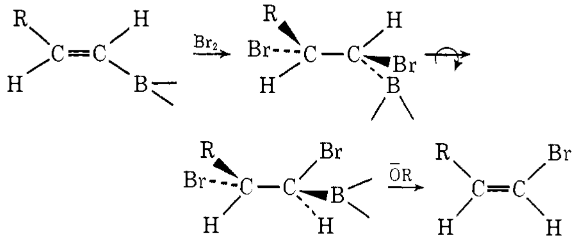
Table I. Stereospecific Conversion of Alkynes to Alkenyl Bromides *via* Hydroboration–Bromination–Elimination

Alkyne	Intermediate brominated (yield, %)[a]	Temp,[b] °C	Base used	Stereochemical purity[c]	Yield of alkenyl bromide,[c] %
1-Octyne	Boronic acid (90)	−20	MeONa–MeOH	99% cis	94,[d] 85[e]
	Catechol ester (90)	0	Aq NaOH	99% cis	100,[d] 90[e] (91,[d] 82[e])
Cyclohexylethyne	Boronic acid (93)	−40	MeONa–MeOH	99% cis	95,[d] 88[e]
	Catechol ester (93)	−40	MeONa–MeOH	99% cis	91,[d] 85[e]
Phenylethyne	Catechol ester	−40	MeONa–MeOH	99% cis	90[e]
3-Hexyne	Catechol ester (92)	−20	MeONa–MeOH	99% trans	92,[d] 85[e]
4,4-Dimethyl-2-pentyne	Catechol ester (97)	−20	MeONa–MeOH	98% trans	99,[d] 96[e]

[a] See ref 2. [b] At higher temperatures the stereochemical purity of the product is lower. [c] The alkenyl bromides were identified and characterized by means of gc, ir, pmr, and mass spectrometry. The stereochemistry of the internal alkenyl bromides was determined by preparation of the lithio derivatives (A. S. Dreiding and R. J. Pratt, *J. Amer. Chem. Soc.*, **76**, 1902 (1954); D. Y. Curtin and J. W. Crump, *ibid.*, **80**, 1922 (1958)), followed by protonolysis and the identification of the resulting olefin by gc. [d] Based on the intermediate boronic acid or its ester. [e] Based on the alkyne. The yields by isolation are given in parentheses.

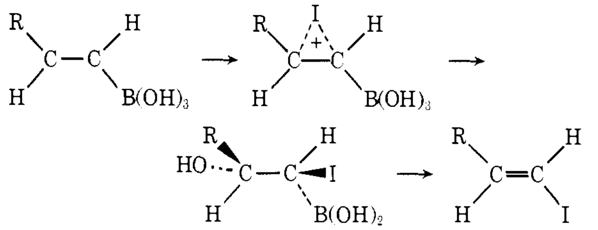
base-induced trans elimination of boron and bromine to give the product[6] (eq 5).



(5)

In the case of the iodine reaction,[1] the interpretation must be less definite at this time. The intermediate undergoing reaction is postulated to be the neutralized boronic acid. It was observed that the vinyl iodide is formed at a rate slower than that at which the iodine disappears.[1] Consequently, the reaction cannot involve a direct electrophilic attack of iodine on the carbon–boron bond.

We wish to propose that there is a trans addition of the elements of hypoiodous acid *via* an iodonium ion intermediate,[7] followed by a cis elimination (eq 6).



(6)

It was suggested earlier that β-substituted organoborane derivatives undergo cis eliminations preferentially when the substituent is one involving oxygen (alkoxy, acetate, etc.) capable of forming a dative bond from oxygen to boron.[6c,8]

A number of modifications of this mechanism can be suggested. However, it is preferable to defer more detailed consideration until such a time as more mechanistic data become available.

Irrespective of the precise mechanism involved, it is evident that we are now in a position to convert alkynes into vinyl bromides and iodides of opposite configurations, very conveniently *via* hydroboration with catecholborane. These vinyl bromides and iodides are readily converted into vinyl Grignard[9] and vinyllithium[10,11] derivatives with retention of their stereochemistry. Consequently, the present developments open up highly practical routes from the readily available alkynes to these valuable vinyl metallics of known stereochemistry.

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(6) (a) D. S. Matteson and J. D. Liedtke, *J. Amer. Chem. Soc.*, **87**, 1526 (1965); (b) H. C. Brown, D. H. Bowman, S. Misumi, and M. K. Unni, *ibid.*, **89**, 4531 (1967); (c) D. J. Pasto and Sr. R. Snyder, O. S. F., *J. Org. Chem.*, 31, 2773 (1966).

(7) (a) G. Zweifel, H. Arzoumanian, and C. C. Whitney, *J. Amer. Chem. Soc.*, **89**, 3652 (1967); (b) G. Zweifel, N. L. Polston, and C. C. Whitney, *ibid.*, **90**, 6243 (1968).

(8) (a) H. C. Brown and E. F. Knights, *ibid.*, **90**, 4439 (1968); (b) H. C. Brown and O. J. Cope, *ibid.*, **86**, 1801 (1964); (c) H. C. Brown and R. M. Gallivan, Jr., *ibid.*, 90, 2902 (1968).

(9) H. Normant, *Advan. Org. Chem.*, 2, 1 (1960).

(10) See references in footnote *c* of Table I.

(11) (a) E. J. Corey and D. J. Beames, *J. Amer. Chem. Soc.*, **94**, 2710 (1972); (b) A. F. Kluge, N. G. Untch, and J. H. Fried, *ibid.*, **94**, 9256 (1972).

(12) Visiting scholar on funds provided by Fuji Photo Film Co., Ltd., Tokyo, Japan.

(13) Postdoctoral research associate on grants provided by G. D. Searle and Co., Chicago, Ill., and the National Science Foundation (Grant No. 27742X).

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Determination of the Preferred Conformations Constrained along the C-4′-C-5′ and C-5′-O-5′ Bonds of β-5′-Nucleotides in Solution. Four-Bond ^{31}P-^{1}H Coupling[1]

Sir:

The Newman projections I–III and IV–VI respectively illustrate the preferred conformations constrained along the C-4′-C-5′ and C-5′-O-5′ bonds of a β-5′-nucleotide. An important stereochemical consequence of a β-5′-nucleotide existing in the gg-g′g′ (I and IV) conformation is that the atoms H-4′, C-4′, C-5′, O-5′, and P-5′ are in the same plane and that the four bond coupling path between H-4′ and P is the familiar "W" (VII). When the molecule is rotated into *any* other conformation this W relationship is destroyed. Studies by Hall, *et al.*,[2-4] indicate that the magnitude of

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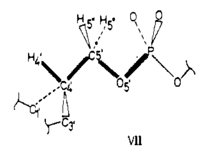
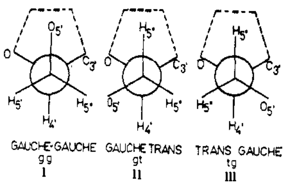
(2) L. D. Hall and R. B. Malcolm, *Can. J. Chem.*, **50**, 2092 (1972).

(3) L. D. Hall and R. B. Malcolm, *Can. J. Chem.*, **50**, 2102 (1972).

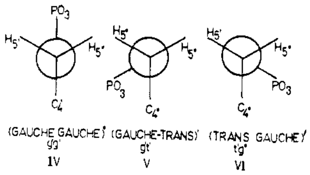
(4) B. Donaldson and L. D. Hall, *Can. J. Chem.*, **50**, 2111 (1972).



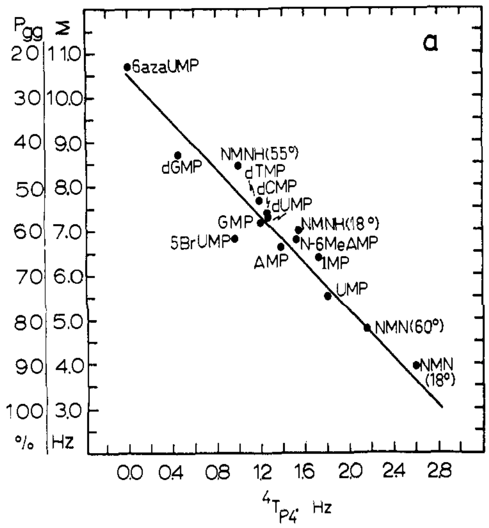
VII



I II III



IV V VI



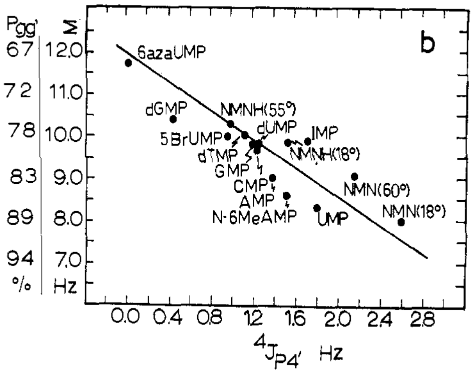


Figure 1. (a) Plot of $\Sigma(P_{gg})$ *vs.* ${}^4J_{P\text{-}4'}$. (b) Plot of $\Sigma'(P_{g'g'})$ *vs.* ${}^4J_{P\text{-}4'}$.

${}^4J_{^1H-^{31}P}$ coupling in W-oriented HCCOP fragments of phosphate esters exhibits a maximum value of ~2.7 Hz and suggest a reduction to ~0.0 Hz when this relationship is absent. As a logical extension we may postulate that ${}^4J_{P\text{-}4'}$ will reflect the conformational preferences about C-4′–C-5′ and C-5′–O-5′ bonds and in particular reflect the extent of planarity (*i.e.*, the gg–g′g′ orientation) of the H-4′–C-4′–C-5′–O-5′–P-5′ fragments of β-5′-nucleotides.

To unravel the interrelationships between the conformers constrained to C-4′–C-5′ and C-5′–O-5′ and ${}^4J_{P\text{-}4'}$ we have determined[5,6] ${}^3J_{4'5'} + {}^3J_{4'5''}(\Sigma)$, ${}^3J_{P\text{-}5'} + {}^3J_{P\text{-}5''}(\Sigma')$, and ${}^4J_{P\text{-}4'}$ for the 14 nucleotides in Figure 1. Other investigators have seen ${}^4J_{P\text{-}4'}$ in certain nucleotides.[7-9] From the sums Σ and Σ′, the fractional populations of gg (P_{gg}) and g′g′ ($P_{g'g'}$) were computed using expressions 1 and 2 developed earlier.[10-13] In

$$P_{gg} \simeq (13 - \Sigma)/10 \qquad (1)$$

$$P_{g'g'} \simeq (24 - \Sigma')/18 \qquad (2)$$

Figures 1a and 1b P_{gg} and $P_{g'g'}$ were plotted against corresponding ${}^4J_{P\text{-}4'}$ values. Reasonably linear correlations[14-16] exist between both $\Sigma(P_{gg})$ and $\Sigma'(P_{g'g'})$ and ${}^4J_{P\text{-}4'}$ with *increases* in ${}^4J_{P\text{-}4'}$ accompanied by *decreases* in Σ and Σ′. The simultaneous appearance of these correlations is exactly what one would predict from earlier work[12] describing correlations between Σ and Σ′. Furthermore, the concurrent variations substantiate our suggestions[12] of an interdependence between rotational preferences about C-4′–C-5′ and C-5′–O-5′ and demonstrate that ${}^4J_{P\text{-}4'}$ *is a simultaneous measure of the conformational distribution about C-4′–C-5′ and C-5′–O-5′ for a β-5′-nucleotide.* The trends are consistent with a depopulation of g′/t′ (V or VI or both) rotamers as the molecule become increasingly gg. Extrapolation to P_{gg} – 100% yields a ${}^4J_{P\text{-}4'}$ value corresponding to $P_{g'g'} \sim 95\%$ and confirms our earlier proposal[12] for the virtual exclusion of g′/t′ conformers in gg-oriented β-5′-nucleotides. It can also be noted for the series of molecules examined that while P_{gg} has a substantial range (20–90%) the range of $P_{g'g'}$ is more limited. Further, extrapolation of the plot to P_{gg} = 0% yields $P_{g'g'}$ = 65% and implies that though g′g′ predominates for g/t (II or III or both) oriented molecules, it is no longer obligatory.[12]

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(5) Spectra of the nucleotides, commercial preparations, 0.1 *M*, pD 8.0, 30° in 100% D₂O, were obtained in a 220-MHz nmr system or a 100-MHz, fast Fourier transform system using a 16K transform in ${}^1H$ and ${}^1H-\{{}^{31}P\}$ modes. Details of the instrumentation are discussed elsewhere.[6] Computer-simulated (LAME) spectra were generated as a final test of the derived data. In molecules in which the ${}^4J_{P\text{-}4'}$ is small (<0.4 Hz), the ${}^4J_{P\text{-}4'}$ was seen as an additional broadening in the 4′ region of the spectra compared to the ${}^1H-\{{}^{31}P\}$ spectra. Estimates of these couplings were made by comparing the band width of the computer-simulated 4′ region (with the observed 4′ region) for a series of ${}^4J_{P\text{-}4'}$ values.

(6) R. H. Sarma and R. J. Mynott, *J. Amer. Chem. Soc.*, **95**, 1641 (1973).

(7) D. Davies and S. S. Danyluk, Abstracts, Second International Symposium on NMR Spectroscopy organized by the Chemical Society at the University of Surrey, July 1972.

(8) I. C. P. Smith, H. H. Mantsch, R. D. Lapper, R. Deslauriers, and T. Schleich, *Conform. Biol. Mol. Polymers, Proc. Jerusalem Symp. Quantum Chem. BioChem.*, **5**, 381 (1973).

(9) B. J. Blackburn, R. D. Lapper, and I. C. P. Smith, *J. Amer. Chem. Soc.*, **95**, 2873 (1973).

(10) F. E. Hruska, D. J. Wood, R. J. Mynott, and R. H. Sarma, *FEBS (Fed. Eur. Biochem. Soc.) Lett.*, 31, 153 (1973).

(11) D. J. Wood, F. E. Hruska, R. J. Mynott, and R. H. Sarma, *Can. J. Chem.*, **51**, 2571 (1973).

(12) D. J. Wood, R. J. Mynott, F. E. Hruska, and R. H. Sarma, *FEBS (Fed. Eur. Biochem. Soc.) Lett.*, in press.

(13) The equations in ref 12 are slightly modified forms of the expressions in ref 10 and 11.

(14) It is important to point out that no sign determinations for ${}^4J_{P\text{-}4'}$ were possible. However, the linear correlations provide indirect evidence that the signs are identical for the series of β-5′-nucleotides examined and probably positive.[12,13]

(15) E. Duval and E. A. C. Lucken, *Mol. Phys.*, **10**, 499 (1966).

(16) E. Duval, J. Ramft, and G. J. Bene, *Mol. Phys.*, **9**, 427 (1965).

It is also interesting to point out that extrapolation to 100% P_{gg} and 100% $P_{g'g'}$ yields $^4J_{P\text{-}4'}$ values of 2.8 and 3.5 Hz, respectively, which in view of the uncertainty of Σ and Σ' values for the pure gg-g′g′ state may be considered to be in good agreement with the Hall[2–4] estimates for W coupling in phosphate esters and with Duval, *et al.*,[15,16] on acyclic esters. It it also noteworthy that a negative $^4J_{P\text{-}4'}$ (−0.8 Hz) is predicted for a β-5′-nucleotide with P_{gg} = 0%. As yet no negative $^4J_{PH}$ coupling has been reported in phosphate esters,[17] though on the basis of the conformational dependence of the sign of $^4J_{HCCCH}$ in propanes[18,19] a negative $^4J_{P\text{-}4'}$ for a g/t β-5′-nucleotide may not be unexpected.[20]

Figures 1a and b can be of some practical value since they may provide crude estimates of Σ and Σ' (as well as P_{gg} and $P_{g'g'}$) from $^4J_{P\text{-}4'}$ and may be useful in those situations where the 5′5″ regions defy analysis. We stress caution in the application since additional splitting (broadening) in the 4′ region can arise from virtual coupling.[21] However, we may safely predict that if $^4J_{P\text{-}4'}$ is >1.0 Hz, the predominant conformer is ggg′g′, whereas if $^4J_{P\text{-}4'}$ is small (<0.3 Hz) it is predominantly g/t-g′g′ with a smaller (but not an insignificant) contribution from g/t-t′/g′. We realize that a small $^4J_{P\text{-}4'}$ is not inconsistent with gg–t′/g′. However, our $\Sigma\Sigma'$ correlations[12] as well as our $^4J_{P\text{-}4'}$ correlations demonstrate that this situation is not accessible to β-5′-nucleotides and is in agreement with X-ray studies on β-5′-nucleotides, dinucleoside monophosphates, RNA, and DNA,[21–26] as well as with steric consideration.

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[17] A −0.55-Hz $^4J_{HCCOP}$ has been reported for triethyl phosphate.[12]

[18] M. Barfield, *J. Amer. Chem. Soc.*, **93**, 1066 (1971).

[19] T. Schaefer and R. Wasylishen, private communications.

[20] It is meaningless to extrapolate the Σ', $^4J_{P\text{-}4'}$ plot to $P_{g'g'}$ = 0% since this work in conjunction with earlier studies[9] demonstrates that for β-5′-nucleotides, the minimum $P_{g'g'}$ is about 65% and occurs for P_{gg} = 0%; this puts a purely g/t–t′/t′ situation into a forbidden domain.

[21] For instance, when the ratio of the chemical-shift difference between H-2′ and H-3′ and $J_{2',3'}$ is small, ^{31}P decoupling experiments confirm the presence of $^4J_{P\text{-}4'}$.

[22] S. Arnott and D. W. L. Hukins, *Nature (London)*, **224**, 886 (1969).

[23] S. Arnott, S. D. Dover, and A. J. Wonacott, *Acta Crystallogr., Sect. B*, **25**, 2192 (1969).

[24] M. Sundaralingam, *Biopolymers*, 7, 821 (1969).

[25] J. Rubin, T. Brennan, and M. Sundaralingam, *Biochemistry*, **11**, 3112 (1972).

[26] W. Saenger and D. Suck, *Nature (London)*, in press.

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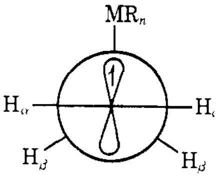
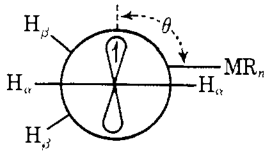
Hyperconjugation in β-Substituted Ethyl Radicals. Does It Determine Conformation?[1]

Sir:

The conformations of β-substituted ethyl radicals, $R_nMCH_2CH_2\cdot$, as determined from the hyperfine splittings due to the β-hydrogens in their epr spectra, are of two principal types. If the atom M is from rows 2, 3, or 4 of the periodic table the most stable conformation (*i.e.*, that favored at low temperatures) is **1a**, while if M is from row 1 the most stable conformation is **2a**.[2–14] For example,[2] with R_nM = Et_3Si conformation **1a** obtains and with R_nM = H_3C conformation **2a** obtains at low temperatures.[15]



1, $\theta = 0°$



2, $\theta = \pi/2$

a, $H_\alpha = H$
b, $H_\alpha = (CH_3)_3C$

Kochi and Krusic[2] proposed that **1a** is favored over **2a** for second-row elements because of 1,3 bonding between the unfilled 3d orbitals of M and the 2p orbital of the carbon radical center (p–d homoconjugation). The subsequent discovery[3,4,7] of unusually large hyperfine coupling to M led to proposals of a hyperconjugative delocalization mechanism between the C_α 2p orbital and the C_β–M σ bond; orbital overlap being maximized in conformation **1a**. Lyons and Symons[3,4] favor hyperconjugation *alone*[16] and point out that **1a** is favored when $R_nM\cdot$ is a pyramidal radical since hyperconjugative contributions of the type $\dot{C}\text{–}C\text{–}MR_n \leftrightarrow C{=}C\cdot MR_n$ require smaller changes in geometry of the R_nM group than when $R_nM\cdot$ is a planar radical.

We have discovered that a series of relatively long-lived ($\tau_{1/2}$ *ca.* 5 sec at 25°) carbon centered radicals can be formed by radical addition to 1,1-di-*tert*-butylethylene in solution

$$R_nM\cdot + [(CH_3)_3C]_2C{=}CH_2 \longrightarrow \underset{3}{[(CH_3)_3C]_2\dot{C}CH_2MR_n}$$

The longevity of these radicals (which is conferred by the di-*tert*-butyl moiety[17]) allowed accumulation of sufficient concentrations that hyperfine splittings owing to ^{13}C in natural abundance could often be measured. The epr parameters of a few representative radicals of type **3** (see Table I) imply that hyperconjugation *alone* is not sufficient to account for the conformational preferences of row 1 and row 2 R_nM adducts to ethylene.

The low values of a^{H_β} imply that all **3** prefer conformation **1b** even at room temperature.[18] Having

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[1] Issued as NRCC No. 13457.

[2] P. J. Krusic and J. K. Kochi, *J. Amer. Chem. Soc.*, **93**, 846 (1971).

[3] A. R. Lyons and M. C. R. Symons, *Chem. Commun.*, 1068 (1971).

[4] A. R. Lyons and M. C. R. Symons, *J. Chem. Soc., Faraday Trans. 2*, **68**, 622 (1972).

[5] A. R. Lyons and M. C. R. Symons, *J. Amer. Chem. Soc.*, **93**, 7330 (1971).

[6] R. O. C. Norman and P. M. Storey, *J. Chem. Soc. B*, 1009 (1971).

[7] T. Kawamura and J. K. Kochi, *J. Amer. Chem. Soc.*, **94**, 648 (1972).

[8] M. C. R. Symons, *ibid.*, **94**, 8589 (1972).

[9] D. J. Edge and J. K. Kochi, *Tetrahedron Lett.*, 2427 (1972).

[10] D. J. Edge and J. K. Kochi, *J. Amer. Chem. Soc.*, **94**, 6486 (1972).

[11] A. J. Bowles, A. Hudson, and R. A. Jackson, *Chem. Phys. Lett.*, **5**, 552 (1970).

[12] T. Kawamura, D. J. Edge, and J. K. Kochi, *J. Amer. Chem. Soc.*, **94**, 1752 (1972).

[13] M. C. R. Symons, *Chem. Phys. Lett.*, **19**, 61 (1973).

[14] J. Cooper, A. Hudson, and R. A. Jackson, *Tetrahedron Lett.*, 831 (1973).

[15] Conformations intermediate between **1a** and **2a** are also possible.[9,10]

[16] The occurrence of C_α–M, p–p homoconjugation when M has lone pairs of electrons appears to be generally accepted.[11–14]

[17] See G. D. Mendenhall and K. U. Ingold, *J. Amer. Chem. Soc.*, **95**, 3422 (1973).

[18] $R_nMCH_2\dot{C}(CH_3)_2$ in conformation **1** have $a^{H_\beta} \simeq 11.4$ G.[2]