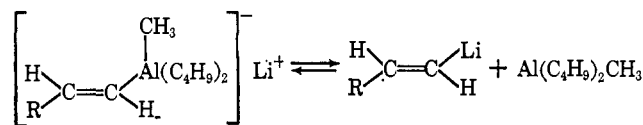


Table I. Reactions of Vinylalanes with Various Reagents in Ether

Vinylalane derived from	Reagent	Product	Yield, % ^{a,b}
1-Hexyne	CO ₂	<i>trans</i> -2-Heptenoic acid	78
	HCHO ^c	<i>trans</i> -2-Hepten-1-ol	73
	CH ₃ CHO	<i>trans</i> -3-Octen-2-ol	68 ^d
Cyclohexyl-acetylene	CO ₂	<i>trans</i> -3-Cyclohexyl-2-propenoic acid	72
2-Butyne	CO ₂	<i>trans</i> -2-Methyl-2-butenic acid	76
3-Hexyne	CO ₂	<i>trans</i> -2-Ethyl-2-pentenoic acid	78

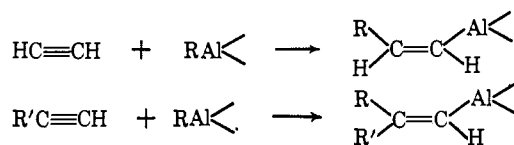
^a By isolation. ^b Yields are based on the amount of alkyne used. ^c Paraformaldehyde. ^d Yield 90% by glpc analysis.

Although the nature of the reactive organometallic intermediates has not been established, it is conceivable that the reactions proceed *via* the vinylolithium derivatives resulting from disproportionation of the vinylalanes. The configurational stability of vinylolithium



compounds in solution, a requirement in view of the high stereospecificity of the above reactions, has been demonstrated by Seyferth and co-workers.⁵ We have observed that tetraalkylalanes do not react with carbon dioxide; however, their disproportionation into alkylolithium compounds and trialkylalanes should be thermodynamically unfavorable.

The synthesis of vinylalanes is not confined to the hydroalumination reaction. Thus trialkylalanes add to acetylene under mild conditions to yield *cis*-vinylalanes, whereas addition of the aluminum-carbon bond to 1-alkynes affords the corresponding disubstituted vinylalanes.² The availability of *cis*- and *trans*-mono-



substituted vinylalanes greatly increases the versatility of the above reactions.

The simplicity of the present procedure for the conversion of alkynes into α,β -unsaturated derivatives *via* vinylalanes is illustrated by the following example.

To 0.10 mole of 1-hexyne in 20 ml of *n*-heptane was added by means of a hypodermic syringe 0.10 mole of diisobutylaluminum hydride, while maintaining the temperature below 40°. After the initial exothermic reaction had subsided, the reaction mixture was heated for 2 hr at 50°. To the vinylalane formed was added at room temperature 0.10 mole of methylolithium in ether (60 ml). The solution was cooled to -30°, then carbonated by introducing a stream of carbon dioxide while maintaining the temperature at -30 to -10°. The reaction mixture was poured slowly into an ice-concentrated hydrochloric acid mixture and the carboxylic acid produced was extracted into ether. Distil-

(5) D. Seyferth, *Record Chem. Progr. (Kresge-Hooker Sci. Lib.)*, **26**, 86 (1965).

lation gave 10.0 g of *trans*-2-heptenoic acid (78%), bp 89° (0.3 mm), *n*_D²² 1.4560, amide mp 124°.⁶

Acknowledgment. This work was supported by National Science Foundation Grants GP-3521 and GP-6633.

(6) P. Bruylants, *Bull. Soc. Chim. Belges*, **41**, 333 (1932), reports for *trans* amide mp 125°.

(7) National Institutes of Health Predoctoral Fellow, 1965-1966.

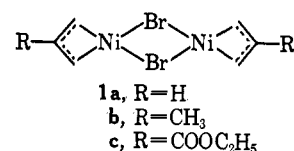
George Zweifel, Roger B. Steele⁷
Department of Chemistry, University of California
Davis, California 95616
Received April 12, 1967

Organonickel Compounds as Reagents for Selective Carbon-Carbon Bond Formation between Unlike Groups

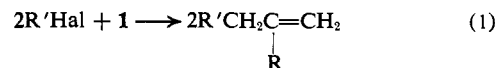
Sir:

The extension of carbon chains by the coupling of two different groups using as reagents an organic halide, RHal, and an alkyl- or arylmetal derivative, R'Met, is seldom employed in synthetic practice if alternative operations are available. This is due in part to the fact that coupling products RR and R'R' are usually formed in substantial amounts¹ and in part to the intervention of a variety of other side reactions, *e.g.*, α - or β -elimination processes. We report here a new and promising method for the *selective combination of unlike groups* at carbon using organonickel reagents.

Reaction of a variety of allylic bromides with excess nickel carbonyl in dry benzene (50°, 2-3 hr) followed by removal of solvent and recrystallization from ether at -70°² gives good yields of π -allylnickel(I) bromides, for example, **1a-c**, in 80-95% yield.^{3,4} These complexes are relatively inert toward alkyl halides in either hydro-



carbon solvents or ether-type solvents (*e.g.*, tetrahydrofuran). In more *polar, coordinating media*, *e.g.*, dimethylformamide, *N*-methylpyrrolidone, or hexamethylphosphoramide, a facile reaction occurs between the complexes **1** and a *wide variety* of halides, with iodides generally being more reactive than (and preferable to) bromides.⁵ Equation 1 summarizes the over-all reaction, and Table I presents the results ob-



(1) For example, because of fast halogen-metal exchange prior to coupling. See D. E. Applequist and D. F. O'Brien, *J. Am. Chem. Soc.*, **85**, 743 (1963).

(2) All operations with organonickel compounds have been conducted with rigorous exclusion of oxygen using an argon atmosphere either with plastic glove bag or argon-line techniques.

(3) The complex **1a**, first prepared by E. O. Fischer and G. Bürger, *Z. Naturforsch.*, **16b**, 77 (1961), was originally obtained only in ca. 10% yield; however, much higher yields are easily realized if thermal or oxidative decomposition of the complexes is avoided.

(4) These complexes can also be obtained efficiently from allylic bromides using bis(1,5-cyclooctadiene)nickel as reagent; see G. Wilke *et al.*, *Angew. Chem. Intern. Ed. Engl.*, **5**, 159 (1966). However, the synthesis from commercially available nickel carbonyl is usually more expeditious.

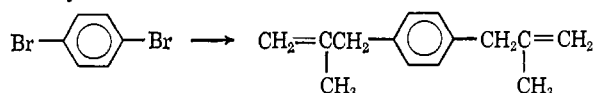
(5) Chlorides are less generally useful because of their much lower reactivity.

Table I. Coupling of π -Methallylnickel(I) Bromide (**1b**) with Halides (Eq 1) in Dimethylformamide

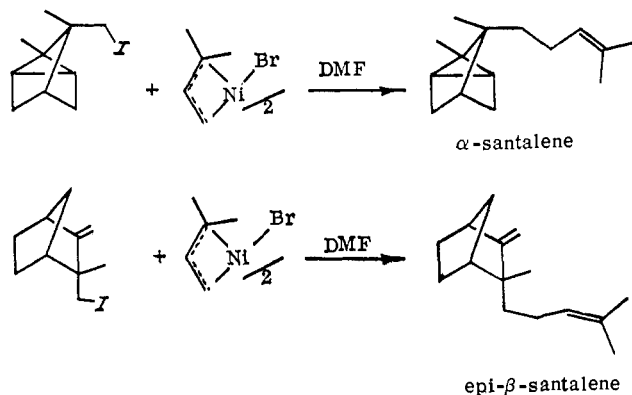
Halide	Reaction time, hr (temp, °C)	Yield, %
Methyl iodide	10 (22)	90 ^a
Methyl bromide	19 (22)	90 ^a
Cyclohexyl iodide	3 (22)	91
4-Hydroxycyclohexyl iodide	10 (22)	88 ^b
<i>t</i> -Butyl iodide	24 (22)	25 ^a
Iodobenzene	1 (22)	98
Vinyl bromide	13 (22)	70 ^a
Benzyl bromide	6 (60)	91
3-Phenylpropyl bromide	46 (65)	92
Phenyl α -chloromethyl ether	18 (60)	50
<i>p</i> -Bromophenacyl bromide	0.5 (22)	75
Chloroacetone	2 (22)	46 ^a

^a These yields were determined by quantitative vpc analysis; others are yields of isolated pure products. ^b Mixture of *cis* and *trans* isomers which are converted by chromic acid oxidation to 4-methylcyclohexanone.

tained with **1b** and a diverse collection of substrates.⁶ The reaction proceeds well not only with alkyl iodides and bromides but also with *aryl* and *vinyl* compounds. Further, the data indicate that the presence of carbonyl or hydroxyl functions in the halide partner need not interfere with coupling. Dihalides undergo disubstitution with the appropriate quantity of nickel(I) complex, as shown by the conversion of 1,6-diiodohexane with **1b** (mole ratio 1:1.25) to 2,11-dimethyl-1,11-dodecadiene (95% yield) and of 1,4-dibromobenzene with **1b** (mole ratio 1:1.25) to 1,4-dimethallylbenzene (97%). The latter substance is not readily accessible by conventional synthetic methods.



The new method has been employed in direct and efficient syntheses of α -santalene (**2**)⁷ (88% yield) and *epi*- β -santalene (**3**)⁸ (90% yield) using the nickel(I) complex from α,α -dimethylallyl bromide as follows.⁹



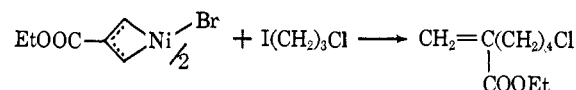
(6) The structures and products obtained by the reactions described herein have been verified by infrared, nmr, and mass spectrometric or elemental analysis. Purity was checked by vapor phase chromatography and quantitative nmr analysis.

(7) E. J. Corey, S. W. Chow, and R. A. Scherrer, *J. Am. Chem. Soc.*, **79**, 5773 (1957).

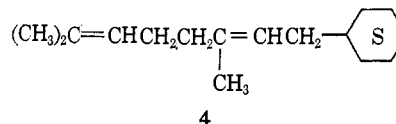
(8) E. J. Corey, R. Hartmann, and P. A. Vatakencherry, *ibid.*, **84**, 2611 (1962). The iodocamphene used in the synthesis of **3** was prepared from the corresponding bromide by successive treatment with magnesium, mercuric chloride, and iodine. The bromocamphene was derived from π -bromocamphor by reduction (BH_4^-) and dehydration with POCl_3 -pyridine.

(9) The nickel(I) π complex from α,α -dimethylallyl bromide generally undergoes preferential coupling at the primary rather than at the

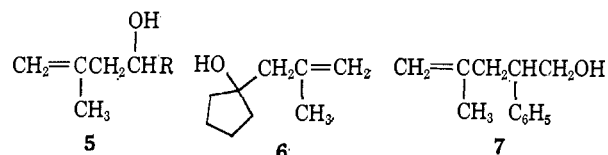
Substances of utility for further chain extension or cyclization can also be produced, for instance



In cases where substitution at C_1 and/or C_3 of the allyl group allows the possibility of geometrically isomeric coupling products, both *cis* and *trans* isomers usually result. For example, the π complex prepared from *trans*-geranyl bromide and nickel carbonyl affords with cyclohexyl iodide the coupling product **4** as a mixture of *cis*-*trans* isomers (40 and 60%).¹⁰



π -Allylnickel(I) complexes also can react with substances other than halides. The methallyl complex **1b** reacts with benzaldehyde, acrolein, and cyclopentanone in dimethylformamide to yield **5**, $R = C_6H_5$ (85%), **5**, $R = CH=CH_2$ (80%), and **6** (50%), respectively, and styrene oxide affords **7** (60%). In general, these reactions are considerably slower than those of **1b** with iodides, and more drastic conditions were used (50°, *ca.* 24 hr).



The more general problem of effecting cross-coupling reactions of unlike *nonallylic* groups is currently the subject of a parallel investigation in this laboratory, not only in the nickel series but also with other transition metal derivatives, for example, organocopper¹¹⁻¹³ and organosilver¹⁴⁻¹⁷ compounds.

An especially crucial part of the coupling process described above is the step in which the new carbon-carbon bond is formed and in particular the precursor for that step. Among the possibilities which presently appear as reasonable is the complex **8** which might be formed, for example, by the route¹⁸

tertiary terminal; with methyl iodide it affords pure 2-methyl-2-pentene (by vpc and nmr analysis) in *ca.* 90% yield.

(10) The interconversion of *cis*-*trans* forms of the allyl group could occur within the nickel complexes, *e.g.*, via reversible σ - π bonding changes. See (a) J. Powell, S. D. Robinson, and B. L. Shaw, *Chem. Commun.*, **78** (1965); (b) K. G. Ramey and G. L. Statton, *J. Am. Chem. Soc.*, **88**, 4387 (1966). Alternatively, isomerization may involve equilibration of primary and tertiary allylic bromides *via* nickel(I) σ and π complexes.

(11) H. Gilman and J. M. Straley, *Rec. Trav. Chim.*, **55**, 821 (1936).

(12) R. G. R. Bacon and H. A. O. Hill, *Quart. Rev. (London)*, **19**, 95 (1965).

(13) C. E. Castro, *et al.*, *J. Org. Chem.*, **28**, 2163, 3313 (1963); **31**, 4071 (1966).

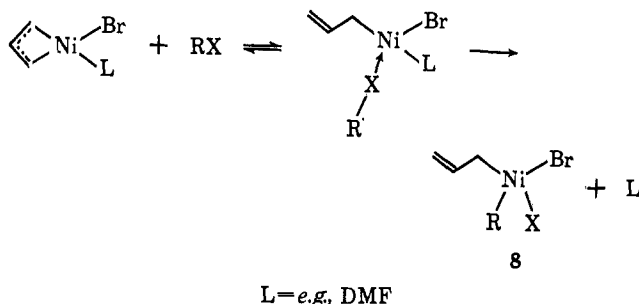
(14) E. A. Bickley and J. H. Gardner, *ibid.*, **5**, 126 (1940).

(15) G. M. Whitesides and C. P. Casey, *J. Am. Chem. Soc.*, **88**, 4541 (1966).

(16) G. Köbrich, H. Frölich, and W. Drischel, *J. Organometal. Chem. (Amsterdam)*, **6**, 194 (1966).

(17) H. C. Brown and C. H. Snyder, *J. Am. Chem. Soc.*, **83**, 1002 (1961).

(18) Experiments in progress have shown that bis- π -allylnickel(0) is unreactive toward bromobenzene and less reactive toward cyclohexyl iodide than is π -allylnickel(I) bromide (unpublished work with L. S. Hegedus and H. A. Kirst). Consequently, **8** is considered a more likely intermediate than analogs which are derived from reaction of nickel(0) complexes with RX.



The behavior of allylic halides toward π -allylnickel(I) derivatives, which contrasts sharply with that of non-allylic halides such as those appearing in Table I, will be detailed in due course.¹⁹

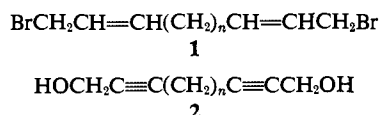
(19) This work was supported by National Science Foundation Grant GP-6527 X, and also by National Science Foundation Fellowships to M. F. S.

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The Synthesis of Large-Ring 1,5-Dienes by Cyclization of Allylic Dibromides with Nickel Carbonyl

Sir:

The method for forming cycloolefins from allylic dihalides and nickel carbonyl which has recently been reported^{1,2} has now been examined in order to ascertain its scope with a series of dibromides of structure 1. The results which have been obtained suggest that this



cyclization process provides an unusually efficient route for the formation of large rings. In addition, because it leads to cyclic 1,5-dienes, it makes available a wide variety of cyclic structures which are not obtainable in a practical way *via* the acyloin reaction, currently the only commonly used general approach to large rings.

The dibromides **1**, $n = 2, 4, 6, 8,$ and $12,$ were synthesized in both *cis,cis* and *trans,trans* forms from the acetylenic diols **2**, $n = 2, 4, 6, 8,$ and $12,$ by selective reduction to the corresponding *cis,cis*-³ or *trans,trans*-ethylenic⁴ diols⁵ followed by reaction with phosphorus tribromide.⁶ The required acetylenic diols **2**, $n = 4, 6,$ and $8,$ were made by alkylation of a dibromide, $\text{Br}(\text{CH}_2)_n\text{Br},$ with the sodio derivative of propargyl alcohol tetrahydropyranyl ether⁷ in liquid ammonia-ether⁸ ($n = 4, 6, 8$) or in tetrahydrofuran-

(1) E. J. Corey and E. Hamanaka, *J. Am. Chem. Soc.*, **86**, 1641 (1964).

(2) E. J. Corey and M. F. Semmelhack, *Tetrahedron Letters*, 6237 (1966).

(3) Using Lindlar catalyst; see H. Lindlar and R. Dubuis, *Org. Syn.*, **46**, 89 (1966).

(4) Using lithium aluminum hydride in tetrahydrofuran; see K. R. Bharucha and B. C. L. Weedon, *J. Chem. Soc.*, 1584 (1953).

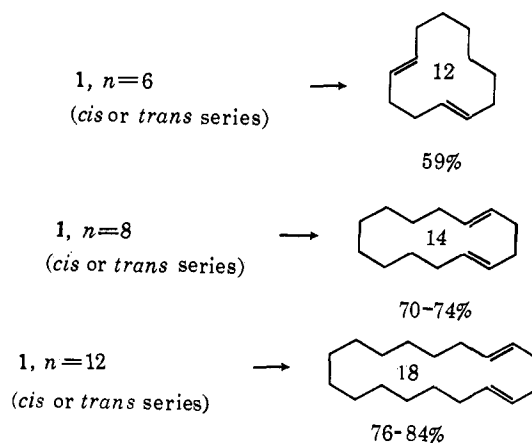
(5) Satisfactory analytical and spectroscopic (infrared and nmr) data have been obtained for the new compounds reported herein. The stereochemical assignments to the *cis,cis*- and *trans,trans*-dibromides **1** and the corresponding diols rest not only on the methods of synthesis (previously shown to be stereospecific) but also on the occurrence of infrared absorption at 10.4 or 10.3μ for the *trans,trans*-dihalides or diols and at 13.1 – 13.4μ for all the *cis,cis*-dibromides.

(6) J. M. Osbond, *J. Chem. Soc.*, 5270 (1961).

(7) R. G. Jones and M. J. Mann, *J. Am. Chem. Soc.*, **75**, 4048 (1953).

dimethyl sulfoxide ($n = 12$), and the diol **2**, $n = 2,$ was obtained from 1,5-hexadiyne⁹ and formaldehyde.¹⁰

The cyclization experiments were conducted by slow addition (motor-driven syringe, 12-hr period of addition) of the allylic dibromide (1 mmole) in dimethylformamide (1 ml) to a solution of nickel carbonyl (5 mmoles) in dimethylformamide (*ca.* 40 ml) under argon at 50° . In the cases of the dibromides **1**, $n = 6, 8,$ and $12,$ the same cyclization product was obtained starting with either *cis,cis* or *trans,trans* isomer.



In each of these cases the cyclization product was principally (95–98%) the *trans,trans*-1,5-diene, but small amounts of an isomeric compound, probably the *cis,trans* isomer, could be detected by vapor phase chromatography.¹¹ The major product from **1**, $n = 6,$ was identified as *trans,trans*-1,5-cyclododecadiene by spectroscopic comparison with the known substance;¹² the infrared spectrum manifested absorption at 10.4μ due to $\text{CH}=\text{CH}$ (*trans*) and no absorption at *ca.* 14.2μ which would be expected for $\text{CH}=\text{CH}$ (*cis*), and hydrogenation afforded cyclododecane, identical with an authentic sample. The principal products from **1**, $n = 8,$ and **1**, $n = 12,$ were identified by their infrared spectra (*e.g.*, absorption at 10.4μ but not at 14.2μ), mass spectra, nmr spectra, and hydrogenation to cyclo-tetradecane, mp 54 – 55° ,¹³ and cyclooctadecane, mp 71 – 72° ,¹³ respectively. The predominant course of cyclization with the dibromides **1**, $n = 2,$ and **1**, $n = 4,$ was formation of six-membered ring structures by 1–6 and 3–8 coupling, respectively; again the product composition was essentially independent of the geometry of the starting dibromide. With nickel carbonyl, **1**, $n = 2,$ afforded 4-vinylcyclohexene (42%) and *cis,cis*-1,5-cyclooctadiene (5%); the same products were also obtained using triphenylphosphinenickel tricarbonyl,¹⁴ but the relative amount of 1,5-cyclooctadiene was somewhat greater (*ca.* 20% of the mixture). In the case of dibromide **1**, $n = 4,$ with either nickel carbonyl or triphenylphosphinenickel tricarbonyl, only

(8) H. Bader, L. C. Cross, I. Heilbron, and E. R. H. Jones, *J. Chem. Soc.*, 619 (1949).

(9) R. A. Raphael and F. Sondheimer, *ibid.*, 120 (1950).

(10) F. Sondheimer, *J. Am. Chem. Soc.*, **74**, 4040 (1952).

(11) Using a column packed with Carbowax 20M (10%) on Chromosorb P at 200° .

(12) Reference spectra were furnished by Dr. Masaji Ohno, Toyo Rayon Co., Kamakura, Japan.

(13) L. Ruzicka, M. Stoll, M. W. Huyser, and H. A. Boekenoogen, *Helv. Chim. Acta*, **13**, 1152 (1930).

(14) See ref 2 for an example of ligand control of product using this reagent.