sulfonamide derivative **22a** (a pale yellow oil) according to the procedure described for the conversion of **1a** to **20a**: 74%; TLC (5:5:90 Et_3N/MeOH/EtOAc) R_f 0.53; ^1H NMR ($CDCl_3$) δ 6.78 (1 H, d, J = 8.2 Hz), 6.74 (1 H, d, J = 1.6 Hz), 6.73 (1 H, dd, J = 1.6, 8.2 Hz), 6.52 (2 H, s), 5.79 (1 H, br s), 3.86 (9 H, s), 3.85 (3 H, s), 3.84 (3 H, s), 3.56 (2 H, br s), 3.41 (1 H, d, J = 14.9 Hz), 2.89 (1 H, d, J = 14.9 Hz), 2.82–1.38 (21 H, m), 2.34 (3 H, s), 1.05 (3 H, s), 0.89 (3 H, s), 0.85 (3 H, d, J = 6.8 Hz), 0.84 (3 H, d, J = 6.8 Hz); IR (neat) 3295, 2970, 2845, 2800, 1748, 1591, 1518, 1469, 1397, 1378, 1335, 1130, 807, 761 cm^{-1}.

***N*-[(2*R*)-2-(3,4,5-Trimethoxyphenyl)-2-isopropyl-5-[(3,4-dimethoxyphenethyl)methylamino]pentyl]-(1*S*)-10-camphorsulfonamide (22b).** (2*R*)-(+)-Gallopamil (**2b**; 130 mg, 0.268 mmol) was converted to 129 mg (0.184 mmol) of camphorsulfonamide derivative **22b** (a pale yellow oil) according to the procedure described for the conversion of **1a** to **20a**: 69%; TLC (5:5:90 Et_3N/MeOH/EtOAc) R_f 0.53; ^1H NMR ($CDCl_3$) δ 6.78 (1 H, d, J = 8.0 Hz), 6.75 (1 H, d, J = 1.6 Hz), 6.73 (1 H, dd, J = 1.6, 8.0 Hz), 6.53 (2 H, s), 5.61 (1 H, br s), 3.86 (9 H, s), 3.85 (3 H, s), 3.84 (3 H, s), 3.59 (2 H, br s), 3.33 (1 H, d, J = 14.9 Hz), 2.86 (1 H, d, J = 14.9 Hz), 2.79–1.37 (21 H, m), 2.33 (3 H, s), 1.02 (3 H, s), 0.87 (3 H, s), 0.83 (3 H, d, J = 6.5 Hz), 0.82 (3 H, d, J = 6.5 Hz); IR (neat) 3290, 2972, 2842, 2700, 1748, 1590, 1518, 1468, 1396, 1380, 1334, 1130, 807, 761 cm^{-1}.

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Alkynylcyanoketenes

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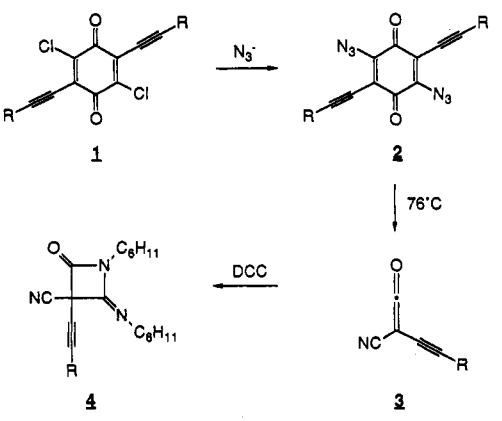
Alkynylcyanoketenes are now available from the thermolysis of 2,5-dialkynyl-3,6-diazido-1,4-benzoquinones. The scope of this reaction is discussed as well as some chemical properties of the resulting ketenes. Specifically, the cycloaddition of hexynylcyanoketene to a series of alkenes and its reaction with alcohols are reported here. The former reaction results in synthetically useful cyclobutanones and the latter in unexpected alkenyl esters (2:1 adducts) arising from intermediate cyanoallenes.

We have previously reported that cyanoketenes can be generated from the thermolysis of 2,5-diazido-1,4-benzoquinones.[1] This reaction has received detailed study for the syntheses of alkyl- and arylcyanoketenes and has been particularly useful as a route to the extensively studied *tert*-butylcyanoketene (TBCK).[2] Reported here is an extension of this reaction which now allows the generation of alkynylcyanoketenes.[3] In addition to the synthesis of a series of alkynylcyanoketenes, some selected reactions of this class will also be reported in this paper. To our knowledge, the ketenes described here are the only examples to appear in which an alkyne group is in direct conjugation with the ketene moiety (alkynylketenes). This is a surprising observation in view of the extensive knowledge gathered on alkenylketenes.[4]

The diazidoquinone precursors **2a–g** of the ketenes **3a–g** are readily obtained from 2,5-dialkynyl-3,6-dichloro-1,4-benzoquinones **1a–g** upon treatment with azide ion (Scheme I). The alkynylquinones **1a–g**, in turn, come from chloranilic acid as reported previously.[5,6] The ketenes **3a–g** were generated in situ from the thermolysis of **2a–g** in refluxing carbon tetrachloride in the presence of dicyclohexylcarbodiimide (DCC). Thus, the ketenes were trapped via their cycloadditions to DCC to give the respective adducts **4a–g** in 42–86% yield.

Scheme I



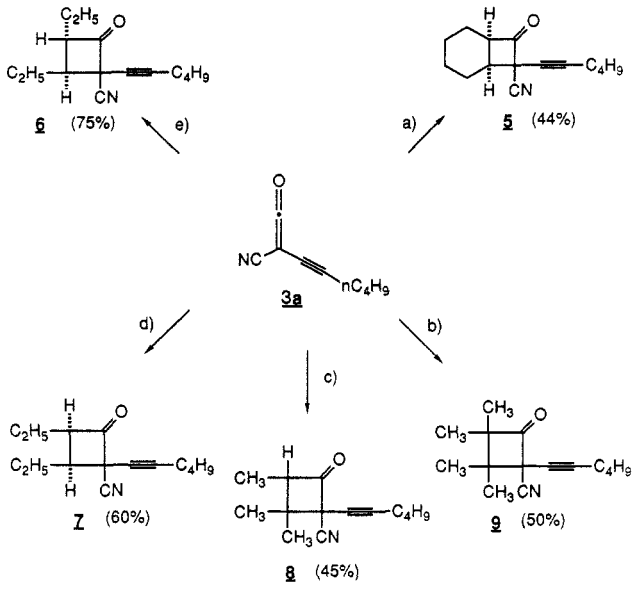
	R	%4
a)	$-nC_4H_9$	86%
b)	$-C_6H_5$	78%
c)	$-C_6H_4$-o-OCH_3	47%
d)	$-C_6H_4$-o-CH_3	56%
e)	$-CH_2$-O-THP	80%
f)	$-CH_2CH_2C_6H_5$	56%
g)	$-C(CH_3)=CH_2$	42%

Hexynylcyanoketene (HCK) **3a** was chosen as a representative member of the alkynylcyanoketene class and utilized to explore selected reactions. Of particular interest was an investigation to establish the facility of the cycloaddition of the alkynylcyanoketenes to alkenes. This study resulted in a number of important observation (Scheme II).[5] First, HCK expresses significant reactivity with di-,

(1) Moore, H. W.; Weyler, W.; Duncan, W. G. *J. Am. Chem. Soc.* **1975**, *97*, 6181.
(2) Moore, H. W.; Gheorghiu, M. D. *Chem. Soc. Rev.* **1981**, *10*, 289.
(3) A preliminary account of this work has appeared: Nguyen, N. V.; Moore, H. W. *J. Chem. Soc., Chem. Commun.* **1984**, 1066.
(4) Ward, R. S. In "The Preparation of Ketenes" *The Chemistry of Ketenes, Allenes, and Related Compounds*; Patai, S., Ed.; Wiley: New York, 1980. For recent elegant examples of the synthetic utility of alkenylketenes, see: Danheiser, R. L.; Gee, S. K. *J. Org. Chem.* **1984**, *49*, 1672. Danheiser, R. L.; Gee, S. K.; Sard, H. *J. Am. Chem. Soc.* **1982**, *104*, 7670.
(5) Moore, H. W.; Sing, Y. L.; Sidhu, R. S. *J. Org. Chem.* **1980**, *45*, 5057.
(6) Moore, H. W.; West, K. F.; Wriede, U.; Chow, K.; Fernandez, M.; Nguyen, N. V. *J. Org. Chem.*, in press.

0022-3263/87/1952-1315$01.50/0

Scheme II[a]

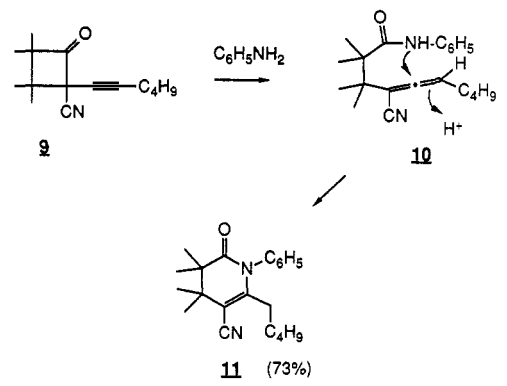


[a] (a) c-C_6H_{10}; (b) $(CH_3)_2C{=}C(CH_3)_2$; (c) $(CH_3)_2C{=}CHCH_3$; (d) (Z)-$C_2H_5CH{=}CHC_2H_5$; (e) (E)-$C_2H_5CH{=}CHC_2H_5$.

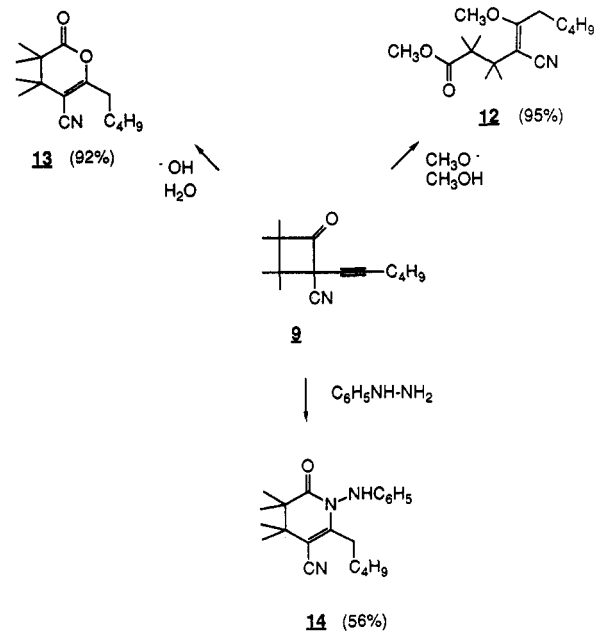
tri-, and tetrasubstituted alkenes to give the corresponding cyclobutanones **5–9**. It is noteworthy that the only other ketenes reported to cycloadd to tetrasubstituted alkenes are dichloro- and chlorocyanoketenes.[7,8] A second important observation is that the cycloadditions proceed with preservation of the alkene stereochemistry. This is based upon the observed coupling constants between the methine protons in cyclobutanones **6** and **7** which arise respectively from (*E*)- and (*Z*)-3-hexene. Specifically this coupling constant for **6** is 9.5 Hz while that for **7** is 10.5 Hz, and it has previously been reported that *E*-disposed methine protons in cyclobutanones have a smaller coupling constant than their *Z* counterparts.[9] Finally, it is noted that a diastereomeric mixture was obtained for the cyclobutanones **5**, **6**, and **7**. Specifically, the respective ratios were 4:1, 1:1, and 4:1. The major isomers for **5** and **7** are assigned as the one having the cyano group at position 2 and the proton at position 3 in a *Z* relationship. This assignment is based upon the observation that the methine proton at position 3 in the major isomer appear at lower field in their ^1H NMR spectra than those of the corresponding minor isomers. This is in agreement with their assigned stereochemistry since it has previously been shown that the 2-cyano group of other cyclobutanones deshields the adjacent *Z*-disposed proton relative to that which is in the *E* position.[10]

The above data are analogous to those obtained from other studies involving the cycloadditions of unsymmetrical ketenes to alkenes.[11] That is, alkene stereochemistry is preserved and contrathermodynamic isomers are generally formed as the major kinetic products. Often such results are interpreted as providing strong evidence for a concerted $2\pi a + 2\pi s$ cycloaddition. However, in view of recent studies reported on the cycloaddition of TBCK to (trialkylsiloxy)alkenes, caution for such an interpretation is warranted.[12]

Scheme III



Scheme IV

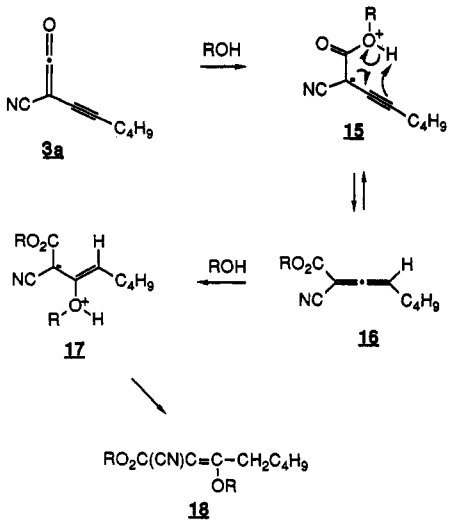


The alkynyl and cyano substituents of the cyclobutanones **5–9** impart properties to these compounds which are of synthetic and mechanistic interest. Specifically, the electron-withdrawing cyano group facilitates ring opening under nucleophilic conditions and the alkyne group provides an additional electrophilic site via its cyanoallene tautomer, formed subsequent to ring opening. Examples of reactions which taken advantage of these properties are outlined in Schemes III and IV. Scheme III illustrates the transformation observed when the cyclobutanone **9** was treated with aniline to give the lactam **11** (73%). The reaction is viewed as proceeding via the intermediate **10**, which leads to product **11** upon Michael addition of the amide nitrogen to the electron-deficient allene moiety of **10**.[13] Other examples are the formation of the acyclic ester **12** (95%), the lactone **13** (92%), and the *N*-anilino lactam **14** (56%) when cyclobutanone **9** is treated with basic methanol, aqueous base, and phenylhydrazine, respectively.

Another unusual reaction which must also involve a cyanoallene intermediate was observed when HCK **3a** was generated in the presence of excess alcohols (Scheme V). Rather than the normal ketene alcoholysis products (alkynyl esters), the ethenyl esters **18a–d** were realized in 30–60% yields as mixtures of the *E* and *Z* stereoisomers.

(7) Fishbein, P. L.; Moore, H. W. *J. Org. Chem.* **1984**, *49*, 2190.
(8) Brady, W. T. *Tetrahedron* **1981**, *37*, 2949.
(9) Frey, H. M.; Tsaacs, N. S. *J. Chem. Soc. B* **1970**, 830.
(10) Weyler, W.; Byrd, L.; Caserio, M. C.; Moore, H. W. *J. Am. Chem. Soc.* **1972**, *94*, 1027.
(11) See, for example: Dominh, T.; Strausz, O. P. *J. Am. Chem. Soc.* **1970**, *92*, 1766. Hassner, A.; Cory, R. M.; Sartoris, N. *Ibid.* **1976**, *98*, 7698.
(12) Al-Husaini, A. H.; Moore, H. W. *J. Org. Chem.* **1985**, *50*, 2595.
(13) For an example of a facile cyanoalkyne/cyanoallene equilibration, see: Smith, L. I.; Swenson, J. S. *J. Am. Chem. Soc.* **1954**, *79*, 2962.

Scheme V



	R	% yield 18	Isomer Ratio
a)	$CH_3CH_2CH_2$-	36	1.5 : 1
b)	$C_6H_5CH_2$-	60	3 : 1
c)	$(CH_3)_2CH$-	49	7 : 1
d)	$(CH_3)C$-	30	8 : 1

The individual stereochemistry was not unambiguously established. However, it is assumed that the major isomer has the *Z* configuration since one isomer becomes more dominant as the steric bulk of the alcohol is increased. For example, **18a** was obtained as a 1.5:1 mixture of geometric isomers while the ratio changed to 8:1 for **18d**.

The formation of **18a–d** is viewed as involving the formation and subsequent trapping of the allene intermediate **16a–d** as outlined in Scheme V. That is, nucleophilic attack of the alcohol on the ketene **3a** would initially give the zwitterionic intermediate **15a–d**, which upon proton transfer would result in the electron-deficient allene **16a–d**. Nucleophilic attack of a second equivalent of the alcohol on the allene would lead to the observed products via the intermediate **17a–d**. Direct evidence for the allene **16d** was obtained when only 1 equiv of *tert*-butyl alcohol was used. In this case an allene absorption at 1950 cm^{-1} was observed in the infrared spectrum of the crude product but disappeared when excess alcohol was added.

In conclusion, we wish to note the following significant points to arise from this investigation: (1) the first examples of alkynylketenes are reported; (2) the conjugated alkyne group imparts unusual properties to the ketenes in that allene intermediates often arise in their reactions, i.e., in the ring expansions of the cyclobutanone **9** and in the alcoholysis reactions of **3a**.

Experimental Section

Thermolysis of 2,5-diazido-3,6-dialkynyl-1,4-benzoquinones in the presence of DCC. The following experimental procedure for the synthesis of **4e** is representative of that used for the preparation of **4a–d,f,g**. A solution of 94.6 mg (0.20 mmol) of **2e** in 75 mL of dry CCl_4 was added dropwise to a refluxing solution of 87.8 mg (0.43 mmol) of DCC in 250 mL of dry carbon tetrachloride while under an argon atmosphere. The solution was heated at reflux for 1.5 h. The reaction mixture was concentrated and the residue absorbed on to silica gel and subjected to flash chromatography (7:3 hexanes/ethyl acetate) to afford 0.13 g (80%) of **4e** as a yellow liquid.

3-Cyano-1-cyclohexyl-4-(cyclohexylimino)-3-(1-hexynyl)-2-azetidone (4a): orange oil (86%, 0.26 g); ^1H NMR δ 3.49–3.65 (m, 2 H), 1.22–2.30 (m, 26 H), 0.91 (t, J = 6 Hz, 3 H); IR 2965 (m), 2880 (w), 1840 (w), 1715 (s), 1450 (w) cm^{-1}; MS, m/z 353 (EI); MS, exact mass calcd for $C_{22}H_{31}N_3O$ 353.24669, found 353.2448.

3-Cyano-1-cyclohexyl-4-(cyclohexylimino)-3-(phenylethynyl)-2-azetidone (4b): yellow crystals (78%, 0.3 g); mp 116 °C dec; ^1H NMR δ 7.32–7.46 (m, 5 H), 3.59–3.71 (m, 2 H), 1.23–2.05 (m, 20 H); IR 3050 (w), 2920 (s), 2860 (m), 2220 (m), 1835 (s), 1710 (s), 1440 (m), 1370 (s); MS, m/z 374 (CI); MS, exact mass calcd for $C_{24}H_{27}N_3O_1$ 373.21539, found 373.2148.

3-Cyano-1-cyclohexyl-4-(cyclohexylimino)-3-[(2-methoxyphenyl)ethynyl]-2-azetidone (4c): orange oil (47%, 64 mg); ^1H NMR δ 7.34 (d, J = 6 Hz, 1 H), 7.40 (d, J = 6 Hz, 1 H), 6.96 (d, J = 6 Hz, 1 H), 6.88 (d, J = 6 Hz, 1 H), 3.84 (s, 3 H), 3.61–3.70 (m, 2 H), 1.22–2.02 (m, 20 H); IR 2935 (m), 2850 (w), 1840 (w), 1715 (s) cm^{-1}; MS, m/z 404 (CI); MS, exact mass calcd for $C_{25}H_{29}N_3O_2$ 403.2260, found 403.2230.

3-Cyano-1-cyclohexyl-4-(cyclohexylimino)-3-[(2-methylphenyl)ethynyl]-2-azetidone (4d): yellow oil (56%, 0.104 g); ^1H NMR δ 7.42 (d, J = 7 Hz, 1 H), 7.15–7.33 (m, 3 H), 3.58–3.74 (m, 2 H), 2.42 (s, 3 H), 1.10–2.06 (m, 20 H); IR (2940 (m), 2860 (w), 1840 (w), 1720 (s) cm^{-1}; MS, m/z 387 (EI); MS, exact mass calcd for $C_{25}H_{29}N_3O_1$ 387.23104, found 397.2305.

3-Cyano-1-cyclohexyl-4-(cyclohexylimino)-3-[3-((tetrahydro-2-pyranyl)oxy)prop-1-ynyl]-2-azetidone (4e): yellow oil (80%, 0.13 g); ^1H NMR δ 4.75 (s, 1 H), 4.33 (s, 2 H), 3.76–3.84 (m, 1 H), 3.49–3.66 (m, 3 H), 1.22–1.99 (m, 26 H); IR 2940 (s), 2860 (m), 1835 (m), 1710 (s), 1445 (w), 1365 (m) cm^{-1}; MS, m/z 412 (CI); MS, exact mass calcd for $C_{24}H_{33}N_3O_3$ 411.252616, found 411.2509.

3-Cyano-1-cyclohexyl-4-(cyclohexylimino)-3-(4-phenylbut-1-ynyl)-2-azetidone (4f): tan solid (56%, 0.12 g); mp 85–86 °C; ^1H NMR δ 7.18–7.32 (m, 5 H), 3.43–3.65 (m, 2 H), 2.83 (t, J = 6 Hz, 2 H), 2.56 (t, J = 6 Hz, 2 H), 1.22–1.97 (m, 20 H); IR 2940 (s), 2870 (m), 2250 (m), 1845 (s), 1720 (s), 1450 (m), 1375 (s) cm^{-1}; MS, m/z 402 (CI); MS, exact mass calcd for $C_{26}H_{31}N_3O_1$ 401.24669, found 401.2483.

3-Cyano-1-cyclohexyl-4-(cyclohexylimino)-3-(3-methyl-3-buten-1-ynyl)-2-azetidone (4g): yellow oil (42%, 68.9 mg); ^1H NMR δ 5.40 (d, J = 9 Hz, 2 H), 3.50–3.68 (m, 2 H), 1.22–2.00 (m, 23 H); IR 2950 (s), 2870 (m), 1845 (m), 1720 (s), 1455 (m), 1375 (m) cm^{-1}; MS, m/z 338 (CI); MS, exact mass calcd for $C_{21}H_{27}N_3O_1$ 337.2154, found 337.2139.

7-Cyano-7-(1-hexynyl)bicyclo[4.2.0]octan-8-one (5). The following is a representative procedure for the synthesis of the cyclobutanones **5–9**. A solution of 1.0 g (2.85 mmol) of 2,5-diazido-3,6-di-1-hexynyl-2,5-cyclohexadien-1,4-dione (**2**) in 50 mL of dry benzene was added dropwise to a refluxing solution of 4.68 g (57.14 mmol) of cyclohexene in 250 mL of dry benzene over a 4-h period, while under an argon atmosphere. The solution was refluxed for an additional 2 h, after which it turned from dark brown to yellow in color. The solution was then concentrated and the residue filtered quickly through Florisil. Bulb distillation gave 0.58 g (44%) of a colorless oil: ^1H NMR δ 4.17–4.21 (m, 0.2 H), 4.23–4.01 (m, 0.8 H), 2.93 (d of t, J = 7.7 Hz, J = 10.4 Hz, 0.8 H), 2.74 (d of t, J = 7.7 Hz, J = 10.4 Hz, 0.2 H), 2.09–2.32 (m, 4 H), 1.11–1.78 (m, 10 H), 0.91 (t, J = 7 Hz, 3 H); ^{13}C NMR 192.01, 191.59, 116.82, 113.40, 90.56, 88.09, 71.48, 67.88, 57.59, 57.30, 54.62, 54.10, 35.92, 34.63, 30.25, 30.19, 26.34, 25.16, 22.10, 21.98, 21.84, 21.71, 21.67, 21.01, 20.93, 18.43, 13.45 ppm; IR (neat) 2940 (s), 2860 (s), 2218 (m), 1812 (s), 1450 (m) cm^{-1}; MS, m/z 229 (EI), 230 (CI).

Anal. Calcd for $C_{15}H_{19}NO$: C, 78.56; H, 8.35. Found: C, 78.59; H, 8.53.

2-Cyano-2-(1-hexynyl)-(*E*)-3,4-diethylcyclobutanone (6): colorless oil (75%, 1.12 g); ^1H NMR δ 3.38 (d of t, J = 9.5 Hz, J' = 7 Hz, 0.5 H), 3.31 (d of t, J = 9.5 Hz, J' = 7 Hz, 0.5 H), 2.20–2.41 (m, 3 H), 1.80–1.98 (m, 2 H), 1.61–1.78 (m, 2 H), 1.32–1.58 (m, 4 H), 0.88–1.15 (m, 9 H); ^{13}C NMR 192.15, 191.53, 114.96, 113.40, 90.94, 89.19, 70.30, 66.79, 66.47, 66.32, 52.95, 50.82, 46.15, 44.47, 30.12, 30.08, 25.80, 24.68, 22.48, 22.14, 21.69, 21.63, 18.25, 13.25, 11.99, 11.16 ppm; IR (neat) 2980 (s), 2950 (s), 2395 (s), 2240 (m), 1818 (s), 1469 (m) cm^{-1}; MS, m/z 231 (EI), 232 (CI).

Anal. Calcd for $C_{15}H_{21}NO$: C, 77.87; H, 9.15. Found: C, 77.88; H, 9.30.

2-Cyano-2-(1-hexynyl)-(*Z*)-3,4-diethylcyclobutanone (7): colorless oil (50%, 1.32 g); ^1H NMR δ 2.27 (t, J = 7 Hz, 2 H),

1.58–1.36 (m, 7 H), 1.32 (s, 3 H), 1.30 (s, 3 H), 1.28 (s, 3 H), 0.91 (t, J = 7 Hz, 3 H); ^{13}C NMR 197.63, 114.33, 91.05, 68.92, 65.14, 57.84, 41.07, 30.11 22.06, 21.71, 21.01, 20.79, 20.16, 18.31, 13.29 ppm; IR (neat) 2971 (s), 2942 (s), 2876 (m), 2212 (s), 1809 (s), 1465 (m), 1455 (m) cm^{-1}; MS, m/z 232 (CI).

Anal. Calcd for $C_{15}H_{21}NO$: C, 77.87; H, 9.15. Found: C, 77.67; H, 9.37.

2-Cyano-2-(1-hexynyl)-3,3,4-trimethylcyclobutanone (8): colorless oil (45%, 1.13 g); ^{1}H NMR δ 3.67 (q, J = 7 Hz, 0.33 H), 3.60 (q, J = 7 Hz, 0.66 H), 2.25 (t, J = 7 Hz, 0.66 H), 2.26 (t, J = 7 Hz, 1.33 H), 1.09–1.58 (m, 13 H), 0.92 (t, J = 7 Hz, 3 H); ^{13}C NMR 192.77, 192.38, 114.88, 113.20, 91.01, 88.12, 68.82, 67.57, 62.90, 62.26, 58.96, 57.76, 39.22, 39.00, 30.20, 25.02, 23.82, 21.76, 20.56, 19.68, 18.37, 13.38, 7.98, 7.78 ppm; IR (neat) 2959 (s), 2935 (s), 2863 (s), 2223 (m), 1809 (s), 1450 (s) cm^{-1}; MS, m/z 217 (EI), 218 (CI).

Anal. Calcd for $C_{14}H_{19}NO$: C, 77.38; H, 8.81. Found: C, 77.41; H, 8.92.

2-Cyano-2-(1-hexynyl)-3,3,4,4-tetramethylcyclobutanone (9): colorless oil (50%; 1.32 g); ^{1}H NMR δ 2.27 (t, J = 7 Hz, 3 H), 1.28 (s, 3 H), 1.30 (s, 3 H), 1.32 (s, 3 H), 1.36–1.58 (m, 7 H); ^{13}C NMR 197.63, 114.33, 91.05, 68.92, 65.14, 57.84, 41.07, 30.11, 22.06, 21.71, 21.01, 20.79, 20.16, 18.31, 13.29 ppm; IR (neat) 2971 (s), 2941 (s), 2876 (m), 2212 (s), 1809 (s), 1465 (m), 1455 (m) cm^{-1}; MS, m/z 232 (CI).

Anal. Calcd for $C_{15}H_{21}NO$: C, 77.88; H, 9.15. Found: C, 77.67; H, 9.37.

5-Cyano-6-pentyl-1-phenyl-3,3,4,4-tetramethyl-3,4-dihydro-2-pyridone (11). To a solution of 0.40 g (1.73 mmol) of 2-cyano-2-(1-hexynyl)-3,3,4,4-tetramethylcyclobutanone **9** in 20 mL of tetrahydrofuran was added 0.32 g (3.46 mmol) of aniline. The solution was stirred for 24 h at room temperature. Then 20 mL of a 5% aqueous KOH solution was added and the reaction stirred for an additional 24 h. Into the stirring solution were then added 50 mL of diethyl ether and 50 mL of distilled water. The organic layer was separated and the aqueous layer was washed twice with 100 mL of diethyl ether. The combined organic layers were washed twice with 100 mL of distilled water and once with 50 mL of saturated brine solution, dried over anhydrous magnesium sulfate, and concentrated. The oily residue was absorbed onto silica gel and subjected to flash chromatography (hexane/ethyl acetate) to give 0.40 g (73%) of a yellowish-colored oil: ^{1}H NMR δ 0.79 (t, J = 7 Hz, 3 H), 1.08–1.15 (m, 4 H), 1.20 (s, 6 H), 1.29 (s, 6 H), 1.30–1.45 (m, 5 H); ^{13}C NMR 175.89, 152.96, 137.52, 129.26, 128.72, 128.55, 117.99, 98.79, 44.71, 37.01, 32.33, 31.16, 27.62, 22.17, 21.79, 19.38, 13.68 ppm; IR (neat) 3080 (w), 3050 (w), 2980 (s), 2942 (s), 2880 (m), 2200 (m), 1725 (s), 1631 (s), 1605 (m), 1490 (m), 1465 (m) cm^{-1}; MS, m/z 324 (EI), 325 (CI); MS, exact mass calcd for $C_{21}H_{28}N_2O$ 324.2202, found 324.2198.

Methyl 4-Cyano-5-methoxy-2,2,3,3-tetramethyldec-4-enoate (12). A solution of 0.40 g (1.73 mmol) of 2-cyano-2-(1-hexynyl)-3,3,4,4-tetramethylcyclobutanone (**9**) in 20 mL of 5% KOH in methanol was stirred at room temperature for 24 h. A portion of 50 mL of dichloromethane and 50 mL of distilled water were added and the layers separated. The aqueous layer was washed twice with 100 mL of dichloromethane. The combined organic layers were washed twice with 100 mL of distilled water and once with 50 mL of saturated brine solution and dried over anhydrous magnesium sulfate. Concentration yielded a yellowish oil, which was absorbed onto silica gel and subjected to flash chromatography (hexane/ethyl acetate) to give 0.49 g (96%) of a colorless oil: ^{1}H NMR δ 0.92 (t, J = 7 Hz, 3 H), 1.18 (s, 6 H), 1.29 (s, 6 H), 1.32–1.44 (m, 4 H), 1.51–1.63 (m, 2 H), 2.61 (t, J = 7 Hz, 2 H), 3.64 (s, 3 H), 3.68 (s, 3 H); IR (neat) 2978 (s), 2950 (s), 2880 (m), 2200 (m), 1740 (s), 1609 (s), 1465 (s) cm^{-1}; MS, m/z 296 (CI).

High-resolution mass spectrometry did not show the molecular ion. The base peak was 194, which corresponds to M − 101 or loss of $C_5H_9O_2$ ($^{\bullet}C(CH_3)_3COOCH_3$): exact mass calcd for this fragment ($C_{12}H_{20}NO$) 194.1545, found 194.1548.

5-Cyano-6-pentyl-3,3,4,4-tetramethyl-3,4-dihydro-2-pyrone (13). Into a solution of 0.35 g (1.51 mmol) of 2-cyano-2-(1-hexynyl)-3,3,4,4-tetramethylcyclobutanone (**9**) in 20 mL of tetrahydrofuran was added 10 mL of 5% aqueous KOH solution and the reaction stirred for 10 h. Into the stirring solution were then added 6 mL of diethyl ether and 50 mL of distilled water. The organic layer was separated, and the aqueous layer was washed twice with 100 mL of diethyl ether. The combined organic layers were washed twice with 100 mL of distilled water and once with 50 mL of saturated brine solution, dried over anhydrous magnesium sulfate, and concentrated. The oily residue was absorbed onto silica gel and subjected to flash chromatography (hexane/ethyl acetate) to give 0.35 g (92%) of a yellowish oil: ^{1}H NMR δ 0.91 (t, J = 7 Hz, 3 H), 1.16 (s, 6 H), 1.23 (s, 6 H), 1.30–1.41 (m, 4 H), 1.56–1.69 (m, 2 H), 2.50 (t, J = 7 Hz, 2 H); ^{13}C NMR 177.64, 163.81, 116.00, 98.34, 43.80, 37.82, 32.35, 30.87, 25.91, 22.38, 2207, 19.39, 13.70 ppm; IR (neat) 2980 (s), 2970 (s), 2880 (m), 2208 (m), 1800 (s), 1660 (m), 1470 (m) cm^{-1}; MS, m/z 249 (EI), 250 (CI); MS, exact mass calcd for $C_{14}H_{23}NO_2$ 249.1729, found 249.1712.

5-Cyano-6-pentyl-1-(phenylamino)-3,3,4,4-tetramethyl-3,4-dihydro-2-pyridone (14). Into a solution of 0.30 g (1.31 mmol) of 2-cyano-2-(1-hexynyl)-3,3,4,4-tetramethylcyclobutanone (**9**) in 20 mL of tetrahydrofuran was added 0.14 g (1.31 mmol) of phenylhydrazine. The solution was stirred for 1 h at room temperature. A portion of 20 mL of 5% aqueous KOH solution was then added, and the reaction was stirred for an additional 24 h. Into the stirring solution were added 50 mL of diethyl ether and 50 mL of distilled water. The organic layer was separated, and the aqueous layer was washed twice with 100 mL of diethyl ether. The combined organic layers were washed twice with 100 mL of distilled water and once with 50 mL of saturated brine solution, dried over anhydrous magnesium sulfate, and concentrated. The oily residue was absorbed onto silica gel and subjected to flash chromatography (hexane/ethyl acetate) to give 0.24 g (56%) of a yellowish oil: ^{1}H NMR δ 0.85 (t, J = 7 Hz, 3 H), 1.11 (s, 3 H), 1.16 (s, 3 H), 1.19 (s, 3 H), 1.20 (s, 3 H), 1.24–1.38 (m, 4 H), 1.42–1.73 (m, 2 H), 2.50–2.78 (m, 2 H), 6.67–7.30 (m, 5 H), 6.62 (s, 1 H); ^{13}C NMR 175.06, 154.69, 147.47, 129.26, 122.02, 117.81, 113.54, 96.61, 45.03, 37.07, 31.25, 28.28 22.14, 22.01, 20.26, 18.75, 13.78 ppm; IR (neat) 3300 (s), 3042 (w), 3020 (w), 2961 (s), 2912 (s), 2860 (s), 2196 (m), 1695 (s), 1600 (s), 1490 (s) cm^{-1}; MS, m/z 339 (EI), 340 (CI); MS, exact mass calcd for $C_{21}H_{29}N_3O$ 339.2310, found 339.2301.

Propyl 2-Cyano-3-(propyloxy)oct-2-enoate (18a). A solution of 0.20 g (0.57 mmol) of 2,5-diazido-3,6-di-1-hexynyl-2,5-cyclohexadiene-1,4-dione (**2**) in 40 mL of toluene was added dropwise to a refluxing solution of 100 mL of dry 1-propanol under an atmosphere of argon, over a 30-min period. After refluxing for 4 h, the dark red solution turned to clear yellow. The reaction was then concentrated and the dark oily residue absorbed onto silica gel and subjected to flash chromatography (hexane/ethyl acetate) to give a yellowish oil (36%): ^{1}H NMR δ 4.20 (t, J = 7 Hz, 2 H), 4.12 (t, J = 7 Hz, 2 H), 2.94–3.00 (m, 2 H), 1.08–1.88 (m, 10 H), 1.02 (t, J = 7 Hz, 3 H), 0.95 (t, J = 7 Hz, 3 H), 0.89 (t, J = 7 Hz, 3 H); IR (neat) 2978 (s); 2955 (s), 2888 (m), 2224 (m), 1750 (m), 1723 (s), 1559 (s) cm^{-1}; MS, m/z 267 (EI), 268 (CI); MS, exact mass calcd for $C_{15}H_{25}NO_3$ 267.1834, found 267.1813.

Benzyl 3-(Benzyloxy)-2-cyanooct-2-enoate (18b). A solution of 0.20 g (0.57 mmol) of 2,5-diazido-3,6-di-1-hexynyl-2,5-cyclohexadiene-1,4-dione (**2a**) in 40 mL of toluene was added dropwise to a refluxing solution of 10 mL of dry benzyl alcohol in 100 mL of dry toluene under an atmosphere of argon for 30 min. After refluxing for 4 h, the dark red solution turned light brown. The reaction was then concentrated and the dark oily residue absorbed onto silica gel and subjected to flash chromatography (hexane/ethyl acetate) to give a yellowish oil (60%): ^{1}H NMR δ 7.21–7.45 (m, 10 H), 5.32 (s, 6 H), 5.20 (s, 2 H), 2.63–3.05 (m, 2 H), 1.22–1.76 (m, 6 H), 0.91 (t, J = 7 Hz, 3 H); IR (neat) 3078 (w), 3041 (w), 2968 (s), 2941 (s), 2871 (m), 2220 (s), 1728 (s), 1574 (s) cm^{-1}; MS, m/z 363 (EI), 364 (CI); MS, exact mass calcd for $C_{23}H_{25}NO_3$ 363.1834, found, 363.1823.

1-Methylethyl 2-Cyano-3-[(1-methylethyl)oxy]oct-2-enoate (18c). Into a refluxing solution of 100 mL of dry isopropyl alcohol was added a solution of 0.20 g (0.57 mmol) of 2,5-diazido-3,6-di-1-hexynyl-2,5-cyclohexadiene-1,4-dione (**2a**) in 40 mL of toluene dropwise under an atmosphere of argon for 30 min. After refluxing for 4 h, the dark red solution turned light brown. The reaction was then concentrated and the dark oily residue absorbed onto silica gel and subjected to flash chromatography (hexane/ethyl acetate) to afford 0.15 g (49%) of a yellowish oil: ^{1}H NMR δ 5.06 (heptet, J = 7 Hz, 1 H), 4.83 (heptet, J = 7 Hz, 1 H), 2.93–2.99 (m, 2 H), 1.40–1.58 (m, 6 H), 1.37 (d, J = 7 Hz, 6 H), 1.29 (d, J = 7 Hz, 6 H), 0.88–0.94 (m, 3 H); IR ($CHCl_3$) 2999 (s), 2980 (s),

2950 (s), 2880 (s), 2230 (m), 1720 (s), 1575 (s), 1460 (m) cm^{-1}; MS, m/z 267 (EI), 268 (CI); MS, exact mass calcd for $C_{15}H_{25}NO_3$ 267.1834, found 267.1819.

1,1-Dimethylethyl 2-Cyano-3-[(1,1-dimethylethyl)oxy]-oct-2-enoate (18d). Into a refluxing solution of 100 mL of dry *tert*-butyl alcohol was added dropwise a solution of 0.20 g (0.57 mmol) of 2,5-diazido-3,6-di-1-hexynyl-2,5-cyclohexadien-1,4-dione (**2a**) in 40 mL of toluene under an atmosphere of argon for 30 min. After refluxing for 4 h, the dark red solution turned clear yellow. The reaction was then concentrated and the dark oily residue absorbed onto silica gel and subjected to flash chromatography (hexane/ethyl acetate) to give 0.11 g (31%) of a yellowish oil: ^1H NMR δ 2.54–2.60 (m, 2 H), 1.66–1.72 (m, 2 H), 1.55 (s, 18 H), 1.33–1.39 (m, 4 H), 0.88–0.93 (m, 3 H); IR ($CHCl_3$) 2999 (s), 2980 (s), 2950 (s), 2880 (s), 2230 (m), 1725 (s), 1580 (s), 1470 (m) cm^{-1}; MS, m/z 295 (EI), 296 (CI).

High-resolution mass spectrometry did not show the molecular ion. Fragmentation gave a peak at 224 which corresponds to M − 71 or loss of C_5H_{11}: exact mass calcd for this fragment ($C_{12}H_{18}O_3N$) 224.1286, found 224.1257.

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Reactions of Azines. 9. Preparation of 4,5-Dihydropyrazolo[1,5-*a*]pyridines, 6,7-Dihydropyrazolo[1,5-*a*]pyridines, and Pyrazolo[1,5-*a*]pyridines

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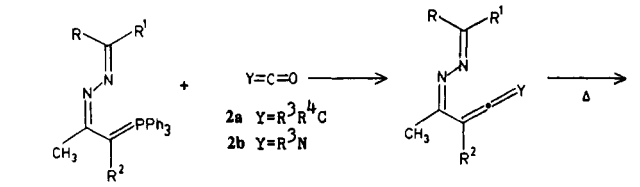
The reactions of (3,4-diaza-2,4,6-heptatrienylidene)triphenylphosphoranes **12** with ketenes **15** provide a general route to 4,5-dihydropyrazolo[1,5-*a*]pyridines **18** via the thermal rearrangements of the allenylazine **16** intermediates. When one of the substituents on the ketene is acetoxy, or phenoxy, elimination may occur to form the corresponding fully aromatized pyrazolo[1,5-*a*]pyridines **19**. When [2-[(diphenylmethylene)hydrazono]propylidene]triphenylphosphorane (**1b**) was allowed to react with vinylketenes **21** the 6,7-dihydropyrazolo[1,5-*a*]pyridines **24** were formed.

Introduction

We have previously reported[1-4] that cumulated azines **3** proved to be versatile synthons for a large variety of fused pyrazolo-substituted species. To date we have prepared all of the azines **3** by allowing the appropriate azine phosphoranes **1** to react with ketenes **2a** or isocyanates **2b**. Preparation of 4,5-dihydropyrazolo[1,5-*b*]isoquinolines **4**,[1-3] pyrazolo[5,1-*c*]-1,4-oxazines **5**,[1,2] 4,9-dihydropyrazolo[5,1-*b*]quinazolines **6**,[4] and 2,3-dihydro-1*H*-imidazo[1,2-*b*]-pyrazol-2-ones **7**[4] have been reported.



1a R=PhCO; R^1=Ph; R^2=H, alkyl
1b R=Ph; R^1=Ph; R^2=H
1c R=CH_3; R^1=Ph; R^2=H

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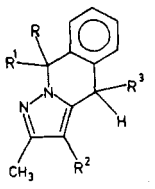

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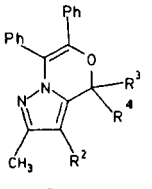

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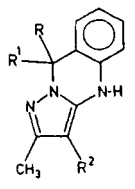

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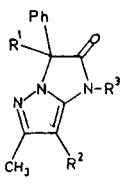

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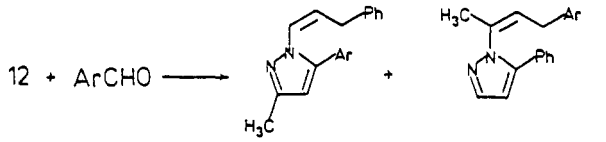
Continuing our interest in the reactions of conjugated azines to prepare fused pyrazolo ring systems, we chose to explore the reactions of allenylazine species that could be used to prepare 4,5- and 6,7-dihydropyrazolo[1,5-*a*]-pyridines.

It has been shown[5] that (2-methyl-7-phenyl-3,4-diaza-2,4,6-heptatrienylidene)triphenylphosphorane (**12a**) and (2,7-diphenyl-3,4-diaza-2,4,6-heptatrienylidene)triphenylphosphorane (**12b**) may be prepared readily by allowing (2-propynyl)triphenylphosphonium bromide (**8**) or (phenylethynyl)triphenylphosphonium bromide (**9**) to react initially with an equivalent amount of hydrazine followed by the addition of cinnamaldehyde (Scheme I). Treatment of salt **11** with ethanolic sodium ethoxide gave the corresponding ylides **12**. When the ylides **12a,b** were



13 **14**

allowed to react with aldehydes, pyrazoles **13** and **14** were formed.[5] The known[6] reactions of phosphonium ylides with ketenes to form allenes suggested a route to the 4,5-dihydropyrazolo[1,5-*a*]pyridines outlined in Scheme II.

We envisioned that the pathway to the pyrazolo[1,5-*a*]pyridines with the 6,7-dihydro orientation could arise from the reaction of vinylketenes **21** with ylide **1b** (Scheme III).

† For X-ray analysis.

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