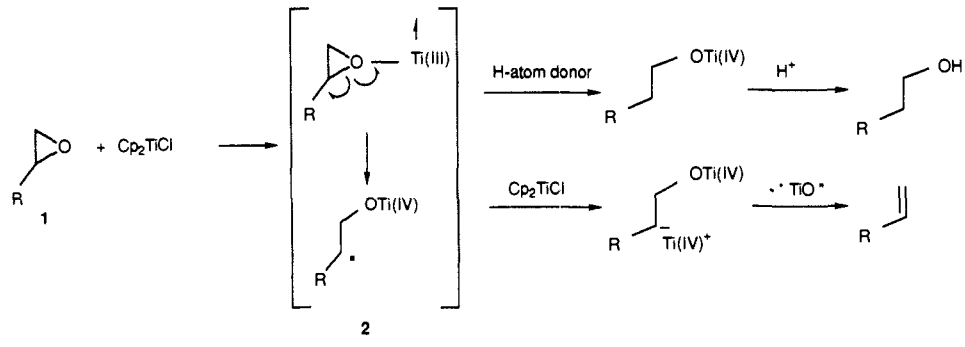
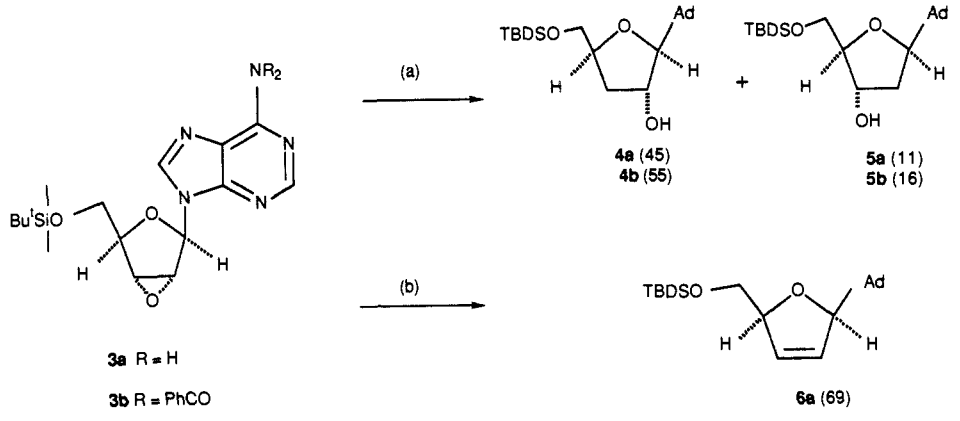
Scheme I

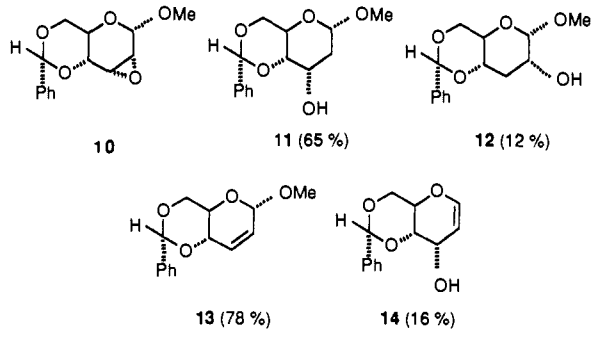


Scheme II. Reduction and Deoxygenation of Adenosine Epoxide[a]



[a] (a) Cp_2TiCl/cyclohexa-1,4-diene/room temperature. (b) $2Cp_2TiCl$/room temperature; % yields shown in brackets.

of 5:1) arising from the β-eliminations of either the Ti–oxo or the OMe species, with the former predominating.



One limitation of this reduction protocol is revealed in the attempted reduction of monosubstituted terminal epoxides like 1,2-epoxydecane where up to 33% deoxygenation is observed even in the presence of a 10-fold excess of 1,4-cyclohexadiene. This may be due to the accessibility of the sterically unencumbered secondary/primary radicals to the Ti^{3+} species resulting in further electron transfer reduction and subsequent deoxygenation rather than H atom transfer from cyclohexa-1,4-diene.

Finally, this deoxygenation reaction appears to be mechanistically different from the stereospecific low-valent W-mediated reaction reported by Sharpless et al.[11] Addition of either *cis*- or *trans*-5-decene oxide to excess Cp_2TiCl afforded an identical 73:27 mixture of *cis*- and *trans*-5-decenes. The mechanistic details of this reaction remain largely unknown except that the β-eliminations of alkoxides and the need for 2 equiv of Ti^{3+} suggest that the reaction proceeds via carbanion-like intermediates.

Supplementary Material Available: Details of typical experimental procedures and ^1H NMR, HRMS, and/or elemental analysis of new compounds (7 pages). Ordering information is given on any current masthead page.

(11) (a) Sharpless, K. B.; Umbreit, M. A.; Nieh, M. T.; Flood, T. C. *J. Am. Chem. Soc.* **1972**, *94*, 6538. See also: Umbreit, M. A.; Sharpless, K. B. *Org. Synth.* **1981**, *60*, 29.

Self-Assembly Based on the Cyanuric Acid–Melamine Lattice[1]

Christopher T. Seto[2] and George M. Whitesides*

Department of Chemistry, Harvard University
Cambridge, Massachusetts 02138

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Reaction of cyanuric acid (CA) with melamine (M) forms a stable, insoluble 1:1 complex CA·M.[3] We, and others, believe that CA·M has a local structure represented by the lattice **1**.[4] We have started a program in the design and synthesis of three-dimensional supramolecular assemblies based on the hydrogen-bonding pattern of CA·M. This program is an extension of the strategy of molecular self-assembly that has been highly successful in forming quasi-two-dimensional monolayers on solid supports.[5]

(1) Supported by the National Science Foundation (Grants CHE-88-12709 to G.M.W. and DMR 86-14003 to the Harvard University Materials Research Laboratory).

(2) NIH Training Grant Predoctoral Fellow, 1987–1988.

(3) Kazuo, M.; Hironobu, K.; Koichiso, Y.; Junichi, N. *Jpn. Kokai Tokkyo Koho* **1979**, *79*, 588.

(4) Ostragorich, G.; Bacaloglu, R. *Timisoara, Studii Cercetari Stiint. Chim.* **1962**, *9*, 273–289. Finkel'shtein, A. I.; Rukevich, O. S. *Zh. Prikl. Specktrosk.* **1983**, *38*, 327–330. The X-ray powder pattern of $CA_3 \cdot M_3$ is consistent with our proposed structure. Zerkowski, J.; Graham, R.; Whitesides, G. M., unpublished results. For the crystal structure of CA-M-3HCl, see: Wang, Y.; Wei, B.; Wang, Q. *J. Crystallogr. Spectrosc. Res.* **1990**, *20*, 79–84.

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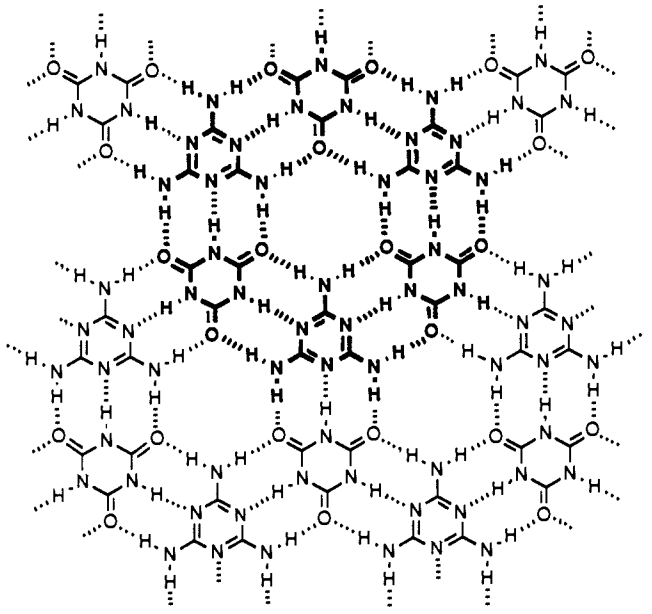

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We set as our first objective the preparation of a soluble, stable derivative of the cyclic hexamer $CA_3 \cdot M_3$ (see the boldfaced section in **1**). To promote the formation of this structure, we preorganized the three M units by connecting them covalently to a central "hub", using "spokes" conformationally compatible with the desired $CA_3 \cdot M_3$ structure.[6] Here we report that the tris(melamine) $hubM_3$ (**2**) reacts with neohexyl cyanurate (R'CA, **3**) in $CHCl_3$ and forms a well-defined 1:3 complex $(hubM_3)_1(R'CA)_3$ (Scheme I).[7]

We monitored the titration of $hubM_3$ (10 mM in $CDCl_3$) with solid aliquots of R'CA by ^1H NMR spectroscopy (Figure 1). The spectrum of uncomplexed $hubM_3$ (bottom trace) has resonances that are broadened by self-association and restricted rotation around the amide and RNH–triazine bonds. At intermediate points in the titration, the spectrum shows resonances for the $(hubM_3)_1(R'CA)_3$ complex against a background of uncomplexed $hubM_3$. The resonances for the complex are sharp because it is locked into a single conformation and exchange between the complex and $hubM_3$ in solution is slow on the NMR time scale. As the titration proceeds, the intensities of the resonances for $(hubM_3)_1(R'CA)_3$ increase until the 1:3 stoichiometry is reached, and beyond this point there is no further change in the spectrum.[8,9]

The peak assignments for $(hubM_3)_1(R'CA)_3$ are shown at the top of Figure 1. Two features support the assigned structure: First, several methylene protons (g,g' and q,q') of $hubM_3$ are diastereotopic in $(hubM_3)_1(R'CA)_3$ and thus appear as two separate resonances. Second, the two imide N–H protons (w and w') of R'CA are in different hydrogen-bonding environments and thus appear as separate resonances in the complex even though they are identical in uncomplexed R'CA. NOESY studies are also consistent with the proposed structure. We observed NOEs between (i) the *tert*-butyl protons of R'CA (v in Scheme I) and the adjacent aromatic protons of $hubM_3$ (l and m) and (ii) the methylene and *tert*-butyl protons of R'CA (t and v) and the adjacent *tert*-butyl protons of $hubM_3$ (s). In the $(hubM_3)_1(R'CA)_3$ complex these groups are close together.

Several other methods support the 1:3 stoichiometry, $(hubM_3)_1(R'CA)_3$. Vapor pressure osmometry (VPO) indicated a MW of 2720[10] (calculated for $(hubM_3)_1(R'CA)_3$ = 2733) over the concentration range 2–16 mM in $CHCl_3$ at 37 °C. Titration of $hubM_3$ (0.1 mM in CH_2Cl_2) with R'CA monitored by UV spectroscopy indicated a 1:3 complex. The complex is also stable enough to withstand chromatography. Reverse-phase TLC (eluted with 5% 2-propanol in CH_2Cl_2) gave three spots: a major spot

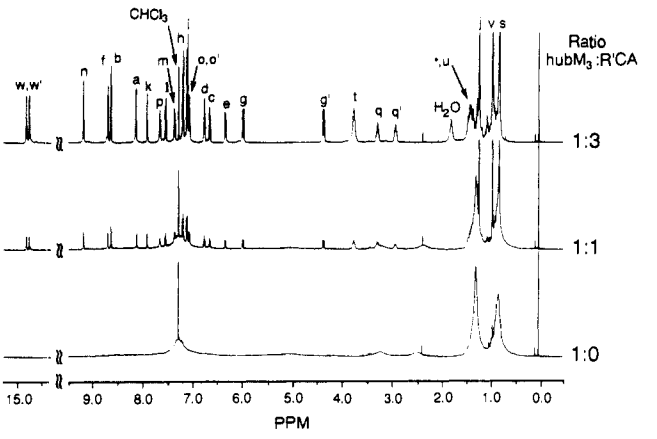
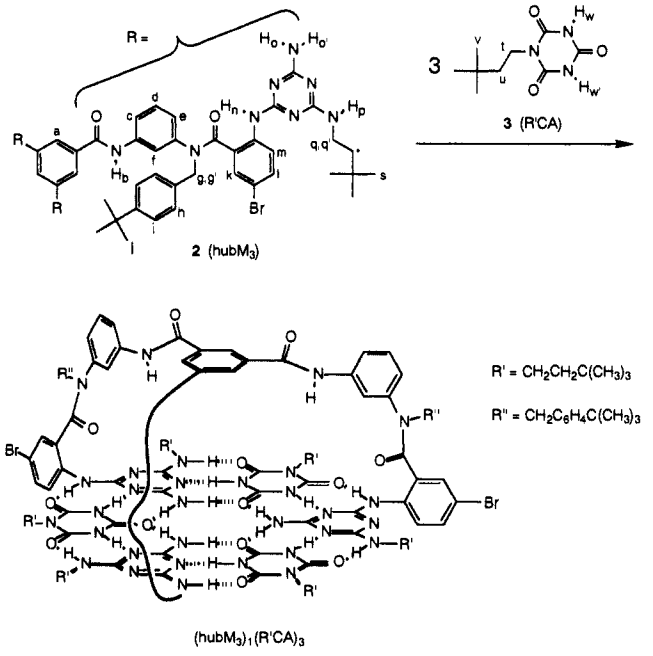


Figure 1. Spectra of ^1H NMR titration of $hubM_3$ (500 MHz, 10 mM in $CDCl_3$) with R'CA. The peak assignments are shown at the top of the figure.

Scheme I. Self-Assembly of $hubM_3$ with R'CA To Give a Supramolecular 1:3 Complex[a]



[a] The third spoke of $(hubM_3)_1(R'CA)_3$ has been drawn schematically for the sake of clarity. The groups R' and R'' were chosen to add solubility to the complex and to provide centers easily analyzed by ^1H NMR spectroscopy.

(5) Whitesides, G. M.; Laibinis, P. E. *Langmuir* **1990**, *6*, 87–96. Bain, C. D.; Whitesides, G. M. *Angew. Chem.* **1989**, *101*, 522–528.

(6) The importance of preorganization is clearly illustrated in the work of Rebek, Cram, and others. Rebek, J., Jr. *Angew. Chem., Int. Ed. Engl.* **1990**, *29*, 245–255 and references therein. Bryant, J.; Ericson, J.; Cram, D. *J. Am. Chem. Soc.* **1990**, *112*, 1255–1256. Hydrogen-bonding networks have been used in many imaginative approaches to the construction of structurally defined, noncovalent complexes. Etter, M. *Acc. Chem. Res.* **1990**, *23*, 120–126.

(7) All new compounds gave satisfactory ^1H NMR (500 MHz), ^{13}C NMR (125 MHz), and mass spectra.

(8) We have examined the complexation of $hubM_3$ with a number of other cyanuric and barbituric acid derivatives. These compounds also seem to lead to complexes analogous in structure to $(hubM_3)_1(R'CA)_3$, although some of them contain up to 10% of other hydrogen-bonded species. We believe these other hydrogen-bonded species to be conformational isomers of a symmetrical 1:3 complex (Scheme I) in which one of the M units has been flipped 180° with respect to the plane of the $CA_3 \cdot M_3$ ring. These isomers have a dissymmetric arrangement of the three "spokes".

(9) R'CA alone has low solubility in $CDCl_3$. Beyond the 1:3 stoichiometry the R'CA in excess of that required to form $(hubM_3)_1(R'CA)_3$ does not go into solution.

(10) The values of three separate determinations were MW = 2670, 2640, 2850.

for the complex $(hubM_3)_1(R'CA)_3$ (R_f 0.35–0.45) and minor spots for uncomplexed $hubM_3$ (R_f 0.15–0.30) and uncomplexed R'CA (R_f 0.0).[11]

These data establish the composition and structure of $(hubM_3)_1(R'CA)_3$. Preorganization, i.e., joining the three melamine units by using the 1,3,5-$C_6H_3R_3$ hub and spokes conformationally compatible with the desired structure (Scheme I), is an important factor contributing to the stability of the complex. Reaction of monomeric derivatives of M and CA in solution forms complexes having approximately the correct molecular weight for $CA_3 \cdot M_3$ by VPO,[12] but crystallization of these complexes yields extended linear structures.[13] The apparent solution molecular weight in these systems may represent a true cyclic hexamer $CA_3 \cdot M_3$ or an average of linear and cyclic oligomers.

Acknowledgment. NMR instrumentation was supported by National Science Foundation Grant CHE-84-10774. Mass spectra were obtained by Dr. Andrew Tyler (Harvard University Mass Spectrometry Facility) using instrumentation provided by JEOL (USA) Inc. We thank Professor Robert Cohen (MIT, Chemical Engineering) for the loan of the vapor pressure osmometer and for helpful discussions.

(11) We have not obtained crystals of the 1:3 complex that are suitable for X-ray diffraction.

(12) VPO indicated a MW of 2710 for a 1:1 mixture of *N,N'*-bis(4-*tert*-butylphenyl)melamine and 3,3,3-triphenylpropyl cyanurate (calculated for (*N,N'*-bis(4-*tert*-butylphenyl)melamine)$_3$(3,3,3-triphenylpropyl cyanurate)$_3$ = 2370) over the concentration range 6–20 mM in $CHCl_3$ at 37 °C. The MW estimated by VPO depends strongly on concentration at lower concentrations.

(13) Lehn, J. M.; Mascal, M.; DeCian, A.; Fischer, J. *J. Chem. Soc., Chem. Commun.* **1990**, 479–481. Zerkowski, J.; Seto, C.; Whitesides, G. M., unpublished results.

Synthesis and X-ray Structure of a Simple Metallaoxetane. Metal-Based Selectivity in Oxidative Addition

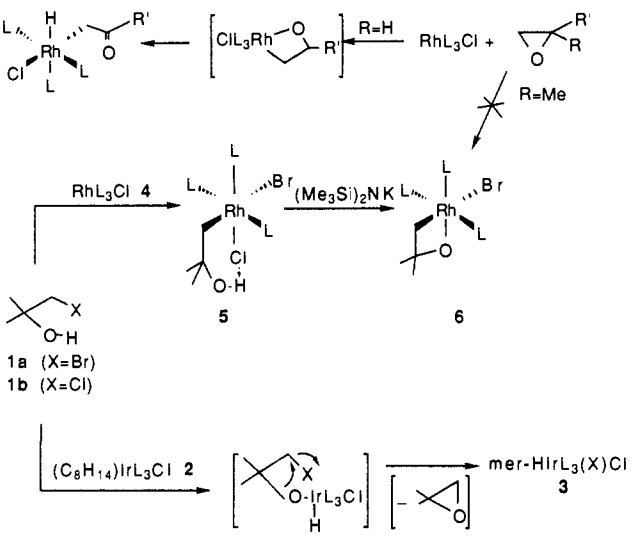
Andrei A. Zlota, Felix Frolow, and David Milstein*

Department of Organic Chemistry
The Weizmann Institute of Science
Rehovot 76100, Israel

Received March 12, 1990

2-Metallaoxetanes are often invoked as crucial intermediates in metal-catalyzed oxidations,[1] including cytochrome P-450 and biomimetic olefin epoxidations.[2] Their intermediacy is also postulated in various metal-mediated reactions of epoxides,[3] in olefin metathesis,[4] and in conversions of carbonyls to alkenes by metal alkylidenes.[5] However, such complexes are exceedingly scarce and have been isolated in special cases where the metallaoxetane ring is stabilized by multiple cyano substitution[6] or by an exocyclic double bond.[7] Only recently has the first example of a simply substituted 2-metallaoxetane been reported.[8] We report here (a) a straightforward route for the preparation of a simple metallaoxetane; (b) the crystallographic characterization of such a complex; (c) the structure of an analogous β-hydroxyalkyl complex, allowing direct evaluation of the structural consequences of ring closure; and (d) unusual metal-based chemoselectivity in oxidative addition of a bifunctional substrate.

Scheme I[a]



[a] L = PMe_3; C_8H_{14} = cyclooctene.

We had reported that epoxides undergo C–O oxidative addition to electron-rich rhodium and iridium complexes to yield β-oxoalkyl metal hydrides, possibly by β-hydride elimination of an intermediate metallaoxetane.[3g,9] However, attempts to isolate the primary oxidative addition product by use of a geminally disubstituted epoxide were not successful. Hence we planned the preparation of a metallaoxetane indirectly from the corresponding halohydrin (Scheme I).

Addition of an equimolar amount of a 0.14 M toluene solution of the halohydrins **1** to a 0.04 M solution of the electron-rich iridium complex **2** in toluene under nitrogen at −30 °C leads after 30 min to formation of the hydrides **3**[10] (ca. 70% yield), possibly by O–H rather than C–X oxidative addition, followed by epoxide elimination. We find this surprising, since oxidative addition of alkyl halides to low valent metal complexes is usually a facile process,[11] taking place even in alcoholic solvents,[12] whereas such

(1) For example: (a) Sharpless, K. B.; Teranishi, A. Y.; Bäckvall, J. E. *J. Am. Chem. Soc.* **1977**, *99*, 3120. (b) Schröder, M.; Constable, E. C. *J. Chem. Soc., Chem. Commun.* **1982**, 734. (c) Sheldon, R. A.; Kochi, J. K. *Metal-Catalyzed Oxidations of Organic Compounds*; Academic Press: New York, 1981. (d) Jorgensen, K. A. *Chem. Rev.* **1989**, *89*, 431.

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(3) (a) De Pasquale, R. J. *J. Chem. Soc., Chem. Commun.* **1973**, 157. (b) Milstein, D.; Buchman, O.; Blum, J. *J. Org. Chem.* **1977**, *42*, 2299. (c) Blum, J.; Zinger, B.; Milstein, D.; Buchman, O. *J. Org. Chem.* **1978**, *43*, 2961. (d) Kamiya, Y.; Kawato, K.; Ohta, H. *Chem. Lett.* **1980**, 1549. (e) Schwartz, J.; Hayasi, Y. *Inorg. Chem.* **1981**, *20*, 3473. (f) Suzuki, M.; Watanabe, A.; Noyori, R. *J. Am. Chem. Soc.* **1980**, *102*, 2095. (g) Milstein, D.; Calabrese, J. C. *J. Am. Chem. Soc.* **1982**, *104*, 3773. (h) Osborne, R. B.; Ibers, J. A. *J. Organomet. Chem.* **1982**, *232*, 273; (i) *Ibid.* **1982**, *232*, 371. (j) Alper, H.; Arzoumanian, H.; Petrignani, J.-F.; Saldana-Maldonado, M. *J. Chem. Soc., Chem. Commun.* **1985**, 340. (k) Miyashita, A.; Ishida, J.; Nohira, H. *Tetrahedron Lett.* **1986**, *27*, 2127. (l) Hase, T.; Miyashita, A.; Nohira, H. *Chem. Lett.* **1988**, 219. (m) Aye, K. T.; Ferguson, G.; Lough, A. J.; Puddephatt, R. J. *Angew. Chem., Int. Ed. Engl.* **1989**, *28*, 767.

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(5) (a) Tebbe, F. N.; Parshall, G. W.; Reddy, G. S. *J. Am. Chem. Soc.* **1978**, *100*, 3611. (b) Buchwald, S. L.; Grubbs, R. H. *Ibid.* **1983**, *105*, 5490. (c) Pine, S. H.; Zahler, R.; Evans, D. A.; Grubbs, R. H. *Ibid.* **1980**, *102*, 3270.

(6) (a) Schlodder, R.; Ibers, J. A.; Lenarda, M.; Graziani, M. *J. Am. Chem. Soc.* **1974**, *96*, 6893. (b) Lenarda, M.; Pahor, N. B.; Calligaris, M.; Graziani, M.; Randaccio, L. *J. Chem. Soc., Dalton Trans.* **1978**, 279. (c) Lenarda, M.; Ros, R.; Traverso, O.; Pitts, W. D.; Baddley, W. H.; Graziani, M. *Inorg. Chem.* **1977**, *16*, 3178.

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(10) **3a**: IR (Nujol) 2161 (m, ν_{Ir-H}), 951 (vs, ν_{P-C}); ^1H NMR (pyridine-d_5) δ 1.49 (t, J_{P-H} = 3.7 Hz, 18 H, $2PMe_3$), 1.20 (d, J = 10 Hz, 9 H, PMe_3), −21.6 (dt, J_{P1-H} = 19.4 Hz, J_{P2-H} = 14 Hz, 1 H); $^{31}P\{^1H\}$ NMR (pyridine-d_5) δ −40 (d, J_{P-P1} = 20 Hz, 2 P), −44 (t, J_{P-P1} = 20 Hz, 1 P).

(11) (a) Collman, J. P.; Hegedus, L. S.; Norton, J. R.; Finke, R. G. *Principles and Applications of Organotransition Metal Chemistry*; University Science Books: Mill Valley, CA, 1987; pp 284–321. (b) Stille, J. K.; Lau, K. S. Y. *Acc. Chem. Res.* **1977**, *10*, 434.

(12) Oxidative addition of organic halides in the presence of alcohols is a key step in metal-catalyzed carbalkoxylation of these substrates. See, for example: Milstein, D. *Acc. Chem. Res.* **1988**, *21*, 428 and references therein.

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