onance Laboratory for instructing us in the use of the HX-360 spectrometer.

Registry No.—1, 5323-87-5; 2, 61484-02-4; 3, 61484-03-5; 4, 61484-04-6; *cis*-5, 61484-05-7; *trans*-5, 61484-06-8; *cis*-6, 61484-07-9; *trans*-6, 61505-79-1; 7, 61484-08-0; 8, 61484-09-1; 9, 61484-10-4; *cis*-10, 61484-11-5; *trans*-10, 61484-12-6; 11, 61484-13-7; 12 isomer A, 61505-42-8; 12 isomer B, 61484-14-8; 13, 61484-15-9; 14, 61484-16-0; 15, 61484-17-1; *cis*-16, 61484-18-2; *trans*-16, 61484-19-3; *cis*-17, 61484-20-6; *trans*-17, 61484-21-7; 18, 61484-22-8; 19, 61484-23-9; 20, 61484-24-0; 21, 61484-25-1; 22, 61521-26-4; 23, 40291-46-1; 1-bromo-2-butyne, 3355-28-0; methyl iodide, 74-88-4; propargyl bromide, 106-96-7; formic acid, 64-18-6; trimethylsilyl chloride, 75-77-4; ozone, 10028-15-6.

References and Notes

(1) See W. S. Johnson, K. Wiedhaup, S. F. Brady, and G. L. Olson, *J. Am. Chem. Soc.*, **96**, 3979 (1974), and previous papers in the series.
(2) For applications of π-cyclization to the synthesis of other types of systems, see, inter alia, (a) R. A. Volkmann, G. C. Andrews, and W. S. Johnson, *J. Am. Chem. Soc.*, **97**, 4777 (1975); (b) S. Murayama, D. Chan, and M. Brown, *Tetrahedron Lett.*, 3715 (1968); (c) J. A. Marshall, G. L. Bundy, and W. I. Fanta, *J. Org. Chem.*, **33**, 3913 (1968).
(3) R. L. Danheiser and G. Stork, *J. Org. Chem.*, **38**, 1775 (1973).
(4) L. Brandsma, "Preparative Acetylenic Chemistry", Elsevier, Amsterdam, 1971, p 158.
(5) J. P. Blanchard and H. L. Goering, *J. Am. Chem. Soc.*, **73**, 5863 (1951).
(6) Infrared spectra (IR) were measured as neat films on a Perkin-Elmer 137 infrared spectrometer. Proton magnetic resonance spectra (^{1}H NMR) were measured in CCl_4 on a Varian T-60 or a Bruker HX-360 nuclear magnetic resonance spectrometer. Chemical shifts are reported in parts per million downfield from internal tetramethylsilane (δ) and are followed in parentheses by the integrated area, multiplicity, and coupling constant in hertz. Carbon magnetic resonance spectra (^{13}C NMR) were measured in $CDCl_3$ on a Nicolet TT-23 nuclear magnetic resonance spectrometer operating at 25.14 MHz. Chemical shifts are referenced to $CDCl_3$ and are reported in parts per million downfield from tetramethylsilane (central peak of $CDCl_3$ triplet = 1936 Hz).
(7) These products are racemic. The name given is that of the enantiomer depicted in the text.
(8) This experiment was first carried out by Phillip Nies.
(9) This experiment was first carried out by Mario Curzi.

Intramolecular 1,3-Dipolar Cycloadditions of Nitrile Imines Bearing an Alkenyl Substituent

Luisa Garanti,*[1] Alberto Sala, and Gaetano Zecchi

Istituto di Chimica Industriale dell'Universita', Centro del C.N.R. per la Sintesi e Stereochimica di Speciali Sistemi Organici, Via Golgi 19, 20133 Milano, Italy

Received September 28, 1976

Two series of nitrile imines bearing an alkenyl substituent were generated in situ from the corresponding 1-chlorohydrazones by treatment with triethylamine in aromatic hydrocarbon solvents. The intramolecular 1,3-dipolar cycloaddition, leading to fused ring 2-pyrazolines, was the exclusive or the predominant reaction with few exceptions. Retention of stereochemistry was observed in the case of 1,2-disubstituted ethylenic functions.

1,3-Dipolar cycloadditions are well known for their utility in heterocyclic syntheses as well as for the interesting mechanistic questions which they raise. In recent years, intramolecular examples have been reported to give fused or bridged ring heterocycles.[2] In these cases, observations have often been in contrast with the usual intermolecular patterns, particularly regarding orientation.

In this context, we now report an extensive study on the behavior of nitrile imines containing a carbon–carbon double bond potentially able to behave as a dipolarophile. In order to investigate electronic and steric effects on these intramolecular reactions, the nitrile imines **4a–e** and **10a–c** were studied (Charts I and II).

Chart I

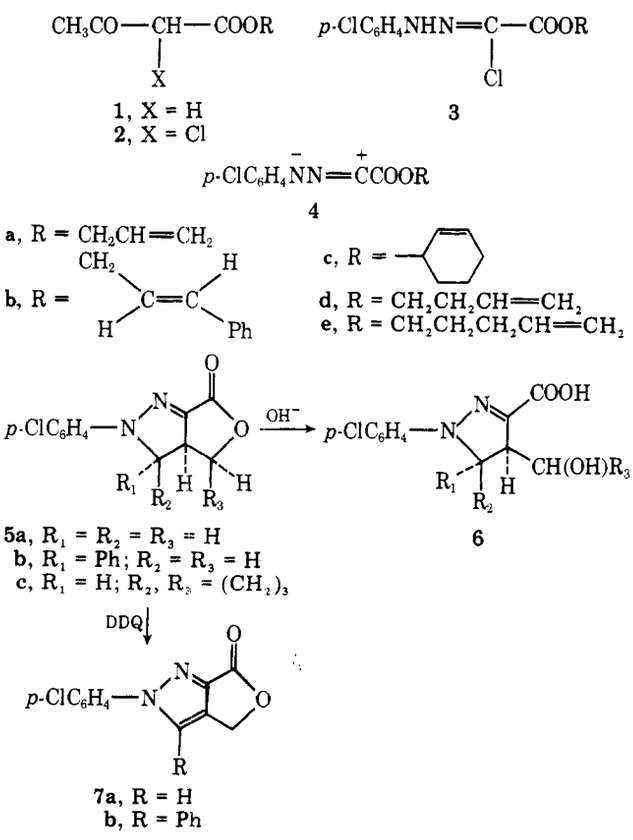


Chart II

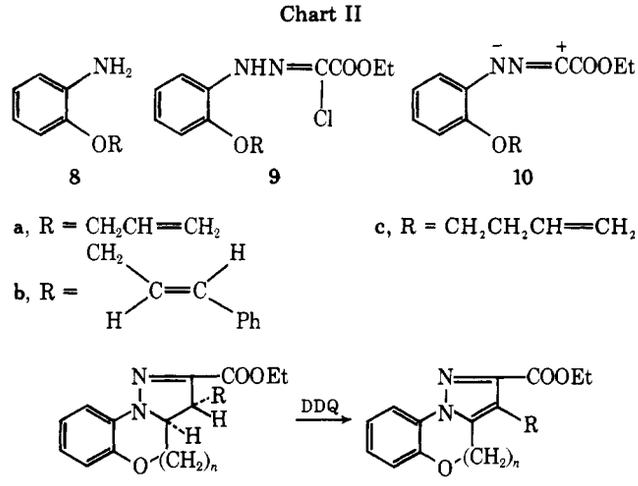


Table I. Preparation of Intermediates 1, 2, 3, and 9[a]

Compd	Yield, %	Mp or bp, °C (mm)	Recrystn solvent
1d	55	89–90 (25)	
1e	63	74–75 (3)	
2a[4]	75	45–48 (2)	
2b	81	*b*	
2c	79	*c*	
2d	73	67–69 (2)	
2e	65	78–80 (2)	
3a	67	127	Ethanol
3b	47	144	Ethanol
3c	51	138	Ethanol
3d	49	96	Ethanol
3e	65	84	*n*-Hexane
9a	30[d]	42	*n*-Pentane
9b	38[d]	95	Diisopropyl ether
9c	29[d]	34	*n*-Pentane

[a] Satisfactory elemental analyses were obtained for the compounds listed with the exception of **2b,c**. [b] Undistilled oil of ca. 90% purity by NMR analysis; attempted distillation in vacuo caused extensive decomposition. [c] Undistilled oil of purity better than 95% (NMR). [d] By chromatography on a silica gel column.

Results and Discussion

Following the common procedure for the preparation of this class of compounds,[3] nitrile imines **4a–e** and **10a–c** were obtained from the corresponding 1-chlorohydrazones **3a–e** and **9a–c**. These intermediates were in turn available as follows.

The treatment of the alkenyl acetoacetates **1a–e** with sulfuryl chloride afforded the corresponding 2-chloroacetoacetates **2a–e**, which gave **3a–e** through the coupling reaction with 4-chlorobenzenediazonium chloride. Analogously, compounds **9a–c** were prepared by diazotization of the ortho-substituted anilines **8a–c** and subsequent coupling with ethyl 2-chloroacetoacetate. Table I collects yields and physical data. (See paragraph at end of paper regarding supplementary material.)

The above 1-chlorohydrazones were treated with a large excess of triethylamine in aromatic hydrocarbon solvents, as reported in Table II. Temperatures were chosen in accord with the differing substrate reactivities, while the reaction times were determined by periodical TLC analyses. Products and yields are indicated in Table II. In the case of **3d** and **3e**, the reaction gave an intractable, tarry mixture; an attempt to isolate characterizable products after a short reaction time was also unsuccessful.

The product structures were determined from elemental analyses and IR and NMR spectra (see Table III and Experimental Section). Mass spectra are available for **14a,b**.

The DDQ oxidation of **5a,b** and **11a–c** led to the corresponding pyrazoles **7a,b** and **12a–c**, thus providing chemical support to the assigned structures.[5] Compounds **7a,b**[6] and **12a,b**[7] had already been prepared by analogous intramolecular cycloadditions of the alkyne derivatives corresponding to **4a,b** and **10a,b**. Also, the lactones **5a–c** readily underwent alkaline hydrolysis to afford the hydroxy acids **6a–c**.

The stereochemistry of the above products was assigned on the basis of the following observations.

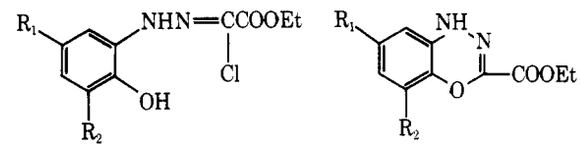
The NMR spectrum of **5b** shows for the pyrazolinic proton in the 5 position a doublet with J = 11.5 Hz. The literature data for the 2-pyrazolines[8] reveal that the vicinal coupling constants of the hydrogens in the 4 and 5 positions are in the range 2.3–10.5 Hz for J_{trans} and 8.5–14 Hz for J_{cis}, with great dependence on the substituents. Thus, the above value may suggest prima facie a cis configuration; such a stereochemistry, however, has to be ruled out for the lactone **5b**, since the hydroxy acid **6b** derived from it has $J_{4,5}$ = 5.5 Hz, which corresponds unequivocally to trans coupling. As the molecular models indicate, the above anomalous value may be related to the torsional strain involved in the fused ring structure **5**.

For the tricyclic compound **5c**, the examination of molecular models shows that only one configuration can be adopted in which the three hydrogens in the bridgehead positions are situated cis to each other; the observed values of the coupling constants are 8.5 and 11 Hz. Compound **11b** presents for the pyrazolinic protons J = 9 Hz, which is more consistent with a trans structure than with a cis one.

The results now reported reveal that the intramolecular 1,3-cycloaddition is the exclusive or predominant reaction of **4a–c** and **11a–c**, while it does not occur in the case of **4d,e**. Since the ethylenic function of **4d,e** is electronically similar to that of **10c**, the lack of intramolecular cycloaddition by the former substrates may be attributable to unfavorable molecular geometries for the intramolecular approach of the reactive centers. Such an approach, on the other hand, is probably facilitated in the case of **10c** by the ortho relationship of the substituents.[9]

The intramolecular cycloadditions of **4b,c** and **10b** are particularly interesting since they involve 1,2-disubstituted double bonds of known stereochemistry. The structure of the products reveals cis stereospecificity, which is in line with the previous findings for intermolecular cycloadditions of nitrile imines with 1,2-disubstituted ethylenes.[10]

The side process leading to the isomeric 1,3,4-benzoxadiazines **14a** and **14b** remains to be considered. These products could arise from the preliminary Claisen-type rearrangement of **9b** to the isomeric phenols **13a** and **13b**, according to the known behavior of aryl allyl ethers.[11] Owing to the presence of triethylamine, the corresponding phenoxide ions should be actually present, from which the final products may well be formed through the intramolecular nucleophilic displacement of the halogen. Control experiments showed that (1) **9b** rearranges in boiling toluene to produce only phenol **13a**, (2) the latter compound readily reacts with triethylamine to afford **14a**. Further work is in progress to provide mechanistic evidence for this interesting side reaction.



13 14

a, R_1 = $CH_2CH{=}CHPh$; R_2 = H;
b, R_1 = H; R_2 = $CH(Ph)CH{=}CH_2$

Experimental Section

Melting points were taken on a Büchi apparatus and are uncorrected. Infrared spectra were recorded on a Perkin-Elmer Model 377 spectrophotometer. NMR spectra were usually obtained on a Varian A-60A instrument with Me_4Si as internal standard; a Varian HA-100 instrument was used for compounds **11a–c** and **14a,b**. Mass spectra were determined on a Hitachi Model RMU-6L apparatus.

Compounds **1a,b**,[12] **1c**,[13] **8a**,[14] **8b**,[15] and **8c**[16] were prepared by literature methods. Compounds **1d,e** were synthesized according to the procedure described for **1b**.[12]

Preparation of Alkenyl 2-Chloroacetoacetates (2). General Procedure. A solution of sulfuryl chloride (72 mmol) in dry chloroform (20 mL) was slowly added (2 h) to a solution of 1 (60 mmol) in dry chloroform (80 mL). During the addition, the temperature was kept at 0 °C and dry nitrogen was bubbled through the reaction mixture. After 2 h at room temperature, chloroform was added and the organic solution was washed with aqueous $NaHCO_3$ and dried over $MgSO_4$. The solvent was removed to give **2** in a crude state. Distillation in vacuo was carried out in the case of **2a,d,e**. See Table I.

Preparation of Alkenyl 2-Chloro-2-(4-chlorophenylhydra-

Table II. Treatment of 1-Chlorohydrazones 3 and 9 with Triethylamine[a]

Compd	Solvent[b]	Time, h	Product(s)	Yield, %	Isolation procedure[c]
3a	Benzene	7	2-Aryl-6-oxo-2,3,3a,6-tetrahydro-4*H*-furo[3,4-*c*]pyrazole (**5a**)[d]	69	A
3b	Toluene	3	2-Aryl-6-oxo-3-phenyl-2,3,3a,6-tetrahydro-4*H*-furo[3,4-*c*]pyrazole (**5b**)[d]	73	A
3c	Benzene	2	4-Aryl-2-oxo-2,4,4a,5,6,7,7a,7b-octahydrofuro[4,3,2-*c*,*d*]indazole (**5c**)[d]	73	A
3d	Toluene	80	*e*		
3e	Xylene	90	*e*		
9a	Benzene	40	2-Carbethoxy-3,3a-dihydro-4*H*-pyrazolo[5,1-*c*][1,4]benzoxazine (**11a**)	85	A
9b	Toluene	108	2-Carbethoxy-3-phenyl-3,3a-dihydro-4*H*-pyrazolo[5,1-*c*][1,4]benzoxazine (**11b**)	36	B
			2-Carbethoxy-6-(1-phenylpropen-3-yl)-4*H*-1,3,4-benzoxadiazine (**14a**)	12	B
			2-Carbethoxy-8-(3-phenylpropen-3-yl)-4*H*-1,3,4-benzoxadiazine (**14b**)	10	B
9c	Toluene	64	2-Carbethoxy-3,3a,4,5-tetrahydropyrazolo[5,1-*d*][1,5]benzoxazepine (**11c**)	45	B

[a] Concentrations were 0.01 M for the 1-chlorohydrazones and 0.05 M for triethylamine. [b] At refluxing. [c] A = crystallization with diisopropyl ether; B = chromatography on silica gel column with benzene–ethyl acetate (9:1) as eluent. [d] Aryl = 4-chlorophenyl. [e] Tarry mixture.

Table III. Physical and Spectral Data of 2-Pyrazoline Derivatives[a]

Compd	Mp, °C (recrystn solvent)	ν_{CO} (Nujol), cm^{-1}	NMR spectrum, δ (*J*, Hz)
5a	130[b] (CCl_4)	1760	$CDCl_3$: 3.7–4.9 (5 H, m, CH_2CHCH_2), 6.9–7.4 (4 H, m, Ar)
5b	175[b] (*n*-hexane–benzene)	1760	$CDCl_3$: 3.7–4.9 (3 H, m, CH_2CH), 5.35 (1 H, d, *J* = 11.5, CHN), 6.8–7.5 (9 H, m, Ar)
5c	140[b] (*n*-hexane–benzene)	1765	$CDCl_3$: 1.2–2.3 [6 H, m, $(CH_2)_3$], 4.09 (1 H, dd, *J* = 8.5 and 11, CHC**H**CH), 4.7–5.2 (2 H, m, C**H**CHC**H**), 6.9–7.4 (4 H, m, Ar)
6a	167[b] (acetone)	1670	C_3D_6O: 3.7–4.3 (5 H, m, CH_2CHCH_2), 4.7 (2 H, broad s, two OH), 7.0–7.4 (4 H, m, Ar)
6b	193[b] (benzene)	1665	C_3D_6O: 3.2–3.6 (1 H, m, C**H**CH_2), 3.97 (2 H, d, *J* = 5, CH_2), 4.8 (2 H, broad s, two OH), 5.56 (1 H, d, *J* = 5.5, C**H**Ph), 7.0–7.4 (9 H, m, Ar)
6c	180[b] (acetone)	1670	Me_2SO-d_6: 1.1–2.2 [6 H, m, $(CH_2)_3$], 3.50 (1 H, dd, *J* = 5 and 11, CHC**H**CH), 4.0–4.8 (2 H, m, C**H**CHC**H**), 6.9–7.4 (4 H, m, Ar), 8.0 (2 H, broad s, two OH)
11a	101[c] (*n*-hexane)	1725	$CDCl_3$: 1.35 (3 H, t, CH_3), 2.90, 3.27 (2 H, AB part of ABX system, J_{AB} = 18, J_{AX} = 6.5, J_{BX} = 11.5, CH_2CHN), 3.4–4.5 (5 H, m, $CHCH_2O$ and C**H**$_2CH_3$), 6.8–7.6 (4 H, m, Ar)
11b	115[c] (*n*-hexane–benzene)	1715	$CDCl_3$: 1.20 (3 H, t, CH_3), 3.69 (1 H, d, *J* = 9, C**H**Ph), 4.0–4.4 (5 H, m, $CHCH_2O$ and C**H**$_2CH_3$), 6.8–7.7 (9 H, m, Ar)
11c	122[d] (diisopropyl ether)	1725	$CDCl_3$: 1.37 (3 H, t, CH_3), 2.1–2.4 (2 H, m, C**H**$_2CH_2O$), 2.84 (1 H, dd, *J* = 13 and 17, one proton of pyrazoline CH_2), 3.3–4.6 (6 H, m, two CH_2O and two pyrazoline protons), 6.9–7.6 (4 H, m, Ar)

[a] All the compounds listed gave correct elemental analyses. [b] Yellow crystals. [c] Pale yellow crystals. [d] Colorless crystals.

zono)acetates (3). General Procedure. A cold aqueous solution of 4-chlorobenzenediazonium chloride (15 mmol) was added dropwise to a solution of **2** (15 mmol) and sodium acetate (30 mmol) in 80% aqueous methanol (60 mL) under vigorous stirring and ice cooling. The mixture was stirred overnight at room temperature. The solid material was collected by filtration, washed several times with water, and recrystallized from ethanol to give pure **3**. See Table I.

Preparation of Ethyl 2-[2-(Alkenyloxy)phenylhydrazono]-2-chloroacetates (9). General Procedure. A solution of $NaNO_2$ (10 mmol) in water (5 mL) was added to a solution of amine **8** (10 mmol) in 0.5 N HCl (60 mL) under stirring and ice cooling. The mixture was then adjusted to pH 4 by sodium acetate and ethyl 2-chloroacetoacetate (10 mmol) was added dropwise at 0–5 °C. After 1 h at room temperature, the mixture was extracted with ether and the organic solution was dried over $MgSO_4$ and evaporated. The residue was chromatographed on a silica gel column with benzene as eluent to afford pure **9**. See Table I.

Treatment of 1-Chlorohydrazones 3 and 9 with Triethylamine. General Procedure. A solution of 1-chlorohydrazone **3** or **9** (15 mmol) and triethylamine (75 mmol) in dry solvent (1.5 L) was heated under reflux as provided in Table II. The mixture was then washed with aqueous HCl, dried over $MgSO_4$, and evaporated. The residue furnished the products indicated in Table II. In the case of **9b**, the column chromatography gave three products in the following order of elution: **11b**, **14a**, and **14b**. Physical and spectral data of **5a–c** and **11a–c** are collected in Table III. The following data are available for **14a,b**.

Compound **14a**: yellow crystals, mp 157 °C (*n*-hexane–benzene); IR (Nujol) 3300 (NH) and 1710 cm^{-1} (CO); NMR (C_6D_6) δ 0.92 (3 H, t, CH_2CH_3), 3.06 (2 H, d, *J* = 6 Hz, C**H**$_2$CH=), 3.96 (2 H, q, C**H**$_2CH_3$), 5.83 (1 H, d, *J* = 2 Hz, Ar), 6.10 (1 H, dt, *J* = 16 and 6 Hz, CH_2C**H**=), 6.2–6.6 (4 H, m, PhC**H**=, NH, and Ar), 7.0–7.3 (5 H, m, Ar); mass spectrum *m/e* (rel intensity) 322 (100), 294 (15), 222 (4), 206 (5), 194 (13), 178 (6), 132 (11), 117 (6). Anal. Calcd for $C_{19}H_{18}N_2O_3$: C, 70.79; H, 5.63; N, 8.69. Found: C, 70.67; H, 5.58; N, 8.63.

Compound **14b**: yellow crystals, mp 119 °C (*n*-hexane–benzene); IR (Nujol) 3300 (NH) and 1720 cm^{-1} (CO); NMR (C_6D_6) δ 0.91 (3 H, t, CH_2CH_3), 3.92 (2 H, q, C**H**$_2CH_3$), 5.03 (1 H, dt, *J* = 9 and 1 Hz, C**H**Ph), 5.1–5.2 (2 H, m, CH_2=), 5.70 (1 H, dd, *J* = 7 and 2 Hz, Ar), 5.95 (1 H, broad s, NH), 6.0–6.7 (3 H, m, CH= and Ar), 6.9–7.4 (5 H, m, Ar); mass spectrum *m/e* (rel intensity) 322 (100), 294 (7), 222 (16), 206 (13), 194 (16), 178 (10), 117 (14). Anal. Calcd for $C_{19}H_{18}N_2O_3$: C, 70.79; H, 5.63; N, 8.69. Found: C, 70.69; H, 5.89; N, 8.50.

Alkaline Hydrolysis of 5a–c. General Procedure. Lactone **5** (2 mmol) was treated with 2.5 N NaOH in 50% aqueous ethanol (30 mL). After 30 min of refluxing, the solution was allowed to cool, acidified by concentrated HCl, and partly evaporated under reduced pressure. The solid material was collected by filtration and recrystallized to afford hydroxy acid **6** in 70–80% yield. See Table III.

Oxidation of 5a–c and 11a–c by DDQ. Typical Procedure. A mixture of **11c** (1.4 mmol) and DDQ (4.2 mmol) in benzene (60 mL) was heated under reflux for 16 h. The solid material was filtered off and the solution was evaporated to dryness. The residue was chromatographed on a silica gel column with 1:1 diethyl ether–petroleum

ether as eluent to give **12c** in 61% yield: mp 78–79 °C (*n*-hexane); NMR ($CDCl_3$) δ 1.40 (3 H, t, CH_2CH_3), 3.06 (2 H, t, CH_2CH_2O), 4.2–4.7 (4 H, m, CH_2CH_3 and CH_2CH_2O), 6.77 (1 H, s, CH=), 7.1–7.4 (3 H, m, Ar), 7.75–8.05 (1 H, m, Ar). Anal. Calcd for $C_{14}H_{14}N_2O_3$: C, 65.10; H, 5.46; N, 10.85. Found: C, 65.19; H, 5.50; N, 10.68.

Rearrangement of 9b. A solution of **9b** (1.3 g) in dry toluene (250 mL) was heated under reflux for 60 h. The solvent was removed under reduced pressure and the residue was chromatographed on a silica gel column. Elution with benzene–ethyl acetate (85:15) gave unchanged **9b** (0.40 g) followed by **13a** (0.49 g); mp 107–109 °C (*n*-hexane); IR (Nujol) 3250–3350 (NH and OH) and 1700 cm^{-1} (CO); NMR ($CDCl_3$) δ 1.32 (3 H, t, CH_2CH_3), 3.40 (2 H, d, J = 6 Hz, CH_2CH=), 4.29 (2 H, q, CH_2CH_3), 6.1–7.3 (10 H, overlapping signals, Ar and CH=CH), 7.6 (1 H, broad s, OH), 8.4 (1 H, broad s, NH). Anal. Calcd for $C_{19}H_{19}ClN_2O_3$: C, 63.59; H, 5.34; N, 7.81. Found: C, 63.29; H, 5.55; N, 7.57.

Treatment of 13a with Triethylamine. A solution of **13a** (0.26 g) and triethylamine (0.50 g) in dry toluene (70 mL) was heated under reflux for 30 min. The mixture was washed with aqueous HCl, dried over $MgSO_4$, and evaporated. The residue was taken up with diisopropyl ether and filtered to afford practically pure **14a** (0.18 g) (NMR analysis).

Registry No.—**1a,** 1118-84-9; **1b,** 61363-91-5; **1c,** 61363-92-6; **1d,** 61363-93-7; **1e,** 61363-94-8; **2a,** 21045-82-9; **2b,** 61363-95-9; **2c,** 61394-29-4; **2d,** 61363-96-0; **2e,** 61363-97-1; **3a,** 61363-98-2; **3b,** 61363-99-3; **3c,** 61364-00-9; **3d,** 61364-01-0; **3e,** 61364-02-1; **5a,** 61364-03-2; **5b,** 61364-04-3; **5c,** 61364-05-4; **6a,** 61364-06-5; **6b,** 61364-07-6; **6c,** 61364-08-7; **8a,** 27096-64-6; **8b,** 61364-09-8; **8c,** 56182-23-1; **9a,** 61364-10-1; **9b,** 61364-11-2; **9c,** 61364-12-3; **11a,** 61364-13-4; **11b,** 61364-14-5; **11c,** 61364-15-6; **12c,** 61364-16-7; **13a,** 61364-17-8; **14a,** 61364-18-9; **14b,** 61364-19-0; sulfuryl chloride, 7791-25-5; 4-chlorobenzenediazonium chloride, 2028-74-2; ethyl 2-chloroacetoacetate, 609-15-4; triethylamine, 121-44-8.

Supplementary Material Available. Full NMR data for compounds **1, 2, 3,** and **9** (2 pages). Ordering information is given on any current masthead page.

References and Notes

(1) Author to whom correspondence should be addressed.
(2) A. Padwa, *Angew. Chem., Int. Ed. Engl.*, **15**, 123 (1976), and references cited therein.
(3) R. Huisgen, *Angew. Chem., Int. Ed. Engl.*, **2**, 565 (1963).
(4) J. G. Morales, U.S. Patent 3 366 715 (1968); *Chem. Abstr.*, **69**, 43475a (1968).
(5) Under the same conditions, compound **5c** gave a complex mixture, including tar, which was not considered.
(6) L. Garanti, A. Sala, and G. Zecchi, *Synthesis*, 666 (1975).
(7) R. Fusco, L. Garanti, and G. Zecchi, *Tetrahedron Lett.*, 269 (1974).
(8) T. J. Batterham, "NMR Spectra of Simple Heterocycles", Wiley-Interscience, New York, N.Y., 1973, p 197.
(9) The lower cyclization yield of nitrile imine **10c** in comparison with **10a** may be accounted for by the greater length of the chain joining the dipole and dipolarophile groups.
(10) R. Huisgen, *J. Org. Chem.*, **33**, 2291 (1968), and references cited therein.
(11) S. J. Rhoads and N. R. Raulins, *Org. React.*, **22**, 1 (1975).
(12) W. Kimel and A. C. Cope, *J. Am. Chem. Soc.*, **65**, 1992 (1943).
(13) A. W. Burgstahler and I. C. Nordin, *J. Am. Chem. Soc.*, **83**, 198 (1961).
(14) J. von Braun and O. Braunsdorf, *Ber.*, **54**, 685 (1921).
(15) R. Fusco, L. Garanti, and G. Zecchi, *J. Org. Chem.*, **40**, 1906 (1975).
(16) A. L. J. Beckwith and W. B. Gara, *J. Chem. Soc., Perkin Trans.* **2**, 593 (1975).

Hydroboration. 45. New, Convenient Preparations of Representative Borane Reagents Utilizing Borane–Methyl Sulfide

Herbert C. Brown,* Arun K. Mandal,[1a] and Surendra U. Kulkarni[1b]

Richard B. Wetherill Laboratory, Purdue University, West Lafayette, Indiana 47907

Received October 28, 1976

Convenient preparations for several highly useful borane reagents, such as thexyl-, disiamyl-, dicyclohexyl-, catechol-, diisopinocampheylborane, 9-borabicyclo[3.3.1]nonane, and 1,6-diboracyclodecane, utilizing the readily available, relatively stable reagent, borane–methyl sulfide (BMS), are described. The reactions of BMS with the respective olefins or with catechol proceed smoothly at room temperature in various solvents, such as tetrahydrofuran (THF), ethyl ether (EE), dichloromethane, and pentane. In some cases, the reaction involving the neat reagents at 0 °C can also be utilized. Methyl sulfide can be readily removed from the products. However, the presence of methyl sulfide does not interfere with typical applications of borane reagents, such as thexyl-, disiamyl-, dicyclohexyl-, and diisopinocampheylborane, normally utilized in situ, without isolation. This feature was examined by carrying out representative hydroborations with these reagents prepared from BMS and then subjecting the resulting organoboranes to subsequent representative transformations. In the case of stable and isolable reagents, such as 9-BBN, catecholborane, and 1,6-diboracyclodecane, methyl sulfide can be readily removed, along with the solvents, by distillation. A detailed study was made of the preparation of pure diisopinocampheylborane from (+)-α-pinene and BMS in various solvents, both at room temperature and at 0 °C. The applicability of this reagent thus produced in asymmetric synthesis was established by the hydroboration of *cis*-2-butene, followed by oxidation, to yield (*R*)-(−)-2-butanol in optical purities of 88–97%.

Both hydroboration and selective reduction based on organoborane derivatives are proving highly useful in organic synthesis.[2] Partially substituted borane reagents,[3] such as thexylborane, disiamylborane, dicyclohexylborane, diisopinocampheylborane (IPC_2BH), 9-borabicyclo[3.3.1]nonane (9-BBN), 1,3,2-benzodioxaborole (catecholborane), and 1,6-diboracyclodecane, are finding an increasing role in these applications.

Thexylborane is a highly versatile reagent,[4] especially valuable for the synthesis of unsymmetrical ketones and in the new annelation reactions leading to pure (100%) transfused bicyclic ketones. Disiamylborane and dicyclohexylborane are highly hindered dialkylboranes possessing better regioselectivity than borane itself.[2,5,6] These hindered reagents are used especially for the monohydroboration of alkynes to the vinylborane stage.[7] Catecholborane is a mild hydroborating[8] and reducing[9] agent, whose chemistry has recently been reviewed.[10] Unlike other dialkylboranes, 9-BBN is exceptionally stable toward disproportionation. Under nitrogen, it is indefinitely stable at room temperature. Its favorable physical properties and unusual stability have made 9-BBN the only commercially available dialkylborane.[11] It is both an exceptionally regioselective hydroborating agent[2,12] and a useful agent for the selective reductions of organic functional