Palladium-Catalyzed Synthesis of Allylic Tertiary Amines from Vinylic Bromides, Olefins, and Secondary Amines

Babu A. Patel and Richard F. Heck* ·

Contribution from the Department of Chemistry, University of Delaware, Newark, Delaware 19711

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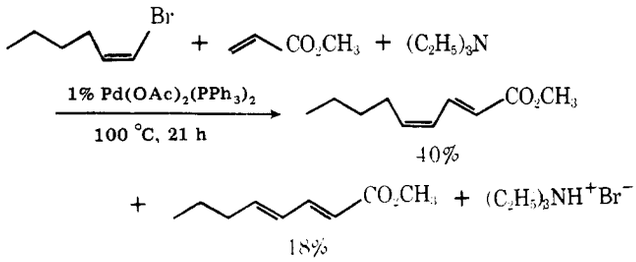
Vinylic bromides, olefins, and basic, unhindered secondary amines react in the presence of a palladium acetate catalyst to form mixtures of dienes and tertiary allylic amines in generally high yields. The reaction is often selective in forming predominantly, or exclusively, one isomeric amine when various vinylic bromides are reacted with 1-hexene and various secondary amines.

The palladium-catalyzed vinylic substitution reaction of α,β-unsaturated esters, styrene, and ethylene with the vinylic group of vinylic halides in the presence of tertiary amines to produce dienes has been reported upon previously.[1] In general, the reactions yielded mixtures of stereoisomers in modest yields. A typical example is the following one.



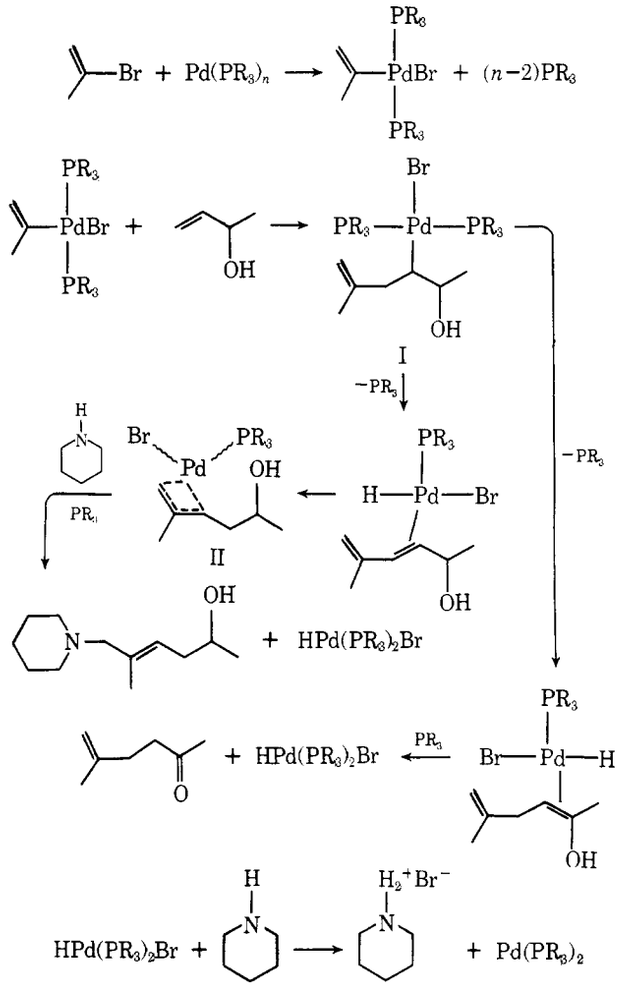
While the selectivity of the reaction can be improved by varying conditions from the 2:1 selectivity above to about 8:1, high stereospecificity was not observed.[1] Since publication of this paper, we have continued to study these reactions. It was clear from our early work that the rates of the reactions and their stereospecificities varied greatly from reactant to reactant. For example, 2-bromopropene reacted both with methyl acrylate[1] and styrene[1] at 100 °C but failed completely to react with 3-buten-2-ol even at higher temperatures.

We proposed previously that the loss of stereochemistry in the vinylic halide reactions was the result of the formation of π-allylic palladium complexes which readily isomerized anti substituents to form the more stable syn structures before they ultimately eliminated the hydridopalladium group to produce the diene.[1] More recently, Larock[2] has shown that presumed vinylic palladium species generated by the exchange reaction of vinylic mercurials with palladium(II) salts do form π-allylic palladium complexes when reacted with olefins. We reasoned that the slow rates and/or incomplete reactions observed in many of our vinylic halide–olefin reactions were due to the formation of relatively stable π-allylic palladium complexes from the catalyst. In order to decompose these complexes under catalytic conditions, we tried employing amines other than the tertiary amines used previously. Certain of these amines have not only turned out to improve the reaction rates dramatically and produce complete reactions but have also altered the products formed.

The amines which are effective in this reaction are unhindered, basic, secondary amines, and the new products produced are allylic tertiary amines. Our preliminary investigation of this reaction is reported herein.

Results and Discussion

The reaction of 2-bromopropene and 3-buten-2-ol with 2% palladium acetate and 4% tri-*o*-tolylphosphine as catalyst, which did not occur significantly with triethylamine, did take place in 90 min at 100 °C in the presence of 3 equiv of piperidine. The products were 63% of 5-methyl-5-hexen-2-one and 33% of 5-methyl-6-piperidino-4-hexen-2-ol. We presume that the piperidino compound is being formed by a nucleophilic attack of piperidine upon the probable π-allylic palladium intermediate. The reaction of π-crotylpalladium complexes with dimethylamine has been reported to form mainly *N,N*-dimethylcrotylamine.[3]



The initial adduct in the 2-bromopropene–3-buten-2-ol reaction, compound I, apparently eliminates the palladium hydride group in both possible directions. Elimination of hydrogen on the carbon bearing the hydroxyl group yields the π complex of the enol of 5-methyl-5-hexen-2-one, which ultimately dissociates to form the ketone and the palladium hydride. Elimination in the other direction yields a π complex of the conjugated dienol. Since no dienol is observed as a reaction product, this complex must entirely undergo an internal readdition of the hydride to form the π-allylic complex II (or re-form I). Complex II has not yet been isolated, and its detailed structure is not known. Quite possibly the hydroxyl

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group is coordinated with the palladium, thereby stabilizing the complex. The complex, however, does react with piperidine, presumably in an S_N2 fashion, exclusively at the terminal allylic carbon to form the piperidinohexenol. We do not know the stereochemistry of the double bond in the product, but it appears to be a single isomer by GLC and NMR. Presumably, it is the *E* isomer based upon the fact that the π-allylic palladium complexes prefer syn arrangements of substituents on the terminal π-allylic positions.

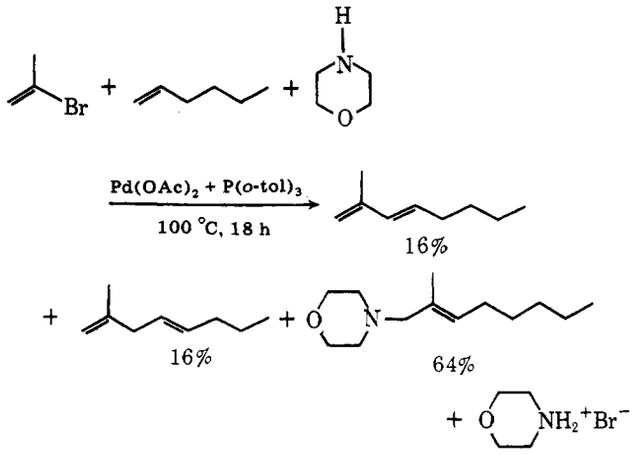
To answer the question, "how general and how selective is the reaction?", we undertook an investigation of the reactions of a series of differently substituted vinylic bromides with 1-hexene and various amines. The results of these reactions are shown in Table I.

The physical properties of the products prepared, NMR spectra, boiling points, and molecular weights, are given in Table II, which appears in the supplementary material.

Vinyl bromide reacts with piperidine in the presence of palladium acetate at 100 °C. We have not determined the products formed (probably acetylene or butadiene), but this reaction occurs more rapidly than the palladium-catalyzed reaction of vinyl bromide with 1-hexene. The competition is more favorable for the olefin reaction when morpholine is used as the base instead of piperidine. Even in this reaction, however, under the usual conditions, about half of the vinyl bromide is lost in the side reaction. The yield of products based upon the vinyl bromide increases with increasing 1-hexene concentration. With a 1-hexene to vinyl bromide ratio of 1.2, the products consist of 3% of *trans*-1,3-octadiene, 3% of 1,4-octadiene, and 47% of *N*-(1-oct-2-enyl)morpholine. The same yields are obtained in the same reaction time in the presence of 2 equiv of tri-*o*-tolylphosphine/equiv of palladium acetate. With a 1-hexene to vinyl bromide ratio of 2.4, the yields increase to 3:3:63, respectively, and with a ratio of 3.6 to 4:4:84, respectively. A small amount of an apparent isomer of the major morpholine adduct is also present in these reaction mixtures. It is probably *N*-(3-oct-1-enyl)morpholine, but we could not isolate a pure sample for identification. Triethylamine does not effectively promote the 1-hexene–vinyl bromide reaction. In 96 h, only 23% of the three octadiene isomers was formed and the vinyl bromide had all reacted. It is notable that in contrast to bromobenzene, where about 20% addition to the second carbon occurred,[4] vinyl bromide adds exclusively to the terminal carbon of the 1-hexene. We also note that the ratios of products in this and the experiments described below do not change with time, showing that the amine products are being formed directly and not by an amination of initially formed dienes.

2-Bromopropene behaves somewhat differently in the reaction with 1-hexene and morpholine. In the absence of an arylphosphine, the bromide is stable in the reaction mixture, but the reaction only consumes about 18% of the bromide and stops. Presumably, an unreactive π-allylic palladium bromide dimer complex is formed, but we have not attempted to identify it yet. The reaction does go to completion if tri-*o*-tolylphosphine is present, in which case 16% of 2-methyl-1,3-octadiene, 16% of 2-methyl-1,4-octadiene, and 64% of *N*-(2-methyloct-2-en-1-yl)morpholine are formed.

In contrast to morpholine, piperidine does cause the complete reaction of 2-bromopropene and 1-hexene even in the absence of an arylphosphine. The reaction products are 93% of *N*-(2-methyloct-2-en-1-yl)piperidine and about 3% each of the 2-methyl-1,3- and 2-methyl-1,4-octadienes. If tri-*o*-tolylphosphine is added, the yield of the piperidine adduct drops to 66% and the dienes increase to 16% each. Tris(2,5-diisopropylphenyl)phosphine in the reaction surprisingly causes less diene formation. In this reaction about 10% of each diene was produced and 74% of the piperidine adduct. The use of triethylamine with the tri-*o*-tolylphosphine catalyst produces an incomplete reaction forming equal amounts, 14% each, of three dienes: the 2-methyl-1,3- and 2-methyl-1,4-octadienes found in the other reactions and, in addition, 2-methyl-2,4-octadiene. In all of the reactions of 2-bromopropene, addition of the 2-propenyl group occurred only to the terminal carbon of the 1-hexene.



Both *trans*- and *cis*-1-bromo-1-propene react with 1-hexene and morpholine in the absence of a phosphine. In the presence or absence of tri-*o*-tolylphosphine, both bromides produce three dienes and two morpholine adducts. Products arise from addition of the 1-propenyl group in both directions to the 1-hexene. The trans bromide in the presence of the phosphine yields 18% of (*E*,*E*)-2,4-nonadiene, 18% of (*E*)-2-butyl-1,3-pentadiene (?), 5% of an unknown diene (probably 2,5-nonadiene), 34% of *N*-(2-non-3-enyl)morpholine, and 11% of *N*-(4-methyloct-3-en-2-yl)morpholine. The ratio of the terminal to internal addition to the 1-hexene is ~1.8. It is interesting that the ratio is considerably higher, ~2.3, in the absence of the phosphine. The cis bromide in the presence of the phosphine produces 15% of (*Z*,*E*)-2,4-nonadiene, 15% of (*E*)-2-butyl-1,3-pentadiene (same isomer as obtained from the trans bromide), 6% of the unknown diene, 42% of *N*-(2-non-3-enyl)morpholine and 15% of *N*-(4-methyloct-3-en-2-yl)morpholine. The ratio of terminal to internal products is 1.8, the same as observed with the trans bromide. In the absence of the phosphine, the cis isomer shows a terminal to internal isomer ratio of ~2.1. The presence of the tri-*o*-tolylphosphine in both the cis and trans reactions increases the amount of dienes formed by 11–16% and decreases the amount of morpholine addition products by a corresponding amount. The use of the tris(2,5-diisopropylphenyl)phosphine in the *cis*-1-bromo-1-propene reaction seems to have little influence on the reaction since the results are similar to those obtained in the absence of a phosphine.

cis-1-Bromo-1-hexene was reacted with morpholine and ethylene in order to compare the products formed with those from vinyl bromide, morpholine, and 1-hexene. The reaction products were 5% of *cis*-1,3-octadiene, 84% of *N*-(2-oct-3-enyl)morpholine, and 11% of *N*-(4-oct-2-enyl)morpholine. Essentially, the same ratio of products is obtained at one-tenth the rate using diethylamine in place of morpholine. As expected by the π-allylic mechanism, the morpholine adducts obtained from the bromohexene reaction are different from those obtained in the vinyl bromide reaction.

The products formed in the reaction of 2-methyl-1-bromo-1-propene with morpholine and 1-hexene clearly show that electronic factors are significant in determining the direction of addition of the vinylic groups to 1-hexene since terminal to internal addition ratios were lower than in the 1-bromo-1-propene reactions. In the absence of a triarylphosphine, this reaction reaches completion in 96 h, forming a mixture of six dienes and two morpholine adducts. The two

Table I. Palladium-Catalyzed Reactions of Vinylic Bromides with 1-Hexene and Amines[a]

vinylic bromide	amine[b]	PAr_3	reaction time, h at 100 °C	products, (% yield) dienes[c]	products, (% yield) amines[c]	% terminal/ % internal
vinyl bromide	M		21	(*E*)-1,3-octadiene (3)[d] (*E*)-1,4-octadiene (3)[d]	1-(*N*-morpholino)-2-octene (47)[d] unknown (5)[d]	>20[e]
vinyl bromide	M	P(*o*-tol)$_3$	18	(*E*)-1,3-octadiene (5) (*E*)-1,4-octadiene (5)	1-(*N*-morpholino)-2-octene (48) unknown (1)	>20[e]
vinyl bromide[f]	M	P(*o*-tol)$_3$	21	(*E*)-1,3-octadiene (3)[d] (*E*)-1,4-octadiene (3)[d]	1-(*N*-morpholino)-2-octene (63)[d] unknown (5)[d]	>20[e]
vinyl bromide[g]	M	P(*o*-tol)$_3$	16	(*E*)-1,3-octadiene (4)[d] (*E*)-1,4-octadiene (4)[d]	1-(*N*-morpholino)-2-octene (84)[d] unknown (2)[d]	>20[e]
vinyl bromide	T	P(*o*-tol)$_3$	96	(*E*)-1,3-octadiene (5)[d] (*E*)-1,4-octadiene (5)[d] (*E,E*)-2,4-octadiene (13)[d]		>20[e]
2-bromopropene	M		60[h]	(*E*)-2-methyl-1,3-octadiene (3)[d] (*E*)-2-methyl-1,4-octadiene (3)[d]	1-(*N*-morpholino)-2-methyl-2-octene (12)[d]	>20
2-bromopropene	M	P(*o*-tol)$_3$	68	(*E*)-2-methyl-1,3-octadiene (16) (*E*)-2-methyl-1,4-octadiene (16)	1-(*N*-morpholino)-2-methyl-2-octene (64)	>20
2-bromopropene	P		48	(*E*)-2-methyl-1,3-octadiene (3)[d] (*E*)-2-methyl-1,4-octadiene (3)[d]	1-(*N*-piperidino)-2-methyl-2-octene (93)[d]	>20
2-bromopropene	P	P(*o*-tol)$_3$	68	(*E*)-2-methyl-1,3-octadiene (16) (*E*)-2-methyl-1,4-octadiene (16)	1-(*N*-piperidino)-2-methyl-2-octene (66)	>20
2-bromopropene	P	P(2,5-*i*-$Pr_2Ph)_3$	56	(*E*)-2-methyl-1,3-octadiene (10)[d] (E)-2-methyl-1,4-octadiene (10)[d]	1-(*N*-piperidino)-2-methyl-2-octene (66)	>20
2-bromopropene	T	P(*o*-tol)$_3$	60[h]	(*E*)-2-methyl-1,3-octadiene (14) (*E*)-2-methyl-1,4-octadiene (14) (*E*)-2-methyl-2,4-octadiene (14)		>20
(*E*)-1-bromo-1-propene	M		32	(*E,E*)-2,4-nonadiene (10)[d] (*E*)-2-*n*-butyl-1,3-pentadiene (10)[d] unknown (5)[d]	*N*-(2-non-3-enyl)morpholine (51)[d] *N*-(4-methyloct-3-en-2-yl)-morpholine (17)[d]	~2.3
(*E*)-1-bromo-1-propene	M	P(*o*-tol)$_3$	47	(*E,E*)-2,4-nonadiene (18) (*E*)-2-*n*-butyl-1,3-pentadiene (18) unknown (5)	*N*-(2-non-3-enyl)morpholine (34) *N*-(4-methyloct-3-en-2-yl)-morpholine (11)	~1.8
(*Z*)-1-bromo-1-propene	M		30	(*Z,E*)-2,4-nonadiene (10)[d] (*E*)-2-*n*-butyl-1,3-pentadiene (10)[d] unknown (5)[d]	*N*-(2-oct-3-enyl)morpholine (52)[d] *N*-(4-methyloct-3-en-2-yl)-morpholine (20)[d]	~2.1
(*Z*)-1-bromo-1-propene	M	P(*o*-tol)$_3$	40	(*Z,E*)-2,4-nonadiene (15) (*E*)-2-*n*-butyl-1,3-pentadiene (15) unknown (6)	*N*-(2-oct-3-enyl)morpholine (42) *N*-(4-methyloct-3-en-2-yl)-morpholine (15)	1.8[e]
(*Z*)-1-bromo-1-propene	M	P(2,5-*i*-$Pr_2Ph)_3$	50	(*Z,E*)-2,4-nonadiene (6)[d] (*E*)-2-*n*-butyl-1,3-pentadiene (6)[d] unknown (3)[d]	*N*-(2-oct-3-enyl)morpholine (40)[d] *N*-(4-methyloct-3-en-2-yl)-morpholine (18)[d]	~1.9

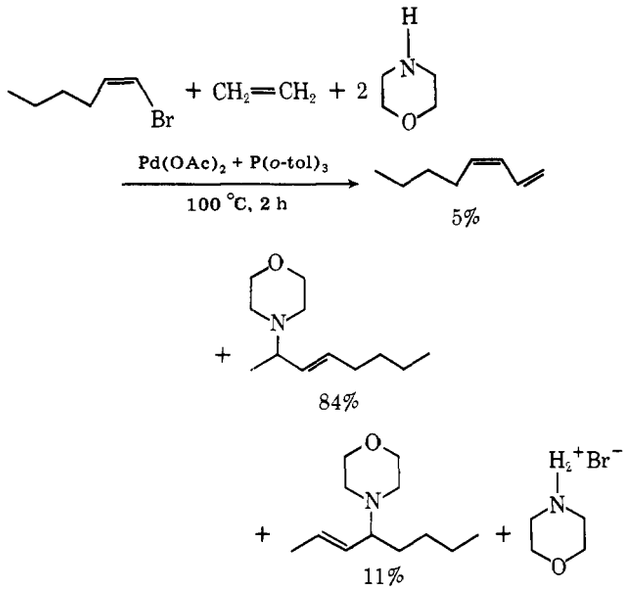
Table I *(Continued)*

vinylic bromide	amine[b]	PAr_3	reaction time, h at 100 °C	products, (% yield) dienes[c]	products, (% yield) amines[c]	% terminal/ % internal
(*Z*)-1-bromo-1-hexene[i]	M	P(*o*-tol)$_3$	2	(*Z*)-1,3-octadiene (5)[d]	*N*-(2-oct-3-enyl)morpholine (84)[d] *N*-(4-oct-2-enyl)morpholine (11)[d]	∞
(*Z*)-1-bromo-1-hexene[i]	D	P(*o*-tol)$_3$	20	(*Z*)-1,3-octadiene (5)[d]	2-diethylamino-3-octene (82)[d] unknown (7)[d]	∞
2-methyl-1-bromo-1-propene	M		96	(*E*)-2-methyl-2,4-nonadiene (25)[d] 2-*n*-butyl-4-methyl-1,3-pentadiene (8)[d] 4 unknowns (31)[d]	*N*-(2-methylnon-3-en-2-yl)morpholine (13) unknown (7)	
2-methyl-1-bromo-1-propene	M	P(*o*-tol)$_3$	48	(*E*)-2-methyl-2,4-nonadiene (13) 2-*n*-butyl-4-methyl-1,3-pentadiene (15) 4 unknowns (30)	*N*-(2-methylnon-3-en-2-yl)morpholine (31)	1.7[e]
2-methyl-1-bromo-1-propene	P		48	(*E*)-2-methyl-2,4-nonadiene (23)[d] 2-*n*-butyl-4-methyl-1,3-pentadiene (5)[d] 4 unknowns (22)[d]	*N*-(2-methylnon-3-en-2-yl)piperidine (21)[d] unknown (3)[d]	
2-methyl-1-bromo-1-propene	P	P(*o*-tol)$_3$	48	(*E*)-2-methyl-2,4-nonadiene (14) 2-*n*-butyl-4-methyl-1,3-pentadiene (11) 4 unknowns (31)	*N*-(2-methylnon-3-en-2-yl)piperidine (35)	1.3
2-methyl-1-bromo-1-propene	DIPA	P(*o*-tol)$_3$	72[j]	(*E*)-2-methyl-2,4-nonadiene (30)[d] 2-*n*-butyl-4-methyl-1,3-pentadiene (30)[d] 4 unknowns (30)[d]		
2-methyl-1-bromo-1-propene	T	PPh_3	96	no reaction		
2-methyl-1-bromo-1-propene	T	P(*o*-tol)$_3$	48[j]	(*E*)-2-methyl-2,4-nonadiene (40) 2-*n*-butyl-4-methyl-1,3-pentadiene (50) 4 unknowns (10)		1.0[e]
2-methyl-1-bromo-1-propene	T	P(2,5-*i*-$Pr_2Ph)_3$	72[g,j]	(*E*)-2-methyl-2,4-nonadiene (32)[d] 2-*n*-butyl-4-methyl-1,3-pentadiene (27)[d] 4 unknowns (25)[d]		
methyl (*E*)-3-bromo-2-methylpropenoate	T	P(*o*-tol)$_3$	20	methyl (*E,E*)-2-methyl-2,4-nonadienoate (63) 5 unknowns (25)		4.6[e]

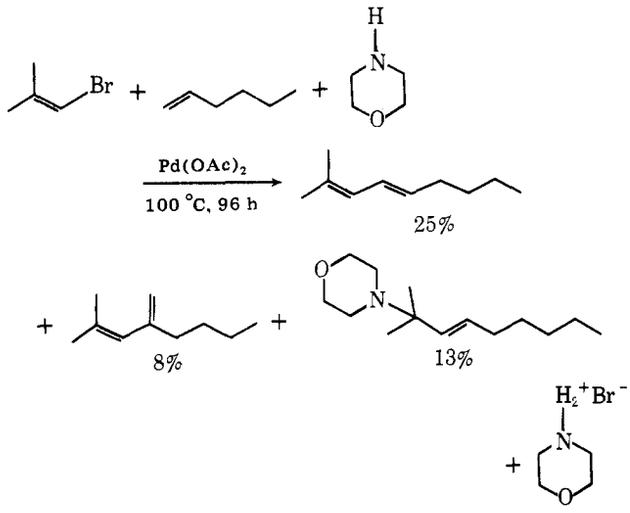
[a] The normal reaction conditions were the following: 10 mmol of vinylic bromide; 12 mmol of 1-hexene; 30 mmol of amine; 0.10 mmol of palladium acetate; and 0.20 mmol of triarylphosphine, if used. The mixtures became homogeneous on warming and were heated in capped Pyrex tubes at 100 °C until the vinylic bromide disappeared as determined by GLC or the reaction stopped. [b] M = morpholine, P = piperidine, D = diethylamine, T = triethylamine, and DIPA = diisopropylamine. [c] Relative amounts of isomers present in mixtures were estimated by GLC assuming equal sensitivity to the GLC detector. [d] Yields were determined by GLC using internal standards calibrated with known samples isolated by preparative GLC. [e] Calculated using the ratio of isomeric dienes determined by complete hydrogenation of the diene mixture. [f] Used 24 mmol of 1-hexene instead of 12. [g] Used 36 mmol of 1-hexene instead of 12. [h] Reaction stopped before vinylic bromide had all reacted. [i] Reacted with ethylene under 200 psi using 4 mL of acetonitrile as solvent. [j] Twice the normal amounts of palladium acetate and triarylphosphine were used.

major dienes are 2-methyl-2,4-nonadiene (25%) and 2-butyl-4-methyl-1,3-pentadiene (8%). Unexpectedly, the major morpholine adduct obtained is the allylic tertiary amine *N*-(2-methylnon-3-en-2-yl)morpholine (13%). The minor morpholine adduct (7%) was not identified.

This reaction proceeded more rapidly in the presence of tri-*o*-tolylphosphine (48 h) and produced only one morpholine adduct, *N*-(2-methylnon-3-en-2-yl)morpholine, in 31% yield. The formation of the related unexpected tertiary allylic amine occurred when piperidine was used in place of morpholine. The structure of these unexpected amines was established from several pieces of evidence. The NMR spectra alone are quite conclusive based upon the presence of two vinylic protons rather than the one in the allylic isomer and by the chemical shift of the gem dimethyl on the carbon bearing the amine function at δ 1.10. If the methyls were on a double-bond carbon, they would appear at δ 1.60 (in 2-methyl-2-butene, for example). Hydrogenation of the morpholine adduct in acetic



acid with platinum oxide as catalyst at 15 psig gave 2-methylnonane as the sole product. The highly hindered nature of the amine is shown by the fact that it fails to react with methyl



iodide over a period of several days at room temperature. The mass spectra of both the morpholine and piperidine adducts show major peaks at M − 15 with only a very weak parent peak in the piperidine case and none in the morpholine adduct. Loss of one of the methyls in the gem dimethyl group would be expected since a highly stabilized carbonium ion would be formed. In contrast to these compounds, the other amine adducts prepared in this study all show significant parent ion peaks. We do not have an explanation for the formation of the more hindered amines in these reactions, but we are now looking at the behavior of isolated π-allylic palladium complexes with secondary amines with the hope of finding an explanation. Probably differences in the trans and cis ligands or in the π- or σ-allylic structures are responsible for the unusual products.

The 2-methyl-1-bromo-1-propene–1-hexene reaction goes to completion, even with the hindered diisopropylamine or triethylamine. With diisopropylamine and tri-*o*-tolylphosphine, the reaction gives a mixture of dienes: 30% of 2-methyl-2,4-nonadiene, 30% of 2-butyl-4-methyl-1,3-pentadiene, and 30% of four other unidentified (presumed) ten-carbon dienes. With triethylamine, the composition of the diene mixture was shown to be dependent upon the arylphosphine employed. Triphenylphosphine caused only a few percent reaction in 48 h, while tri-o-tolylphosphine produced a complete reaction in the same time. The products were 40% of 2-methyl-2,4-nonadiene, 50% of 2-butyl-4-methyl-1,3-pentadiene, and 10% of four other dienes. The use of tris(2,5-diisopropylphenyl)phosphine changed the product yields to 32, 27, and 25%, respectively. The yields of the various dienes in these reactions therefore may vary significantly with the reactants and reaction conditions.

Further evidence of the importance of electronic effects in determining the direction of addition of vinylic halides to alkenes was found in the reaction of methyl (*E*)-3-bromo-2-methylacrylate with 1-hexene. Unhindered secondary amines cannot be used in this reaction because Michael additions and amide formation occur under the reaction conditions. With triethylamine, the reaction goes well, however, presumably because the carboxyl group facilitates elimination and dissociation of the palladium hydride group. The major product, 63%, of this reaction is (presumed *E*) methyl 2-methyl-2,4-nonadienoate. Five other minor products which have similar GLC retention times, obtained in 25% yield, are believed to be other isomers of this ester. Complete hydrogenation of the mixture reveals that two basic carbon skeletons are present, that formed by terminal addition of the bromo ester and that formed by addition of it to the second carbon of the 1-hexene. The ratio of the two was 4.6, considerably less than the 1.0 value obtained in the addition of 1-bromo-2-methyl-1-propene to 1-hexene under similar conditions. The change is in the direction expected if the ester group withdraws electrons from the terminal vinyl carbon relative to methyl, and therefore this causes the vinyl group to add more easily to the more negative terminal carbon of the 1-hexene. Previously we observed essentially complete terminal addition of this bromide to methyl acrylate.[1] The direction of addition depends upon the substituents in both reactants.

Several trends can be seen in the data in Table I which will be of value in predicting the products which will be formed in various vinylic halide–olefin reactions.

(1) Vinyl bromide and α-substituted vinylic bromides add exclusively to the less substituted carbon of a double bond.

(2) β-Substituted vinylic halides may add either way to an unsymmetrical double bond. The less substituted carbon is preferred and may be the only position attacked if the β substituent or substituents are electron withdrawing. Selective attack at the double-bond carbon β to an electron-withdrawing group in the olefin will occur if there are no major steric problems at this site.

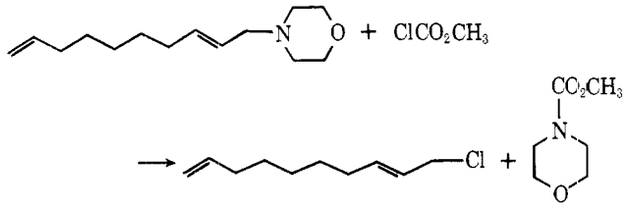
(3) Dienes formed in the reaction of olefins with vinylic bromides and basic unhindered secondary amines generally retain the stereochemistry present in the vinylic bromide double bond to a high degree. The amine adducts lose any stereochemistry present in the vinylic bromides. If triethylamine is used as the base, stereochemistry in the dienes may be lost and double-bond migration may occur.

(4) Amine attack upon the presumed π-allylic palladium complex intermediate occurs at the least substituted or least hindered end of the allylic systems unless a tertiary–secondary system is present, in which case tertiary attack may occur.

(5) Many vinylic bromide–olefin–secondary amine reactions occur in the absence of triarlyphosphines, but all do not. Tri-*o*-tolylphosphine is often useful to cause slow or incomplete reactions to go faster and in higher yield. Product ratios may also be altered by use of a phosphine with the palladium acetate catalyst.

From the results reported in Table I, it is clear that the palladium-catalyzed vinylic substitution reaction will have some important applications in aliphatic chemistry as well as in the aromatic areas reported upon previously. Since allylic tertiary amines are readily converted into other types of compounds by reactions such as the von Braun, Hofmann elimination, hydrogenolysis, and Polonovski reactions, the

vinylic substitution will be generally useful. For example, we have converted 1-(*N*-morpholino)-2,9-decadiene (obtained from vinyl bromide, 1,7-octadiene, and morpholine in 80% yield) into 1-chloro-2,9-decadiene in 69% (isolated) yield by



a very useful modification of the von Braun reaction with methyl chloroformate.[5] The reaction occurred in 4 h at room temperature, and none of the 3-chloro allylic isomer was seen.[6]

The tolerance of the olefinic substitution reactions for nearly all functional groups[7,8] may make this method of major synthetic value in the preparation of complex polyfunctional aliphatic structures.

Experimental Section

Reagents. The amines used were all commercial materials used without further purification, but they were dried and stored over Linde 4A molecular sieves. Palladium acetate,[9] tri-*o*-tolylphosphine,[6] tris(2,5-diisopropylphenyl)phosphine,[5] *cis*-1-bromo-1-hexene,[10] and 1-bromo-2-methyl-1-propene[11] were prepared by published procedures. The methyl (*E*)-3-bromo-2-methylpropenoate was obtained by the method of Canbere,[13] but heating of the reaction mixture was necesary to get mainly the *E* isomer (95%). Vinyl bromide (Aldrich), 2-bromopropene (Chemical Samples Co.), and 1-bromo-1-propene (Columbia Organic Chemicals) were commercial samples, but the 1-bromo-1-propene was fractionated to separate 95% pure samples of the cis and trans isomers.

The Reaction of 2-Bromopropene with 3-Buten-2-ol and Piperidine. A solution of 0.449 g (2.0 mmol) of palladium acetate and 1.216 g (4.0 mmol) of tri-*o*-tolylphosphine in 12.1 g (100 mmol) of 2-bromopropene, 30 mL (~300 mmol) of piperidine, and 8.0 g (110 mmol) of 3-buten-2-ol was heated at 100 °C in a steam bath in a capped 200 mL Pyrex bottle for 90 min. Analysis at 125 °C on a 10 ft 20% DC-550 column showed that all of the bromide had reacted. The cooled, semisolid reaction mixture was rinsed into a separatory funnel with ether and water. The ether layer was separated, washed twice with 100-mL portions of water, dried over potassium carbonate and distilled. There was obtained 7.0 g (63%) of 5-methyl-5-hexen-2-one, bp 100 °C (185 mm), and 6.5 g (33%) of 5-methyl-6-piperidino-4-hexen-2-ol, bp 142 °C (15 mm).

General Procedure for the Reaction of Vinylic Bromides with Hexene and Amines. A solution of 0.0224 g (0.1 mmol) of palladium acetate and 0.061 g (0.2 mmol) of tri-*o*-tolylphosphine, or an equivalent amount of another phosphine if one is used, in 10 mmol of the vinylic bromide, 30 mmol of the secondary amine or triethylamine, and 1.00 g (12 mmol) of 1-hexene was heated in a capped heavy-walled "Pyrex" tube at 100 °C until GLC analysis of the solution showed that the bromide had all reacted or else that the reaction had ceased. Samples for VPC analysis were removed from the hot reaction mixture by syringe through a needle injected through a small hole in the metal cap and the self-sealing rubber cap liner. Analyses of the cooled reaction mixtures were generally performed by GLC on a 10 ft × 0.25 in 20% DC-550 column by adding an internal standard either before the reaction or afterwards using predetermined sensitivity coefficients for the products to calculate yields. Generally, naphthalene, alkylnaphthalenes, or alkylbenzenes were used as the internal standards. For preparative scale experiments, the reactions were carried out with ten times the amounts given and the products were isolated as described in the preceding experiment.

Hydrogenation of Diene Mixtures. A solution of 10 mmol of the diene mixture dissolved in 10 mL of acetic acid and 100 mg of 5% platinum on carbon (Engelhard Industries) in a 60 mL Parr bomb was hydrogenated at room temperature with magnetic stirring under 500 psi of hydrogen until absorption stopped. The pressure was released, the catalyst was removed by filtration, and the filtrate was diluted with water. The product was extracted with ether, and after washing the ether with aqueous base the solution was dried and concentrated. Products were than purified by preparative GLC.

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Registry No.—Vinyl bromide, 593-60-2; 2-bromopropene, 557-93-7; (*E*)-1-bromo-1-propene, 590-15-8; (*Z*)-1-bromo-1-propene, 590-13-6; (*Z*)-1-bromo-1-hexane, 13154-12-6; 2-methyl-1-bromo-1-propene, 3017-69-4; methyl (*E*)-3-bromo-2-methylpropenoate, 40053-01-8; morpholine, 110-91-8; triethylamine, 121-44-8; piperidine, 110-89-4; tri-*o*-tolylphosphine, 109-89-7; diisopropylamine, 108-18-9; (*E*)-1,3-octadiene, 39491-65-1; (*E*)-1,4-octadiene, 53793-31-0; (*E,E*)-2,4-octadiene, 60919-80-4; (*E*)-2-methyl-1,3-octadiene, 67350-81-6; (*E*)-2-methyl-1,4-octadiene, 67350-82-7; (*E,E*)-2,4-nonadiene, 56700-78-8; (*E*)-2-*n*-butyl-1,3-pentadiene, 67350-83-8; (*Z,E*)-2,4-nonadiene, 67350-84-9; (*Z*)-1,3-octadiene, 39491-64-0; (*E*)-2-methyl-2,4-nonadiene, 67350-85-0; 2-*n*-butyl-4-methyl-1,3-pentadiene, 67350-86-1; methyl (*E,E*)-2-methyl-2,4-nonadienoate, 61382-50-1; 1-(*N*-morpholino)-2-octene, 67350-87-2; 1-(*N*-morpholino)-2-methyl-2-octene, 67350-88-3; 1-(*N*-piperidino)-2-methyl-2-octene, 67350-89-4; *N*-(2-non-3-enyl)morpholine, 67350-90-7; *N*-(4-methyloct-3-en-2-yl)morpholine, 67350-91-8; *N*-(2-oct-3-enyl)morpholine, 67350-92-9; *N*-(4-oct-2-enyl)morpholine, 67350-93-0; 2-(diethylamino)-3-octene, 67350-94-1; *N*-(2-methylnon-3-en-2-yl)morpholine, 67350-95-2; *N*-(2-methylnon-3-en-2-yl)piperidine, 67350-96-3; 1-hexene, 592-41-6; 5-methyl-5-hexen-2-one, 3240-09-3; 5-methyl-6-piperidino-4-hexen-2-ol, 67350-97-4; 2-methylnonane, 871-83-0; 2,4-dimethyloctane, 4032-94-4; methyl 2-methylnonanoate, 56898-37-4; methyl 2,4-dimethyloctanoate, 67350-98-5.

Supplementary Material Available: Table II, containing NMR spectra, boiling points, and molecular weights of the products prepared (7 pages). Ordering information is given on any current masthead page.

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