1 H), 6.90 (d, J = 5.1 Hz, 1 H), 7.13 (d, J = 5.1 Hz, 1 H). Anal. Calcd for $C_{13}H_{23}NOS$: C, 64.68; H, 9.60; N, 5.80. Found: C, 64.86; H, 9.85; N, 5.66.

Treatment of 12o with Equimolar *n*-BuLi Followed by Benzaldehyde. In a manner similar to that described above, **12o** (128 mg, 0.9 mmol) was treated with *n*-BuLi (0.66 mL, 1.1 mmol) and then benzaldehyde (117 mg, 1.1 mmol) in ether (11 mL) to give a mixture of 2-[(dimethylamino)methyl]-5-(α-hydroxybenzyl)-3-methylfuran (**22o**), 2-[(dimethylamino)methyl]-3-(2-hydroxy-2-phenylethyl)furan (**27o**), and **17o**. Compound **22o** and **27o** were separated on a silica gel column (EtOAc/MeOH). The result is shown in Table IV.

22o: bp 100 °C (0.2 mmHg, Kugelrohr); IR (film) 3330, 1602 cm^{-1}; ^1H NMR ($CDCl_3$) δ 1.93 (s, 3 H), 2.20 (s, 6 H), 3.36, 3.39 (AB-q, J = 13.7 Hz, 2 H), 5.78 (s, 1 H), 5.81 (s, 1 H), 7.31–7.37 (m, 3 H), 7.42–7.45 (m, 2 H). Anal. Calcd for $C_{15}H_{19}NO_2$: C, 73.44; H, 7.81; N, 5.71. Found: C, 73.62; H, 7.83; N, 5.61.

27o: bp 100 °C (0.2 mmHg, Kugelrohr); IR (film) 3350, 1605 cm^{-1}; ^1H NMR ($CDCl_3$) δ 2.30 (s, 6 H), 2.78 (dd, J = 8.1, 14.7 Hz, 1 H), 2.90 (dd, J = 2.9, 14.7 Hz, 1 H), 3.37, 3.48 (AB-q, J = 13.7 Hz, 2 H), 7.22 (d, J = 1.7 Hz, 1 H), 7.21–7.25 (m, 5 H). Anal. Calcd for $C_{15}H_{19}NO_2$: C, 73.44; H, 7.81; N, 5.71. Found: C, 73.35; H, 7.98; N, 5.61.

Acknowledgment. This work was supported by a Grant-in-Aid for Scientific Research (No. 04671301) provided by the Ministry of Education, Science and Culture, Japan.

Preparation of New Classes of Aliphatic, Allylic, and Benzylic Zinc and Copper Reagents by the Insertion of Zinc Dust into Organic Halides, Phosphates, and Sulfonates

Carole Jubert[1a] and Paul Knochel*[,1b]

The Willard H. Dow Laboratories, Department of Chemistry, The University of Michigan, Ann Arbor, Michigan 48109

Received June 15, 1992

The insertion of zinc dust into primary alkyl chlorides, bromides, phosphates, and sulfonates in a polar solvent (DMPU, DMA) and in the presence of a catalytic amount of LiI (0.2 equiv) provides new organozinc reagents of the type RZnX (X = Cl, Br, OSO_2R, $OP(O)(OR)_2$) in excellent yields. After the transmetalation to the corresponding copper reagent RCu(CN)ZnX using CuCN·2LiCl, the addition of electrophiles, such as Michael acceptors, affords the desired adducts. Similarly, various new allylic and benzylic zinc reagents were prepared without the formation of any Wurtz-coupling side product and reacted with various electrophiles.

Polyfunctional organozinc and copper reagents are important intermediates in organic synthesis.[2] They react efficiently with various classes of electrophiles[2,3] allowing the construction of highly functionalized molecules without having to use extensively protection–deprotection or functional group interconversion methodologies. They are conveniently prepared by the insertion of zinc dust into alkyl iodides in THF between 25 and 50 °C.[2,3] The less expensive alkyl bromides or chlorides are usually not reactive enough to insert zinc dust and require the use of highly activated zinc metal.[4] We wish to report herein reaction conditions allowing the insertion of zinc dust (Aldrich) to primary alkyl chlorides, bromides, sulfonates, or phosphates **1** (eq 1).

$$\underset{\textbf{1: X = Cl, Br, OMs, OTs, OP(O)(OPh)}_2}{\text{R–X}} \xrightarrow[\text{DMA or DMPU, 40–80 °C, 2–12 h}]{\text{Zn, MI (0.2 equiv), MBr (1.0 equiv)}} \underset{\textbf{2}}{\text{RZnX}} \qquad (1)$$

Thus, the treatment of the primary alkyl bromide with zinc dust in a polar solvent such as *N*,*N*-dimethylacetamide (DMA)[5] or *N*,*N*-dimethylpropyleneurea (DMPU)[6] in the presence of a catalytic amount of an alkali iodide (0.2 equiv) furnishes the corresponding alkylzinc bromide in excellent yields (>85%). Remarkably, the reaction can be extended to the preparation of new alkylzinc chlorides, tosylates, mesylates and diphenylphosphates **2** (RZnX; X

(1) (a) Centre de Recherches, Roussel-Uclaf, 102, 111 route de Noisy, F-92230 Romainville, France. (b) Present address: Philipps-Universität Marburg, Fachbereich Chemie, Hans-Meerwein-Strasse, D-3550 Marburg, Germany.

(2) (a) Knochel, P.; Yeh, M. C. P.; Berk, S. C.; Talbert, J. *J. Org. Chem.* **1988**, *53*, 2390. (b) Knoess, H. P.; Furlong, M. T.; Rozema, M. J.; Knochel, P. *J. Org. Chem.* **1991**, *56*, 5974. (c) Knochel, P.; Rozema, M. J.; Tucker, C. E.; Retherford, C.; Furlong, M.; AchyuthaRao, S. *Pure Appl. Chem.* **1992**, *64*, 361. (d) Tsujiyama, H.; Ono, N.; Yoshino, T.; Okamoto, S.; Sato, F. *Tetrahedron Lett.* **1990**, *31*, 4481. (e) Sörenson, H.; Greene, A. E. *Tetrahedron Lett.* **1990**, *31*, 7597. (f) Tanaka, T.; Bannai, K.; Hazato, A.; Koga, M. Kurozumi, S.; Kato, Y. *Tetrahedron* **1991**, *47*, 1861.

(3) (a) Yeh, M. C. P.; Knochel, P.; Santa, L. E. *Tetrahedron Lett.* **1988**, *29*, 3887. (b) Yeh, M. C. P.; Knochel, P.; Butler, W. M.; Berk, S. C. *Tetrahedron Lett.* **1988**, *29*, 6693. (c) Yeh, M. C. P.; Knochel, P. *Tetrahedron Lett.* **1989**, *30*, 4799. (d) Retherford, C.; Yeh, M. C. P.; Schipor, I.; Chen, H.-G.; Knochel, P. *J. Org. Chem.* **1989**, *54*, 5200. (e) Chen, H.-G.; Gage, J. L.; Barrett, S. D.; Knochel, P. *Tetrahedron Lett.* **1990**, *31*, 1829. (f) Retherford, C.; Knochel, P. *Tetrahedron Lett.* **1991**, *32*, 441. (g) AchyuthaRao, S.; Knochel, P. *J. Am. Chem. Soc.* **1991**, *113*, 5735.

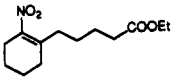
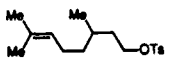
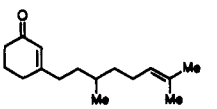
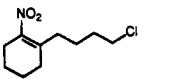
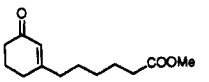
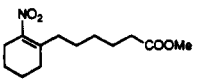
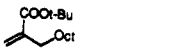
(4) (a) Zhu, L.; Wehmeyer, R. M.; Rieke, R. D. *J. Org. Chem.* **1991**, *56*, 1445. (b) The insertion of highly activated copper metal to alkyl chlorides and bromides is also possible: Ebert, G. W.; Rieke, R. D. *J. Org. Chem.* **1984**, *49*, 5280. (c) Rieke, R. D.; Wehmeyer, R. M.; Wu, T.-C.; Ebert, G. W. *Tetrahedron* **1989**, *45*, 443. (d) Ebert, G. W.; Rieke, R. D. *J. Org. Chem.* **1988**, *53*, 4482. (e) Wu, T.-C.; Wehmeyer, R. M.; Rieke, R. D. *J. Org. Chem.* **1987**, *52*, 5056. (f) Wehmeyer, R. M.; Rieke, R. D. *J. Org. Chem.* **1987**, *52*, 5056.

(5) Tamaru, Y.; Ochiai, H.; Nakamura, T.; Tusbaki, K.; Yoshida, Z. *Tetrahedron Lett.* **1985**, *26*, 5559.

(6) (a) Mukhopadhyay, T.; Seebach, D. *Helv. Chim. Acta* **1982**, *65*, 385. (b) Seebach D.; Beck, A. K.; Mukhopadhyay, T.; Thomas, E. *Helv. Chim. Acta* **1982**, *65*, 1101. (c) Bengtsson, M.; Liljefors, T. *Synthesis* **1988**, 250.

0022-3263/92/1957-5425$03.00/0

Table I. Products 4 Obtained by the Reaction of Primary Alkyl Chlorides, Bromides, Tosylates, Mesylates, or Phosphates with Zinc Dust, Followed by the Addition of CuCN•2LiCl and an Electrophile

entry	RX		reactn condns[a] MI (equiv); MBr (equiv); (°C, h)	electrophile	products of type 4		yield[b] (%)
1	$EtO_2C(CH_2)_4Br$	1a	LiI (0.25); (80, 2.5)[c]	nitrostyrene	$EtO_2C(CH_2)_4(Ph)CHCH_2NO_2$	4a	85
2	$EtO_2C(CH_2)_3Br$	1b	CsI (0.2); (80, 0.3)[d]			4b	87
3	$Cl(CH_2)_4Br$	1c	CsI (0.2); (70, 2)[d]	1-nitropentene	$Cl(CH_2)_4CH(Pr)CH_2NO_2$	4c	76
4	$EtO_2C(CH_2)_3I$	1d	NaI (0.2); NaBr (1.0); (75, 12)[e]	(*E*)-$PhSO_2CH=CH-NO_2$	(*E*)-$EtO_2C(CH_2)_3CH=CH-NO_2$	4d	78
5	$EtO_2C(CH_2)_3Cl$	1d	CsI (0.2); CsBr (1.0); (80, 12)[e]	H–C≡C–COOEt	(*E*)-$EtO_2C(CH_2)_3CH=CH-CO_2Et$	4e	78
6		1e	LiI (0.2); LiBr (1.0); (50, 12)[e]			4f	85
7	$Cl(CH_2)_4OMs$	1f	LiI (0.2); LiBr (1.0); (50, 12)[d]			4g	85
8	$MeO_2C(CH_2)_5OMs$	1g	LiI (0.2); LiBr (1.0); (40,6)[d]			4h	86
9	$MeO_2C(CH_2)_5OMs$	1g	LiI (0.2); LiBr (1.0); (40,6)[d]			4i	82
10	$OctOP(O)(OPh)_2$	1h	LiI (0.2); LiBr (1.0); (60, 12)[d]			4j	85

[a] Reaction conditions used to prepare the zinc organometallic reagent. [b] All yields refer to isolated yields of compounds being over 98% use by GC analysis. [c] In DME/DMSO (5:1). [d] In DMPU. [e] In DMA.

= Cl, OTs, OMs, $OP(O)(OPh)_2$) if an additional equivalent of LiBr (or NaBr) is added. After the addition of CuCN·2LiCl, the copper reagents RCu(CN)ZnX **3** (X = Cl, Br, OTs, OMs, $OP(O)(OPh)_2$) are formed and were found to react with several classes of electrophiles affording the expected products RE **4** (eq 2 and Table I). The rate-

$$\underset{\mathbf{2}}{RZnX} \xrightarrow[THF]{CuCN\cdot 2LiCl} \underset{\mathbf{3}:\ X = Cl, Br, OMs, OTs, OP(O)(OPh)_2}{RCu(CN)ZnX} \xrightarrow{E^+} \underset{\mathbf{4}}{RE} \qquad (2)$$

determining step in the alkylzinc bromide formation is the Br/I exchange reaction, the zinc insertion being fast under the reaction conditions (40–80 °C, see Table I). In the case of primary alkyl chlorides, sulfonates, and phosphates, the addition of a stoichiometric amount of LiBr (or NaBr), besides LiI (0.2 equiv), is necessary; it enhances considerably the rate of the zinc organometallic formation. The organic precursor RX **1** can contain several functionalities such as an ester or a chloride (entries 1–5, 7–9); interestingly, substrates bearing both a carbon–chloride and a carbon–bromine or –sulfonate bond insert specifically zinc into the carbon–bromide or –sulfonate bond (entries 3 and 7). Michael acceptors such as nitro olefins, ethyl propiolate, 3-iodo-2-cyclohexenone,[7] or ethyl α-(bromomethyl)-acrylate[8] react in excellent yields with the copper reagents RCu(CN)ZnX **3** (76–86%; Table I).

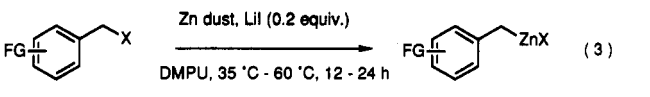
Benzylic zinc halides can be prepared in high yields by the zinc insertion to benzylic bromides or chlorides.[9] However, if the aromatic ring is substituted by donor groups, extensive Wurtz-coupling reactions are observed. Thus, the reaction of 1-(bromomethyl)-3,4-(methylenedioxy)benzene with zinc dust in THF produces *only* the Wurtz-coupling product. We now found that the reaction of functionalized benzylic mesylates and phosphates **5** with zinc dust in the presence of LiI (0.2 equiv) in DMPU (35–60 °C, 12–24 h) provides the new benzylic zinc mesylates and phosphates **6** without the formation of even traces of Wurtz-coupling side products (eq 3). After the addition of CuCN·2LiCl and of the electrophile, the expected products **7** are obtained in 72–95% yield (eq 4 and Table II).

The phosphates are the substrates of choice since they can be prepared from the benzylic alcohols in excellent yields ($ClP(O)(OR)_2$ (1.05 equiv), pyridine (2 equiv), 0 °C, 3 h) without the complications observed during the preparation of the corresponding mesylates.[10] Similarly,

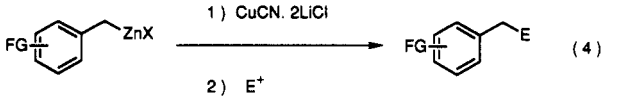
(7) Piers, E.; Nagakura, I. *Synth. Commun.* **1975**, *5*, 193.

(8) Villieras, J.; Rambaud, M. *Synthesis* **1982**, 924.

(9) (a) Berk, S. C.; Knochel, P.; Yeh, M. C. P. *J. Org. Chem.* **1988**, *53*, 5789. (b) Berk, S. C.; Yeh, M. C. P.; Jeong, N.; Knochel, P. *Organometallics* **1990**, *9*, 3053. (c) Chen, H. G.; Hoechstetter, C.; Knochel, P. *Tetrahedron Lett.* **1989**, *30*, 4795.

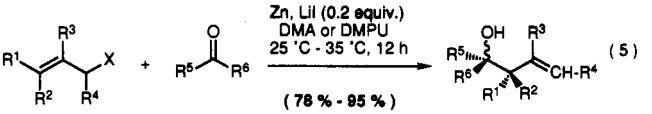


5 : X = OMs, OP(O)(OR)$_2$ 6 : X = OMs, OP(O)(OR)$_2$



6 7

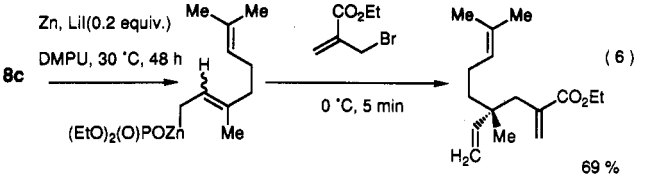
whereas allyl bromide is converted to allylzinc bromide in almost quantitative yield (zinc, THF, 10 °C, 3 h),[11] substituted allylic bromides such as 2-(bromomethyl)hexene lead under similar reaction conditions (zinc, THF, 0 °C, 5 h) to appreciable amounts of Wurtz-coupling products. The use of allylic mesylates or the more stable[12] allylic phosphates 8 (X = OP(O)(OEt)$_2$) allows the generation of the corresponding allylic zinc organometallic under Barbier conditions[13,14] in the presence of zinc (ca. 2.0 equiv), a catalytic amount of LiI (0.2 equiv), and the carbonyl compound in DMA or DMPU leading to homoallylic alcohols 9 in excellent yields (78–95%; eq 5 and Table III).



8 : X = OMs, OP(O)(OEt)$_2$ 9

No homocoupling products were produced under these conditions even in the case of disubstituted allylic precursors (entries 5–8 of Table III). The new carbon–carbon bond was formed from the most substituted end of the allylic system leading to a mixture of diastereoisomers with moderate diastereoselectivity (4:1–9:1). This diastereoselectivity can be substantially improved by replacing zinc dust with chromium chloride allowing a very convenient construction of homoallylic alcohols bearing quaternary carbon centers with a defined stereochemistry.[15]

The preparation of the allylic organometallic in a first step followed in a second step by the addition of an electrophile is also possible. Thus, the treatment of **8c** with Zn (3.0 equiv) in the presence of LiI (0.2 equiv) in DMPU (30 °C, 48 h) provides the allylic zinc phosphate **10** which reacts readily with ethyl α-(bromomethyl)acrylate[8] (0 °C, 0.1 h) affording the unsaturated ester **11** in 69% yield (eq 6).



10 11

In summary, we have developed the preparation of several new classes of aliphatic, allylic, and benzylic zinc organometallics RZnX (X ≠ iodide) starting from readily available organic precursors. Especially noteworthy is the absence of Wurtz-coupling side products in the preparation of benzylic and allylic zinc derivatives starting from the corresponding sulfonates or phosphates. These procedures will significantly extend the scope of organozinc preparations and should find broad synthetic applications.

Experimental Section

General. All reactions were carried out under an inert atmosphere. The solvents and cosolvents THF, DMPU, and DMA were distilled from CaH_2. Anhydrous LiI, LiBr, CsI, and NaBr (Aldrich) were dried for 1 h at 120 °C (0.1 mmHg) before use. The tosylates, mesylates,[16] and phosphates[12] as well as 2-(ethylthio)-1-nitrocyclohexene,[3f,17] (*E*)-2-(phenylsulfonyl)nitroethylene,[3f,17] 3-iodocyclohexenone,[7] *tert*-butyl-α-(bromomethyl)acetylene,[8] 2-butyl-2-propenol,[18] and 1-nitropentene[19] were prepared according to the literature.

Typical Procedure: Preparation of an Alkylzinc–Copper Sulfonate and Its Reaction with an Electrophile. Preparation of 3-(3,7-Dimethyl-6-octenyl)-2-cyclohexenone (4f).

(10) Attempts to prepare the mesylates of 3,4-methylenedioxybenzylic alcohol and 1-phenylethanol lead only to the formation of the dibenzyl ether and styrene, respectively.

(11) Gaudemar, M. *Bull. Soc. Chim. Fr.* **1962**, 974.

(12) Allylic phosphates are readily prepared from the corresponding alcohols ((EtO)$_2$P(O)Cl (1.05 equiv), Pyr (2 equiv), 0 °C, 4 h, 95% yield) and are considerably more stable and easier to handle than the corresponding mesylates: (a) Poulter, C. D.; Satterwhite, D. M. *Biochemistry* **1977**, *16*, 5471. (b) Poulter, C. D.; King, C.-H. R. *J. Am. Chem. Soc.* **1982**, *104*, 1422. For a recent use of allylic phosphates as electrophiles see: (c) Yanagisawa, A.; Nomura, N.; Yamamoto, H. *Synlett* **1991**, 513. (d) Lithium halides react rapidly with allylic phosphates in DMF at 25 °C to afford the corresponding allylic halide with retention of the stereochemistry of the double bond: Araki, S.; Ohmori, K.; Butsugan, Y. *Synthesis* **1984**, 841.

(13) Blomberg, C.; Hartog, F. A. *Synthesis* **1977**, 18.

(14) Allylic halides or acetates add to aledhydes in the presence of various metals under Barbier conditions: (a) Öhler, E.; Reininger, K.; Schmidt, U. *Angew. Chem., Int. Ed. Engl.* **1970**, *9*, 457. (b) Mukaiyama, T.; Harada, T. *Chem. Lett.* **1981**, 1527. (c) Hiyama, T.; Okude, Y.; Kimura, K.; Nozaki, H. *Bull. Chem. Soc. Jpn.* **1982**, *55*, 561. (d) Nokami, J.; Otera, J.; Sudo, T.; Okawara, R. *Organometallics* **1983**, *2*, 191. (e) Augé, J.; David, S. *Tetrahedron Lett.* **1983**, *24*, 4009. (f) Mandai, T.; Nokami, J.; Yano, T.; Yoshinaga, Y.; Otera, J. *J. Org. Chem.* **1984**, *49*, 3904. (g) Imamoto, T.; Kusamoto, T.; Tawarayama, Y.; Sugiura, Y.; Mita, T.; Hatanaka, Y.; Yokoyama, M. *J. Org. Chem.* **1984**, *49*, 172. (h) Uneyama, K.; Kamaki, N.; Moriya, A.; Torii, S. *J. Org. Chem.* **1985**, *50*, 5396. (i) Sasaoka, S.; Yamamoto, T.; Kinoshita, H. *Chem. Lett.* **1985**, 315. (j) Augé, J. *Tetrahedron Lett.* **1985**, *26*, 753. (k) Petrier, C.; Einhorn, J.; Luche, J. L. *Tetrahedron Lett.* **1985**, *26*, 1449. (l) Suzuki, K.; Katayama, E.; Tomooka, K.; Matsumoto, T.; Tsuchihashi, G. *Tetrahedron Lett.* **1985**, *26*, 3707, 3711. (m) Coxon, J. M.; van Eyk, S. J.; Steel, P. J. *Tetrahedron Lett.* **1985**, *26*, 6121. (n) Nokami, J.; Tamaoka, T.; Ogawa, H.; Wakabayashi, S. *Chem. Lett.* **1986**, 541. (o) Uneyama, K.; Ueda, K.; Torii, S. *Chem. Lett.* **1986**, 1201. (p) Kato, N.; Tanaka, S.; Takeshita, H. *Chem. Lett.* **1986**, 1989. (q) Tabuchi, T.; Inanaga, J.; Yamaguchi, M. *Tetrahedron Lett.* **1986**, *27*, 1195. (r) Butsugan, Y.; Ito, H.; Araki, S. *Tetrahedron Lett.* **1987**, *28*, 3707. (s) Masuyama, Y.; Takahara, J. P.; Kurusu, Y. *J. Am. Chem. Soc.* **1988**, *110*, 4473. (t) Araki, S.; Ito, H.; Butsugan, Y. *J. Org. Chem.* **1988**, *53*, 1831. (u) Chen, C.; Shen, Y.; Huang, Y.-Z. *Tetrahedron Lett.* **1988**, *29*, 1395. (v) Masuyama, Y.; Hayashi, R.; Otake, K.; Kurusu, Y. *J. Chem. Soc., Chem. Commun.* **1988**, 44. (w) Cahiez, G.; Chavant, P.-Y. *Tetrahedron Lett.* **1989**, *30*, 7373. (x) Still, I. W. J.; Drewery, M. J. *J. Org. Chem.* **1989**, *54*, 290. (y) Schmid, W.; Whitesides, G. M. *J. Am. Chem. Soc.* **1991**, *113*, 6674. (z) Masuyama, Y.; Himura, Y.; Kurusu, Y. *Tetrahedron Lett.* **1991**, *32*, 225.

(15) The relative stereochemistry of compound **9h** was established by a detailed stereochemical study performed by Professor Koreeda: (a) Koreeda, M.; Tanaka, Y. *Chem. Lett.* **1982**, 1299. The palladium(0)-catalyzed generation of allylic zinc reagents from geranyl acetate is also not stereoselective: (b) Masuyama, Y.; Kinugawa, N.; Kurusu, Y. *J. Org. Chem.* **1987**, *52*, 3702. A study describing the stereoselective addition of γ-disubstituted allylic phosphates to aldehydes in the presence of $CrCl_2$ will be reported in a separate paper.

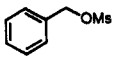
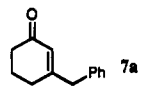
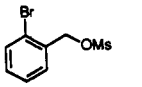
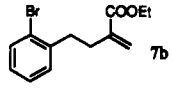
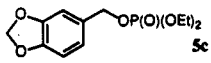
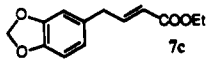
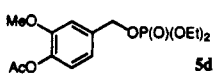
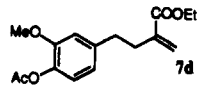
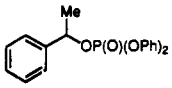
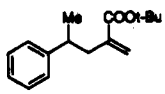
(16) Crossland, R. K.; Servis, K. L. *J. Org. Chem.* **1970**, *35*, 3195.

(17) (a) Ono, N.; Kamimura, A.; Kaji, A. *J. Org. Chem.* **1986**, *51*, 2139. (b) Fuji, K.; Khanapure, S. P.; Node, M.; Kawabata, T.; Ito, A. *Tetrahedron Lett.* **1985**, *26*, 779. (c) Tominaga, Y.; Chihara, Y.; Hosomi, A. *Heterocycles* **1988**, *27*, 2345. (d) Kamimura, A.; Ono, N. *Synthesis* **1988**, 921. (e) Jung, M. E.; Grove, D. D. *J. Chem. Soc., Chem. Commun.* **1987**, 753. (f) Jung, M. E.; Grove, D. D.; Khan, S.I. *J. Org. Chem.* **1987**, *52*, 4570. (g) Hanessian, S.; Desilets, D.; Bennani, Y. L. *J. Org. Chem.* **1990**, *55*, 3098. (h) Node, M.; Kawabata, T.; Fujimoto, M.; Fuji, K. *Synthesis* **1984**, 234. (i) Ono, N.; Kamimura, A.; Kaji, A. *Tetrahedron Lett.* **1986**, *27*, 1595.

(18) Prepared from 2-butylacrolein by a $NaBH_4$ reduction in the presence of $CeCl_3 \cdot 7H_2O$, followed by a bromination using PBr_3: Gemal, A. L.; Luche, J. L. *J. Am. Chem. Soc.* **1981**, *103*, 5454.

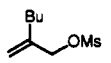
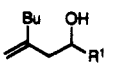
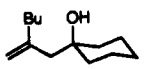
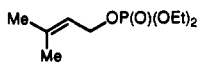
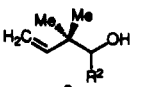
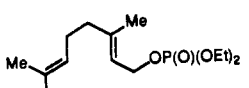
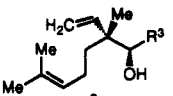
(19) Knochel, P.; Seebach, D. *Synthesis* **1982**, 1017.

Table II. Products 7 Obtained by the Reaction of Benzylic Mesylates or Phosphates with Zinc Dust in the Presence of LiI in DMPU, Followed by the Addition of CuCN•2LiCl and an Electrophile

entry	benzylic precursor 5	reactn condns[a] (°C, h)	electrophile	products 7	yield[b] (%)
1	 5a	(35,12)		 7a	95
2	 5b	(60,24)		 7b	86[c]
3	 5c	(50,12)	H–C≡C–COOEt	 7c	84
4	 5d	(60,24)		 7d	82[c]
5	 5e	(40,24)		 7e	72

[a] Reaction conditions used to prepare the zinc organometallic reagent. [b] All yields refer to isolated yields of compounds being over 98% pure by GC analysis. [c] The addition of LiBr (1.0 equiv) was necessary to promote the zinc insertion.

Table III. Homoallylic Alcohols 9 Prepared by the Reaction of Allylic Mesylates or Phosphates with a Carbonyl Compound and Zinc in DMA or DMPU

entry	allylic precursor 8	reactn condns	aldehyde or ketone	alcohol 9	yield[a] (%)
					
1	8a	(25,48)[b]	PhCHO	9a: R^1 = Ph	88
2	8a	(35,24)[b]	c-HexCHO	9b: R^1 = c-Hex	80
3	8a	(35,24)[b]	PentCHO	9c: R^1 = Pent	81
4	8a	(35,24)[b]	cyclohexanone	 9d	80
					
5	8b	(25,12)[b]	PhCHO	9e: R^2 = Ph	95
6	8b	(25,12)[c]	PentCHO	9f: R^2 = Pent	85
					
7	8c	(25,12)[c]	c-HexCHO	9g: R^3 = c-Hex[d]	78
8	8c	(25,12)[c]	PhCHO	9h: R^3 = Ph[e]	95

[a] All yields refer to isolated yields of compounds being over 98% pure by GC analysis. [b] Reactions performed in DMPU. [c] Reactions performed in DMA. [d] Mixture of two diastereoisomers, 9:1 (1*R**,2*R**/1*R**,2*S**). [e] Mixture of two diastereoisomers, 4:1 (1*S**,2*S**/1*S**,2*R**).

3,7-Dimethyl-6-octenyl *p*-toluenesulfonate (1e) (1.55 g, 5 mmol), LiI (0.13 g, 1 mmol), and LiBr (0.44 g, 5 mmol) were added at 25 °C to a zinc dust (Aldrich) suspension (0.98 g, 15 mmol in 4 mL of DMA) previously activated with 1,2-dibromoethane (0.10 mL) and Me_3SiCl (0.05 mL). The reaction mixture was stirred at 50 °C for 12 h until GC analysis of a hydrolyzed aliquot showed the complete consumption of the starting tosylate and the formation of 2,6-dimethyl-2-octene. After the excess zinc was settled, the zinc reagent solution was added via syringe to a solution of CuCN (0.4 g, 4.5 mmol) and LiCl (0.38 g, 9 mmol) in 2 mL of THF at −40 °C. The reaction mixture was then warmed to 0 °C, and 3-iodo-2-cyclohexenone[7] (0.78 g, 3.5 mmol) was added at −78 °C. After 12 h at −30 °C, the reaction mixture was worked up as usual and the residue was purified by flash chromatography (hexane-/Et_2O (6:1)) to give the analytically pure product **4f** (0.78 g, 85% yield); see entry 6 of Table I: IR (neat) 2925 (s), 2869 (m), 2856 (m), 1672 (s), 1626 (w) cm^{-1}; ^1H-NMR ($CDCl_3$, 200 MHz) δ 5.84 (s, 1 H), 5.05 (m, 1 H), 2.27 (m, 6 H), 1.94 (m, 4 H), 1.65, (s, 3 H), 1.57 (s, 3 H), 1.32 (m, 5 H), 0.87 (d, 3 H, *J* = 7.8 Hz); ^{13}C-NMR ($CDCl_3$, 75.5 MHz) δ 199.3, 166.5, 131.0, 125.4, 124.4, 37.1, 36.6, 35.4, 33.9, 31.9, 29.5, 25.4, 25.2, 22.5, 19.1, 17.3; MS (EI, 70 eV) 234 (8), 163 (4), 123 (100), 110 (30), 82 (7); exact mass calcd for $C_{16}H_{26}O$ 234.1984, obsd 234.1983.

Ethyl 7-Nitro-6-phenylheptanoate (4a). Oil; 0.83 g (85% yield) prepared from ethyl 5-bromopentanoate (1.05 g, 5.0 mmol) and nitrostyrene (0.52 g, 3.5 mmol). Reaction conditions: 5 °C, 12 h. Purified by flash chromatography (hexane/EtOAc = 5/1): IR (neat) 2981 (w), 2937 (m), 1732 (s), 1553 (s), 1379 (m) cm^{-1}; ^1H-NMR ($CDCl_3$, 300 MHz) δ 7.29 (m, 3 H), 7.17 (d, 2 H, *J* = 7.2 Hz), 4.53 (dd, 2 H, *J* = 7.6, 2.0 Hz), 4.07 (q, 2 H, *J* = 7.1 Hz), 3.43 (quint, 1 H, *J* = 7.6 Hz), 2.22 (t, 2 H, *J* = 7.4 Hz), 1.70 (q, 2 H, *J* = 7.6 Hz), 1.55 (m, 2 H), 1.29 (m, 2 H), 1.20 (t, 3 H, *J* = 7.1 Hz); ^{13}C-NMR ($CDCl_3$, 75.5 MHz) δ 173.1, 139.2, 128.7, 127.4, 127.3, 80.6, 59.9, 44.0, 33.7, 32.4, 26.1, 24.4, 13.9; MS (CI, NH_4^+) 297 (MNH_4^+, 100), 280 (4), 263 (21), 248 (7), 136 (10); exact mass calcd for $C_{15}H_{21}NO_4H^+$ 280.1549, obsd 280.1548.

Ethyl 5-[1-(2-Nitro-1-cyclohexenyl)]pentanoate (4b). Oil, 0.73 g (87% yield) prepared from ethyl 4-bromobutanoate (0.98 g, 5.0 mmol) and 1-(ethylthio)-2-nitrocyclohexene[3f] (0.65 g, 3.5 mmol). Reaction conditions: 0 °C, 12 h. Purified by flash

chromatography (hexane/Et_2O = 19/1); IR (neat) 2979 (m), 2942 (s), 2867 (m), 1734 (s), 1515 (s), 1421 (w), 1329 (s), 1271 (m), 1139 (m), 784 (w) cm^{-1}; ^1H-NMR ($CDCl_3$, 300 MHz) δ 4.13 (q, 2 H, J = 7.1 Hz), 2.56 (m, 2 H), 2.31 (m, 6 H), 1.85 (m, 2 H), 1.68 (m, 4 H), 1.26 (t, 3 H, J = 7.1 Hz); ^{13}C-NMR ($CDCl_3$, 90 MHz) δ 172.9, 145.9, 141.3, 60.2, 33.7, 33.1, 30.2, 26.4, 22.8, 22.1, 21.4, 14.0; MS (CI, CH_4) 242 (MH^+, 16), 224 (14), 194 (87), 178 (16), 166 (37), 149 (100), 136 (35), 121 (29), 107 (32). Anal. Calcd for $C_{12}H_{19}NO_4$: C, 59.73; H, 7.94; N, 5.80. Found: C, 59.35; H, 7.74; N, 5.40.

1-Chloro-5-(nitromethyl)octane (4c). Oil, 0.55 g (76% yield) prepared from 1-bromo-4-chlorobutane (0.86 g, 5.0 mmol) and 1-nitropentene[19] (0.40, 3.5 mmol). Reaction conditions: 0 °C, 12 h. Purified by flash chromatography (hexane/Et_2O = 20/1): IR (neat) 2959 (s), 2935 (s), 2872 (m), 1557 (s), 1546 (s), 1383 (m) cm^{-1}; ^1H-NMR ($CDCl_3$, 300 MHz) δ 4.28 (dd, 2 H, J = 7.0, 2.2 Hz), 3.50 (t, 2 H, J = 6.5 Hz), 2.18 (m, 1 H), 1.73 (quint, 2 H, J = 6.5 Hz), 1.37 (m, 8 H), 0.88 (t, 3 H, J = 6.0 Hz); ^{13}C-NMR ($CDCl_3$, 90 MHz) δ 79.2, 44.2, 36.9, 33.1, 32.2, 30.3, 23.2, 19.2, 13.9; MS (CI, CH_4) 208 (MH^+, 22), 161 (100), 125 (25); exact mass calcd for $C_9H_{18}ClNO_2H^+$ 208.1104, obsd 208.1118.

(*E*)-Ethyl 6-Nitro-5-hexenoate (4d). Oil, 1.10 g (79% yield) prepared from ethyl 4-iodobutanoate (2.42 g, 10.0 mmol) and (*E*)-1-nitro-2-(phenylsulfonyl)ethylene[3f,17] (1.60 g, 7.5 mmol). Reaction conditions: −40 °C, 1 h. Purified by flash chromatography (hexane/EtOAc = 9/1): IR (neat) 2983 (m), 2940 (m), 1732 (s), 1650 (m), 1526 (s), 1354 (s) cm^{-1}; ^1H-NMR ($CDCl_3$, 300 MHz) δ 7.23 (dt, 1 H, J = 13.8, 6.9 Hz), 6.98 (d, 1 H, J = 13.4 Hz), 4.12 (q, 2 H, J = 7.1 Hz), 2.35 (m, 4 H), 1.84 (quint, 2 H, J = 7.4 Hz), 1.24 (t, 3 H, J = 7.1 Hz); ^{13}C-NMR ($CDCl_3$, 75.5 MHz) δ 172.4, 141.2, 140.0, 60.3, 33.1, 27.4, 22.8, 14.0; MS (CI, CH_4 and NH_4^+) 205 (MNH_4^+, 5), 188 (20), 170 (21), 153 (12), 142 (100). Anal. Calcd for $C_8H_{13}NO_4$: C, 51.33; H, 7.00; N, 7.48. Found: C, 51.73; H, 6.87; N, 6.79.

(*E*)-Ethyl 6-Carbethoxyhex-2-enoate (4e).[3c] Oil, 0.58 g (78% yield) prepared from ethyl 4-chlorobutanoate (0.75 g, 5.0 mmol) and ethyl propiolate (0.34 g, 3.5 mmol). Reaction conditions: −20 °C, 12 h. Purified by flash chromatography (hexane/Et_2O = 9/1): ^1H-NMR ($CDCl_3$, 200 MHz) δ 6.92 (dt, 1 H, J = 15.6, 6.8 Hz), 5.82 (dd, 1 H, J = 15.6, 1.3 Hz), 4.17 (m, 4 H), 2.39 (m, 4 H), 1.79 (quint, 2 H, J = 7.3 Hz), 1.24 (m, 6 H); ^{13}C-NMR ($CDCl_3$, 75.5 MHz) δ 172.7, 166.1, 147.4, 122.0, 60.1, 59.9, 33.3, 31.1, 23.1, 14.0.

1-(4-Chlorobutyl)-2-nitrocyclohexene (4g). Oil, 0.65 g (85% yield) prepared from 4-chlorobutyl methanesulfonate (0.93 g, 5.0 mmol) and 1-(ethylthio)-2-nitrocyclohexene[3f] (0.65 g, 3.5 mmol). Reaction conditions: 25 °C, 12 h. Purified by flash chromatography (hexane/Et_2O = 20/1): IR (neat) 2866 (m), 1549 (w), 1513 (s), 1358 (m) cm^{-1}; ^1H-NMR ($CDCl_3$, 300 MHz) δ 3.55 (t, 2 H, J = 6.4 Hz), 2.55 (br s, 2 H), 2.27 (m, 4 H), 1.69 (m, 8 H); ^{13}C-NMR ($CDCl_3$, 75.5 MHz) δ 145.8, 141.4, 44.4, 33.0, 32.3, 30.3, 26.5, 24.9, 22.2, 21.5; MS (CI, NH_4^+) 235 (MNH_4^+, 100), 202 (16), 188 (11), 166 (10), 150 (6), 136 (86); exact mass calcd for $C_{10}H_{16}NO_2{}^{35}ClNH_4^+$ 235.1213, obsd 235.1195.

3-[1-(5-Carbomethoxypentyl)]cyclohex-2-enone (4h). Oil, 0.67 g (86% yield) prepared from 5-carbomethoxypentyl methanesulfonate (1.12 g, 5.0 mmol) and 3-iodocyclohex-2-enone[7] (0.78 g, 3.5 mmol). Reaction conditions: −10 °C, 12 h. Purified by flash chromatography (hexane/Et_2O = 3/1): IR (neat) 2939 (s), 2865 (m), 1739 (s), 1671 (s), 1625 (m) cm^{-1}; ^1H-NMR ($CDCl_3$, 360 MHz) δ 5.82 (t, 1 H, J = 1.3 Hz), 3.63 (s, 3 H), 2.25 (m, 8 H), 1.95 (quint, 2 H, J = 6.2 Hz), 1.61 (quint 2 H, J = 7.8 Hz), 1.49 (quint, 2 H, J = 8.1 Hz), 1.31 (m, 2 H); ^{13}C NMR ($CDCl_3$, 90 MHz) δ 199.1, 173.4, 165.7, 125.2, 51.0, 37.3, 36.9, 33.3, 29.2, 28.2, 26.1, 24.2, 22.3; MS (EI, 70 eV) 224 (8), 165 (8), 136 (8), 123 (100), 110 (42); exact mass calcd for $C_{13}H_{20}O_3$ 224.1412, obsd 224.1403.

Methyl 6-[1-(2-Nitro-1-cyclohexenyl)]hexanoate (4i). Oil, 1.12 g (82% yield) prepared from 5-carbomethoxypentyl methanesulfonate (1.12 g, 5.0 mmol) and 1-(ethylthio)-2-nitrocyclohexene[3f] (0.65 g, 3.5 mmol). Reaction conditions: 0 °C, 12 h. Purified by flash chromatography (hexane/EtOAc = 49/1): IR (neat) 2944 (s), 2864 (m), 1734 (s), 1649 (w), 1510 (s), 1345 (s) cm^{-1}; ^1H-NMR ($CDCl_3$, 360 MHz) δ 3.66 (s, 3 H), 2.55 (m, 2 H), 2.26 (m, 6 H), 1.72 (m, 2 H), 1.64 (m, 4 H), 1.50 (m, 2 H), 1.35 (m, 2 H); ^{13}C-NMR ($CDCl_3$, 90 MHz) δ 173.7, 145.2, 142.40, 51.1, 33.7, 33.6, 30.3, 28.9, 27.2, 26.3, 24.4, 22.0, 21.3; MS (CI, NH_4^+) 273 (MNH_4^+, 84), 226 (10), 205 (13), 136 (100); exact mass calcd for $C_{13}H_{21}NO_4H^+$ 256.1549, obsd 256.1546.

***tert*-Butyl 2-Methyleneundecanoate (4j).** Oil, 0.76 g (85% yield) prepared from diphenyl octyl phosphate (1.81 g, 5.0 mmol) and *tert*-butyl α-(bromomethyl)acrylate[8] (0.77 g, 3.5 mmol). Reaction conditions: −20 °C, 12 h. Purified by flash chromatography (hexane/Et_2O = 49/1): IR (neat) 3012 (w), 2928 (s), 2855 (s), 1715 (s), 1631 (w) cm^{-1}; ^1H-NMR ($CDCl_3$, 300 MHz) δ 6.01 (s, 1 H), 5.42 (s, 1 H), 2.24 (t, 2 H, J = 7.2 Hz), 1.49 (s, 9 H), 1.46 (m, 2 H), 1.26 (m, 12 H), 0.87 (t, 3 H, J = 6.7 Hz); ^{13}C-NMR ($CDCl_3$, 75.5 MHz) δ 166.6, 142.9, 122.7, 80.1, 32.0, 31.8, 29.5, 29.4, 29.2, 28.6, 28.1, 22.6, 13.9; MS (CI, NH_4^+) 272 (MNH_4^+, 34), 255 (10), 216 (10), 136 (100); exact mass calcd for $C_{16}H_{30}O_2H^+$ 255.2324, obsd 255.2331.

Typical Procedure: Preparation of a Benzylic Zinc–Copper Phosphate ($ArCH_2Cu(CN)ZnOP(O)(OEt)_2$) and Its Reaction with an Electrophile. Preparation of (*E*)-Ethyl 4-[3,4-(Methylenedioxy)phenyl]but-2-enoate (7c). Diethyl 3,4-(methylenedioxy)benzyl phosphate **5c** (1.44 g, 5 mmol) and LiI (0.13 g, 1 mmol) were added to a zinc dust suspension (0.98 g, 15 mmol) in DMA (4 mL) activated as described above. After 12 h at 50 °C, the formation of the zinc reagent was complete. After a transmetalation with CuCN·2LiCl (see above), addition of ethyl propiolate (0.39 g, 4 mmol; 0 °C, 5 min), usual workup, and flash chromatography (hexane/Et_2O = 19/1), the unsaturated ester **7c** (0.79 g, 84% yield; entry 3 of Table II) was obtained as a pure oil (>98% pure by GC analysis): IR (neat) 2902 (m), 2779 (w), 1715 (s), 1654 (s) cm^{-1}; ^1H-NMR ($CDCl_3$, 200 MHz) δ 7.04 (dt, 1 H, J = 16.4, 6.5 Hz), 6.75 (d, 1 H, J = 7.7 Hz), 6.63 (m, 2 H), 5.94 (s, 2 H), 5.78 (dt, 1 H, J = 15.5, 1.6 Hz), 4.17 (q, 2 H, J = 7.1 Hz), 3.42 (dd, 2 H, J = 6.7, 1.6 Hz), 1.27 (t, 3 H, J = 7.1 Hz); ^{13}C-NMR ($CDCl_3$, 75.5 MHz) δ 166.4, 147.9, 147.2, 146.4, 131.4, 122.3, 121.7, 109.2, 108.4, 100.9, 60.2, 38.0, 14.1; MS (EI, 70 eV) 234 (100), 205 (21), 189 (38), 159 (51), 131 (90), 103 (60); exact mass calcd for $C_{13}H_{14}O_4$ 234.0892, obsd 234.0887.

3-Benzylcyclohex-2-enone (7a). Oil, 0.62 g (95% yield) prepared from benzyl methanesulfonate (0.93 g, 5.0 mmol) and 3-iodocyclohex-2-enone[7] (0.78 g, 3.5 mmol). Reaction conditions: −30 °C, 12 h. Purified by flash chromatography (hexane/Et_2O = 5/1): IR (neat) 3061 (w), 3028 (w), 2928 (m), 1669 (s), 1626 (s) cm^{-1}; ^1H-NMR ($CDCl_3$, 360 MHz) δ 7.29 (m, 3 H), 7.14 (d, 2 H, J = 6.8 Hz), 5.86 (s, 1 H), 3.50 (s, 2 H), 2.34 (t, 2 H, J = 6.7 Hz), 2.25 (t, 2 H, J = 5.9 Hz), 1.94 (m, 2 H); ^{13}C-NMR ($CDCl_3$, 90 MHz) δ 198.6, 163.8, 136.6, 128.5, 128.1, 126.3, 43.8, 36.7, 28.6, 22.1; MS (EI, 70 eV) 186 (65), 168 (8), 158 (100), 129 (72), 115 (38), 91 (37); exact mass calcd for $C_{13}H_{14}O$ 186.1045, obsd 186.1040.

Ethyl 4-(2-Bromophenyl)-2-methylenebutanoate (7b). Oil, 0.85 g (86% yield) prepared from (2-bromophenyl)methyl methanesulfonate (1.62 g, 5.0 mmol) and ethyl α-(bromomethyl)acrylate[8] (0.68 g, 3.5 mmol). Reaction conditions: −20 °C, 12 h. Purified by flash chromatography (hexane/Et_2O = 32/1): IR (neat) 3057 (w), 2981 (m), 1717 (s), 1631 (m) cm^{-1}; ^1H-NMR ($CDCl_3$, 360 MHz) δ 7.52 (d, 1 H, J = 7.7 Hz), 7.23 (m, 2 H), 7.05 (m, 1 H), 6.17 (s, 1 H), 5.52 (s, 1 H), 4.22 (q, 2 H, J = 7.1 Hz), 2.92 (t, 2 H, J = 8.2 Hz), 2.61 (t, 2 H, J = 8.2 Hz), 1.32 (t, 3 H, J = 7.1 Hz); ^{13}C-NMR ($CDCl_3$, 90 MHz) δ 166.9, 140.6, 139.7, 132.7, 130.4, 127.6, 127.3, 125.3, 124.4, 60.5, 35.2, 32.1, 14.1; MS (EI, 70 eV) 282 (1), 169 (100), 157 (47), 129 (42); exact mass calcd for $C_{13}H_{15}O_2{}^{79}Br$ 282.0255, obsd 282.0252.

Ethyl 4-(4-Acetoxy-3-methoxyphenyl)-2-methylenebutanoate (7d). Oil, 0.84 g (82% yield) prepared from diethyl (4-acetoxy-3-methoxyphenyl)methyl phosphate (1.66 g, 5.0 mmol) and ethyl α-(bromomethyl)acrylate[8] (0.77 g, 3.5 mmol). Reaction conditions: −20 °C, 12 h. Purified by flash chromatography (hexane/Et_2O = 24/1): IR (neat) 2981 (m), 2939 (m), 2845 (w), 1767 (s), 1710 (s), 1630 (m) cm^{-1}; ^1H-NMR ($CDCl_3$, 200 MHz) δ 6.86 (m, 3 H), 6.16 (s, 1 H), 5.52 (s, 1 H), 4.21 (t, 2 H, J = 7.1 Hz), 3.80 (s, 3 H), 2.68 (m, 4 H), 2.28 (s, 3 H), 1.30 (t, 3 H, J = 7.0 Hz); ^{13}C-NMR ($CDCl_3$, 75.5 MHz) δ 168.9, 166.9, 150.9, 140.3, 140.1, 138.1, 125.0, 122.4, 120.5, 112.8, 60.6, 55.8, 34.9, 33.8, 20.5, 14.1; MS (EI, 70 eV) 292 (1), 250 (15), 137 (100); exact mass calcd for $C_{16}H_{20}O_5$ 292.1311, obsd 292.1317.

***tert*-Butyl 2-Methylene-4-phenylpentanoate (7e).** Oil, 0.62 g (72% yield) prepared from diphenyl 1-phenylethyl phosphate (1.77 g, 5.0 mmol), and *tert*-butyl α-(bromomethyl)acrylate[8] (0.77 g, 3.5 mmol). Reaction conditions: −20 °C, 12 h. Purified by flash chromatography (hexane/Et_2O = 49/1): IR (neat) 2975 (s), 1712 (s), 1630 (m), 1603 (w) cm^{-1}; ^1H-NMR ($CDCl_3$, 300 MHz)

δ 7.25 (m, 5 H), 6.03 (s, 1 H), 5.30 (s, 1 H), 3.00 (m, 1 H), 2.54 (m, 2 H), 1.51 (s, 9 H), 1.27 (d, 3 H, J = 7.0 Hz); ^{13}C-NMR ($CDCl_3$, 75.5 MHz) δ 166.3, 146.6, 140.7, 128.1, 126.9, 125.8, 124.9, 80.1, 41.0, 39.0, 28.0, 21.1; MS (CI, NH_4^+) 264 (MNH_4^+, 19), 208 (100), 136 (70); exact mass calcd for $C_{16}H_{22}O_2H^+$ 247.1698, obsd 247.1698.

Typical Procedure: Barbier Reaction with Zinc, an Allylic Phosphate, and an Aldehyde. Preparation of 7,7-Dimethylnon-8-en-6-ol (9f). Diethyl 3-methylbut-2-enyl phosphate (**8b**) (1.11 g, 5 mmol), hexanal (0.35 g, 3.5 mmol), and LiI (0.13 g, 1 mmol) were added at 25 °C to a zinc dust suspension (0.98 g, 15 mmol) in 4 mL of DMPU activated as described above. The reaction mixture was stirred at 25 °C for 12 h and worked up as usual. Purification by flash chromatography of the residue afforded the analytically pure alcohol **9f** as an oil (0.51 g, 85% yield; see entry 6 of Table III): IR (neat) 3390 (s), 2941 (s), 2860 (s), 1638 (w) cm^{-1}; ^{1}H-NMR ($CDCl_3$, 200 MHz) δ 5.81 (dd, 1 H, J = 17.3, 11.0 Hz), 5.06 (dd, 2 H, J = 17.4, 11.0 Hz), 3.24 (d, 1 H, J = 10.0 Hz), 1.49 (m, 3 H), 1.29 (m, 6 H), 1.00 (s, 6 H), 0.88 (t, 3 H, J = 6.5 Hz); ^{13}C-NMR ($CDCl_3$, 75.5 MHz) δ 145.7, 112.9, 78.4, 41.6, 31.9, 31.5, 26.7, 22.9, 22.6, 22.3, 13.9; MS (CI, NH_4^+) 188 (MNH_4^+, 71), 170 (93), 153 (100) 136 (94); exact mass calcd for $C_{11}H_{22}ONH_4^+$ 188.2014, obsd 188.2001.

3-Methylene-1-phenylheptanol (9a). Oil, 0.36 g (88% yield) prepared from 2-methylenehexyl methanesulfonate (0.48 g, 2.5 mmol) and benzaldehyde (0.21 g, 2.0 mmol). Reaction conditions: 25 °C, 48 h. Purified by flash chromatography (hexane/Et_2O = 24/1): IR (neat) 3387 (m) 2956 (s), 2929 (s), 2873 (s), 2860 (s), 1644 (m) cm^{-1}; ^{1}H-NMR ($CDCl_3$, 300 MHz) δ 7.33 (m, 5 H), 4.94 (s, 1 H), 4.92 (s, 1 H), 4.80 (m, 1 H), 2.43 (m, 2 H), 2.20 (s, 1 H), 2.08 (t, 2 H, J = 7.5 Hz), 1.47 (m, 2 H), 1.32 (m, 2 H), 0.93 (t, 3 H, J = 7.2 Hz); ^{13}C-NMR ($CDCl_3$, 75.5 MHz) δ 146.4, 144.2, 128.2, 127.3, 125.7, 112.5, 71.5, 46.5, 35.4, 29.7, 22.2, 13.8; MS (CI, NH_4^+) 222 (MNH_4^+, 10), 204 (91), 187 (79), 136 (33), 106 (100); exact mass calcd for $C_{14}H_{20}ONH_4^+$ 222.1858, obsd 222.1848.

1-Cyclohexyl-3-methyleneheptanol (9b). Oil, 0.63 g (85% yield) prepared from 2-methylenehexyl methanesulfonate (0.96 g, 5.0 mmol) and cyclohexanecarboxaldehyde (0.39 g, 3.5 mmol). Reaction conditions: 35 °C, 24 h. Purified by flash chromatography (hexane/Et_2O = 32/1): IR (neat) 3434 (w), 2955 (s), 1643 (w) cm^{-1}; ^{1}H-NMR ($CDCl_3$, 300 MHz) δ 4.88 (s, 1 H), 4.83 (s, 1 H), 3.45 (m, 1 H), 1.97 (m, 10 H), 1.26 (m, 10 H), 0.91 (t, 3 H, J = 7.3 Hz); ^{13}C-NMR ($CDCl_3$, 75.5 MHz) δ 147.3, 111.8, 72.6, 43.4, 41.3, 35.4, 29.8, 29.0, 28.1, 26.5, 26.2, 26.1, 22.3; MS (CI, NH_4^+) 228 (MNH_4^+, 100), 211 (13), 193 (66); exact mass calcd for $C_{14}H_{26}OH^+$ 211.2062, obsd 211.2064.

8-Methylenedodecan-6-ol (9c). Oil, 0.56 g (81% yield) prepared from 2-methylenehexyl methanesulfonate (0.96 g, 5.0 mmol) and hexanal (0.35 g, 3.5 mmol). Reaction conditions: 35 °C, 24 h. Purified by flash chromatography (hexane/Et_2O = 24/1): IR (neat) 3366 (m), 2957 (s), 2930 (s), 2860 (s), 1644 (m) cm^{-1}; ^{1}H-NMR ($CDCl_3$, 300 MHz) δ 4.87 (s, 1 H), 4.82 (s, 1 H), 3.69 (m, 1 H), 2.16 (m, 4 H), 1.71 (s, 1 H), 1.38 (m, 12 H), 0.94 (m, 6 H); ^{13}C-NMR ($CDCl_3$, 75.5 MHz) δ 147.2, 111.8, 69.1, 44.7, 37.2, 35.8, 31.9, 30.0, 25.3, 22.5, 22.4, 13.8, 13.7; MS (CI, NH_4^+) 216 (MNH_4^+, 74), 199 (19), 198 (17), 181 (100), 118 (52), 109 (17), 98 (67); exact mass calcd for $C_{13}H_{26}ONH_4^+$ 216.2327, obsd 216.2326.

1-(2-Methylenehexyl)cyclohexanol (9d). Oil, 0.55 g (80% yield) prepared from 2-methylenehexyl methanesulfonate (0.96 g, 5.0 mmol) and cyclohexanecarboxaldehyde (0.34 g, 3.5 mmol). Reaction conditions: 35 °C, 24 h. Purified by flash chromatography (hexane/Et_2O = 32/1): IR (neat) 2935 (s), 2929 (s), 1637 (w) cm^{-1}; ^{1}H-NMR ($CDCl_3$, 300 MHz) δ 4.91 (s, 1 H), 4.79 (s, 1 H), 2.17 (s, 2 H), 2.09 (t, 2 H, J = 7.4 Hz), 1.45 (m, 15 H), 0.90 (t, 3 H, J = 7.3 Hz); ^{13}C-NMR ($CDCl_3$, 75.5 MHz) δ 146.8, 113.2, 70.9, 48.2, 37.9, 37.8, 30.3, 25.8, 22.4, 22.3, 13.8; MS (CI, NH_4^+) 214 (MNH_4^+, 3), 196 (20), 179 (100); exact mass calcd for $C_{13}H_{24}ONH_4^+$ 214.2171, obsd 214.2165.

2,2-Dimethyl-1-phenylbut-3-enol (9e). Oil, 0.60 g (97% yield) prepared from diethyl 3-methylbut-2-enyl phosphate (1.11 g, 5.0 mmol) and benzaldehyde (0.37 g, 3.5 mmol). Reaction conditions: 35 °C, 12 h. Purified by flash chromatography (hexane/Et_2O = 16/1): IR (neat) 3448 (s), 2965 (s), 2871 (m), 1636 (w) cm^{-1}; ^{1}H-NMR ($CDCl_3$, 200 MHz) δ 7.30 (m, 5 H), 5.91 (dd, 1 H, J = 17.4, 10.8 Hz), 5.15 (d, 1 H, J = 10.7 Hz), 5.12 (d, 1 H, J = 17.4 Hz), 4.43 (d, 1 H, J = 2.8 Hz), 2.07 (d, 1 H, J = 3.0 Hz), 1.02 (s, 3 H), 0.97 (s, 3 H); ^{13}C-NMR ($CDCl_3$, 75.5 MHz) δ 145.1, 141.1, 127.8, 127.4, 127.3, 113.4, 80.7, 42.1, 24.2, 21.4; MS (CI, NH_4^+) 194 (MNH_4^+, 19), 176 (57), 159 (100); exact mass calcd for $C_{12}H_{16}ONH_4^+$ 194.1545, obsd 194.1542.

2,6-Dimethyl-1-cyclohexyl-2-ethylenehept-5-enol (9g). Mixture of Two Diastereoisomers (1R*,2R*,2S* = 9/1). Oil, 0.68 g (78% yield) prepared from (*E*)-diethyl 3,7-dimethyl-2,6-octadienyl phosphate (1.45 g, 5.0 mmol) and cyclohexanecarboxaldehyde (0.39 g, 3.5 mmol). Reaction conditions: 25 °C, 12 h. Purified by flash chromatography (hexane/Et_2O = 16/1): IR (neat) 3487 (m), 2967 (s), 2919 (s), 1731 (w), 1636 (w) cm^{-1}; ^{1}H-NMR ($CDCl_3$, 300 MHz) δ 5.79 (dd, 1 H, J = 17.6, 10.9 Hz), 5.06 (m, 3 H), 3.11 (d, 1 H, J = 10.0 Hz), 1.87 (m, 2 H), 1.44 (m, 20 H), 1.04 (s, 3 H); ^{13}C-NMR ($CDCl_3$, 75.5 MHz) δ 144.0, 130.9, 124.9, 113.7, 81.7, 45.5, 39.3, 38.3, 33.4, 27.6, 26.7, 26.2, 25.4, 22.6, 18.9, 17.4; MS (EI, 70 eV) 250 (1), 123 (28), 95 (100), 83 (15); exact mass calcd for $C_{17}H_{30}O$ 250.2297, obsd 250.2289.

2,6-Dimethyl-2-ethenyl-1-phenyl-5-heptanol (9h): Mixture of Two Diastereoisomers (1R*,2R*/1R*,1S* = 4/1). Oil, 0.87 g (95% yield) prepared from (*E*)-diethyl 3,7-dimethyl-2,6-octadienyl phosphate (**8c**) (1.45 g, 5 mmol) and benzaldehyde (0.37 g, 3.5 mmol). Reaction conditions: 25 °C, 12 h. Purified by flash chromatography (hexane/Et_2O = 16/1): IR (neat) 3456 (m), 2969 (s), 2926 (s), 1638 (w) cm^{-1}; ^{1}H-NMR ($CDCl_3$, 200 MHz) δ 7.30 (m, 5 H), 5.86 (dd, 1 H, J = 18, 12 Hz, major diast), 5.81 (dd, 1 H, J = 17.7, 8.7 Hz, minor diast), 5.29 (d, 1 H, J = 11 Hz, major diast), 5.20 (d, 1 H, J = 11.8 Hz, minor diast), 5.08 (m, 2 H), 4.42 (m, 1 H), 2.15 (bs, 1 H), 1.87 (q, 2 H, J = 7.5 Hz), 1.69 (s, 3 H), 1.58 (s, 3 H), 1.35 (m, ca. 2 H), 1.07 (s, 3 H, minor diast), 0.94 (s, 3 H, major diast); ^{13}C-NMR ($CDCl_3$, 75.5 MHz) δ 143.7, 142.8, 141.3, 140.7, 130.8, 130.7, 127.9, 127.7, 127.2, 127.1, 127.0, 125.0, 124.7, 115.2, 114.5, 80.5, 80.1, 45.6, 45.1, 37.3, 36.3, 25.5, 22.7, 22.5, 18.5, 17.4, 16.6; MS (CI, NH_4^+) 262 (MNH_4^+, 34), 244 (10), 227 (100), 136 (72); exact mass calcd for $C_{17}H_{24}ONH_4^+$ 262.2171, obsd 262.2169.

Ethyl 4-Ethylene-4,8-dimethyl-2-methylenenon-7-enoate (11). Oil, 0.86 g (69% yield) prepared from (*Z*)-diethyl-3,7-dimethyl-2,6-octadienyl phosphate (**8c**) (1.45 g, 5 mmol) and ethyl α-(bromomethyl)acrylate[8] (0.97 g, 5 mmol). Reaction conditions: 5 °C, 5 min. Purified by flash chromatography (hexane/Et_2O = 99/1): IR (neat) 3083 (w), 2970 (s), 2919 (s), 1720 (s), 1628 (m) cm^{-1}; ^{1}H-NMR ($CDCl_3$, 360 MHz) δ 6.13 (s, 1 H), 5.68 (dd, 1 H, J = 17.5, 10.8 Hz), 5.41 (s, 1 H), 5.06 (t, 1 H, J = 7.2 Hz), 4.95 (d, 1 H, J = 10.9 Hz), 4.83 (d, 1 H, J = 17.5 Hz), 4.16 (q, 2 H, J = 7.1 Hz), 2.37 (q, 2 H, J = 13.1 Hz), 1.87 (m, 2 H), 1.66 (s, 3 H), 1.57 (s, 3 H), 1.30 (m, 5 H), 0.94 (s, 3 H); ^{13}C-NMR ($CDCl_3$, 50.3 MHz) δ 168.0, 145.7, 138.1, 130.9, 126.7, 124.7, 112.0, 60.4, 42.3, 40.9, 40.3, 25.5, 22.8, 21.1, 17.4, 14.0; MS (CI, NH_4^+) 268 (MNH_4^+, 6), 251 (37), 222 (2), 205 (7), 136 (100); exact mass calcd for $C_{16}H_{26}O_2H^+$ 251.2011, obsd 251.2003.

Acknowledgment. We wish to thank the donors of the Petroleum Research Fund, administered by the American Chemical Society for support of this research. We thank also Professor M. Koreeda for providing the ^{1}H and ^{13}C NMR spectra of compound **9h** for comparison.

Registry No. **1a**, 14660-52-7; **1b**, 2969-81-5; **1c**, 6940-78-9; **1e**, 41144-01-8; **1f**, 115902-61-9; **1g**, 110544-74-6; **1h**, 115-88-8; **4a**, 143238-77-1; **4b**, 143238-78-2; **4c**, 123464-45-9; **4d**, 132839-63-5; **4e**, 126761-20-4; **4f**, 143238-79-3; **4g**, 143238-80-6; **4h**, 143238-81-7; **4i**, 143238-82-8; **4j**, 143238-83-9; **5a**, 55791-06-5; **5b**, 143238-84-0; **5c**, 143238-85-1; **5d**, 143238-86-2; **5e**, 76263-88-2; **7a**, 103130-93-4; **7b**, 143238-87-3; **7c**, 99557-74-1; **7d**, 143238-88-4; **7e**, 143238-89-5; **9a**, 143238-90-8; **9b**, 143238-91-9; **9c**, 143238-92-0; **9d**, 143238-93-1; **9e**, 27644-02-6; **9f**, 52922-12-0; **9g** (isomer 1), 84363-95-1; **9g** (isomer 2), 84363-96-2; **9h** (isomer 1), 84363-97-3; **9h** (isomer 2), 84363-98-4; 11, 143238-94-2; $EtO_2C(CH_2)_3I$, 7425-53-8; LiI, 10377-51-2; LiBr, 7550-35-8; CsI, 7789-17-5; (*E*)-$PhSO_2CH{=}CHNO_2$, 101933-29-3; $HC{\equiv}CCOOEt$, 623-47-2; NaI, 7681-82-5; NaBr, 7647-15-6; CsBr, 7787-69-1; CuCN, 544-92-3; $EtO_2C(CH_2)_3Cl$, 3153-36-4; PhCHO, 100-52-7; nitrostyrene, 102-96-5; 1-(ethylthio)-2-nitrocyclohexene, 90877-98-8; 1-nitropentene, 3156-72-7; 3-iodocyclohex-2-enone, 56671-82-0; *tert*-butyl α-(bromomethyl)acrylate, 53913-96-5; Zinc, 7440-66-6; ethyl α-(bromomethyl)acrylate, 17435-72-2; 2-methylenehexyl methanesulfonate, 143238-95-3; diethyl 3-methylbut-2-enyl phosphate, 64135-15-5; (*E*)-diethyl 3,7-di-

methyl-2,6-octadienyl phosphate, 60699-32-3; cyclohexanecarboxaldehyde, 2043-61-0; hexanal, 66-25-1; cyclohexanone, 108-94-1; lithium chloride, 7447-41-8.

Supplementary Material Available: A carbon NMR spectrum of each new compound (24 pages). This material is contained in many libraries on microfiche, immediately follows this article in the microfilm version of the journal, and can be ordered from the ACS; see any current masthead page for ordering information.

Preparation of Polyfunctional Nitro Olefins and Nitroalkanes Using the Copper-Zinc Reagents RCu(CN)ZnI

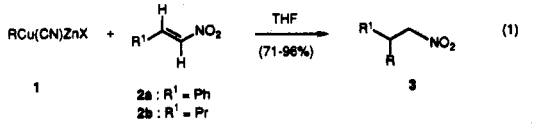
Carole Jubert[1a] and Paul Knochel*,[1b]

The Willard H. Dow Laboratories, Department of Chemistry, The University of Michigan, Ann Arbor, Michigan 48109

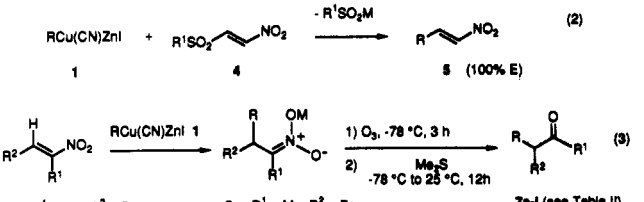
Received April 24, 1992

The addition of the copper-zinc reagents RCu(CN)ZnX to a variety of nitro olefins produces polyfunctional nitroalkanes in high yields. The intermediate zinc or copper nitronates can be directly submitted to a Nef reaction (O_3, -78 °C) and converted to polyfunctional ketones in a one-pot procedure. The addition of RCu(CN)ZnX to nitro olefins bearing a leaving group (RSO_2, RS) in the β-position provides pure (*E*)-nitro olefins in excellent yields. The reaction has been applied for the stereoselective preparation of 1,3-nitrodienes and for a Diels-Alder reaction precursor.

Nitro olefins are exceptional Michael acceptors, and this property dominates the chemistry of this class of compounds.[2] They provide a unique and very general way for constructing polyfunctional nitro derivatives since a wide range of nucleophiles add in good yields to nitro olefins.[3] Several types of organometallic reagents such as organolithium,[2-4] -magnesium,[5] -cadmium,[6] -zinc,[7] and -aluminum[8] reagents as well as allylic or allenic tin[9] and silicon[10] derivatives add to nitro olefins in fair to excellent yields. Copper reagents derived from organolithiums have also been used;[11] however, in this case the intermediate lithium nitronates are reactive enough to add to the remaining nitro olefin leading to a partial polymerization and to moderate yields of the Michael-adduct. In strong contrast, we have found that the copper compounds RCu(CN)ZnX **1** prepared from organozinc halides[12] add very cleanly to various nitro olefins **2** affording polyfunctional nitroalkanes **3** in excellent yields (eq 1).[13]



Obviously, the intermediate zinc nitronate is not reactive enough to induce a polymerization of the nitro olefin **2**. It is also possible to add these reagents to nitro olefins **4** bearing a leaving group in the β-position[14,15] providing a unique synthesis of pure (*E*)-nitro olefins of type **5** (eq 2).



Here we report the scope and limitations of these methods as well as a new one-pot reaction allowing us convert di-

(1) (a) Centre de Recherches, Roussel-Uclaf, 102, 111 route de Noisy, F-92230, Romainville, France. (b) Present address: Philipps-Universität Marburg, Fachbereich Chemie, Hans Meerwein Strasse, D-3550 Marburg, Germany.

(2) For excellent reviews on the chemistry of nitro olefins and related nitro derivatives see: (a) Seebach, D.; Colvin, E. W.; Lehr, F.; Weller, T. *Chimia* **1979**, *33*, 1. (b) Yoshikoshi, A.; Miyashita, M. *Acc. Chem. Res.* **1985**, *18*, 284. (c) Barrett, A. G. M.; Graboski, G. G. *Chem. Rev.* **1986**, *86*, 751. (d) Rosini, G.; Ballini, R. *Synthesis* **1988**, 833. (e) Tamura, R.; Kamimura, A.; Ono, N. *Synthesis* **1991**, 423. (f) Kalbalka, G. W.; Varma, R. S. *Org. Prep. Proced. Int.* **1987**, *19*, 283.

(3) For the addition of relatively stabilized nucleophiles see: (a) Seebach, D.; Leitz, H. F. *Angew. Chem.* **1971**, *83*, 542; *Angew. Chem., Int. Ed. Engl.* **1971**, *10*, 501. (b) Seebach, D.; Leitz, H. F.; Ehrig, V. *Chem. Ber.* **1975**, *108*, 1924. (c) Seebach, D.; Ehrig, V.; Leitz, H. F.; Henning, R. *Chem. Ber.* **1975**, *108*, 1946. (d) Ehrig, V.; Seebach, D. *Chem. Ber.* **1975**, *108*, 1961. (e) Miyashita, M.; Awen, B. Z. E.; Yoshikoshi, A. *Synthesis* **1990**, 563. (f) Miyashita, M.; Awen, B. Z. E.; Yoshikoshi, A. *Chem. Lett.* **1990**, 239. (g) Stevens, R. W.; Mukaiyama, T. *Chem. Lett.* **1985**, 855. (h) Kamimura, A.; Sasatani, H.; Hashimoto, T.; Kawai, T.; Hori, K.; Ono, N. *J. Org. Chem.* **1990**, *55*, 2437.

(4) (a) Bedford, C. D.; Nielson, A. T. *J. Org. Chem.* **1978**, *43*, 2460. (b) Severin, T.; Scheel, D.; Adhikary, P. *Chem. Ber.* **1969**, *102*, 2966. (c) Seebach, D.; Knochel, P. *Helv. Chim. Acta* **1984**, *67*, 261. (d) Seebach, D.; Calderari, G.; Knochel, P. *Tetrahedron* **1985**, *41*, 4861. (e) Hayama, T.; Tomoda, S.; Takeuchi, Y.; Nomura, Y. *Tetrahedron Lett.* **1983**, *24*, 2795.

(5) (a) Buckley, G. D. *J. Chem. Soc.* **1947**, 1494. (b) Buckley, D. G.; Ellery, E. *J. Chem. Soc.* **1947**, 1497. (c) Corey, E. J.; Estreicher, H. *J. Am. Chem. Soc.* **1978**, *100*, 6294. (d) Ashwood, M. S.; Bell, L. A.; Houghton, P. G.; Wright, S. H. B. *Synthesis* **1988**, 379.

(6) Michel, J.; Henry-Basch, E. C. R. *Acad. Sci., Ser. C* **1966**, *262*, 1274.

(7) Langer, W.; Seebach, D. *Helv. Chim. Acta* **1979**, *62*, 1710.

(8) (a) Pecunioso, A.; Menicagli, R. *Tetrahedron* **1987**, *43*, 5411. (b) Pecunioso, A.; Menicagli, R. *J. Org. Chem.* **1988**, *53*, 45. (c) Pecunioso, A.; Menicagli, R. *J. Org. Chem.* **1989**, *54*, 2391.

(9) (a) Uno, H.; Watanabe, N.; Fujiki, S.; Suzuki, H. *Synthesis* **1987**, 471. (b) Haruta, J.; Nishi, K.; Matsuda, S.; Akai, S.; Tamura, Y.; Kita, Y. *J. Org. Chem.* **1990**, *55*, 4853.

(10) (a) Ochiai, M.; Arimoto, M.; Fujita, E. *Tetrahedron Lett.* **1981**, *22*, 1115. (b) Uno, H.; Fujiki, S.; Suzuki, H. *Bull. Chem. Soc. Jpn.* **1986**, *59*, 1267.

(11) (a) Bowlus, S. B. *Tetrahedron Lett.* **1975**, 3591. (b) Hansson, A.-T.; Nilsson, M. *Tetrahedron* **1982**, *38*, 389. (c) Stiver, S.; Yates, P. *J. Chem. Soc., Chem. Commun.* **1983**, 50.

(12) (a) Knochel, P.; Yeh, M. C. P.; Berk, S. C.; Talbert, J. *J. Org. Chem.* **1988**, *53*, 2390. (b) Knochel, P.; Rozema, M. J.; Tucker, C.; Retherford, C.; Furlong, M. T.; AchyuthaRao, S. *Pure Appl. Chem.* **1992**, *64*, 361.

(13) Retherford, C.; Yeh, M. C. P.; Schipor, I.; Chen, H. G.; Knochel, P. *J. Org. Chem.* **1989**, *54*, 5200.

(14) Retherford, C.; Knochel, P. *Tetrahedron Lett.* **1991**, *32*, 441.

(15) For a review on β-substituted nitro olefins: Fuji, K.; Node, M. *Synlett* **1991**, 603.

0022-3263/92/1957-5431$03.00/0