with the most accessible oxygen of the acetal.[10] In addition, oxonium ion **4** can potentially be stabilized by hyperconjugation, analogous to the stabilization of β-carbocations, by the trialkylsilyl or trialkylstannyl substituent.[11] Several (α-alkoxyalkyl or -aryl)trialkylsilanes and -stannanes have been investigated in this reaction using silyl enol ethers and ketene silyl acetals (see Table I).

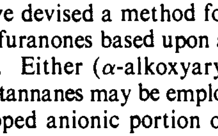
Several attempts to effect nucleophilic ring closure of **5** using sources of fluoride anion to expose the "capped" anionic portion of the ylide met with no success. In contrast, treatment of **6** with anhydrous cesium fluoride (catalytic or stoichiometric) in dry *N*,*N*-dimethylformamide resulted in the ring-closed THF **12** as

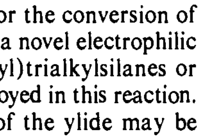


a 90:10 mixture of diastereomers in 65% yield. The desilylation and ring closure of aldol product **13** was a facile reaction, providing the THF **14** in 94% yield. Oxidation of **14** with Jones reagent provided the spiroannelated tetrahydrofuran-3-one **15** in excellent yield (Scheme I). The overall transformation is equivalent to the regiospecific addition of a carbonyl ylide to a silyl enol ether.

Although we were successful in achieving a synthetically useful carbonyl ylide synthon using aryl-substituted silyl derivatives, a route to alkyl-substituted species was still desired.[12] The direct transmetalation of the Bu_3Sn moiety of **8** was attempted; however, the ester carbonyl effectively competed with the Sn atom as the electrophilic site for reaction of BuLi, leading predominately to 1,2-addition. McGarvey and co-workers[13] had reported that α-alkoxyorganostannanes could be preferentially transmetalated in the presence of an amide by using BuLi in DME/TMEDA. The ester aldol product **8** was then converted to the dimethyl amide **18** (Scheme II). Carboxylic acid **16** proved to be unstable and was immediately converted to the amide via the acid chloride **17**. Transmetalation of the Bu_3Sn-functionalized amide **18** proved to be straightforward (2 equiv of BuLi, THF, -63 °C), providing the furanone **19** in excellent yield. In the same fashion, aldol products **9**, **10**, and **11** were converted to furanones **20**, **21**, and **22** in 90%, 91%, and 89% overall yield, respectively. As an







alternative route which would remove the necessity for transmetalation using BuLi, the intramolecular Pd^0 coupling[14] of the acid chloride **17** was also examined. Refluxing **17** in THF with 0.4 mol % tetrakis(triphenylphosphine)palladium(0) provided the furanone **19** in 77% (unoptimized) yield. No trace of the possible intramolecular butyl transfer product was detected.

In summary, we have devised a method for the conversion of electron-rich olefins to furanones based upon a novel electrophilic capped carbonyl ylide. Either (α-alkoxyaryl)trialkylsilanes or (α-alkoxyalkyl)trialkylstannanes may be employed in this reaction. Unmasking of the capped anionic portion of the ylide may be achieved by fluoride-induced desilylation or transmetalation (Li or Pd) of a trialkylstannyl substituent.

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(9) Silicon: (a) Majetich, G.; Casares, A.; Chapman, D.; Behnke, M. *J. Org. Chem.* **1986**, *51*, 1745–1753. (b) Vedejs, E.; Martinez, G. R. *J. Am. Chem. Soc.* **1979**, *101*, 6452–6454. (c) Degl'Innocenti, A.; Pike, S.; Walton, D. R. M.; Seconi, G.; Ricci, A.; Fiorenga, M. *J. Chem. Soc., Chem. Commun.* **1980**, 1201–1202. (d) Shimigu, S.; Ogata, M. *Tetrahedron* **1989**, *45*, 637–642. (e) Heathcock, C. H.; Schinzer, D. *Tetrahedron Lett.* **1981**, *22*, 1881–1889. (f) Fujita, M.; Obayshi, M.; Hiyama, T. *Tetrahedron* **1988**, *44*, 4135–4145. (g) Blankenship, C.; Wells, G. J.; Paquette, L. A. *Tetrahedron* **1988**, *44*, 4023–4032. Tin: (h) Macdonald, T. L.; Mahalingam, S.; O'Dell, D. E. *J. Am. Chem. Soc.* **1981**, *103*, 6767–6769. (i) Macdonald, T. L.; Mahalingam, S. *J. Am. Chem. Soc.* **1980**, *102*, 2113–2115. (j) Macdonald, T. L.; Delahunty, C. M.; Mead, K.; O'Dell, D. E. *Tetrahedron Lett.* **1989**, *30*, 1473–1476. (k) Fleming, I.; Rowley, M. *Tetrahedron* **1986**, *42*, 3181–3198. (l) Sato, T.; Watanabe, M.; Watanabe, T.; Onoda, Y.; Murayama, E. *J. Org Chem.* **1988**, *53*, 1894–1899.

(10) For regioselective cleavage reactions of mixed acetals, see, inter alia: (a) Kocienski, P. J.; Street, S. D.; Yeats, C.; Campbell, S. F. *J. Chem. Soc., Perkin Trans. 1*, **1987**, 2171–2181. (b) Overman, L. E.; Thompson, A. S. *J. Am. Chem. Soc.* **1988**, *110*, 2248–2256. (c) Nishiyama, N.; Itoh, K. *J. Org. Chem.* **1982**, *47*, 2496–2498. (d) Melany, M. L.; Lock, G. A.; Thompson, D. W. *J. Org. Chem.* **1985**, *50*, 3925–3927. (e) Frauenroth, H.; Runsink, J. *J. Org. Chem.* **1987**, *52*, 2707–2712. (f) Walker, D. M.; Logusch, E. W. *Tetrahedron Lett.* **1989**, *30*, 1181–1184.

(11) Our efforts to determine the extent of this possible stabilization will be described elsewhere. For hyperconjugative carbocation stabilization, see the following references. Silicon: Lambert, J. B.; Wang, G.; Finzel, R. D.; Teramura, D. H. *J. Am. Chem. Soc.* **1987**, *109*, 7838–7845. Block, E.; Yencha, A. J.; Aslam, M.; Eswarakrishnan, V.; Luo, J.; Sano, A. *J. Am. Chem. Soc.* **1988**, *110*, 4748–4753. Tin and germanium: Lambert, J. B.; Wang, G. T.; Teramura, D. H. *J. Org. Chem.* **1988**, *53*, 5422–5428.

(12) For a recent furanone synthesis via Rh(II)-catalyzed carbenoid C–H insertion, see: Adams, J.; Poupart, M.-A.; Grenier, L.; Scholler, C.; Ouimet, N.; Frenette, R. *Tetrahedron Lett.* **1989**, *30*, 1749–1756. Adams, J.; Poupart, M.-A.; Grenier, L. *Tetrahedron Lett.* **1989**, *30*, 1753–1756. For a study on furanone chemistry, see: Smith, A. B., III; Levenberg, P. A.; Jerris, P. J.; Scarborough, R. M.; Wovkulich, P. M. *J. Am. Chem. Soc.* **1981**, *103*, 1501–1513.

(13) McGarvey, G. J.; Kimura, M. *J. Org. Chem.* **1985**, *50*, 4657–4659.

(14) Labadie, J. W.; Tueting, D.; Stille, J. K. *J. Org. Chem.* **1983**, *48*, 4634–4642.