Acknowledgment. We express our appreciation to Dr. U. Weiss for valuable discussions.

Registry No. (*S*)-(−)-**2a**, 65915-63-1; (*S*)-(−)-**2b**, 84580-10-9; (*S*)-(−)-**3**, 84499-95-6; (±)-**4a**, 79605-67-7; (*S*)-(−)-**4a**, 84580-11-0; (*S*)-(−)-**4a** camphanate, 84520-47-8; (*S*)-(−)-**4b**, 78341-38-5; **5**, 6786-30-7; (*S*)-(−)-**6a**, 84499-96-7; (*S*)-(−)-**6b**, 84499-97-8; (*S*)-(−)-**7**, 55095-00-6; **8**, 829-14-1; (*S*)-(−)-**9a**, 84499-98-9; (*S*)-(−)-**9b**, 84499-99-0; (*R*)-(+)-**10**, 84500-00-5; (*S*)-(−)-**10**, 84500-01-6; (±)-**11a**, 62249-35-8; (*R*)-(−)-**11a**, 62210-83-7; (*R*)-(−)-**11a** camphanate, 84580-12-1; (*R*)-(−)-**11b**, 84580-13-2; benzocyclohepten-3-one, 826-73-3.

Alkylation of Allylic Derivatives. 4.[1] On the Mechanism of Alkylation of Allylic *N*-Phenylcarbamates with Lithium Dialkylcuprates

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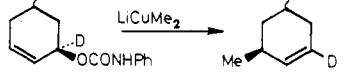
Alkylation of allylic *N*-phenylcarbamates by deprotonation, complexation with CuI in THF, and addition of 1 equiv of RLi results in syn γ-alkylation in both cyclic and acyclic systems. This procedure gives higher stereo- and regiospecificity than when allylic *N*-phenylcarbamates are reacted with 3 equiv of ethereal $LiCuR_2$. A mechanism is presented which incorporates an intramolecular oxidative addition leading to a σ-allyl complex (**3**) which undergoes reductive elimination to give the syn γ-alkylation product.

Gallina and Ciattini[3] recently reported that alkylation of allylic *N*-phenylcarbamates with lithium dimethylcuprate gives exclusive γ-alkylation in both cyclic and acyclic systems. Moreover, in the 5-phenyl-2-cyclohexenyl system (**1**), the reaction results in exclusive syn γ-alkylation as illustrated by eq 1. This regio- and stereochemistry



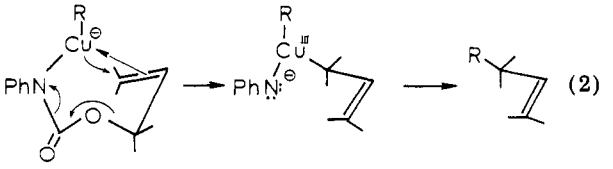
(1)

1-OCONHPh

is in striking contrast to that observed for alkylation of other allylic carboxylates with dialkylcuprates. In general, little if any regiospecificity is observed with allylic esters;[1,3-5] a copper(III) π-allyl complex common to α- and γ-alkylation products is thought to be involved.[1,6] Also, usually stereochemistry favoring anti γ-alkylation and α-alkylation with inversion is observed in both cyclic[3,4,5b] and acyclic systems.[7]

Two or more equivalents of $LiCuMe_2$ are required for alkylation of allylic *N*-phenylcarbamates in ether. With 1 equiv a yellow precipitate (presumed to be CuMe)[3] is formed, and only starting carbamate is recovered on quenching. From this it was concluded that the unique regio- and stereochemistry results from a concerted syn γ-alkylation of the lithium carbamate, whereas alkylations of other carboxylates involve allylic ion-pair intermediates.[3]

An alternate interpretation is that the carbamate is converted to a mixed cuprate (**2**) which undergoes a cyclic intramolecular oxidative addition of the γ carbon to the copper to give a copper(III) σ-allyl complex (**3**). Reductive elimination converts the latter to the syn γ-alkylation product as illustrated in eq 2. This mechanistic pathway



(2)

2 **3**

parallels that proposed earlier for alkylation of allylic carboxylates with mixed cuprates (e.g., RCu(CN)Li).[6] The major difference is that in the present case the oxidative addition step (**2** → **3**) is intramolecular instead of intermolecular, and this requires syn γ bonding. We now report evidence that supports this cyclic mechanism, and we also

Table I. Regiochemistry of Alkylation of α- and γ-D-*cis*-5-Methyl-2-cyclohexenyl *N*-Phenylcarbamate (*cis*-4-OCONHPh)

cis-4 OCONHPh	method[a]	% 1-D-5[b]	% 3-D-5	% yield[c]
α-D	A	98	2	79
α-D	B	52	48	88
α-D	C	>99		66
α-D	D	>99		70
γ-D	D		>99	68

[a] Method A: three equiv of 0.1 M ethereal $LiCuMe_2$ was added slowly to 4-OCONHPh in ether at 0 °C and stirred 10 h at 25 °C. Method B: same as above except 0.4 M ethereal $LiCuMe_2$ was added rapidly. Method C: 1 equiv of 0.4 M ethereal $LiCuMe_2$ was added to 4-OCONHPh in THF at 0 °C and stirred 10 h at 25 °C. Method D: the lithium anion of carbamate was complexed with 1 equiv of CuI in THF followed by addition of 1 equiv of MeLi at 0 °C and stirring at 25 °C. [b] This isomer results from γ-alkylation of α-D-4-OCONHPh and α-alkylation of γ-D-4-OCONHPh. [c] GC yield; 1,5-cyclooctadiene was used as an internal standard.

(1) Previous paper in this series is Goering, H. L.; Seitz, E. P., Jr.; Tseng, C. C. *J. Org. Chem.* **1981**, *46*, 5304.
(2) National Science Foundation Fellow 1977-1980.
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(4) Goering, H. L.; Singleton, V. D., Jr. *J. Am. Chem. Soc.* **1976**, *98*, 7854.
(5) (a) Anderson, R. J.; Henrick, C. A.; Siddall, J. B. *J. Am. Chem. Soc.* **1970**, *92*, 735. (b) Kreft, A. *Tetrahedron Lett.* **1977**, 1035.
(6) Goering, H. L.; Kantner, S. S. *J. Org. Chem.* **1981**, *46*, 2144.
(7) Tseng, C. C., unpublished observations in these laboratories.

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Table II. Stereochemistry of Alkylation of *cis*- and *trans*-5-Methyl-2-cyclohexenyl *N*-Phenylcarbamate (4-OCONHPh)

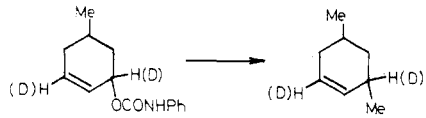
4-OCONHPh	method[a]	% *cis*-5[b]	% *trans*-5
96% cis	A	92	8
96% cis	B	13	87
99% cis	C	99	1
96% cis	D	96	4
100% cis	D	100	0
99% trans	D	0	100

[a] See footnote *a* in Table I. [b] Isomeric composition determined by capillary GC.

report an alternate procedure for alkylation of allylic *N*-phenylcarbamates which gives improved regio- and stereospecificity and has other important advantages.

In this work we have examined the regio- and stereochemistry of alkylation of allylic *N*-phenylcarbamates in the 5-methyl-2-cyclohexenyl (**4**), *trans*-α-methyl-γ-phenylallyl (**8**), and bicyclo[3.2.1]oct-3-en-2-yl (**20**) systems. The regiochemistry was also examined in the *trans*-α-methyl-γ-mesitylallyl system (**13**).

The regiochemistry of methylation of the unbiased 5-methyl-2-cyclohexenyl system (**4**) was investigated with *cis*-α- and -γ-D-4-OCONHPh, and results are presented in Table I. In these experiments the alkylation product, 3,5-dimethylcyclohexene (**5**), was isolated without fractionation of the cis and trans isomers, and the deuterium distribution at C-1 and C-3 was determined by 30.6-MHz ^{2}H NMR. In all cases unreacted 4-OCONHPh remained discretely labeled.



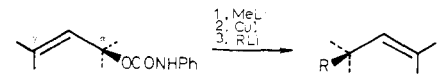
4-OCONHPh 5

Results of stereochemical studies in the 5-methyl-2-cyclohexenyl system (**4**) are presented in Table II. In these experiments isomer ratios were determined by capillary GC. A small amount (5–10%) of 5-methyl-2-cyclohexenol (**4**-OH) with the original configuration was present in the product. Presumably this results from carbonyl attack by an organometallic species.

Four procedures were used in these experiments. Two of these involved alkylation with 3 equiv of $LiCuMe_2$ in ether. This is the cuprate/carbamate ratio used in the original work.[3] Method A involved slowly adding 3 equiv of ethereal $LiCuMe_2$ to an ether solution of carbamate at 0 °C and stirring 10 h at 25 °C. Presumably these conditions are similar to those used in the earlier work.[3] As shown by the first entries in the tables, this procedure gives 98% γ-alkylation and 96% syn alkylation. The regio- and stereospecificities are greatly reduced when the cuprate is added rapidly (method B). These results suggest that two processes are involved. One gives syn γ-alkylation and the other is nonregiospecific but is stereospecific and gives anti alkylation. Presumably the former involves the cyclic process illustrated by eq 2. The latter, which is favored by a high concentration of cuprate, is thought to be an intermolecular alkylation of carbamate with $LiCuMe_2$ with the same regio- and stereochemistry as observed for alkylation of other allylic carboxylates.[4]

Apparently the role of the excess $LiCu(Me)_2$ required for alkylation in ether is to bring the precipitate which results from addition of 1 equiv of $LiCu(Me)_2$ back into solution. Addition of 1 equiv of ethereal $LiCuMe_2$ to a THF solution of carbamate at 0 °C gives a clear solution. Alkylation proceeds smoothyl, and a workup after stirring 10 h at 25 °C (method C) gives reasonable yields of products. As shown in the tables, exclusive syn γ-alkylation is observed under these conditions.

The final procedure is a three-step one-pot process shown by eq 3 (method D). This procedure involves initial



(3)

deprotonation of the carbamate with 1 equiv of methyllithium (first step) followed by complexation of the lithium carbamate with 1 equiv of CuI in THF at 0 °C (second step). The final step is the addition of 1 equiv of alkyllithium (alkylating reagent) to the homogeneous solution. Presumably this gives the mixed cuprate **2** which is converted to product by stirring the solution for several hours at 25 °C.

For most applications method D is the procedure of choice for alkylation of allylic *N*-phenylcarbamates. As shown by Tables I and II, this method gives exclusive syn γ-alkylation. The distinguishing feature of this method is that only 1 equiv of alkyllithium is used in the third step, and this becomes especially important for applications in which an alkyllithium is difficult to obtain. Alkylation using the original procedure[3] (e.g., methods A or B) requires 6 equiv of alkyllithium for good results, and 2 equiv are required for method C. A practical application of a regio- and stereospecific alkylation using method D has been demonstrated.[8]

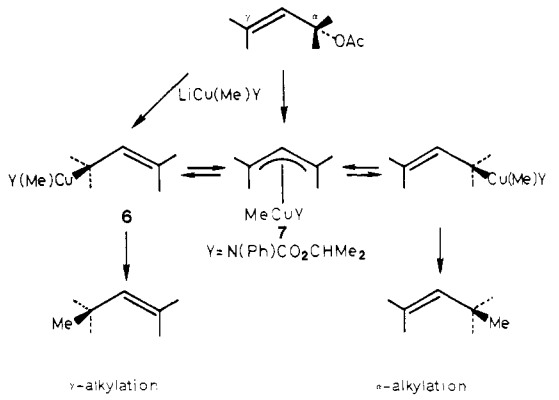
Evidence for the intramolecular cyclic mechanism illustrated by eq 2 was obtained as follows. 2-Cyclohexenyl *N*-phenylcarbamate was alkylated with methyllithium by using method D. After addition of the second equivalent of methyllithium (formation of the mixed cuprate **2**), 5-methyl-2-cyclohexenyl acetate (**4**-OAc) was added to the mixture. After 5 min 16% of the carbamate had been converted to alkylation product, but the allylic acetate (**4**-OAc) was unreacted. After the mixture had been stirred overnight, 86% of the carbamate had been alkylated and only 3% of the **4**-OAc was converted to alkylation product **5**. This shows that the mixed cuprates derived from the carbamate **2** (R = Me) are converted to alkylation product by an intramolecular process (eq 2) much faster than they undergo an intermolecular reaction with the added allylic acetate.

To determine if mixed cuprates containing a nontransferable carbamate ligand will undergo intermolecular alkylation reactions, we prepared $LiCu(Me)N[(Ph)CO_2CHMe_2]$ from 2-propyl *N*-phenylcarbamate by the sequence shown by eq 3. Reaction of this cuprate with 5-methyl-2-cyclohexenyl acetate (**4**-OAc) in THF at 25 °C gave a 55% yield of alkylation product **5** together with substantial amounts of **4**-OH which results from carbonyl attack. The alkylation is stereospecific (100% *cis*-**4**-OAc gives 99% *trans*-**5**) and regiospecific (65% γ-alkylation, 35% α-alkylation). The partial loss of regiochemistry indicates that a π-allyl copper(III) complex (**7**) is involved in this reaction. Presumably this complex is either formed together with the σ-allyl complex (**6**) that results from anti γ oxidative addition[6] or is derived from the intially formed σ complex as illustrated in Scheme I.

The opposite stereochemistry (100% syn) and complete regiospecificity (100% γ-alkylation) for reaction of mixed cuprates derived from secondary allylic *N*-phenylcarbamates **2** is additional evidence that these intermediates react via an intramolecular cyclic process to give the

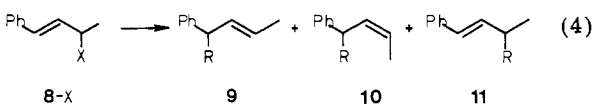
(8) Schmuff, N. J.; Trost, B. M. *J. Org. Chem.*, in press.

Scheme I. Reaction Pathway for Alkylation of Allylic Acetates with Mixed Cuprates



σ-allyl complex **3**. The regiospecificity shows that in this case a π-allyl complex is not involved. The proposal that **6** may isomerize to a π-allyl complex (**7**) whereas **3** clearly does not is not inconsistent because it is known that electron-donating ligands stabilize σ-allyl complexes relative to π-allyl complexes.[9]

In other work we observed that alkylation of *trans*-α-methyl-γ-phenylallyl acetate (**8-OAc**) with dialkylcuprates is nonregiospecific and gives a mixture consisting mainly (~95%) of the thermodynamically favored product, (*E*)-3-alkyl-1-phenyl-1-butene (**11**).[1] In this system alkylation of the *N*-phenylcarbamate (**8-OCONHPh**) with methyllithium by using method D gives 89% (*E*)-4-phenyl-2-pentene (**9**, R = Me) and 11% (*Z*)-4-phenyl-2-pentene (**10**, R = Me) (eq 4). Thus, the thermodynamic

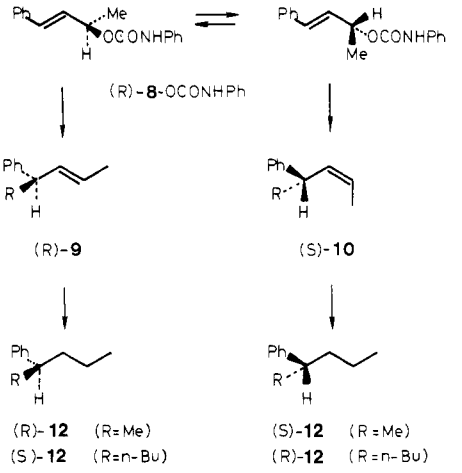


(4)

bias is overcome and exclusive γ-alkylation is observed. The results are essentially the same for alkylation of **8-OCONHPh** with butyllithium (method D). In this case the product consists of 91% **9** (R = Bu), 9% **10** (R = Bu) and a trace (<1%) of the conjugated isomer (**11**, R = Bu). The latter may result from the presence of a slight excess of butyllithium. The *E*/*Z* ratio for alkylation of **8-OCONHPh** (*E*/*Z* = 9) is quite different from that observed earlier[6] for alkylation of **8-OH** with methyllithium by the Murahashi reaction (*E*/*Z* = 2). Presumably this ratio is controlled by the activation barriers for the two reactive conformations[6] as illustrated in Scheme II.

The stereochemistry of alkylation in this acyclic system was determined by using optically active **8-OCONHPh** of known optical purity and configuration. In earlier work[10] we prepared (+)-**8-OH** ($[\alpha]^{30}_D$ +35° ($CHCl_3$)) and reported that this material was 44% optically pure. This was determined by the method of Mislow and Raban[11] which involves esterification with excess optically pure *O*-methylmandelyl chloride and determination of the ratio of the resulting two diastereomers by NMR analysis. In this work we have reexamined the absolute rotation of **8-OH** with a chiral NMR shift reagent, tris[(heptafluorobutyryl)camphorato]europium,[12] and find that the absolute rotation is $[\alpha]^{30}_D$ +35° and $[\alpha]^{20}_D$ 38° ($CHCl_3$). Thus the

Scheme II. Conformations Related to Transition States Leading to (*R*)- and (*S*)-Phenylalkanes



sample that we had in hand in the earlier work was in fact optically pure instead of 44% optically pure.[13] Evidently the reason for the earlier erroneous determination[10] is that the *O*-methylmandelyl chloride was partially racemic or the initially formed *O*-methylmandelate underwent loss of configuration at the allylic position prior to analysis. The absolute configuration of active **8-OH** is known from correlation[14] with the saturated analogue, 4-phenyl-2-butanol, of known absolute configuration.[15]

Alkylation of 82% optically pure (*R*)-(+)-α-methyl-γ-phenylallyl *N*-phenylcarbamate (**8-OCONHPh**), derived from (*R*)-(+)-**8-OH** ($[\alpha]^{30}_D$ +28.7° ($CHCl_3$)), with methyllithium by method D gave a binary mixture of 89% **9** (R = Me) and 11% **10** (R = Me) in 83% isolated yield. As illustrated in Scheme II, syn γ-alkylation of the two reactive conformations of (*R*)-(+)-**8-OCONHPh** gives **9** with the *R* configuration and **10** with the *S* configuration. Diimide reduction[16] converts **9** and **10** into enantiomers, and thus the optical purity of the resulting 2-phenylpentane (**12**, R = Me) is 22% less than that of **9** and **10**. Thus if the optical configuration is fully preserved in the transformation of (*R*)-**8-OCONHPh** to (*R*)-**9** and (*S*)-**10** (syn γ-alkylation), reduction will give **12** (R = Me) with the *R* configuration, and the optical purity will be 78% that of the starting carbamate. In this case the optical purity of **12** (R = Me) will be 78% × 0.82 = 64%. The rotation observed for **12** (R = Me) was $[\alpha]^{20}_D$ −12.8° (*n*-hexane) and α^{23}_D −10.7° (neat). This gives calculated absolute rotations of $[\alpha]^{20}_D$ −20° (*n*-hexane) and α^{23}_D −16.7° (neat). These rotations have the correct sign for (*R*)-**12** (R = Me),[17] and the values compare favorably with rotations presumed to be absolute rotations, $[\alpha]^{13}_D$ −19.4° (*n*-hexane)[17] and α^{23}_D 15° (neat).[18] From this we conclude that exclusive syn γ-alkylation is involved in this acyclic system.

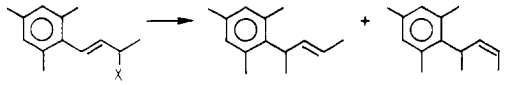
In other work we have used this method to establish the absolute configuration and rotation of 4-phenyloctane (**12**, R = *n*-Bu). Alkylation of 88% optically pure (*S*)-(−)-**8-**

(9) Walter, D.; Wilke, G. *Angew. Chem., Int. Ed. Engl.* **1966**, *5*, 897.
(10) Goering, H. L.; Koermer, G. S.; Linsay, E. C. *J. Am. Chem. Soc.* **1971**, *93*, 1230.
(11) Raban, M.; Mislow, K. *Top. Stereochem.* **1967**, *2*, 199.
(12) Goering, H. L.; Eikenberry, J. N.; Koermer, G. S.; Lattimer, C. J. *J. Am. Chem. Soc.* **1974**, *96*, 1493.
(13) In two recent stereochemical studies the absolute rotation of **8-OH** has been assumed to be substantially lower ($[\alpha]^{20}_D$ +25°) than the value we reported earlier.[10] Brown, H. C.; Pai, G. G. *J. Org. Chem.* **1982**, *47*, 1606. Terashima, S.; Tanno, N.; Koga, K. *J. Chem. Soc., Chem. Commun.* **1980**, 1026. The results of those studies should be corrected accordingly.
(14) Kenyon, J.; Partridge, S. M.; Phillips, H. *J. Chem. Soc.* **1937**, 207.
(15) Cervinka, O.; Kroupova, E.; Belovsky, *Collect. Czech. Chem. Commun.* **1968**, *33*, 3551.
(16) Garbish, E. W., Jr.; Schildcrout, S. M.; Patterson, D. B.; Sprecher, C. M. *J. Am. Chem. Soc.* **1965**, *87*, 2932.
(17) Kawazu, K.; Fujita, T.; Mitsui, T. *J. Am. Chem. Soc.* **1959**, *81*, 932.
(18) Cram, D. J. *J. Am. Chem. Soc.* **1952**, *74*, 2152.

OCONHPh, derived from (*S*)-(−)-**8**-OH ($[\alpha]^{30}_D$ −31° ($CHCl_3$)), with *n*-butyllithium by method D gave a mixture of 91% **9** (R = *n*-Bu), 8.4% **10** (R = *n*-Bu), and ~0.5% of **11** (R = *n*-Bu) in 63% isolated yield. Starting carbamate having the original optical purity was also isolated from the reaction mixture in 24% yield. Diimide reduction of the alkylation product gave 4-phenyloctane (**12**, R = *n*-Bu), $[\alpha]^{25}_D$ −6.3° (*n*-hexane). As shown in Scheme II, (*S*)-**8**-OCONHPh leads to (*R*)-**12** (R = *n*-Bu) via the alkylation product mixture rich in the (*S*)-**9** (R = *n*-Bu) isomer. Thus (−)-**12** (R = *n*-Bu) has the *R* configuration. This demonstrates that the earlier assignment[19] is incorrect.

The 4-phenyloctane derived from the **9**/**10** (R = *n*-Bu) mixture should be 83% as optically pure as the starting carbamate or in this case 83% × 0.88 = 73% optically pure. Therefore, the absolute rotation for (*R*)-**12** (R = *n*-Bu) is −6.3°/0.73 = $[\alpha]^{25}_D$ −8.6° (*n*-hexane).

Two sterically biased systems were also investigated. One of these is the *trans*-α-methyl-γ-mesitylallyl system (**13**). In this system the *N*-phenylcarbamate (**13**-OCONHPh), derived from the corresponding alcohol (**13**-OH),[20] was alkylated with methyllithium by using method D. This alkylation is much slower than that of **8**-OCONHPh, and little, if any, alkylation product was observed. However, yields of up to 25% were obtained by using a reaction time of several days at 0 °C. Evidently the thermal stability of the mixed cuprate **2** is such that the slow alkylation competes more effectively with decomposition at 0 °C than at 25 °C. The alkylation product consisted of 97% (*E*)-**14** and 3% (*Z*)-4-(2,4,6-trimethylphenyl)-2-pentene (**15**) (eq 5); α-alkylation products, (*E*)-**18**

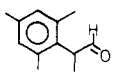


(5)

13-X **14** **15**

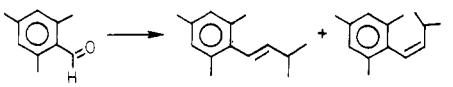
and (*Z*)-1-(2,4,6-trimethylphenyl)-3-methyl-1-butene (**19**), could not be detected. Thus the steric and thermodynamic biases are overcome, and exclusive γ-alkylation obtains. It is noteworthy that in this system the original procedure[3] for alkylation of allylic *N*-phenylcarbamates (method A) is not completely regiospecific. Under these conditions **13**-OCONHPh gives 19% **18** (α-alkylation) together with 71% **14** and 10% **15** (γ-alkylation). Evidently under these conditions an intermolecular process competes with the cyclic intramolecular oxidative addition.

Alkylation products were identified by comparison with authentic samples prepared as follows. Mesitylacetonitrile[21] was converted to 2-(2,4,6-trimethylphenyl)propionaldehyde (**16**) by a recently reported method.[22] This transformation gave a 3:1 mixture of **16** and (2,4,6-trimethylphenyl)acetaldehyde from which pure **16** was isolated by column chromatography. The Wittig reaction[23] of **16** and ethylidenetriphenylphosphorane gave a 14:86 mixture of **14** and **15** (eq 6). Similarly, a 39:61 mixture of (*E*)- and (*Z*)-1-(2,4,6-trimethylphenyl)-3-methyl-1-butene (**18** and **19**) was obtained from the reaction[23] of mesitaldehyde (**17**)[24] and 2-methylpropylidenetriphenylphosphorane (eq 7).



→ 14 + 15 (6)

16



(7)

17 18 19

Pure isomers were isolated from the Wittig mixture of **18** and **19** by preparative GC and identified by their spectral properties. Although the four possible alkylation products (**14**, **15**, **18**, and **19**) are cleanly separated by capillary GC, homogeneous samples of **14** and **15** could not be separated from binary mixtures of the two obtained by alkylation (eq 5) or the Wittig reaction (eq 6). The major and minor components of the binary mixtures of **14** and **15** were identified by decoupled 270-MHz NMR spectrum. Comparison of NMR properties and GC retention times demonstrated that the alkylation product (eq 5) contained the same two components as the authentic binary mixture of **14** and **15** obtained by Wittig reaction (eq 6).

The slow rate of alkylation of **13**-OCONHPh relative to **8**-OCONHPh presumably results from steric crowding in the transition state for the intramolecular cyclic oxidative addition step (i.e., 2 → 3). It has been calculated that the angle between the planes of the ring and double bond in **13**-OH is 57°.[25] Thus the ortho methyl groups are located on each side of the double bond and interfere with bonding to the γ-carbon atom. This twisting of the double bond out of conjugation with the ring also retards intermolecular oxidative addition. In other work we have found that a γ-phenyl substituent increases the rate of alkylation of allylic carboxylates with dialkylcuprates by over 50-fold.

The other sterically biased system that was investigated is the bicyclo[3.2.1]oct-3-en-2-yl system (**20**). Absolute configurations and rotations for this system have been reported previously.[26] Alkylation of (+)-(1*S*,2*S*,5*R*)-*exo*-**20**-OCONHPh, prepared from (+)-*exo*-**20**-OH[27] ($[\alpha]^{25}_D$ +58° ($CHCl_3$), 26.5% optically pure),[26] with methyllithium by method D gave *exo*-2-methylbicyclo[3.2.1]oct-3-ene (*exo*-**21**; $[\alpha]^{25}_D$ −61° ($CHCl_3$)) which was isolated and purified by preparative GC. The rotation of the alkylation product corresponds to 25% optical purity, and the sign corresponds to the 1*R*,2*S*,5*S* configuration.[26] Hence this reaction proceeds with exclusive syn γ-alkylation as illustrated by eq 8.

(8)

exo-(1S,2S,5R)-20 exo-(1R,2S,5S)-21

Attempts to alkylate the endo *N*-phenylcarbamate (*endo*-**20**-OCONHPh) were unsuccessful. No alkylation product was observed regardless of reaction time or temperature. Evidently in this case the reaction is so slow that the intermediate mixed cuprate (**2**) decomposes prior to formation of alkylation products. The reduced reactivity in this case is probably due to steric factors which preclude a cyclic oxidative addition process on the endo surface of

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this hindered rigid system.[28]

Experimental Section

General Methods. All reactions were carried out under a positive pressure of dry nitrogen. Infrared spectra are in reciprocal centimeters. The relative intensity is designated as follows: w, weak; m, medium; s, strong. NMR spectra were determined with a JEOLCO MH-100 or a Bruker WH-270 instrument, chemical shifts are reported in parts per million downfield from Me_4Si. Splitting patterns are designated as follows: s, singlet; d, doublet; q, quartet, m, multiplet; addition of br indicates a broadened pattern. Mass spectra were obtained with an AEI MS-902 high-resolution mass spectrometer. Deuterium spectra were obtained with a Varian XL-100 (15.3 MHz) or a JEOLCO FX-200 (30.6 MHz) instrument. Boiling points and melting points are uncorrected. Satisfactory spectral data were obtained for all compounds. Rotations were determined by using a water-jacketed 1-dm cell. Ether and THF were dried by distillation from sodium benzophenone ketyl or $LiAlH_4$. Ethereal CH_3Li (Ventron, 1:1 LiBr complex) was standardized by double titration,[29] and *n*-BuLi in hexane was standardized by titration with 2-butanol by using *o*-phenanthroline indicator.[30] Cuprous iodide was purified by a published method.[31]

Materials. *cis*- and *trans*-5-methyl-2-cyclohexenol (4-OH) and α- and γ-deuterated *cis*-4-OH were prepared as described earlier.[6]

***cis*- and *trans*-5-methyl-2-cyclohexenyl *N*-phenylcarbamate (4-OCONHPh)** were prepared from 4-OH and phenyl isocyanate.[32] *cis*-4-OCONHPh: mp 91.5–92.5 °C (hexane); IR ($CHCl_3$) 3430 (m), 3020 (w), 2950 (m), 2920 (m), 2870 (w), 2815 (w), 1725 (s), 1600 (s), 1520 (s), 1445 (m); NMR ($CDCl_3$) δ 7.4–6.9 (m, 5 H), 6.68 (br s, 1 H), 5.9–5.6 (m, 2 H), 5.5–5.3 (m, 1 H), 2.3–1.1 (m, 5 H), 0.98 (d, 3 H, J = 6 Hz); mass spectrum, m/e (relative intensity) 232 (M + 1, 4.4), 231 (M^+, 41.5), 188 (6), 187 (45), 186 (5), 146 (6), 145 (53), 138 (13), 137 (6), 120 (13), 119 (48), 112 (17), 111 (19), 96 (60), 95 (98), 94 (61), 93 (83), 92 (44), 91 (60), 70 (74), 67 (76), 55 (100), 43 (74), 41 (78); high-resolution mass spectrum, calcd for $C_{14}H_{17}NO_2$ m/e 231.1259, found m/e 231.1258. *trans*-4-OCONHPh: mp 99–100 °C (hexane); IR ($CHCl_3$) 3430 (m), 3020(w), 2950 (m), 2910 (m), 2870 (w), 2820 (w), 1725 (s), 1600 (m), 1520 (s), 1445 (m); NMR ($CDCl_3$) δ 7.4–6.9 (m, 5 H), 6.60 (br s, 1 H), 6.1–5.7 (m, 2 H), 5.2 (m, 1 H), 2.3–1.4 (m, 5 H), 0.97 (d, 3 H, J = 6 Hz); mass spectrum, m/e (relative intensity) 231 (M^+, 4), 145 (6), 119 (3), 96 (7), 95 (100), 94 (8), 93 (51), 79 (11), 77 (6), 67 (21), 55 (15), 44 (6), 41 (12), 40 (33); high-resolution mass spectrum, calcd for $C_{14}H_{17}NO_2$ m/e 231.1259, found m/e 231.1256.

***trans*-α-Methyl-γ-phenylallyl alcohol (8-OH)** was prepared and resolved as reported previously.[10] A sample of (+)-8-OH ($[\alpha]^{30}_D$ +34.9° (*c* 5.78, $CHCl_3$)) was converted to *trans*-1-phenyl-1-buten-3-yl acetate (8-OAc), $[\alpha]^{20}_D$ +151.5° (*c* 5.27, $CHCl_3$). A 134-mg sample of (+)-8-OAc was combined with 140.9 mg of *dl*-8-OAc and mixed thoroughly. This mixture had $[\alpha]^{20}_D$ +74.3° (5.32, $CHCl_3$). With $Eu(hfbc)_3$,[12] $\Delta\Delta\delta$ = 0.102 for the acetoxy methyl group using an R/S ratio of 0.20. The above mixture was found to be 48.6 ± 1.5% optically pure. Therefore the absolute rotations for (+)-8-OAc and (+)-8-OH are 153 ± 4° and 35.2 ± 1.1° ($CHCl_3$).

***(R)*-(+)-*trans*-α-Methyl-γ-phenylallyl *N*-phenylcarbamate (8-OCONHPh)** was prepared from (*R*)-(+)-8-OH ($[\alpha]^{30}_D$ +28.7° ($CHCl_3$), 82% optically pure) and phenyl isocyanate.[32] This was used in the alkylation experiment without further purification in order to avoid optical fractionation. A sample was recrystallized from ether–pentane to yield (+)-8-OCONHPh: $[\alpha]^{24}_D$ +108.4° (*c* 3.88, $CHCl_3$); mp 106.5–108.5 °C. Two further recrystallizations gave fluffy crystals: mp 109–109.5 °C; $[\alpha]^{24}_D$ +116.2° (*c* 4.1, $CHCl_3$). Similarly, (−)-8-OCONHPh prepared from (−)-8-OH ($[\alpha]^{30}_D$ −30.9° (*c* 5.18, $CHCl_3$), 88% optically pure) gave fluffy white crystals after three recrystallizations from ether–pentane: mp 109–110.5 °C; $[\alpha]^{24}_D$ −115.4° (*c* 4.16, $CHCl_3$). This shows that the absolute rotation of 8-OCONHPh has a lower limit of 116° ($CHCl_3$).

***trans*-α-Methyl-γ-mesitylallyl alcohol (13-OH)**, mp 48–49.5 °C (lit.[20] mp 49 °C), was obtained in 80% yield from the cerium chloride catalyzed sodium borohydride reduction[30] of *trans*-1-(2,4,6-trimethylphenyl)-1-buten-3-one.[20] Reaction of **13**-OH with phenyl isocyanate yielded *trans*-α-methyl-γ-mesitylallyl *N*-phenylcarbamate (13-OCONHPh): mp 96–97 °C (hexane); IR ($CHCl_3$) 3620 (m), 3020 (w), 2970 (m), 2910 (m), 2860 (w), 1725 (s), 1600 (m), 1535 (s), 1445 (m); NMR ($CDCl_3$) δ 7.4–7.0 (m, 5 H), 6.85 (s, 2 H), 6.70 (br s, 1 H), 6.61 (d, 1 H, J = 16.2 Hz), 5.71 (dd, 1 H, J = 16.2, 6.6 Hz), 5.53 (dq, 1 H, J = 6.6, 6.3 Hz), 2.25 (s, 9 H), 1.48 (d, 3 H, J = 6.3 Hz); mass spectrum, m/e (relative intensity) 309 (M^+, 0), 190 (2), 175 (3), 174 (35), 173 (11), 159 (7), 158 (18), 157 (21), 143 (10), 142 (10), 133 (12), 132 (5), 129 (6), 119 (11), 93 (18), 44 (10), 43 (10); high-resolution mass spectrum, calcd for $C_{20}H_{23}NO_2$ m/e 309.1728, found m/e 309.1729.

***exo*-Bicyclo[3.2.1]oct-3-en-2-ol (*exo*-20-OH)** was prepared and resolved as previously described.[27] A sample of (+)-*exo*-20-OH ($[\alpha]^{25}_D$ +57.6° (*c* 1.24, $CHCl_3$), 26 ± 1% optically pure)[26] was converted to **(+)-*exo*-bicyclo[3.2.1]oct-3-en-2-yl *N*-phenylcarbamate** ((+)-*exo*-20-OCONHPh) with phenyl isocyanate. This compound was purified by dissolving it in hot hexane, filtering the solution to remove diphenylurea, and then removing the solvent in vacuo to recover all the carbamate and avoid optical fractionation. This sample had $[\alpha]^{25}_D$ +56.4° (*c* 1.36, $CHCl_3$); mp 124.5–125.5 °C.

***endo*-Bicyclo[3.2.1]oct-3-en-2-yl *N*-phenylcarbamate (*endo*-20-OCONHPh)** was prepared from *endo*-bicyclo[3.2.1]-oct-3-en-2-ol[27] (*endo*-20-OH) and phenyl isocyanate. Addition of a small amount of anhydrous sodium acetate facilitated this reaction. This material had the following: mp 113–115 °C (hexane); IR ($CHCl_3$) 3430 (m), 3020 (w), 2940 (m), 2860 (w), 1725 (s), 1600 (m), 1520 (s), 1440 (s); NMR ($CDCl_3$) δ 7.4–6.9 (m, 5 H), 6.80 (br s, 1 H), 6.02 (ddm, 1 H, J = 9, 6 Hz), 5.6 (m, 1 H), 5.32 (ddd, 1 H, J = 9, 2, 2 Hz), 2.7–1.5 (m, 8 H); mass spectrum, m/e (relative intensity) 243 (M^+, 5), 200 (2), 199 (21), 193 (39), 187 (6), 180 (6), 166 (8), 158 (7), 151 (7), 137 (33), 124 (26), 123 (57), 122 (47), 120 (27), 119 (20), 111 (26), 107 (80), 95 (53), 93 (84), 81 (100), 80 (63), 79 (91), 77 (61), 67 (76), 57 (93), 55 (85), 41 (81); high-resolution mass spectrum, calcd for $C_{15}H_{17}NO_2$ m/e 243.1259, found m/e 243.1256.

Alkylation of 5-Methyl-2-cyclohexenyl *N*-Phenylcarbamate (4-OCONHPh). Method A. In a typical experiment 22.6 mL of 1.06 M ethereal CH_3Li was added to a cooled (0 °C) suspension of 2.29 g (12 mmol) of CuI in 100 mL of dry ether. After the mixture was stirred 15 min at 0 °C, a homogeneous 0.10 M $LiCu(CH_3)_2$ solution was obtained. Twenty milliliters of this cuprate solution was added to a cooled solution (0 °C) of 0.46 g (2 mmol) of *cis*-α-D-4-OCONHPh in 5 mL of dry ether containing 0.22 g (2 mmol) of 1,5-cyclooctadiene as an internal standard. After the mixture was stirred for 3 min, an additional 40 mL of cuprate solution was added, and the reaction mixture was stirred for 10 h at room temperature. The reaction was quenched by addition of 5 mL of saturated NH_4Cl. The resulting mixture was filtered, and the aqueous layer was extracted with 10 mL of ether. The combined organic extracts were washed with 5 mL of 0.2 M HCl and 10 mL of saturated aqueous $NaHCO_3$. After being dried ($MgSO_4$) the solution was concentrated by fractional distillation, and isomer ratios and yields of 3,5-dimethylcyclohexene (**5**) were determined by capillary GC (230-ft column, UCON-LB-550-X, 80 °C). A pure sample of **5** was isolated by preparative GC (10 ft × $^3/_8$ in. column, 20% UCON LB-550-X on Chromasorb W, 80 °C) for determination of the deuterium distribution.

Method B. This procedure was the same as that for method A except that 15 mL of 0.40 M $LiCu(CH_3)_2$ was added at the outset.

Method C. Ethereal $LiCu(CH_3)_2$ (5 mL, 0.40 M) was added with stirring to a cooled solution of 0.46 g (2 mmol) of *cis*-α-D-4-OCONHPh in 10 mL of dry THF containing 0.22 g (2 mmol)

(28) For discussion of steric and stereoelectronic factors in this system see ref 24 and: Goering, H. L.; Mayer, U. *J. Am. Chem. Soc.* **1964**, *86*, 3753. Goering, H. L.; Vlazny, J. C. *Ibid.* **1979**, *101*, 1801.
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of 1,5-cyclooctadiene as an internal standard. After the mixture was stirred overnight at room temperature, the workup and analysis were performed as in method A. This may be the method of choice when the substrate contains remote functional groups (e.g., carbonyl groups) that would react with the strong base in method D.

Method D. A 1.3-mL portion of 1.57 M CH_3Li was added to a solution of 0.46 g (2 mmol) *cis*-α-D-4-OCONHPh in 5 mL dry THF at 0 °C, and the resulting mixture was stirred 5 min (step 1, eq 3). This was transferred with a double-ended needle into a flask containing 0.38 g (2 mmol) of CuI, 10 mL of dry THF, and 0.22 g (2 mmol) of 1,5-cyclooctadiene as an internal standard. After the mixture was stirred 20 min at room temperature, a homogeneous yellow solution was obtained (step 2, eq 3). For good yields complete complexation is important (as evidenced by homogeneity) before proceeding with the third step in eq 3. The solution was then cooled (0 °C), and 1.3 mL of 1.57 M CH_3Li was added (step 3, eq 3). The reaction mixture was then allowed to warm to room temperature and stirred overnight. The workup and analysis were carried out as in method A. Results of these experiment are presented in Tables I and II.

Alkylation of *trans*-α-Methyl-γ-phenylallyl *N*-Phenylcarbamate (8-OCONHPh). (*A*) Alkylation with CH_3Li. The reaction was performed as described for 4-OCONHPh by using method D except the anion of (*R*)-(+)-8-OCONHPh (82% optically pure) was generated at −78 °C and added to CuI at −30 °C. A homogeneous solution was obtained after 30 min at −30 °C to which 1 equiv of CH_3Li was added. Gradual warming to room temperature and 12 h of stirring gave an 83% isolated yield of an 89.3:10.7 mixture of (*R*)-(*E*)-4-phenyl-2-pentene (**9**, R = Me) and (*S*)-(*Z*)-4-phenyl-2-pentene (**10**, R = Me) after workup and distillation [bp 43–44 °C (1.6 mmHg)]. Isomer ratios were determined by capillary GC as reported previously.[1] This mixture was reduced with diimide[16] to yield (−)-2-phenylpentane (**12**, R = Me): bp 38–39 °C (1.7 mmHg) (lit.[18] bp 193 °C); α^{23}_D −10.65° (neat), $[\alpha]^{20}_D$ −12.77° (*c* 1.51, *n*-hexane).

(B) Alkylation with *n*-BuLi. Alkylation of (*S*)-(−)-8-OCONHPh ($[\alpha]^{24}_D$ −102° (*c* 5, $CHCl_3$), 88% optically pure) was performed as described above except that *n*-BuLi in hexane was used in place of CH_3Li and that the reaction mixture was stirred 40 h at room temperature. Column chromatography and distillation [bp 69 °C (0.55 mmHg)] gave a 63% isolated yield of (*E*)-4-phenyl-2-octene (**9**, R = *n*-Bu), (*Z*)-4-phenyl-2-octene (**10**, R = *n*-Bu), and (*E*)-3-methyl-1-phenyl-1-heptene (**11**, R = *n*-Bu) in a ratio of 90.9:8.4:0.7. Isomer ratios were determined by capillary GC as described previously.[1] A 24% yield of starting material which had $[\alpha]^{24}_D$ −101° (*c* 4.5, $CHCl_3$) was recovered by column chromatography. The olefin mixture was reduced with diimide, and the resulting product was purified by distillation and preparative GC (10 ft × $^3/_8$ in. column, 30% UCON LB-550-X on Chromasorb P, 130 °C). The (−)-4-phenyloctane (**12**, R = n-Bu) had the following: $[\alpha]^{25}_D$ −6.32° (*c* 4.56, *n*-hexane); bp 67.5–68.5 °C (0.7 mmHg); Ir (neat) 3080 (w), 3055 (w), 3020 (m), 2955 (s), 2925 (s), 2865 (m), 2850 (m), 1604 (w), 1494 (m), 1468 (m), 1460 (m), 1454 (m), 1380 (w), 765 (m), 704 (s); NMR (CCl_4) δ 7.6–6.6 (m, 5 H), 2.42 (m, 1 H), 2.0–1.4 (m, 4 H), 1.4–1.0 (m, 6 H), 0.82 (br t, 6 H, *J* = 6.5 Hz); mass spectrum, *m/e* (relative intensity) 191 (M + 1, 0.5), 190 (M^+, 10.5), 147 (15), 134 (1), 133 (18), 105 (2), 104 (2), 92 (4), 91 (100), 44 (4), 41 (2), 40 (2). Anal. Calcd for $C_{14}H_{12}$: C, 88.35; H, 11.65. Found: C, 88.29; H, 11.57. The spectral properties and GC retention time were identical with those of authentic *dl*-**12** (R = *n*-Bu) obtained by reaction[34] of 1-bromo-1-phenylbutane[35] and $LiCu(n\text{-}Bu)_2$.

Alkylation of *trans*-α-Methyl-γ-mesitylallyl *N*-Phenylcarbamate (13-OCONHPh). This reaction was performed as described for 4-OCONHPh by using method D and allowing the reaction mixture to stir 7 days at 0 °C. Mesitylene was used as an internal standard. Quenching and concentrating as before gave a 25% yield of (*E*)-4-(2,4,6-trimethylphenyl)-2-pentene (**14**) and (*Z*)-4-(2,4,6-trimethylphenyl)-2-pentene (**15**) in a 96.8:3.2 ratio. The presence and assignment of **14** and **15** and the absence of (*E*)- and (*Z*)-1-(2,4,6-trimethylphenyl)-3-methyl-1-butene (**18** and **19**) was verified by comparison of capillary GC retention times (94-ft column, UCON LB-550-X, 120 °C) with authentic samples.

Authentic samples of (*E*)- and (*Z*)-1-(2,4,6-trimethylphenyl)-3-methyl-1-butene (**18** and **19**) were obtained as follows. A binary mixture of these isomers was prepared by the Wittig reaction[23] of mesitylaldehyde[24] and (2-methylpropyl)triphenylphosphonium bromide. Samples of the isomers were separated from the mixture by preparative GC (10 ft × $^3/_8$ in. column, 15% UCON 50-LB-2000 on Chromasorb P, 70 °C). The homogeneity of the samples was established by capillary GC (94-ft column, UCON LB-550-X, 120 °C).

(*E*)-1-(2,4,6-Trimethylphenyl)-3-methyl-1-butene (18): IR (neat) 3020 (w), 2960 (s), 2920 (m), 1615 (w), 1465 (m), 1385 (w), 1370 (w), 975 (m), 860 (m); NMR (CCl_4) δ 6.58 (s, 2 H), 6.10 (d, 1 H, *J* = 16 Hz), 5.40 (dd, 1 H, *J* = 16, 8 Hz), 2.6–2.1 (m, 1 H), 2.16 (s, 9 H), 1.08 (d, 6 H, *J* = 8 Hz); mass spectrum, *m/e* (relative intensity) 189 (M + 1, 5.6), 188 (M^+, 53.0), 174 (13), 173 (100), 158 (29), 145 (8), 143 (12), 133 (11), 132 (51), 131 (7), 129 (11), 128 (2), 115 (8), 41 (7); high-resolution mass spectrum, calcd for $C_{14}H_{20}$ *m/e* 188.1564, found *m/e* 188.1565. Anal. Calcd for $C_{14}H_{20}$: C, 89.29; H, 10.71. Found: C, 89.28; H, 10.69.

(*Z*)-1-(2,4,6-Trimethylphenyl)-3-methyl-1-butene (19): IR (neat) 2980 (m), 2960 (s), 2860 (m), 1615 (w), 1465 (m), 1385 (w), 1370 (w), 865 (m), 850 (m), 755 (m); NMR (CCl_4) δ 6.60 (s, 2 H), 5.98 (d, 1 H, *J* = 10 Hz), 5.38 (dd, 1 H, *J* = 10, 8 Hz), 2.3–1.9 (m, 1 H), 2.16 (s, 3 H), 2.08 (s, 6 H), 0.84 (d, 6 H, *J* = 8 Hz); mass spectrum, *m/e* (relative intensity) 188 (M^+, 3), 173 (11), 158 (1), 132 (1), 117 (2), 91 (2), 82 (4), 73 (6), 45 (18), 44 (100), 43 (18), 41 (15), 40 (29); high-resolution mass spectrum, calcd for $C_{14}H_{20}$ *m/e* 188.1564, found *m/e* 188.1565. Anal. Calcd for $C_{14}H_{20}$: C, 89.29; H, 10.71. Found: C, 89.29; H, 10.52.

2-(2,4,6-Trimethylphenyl)propionaldehyde (16) was prepared from mesitylacetonitrile[21] by the general method[22] developed in these laboratories. This gave a 3:1 mixture of **16** and the unalkylated product, (2,4,6-trimethylphenyl)acetaldehyde, from which **16** was isolated by column chromatography (silica gel, pentane–ether eluent) as a colorless oil: IR (neat) 2980 (m), 2930 (m), 2870 (w), 2810 (w), 2705 (w), 1730 (s), 1620 (w), 1460 (w); NMR ($CDCl_3$) δ 9.78 (s, 1 H), 6.89 (s, 2 H), 3.76 (q, 1 H, *J* = 7 Hz), 2.26 (s, 3 H), 2.22 (s, 6 H), 1.39 (d, 3 H, *J* = 7 Hz); mass spectrum, *m/e* (relative intensity) 176 (M^+, 17), 149 (15), 148 (7), 147 (100), 121 (4), 119 (5), 110 (26), 109 (3), 91 (6), 77 (6), 55 (6), 45 (6), 44 (77), 43 (12), 41 (15), 40 (71), 39 (7); high-resolution mass spectrum, calcd for $C_{12}H_{16}O$ *m/e* 176.1200, found *m/e* 176.1201. The aldehyde **16** was somewhat unstable, so the 2,4-DNP derivative, mp 201.5–202 °C (95% ethanol), was used for elemental analysis. Anal. Calcd for $C_{18}H_{20}N_4O_4$: C, 60.66; H, 5.66; N, 15.72. Found: C, 60.49; H, 5.62; N, 15.50.

(*E*)- and (*Z*)-4-(2,4,6-trimethylphenyl)-2-pentene (14 and 15) were obtained as a binary mixture from the Wittig reaction[23] of ethyltriphenylphosphonium iodide and 2-(2,4,6-trimethylphenyl)propionaldehyde (**16**). Capillary GC (94-ft column, UCON-LB-55-X, 120 °C) showed that the composition of this mixture (mixture A) was 14% **14** and 86% **15**. Purification by preparative GC (20 ft × $^3/_8$ in. column, 5% LAC 2R-446 on Chromasorb P, 160 °C) gave a mixture of 81% **15** and 19% **14**. This mixture had the following: high-resolution mass spectrum, calcd for $C_{14}H_{20}$ *m/e* 188.1564, found *m/e* 188.1565. Anal. Calcd for $C_{14}H_{20}$: C, 89.29; H, 10.71. Found: C, 89.05; H, 10.81.

A binary mixture consisting of 95% **14** and 5% **15** (mixture B) was isolated from the alkylation product of **13**-OCONHPh. A 270-MHz NMR spectrum of mixture B showed that (*E*)-4-(2,4,6-trimethylphenyl)-2-pentene (**14**) has the following: NMR ($CDCl_3$) δ 6.81 (s, 2 H), 5.70 (ddg, 1 H, *J* = 15.4, 4.4, 1.8 Hz), 5.38 (dqd, 1 H, *J* = 15.4, 6.6, 2.2 Hz), 3.9 (m, 1 H), 2.30 (s, 6 H), 2.23 (s, 3 H), 1.67 (ddd, 3 H, *J* = 6.6, 1.8, 1.8 Hz), 1.35 (d, 3 H, *J* = 7 Hz).

Similarly, the 270-MHz NMR spectrum of mixture A corrected for the presence of **14** showed that (*Z*)-4-(2,4,6-trimethylphenyl)-2-pentene (**15**) has the following: NMR ($CDCl_3$) δ 6.80 (s, 2 H), 5.78 (ddq, 1 H, *J* = 10.8, 7.0, 1.5 Hz), 5.40 (dqd, 1 H, *J* = 10.8, 7.0, 1.8 Hz), 4.1 (m, 1 H), 2.35 (s, 6 H), 2.22 (s, 3 H), 1.44 (ddd, 3 H, *J* = 7.0, 1.5, 0.7 Hz), 1.31 (d, 3 H, *J* = 7.4 Hz).

Alkylation of *exo*-Bicyclo[3.2.1]oct-3-en-2-yl *N*-Phenylcarbamate (*exo*-20-OCONHPh). This reaction was performed as described for 4-OCONHPh by using method D. (+)-*exo*-20-OCONHPh ($[\alpha]^{25}_D$ 56.4° (*c* 1.36, $CHCl_3$), 26 ± 1% optically pure)

(35) Levene, P. A.; Rothen, A.; Kuna, M. *J. Biol. Chem.* **1937**, *120*, 777.

gave *exo*-2-methylbicyclo[3.2.1]oct-3-ene (*exo*-**21**). No endo product was detected by capillary GC (230-ft column, UCON LB-550-X, 85 °C). A sample was obtained by preparative GC (10 ft × $^3/_8$ in. column, 20% UCON LB-550-X on Chromasorb W, 80 °C): $[\alpha]^{25}_D$ −61.3°, $[\alpha]^{25}_D$ −211° (*c* 1.01, $CHCl_3$). Comparison with published values[26] shows that this is 25 ± 1% optically pure (−)-(1*R*,2*S*,5*S*)-*exo*-**21**.

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Registry No. *cis*-4-OCONHPh, 84473-17-6; *trans*-4-OCONHPh, 84473-18-7; *cis*-1-D-**5**, 84473-19-8; *dl*-**8**-OH, 84519-62-0; (*R*)-(+)-**8**-OH, 62413-47-2; (*S*)-(−)-)**8**-OH, 81176-43-4; *dl*-**8**-OAc, 82045-04-3; (*R*)-(+)-**8**-OAc, 84519-63-1; (*R*)-(+)-**8**-OCONHPh, 84473-20-1; (*S*)-(−)-**8**-OCONHPh, 84473-21-2; (*R*)-**9** (R = Me), 84519-64-2; (*R*)-**9** (R = *n*-Bu), 84519-65-3; (*S*)-**10** (R = Me), 84519-66-4; (*S*)-**10** (R = *n*-Bu), 84519-67-5; **11** (R = *n*-Bu), 79594-10-8; (*R*)-(−)-**12** (R = Me), 36667-55-7; *dl*-**12** (R = *n*-Bu), 84473-22-3; (*R*)-(−)-**12** (R = *n*-Bu), 84519-68-6; **13**-OH, 84473-23-4; **13**-OCONHPh, 84473-24-5; **14**, 84473-25-6; **15**, 84473-26-7; **16**, 84473-27-8; **16** 2,4-DNP, 84473-28-9; **18**, 16204-62-9; **19**, 84473-29-0; *endo*-**20**-OH, 32222-49-4; (+)-*exo*-**20**-OH, 84519-69-7; *endo*-**20**-OCONHPh, 84473-30-3; (+)-*exo*-**20**-OCONHPh, 84519-70-0; *exo*-**21**, 78965-86-3; $LiCuMe_2$, 15681-48-8; Li, 7439-93-2; CuI, 7681-65-4; MeLi, 917-54-4; *n*-BuLi, 109-72-8; $LiCu(n\text{-}Bu)_2$, 24406-16-4; phenyl isocyanate, 103-71-9; cerium chloride, 7790-86-5; *trans*-1-(2,4,6-trimethylphenyl)-1-buten-3-one, 42811-78-9; *dl*-1-bromo-1-phenylbutane, 84473-31-4; mesitylaldehyde, 487-68-3; (2-methylpropyl)triphenylphosphonium bromide, 22884-29-3; mesitylacetonitrile, 34688-71-6; ethyltriphenylphosphonium iodide, 4736-60-1.

Alkylation of Allylic Derivatives. 5.[1] Loss of Double-Bond Configuration Associated with α-Alkylation of Allylic Carboxylates with Dialkylcuprates

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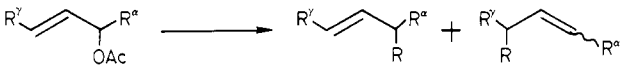
Alkylation of *cis*- and *trans*-cinnamyl acetate with $LiCuMe_2$ gives primarily the conjugated α-alkylation product, 1-phenyl-1-butene. Detectable loss of double-bond configuration is observed with the *trans*-acetate and substantial loss of configuration is observed with the *cis*-acetate. The partial loss of double-bond configuration in the α-alkylation product has profound mechanistic implications, which are discussed.

In the earlier work we showed that alkylation of cyclic[3] and acylic[4] allylic carboxylates with dialkylcuprates is nonregiospecific and gives mixtures of α- and γ-alkylation products (eq 1). The double-bond configuration of the

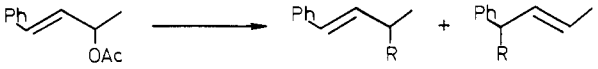


α-alkylation γ-alkylation (1)

α-alkylation product, relative to that of the starting ester, provides important information with regard to the nature of intermediates involved. Put another way, it is necessary to know whether or not double-bond geometry is preserved to distinguish between possible mechanistic pathways.

Our original mechanistic interpretation[5] included bothersome features to accommodate our impression that original double-bond configuration is fully preserved in the unrearranged α-alkylation product. This impression was based on fragmentary evidence such as the report[6] that in the geranyl–neryl system, alkylation of the *E* and *Z* allylic acetates with $LiCuMe_2$ gives α-alkylation without detectable loss of double-bond configuration. The reported[7a] α-alkylation of *cis*-cinnamyl alcohol and (*Z*)-2-buten-1-ol with methyllithium by the Murahashi method without isomerization of the double bond seemed particularly relevant because this reaction is thought to be mechanistically similar to, and involve the same types of intermediates as, alkylation of allylic carboxylates with alkylcuprates.[5,7]

In other work[4] we observed that alkylation of *trans*-α-methyl-γ-phenylallyl acetate (**1**) with dialkylcuprates gives about 95% α-alkylation with preservation of double-bond configuration and about 5% γ-alkylation as illustrated by eq 2. However, in this case the configuration at the outset



1 ~95% ~5% (2)

is the more stable one and retention could result from thermodynamic rather than stereoelectronic factors. In this connection it is noteworthy that in this system γ-alkylation gives only the *E* olefin. Generally, γ-alkylation products are *E*/*Z* mixtures,[1,5,8] but in some cases only the more stable *E* isomer is formed.[4,6]

Conflicting evidence with regard to preservation of double-bond geometry involves the copper(I)-catalyzed alkylation of *E* and *Z* isomeric allylic ethers with methyl Grignard.[9] Presumably this reaction involves a methylcuprate reagent and is mechanistically similar to the alkylation of allylic carboxylates with organocuprates. In the system investigated[9] (disubstituted double bond) the isomeric ethers give the same α-alkylation product (pri-

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