calcd for $C_{15}H_{19}O_2Cl$, 266.1074; found, 266.1066.

(*E*)-**44**: ^1H NMR (CCl_4) δ 7.47 (s, 1 H), 7.28 (s, 5 H), 4.19 (q, J = 7 Hz, 2 H), 1.86 (s, 3 H), 1.29 (t, J = 7 Hz, 3 H); IR (CCl_4) 1721, 1705, 1627, 1453, 1371, 1260, 1202, 1187, 1061; mass spectrum (10 eV), m/z (%) 218 (M^+, 100), 217 (79.3), 203 (24.2), 173 (21.4), 131 (38.6).

(*Z*)-**44**: ^1H NMR (CCl_4) δ 7.42 (s, 1 H), 7.37-7.23 (m, 5 H), 4.19 (q, J = 7 Hz, 2 H), 2.26 (s, 3 H), 1.22 (t, J = 7 Hz, 3 H); IR (CCl_4) 1725, 1696, 1666, 1624, 1604, 1382, 1247, 1231, 1202, 1193, 1185, 1043; mass spectrum (10 eV), m/z (%) 218 (M^+, 100), 217 (71.8), 203 (23.6), 173 (22.9), 131 (33.3). Authentic samples of isomeric ethyl 2-acetylcinnamate (**44**) were prepared by Knoevenagel condensation of ethyl acetoacetate with benzaldehyde for spectroscopic comparison.[72] HRMS calcd for $C_{13}H_{14}O_3$, 218.0943; found, 218.0941.

Anal. Calcd for $C_{13}H_{14}O_3$: C, 71.54; H, 6.47. Found: C, 71.16; H, 6.51.

Reaction of 12 with Trimethylacetyl Chloride. Procedure A was followed using 0.04 mL (0.38 mmol) of $TiCl_4$, 0.05 mL (0.38 mmol) of trimethylacetyl chloride, and 0.074 g (0.34 mmol) of **12**. The reaction mixture was stirred at -78 °C for 8 h before being warmed slowly to room temperature and being allowed to stir for 39.5 h. After the usual workup, GLC analysis indicated protodesilylated material and two products. Thin-layer chromatography (one development, 10% ethyl acetate/hexane as eluent) afforded 20 mg (26%) of the δ-keto esters **41** as a peach-colored oil and 5 mg (10%) of the α-pyrone **42** as an apricot-colored oil.

41: mass spectrum (10 eV), m/e (%) 226 (M^+, 32.1), 181 (32.9), 180 (61.5), 169 (100), 142 (57.6), 141 (43.4), 113 (42.4), 85 (100), 57 (100).

42: mass spectrum (10 eV), m/z (%) 180 (M^+, 100), 137 (72.8), 135 (35.7), 123 (34.3), 85 (23.6), 57 (28.4).

Reaction of 8 with *p*-Anisaldehyde Di-*n*-butyl Acetal. Procedure B was followed using 0.012 mg (0.05 mmol) of Me_3SiOTf, 0.420 g (1.58 mmol) of *p*-anisaldehyde di-*n*-butyl acetal, and 0.405 g (1.54 mmol) of **8**. The reaction mixture was stirred at -78 °C for 4.5 h before being warmed to room temperature and allowed to stir for 17 h. The usual workup afforded 0.596 g (100%) of a brown oil. GLC analysis indicated three product peaks and a minor amount of **8** remaining. Preparative thin-layer chromatography of 298 mg of crude material (two developments, 1% ether/CH_2Cl_2 as eluent) afforded 20 mg (20%) of protodesilylated material and 180 mg (60%) of the isomeric adducts **45**. Separation of the latter (5-μm SiO_2 HPLC column, 0.1% 2-propanol/hexane as eluent) afforded two diastereomers in an average ratio of 65:35, the major diastereomer eluting first. A very minor amount of a third diasteromer eluted last, but the quantity isolated was insufficient for characterization. The major isomer is the 2(*E*) adduct **45a**: ^1H NMR (CCl_4) δ 7.26-7.16 (m, 7 H), 6.83 (d, J = 8.5 Hz, 2 H), 6.17 (d, J = 16 Hz, 1 H), 5.91 (dd, J = 8.8, 16 Hz, 1 H), 4.51 (d, J = 10 Hz), 4.32 (q, J = 7.1 Hz, 2 H), 3.77 (s, 3 H), 3.44 (pseudotriplet, J = 9.4 Hz, 1 H), 3.32-3.19 (m, 2 H), 1.50-1.42 (m, 2 H), 1.39-1.26 (m, 5 H), 0.89-0.83 (t, J = 7.2 Hz, 3 H); mass spectrum (10 eV), m/z (%) no M^+, 193 (100), 137 (50.9); field-desorption mass spectrum found $M^+ + 2$, $M^+ + 1$, and weak M^+.

The minor isomer is the 2(*Z*) adduct **45b**: ^1H NMR (CCl_4) δ 7.27-7.05 (m, 7 H), 6.69 (d, J = 8 Hz, 2 H), 6.22 (d, J = 4 Hz, 2 H), 4.44 (d, J = 7.5 Hz, 1 H), 3.86 (q, J = 8 Hz, 2 H), 3.72 (s, 3 H), 3.33-3.11 (m, 3 H), 1.52-1.38 (m, 2 H), 1.38-1.23 (m, 2 H), 1.04 (t, J = 7.3 Hz, 3 H), 0.83 (t, J = 4.5 Hz, 3 H); mass spectrum (10 eV), m/z (%) no M^+, 193 (100), 137 (56.7).

Acknowledgment. This research was supported by a grant from the National Science Foundation (NSF PCM 80-16752). High-field ^1H NMR spectra (360 MHz) were obtained in the NSF Regional Instrumentation Facility (supported by NSF CHE 79-16100) and high-resolution mass spectra were obtained in the Mass Spectrometry Center (supported by NIH PHS GM-27029). We are grateful to Dr. S. E. Denmark for his helpful comments and to a referee for suggesting the mechanism shown in Scheme VI.

Registry No. **7**, 82343-39-3; (*E*)-**8**, 87696-52-4; (*Z*)-**9a**, 87696-53-5; (*Z*)-**9b**, 87696-54-6; (*E*)-**10a**, 87696-55-7; (*E*)-**10b**, 87696-56-8; (*E*)-**11**, 87696-57-9; (*Z*)-**11**, 87696-69-3; **12**, 87696-58-0; **14**, 4071-88-9; **15**, 87696-70-6; **18**, 61501-32-4; (*E*)-**19**, 87696-71-7; (*Z*)-**19**, 87696-75-1; (*E*)-21, 82343-40-6; **22**, 87696-59-1; (*E*,*E*)-**23**, 82343-43-9; (*E*,*Z*)-**23**, 82343-44-0; (*E*)-**24**, 82343-45-1; **25**, 82343-51-9; **26**, 4467-30-5; (*E*)-**27**, 87696-60-4; (*Z*)-**27**, 87696-73-9; **28**, 82343-53-1; (*E*)-**29**, 57003-45-9; **30**, 6970-56-5; (*E*)-**31**, 82343-50-8; (*E*)-**32**, 82343-46-2; (*Z*)-**32**, 82343-47-3; (*E*)-**33**, 82343-48-4; (*Z*)-**33**, 82343-49-5; (*E*)-**34**, 57003-46-0; **35**, 87696-61-5; (*E*,*E*)-**36**, 41436-08-2; **37**, 87696-62-6; (*E*)-**38**, 82353-28-4; (*Z*)-**38**, 82353-27-3; (*E*)-**39**, 87696-63-7; (*Z*)-**39**, 87696-64-8; (*E*)-**40**, 87696-77-3; (*Z*)-**40**, 87758-35-8; **41**, 87696-65-9; **42**, 87696-66-0; (*R**,*S**-*Z*)-**43**, 87696-67-1; (*R**,*S**-*E*)-**43**, 87696-74-0; (*R**,*R**-*Z*)-**43**, 87696-75-1; (*R**,*R**-*E*)-**43**, 87696-76-2; (*E*)-**44**, 15802-62-7; (*Z*)-**44**, 15802-63-8; **45**, 87696-68-2; **53**, 87696-72-8; $C_5H_{11}CHO$, 66-25-1; *p*-$MeOC_6H_4CHO$, 123-11-5; *p*-$NO_2C_6H_4CHO$, 555-16-8; PhCOCl, 98-88-4; Me_3CCOCl, 3282-30-2; $(CH_3)_2CO$, 67-64-1; $Me_2C(OMe)_2$, 77-76-9; *p*-$MeOC_6H_4CH(O\text{-}n\text{-}Bu)_2$, 82343-41-7; PhCHO, 100-52-7; $PhSCH_2Cl$, 7205-91-6; Me_3SiOTf, 27607-77-8; TiF_4, 7783-63-3; $FeCl_3$, 7705-08-0; $TiCl_4$, 7550-45-0; ethyl α-(diphenylmethylsilyl)acetate, 13950-57-7; ethyl α-bromoacetate, 105-36-2; diphenylmethylsilyl chloride, 144-79-6; ethyl α-(trimethylsilyl)acetate lithium enolate, 54886-62-3; 2-bromopropene, 557-93-7; β-bromostyrene, 103-64-0; (*Z*)-1-bromo-1-propene, 590-13-6; 2-bromo-2-butene, 13294-71-8; propionaldehyde, 123-38-6; tri-*n*-butyl orthoformate, 588-43-2.

(72) (a) Phillips, W. M.; Currie, D. J. *Can. J. Chem.* **1969**, *47*, 3137. (b) Reed, R. I.; Takhistov, V. V. *Tetrahedron* **1967**, *23*, 4425. (c) Currie, D. J.; Lough, C. E.; McClusky, F. K.; Holmes, H. L. *Can. J. Chem.* **1969**, *47*, 3147.

Organotin Nucleophiles. 5.[1] Palladium-Catalyzed Allylic Propargylation with Allenylstannane

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Allenyltrialkylstannanes were found to react with various allylic acetates in the presence of catalytic amounts of $Pd(PPh_3)_4$ under mild neutral conditions, providing a novel approach for obtaining the 1,5-enyne carbon skeleton. The regioselectivity of propargylation depends largely on the electron-withdrawing properties of the substituents at the two ends of the allylic system: substitution occurs at the end of closer proximity to the more electronegative group. Allylic cyanohydrin acetates are substituted at a position α to the cyano group along with formation of a reduced side product. Several mechanistic aspects of these reactions are discussed.

Allenyl metallic species of group 4A are potentially useful and interesting synthetic reagents due to their reactivities at both the allylic and vinylic positions. Although these allenyl metallic compounds are more reactive nu-

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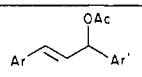
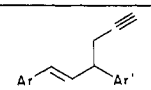
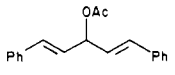
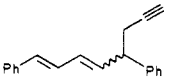
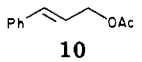
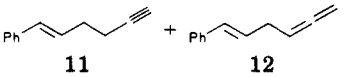
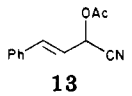
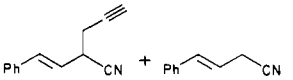
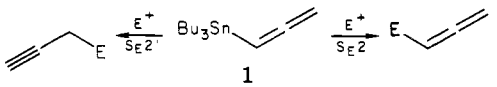
Table I. Palladium-Catalyzed Propargylations of Allylic Acetates

starting material	product	yield, % (isomeric ratio)
		
2, Ar = C_6H_5; Ar′ = 4-FC_6H_4 **4**, Ar = C_6H_5; Ar′ = 4-BrC_6H_4 **6**, Ar = C_6H_5; Ar′ = 4-MeC_6H_4	**3**, Ar, Ar′ = C_6H_5, 4-FC_6H_4 **5**, Ar, Ar′ = C_6H_5, 4-BrC_6H_4 **7**, Ar, Ar′ = C_6H_5, 4-MeC_6H_4	93 (56:44) 80 (53:47) 94 (50:50)
 **8**	 **9**	23 (55:45 *E*/*Z*)
 **10**	 **11** + **12**	62 (60:40)
 **13**	 **14** + **15**	36 (50:50)

cleophiles than their allyl and vinyl analogues, they have, surprisingly, not been investigated thoroughly and, in fact, have been almost overlooked in organic synthesis. This neglect may be a result of the configurational instability[2] of some of these compounds, as well as their ambident nucleophilicity,[3] which is manifested by their participation in both S_E2 (in which they react as vinyl derivatives) and S_E2' (in which they react as allyl derivatives) processes (eq 1).



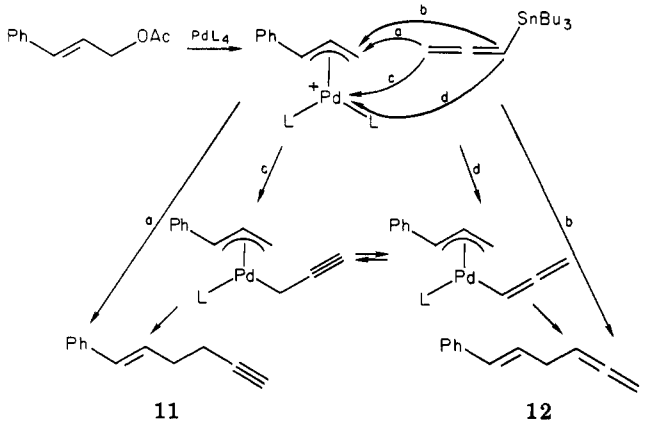
1 (1)

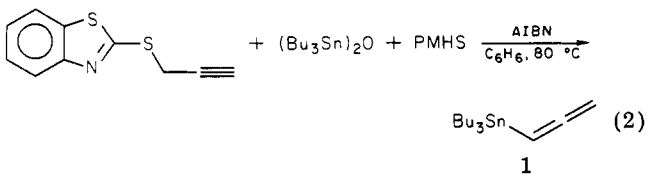
Nevertheless, the synthetic use of allenylsilanes has recently been examined.[4] Allenylstannanes, on the other hand, have received much less attention, particularly with regard to their use in carbon–carbon bond formation. Their nucleophilic reactivity toward *inorganic* electrophiles, however, has been examined.[2,3,5]

Encouraged by the reactivity of enol and allylstannanes toward electrophilic (π-allyl)palladium intermediates,[6] we turned our attention to the related and more intriguing allenylstannanes.

Because trialkyltin species form reasonably stable free radicals, anions, or cations, allenylstannanes can be synthesized by using a variety of approaches. Nevertheless, the best way to prepare allenyltributylstannane is by reacting tributyltin hydride (generated in situ) with 2-(propargylthio)benzothiazole[7] via a free-radical process (eq 2).

Scheme I





1 (2)

PMHS = polymethylhydrosiloxane

Attempts to synthesize the allenyltributylstannane by polar reactions by using either nucleophilic tributyltin anion[8] and propargyl bromide or electrophilic tributyltin chloride and propargylmagnesium[9] or propargyllithium were disappointing. In all of these reactions the allenylstannane produced was contaminated to various extents with the isomeric, thermodynamically more stable (1-propynyl)tributylstannane, which is difficult to separate and, when present, produces undesirable side products.

It was hoped that allenylstannane would react with (π-allyl)palladium electrophiles via allylic inversion (S_E2' mechanism), providing a novel approach to produce the synthetically useful 1,5-enyne carbon skeleton under mild neutral conditions.

Indeed, when various allylic acetates were treated with allenyltributylstannane in THF at room temperature for 0.5–2 h, in the presence of catalytic $Pd(PPh_3)_4$, the ex-

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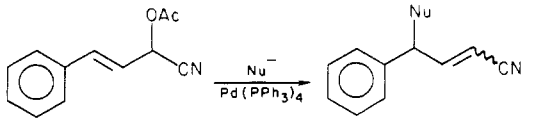
(9) LeQuan, M.; Cadiot, P. *Bull. Soc. Chem. Fr.* **1965**, 45.

pected propargylation took place, as given in Table I.

As expected, it was found that allylic propargylation is nonregioselective when the two ends of the allylic system are similar. The allylic acetates **2**, **4**, and **6** were designed as models for studying how electronegativity of the end substituents affects the regioselectivity of propargylation. Surprisingly, in the model compounds studied, the electronegativity effect is negligibly small, and equal amounts of each regioisomer were produced.

Complete regioselectivity, however, is observed with substrates in which the two ends of the allylic system are substantially different from one another (substrates **8**, **10**, **13**). For example, the propargylation of cinnamyl acetate (**10**) gave substitution exclusively at the primary carbon atom, producing two isomeric products,[10] **11** and **12**, which can, in principle, be formed via at least four different mechanistic pathways (Scheme I). The relative importance of these alternatives in the actual reaction mechanism requires further investigation.

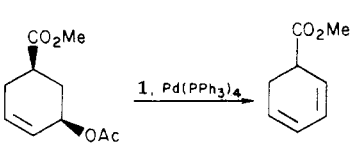
While regioselectivity in substitution of model compounds **8** and **10** may be rationalized by using thermodynamic arguments such as product stability, the regioselective substitution of cyanohydrin acetate **13** is quite puzzling. Exclusive substitution at a position α to the cyano group[11] along with formation of reduced side product **15** contrasts sharply with the known preference of stabilized carbanions, amines, and alkoxides, which attack at the γ-position[12,13] and do not yield reduced products (eq 3). This significant difference may suggest that each regioisomer is produced by a different mechanistic pathway.



(3)

Nu = $NaCH_2(CO_2Me)_2$, Bu_3SnOPh, R_2NH

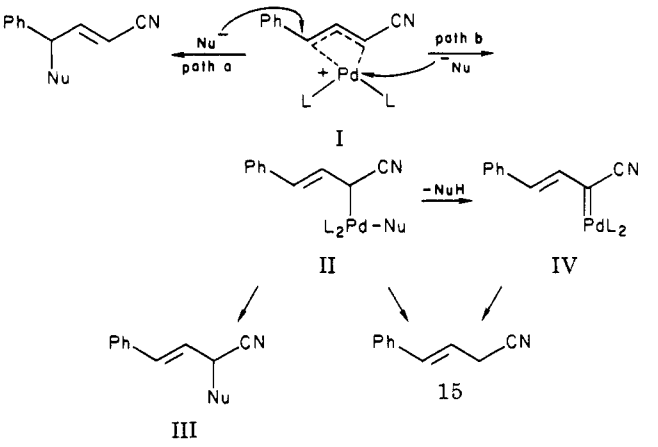
Tetraalkylstannanes are known to undergo facile tin–palladium transmetalation reactions.[14] Therefore, it seems likely that nucleophilic attack of allenylstannane may also occur directly at the palladium atom, followed by reductive elimination to form the C–C bond. Unfortunately, attempts to verify this assumption by elucidation of the stereochemical course of the propargylation by using a stereochemically defined substrate, **16**,[13] were thwarted by the dominance of β-hydride elimination (eq 4), which is also observed when allylstannanes are used as nucleophiles.[6b]



(4)

16

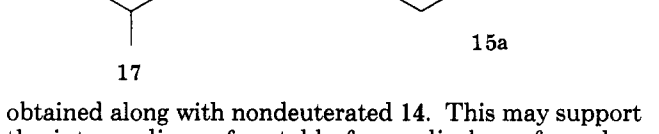
Scheme II



The two types of nucleophilic attack of cyanohydrin acetate may be explained if one assumes that the palladium atom in the η^3 reactive intermediate is asymmetrically bonded to the allylic system and lies closer to the α-carbon[13] (I in Scheme II). This may cause external nucleophilic attack by a stabilized carbanion to occur at the more weakly bound γ-carbon (path a). However, if the carbanion attacks directly at the metal (path b), then a neutral (π-allyl)palladium or (σ-allyl)palladium complex II may be formed, which upon reductive elimination will yield the α-substituted product III.

The formation of a reduced side product, **15**, in the reaction of **13** with **1** or its exclusive formation in reactions involving "hard" nucleophiles[13] (such as (1-propynyl)tributylstannane, phenyllithium, phenylzinc chloride, and lithium dimethylcuprate) is yet more interesting.

Here, one could envision the involvement of an electron-rich intermediate resulting from a one- or two-electron transfer process that forms a stable free radical or carbanion precursor to **15**. Another plausible intermediate is a carbene complex, IV, perhaps resulting from the corresponding σ-allyl complex via an α-hydride elimination process.[14,15] Several deuteration experiments were carried out in order to verify this point. No incorporation of deuterium into products **14** or **15** was observed when the reaction was performed in dry C_6D_6 or even in C_6D_6 saturated with D_2O. This may rule out the intermediacy of an unstable free radical or carbanion species. When the reaction was carried out in the presence of a monodeuterated BHT, **17** (eq 5), partially deuterated **15a** was



(5)

17 15a

obtained along with nondeuterated **14**. This may support the intermediacy of a stable free radical or of an electron-rich organometallic species such as II or IV.

The identity of the hydrogen-radical or hydride donor in the original reaction, where no additives such as **17** were present, remains open. It is tempting to suspect that substrate **13** itself may serve as a hydrogen donor, as it possesses a weak C–H bond due to its allylic nature, as well as to its positioning adjacent to both an acetoxy and a cyano group. For examination of this possibility, mono-

(10) It seems that in the three cases in which mixtures of acetylenic and allenic products were obtained (with substrates **10**, **22**, **23**), these are indeed the authentic coupling products and not secondary products arising from [1,3] or [3,3] sigmatropic rearrangements. The ratio between the isomeric products was found to be reproducible in several runs and independent of reaction time. Also, the purified isomers are stable under the conditions used for these reactions.

(11) It should be emphasized that regioselectivity was found to be independent of the time between the addition of catalyst and the addition of **1** to the solution of **13**. This implies that initial location of the acetate in the starting material (see eq 7) is irrelevant to the regiochemistry of the final product, **14**.

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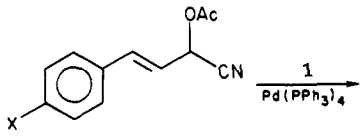
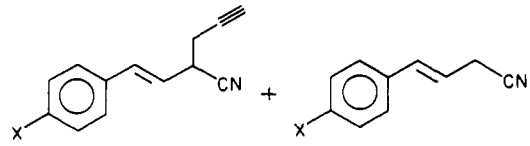
(15) Milstein, D.; Stille, J. K. *J. Am. Chem. Soc.* **1979**, *101*, 4981, 4992.

Table II. Substituent Effect on Propargylation of 13



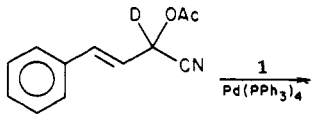
13, 18-21



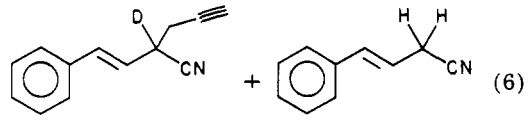
a b

reactant	X	products (% yield)
18	Me	18a (33), 18b (13)
19	OMe	19a (24), 19b (23)
13	H	14 (19), 15 (19)
20	Cl	20a (15), 20b (10)
21	NO_2	

deuterated starting material **13a** was prepared[16] and allowed to react with 1 and Pd(0) catalyst (eq 6). The



13a



(6)

14a 15

monodeuterated product **14a** was obtained, as expected. Obtaining reduced product **15**, however, with no deuterium labeling is quite surprising, supporting the intermediacy of a palladium–carbene complex,[14,15] IV. The option of the formation of **15** via exchange of acidic hydrogens during the reaction mixture workup does not appear reasonable from the evident stability of **14a** under those conditions.

Another possible source for hydride transfer could be the organotin reagent. A competitive transfer of an *n*-butyl group from **1** to palladium followed by β-hydride elimination would produce a palladium hydride species. Nevertheless, the following three observations rule out such a possibility: (a) no side products arising from substitution of allylic acetate by an *n*-butyl group could be detected in any of the reactions; (b) no reaction took place when tetra-*n*-butyltin was employed instead of **1**; (c) identical results were obtained when **13** was allowed to react with either allenyltributyltin, **1**, or allenyltrimethyltin.

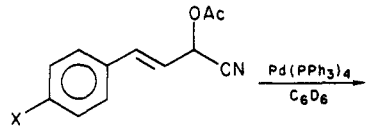
That reductive elimination from intermediate complex II may be one of the steps, and may even be the slowest step in the entire process, is supported by the interesting role played by added benzyl bromide. It has already been demonstrated by Milstein and Stille[15] that reductive elimination from dialkylpalladium(II) is greatly facilitated by stoichiometric quantities of benzyl bromide, which leads to oxidatively induced reductive elimination via an unstable palladium(IV) intermediate.

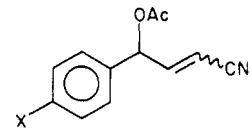
We also observed a significant increase in the yield of **14** when stoichiometric amounts of benzyl bromide were added to the reaction mixture. (see Table III). Interestingly, large quantities of Pd(0) had a deteriorating effect on the yield of **14** due to enhanced decomposition of either **13** or **14**.

Substitution of various groups on to the aromatic ring in **13** (Table II) did not dramatically affect either the yield or product distribution of propargylation. However, slightly higher yields were obtained when electron-donating substituents were present. Reaction with the *p*-nitro derivative produced a mixture of unidentified decomposition products which included metallic palladium.

The small substituent effect upon propargylation of substrates **18–21** may imply that the interaction between the substituent and the (π-allyl)palladium system operates mainly via an inductive mechanism rather than resonance.

Interestingly, a similarly small substituent effect was also observed in the palladium-catalyzed isomerization of allylic acetates **18–21**. Treating these substrates with catalytic amounts of $Pd(PPh_3)_4$ (in the absence of any added nucleophile) induced quantitative allylic isomerization, as was evident from ^1H NMR[17,18] (eq 7). The only apparent





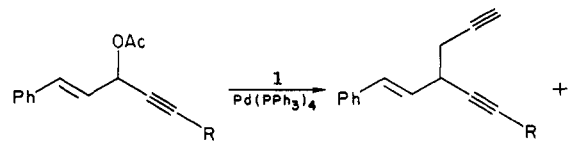
(7)

>99%

X = Me, MeO, H, Cl, NO_2

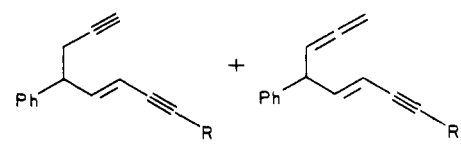
substituent effect observed was an increase in the rate of isomerization as the electron-withdrawing power of the substituent increased.

Substrates **22** and **23**, which are the isostructural acetylenic analogues of **13**, were designed in order to determine whether the observed regioselectivity with **13** results from mere differences in substituent polarity or whether internal complexation of the adjacent triple bond to the palladium atom (a factor forcing it to bond assymmetrically to the two ends of the allylic system) dictates the observed regioselectivity (eq 8).



22, R = Me
23, R = $SiMe_3$

22a (65%)
23a (52%)



(8)

22b (19%)
23b (10%)

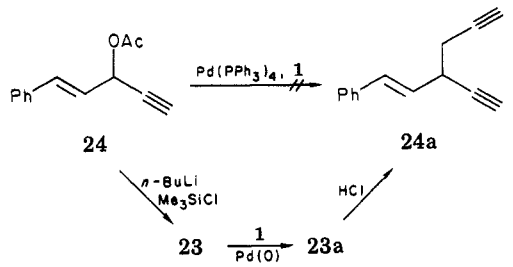
22c (13%)
23c (6%)

The regioselectivity found with the acetylenic substrates may suggest that internal complexation is not of major importance. The selectivity seen with substrates **22** and **23** as well as with most of the other substrates seems to result mainly from electronegativity differences[19] between

(16) Preparation of mondeuterated **13a** was carried out by deprotonation of **13** with LDA in THF at −78 °C, followed by treatment with CD_3CO_2D, at the same temperature.

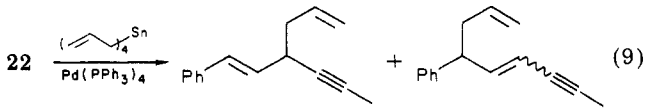
(17) Keinan, E.; Roth, Z., a detailed account to be published elsewhere.
(18) Nudelman, A.; Keinan, E. *Synthesis* **1982**, 687.

Scheme III



the substituents at the two ends of the allylic system which directs propargylation toward the end in closer proximity to the more electron-withdrawing substituent.

A very similar product distribution was observed when substrate **22** was allowed to react with tetraallylstannane[6b] instead of 1 under the same conditions (eq 9).



(9)

25 (66%) 26 (30%)

Compounds possessing a 1,4-diyne skeleton such as **22a** and **23a** are of special importance as they are useful for the cobalt-catalyzed trimerization of acetylenes.[20] The parent system, **24**, unfortunately, when reacted with **1** led to unidentified decomposition products and not to the desired product **24a**. However, this difficulty was eliminated by protecting the terminal acetylene with an easily removable trimethylsilyl group (Scheme III).

Experimental Section

General Remarks. Melting points (uncorrected) were determined on a Büchi apparatus. Elemental analyses were performed in the microanalytical laboratory of the Weizmann Institute of Science. ^{1}H NMR spectra were recorded on Bruker WH-270 and Varian FT-80 NMR spectrometers. Chemical shifts were measured relative to tetramethylsilane (δ 0.00) and are given as δ values. Splitting patterns are designated as follows: s, singlet; d, doublet; t, triplet; q, quartet; m, multiplet; br, broad. Infrared spectra were taken in KBr pellets or neat by using NaCl plates on a Perkin Elmer-467 spectrometer. High-resolution mass spectra were determined on a Varian MAT-731 instrument.

The progress of all reactions was monitored by thin-layer chromatography (TLC) which was performed on aluminum sheets precoated with silica gel (Merck, Kieselgel 60, F_{254}, Art. 5549). Flash chromatography was carried out on silica gel (Merck, Kieselgel 60, 230–400 mesh, Art. 9385). Preparative TLC was performed on glass plates precoated with silica gel (Merck, Kieselgel 60 F_{254}, Art. 5717).

Preparation of Organotin Compounds. (A) Allenyltributylstannane (1) was prepared from 2-(propargylthio)benzothiazole, bis(tributyltin) oxide, and polymethylhydrosiloxane according to the procedure described by Ueno.[7]

(B) Allenyltrimethylstannane. Trimethyltin chloride (24.55 g, 0.123 mol) was added to THF (100 mL) containing sodium (6.25 g, 0.27 mol). The mixture was stirred at room temperature under N_2 for 24 h, and the reaction was then quenched with propargyl bromide (11 mL, 0.137 mol). The precipitate was removed by filtration and the solvent by distillation. Further purification of the product[9] by distillation (99–100 °C) afforded a colorless oil: 10 g (40%); NMR 4.96 (t, J = 7.4 Hz, 1 H), 4.2 (d, J = 7.4 Hz, 2 H), 0.2 (s, 9 H); IR 2990, 2950, 1920, 1200 cm^{-1}.

(C) (1-Propynyl)tributylstannane. Allene was condensed into a cold (−78 °C) solution of THF (43 mL) and HMPA (5 mL) until the weight increased by 2.95 g (0.073 mol). A solution of *n*-butyllithium (24.5 mL of a 1.5 M solution of hexane) was added, and the mixture was warmed to 25 °C, followed by addition of tributyltin chloride (4.9 mL, 0.018 mol). After additional stirring for 30 min, the solvent was removed under reduced pressure, and the product was Kugelrohr distilled at 80–100 °C (0.2 mm): 3.8 g (65%); NMR 1.9 (s, 3 H), 1.6 (m, 6 H), 1.4 (m, 6 H), 1.0 (m, 15 H); IR 2950, 2125, 1915, 1455, 1370, 1335, 1290, 1250 cm^{-1}.

Preparation of Allylic Acetates. 3-Acetoxy-1,3-diarylpropene (General Procedure). The corresponding chalcone was prepared by condensation of an appropriately substituted benzaldehyde with acetophenone.[21] Subsequent reduction with $LiAlH_4$ in ether afforded the allylic alcohol which was then acetylated by using acetic anhydride (3 equiv) and pyridine (7 equiv) with catalytic amounts of 4-(dimethylamino)pyridine. The mixture was worked up with ether–water, and the product was purified by Kugelrohr distillation [140–160 ° (0.2 mm)].

(A) 3-Acetoxy-3-(4-fluorophenyl)-1-phenylpropene (2): NMR 7.35 (m, 9 H), 6.45 (m, 3 H), 2.1 (s, 3 H); IR 3100, 1720, 1600, 1510, 1360, 1220, 1010 cm^{-1}.

(B) 3-Acetoxy-3-(4-bromophenyl)-1-phenylpropene (4): NMR 7.5 (m, 9 H), 6.6 (m, 3 H), 2.2 (s, 3 H); MS *m/e* (relative intensity) 332 (9), 330 (9), 290 (26), 288 (28), 272 (45), 193 (50), 191 (100), 115 (44).

(C) 3-Acetoxy-3-(4-methylphenyl)-1-phenylpropene (6): NMR 7.35 (m, 9 H), 6.45 (m, 3 H), 2.3 (s, 3 H), 2.09 (s, 3 H); IR 3010, 2920, 1730, 1600, 1450, 1240 cm^{-1}.

3-Acetoxy-1,5-diphenyl-1,4-pentadiene (8). Cinnamaldehyde (6.8 mL, 0.054 mol) was added to a cold (0 °C) solution of styryl Grignard reagent (prepared from 15 g magnesium turnings and 7 mL of β-bromostyrene in 100 mL of THF). After 30 min at room temperature, the mixture was quenched with saturated NH_4Cl and dried over anhydrous Na_2SO_4, and the solvent was removed under reduced pressure. The crude allylic alcohol was acetylated with acetic anhydride in pyridine. The crude acetate 8 was purified by flash chromatography: 3.5g (24%); NMR 7.4 (m, 10 H), 6.6 (d, J = 15 Hz, 2 H), 6.2 (dd, J = 15, 8 Hz, 2 H), 3.9 (t, J = 6 Hz, 1 H), 2.65 (s, 10 H); IR 3050, 2900, 1740, 1600, 1510, 1390, 1250 cm^{-1}.

3-Acetoxy-3-cyano-1-arylpropene (General Procedure). The appropriately substituted cinnamaldehyde was prepared from the corresponding benzaldehyde and acetaldehyde under either basic[22] or acidic[23] conditions. The resulting cinnamaldehyde was converted to its cyanohydrin derivative by one of the following procedures.

Procedure A.[18] Concentrated HCl (0.25 mol) was added dropwise into a cold (0 °C) mixture of cinnamaldehyde (0.07 mol) and sodium cyanide (0.3 mol) in CH_2Cl_2 (30 mL). The mixture was extracted with ether and the product was purified, either by recrystallization or by chromatography. Acetylation was carried out as described in procedure B.

Procedure B. Trimethylsilyl cyanide (0.03 mol) was added to a mixture of cinnamaldehyde (0.02 mol) in CH_2Cl_2 (10 mL) containing catalytic amounts of ZnI_2. The mixture was stirred at 25 °C for 10 min, diluted with CH_2Cl_2 (50 mL) and concentrated HCl (0.5 mL), and stirred for an additional 8 h. The mixture was washed with water, concentrated, and mixed with acetic anhydride (0.2 mol), pyridine (0.3 mol), and catalytic amounts of 4-(dimethylamino)pyridine. After 1 h at room temperature, the mixture was worked up with ether and water, and the product was subsequently purified by flash chromatography.

3-Acetoxy-3-cyano-1-phenylpropene (13). Cinnamaldehyde was treated with sodium cyanide according to procedure A to give compound **13** as a colorless oil, which was purified by Kugelrohr distillation [110–120 °C (0.2 mm)]:[18] 70% overall yield; NMR 7.36 (m, 5 H), 7.1 (d, J = 15.5 Hz, 1 H), 6.1 (dd, J = 15.5, 6.5 Hz, 1 H), 5.98 (d, J = 6.5 Hz, 1 H), 2.14 (s, 3 H); MS *m/e* (relative intensity) 201 (16), 159 (67), 141 (100), 140 (67), 115 (66); IR 3010, 2910, 1750, 1445, 1360, 1210 cm^{-1}.

3-Acetoxy-3-cyano-1-(4-methylphenyl)propene (18). 4-Methylcinnamaldehyde was prepared under basic conditions[22] and purified first by Kugelrohr distillation [90–100 °C (0.4 mm)]

(19) Hine, J. In "Structural Effects on Equilibria in Organic Chemistry"; Wiley: New York, 1975; Chapter 3.
(20) Funk, R. L.; Vollhardt, P. C. *J. Am. Chem. Soc.* **1980**, *102*, 5245, 5253.
(21) Vogel, A. I. "Practical Organic Chemistry", 3rd. ed.; Longman: London, 1957; p 718.
(22) Quiniou, H.; Lozach, N. *Bull. Soc. Chim. Fr.* **1963**, 1171.
(23) Waley, S. G. *J. Chem. Soc.* **1948**, 2008.

and then by recrystallization from ethanol–water (34% yield). Further treatment according to procedure A, followed by flash chromatography (with hexane–ethylacetate, 4:1) and recrystallization from ether–hexane, afforded **18** as a white crystalline material: mp 81 °C; NMR 7.2 (m, 4 H), 6.9 (d, J = 14.4 Hz, 1 H), 6.1 (dd, J = 14.4, 6.5 Hz, 1 H), 6.0 (d, J = 6.5 Hz, 1 H), 2.35 (s, 3 H), 2.16 (s, 3 H); MS m/e (relative intensity) 215 (43), 173 (93), 156 (81), 154 (74), 140 (100), 129 (48), 115 (53), 91 (20); IR 2900, 1740, 1600, 1360, 1330, 1210 cm^{-1}.

3-Acetoxy-3-cyano-1-(4-methoxyphenyl)propene (19). 4-Methoxycinnamaldehyde was prepared from p-anisaldehyde under basic conditions (36% yield, reported[22] 23.5%) and was further elaborated according to procedure B to give compound **19** in the form of a colorless viscous oil: NMR 7.1 (m, 4 H), 6.9 (d, J = 13.8 Hz, 1 H), 6.6 (dd, J = 13.8, 6.8 Hz, 1 H), 5.97 (d, J = 6.8 Hz, 1 H), 3.82 (s, 3 H), 2.16 (s, 3 H); MS m/e (relative intensity) 173 (8), 136 (76), 135 (100), 107 (15), 93 (19), 92 (21); IR 2920, 1740, 1600, 1500, 1350, 1220 cm^{-1}.

3-Acetoxy-3-cyano-1-(4-chlorophenyl)propene (20). 4-Chlorocinnamaldehyde was prepared under acidic conditions[23] (51% yield), recrystallized from methanol–water, and then subjected to procedure A. Purification by flash chromatography and recrystallization from ethyl acetate–hexane afforded compound **20** (33%) as white crystalline material: mp 68 °C; NMR 7.3 (br s, 4 H), 6.9 (d, J = 15 Hz, 1 H), 6.1 (dd, J = 15, 6.5 Hz, 1 H), 5.9 (d, J = 6.5 Hz, 1 H), 2.2 (s, 3 H); MS m/e (relative intensity) 235 (6), 193 (15), 176 (15), 152 (17), 141 (23), 140 (100).

3-Acetoxy-3-cyano-1-(4-nitrophenyl)propene (21). 4-Nitrocinnamaldehyde was prepared from 4-nitrobenzaldehyde by condensation with acetaldehyde under acidic conditions[23] and recrystallized from methanol–water. The cyanohydrin acetate was prepared according to procedure A. Purification by flash chromatography yielded a yellowish solid product: mp 98–99 °C; NMR 7.3 (m, 4 H), 6.9 (d, J = 14 Hz, 1 H), 6.3 (dd, J = 14, 6.1 Hz, 1 H), 6.1 (d, J = 6.1 Hz, 1 H), 2.21 (s, 3 H); MS m/e (relative intensity) 246 (0.13), 155 (100), 153 (21), 128 (14), 105 (23), 91 (4).

3-Acetoxy-5-phenylpent-4-en-1-yne (24). Acetylene was condensed into cold (−78 °C) THF (50 mL) until the weight increased by 3.25 g (0.25 mol). A hexane solution of n-BuLi (41.6 mL of a 1.5 M solution) was added slowly at −78 °C, followed by the addition of cinnamaldehyde. The mixture was then warmed to room temperature and quenched with saturated aqueous NH_4Cl. Flash chromatography with hexane–ethyl acetate (3:1) afforded the corresponding propargylic alcohol,[24] which was acetylated with acetic anhydride–pyridine to give compound **24** as a colorless oil: NMR 7.3 (m, 5 H), 6.8 (d, J = 14 Hz, 1 H), 6.1 (dd, J = 14.6, 6.3 Hz, 1 H), 6.05 (d, J = 6.3 Hz, 1 H), 2.64 (d, J = 1.8 Hz, 1 H), 2.1 (s, 3 H); MS m/e (relative intensity) 200 (5), 159 (5), 158 (38), 157 (12), 141 (48), 140 (100), 139 (64), 115 (39); IR 3020, 2900, 2210, 1730, 1340, 1210 cm^{-1}.

4-Acetoxy-6-phenylhex-5-en-2-yne (22). Allene (5 g, 0.12 mol) was condensed into a cold (−78 °C) solution of THF (50 mL) and HMPA (5 mL). A solution of n-BuLi (41.6 mL, 1.5 M solution in hexane) was added slowly, and then the mixture was warmed to 25 °C. Cinnamaldehyde (6 mL, 0.04 mol) was added, and the mixture was stirred at 25 °C for 30 min and then quenched with aqueous NH_4Cl. The crude propargylic alcohol was purified by chromatography affording a colorless oil (3.5g, 47%) which was quantitatively acetylated with acetic anhydride–pyridine to give compound **22**: NMR 7.35 (m, 5 H), 6.85 (d, J = 14 Hz, 1 H), 6.2 (dd, J = 14, 7.1 Hz, 1 H), 6.0 (d, J = 7.1 Hz, 1 H), 2.1 (s, 3 H), 1.9 (d, J = 2 Hz, 3 H); MS m/e (relative intensity) 214 (8), 199 (4), 172 (26), 154 (100), 153 (83), 115 (27); IR 3010, 2960, 2200, 1520, 1430, 1360, 1210 cm^{-1}.

3-Acetoxy-5-phenyl-1-(trimethylsilyl)pent-4-en-1-yne (23). A solution of 3-acetoxy-5-phenylpent-4-en-1-yne (**24**; 0.75 g, 0.0037 mol) in THF (50 mL) was cooled to −78 °C. A solution of n-BuLi (2.5 mL, 1.5 M solution in hexane) was added followed by addition of trimethylsilyl chloride (0.8 g, 0.0074 mol). The mixture was warmed to room temperature and stirred for 1 h. The solvent was removed under reduced pressure, and the crude product was purified by chromatography with ethyl acetate–hexane (1:9): NMR 7.2 (m, 5 H), 6.9 (d, J = 14.6 Hz, 1 H), 6.1 (dd, J = 14.6, 6.4 Hz, 1 H), 6.0 (d, J = 6.4 Hz, 1 H), 2.1 (s, 3 H), 0.2 (s, 9 H); MS m/e (relative intensity) 274 (0.9), 272 (9), 230 (23), 229 (28), 197 (53), 140 (32), 97 (21), 73 (100); IR 2920, 2120, 1730, 1590, 1450, 1360, 1220 cm^{-1}.

General Procedure for Allylic Propargylation. A flame-dried round-bottomed flask was loaded with allylic acetate (0.25 mmol), dry THF (3 mL), allenylstannane (0.5 mmol), and Pd(PPh_3)$_4$ (5 mol %). The mixture was stirred at room temperature for 0.5–3 h or refluxed for 0.5 h under a nitrogen atmosphere. After the disappearance of the starting material (followed by TLC), the solvent was removed by a stream of argon, and the products were isolated by flash chromatography. Yields were determined either by the weight of the product or by NMR integration with bibenzyl as an internal reference.

Reaction of 1 with 3-Acetoxy-3-(4-fluorophenyl)-1-phenylpropene (2). The reaction was completed within 1 h at room temperature. Flash chromatography with hexane afforded a mixture of two isomeric products **3** (93%) at a ratio of 56:44 (by NMR integration): NMR 6.7–7.5 (m, 9 H), 6.2 (m, 2 H), 3.50 (q, J = 7 Hz) and 3.38 (q, J = 7 Hz) in a 56:44 ratio (together 1 H), 2.45 (dd, J = 7, 2.6 Hz) and 2.36 (dt, J = 7.1, 2.2 Hz) in a 56:44 ratio (together 2 H), 1.77 (t, J = 2.2 Hz) and 1.76 (t, J = 2.2 Hz) (together 1 H); MS m/e (relative intensity) 250 (2.3), 212 (16), 211 (100), 196 (12), 133 (36), 115 (32), 109 (14), 91 (17); IR 3300, 3020, 1910, 2100, 1600, 1500, 1270, 1240 cm^{-1}. Anal. Calcd for $C_{18}H_{15}F$: C, 86.37; H, 6.04. Found: C, 86.20; H, 6.09.

Reaction of 1 with 3-Acetoxy-3-(4-bromophenyl)-1-phenylpropene (4). The reaction was completed within 1 h at room temperature. The two isomeric products **5** (80% together) were isolated as a mixture by flash chromatography with hexane. The isomeric ratio (52:48) was determined by HPLC (SI-100; CH_2Cl_2/hexane, 1:9): NMR 7.3 (m, 9 H), 6.4 (m, 2 H), 3.68 (q, J = 5.6 Hz, 1 H), 2.68 (dd, J = 7.1, 2.6 Hz, 2 H), 1.99 (t, J = 2.6 Hz, 1 H); MS m/e (relative intensity) 312 (3.4), 310 (3.4), 273 (61), 271 (61), 192 (100), 115 (25), 91 (12); IR 3290, 3005, 2105, 1900, 1700, 1480 cm^{-1}. Anal. Calcd for $C_{18}H_{15}Br$: C, 69.47; H, 4.86. Found: C, 68.97; H, 5.10.

Reaction of 1 with 1-Acetoxy-3-(4-methylphenyl)-1-phenylpropene (6). The reaction was completed within 45 min at room temperature. The two isomeric products **7** were present in a 50:50 ratio: 94% yield; NMR 7.3 (m, 9 H), 6.63 (m, 2 H), 3.75 (m, 1 H), 2.69 (dd, J = 7.5, 2.5 Hz, 2 H), 2.32 (s) and 2.31 (s) in a 1:1 ratio (together 3 H), 1.96 (t, J = 2.5 Hz, 1 H); MS, m/e (relative intensity) 246 (1.2), 211 (12), 210 (59), 207 (31), 115 (16), 91 (100); IR 3300, 3020, 2910, 2110, 1600, 1490, 1350 cm^{-1}.

Reaction of 1 with 3-Acetoxy-1,5-diphenylpenta-1,4-diene (8). The reaction was completed within 1.5 h at room temperature. Flash chromatography with hexane afforded 1,5-diphenyl-1-propargylpenta-2,4-diene (**9**, 23%) as a mixture of two isomers at the C_2–C_3 double bond (55:45 E/Z). The two isomers were not separated. The NMR absorptions were assigned on the basis of eight double-irradiation experiments at the following lines: 7.12, 6.78, 6.58, 6.49, 6.25, 6.04, 4.14, 3.65 ppm. NMR (E isomer) 7.3 (m, 10 H), 6.78 (dd, J = 15.2, 10.3 Hz, 1 H), 6.49 (d, J = 15.2 Hz, 1 H), 6.26 (dd, J = 15.2, 10.3 Hz, 1 H), 6.04 (dd, J = 15.3, 7.3 Hz, 1 H), 3.65 (q, J = 7 Hz, 1 H), 2.66 (m, 2 H), 2.0 (m, 1 H). NMR (Z isomer) 7.3 (m, 10 H), 7.12 (dd, J = 15.4, 14.8 Hz, 1 H), 6.58 (d, J = 15.4 Hz, 1 H), 6.29 (t, J = 10.8 Hz, 1 H), 5.73 (t, J = 10.3 Hz, 1 H), 4.14 (dt, J = 9, 6.4 Hz, 1 H), 2.65 (m, 2 H), 1.2 (m, 1 H); MS m/e (relative intensity) 258 (11), 219 (84), 141 (20), 115 (45), 91 (100).

Reaction of 1 with Cinnamyl Acetate (10). The mixture was refluxed for 2 h, the solvent was removed, and the crude mixture was Kugelrohr distilled [50–60 °C (0.1 mm)], followed by separation of the two products on preparative TLC, 6-phenylhex-1-yn-5-ene (**11**, 37%) and 6-phenylhexa-1,2,5-triene (**12**, 25%). Spectral data of **11**: NMR 7.3 (m, 5 H), 6.4 (d, J = 16.1 Hz, 1 H), 6.1 (dt, J = 16.1, 5.8 Hz 1 H), 2.43 (t, J = 5.8 Hz, 2 H), 2.37 (m, 2 H), 2.0 (t, J = 2.5 Hz, 1 H); IR 3300, 3015, 2950, 2110, 1700, 1600, 1445 cm^{-1}. Spectral data of **12**: 7.3 (m, 5 H), 6.5 (d, J = 16 Hz, 1 H), 6.1 (dt, J = 16, 5.8 Hz, 1 H), 5.8 (m, 1 H), 5.04 (m, 2 H), 2.2 (m, 2 H); IR 3010, 2930, 1915, 1640, 1600, 1590, 1450 cm^{-1}. Anal. Calcd for $C_{12}H_{12}$ (**11**): C, 92.26; H, 7.74. Found: C, 91.95; H, 7.53. Calcd for $C_{12}H_{12}$ (**12**): C, 92.26; H, 7.74. Found: C, 91.83; H, 7.89.

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Table III. Role of Added Benzyl Bromide in the Propargylation of 13

amt of reactant,[a] mmol			% yield	
1	$Pd(PPh_3)_4$	$PhCH_2Br$	14	15
2	0.17		19	19
2	0.17	0.17	25	19
3	0.17	1	34	20
3	1	1	6	25
2	1		3	27

[a] The amount of **13** used was 1 mmol in all cases.

Reaction of 1 with 3-Acetoxy-3-cyano-1-phenylpropene (13). (A) The reaction was completed within 30 min in refluxed THF, and the two products **14** (19%) and **15** (19%)[25] were isolated by flash chromatography and Kugelrohr distillation [100–120 °C (0.2 mm)]: NMR of **14** 7.3 (m, 5 H), 6.8 (d, J = 15.7 Hz, 1 H), 6.1 (dd, J = 15.7, 6 Hz, 1 H), 3.6 (br q, J = 6 Hz, 1 H), 2.7 (dd, J = 6.8, 2.6 Hz, 2 H); 2.18 (t, J = 2.6 Hz, 1 H); MS, m/e (relative intensity) 181.0890 (16) (calcd for $C_{13}H_{11}N$ 181.1467), 143 (40), 142 (100), 116 (30), 115 (79); IR 3390, 3010, 2910, 2230, 1750, 1480, 1440, 1425, 1210 cm^{-1}; NMR of **15** 7.3 (m, 5 H), 6.55 (dt, J = 16, 1.2 Hz, 1 H), 5.95 (dt, J = 16, 6.1 Hz, 1 H), 3.25 (dd, J = 6.1, 1.2 Hz, 2 H); mp 59.5–60 °C.

(B) The reaction was repeated under the same conditions with varying amounts of catalyst and added benzyl bromide (Table III). The crude mixture of products was Kugelrohr distilled, and the yields were determined by 270-MHz ^1H NMR with bibenzyl as the internal reference.

Reaction of 1 with 3-Acetoxy-3-cyano-1-(4-methylphenyl)propene (18). The reaction mixture was refluxed for 30 min to give two products, **18a** (33%) and **18b** (13%). Spectral characteristics of **18a**: NMR 7.24 (m, 4 H), 6.7 (d, J = 16.2 Hz, 1 H), 6.05 (dd, J = 16.2, 6.3 Hz, 1 H), 3.6 (br q, J = 6.3 Hz, 1 H), 2.67 (dd, J = 6.8, 2.7 Hz, 2 H), 2.34 (s, 3 H), 2.17 (t, J = 2.5 Hz, 1 H); MS, m/e (relative intensity) 195.1027 (17) (calcd for $C_{14}H_{13}N$ 195.1668), 157 (19), 156 (100), 129 (28), 128 (11); IR 3290, 3010, 2900, 2240, 1600 cm^{-1}. Spectral characteristics of **18b**: NMR 7.3 (m, 4 H), 6.5 (dt, J = 16, 1.1 Hz, 1 H), 5.95 (dt, J = 16, 6 Hz, 1 H), 3.3 (dd, J = 6, 1.1 Hz, 2 H), 2.3 (s, 3 H); MS, m/e (relative intensity) 157 (100), 156 (59), 142 (35), 130 (16), 129 (22), 115 (48), 105 (15), 91 (21). IR 3000, 2300, 1650, 1600, 1500, 1410, 1250, 1150 cm^{-1}.

Reaction of 1 with 3-Acetoxy-3-cyano-1-(4-methoxyphenyl)propene (19). The reaction mixture was refluxed for 30 min to give two products, 3-cyano-3-propargyl-1-(4-methoxyphenyl)propene (**19a**, 24%) and 3-cyano-1-(4-methoxyphenyl)propene (**19b**, 23%). Spectral data of **19a**: NMR 7.1 (m, 4 H), 6.73 (d, J = 15.7 Hz, 1 H), 6.0 (dd, J = 15.7, 6.2 Hz, 1 H), 3.8 (s, 3 H), 3.2 (m, 1 H), 2.66 (dd, J = 6.8, 2.7 Hz, 2 H); 2.18 (t, J = 2.7 Hz, 1 H); MS m/e (relative intensity) 172 (100), 171 (69), 156 (41), 145 (35), 128 (36); IR 3300, 2900, 2740, 1600, 1500, 1240 cm^{-1}. Anal. Calcd for $C_{14}H_{13}NO$: C, 79.59; H, 6.20. Found: C, 79.08; H, 6.11. Spectral data of **19b**: NMR 7.1 (m, 4 H), 6.6 (br d, J = 15.7 Hz, 1 H), 5.85 (dt, J = 15.7, 5.5 Hz, 1 H), 3.81 (s, 3 H), 3.26 (dd, J = 5.5, 1.4 Hz, 2 H); MS m/e (relative intensity) 173 (100), 172 (40), 158 (27), 130 (45), 103 (28).

Reaction of 1 with 3-Acetoxy-3-cyano-1-(4-chlorophenyl)propene (20). The reaction mixture was refluxed for 30 min. The two products **20a** (15%) and **20b** (10%) were purified by flash chromatography. NMR of **20a**: 7.3 (m, 4 H), 6.8 (d, J = 15.7 Hz, 1 H), 6.1 (dd, J = 15.7, 6.1 Hz, 1 H), 3.3 (m, 1 H), 2.7 (dd, J = 6.1, 2.6 Hz, 2 H); 2.19 (t, J = 2.6 Hz, 1 H); IR 2900, 2250, 1630, 1590, 1500, 1330, 1100 cm^{-1}. NMR of **20b**: 7.3 (m, 4 H), 6.6 (dd, J = 15.8, 1.6 Hz, 1 H), 6.0 (dt, J = 15.8, 5.5 Hz, 1 H), 3.28 (dd, J = 5.5, 1.6 Hz, 2 H).

Reaction of 1 with 4-Acetoxy-6-phenylhex-5-en-2-yne (22). The mixture was stirred at 25 °C for 1 h and then worked up and separated by flash chromatography to give three products. The first was 6-phenyl-6-propargylhex-4-en-2-yne (**22b**, 19%) as a 3:1 mixture of the E/Z isomers. E isomer: NMR 7.3 (m, 5 H), 6.26 (dd, J = 16.9, 7.2 Hz, 1 H), 5.49 (dq, J = 16.9, 2.4 Hz, 1 H), 3.56 (q, J = 7.2 Hz, 1 H), 2.6 (dd, J = 7.2, 2.6 Hz, 2 H), 1.95 (t, J = 2.6 Hz, 1 H), 1.91 (d, 2.4 Hz, 3 H). Z isomer: NMR 7.3 (m, 5 H), 6.0 (br t, J = 10 Hz, 1 H), 5.5 (dq, J = 10, 2.4 Hz, 1 H), 4.19 (dt, J = 10, 7.2 Hz, 1 H), 2.6 (dd, J = 7.2, 2.6 Hz, 2 H), 1.97 (d, J = 2.4 Hz, 3 H), 1.94 (t, J = 2.6 Hz, 1 H); MS, m/e (relative intensity) 194 (2), 155 (100), 153 (99), 115 (22). IR 3280, 3005, 2900, 2190, 2120, 1600, 1480, 1440, 1260 cm^{-1}.

The other two products, 6-phenyl-4-propargylhex-5-en-2-yne (**22a**, 65%) and 6-phenyl-6-allenylhex-4-en-2-yne (**22c**, 13%), were not separated from one another. NMR assignments were done on the basis of nine double irradiation experiments at the following lines: 6.66, 6.23, 5.99, 5.49, 5.32, 4.78, 4.08, 2.08, 1.98 ppm. NMR of **22a**: 7.3 (m, 5 H), 6.6 (dd, J = 15.55, 9.68 Hz, 1 H), 6.49 (d, J = 15.55 Hz, 1 H), 6.0 (d of sextets, J = 9.68, 2.6 Hz, 1 H), 2.97 (t, J = 2.6 Hz, 2 H), 2.08 (t, J = 2.6 Hz, 1 H), 1.45 (d, J = 2.6 Hz, 3 H). NMR of **22c**: 7.3 (m, 5 H), 6.2 (dd, J = 17.0, 7.0 Hz, 1 H), 5.49 (dm, J = 17.0 Hz, 1 H), 5.31 (br q, J = 6.7 Hz, 1 H), 4.78 (dd, J = 6.7, 2.6 Hz, 2 H), 4.12 (m, 1 H), 1.91 (d, J = 2.3 Hz, 3 H).

Reaction of 1 with 3-Acetoxy-5-phenyl-1-(trimethylsilyl)pent-4-en-1-yne (23). The mixture was allowed to react at room temperature for 1 h and then subjected to flash chromatography with hexane. The main product, 1-(trimethylsilyl)-3-propargyl-5-phenylpent-4-en-1-yne (**23a**, 52%), was contaminated with 1-(trimethylsilyl)-5-propargyl-5-phenylpent-3-en-1-yne (**23b**, 10%) and 1-(trimethylsilyl)-5-allenyl-5-phenylpent-3-en-1-yne (**23c**, 6%). NMR of **23a**: 7.3 (m, 5 H), 6.6 (dd, J = 15.8, 9.9 Hz, 1 H), 6.46 (d, J = 15.8 Hz, 1 H), 5.88 (dt, J = 9.9, 3.0 Hz, 1 H), 3.0 (br t, J, 2.8 Hz, 2 H), 2.1 (t, J = 2.6 Hz, 1 H), 0.17 (s, 9 H).

3-Propargyl-5-phenylpent-4-en-1-yne (24a). 1-(Trimethylsilyl)-3-propargyl-5-phenylpent-4-en-1-yne (**23a**, 16 mg) was dissolved in CH_2Cl_2 (2 mL) and treated with a 1 M THF solution of tetrabutylammonium fluoride (0.2 mL) for 10 min. The mixture was filtered through a short silica gel column, and the solvent was removed under reduced pressure, affording **24a** (92%) as a viscous oil: NMR 7.3 (m, 5 H), 6.61 (dd, J = 15.26, 9.4 Hz, 1 H), 6.52 (d, J = 15.26 Hz, 1 H), 6.1 (m, 1 H), 2.98 (m, 2 H), 2.09 (t, J = 2.6 Hz, 1 H), 1.85 (d, J = 2.6 Hz, 1 H).

Reaction of Tetraallyltin with 4-Acetoxy-6-phenylhex-5-en-2-yne (22). Tetraallyltin was allowed to react with **22** at room temperature according to the procedure described for the reaction with allenyltributyltin. The two regioisomeric products were separated by flash chromatography with hexane to give 4-(1-propynyl)-6-phenylhexa-1,5-diene (**25**, 66%) and 6-phenylnona-4,8-dien-2-yne (**26**, 30%) (a mixture of two isomers with respect to C_4–C_5 double bond in a 3:1 E/Z ratio). Spectral data of **25**: NMR 7.3 (m, 5 H), 6.55 (dd, J = 16, 10.4 Hz, 1 H), 6.42 (d, J = 16 Hz, 1 H), 5.8 (m, 2 H), 5.08 (d, J = 16.4 Hz, 1 H), 5.04 (d, J = 8.8 Hz, 1 H), 2.77 (m, 2 H), 1.72 (d, J = 2.4 Hz, 3 H); IR 3450, 2990, 2950, 2210, 1940, 1700, 1630, 1450 cm^{-1}; MS, m/e (relative intensity) 196 (9), 181 (7), 155 (100), 153 (23), 128 (16), 115 (26), 91 (19). Anal. Calcd for $C_{15}H_{16}$: C, 91.78; H, 8.22. Found: C, 91.04; H, 8.41. Spectral data of **26**: NMR (of the Z isomer) 7.3 (m, 5 H), 5.9 (t, J = 10 Hz, 1 H), 5.74 (m, 1 H), 5.47 (dq, J = 10.8, 2.4 Hz, 1 H), 5.0 (m, 2 H), 3.22 (dt, J = 10, 8 Hz, 1 H), 2.49 (m, 2 H), 1.98 (d, J = 2.4 Hz, 3 H). NMR (of the E isomer) 7.3 (m, 5 H), 6.2 (dd, J = 16.6, 7.4 Hz, 1 H), 5.74 (m, 1 H), 5.41 (dq, J = 16.6, 2.4 Hz, 1 H), 5.0 (m, 2 H), 3.36 (br q, J = 7 Hz, 1 H), 2.49 (m, 2 H), 1.9 (d, J = 2.4 Hz, 3 H); IR 3450, 3010, 2960, 2210, 1640, 1600, 1490, 1440 cm^{-1}; MS, m/e (relative intensity) 196 (2.4), 155 (100), 153 (22), 129 (14), 128 (14), 115 (24), 91 (11).

Reaction of 1-Propynyltributyltin with 3-Acetoxy-3-cyano-1-phenylpropene (13). The mixture was stirred at room temperature for 24 h and worked up in the usual way, affording a single isolable product, **15** (67%).

Reaction of Allenyltrimethyltin with 18. The reaction was carried out at room temperature for 1.5 h, followed by flash chromatography, leading to **18a** (18%) and **18b** (16%).

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Registry No. **1**, 53915-69-8; **2**, 87639-09-6; **3** (isomer 1), 87639-10-9; **3** (isomer 2), 87639-11-0; **4**, 86668-24-8; **5** (isomer 1), 87639-12-1; **5** (isomer 2), 87639-13-2; **6**, 87639-14-3; **7** (isomer 1), 87639-15-4; **7** (isomer 2), 87639-16-5; **8**, 87639-17-6; **9**, 87639-18-7; **10**, 103-54-8; **11**, 87639-19-8; **12**, 87639-20-1; **13**, 79265-03-5; **14**,

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87655-06-9; **15**, 16170-45-9; **18**, 81981-13-7; **18a**, 87639-21-2; **18b**, 81981-14-8; **19**, 87639-22-3; **19a**, 87639-23-4; **19b**, 87639-24-5; **20**, 81981-17-1; **20a**, 87639-25-6; **20b**, 81981-18-2; **21**, 87639-26-7; **22**, 87639-27-8; **22a**, 87639-28-9; (*E*)-**22b**, 87639-29-0; (*Z*)-**22b**, 87639-30-3; **22c**, 87639-31-4; **23**, 87639-32-5; **23a**, 87639-33-6; **23b**, 87655-08-1; **23c**, 87639-34-7; **24**, 63399-81-5; **24a**, 87639-35-8; **25**, 87639-36-9; (*E*)-**26**, 87639-37-0; (*Z*)-**26**, 87639-38-1; Bu_3SnH, 688-73-3; $(Bu_3Sn)_2O$, 56-35-9; PMHS, 9004-73-3; $Pd(PPh_3)_4$, 14221-01-3; $PhCH_2Br$, 100-39-0; 2-(propargylthio)benzothiazole, 42477-59-8; (1-propynyl)tributylstannane, 64099-82-7; allenyltrimethylstannane, 4104-88-5; trimethyltin chloride, 1066-45-1; propargyl bromide, 106-96-7; allene, 463-49-0; tributyltin chloride, 1461-22-9; cinnamaldehyde, 104-55-2; β-bromostyrene, 103-64-0; 1,5-diphenyl-1,4-pentadien-3-ol, 3185-53-3; sodium cyanide, 143-33-9; trimethylsilyl cyanide, 7677-24-9; 4-methylcinnamaldehyde, 1504-75-2; 4-methoxycinnamaldehyde, 1963-36-6; *p*-anisaldehyde, 123-11-5; 4-chlorocinnamaldehyde, 1075-77-0; 4-nitrocinnamaldehyde, 1734-79-8; acetylene, 74-86-2; 5-phenylpent-4-en-1-yn-3-ol, 14604-31-0; 6-phenylhex-5-en-2-yn-4-ol, 87639-39-2; trimethylsilyl chloride, 75-77-4; tetraallytin, 7393-43-3.

Synthesis of Daunosamine[1]

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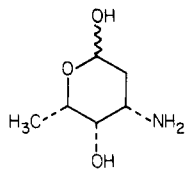
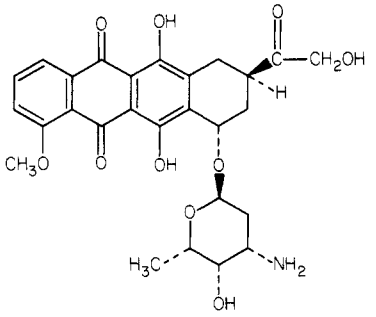
An efficient synthesis of daunosamine (1), the carbohydrate component of a group of biologically important anthracycline antibiotics, from readily available arabinose is reported.

Daunosamine (1, 3-amino-2,3,6-trideoxy-L-*lyxo*-hexose)[2]



1



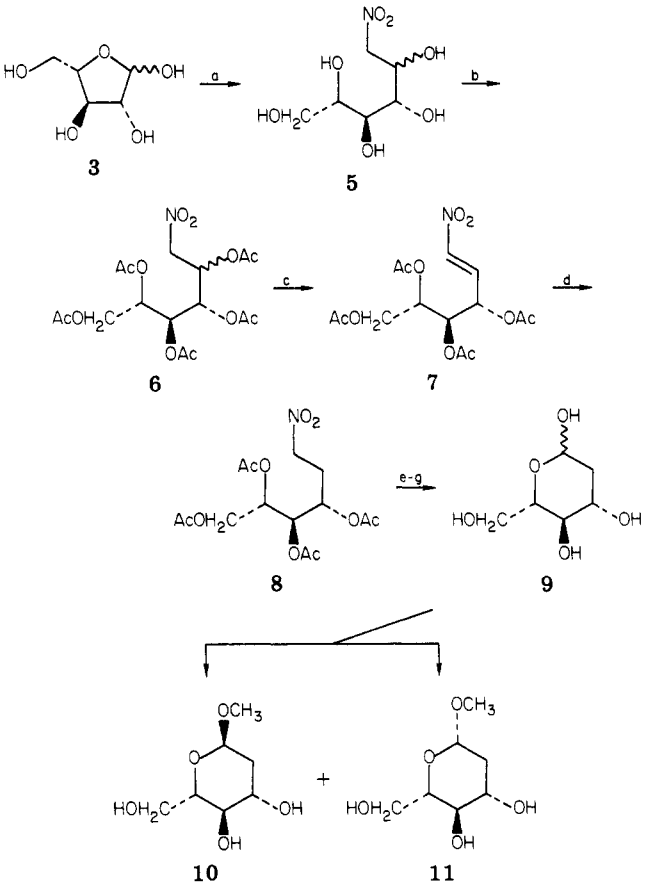
2

is the carbohydrate component of a group of anthracycline antibiotics which have attracted great attention because of their activity against a wide range of experimental and human tumors.[3] Adriamycin (**2**),[4] in particular, possesses impressive activity against a broad range of solid tumors, especially against soft tissues and bone sarcomas, and has established itself clinically as a potent agent in various chemotherapeutic combination regimens.

These results stimulated considerable research on the synthesis of these antibiotics and their analogues in many laboratories. Our efforts were directed towards the preparation of semisynthetic antibiotics from modified aglycones and daunosamine. Studies on the mode of action of these antibiotics and on structure–activity relationships clearly revealed the importance of the daunosamine portion toward activity.[5,6]

The need for large amounts of this amino sugar could be met only by synthesis. Previous to our work, two syntheses of L-daunosamine from L-rhamnose[7] and D-mannose,[8] respectively, had been reported. Since then three additional preparations of **1** from carbohydrate

Scheme I[a]



[a] (a) CH_3NO_2, CH_3ONa, CH_3OH; (b) $BF_3{\cdot}(C_2H_5)_2O$, $(CH_3CO)_2O$; (c) $NaHCO_3$, $C_6H_5CH_3$, Δ; (d) H_2/Pd-C, EtOAc; (e) $Ba(OH)_2{\cdot}8H_2O$; (f) H_2SO_4; (g) $BaCO_3$; (h) AG 50-X4(H^+), CH_3OH.

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