2-propanol (Baker) were used as received.

The surfactant-containing microemulsions had the same component compositions as the detergentless microemulsions except that the water was made 3×10^{-3} M in HTAB and 2×10^{-2} M in $NaDodSO_4$. To the above solutions was added 0.5 mL of each reactant (cyclopentadiene and methyl methacrylate), and the resulting mixtures were placed in a temperature-controlled water bath (26 °C) for 3 days in order to achieve a convenient yield of products. The product analyses were carried out by gas chromatography, using a Varian aerograph series 2700 gas chromatograph. Separations of exo/endo isomers were made on a 6 ft × 0.25 in. 8 Carbowax 1500 on Chromosorb W column. The helium flow rate was 10 mL/min and the column temperature was 105 °C. The retention times were 500 and 650 s for the endo and exo, respectively. The proportions of isomers were determined with a Perkin-Elmer computing integrator and a Perkin-Elmer Sigma 10 data system.

Registry No. Cyclopentadiene, 542-92-7; methyl methacrylate, 80-62-6.

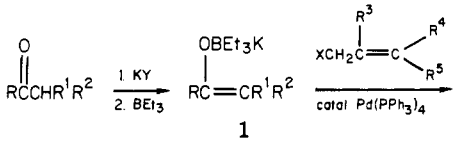
Communications

Highly Regio- and Stereospecific Palladium-Catalyzed Allylation of Enolates Derived from Ketones[1]

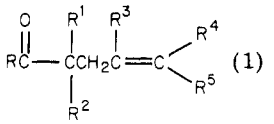
Summary: The reaction of potassium enoxyborates, readily obtainable by treating potassium enolates with a trialkylborane, e.g., triethylborane, with allylic electrophiles such as allylic chlorides and acetates in the presence of a catalytic amount of a palladium–phosphine complex, e.g., $Pd(PPh_3)_4$, proceeds readily at room temperature to produce the corresponding α-allylated ketones in high yields with essentially complete retention of both the enolate regiochemistry and the allyl geometry.

Sir: Allylation of enolates[2] is an important synthetic methodology, since it not only serves as an obvious route to γ,δ-unsaturated carbonyl compounds but also provides attractive routes to α-alkylated carbonyl compounds as well as 1,4- and 1,5-dicarbonyl compounds.

We report here a remarkably facile and selective procedure for allylation of enolates involving the reaction of potassium enoxyborates,[3] readily obtainable by treating potassium enolates[4] with a trialkylborane, e.g., triethylborane, with allylic electrophiles in the presence of a catalytic amount of a palladium complex, e.g., $Pd(PPh_3)_4$ (eq 1).



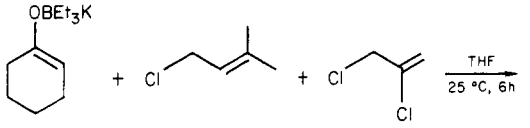
1



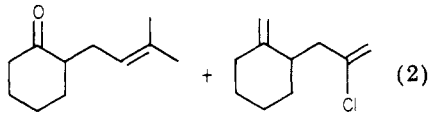
(1)

Y = H, $N(SiMe_3)_2$; X = Cl, OAc

We have recently reported that whereas lithium enolates derived from ketones do not react with trialkylboranes to form the corresponding enoxyborates,[5] the corresponding potassium enolates do[6] and that the resultant potassium enoxyborates (1) selectively react with various alkylating agents to give α-monoalkylated ketones in good yields.[3] Unfortunately, our attempts to apply this procedure to various allylic electrophiles other than allyl bromide have often led to disappointing results. Thus, for example, potassium triethyl(cyclohexenyloxy)borate (2, eq 2) does



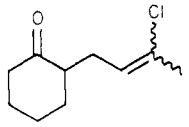
2



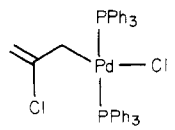
3 (2)

no catalyst	51%	0%
5% $Pd(PPh_3)_4$	6%	92%

not readily react with either 2,3-dichloropropene or 1,3-dichloro-2-butene under conditions suitable for its reaction with allyl bromide.[3,7] We have found, however, that these reactions can be markedly catalyzed by a palladium–phosphine complex such as $Pd(PPh_3)_4$. Thus, whereas the uncatalyzed reactions gave only trace amounts of the allylated products in 3 h, the same reactions run in the presence of 5 mol % of $Pd(PPh_3)_4$ were essentially complete in 3 h, producing 3 or 4 in 80–95% yields.



4



5

That these reactions are genuinely catalyzed by $Pd(PPh_3)_4$ is clearly indicated by the following competitive experiments. Thus, the reaction of 2 with a 1:1 mixture of isoprenyl chloride and 2,3-dichloropropene in THF in

(1) Selective Carbon–Carbon Bond Formation vis Transition Metal Catalysis. 29. Part 28: Negishi, E.; Jadhav, K. P.; Daotien, N. *Tetrahedron Lett.*, in press.

(2) For general reviews on alkylation of enolates, see: (a) House, H. O. "Modern Synthetic Reactions"; W. A. Benjamin: Menlo Park, CA, 1972. (b) Negishi, E. "Organometallics in Organic Synthesis"; Wiley-Interscience: New York, 1980. (c) For allylation of enolates, see: Jung, M. E. *Tetrahedron* **1976**, *32*, 3.

(3) Negishi, E.; Idacavage, M. J.; DiPasquale, F.; Silveira, A., Jr. *Tetrahedron Lett.* **1979**, 845.

(4) Brown, C. A. *J. Org. Chem.* **1974**, *39*, 3913.

(5) Negishi, E.; Idacavage, M. J.; Chiu, K. W.; Yoshida, T.; Abramovitch, A.; Goettel, M. E.; Silveira, A., Jr.; Bretherick, H. D. *J. Chem. Soc., Perkin Trans. 2* **1978**, 1225.

(6) Idacavage, M. J.; Negishi, E.; Brown, C. A. *J. Organomet. Chem.* **1980**, *186*, C55.

(7) Under comparable reaction conditions, the corresponding reaction of lithium cyclohexenolate is also very sluggish, the product yield after 19 h being ≤6%.

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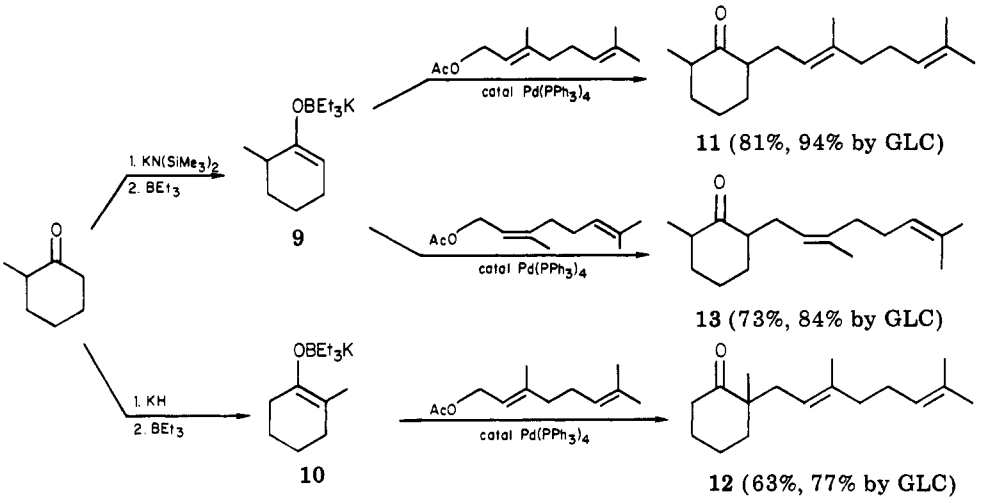
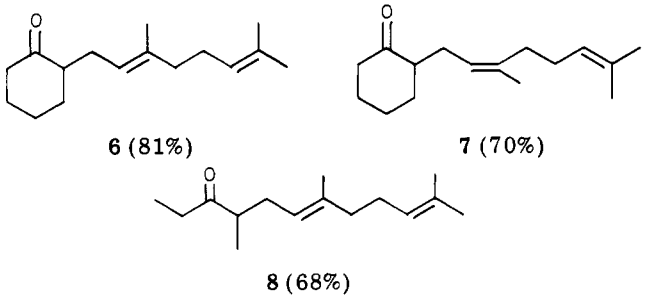
Scheme I



the absence of $Pd(PPh_3)_4$ gave, after 6 h at room temperature, only the isoprenylated cyclohexanone in 51% yield with no sign of the formation of **3**. On the other hand, when the reaction was carried out in the presence of 5 mol % of $Pd(PPh_3)_4$, the major product was **3** formed in 92% yield with only 6% of the isoprenylated product (eq 2). The dramatic reversal of the product ratio appears to be consistent only with an extensive involvement of a (2-chloroallyl)palladium derivative, e.g., **5**, as an intermediate.[8] From the synthetic viewpoint, it is important that those allylic electrophiles that are relatively unreactive in the traditional sense may now be readily used for allylation of enolates under very mild conditions.

Although allylation of alkali metal enolates derived from simple ketones with allylic acetates catalyzed by $Pd(PPh_3)_4$ was reported to be generally unsatisfactory,[9] we have found that the corresponding reaction of potassium enoxyborates proceeds readily at room temperature, as indicated by the stereoselective synthesis of **6**–**8** from geranyl and neryl



6 (81%) 7 (70%)

8 (68%)

acetates with 5 mol % of $Pd(PPh_3)_4$ as a catalyst. Examination by GLC as well as by ^1H and ^{13}C NMR indicates that both the stereoselectivity and regioselectivity with respect to the C_{10} side chain are ≥98% in each case. The remarkably high stereospecificity observed in these reactions is in sharp contrast with that reported recently for a related Pd-catalyzed allylation of enoxystannanes,[11] in which an essentially complete isomerization of *cis*-allylic groups into the *trans*-allylic groups occurs. During the course of our study we became aware of a paper by Fiaud and Malleron[10] reporting allylation of lithium enolates with allylic acetates in the presence of 1 mol % each of bis(dibenzylideneacetonato)palladium and 1,2-bis(diphenylphosphino)ethane at room temperature. Neither the regiospecific trapping of "kinetic" enolates nor the stereospecific allylation (with respect to the alkenyl geometry) is discussed in this paper, however. With $Pd(PPh_3)_4$ as a catalyst we have been unable to achieve a clean and facile allylation of lithium enolates with allylic acetates (vide infra), confirming Trost's earlier finding.[11]

We then examined the regiospecificity of the Pd-catalyzed allylation with respect to the regiochemistry of enolates. To this end, 2-methylcyclohexanone was treated with $KN(SiMe_3)_2$ and KH to product the "kinetic" and "thermodynamic" enolates,[4] respectively, which were then treated with BEt_3 to form the corresponding potassium triethyl(cyclohexenyloxy)borates **9** and **10**, respectively. The reaction of **9** and **10** with geranyl acetate in the presence of 5 mol % of $Pd(PPh_3)_4$ for 24 h at room temperature selectively produced **11** (81% yield, 2,6-*cis*/2,6-*trans* ratio of 2.9/1) and **12** (63% yield), respectively. Moreover, the Pd-catalyzed reaction of **9** with neryl acetate selectively produced **13** (2,6-*cis*/2,6-*trans* ratio of 2.9/1) in 73% yield (Scheme I). The ^1H and ^{13}C NMR spectra of **11** and **13**, isolated without attempts to separate isomers, indicate that the regiochemical purity in each case is ca. 95%, while the stereochemical purity is ≥98%. The observed regiochemistry is comparable to that reported for the generation of the enolate,[4] indicating that the allylation proceeded with essentially complete retention of the enolate regiochemistry. Clean trapping of "kinetic" enolates with *cis*-allyl electrophiles with such high degrees of regio- and stereocontrol appears to be unprecedented.

The ^1H and ^{13}C NMR spectra of **12**, isolated without attempts to separate isomers, indicate that its regiochemical and stereochemical purities are ca. 95% and ≥98%, respectively. Since the regioselectivity in the generation of the "thermodynamic" enolate with KH as a base (6 min at 20 °C) is reported to be only 67%,[4] the observed high regiochemical purity of **12**, while very attractive from the synthetic viewpoint, remains as a puzzle to be clarified.[12]

The marked activation of otherwise relatively unreactive allylic electrophiles and the remarkably high regio- and stereospecificity promise to broaden significantly the applicability of allylation of enolates to the selective synthesis

(8) The oxidative addition of organic halides to Pd(0) complexes is known to be promoted by proximal electron-withdrawing substituents. We believe that the oxidative addition of 2,3-dichloropropene to the Pd(0) catalyst to form an allylpalladium derivative, e.g., **5**, is faster than that of isoprenyl chloride and that this is responsible for the faster rate for the formation of **3**. For a review on the oxidative addition, see: Stille, J. K. *Acc. Chem. Res.* **1977**, *10*, 434.

(9) Trost, B. M. *Acc. Chem. Res.* **1980**, *13*, 385.

(10) Fiaud, M.-C.; Malleron, J.-L. *J. Chem. Soc., Chem. Commun.* **1981**, 1159.

(11) Trost, B. M.; Keinan, E. *Tetrahedron Lett.* **1980**, *21*, 2591.

(12) Currently under investigation.

of complex organic compounds.

The following procedure for the conversion of 2-methylcyclohexanone to 2-methyl-6-nerylcyclohexanone is representative. Bis(trimethylsilyl)amine (3.87 g, 24 mmol) is added to a suspension of KH[4] (0.88 g, 22 mmol) in dry THF (15 mL) at 25 °C. After the evolution of hydrogen is complete (<30 min), the reaction mixture is cooled to −78 °C, and 2-methylcyclohexanone (2.24 g, 20 mmol) in 10 mL of THF is added dropwise, followed by addition of 27 mL (27 mmol) of a 1 M solution of triethylborane in THF. After the resultant mixture is warmed to 25 °C, it is added to a mixture of neryl acetate (3.92 g, 20 mmol), $Pd(PPh_3)_4$[13] (1.15 g, 1 mmol), and 10 mL of THF. The reaction mixture is stirred for 24 h and is treated with 10 mL each of 3 M NaOH and 30% H_2O_2 for 1 h at 0 °C to oxidize triethylborane. The organic layer is separated, and the aqueous layer is extracted with ether. The combined organic layer is sequentially treated with 3 N HCl, aqueous $NaHCO_3$, and water, dried over $MgSO_4$, concentrated, and passed through a short Florisil (100–200 mesh) column (10% ether–hexane) to remove any palladium-containing compounds.[14] After evaporation of the solvents, distillation gives 3.62 g (73% yield) of **13**: bp 145–149 °C (0.5 mm); IR (neat) 1710 (s) cm^{-1}; ^1H NMR ($CDCl_3$, Me_4Si) δ 0.95–1.15 (m with peaks at 0.95, 1.03 and 1.10, 3 H), 1.5–2.5 (m with peaks at 1.61 and 1.68, 23 H), 4.9–5.2 (m, 2 H). The ^1H NMR spectrum of **13** taken at 470 MHz shows two sets of doublets for the cis- and trans-2,6 isomers at 1.05 and 0.99 ppm (J = 6.6 Hz) along with a partially resolved singlet at 1.03 ppm for the regioisomer. This and the ^{13}C NMR spectrum of **13** indicate that the regioselectivity of the reaction is ca. 95%.

Finally, we briefly examined the possibility of using other countercations by reacting various metal cyclohexenolates with geranyl acetate in THF at room temperature in the presence of 5 mol % of $Pd(PPh_3)_4$. Although the metal enolates containing Li,[10,11,15] Me_3Si,[11] and ClZr (η^5-$C_5H_5)_2$ did not produce any detectable amount of **6** in 24 h, those obtained by treating lithium cyclohexenolate with $MgCl_2$, $ZnCl_2$, and $AlEt_3$ gave **6** in 15%, 70%, and 65% yields, respectively. Efforts are being made to clarify the relative merits and demerits of these enolates as well as of potassium enoxyborates.

Acknowledgment. We thank the National Science Foundation and the National Institutes of Health for support. The high-field NMR study was supported by the Purdue University Biochemical Magnetic Resonance Laboratory (Grant NIH RR 01077). H.M. was on leave from the Japan Tobacco and Salt Public Corp. (Jan 1980–Dec 1981) on funds partially provided by that corporation. S.C. was recipient of a National Scholarship awarded by the Ministry of Education, Government of India.

Registry No. **2**, 82167-44-0; **3**, 17392-07-3; **6**, 74016-20-9; **7**, 82167-42-8; **8**, 74016-21-0; **9**, 82167-45-1; **10**, 82167-46-2; **11** (isomer 1), 82167-43-9; **11** (isomer 2), 82189-53-5; **12**, 76524-73-7; **13** (isomer 1), 82189-52-4; **13** (isomer 2), 82189-54-6; $Pd(PPh_3)_4$, 14221-02-4; isoprenyl chloride, 503-60-6; 2,3-dichloropropene, 78-88-6; isoprenylated cyclohexanone, 704-99-4; 2-methylcyclohexanone, 583-60-8; geranyl acetate, 105-87-3; neryl acetate, 141-12-8.

(13) The Pd catalyst was prepared according to the literature procedure (Coulson, D. R. *Inorg. Synth.* **1972**, *13*, 121) and used within a few weeks. This catalyst slowly decomposes on standing. It is not known how long it can be stored at room temperature.

(14) This short-path column chromatography has been used in our laboratories as a precautionary measure. In this case, its need has not been rigorously established. No isomeric separation is achieved in this step.

(15) The reason for the striking difference between our results with lithium enolates and those reported by Fiaud and Malleron[10] is not clear, although it may be suspected to be due to the difference in catalysts. It is clear to us, however, that, in our reaction, metal enolates containing ZnCl and $AlEt_3Li$ are far more reactive than the corresponding lithium enolates under the same reaction conditions.

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Alkoxide-Accelerated Sigmatropic Rearrangements. A Novel Entry to the Bicyclo[5.3.1]undec-7-ene System of the Taxane Diterpenes

Summary: An anionic oxy-Cope rearrangement serves as the key step in a novel route to the bicyclo[5.3.1]undec-7-ene ring system, which is an important structural element of the taxane diterpenes.

Sir: One of the principal challenges in designing a synthetic approach to the taxane class of diterpenes,[1] which includes taxusin (**1**),[2] is the development of a general and efficient technique for the construction of suitably substituted bicyclo[5.3.1]undec-7-enes such as **2**.[3] It occurred to us that one eminently attractive entry to the bicyclo[5.3.1]undecene **2** would involve the skeletal reorganization of the bicyclo[2.2.2]octane **3** via an anionic oxy-Cope rearrangement, a reaction which was originally investigated by Evans[4-6] and subsequently exploited in numerous synthetic applications.[3i,j,6,7] We herein report that this expectation has now been realized in practice (Scheme I).

In order to test the feasibility of employing an anionic oxy-Cope rearrangement for the construction of bicyclo[5.3.1]undec-7-enes, it was necessary to prepare simple

(1) For a leading reference, see Miller, R. W. *J. Nat. Prod.* **1980**, *43*, 425–437.

(2) Della Casa de Marcano, D. P.; Halsall, T. G. *J. Chem. Soc., Chem. Commun.* **1969**, 1282–1283.

(3) For approaches to substituted bicyclo[5.3.1]undecenes, see: (a) Prelog, V.; Barman, P.; Zimmerman, M. *Helv. Chim. Acta* **1949**, *32*, 1284–1296. (b) Marshall, J. A.; Scanio, C. J. V. *J. Org. Chem.* **1965**, *30*, 3019–3023. (c) Warnhoff, E. W.; Wong, C. M.; Tai, W. T. *Ibid.* **1967**, *32*, 2664–2669. (d) Buchanan, G. L.; Jamieson, G. *Tetrahedron* **1972**, *28*, 1129–1135. (e) Dauben, W. G.; Ipaktschi, J. *J. Am. Chem. Soc.* **1973**, *95*, 5088–5089. (f) Roth, W. R.; Erker, G. *Angew. Chem., Int. Ed. Engl.* **1973**, *12*, 503–504. (g) Masamune, S.; Brooks, D. W. *Tetrahedron Lett.* **1977**, 3239–3240. (h) Shea, K. J. *Tetrahedron* **1980**, *36*, 1683–1715. (i) Kahn, M. *Tetrahedron Lett.* **1980**, *21*, 4547–4548. (j) Levine, S. G.; McDaniel, R. L., Jr. *J. Org. Chem.* **1981**, *46*, 2199–2200. (k) Trost, B. M.; Hiemstra, H. *J. Am. Chem. Soc.* **1982**, *104*, 886–887.

(4) Evans, D. A.; Golob, A. M. *J. Am. Chem. Soc.* **1975**, *97*, 4765–4766.

(5) (a) Evans, D. A.; Baillargeon, D. J. *Tetrahedron Lett.* **1978**, 3315–3318, 3319–3322. (b) Steigerwald, M. L.; Goddard, W. A., III; Evans, D. A. *J. Am. Chem. Soc.* **1979**, *101*, 1994–1997.

(6) (a) Evans, D. A.; Baillargeon, D. J.; Nelson, J. V. *J. Am. Chem. Soc.* **1978**, *100*, 2242–2244. (b) Evans, D. A.; Golob, A. M.; Mandel, N. S.; Mandel, G. S. *J. Am. Chem. Soc.* **1978**, *100*, 8170–8174.

(7) (a) Seebach, D.; Geiss, K.-H.; Pohmakotr, M. *Angew. Chem., Int. Ed. Engl.* **1976**, *15*, 437. (b) Still, W. C. *J. Am. Chem. Soc.* **1977**, *99*, 4186–4187; **1979**, *101*, 2493–2495. (c) Kozikowski, A. P.; Schmiesing, R. J. *J. Chem. Soc., Chem. Commun.* **1979**, 106–108. (d) Jung, M. E.; Hudspeth, J. P. *J. Am. Chem. Soc.* **1980**, *102*, 2463–2464. (e) Koreeda, M.; Tanaka, Y.; Schwartz, A. *J. Org. Chem.* **1980**, *45*, 1172–1174. (f) Paquette, L. A.; Crouse, G. D.; Sharman, A. K. *J. Am. Chem. Soc.* **1980**, *102*, 3972–3974. (g) Tice, C. M.; Heathcock, C. H. *J. Org. Chem.* **1981**, *46*, 9–13. (h) Crouse, G. D.; Paquette, L. A. *J. Org. Chem.* **1981**, *46*, 4272–4274; *J. Am. Chem. Soc.* **1981**, *103*, 6235–6236. (i) Schreiber, S. L.; Santini, C. *Tetrahedron Lett.* **1981**, *22*, 4651–4654. (j) Wender, P. A.; Sieburth, S. M.; Petraitis, J. J.; Singh, S. K. *Tetrahedron* **1981**, *37*, 3967–3975. (k) Geetha, P.; Huq, C. A. M. A.; Rajagopalan, K.; Swaminathan, S. *Tetrahedron Lett.* **1982**, *23*, 569–570.

0022-3263/82/1947-3190$01.25/0