water is a Wurtz-type coupling of alkyl iodides.[10] As the reactions depicted here are Barbier-type reactions, the possibility of a free radical pair process occurring on the metallic surface, as suggested by Molle and Bauer[11] for the classical Barbier reaction, deserves consideration.

The positive results obtained with allylic halides could not be achieved with other halides such as benzyl and butyl bromides. However, the addition of an allylic moiety is synthetically important[12] and we expect that this simple procedure will prove quite useful.

In conclusion, the zinc-mediated addition of an allylic group to a carbonyl function can in fact occur in aqueous media. Synthetic applications and mechanistic implications of this reaction are currently being studied.

**Acknowledgment.** We thank Dr. A. E. Greene for fruitful discussions. Financial support by the Centre National de la Recherche Scientifique (LA 332, ATP Chimie Fine) is gratefully acknowledged.

**Registry No.** 1, 936-58-3; 2, 94597-04-3; 3, 28920-33-4; 4, 36971-11-6; 5, 17920-92-2; (*R**,*R**)-6, 65203-02-3; (*R**,*S**)-6, 65203-03-4; PhCHO, 100-52-7; $CH_3(CH_2)_3COCH_3$, 591-78-6; $(CH_3)_2CHCHO$, 78-84-2; $(CH_3)_2C{=}CH(CH_2)_2COCH_3$, 110-93-0; $CH_2{=}CHCH_2Br$, 106-95-6; $(CH_3)_2C{=}CHCH_2Cl$, 503-60-6; $CH_3CH{=}CHCH_2Br$, 4784-77-4; $CH_2{=}CHCH_2Cl$, 107-05-1; $BrCH_2CH{=}CHCO_2Me$, 1117-71-1; Zn, 7440-66-6; $NH_4Cl$, 12125-02-9; cyclohexanone, 108-94-1.

(10) Nosek, J. *Collect. Czech. Chem. Commun.* **1964**, *29*, 597-602. For a reaction related to the presently described (allylzinc reagents in refluxing alcohols, giving lower yields), see: Killinger, T. A.; Boughton, N. A.; Runge, T. A.; Wolinski, J. *J. Organomet. Chem.* **1977**, *124*, 131-134.

(11) Molle, G.; Bauer, P. *J. Am. Chem. Soc.* **1982**, *104*, 3481-3487.

(12) For recent papers related to this reaction, see: Hiyama, T.; Sawahata, M.; Obayashi, M. *Chem. Lett.* **1984**, 1237-1238. Yamamoto, Y.; Yatagai, H.; Ishihara, Y.; Maeda, N.; Maruyama, K. *Tetrahedron* **1984**, *40*, 2239-2246. Souppe, J.; Namy, J. L.; Kagan, H. B. *Tetrahedron Lett.* **1982**, *23*, 3497-3500. Mukaiyama, T.; Harada, T. *Chem. Lett.* **1981**, 1527-1528. Augé, J.; David, S. *Tetrahedron Lett.* **1983**, *24*, 4009-4012. Nokami, J.; Otera, J.; Sudo, T.; Okawara, R. *Organometallics* **1983**, *2*, 191-193.

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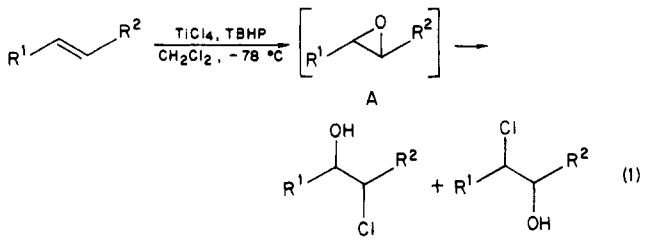
*Received November 15, 1984*

## Chlorohydroxylation of Olefins with Peroxides and Titanium Tetrachloride

*Summary:* $TiCl_4$/TBHP (DTBP) is a powerful reagent for the direct chlorohydroxylation of olefins. Moderate diastereoselectivity has been observed in the reactions of chiral substrates bearing allylic or homoallylic substituents.

*Sir:* We have recently reported the asymmetric chlorohydroxylation of allylic alcohols, employing $TiCl_2(O\text{-}i\text{-}Pr)_2$ in place of $Ti(O\text{-}i\text{-}Pr)_4$ in the standard asymmetric epoxidation process.[1] We have now discovered that nonfunctionalized olefins can also be chlorohydroxylated, employing either *tert*-butyl hydroperoxide (TBHP) or di-*tert*-butyl peroxide (DTBP) in the presence of titanium tetrachloride, as depicted in eq 1.[2,3]




The intermediacy of an epoxide (A) in this reaction appears probable, and, in fact, epoxides are rapidly opened to chlorohydrins under the reaction conditions. Although the epoxide is not generally observed under standard conditions, it may be detected in many cases upon rapid workup (<5 min). The epoxides of adamantylideneadamantane[4] and methyl ricinoleate were more resistant to ring opening and were isolated in 20% and 40% yields, respectively, from standard chlorohydroxylation reactions.

The stereochemical integrity (i.e., pure anti addition) of the chlorohydroxylation process was demonstrated by ring closure ($K_2CO_3$/MeOH) of the chlorohydrins from *cis*- and *trans*-5-decene and (*E*)-1-methoxy-2-decene and correlation to epoxides of known geometry. The above mechanism also raises the issue of regioselectivity in the ring-opening process. Generally, the reaction gives rise to a mixture of regioisomers, although selectivity may be quite high in some cases (Table I, entry 4 (96:4) and entry 3 (only one regioisomer detected)).

Chlorohydrins are typically prepared as follows: a flame-dried flask under $N_2$ is charged with the olefin (1.5 mmol) and dry $CH_2Cl_2$ to produce a 0.05 M solution. This is cooled to −78 °C and anhydrous TBHP (1.2 equiv, $CH_2Cl_2$ solution)[5] is added via syringe, followed by $TiCl_4$ (1.2 equiv, $CH_2Cl_2$ solution). The reaction is monitored by TLC (EtOAc/hexane). If TLC shows much remaining starting material after 1 h, additional $TiCl_4$ is added. Functionalized olefins often require additional $TiCl_4$. The reaction is quenched by pouring the cold solution into a stirring mixture of $Et_2O$–saturated $Na_2SO_4$, followed by stirring at room temperature for 1 h. The ethereal layer is then washed with saturated $Na_2SO_3$ and saturated NaCl, dried over $MgSO_4$, and evaporated. The residual oil is purified by flash chromatography (EtOAc:hexane mixtures).

One is initially struck by the power of this reagent. Both with TBHP and with DTBP, reaction is generally complete within 15 min at −78 °C, even with simple monosubstituted olefins. The very high reactivity of DTBP under these nonradical conditions[7] is especially noteworthy. It was,

(1) Lu, L.D.-L.; Johnson, R. A.; Finn, M. G.; Sharpless, K. B. *J. Org. Chem.* **1984**, *49*, 728.

(2) (a) Sharpless, K. B.; Johnson, R. A., U.S. Pat. 571961, Jan 1984. (b) A number of other Lewis acids were tried, including $TiCl(O\text{-}i\text{-}Pr)_3$, $TiCl_2(O\text{-}i\text{-}Pr)_2$, $BF_3{\cdot}OEt_2$, $AlCl_3$, $SnCl_4$, $TaCl_5$, $ZrCl_4$, $VOCl_3$, and HCl, but results with $TiCl_4$ were far superior.

(3) The oxidation of aromatics with peroxides in the presence of a Lewis acid has been reported previously. See, for example: (a) Apatu, J. O.; Chapman, D. C.; Heaney, H. *J. Chem. Soc., Chem. Commun.* **1981**, 1079. (b) Kurz, M. E.; Johnson, G. J. *J. Org. Chem.* **1971**, *36*, 3184. (c) Hashimoto, K. *Bull. Chem. Soc. Jpn.* **1970**, 293. (d) Chip, G. K.; Grossert, J. S. *Can. J. Chem.* **1971**, *50*, 1233. These last authors also report the chlorohydroxylation, in low yield (37%), of cyclohexene with mCPBA/$TiCl_4$.

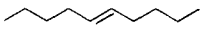
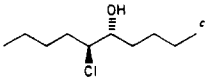
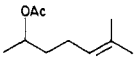
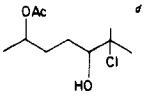
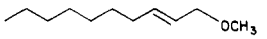
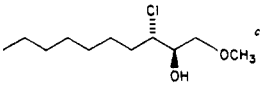
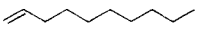
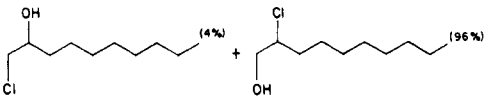
(4) Wynberg, H.; Boelema, E.; Wieringa, J. H.; Strating, J. *Tetrahedron Lett.* **1970**, 3613. These authors report the resistance of this epoxide toward normal ring-opening reactions.

(5) The use of anhydrous TBHP solutions in toluene[6] sometimes leads to byproducts resulting from competing aromatic oxidation. See ref 3.

(6) Hill, J. G.; Rossiter, B. E.; Sharpless, K. B. *J. Org. Chem.* **1983**, *48*, 3607.

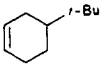
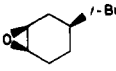
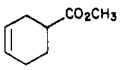
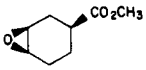
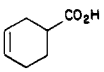
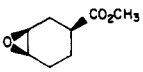
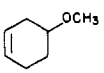
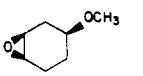
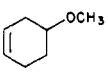
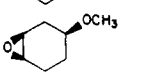
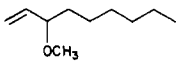
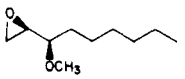
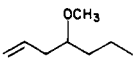
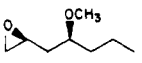
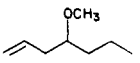
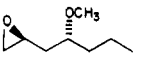
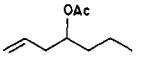
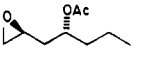
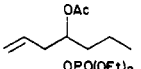
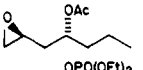
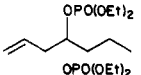
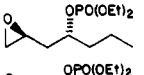
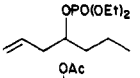
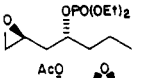
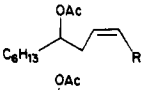
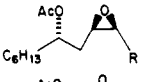
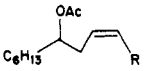
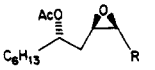
0022-3263/85/1950-0912$01.50/0 

**Table I. $TiCl_4$/TBHP (DTBP) Chlorohydroxylation of Olefins**

| entry | olefin[a] | oxidant | yield[b] % | product(s) |
|---|---|---|---|---|
| 1 |  | TBHP | 91 |  |
| 2 |  | DTBP | 88 |  |
| 3 |  | TBHP | 92 |  |
| 4 |  | TBHP | 62 |  |

[a] All substrates were used as available commercially or after standard acetylation or methylation procedures. [b] Isolated yields of chromatographed chlorohydrins, uncorrected for recovered starting material. [c] The stereochemistry of the chlorohydrin was established by closure to the epoxide and correlation to epoxides of known geometry. [d] Byproducts of this reaction include 6-acetoxy-2-chloro-2-methylheptene.

**Table II. Stereoselectivity in the $TiCl_4$/TBHP (DTBP) Chlorohydroxylation of Olefins**

| entry | olefin[a] | oxidant | chlorohydrin yield,[b] % | major epoxide[c] | C/T or E/T selectivity[d] | C/T or E/T mCPBA |
|---|---|---|---|---|---|---|
| 1 |  | TBHP | 95 |  | 60:40 | 60:40[e] |
| 2 |  | TBHP | 54[g] |  | 86:14 | 31:69[j] |
| 3 |  | TBHP | 74[h,i] |  | 82:18 | |
| 4a |  | TBHP | |  | 90:10 | 50:50 |
| 4b |  | DTBP | 70 |  | 90:10 | 50:50 |
| 5 |  | TBHP | 20 |  | 20:80 | 56:44 |
| 6a |  | TBHP | 78[h] |  | 71:29 | 53:47 |
| 6b |  | DTBP | 86[h] |  | 29:71 | 53:47 |
| 7a |  | TBHP | 70[h] |  | 23:77 | 50:50 |
| 7b |  | DTBP | 69[h] |  | 29:71 | 50:50 |
| 8a |  | TBHP | 88[h] |  | 24:76[j] | |
| 8b |  | DTBP | 85[h] |  | 20:80[j] | |
| 9a[k] |  | TBHP | 76[h] |  | 38:62 | 50:50 |
| 9b[k] |  | DTBP | 72[h] |  | 40:60 | 50:50 |

[a] Most substrates were used as available commercially or after standard acetylation or methylation procedures. The diethyl phosphate of entry 8 was prepared from the alcohol, using NaH and $ClPO_3Et_2$. [b] Isolated yields of chromatographed chlorohydrin. [c] Formed by treatment of the chlorohydrin with either $K_2CO_3$/MeOH (entries 1–3, 5) or NaH/THF (entries 4, 6–7). Stereochemical assignments are described in the supplementary material. [d] Determined by GLC (entries 2–4) or $^1H$ NMR (entries 5–8). Further information may be found in the supplementary material. [e] Rickborn, B.; Quartucci, J. *J. Org. Chem.* **1964**, *29*, 2476. [f] Harrison, C. R.; Hodge, P. *J. Chem. Soc., Perkin Trans. 1*, **1976**, 605. [g] Recovered starting material. At −20 °C reaction went to completion to give a 91% yield with a cis:trans ratio of 81:19. [h] $TiCl_4$ (2.4 equiv) was used. [i] Yield after esterification (MeOH, $Me_3SiCl$). [Brook, M. A.; Chan, T. H. *Synthesis* **1983**, 201.] [j] Epoxide illustrated here for comparison only. The chlorohydrin was directly reduced to the diol, at which stage stereochemical assignment and ratio determinations were made. [k] R = $(CH_2)_7CO_2CH_3$.

therefore, hoped that the reagent would prove useful in the oxidation of electronically deactivated olefins, which are resistant to other oxidation procedures. Unfortunately, no reaction was observed when an $\alpha,\beta$-unsaturated ester

(ethyl crotonate) was employed as substrate. It seems likely that coordination of the ester moiety to the Lewis acid resulted in further deactivation of the double bond, so that even the present powerful oxidant failed to react.

Most mono- and disubstituted olefins examined were oxidized effectively, affording chlorohydrin in moderate to high yield (Tables I and II). In at least one case (entry 2, Table I) a trisubstituted olefin could also be successfully chlorohydroxylated, provided DTBP was used as oxidant. With TBHP, reaction afforded primarily the tertiary chloride corresponding to addition of HCl across the double bond. Other trisubstituted olefins and 4-*tert*-butylmethylenecyclohexane afforded intractable mixtures regardless of the oxidant employed.

We then turned our attention to the stereochemical aspects of the reaction, hoping to observe directive effects by functionality other than an allylic hydroxyl group. Of particular interest were protected hydroxyl functionalities, such as ethers and esters, potentially useful for applications in which the presence of a free hydroxyl moiety is either impossible or undesirable. Unfortunately, secondary allylic substituents are readily cleaved under the reaction conditions. Thus, reaction of 3-acetoxy-1-nonene afforded only a mixture of the allylic chlorides 3-chloro-1-nonene and 1-chloro-3-nonene. These were also the predominant products from the reaction of 3-methoxy-1-nonene (entry 5, Table II), but in that case chlorohydrin was also isolated in 20% yield. Treatment with $K_2CO_3$/MeOH afforded a mixture of epoxides in the ratio of 81:19, with the threo isomer predominating.

Reactions of olefins bearing substituents at the homoallylic position were more successful, and the stereochemical results are outlined in Table II. A comparison of entry 1 with the remaining entries reveals that the presence of a site of Lewis basicity in the olefin substrate is necessary in order to achieve any selectivity different from a normal mCPBA epoxidation, suggesting that these groups are, in fact, exerting a directive effect upon the reaction, presumably via coordination to the Lewis acidic metal center.[8] Entries 2–4 provide the strongest examples of the effect of coordination in this reaction. In all cases oxidation is directed to the cis face of the olefin, with the exact nature of the coordinating group having little effect on the degree of selectivity. In the case of entry 2, this represents a reversal of the trans selectivity of the system with peracid.

Modest selectivity has also been observed in acyclic systems. It is interesting to note that the major product from the reaction of acyclic allylic and homoallylic ethers and esters (entries 5–8, Table II) with this reagent is the opposite diastereomer from that produced by vanadium-catalyzed epoxidations[10a,c] or by Bartlett's phosphate cyclization process.[10b] It is as yet unclear why, in the case of entry 6, the use of TBHP results in a reversal of this predominantly threo selectivity.

Classically, methods for the direct preparation of chlorohydrins have involved the use of electrophilic chlorine species (e.g., hypochlorous acid, alkyl hypochlorites,[11] chlorourea,[12] and Chloramine T[13]). As a source of electrophilic oxygen, the $TiCl_4$/peroxide reagent is expected to provide preferentially the opposite regioisomer from that provided by the above reagents (note, for example, entry 2, Table I).[14] In summary, the reagent described here offers an extremely rapid, convenient[15] method for the direct chlorohydroxylation of olefins, which exhibits potentially useful regio- and stereoselectivity in some cases.

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**Registry No.** A, 94904-76-4; B, 94904-77-5; C, 94904-78-6; $Ac_2O$, 108-24-7; (*E*)-5-decene, 7433-56-9; 6-acetoxy-2-methyl-2-heptene, 19162-00-6; (*E*)-1-methoxy-2-decene, 57648-47-2; 1-decene, 872-05-9; (*R**,*S**)-5-chloro-6-decanol, 63475-56-9; 6-acetoxy-2-chloro-2-methyl-3-heptanol, 94904-64-0; (*R**,*S**)-3-chloro-1-methoxy-2-decanol, 94904-65-1; 1-chloro-2-decanol, 39579-73-2; 2-chloro-1-decanol, 39579-78-7; 4-*tert*-butyl-1-cyclohexene, 2228-98-0; methyl 3-cyclohexene-1-carboxylate, 6493-77-2; 3-cyclohexene-1-carboxylic acid, 4771-80-6; 4-methoxy-1-cyclohexene, 15766-93-5; 3-methoxy-1-nonene, 94904-66-2; 4-methoxy-1-heptene, 54267-82-2; 4-acetoxy-1-heptene, 2833-32-1; 1-hepten-4-yl diethyl phosphate, 64020-35-5; (*Z*)-methyl 12-acetoxy-9-octadecenoate, 41015-43-4; 1$\alpha$,3$\beta$,6$\alpha$-3-*tert*-butyl-7-oxabicyclo[4.1.0]heptane, 14753-39-0; 1$\alpha$,3$\alpha$,6$\alpha$-3-*tert*-butyl-7-oxabicyclo[4.1.0]heptane, 14753-40-3; 1$\alpha$,3$\beta$,6$\alpha$-methyl 7-oxabicyclo[4.1.0]heptane-3-carboxylate, 1630-02-0; 1$\alpha$,3$\alpha$,6$\alpha$-methyl 7-oxabicyclo[4.1.0]heptane-3-carboxylate, 1630-01-9; 1$\alpha$,3$\beta$,6$\alpha$-3-methoxy-7-oxabicyclo[4.1.0]heptane, 94904-67-3; 1$\alpha$,3$\alpha$,6$\alpha$-3-methoxy-7-oxabicyclo[4.1.0]heptane, 94943-29-0; (*R**,*R**)-1,2-epoxy-3-methoxynonane, 94904-68-4; (*R**,*S**)-1,2-epoxy-3-methoxynonane, 94904-69-5; (*R**,*R**)-1,2-epoxy-4-methoxyheptane, 94904-70-8; (*R**,*S**)-1,2-epoxy-4-methoxyheptane, 94904-71-9; (*R**,*S**)-1,2-epoxy-4-acetoxyheptane, 94904-72-0; (*R**,*R**)-1,2-epoxy-4-acetoxyheptane, 94904-73-1; (*R**,*S**)-1,2-epoxyheptan-4-yl diethyl phosphate, 94904-74-2; (*R**,*R**)-1,2-epoxyheptan-4-yl diethyl phosphate, 64020-44-6; (9*R**,10*S**,12*R**)-methyl 9,10-epoxy-12-acetoxyoctadecanoate, 94904-75-3; (9*R**,10*S**,12*S**)-methyl 9,10-epoxy-12-acetoxyoctadecanoate, 94943-30-3; *cis*-1-acetoxy-4-*tert*-butylcyclohexane, 10411-92-4; *trans*-1-acetoxy-3-*tert*-butylcyclohexane, 20298-71-9; (*R**,*S**)-2,4-dimethoxyheptane, 94904-79-7; (*R**,*R**)-2,4-dimethoxyheptane, 94904-80-0; (*R**,-

(7) Russian workers have reported that the Lewis acid catalyzed decomposition of TBHP is partially homolytic in nature, although heterolytic cleavage is the predominant pathway. See: (a) Solyanikov, V. M.; Petrov, L. V.; Kharlampidi, Kh. E. *Dokl. Akad. Nauk SSSR* **1975**, 1412. (b) Petrov, L. V.; Solyanikov, V. M. *Izv. Akad. Nauk SSSR, Ser. Khim.* **1980**, *29*, 1081. In the present case, reaction with DTBP proceeds well, even in the presence of the radical inhibitor 4,4'-thiobis(6-*tert*-butyl-*m*-cresol). [Kishi, Y.; Aratani, M.; Tanino, H.; Fukuyama, T.; Goto, T.; Inoue, S.; Sugiura, S.; Kakoi, H. *J. Chem. Soc., Chem. Commun.* **1972**, 64.] In addition, the product chlorohydrins correspond only to anti addition of Cl and OH across the double bond, a result not expected for a radical reaction.

(8) A comparison of the rates of reaction of functionalized and nonfunctionalized olefins has provided some evidence for such coordination. Thus, in the presence of 1.2 equiv of $TiCl_4$ (with respect to 0.5 equiv each of the two olefinic substrates), (*E*)-1-methoxy-2-decene reacts only 6 times slower than *trans*-5-decene. Henbest[9] has noted that 3-methoxycyclohexene is epoxidized by peracid 15 times slower than cyclohexene itself, due to deactivation of the olefin by the adjacent electron-withdrawing C–O bond. This electronic deactivation by the ether moiety is expected to diminish with increasing distance from the olefin and, in fact, in the presence of 1.2 equiv of $TiCl_4$, 4-methoxy-1-heptene reacts at a rate comparable to 1-decene ($k_{rel} \sim 1$). The concentration of $TiCl_4$ relative to donor ligand is important; when 2.4 equiv of $TiCl_4$ is employed, the relative rate jumps to 30, in favor of 1-decene. When 1.2 equiv of diethyl ether is added to this latter system the relative rate drops to 6. While the mechanistic implications of these preliminary experiments are not fully understood, the ability of ether moieties to affect the reactivity of $TiCl_4$–peroxide reagents by coordination to the metal is supported by these results.

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(10) (a) Mihelich, E. D.; Daniels, K.; Eickhoff, D. J. *J. Am. Chem. Soc.* **1981**, *103*, 1690. (b) Bartlett, P. A.; Jernstedt, K. K. *J. Am. Chem. Soc.* **1977**, *99*, 4829. (c) Hiyama, T.; Obayashi, M. *Tetrahedron Lett.* **1983**, *24*, 395.

(11) Anbar, M.; Ginsburg, D. *Chem. Rev.* **1954**, *54*, 925.

(12) Donahoe, H. B.; Vanderwerf, C. A. "Organic Syntheses"; Wiley: New York, 1963; Collect. Vol. IV, p 157.

(13) Damin, B.; Garapon, J.; Sillion, B. *Synthesis* **1981**, 362.

(14) Another one-step method of chlorohydroxylation which proceeds via an epoxide intermediate, employing $Me_3SiCl$ and 30% $H_2O_2$, has previously been reported. Ho, T.-L. *Synth. Commun.* **1979**, 37.

(15) The commercial availability of anhydrous di-*tert*-butyl peroxide of high purity makes the use of the $TiCl_4$/DTBP reagent especially convenient. For this study DTBP was employed as a solution in $CH_2Cl_2$, following the same procedure as that described for TBHP.

*S**)-4-methoxy-2-heptanol, 94904-81-1; (*R**,*R**)-4-methoxy-2-heptanol, 94904-82-2; (*R**,*S**)-2,4-heptanediol, 94904-83-3; (*R**,*R**)-2,4-heptanediol, 94904-84-4.

**Supplementary Material Available:** Erythro/threo correlations and ratio determinations for Table II; experimental details for the relative rate experiments outlined in ref 8 (6 pages). Ordering information is given on any current masthead page.

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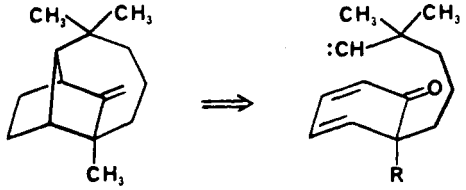
## The Intramolecular Diene–Carbene Cycloaddition Equivalence and an Enantioselective Birch Reduction–Alkylation by the Chiral Auxiliary Approach. Total Synthesis of (±)- and (–)-Longifolene

*Summary:* Total syntheses of racemic and optically pure (–)-longifolene (1) illustrate (1) a preparation of 6-alkyl-6-(methoxycarbonyl)-2,4-cyclohexadien-1-ones (e.g., **5a**) by Birch reduction–alkylation of methyl *o*-methoxybenzoate and the chiral benzoic acid derivative **10** and (2) seven-membered ring construction by use of the synthetic equivalence of an intramolecular Diels–Alder reaction between a diene and a carbene (e.g., **5a** → **8**).

*Sir:* The tricyclic sesquiterpene (+)-longifolene (1) has provided a challenging test of proximity effects in the development of new annelation methodology.[1,2] We have considered the possibility of constructing longifolene (and other tricyclic frameworks) by performing the synthetic equivalence of an intramolecular cycloaddition between a diene and a carbene, e.g., **2** → **1**. Such a construction

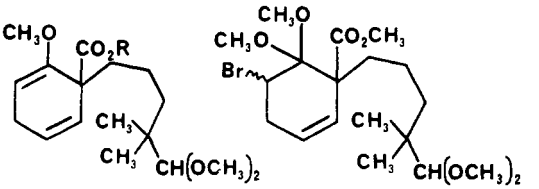



**1** **2**

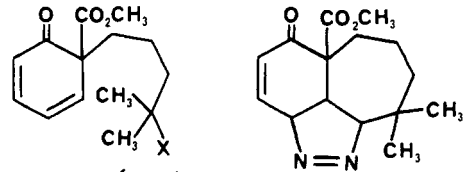
would be of value, because relatively few methods are available for direct synthesis of seven-membered rings. Only the Johnson synthesis of longifolene[1c] incorporates a direct seven-membered ring construction by use of a variation of the cation–polyene cyclization technique; the intramolecular Diels–Alder approach with a substituted cyclopentadiene has failed thus far because of a competing rearrangement pathway.[2e,f]

Realization of the synthesis plan required the development of a practical synthesis of 6,6-disubstituted 2,4-cyclohexadien-1-ones.[3] The diene–carbene synthetic equivalence has been demonstrated in the construction of tricyclo[4.3.0.0$^{3,7}$]non-4-en-2-ones by intramolecular cycloaddition of a diazoalkane to the C(4)–C(5) double bond of a 2,4-cyclohexadien-1-one and photorearrangement of the resulting pyrazoline (and derived vinylcyclopropane).[4] We now report a new total synthesis of (±)-longifolene patterned after the retrosynthetic analysis **2** → **1**. An enantiospecific synthesis of (–)-longifolene, via Birch reduction–alkylation of a chiral benzoic acid derivative, **10**, also is presented. This route to optically active cyclohexanes from *o*-hydroxybenzoic acids should find extensive use in organic synthesis.

Cyclohexadiene **3a** was prepared by Birch reduction–alkylation of methyl 2-methoxybenzoate[3] with the dimethyl acetal of 2,2-dimethyl-5-iodopentanal[5] (98%, oil). Conversion of **3a** to the key 2,4-cyclohexadien-1-one **5b** was




**3a** R = $CH_3$ **4**
**b** R = $C_7H_{12}NO_2$




**5a** X = $CH(OCH_3)_2$ **6**
**b** X = CHO
**c** X = CHN–NCHPh–CHPh
**d** X = CN

accomplished by (1) treatment of **3a** with *N*-bromoacetamide in methanol to give a diastereoisomeric mixture of bromo ketals **4** (95%, oil), (2) dehydrobromination of **4** with 1,5-diazabicyclo[4.3.0]non-5-ene in refluxing toluene followed by ketal hydrolysis during silica gel chromatography to give **5a** (85%, oil), and (3) acetal exchange by refluxing an acetone solution of **5a** in the presence of *p*-toluenesulfonic acid for 3 h (86%, oil).

The aziridinyl imine **5c** generated by reaction of **5b** with 1-amino-*trans*-2,3-diphenylaziridine,[6] on thermolysis in refluxing toluene solution, gave pyrazoline **6**. As anticipated,[4] **6** was converted to vinylcyclopropane **7** (mp 78–80 °C) on irradiation with 366-nm light in benzene solution.

(1) For total syntheses of longifolene, see: (a) Corey, E. J.; Ohno, M.; Mitra, R. B.; Vatakencherry, P. A. *J. Am. Chem. Soc.* **1964**, *86*, 478. (b) McMurry, J. E.; Isser, S. J. *J. Am. Chem. Soc.* **1972**, *94*, 7132. (c) Volkmann, R. A.; Andrews, G. C.; Johnson, W. S. *J. Am. Chem. Soc.* **1975**, *97*, 4777. (d) Oppolzer, W.; Godel, T. *J. Am. Chem. Soc.* **1978**, *100*, 2583.

(2) For additional synthetic studies, see: (a) Scherrer, R. A. Ph.D. Thesis, University of Illinois, 1958; *Diss. Abstr.* **1958**, *19*, 960. (b) Hudak, N. J. Ph.D. Thesis, Cornell University, 1959; *Diss. Abstr.* **1959**, *20*, 79. (c) Napier, R. P. Ph.D. Thesis, University of Rochester, 1964; *Diss. Abstr.* **1964**, *25*, 1577. (d) Grant, J. E., Jr.; Ph.D. Thesis, Pennsylvania State University, 1969; *Diss. Abstr. B.* **1969**, *29*, 3653. (e) Brieger, G. *J. Am. Chem. Soc.* **1963**, *85*, 3783. (f) Glass, R. S.; Herzog, J. D.; Sobczak, R. L. *J. Org. Chem.* **1978**, *43*, 3209.

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(4) Schultz, A. G.; Dittami, J. P.; Eng, K. K. *Tetrahedron Lett.* **1984**, *25*, 1255.

(5) The dimethyl acetal of 2,2-dimethyl-5-iodopentanal was prepared from the dimethyl acetal of 2,2-dimethylpent-4-en-1-al (Brannock, K. C. *J. Am. Chem. Soc.* **1959**, *81*, 3379) by (1) hydroboration ($BH_3$)–oxidation ($H_2O_2$) to give the dimethyl acetal of 2,2-dimethyl-5-hydroxypentanal (94%, oil, C, H analysis), (2) conversion to the mesylate with methanesulfonyl chloride–triethylamine (95%, oil), and (3) substitution with sodium iodide in acetone (91%, oil, C, H analysis).

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