mixture was worked up in the usual way to afford after column chromatography (10% Et_2O/90% petroleum ether) 0.095 g (76%) of **7** as a crystalline solid.

(*E*,*E*,*E*)-4-[4-Methyl-6-(2,6,6-trimethyl-1-cyclohexen-1-yl)-1,3,5-hexatrienyl]-2(5*H*)-furanone (4). By use of the procedure cited for a **2a**, with 5.0 mmol of **1**[7,8] there was obtained 0.929 g (42%) of the alkylated sulfone upon trituration of the crude product with Et_2O: mp 125.5–127.0 °C (Et_2O); IR ($CHCl_3$) 1780, 1750 cm^{-1}; NMR ($CDCl_3$) δ 1.00 (s, 6), 1.23 (s, 3), 1.4–1.7 (m, 4), 1.67 (s, 3), 2.0–2.3 (m, 2), 2.55–3.65 (m, 2), 3.90–4.39 (m, 1), 4.75 (d, 2, J = 1 Hz), 5.15 (d, 1, J = 10 Hz), 5.85 (t, 1, J = 1 Hz), 5.98 (s, 2), 7.3–8.0 (m, 5). Anal. Calcd for $C_{26}H_{32}O_4S$: C, 71.66; H, 7.13. Found: C, 71.58; H, 7.06. To this sulfone (0.450 g, 1.02 mmol) in dry DMF (15 mL) maintained at −78 °C was added a solution of *t*-BuOK in 1:4 DMF/*tert*-butyl alcohol [1.2 mmol, 2.04 mL; 0.5 M solution prepared from potassium (195 mmol), dry *tert*-butyl alcohol (8 mL), and DMF (2 mL)]. When the addition was completed (approximately 3 min), the mixture was allowed to warm to 10 °C (3 h) and quenched with AcOH (3.0 mL). This mixture was partitioned between saturated $NaHCO_3$ (50 mL) and Et_2O (200 mL). The organic solution was extracted with saturated $NaHCO_3$ (2 × 50 mL), dried ($MgSO_4$), and concentrated in vacuo. Column chromatography (50% CH_2Cl_2/50% pentane) afforded 0.195 g (67%) of **4** as a crystalline solid.

Dimethyl (*all-E*)-2-[4-Methyl-6-(2,6,6-trimethyl-1-cyclohexen-1-yl)-1,3,5-hexatrienyl]-2-butenedioate (3e). To bromide **2e** (2.84 g, 12.0 mmol) in DMF (25 mL) maintained at −15 °C (ice–methanol bath) was added a solution of $NaSO_2Na$ (0.984 g, 6.0 mmol) in DMF (30 mL) over 5 min. The reaction mixture was stirred at −15 °C for 45 min and then poured into Et_2O (200 mL) and extracted with saturated $NaHCO_3$ (3 × 100 mL). The organic phase was dried ($MgSO_4$) and concentrated in vacuo. NMR analysis of this crude product indicated a 62:29:9 ratio of **2e**/**9b**/**10b**. MPLC with 40% Et_2O/60% petroleum ether as the eluant gave 0.805 g (45% yield based on $NaSO_2Ph$) of sulfone **9b** as a colorless oil: IR (film) 1750 (CO_2Me), 1722 (CO_2Me), 1625 (C=C) cm^{-1}; NMR ($CDCl_3$) δ 3.67 (s, 6, $2CO_2CH_3$), 5.53 (s, 1, $SCHCO_2CH_3$), 6.52 (s, 1, C=CH), 6.72 (s, 1, C=CH), 7.5–8.0 (m, 5, Ar H). Without further manipulation, characterization, or attempts to maximize the conversion of **2e** to **9b**, sulfone **9b** was utilized directly in the next reaction. To a solution of sulfone **1** (0.619 g, 1.80 mmol) in THF (15 mL) cooled to −78 °C (dry ice bath) was added *n*-butyllithium (1.3 mL, 1.8 mmol, 1.4 M in hexane). The reaction mixture was warmed to 0 °C for 30 min and then recooled to −78 °C. Then a solution of sulfone **9b** (0.805 g, 2.70 mmol, precooled to −78 °C) in THF (6 mL) was added rapidly. After 10 min the reaction mixture was poured into Et_2O (200 mL) and extracted with saturated $NaHcO_3$ (2 × 30 mL). The organic phase was dried ($MgSO_4$) and concentrated in vacuo. This crude product was dissolved in Et_2O (100 mL) and treated with DBU (0.410 g, 2.70 mmol). After 1 h at room temperature, Et_2O (100 mL) was added, and the mixture was washed with saturated $NaHCO_3$ (2 × 50 mL), dried ($MgSO_4$), and concentrated in vacuo. Column chromatography (10% Et_2O/90% petroleum ether) afforded 0.110 g (17%) of **3e** as a yellow oil.

(*all-E*)-2,3-Bis(carbomethoxy)-6-methyl-8-(2,6,6-trimethyl-1-cyclohexen-1-yl)-1,3,5,7-octatetraene (8). The procedure described for the synthesis of **3d** was used by starting with 2.54 mmol of **1** and 5.0 mmol of **2d**. Column chromatography (20% Et_2O/80% petroleum ether) afforded 0.457 g (50%) of **8** as a yellow oil: UV max (95% C_2H_5OH) 334 nm; IR (film) 1715 (CO_2CH_3) 1585 (C=C) cm^{-1}; NMR ($CDCl_3$) 1.00 (s, 6, 2 C-1 CH_3's), 1.68 (s, 3, C-5 CH_3), 2.06 (s, 3, C-9 CH_3), 3.72 (s, 6, $2CO_2CH_3$), 5.55–5.60 (m, 5, C=CH), 7.75 (d, 1, J = 12 Hz, C-12 C=CH); low-resolution mass spectrum (relative intensity) 358 (m^+, 32), 326 (16), 311 (19), 105 (63), 69 (100), 59 (52), 55 (98), 41 (84); calcd for $C_{22}H_{30}O_4$ m/z 358.2144, found m/z 358.2130 (3.9 ppm error by high-resolution mass spectroscopy.

Acknowledgment. We graciously thank the National Cancer Institute, Division of Cancer Cause and Prevention, for the funds (Grant No. CP 75935) to support this research program. We express our sincere gratitude to Hoffmann-La Roche, and BASF for generous gifts of retinoid starting materials. We also thank Professor E. Wenkert and Mr. Perry Marriott, Rice University, for the mass spectra.

Reactions of Propargyl Alcohols with Amide Acetals[1]

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The reaction of a propargyl alcohol with an amide acetal affords enamine products, an allenic amide (a sigmatropic rearrangement product), or a product resulting from enamine formation followed by sigmatropic rearrangement. Subsequent procedures afforded α,β-unsaturated aldehydes, α-hydroxy ketones, β-keto amides, and spiro lactones.

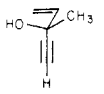
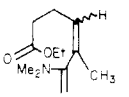
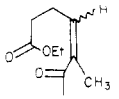
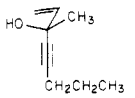
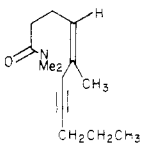
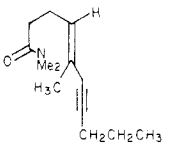
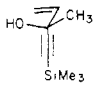
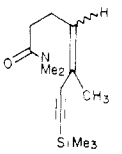
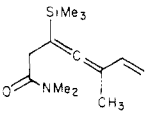
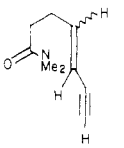
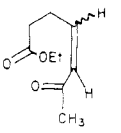
A number of reactions of the amide acetal reagents have been reported.[2] We have found that mixed amide acetals derived from propargyl alcohols react to give one or more products resulting from intramolecular amine addition to the carbon–carbon triple bond and/or rearrangement. The pathway which such mixed amide acetals follow is dependent in a predictable way on the nature of substituents

* Camille and Henry Dreyfus Teacher-Scholar Award Recipient, 1980–1985; Alfred P. Sloan Fellow, 1979–1983.

(1) Portions of this work have been reported in communication form: (a) K. A. Parker and J. J. Petraitis, *Tetrahedron Lett.*, 4561 (1977); (b) K. A. Parker, R. W. Kosley, Jr., S. L. Buchwald, and J. J. Petraitis, *J. Am. Chem. Soc.*, **98**, 7104 (1976); (c) K. A. Parker and R. W. Kosley, Jr., *Tetrahedron Lett.*, 341 (1976); (d) K. A. Parker and R. W. Kosley, Jr., *ibid.*, 3039 (1975).

0022-3263/82/1947-0389$01.25/0

Table I. Reactions of Alkynyl Allylic Alcohols with DMA-DEA

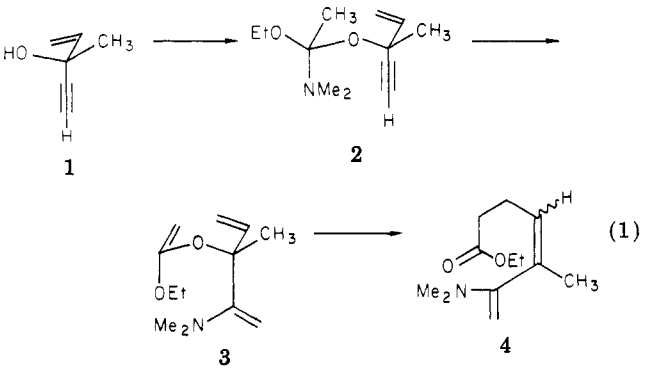
alcohol (amt)	products (% yield)		procedure[a]	temp, °C	time, h
			A	120	3
1[5] (1.06 g)	4 (72)				
1 (518 mg)			B	115	3
	5 (69)				
			B	115	2
6 (959 mg)	7 (47)	8 (11)			
			C[b]	165	40
9[7] (496 mg)	10 (38)[b]	11 (8)[b]			
			B	105	1
12[8] (938 mg)	13 (21)[b]	14 (7)[b]			

[a] A 5-mL sample of DMA-DEA was used in all cases. [b] See the Experimental Section.

and, to some extent, on the reaction conditions.

Background

The reaction of an allylic alcohol with a acetamide dialkyl acetal[3] or a substituted acetamide dialkyl acetal[4] has proved a popular alternative to the classical Claisen rearrangement as a method of obtaining γ,δ-unsaturated carbonyl compounds. While 3-methyl-4-penten-1-yn-3-ol (1)[5] undergoes the predicted ortho ester Claisen rearrangement,[6] treatment of this alcohol with dimethylacetamide diethyl acetal (DMA-DEA) affords the unexpected product, enamine 4[1d] (eq 1). We assumed that this



(1)

product results from Claisen rearrangement of 3 and, therefore, that the terminal acetylene in 2 is undergoing addition of the dimethylamine group from the amide acetal moiety. Since the conversion of acetylenes to enamines under the relatively mild conditions of the amide acetal reaction (140 °C, several hours, small amount of pivalic acid) might have synthetic potential, a study of the generality and possible applications of this transformation was warranted. The structural features of the substrate and reagent which are required for "amine migration" in mixed amide acetals have been determined; a summary of these findings follows.

Results and Discussion

Dimethylacetamide Acetals with Alkynyl Allylic Alcohols. Varying the structure of the alkynyl allylic alcohol (Table I) indicated two limitations on substrates

(2) The reactions of amide acetals have been reviewed: R. H. DeWolfe, "Carboxylic Ortho Acid Derivatives, Preparation and Synthetic Applications", Academic Press, New York, 1970, Chapter 7. Also, the chemistry of formamide acetals was reviewed recently: R. F. Abdulla and R. S. Brinkmeyer, *Tetrahedron*, **35**, 1675 (1979).

(3) D. Felix, K. Gschwend-Steen, A. E. Wick, and A. Eschenmoser, *Helv. Chim. Acta*, **52**, 1030 (1969).

(4) (a) W. Sucrow and W. Richter, *Chem. Ber.*, **104**, 3679 (1971); (b) W. Sucrow, B. Schubert, W. Richter, and M. Slopianka, *ibid.*, **104**, 3689 (1971).

(5) C.-H. Ou and T.-H. Hua, *Hsueh-Hsueh Pao*, **26**, 169–72 (1960); cited in *Chem. Abstr.* **59**, 2631*h* (1963).

(6) K. A. Parker and R. W. Kosley, Jr., *Tetrahedron Lett.*, 691 (1975).

(7) Prepared by the method of M. F. Shostakovskii, I. A. Shikhiev, and N. V. Komarov, *Izv. Akad. Nauk SSSR, Ser. Khim.* 1271 (1956).

(8) Lespieau and Lombard, *Bull. Soc. Chim. Fr.* **2**, 369 (1935).

(9) M. Andrac, *Ann. Chim. (Paris)*, **9**, 287 (1964).

(10) Prepared by the Grignard reagent method of B. R. Fleck and J. E. Kmiecik, *J. Org. Chem.*, **22**, 90 (1957).

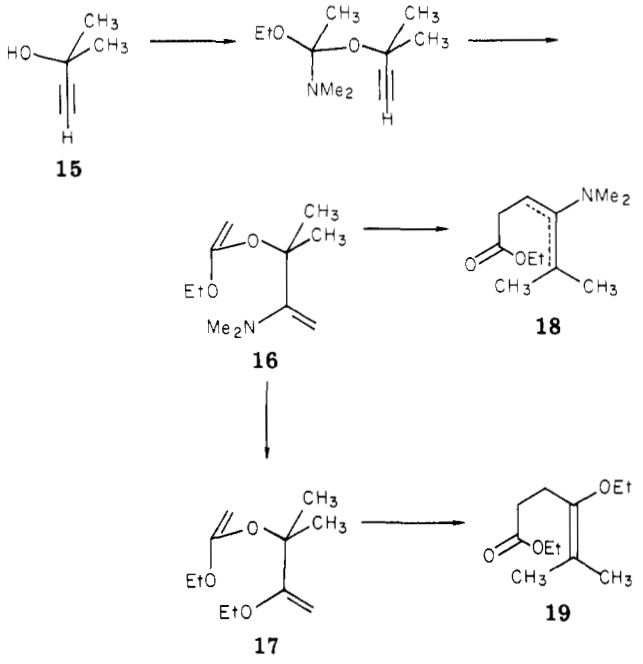
(11) N. R. Kamarov, O. G. Yarosh, and L. N. Asmafev, *J. Gen. Chem. USSR (Engl. Transl.)* **36**, 920 (1966).

(12) N. V. Kamarov and M. F. Shostakovskii, *Izv. Akad. Nauk SSSR, Ser. Khim.* 1300 (1960).

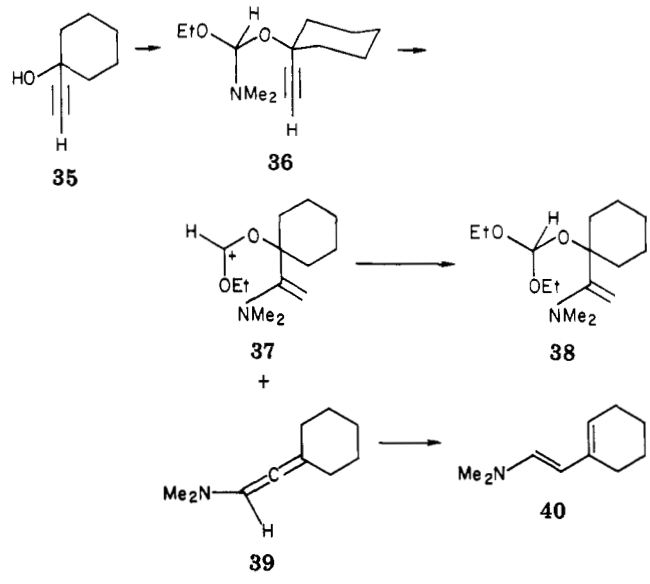
(13) (a) W. R. Benn, *J. Org. Chem.*, **33**, 3113 (1968). (b) See also G. L. Olson, K. D. Morgan, and G. Saucy, *Synthesis*, 25 (1975).

(14) J. Kriz, M. J. Benes, and J. Peska, *Collect. Czech. Chem. Commun.*, **32**, 398 (1967).

Scheme I



Scheme II



which would undergo amine transfer with amide acetals. First, *an alkyl or trimethylsilyl substituent on the acetylene precludes amine migration*, and simple Claisen-type transformations occur. Thus alcohol **6** affords a mixture of products **7** and **8**, in which **7** predominates. Alcohol **9** gave a mixture of Claisen products **10** and **11**; **11** results from participation of the alkyne rather than alkene in the Claisen rearrangement.

The second limitation on amine transfer is the degree of substitution at the carbinol carbon; *with secondary alcohols amine transfer is a minor process, and classical rearrangement products predominate.* Thus alcohol **12** affords (after hydrolytic workup) a poor yield of a mixture of **13** and **14** in which the amine migration product **14** is the minor component. *These restrictions suggest that the mechanism of enamine formation is one in which the dimethylamino group adds to the acetylenic bond in a nucleophilic, intramolecular process* which becomes more facile when the acetylenic bond is forced by larger geminal groups into proximity with the dimethylamino group.[1d]

Dimethylacetamide Acetals with Propargyl Alcohols. These limitations were found to apply to the reactions of simple propargyl alcohols as well. Thus amine transfer followed by Claisen rearrangement converts alcohol **15** to the rearranged enamine **18** (Scheme I); in this transformation, a significant amount of enol ether **19** was observed. The mechanism by which enol ether **19** is produced has not been elucidated; however, as it does not arise when enamine **18** is subjected to the reaction conditions, we have concluded that it is formed prior to Claisen rearrangement, probably from enol **17**, which, in turn, is derived from enamine **16**.

When amine migration does not take place, Claisen rearrangement involving the carbon–carbon triple bond proceeds. Thus, alcohols **27**, **29**, **31**, and **33** all give substituted allenes (**28**, **30**, **32**, and **34**, respectively) in good yield.

In this series of compounds, as above, amine transfer becomes a minor process, and overall yields fall dramatically if the substrate is not tertiary (Table II; **21** → **22** + **23**, total yield 30%, and **24** → **25** + **26**, total yield 25%). Products **22** and **25** presumably arise from double bond migration of the Claisen allene products.

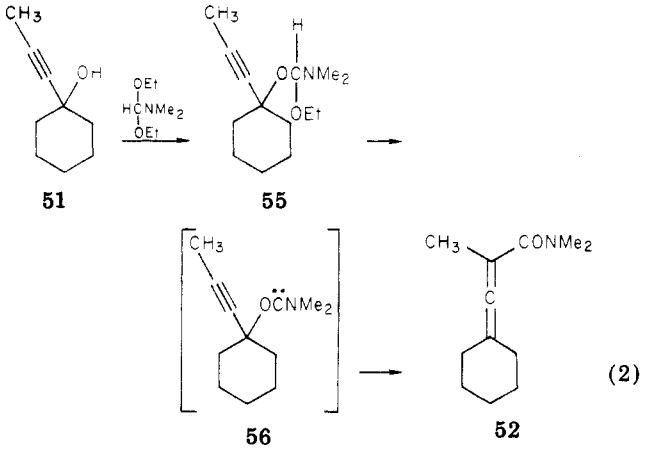
Dimethylformamide Acetals with Propargyl Alcohols. Amine migration was also observed in the reaction of tertiary propargyl alcohols with dimethylformamide diethyl acetal. Competing Claisen rearrangements are not possible with this reagent; however, two new transformations were observed. First, products resulting from amine migration to both the internal and terminal positions of the ethynyl substituent were observed. Thus, in the reaction of 1-ethynylcyclohexanol (**35**), migration to the internal carbon of intermediate **36** leads eventually to enamine orthoformate **38** (Scheme II) whereas migration to the terminal carbon (**36** → **39**) results in the formation of dienamine **40**. (We have never observed evidence for the intermediacy of allenamines such as **39**; however, they are conceptually convenient intermediates.)

A number of examples of tertiary ethynyl alcohols were studied; most afford the products from both pathways (Table III).

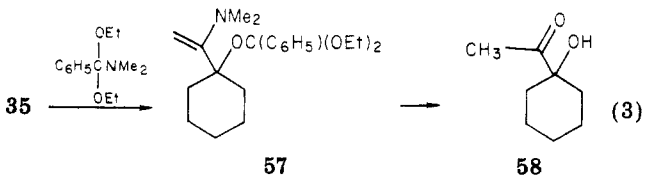
Special structural features of the tertiary ethynyl alcohol led to the production of one product to the exclusion of the other. The steroid substrate **47** was converted cleanly and in high yield to the dienamine product **48**. On the other hand, alcohol **53** afforded only enamine orthoformate, presumably because nucleophilic addition to the internal carbon of the acetylene was favored by the stabilizing effect of the phenyl substituent. Alcohol **15** also afforded a single product. The formation of dienamine cannot be ruled out however; distillation would not necessarily have allowed recovery of this volatile product from the excess DMF-DEA.

As in the case of the mixed acetamide acetals from alkyl-substituted propargyl alcohols, no amine migration was observed in the corresponding mixed formamide acetals. Rather, sigmatropic processes were observed. For example, alcohol **51** was converted cleanly to allenic amide **52** (eq 2). This reaction is analogous to the rearrangement of the mixed formamide acetals of allylic alcohols[15] and may be envisioned as a [2,3] sigmatropic rearrangement of an N,O-substituted carbene. Some support for this postulated mechanism can be derived from the observation that the conversion of **51** to **52** is made more efficient by the removal of methanol.

(15) G. Büchi, M. Cushman, and H. Wüest, *J. Am. Chem. Soc.*, **96**, 5563 (1974).
(16) R. Baudouy and J. Goré, *Synthesis*, 573 (1974).



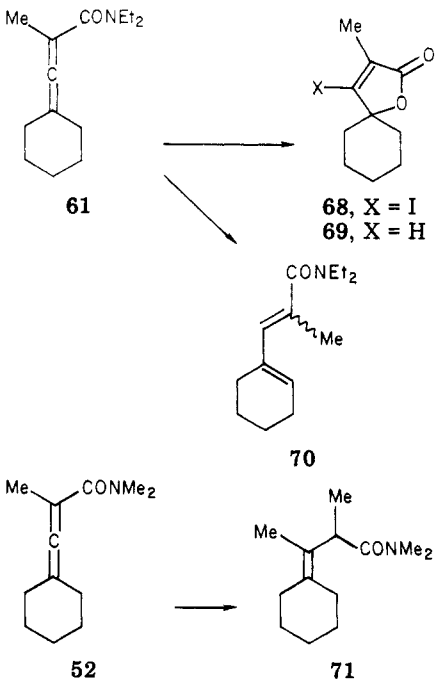
***N,N*-Dimethylbenzamide Acetal.** When the amide acetal reagent is derived from *N,N*-dimethylbenzamide, only amine migration to the internal carbon of tertiary ethynyl alcohols occurs. Thus, only 1-acetylcyclohexanol **58**, presumably derived from enamine **57** (eq 3), was isolated (62% yield) from a hydrolytic workup (acid followed by sodium hydroxide) of the reaction mixture from 1-ethynylcyclohexanol with benzamide acetal. In this case, we are confident that if dienamine product **40** had been formed, we would have detected it as well as its hydrolysis product, (formylmethylidene)cyclohexane.



Diethylformamide Acetals. Although the product distribution in the reaction of 1-ethynylcyclohexanol with DMF acetal(s) was essentially independent of reaction conditions, the condensation of 1-ethynylcyclohexanol (**35**) with diethylformamide (DEF) acetals gave dienamine and enamine orthoformates when conducted in ethanol but afforded only allenic amide **59** when carried out in xylene. We have attributed this change in reaction pathway to the increased steric bulk around the nitrogen in the intermediate mixed orthoformate; this raises the energy barrier to amine migration reactions and allows the appearance of products derived from the carbene-initiated [2,3] sigmatropic rearrangement. The appearance of allenic amide products from condensation with the diethylformamide acetal reagent in hydrocarbon solvents is general for tertiary ethynyl alcohols and secondary propargyl alcohols; however, the product from a secondary ethynyl alcohol can react further under the reaction conditions and during the workup to give eventually a β-keto amide (**65** → **66** → **67**, Table IV).

Reactions of Allenic Amides. This simple high-yield synthesis of allenic amides makes them attractive intermediates. In fact, the reactions of amides **52** and **61** illustrate the variety of structures which can be obtained from further transformations of these compounds. Thus, reaction of **61** with iodine in aqueous THF afforded iodobutenolide **68** in 48% yield (Scheme III). Similarly, aqueous formic acid treatment converted amide **61** to butenolide **69** in 74% yield. Anhydrous formic acid, on the other hand, merely effected isomerization of **61** to **70** (49% yield). Nucleophilic reagents add to allenic amide **52** at the β-position to give the β,γ-unsaturated amide. For example, reaction of **52** with methylmagnesium chloride affords amide **71** in 53% yield.

Scheme III



In summary, mixed amide acetals derived from propargyl alcohols afford one or more predictable products as a result of pathways involving rearrangement. Enamine products and allenic amides undergo further transformations to give carbonyl containing products which may prove useful in synthesis.

Experimental Section

Dimethylacetamide diethyl acetal (DMA-DEA) was prepared according to Meerwein.[19] Dimethylformamide diethyl acetal (DMF-DEA) and dimethylformamide dimethyl acetal (DMF-DMA) were purchased from Aldrich. Organic solutions were routinely dried over magnesium sulfate.

Analytical and preparative gas chromatography (GC) was performed with a Hewlett-Packard Research gas chromatograph, Model 5750, fitted with a thermal-conductivity detector and a Hewlett-Packard 3370 electronic integrator. No correction was made for detector response. Columns employed were as follows: 0.25 in. × 20 ft, 20% SE-30 on Chromosorb W (80–100 mesh), acid-washed DMCS (dimethylchlorosilane) (column A); 0.25 in. × 15 ft 20% Carbowax 20M on Diatoport S, 80–100 mesh (column B). The carrier gas flow (helium) was 60 mL/min.

Thin-layer chromatography (TLC) was performed by using Analtech glass plates coated with silica gel GF (250 μm). Products were located under UV illumination or by development in an iodine atmosphere. Column chromatography was performed on Baker silica gel (60–250 mesh).

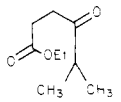
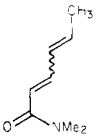
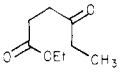
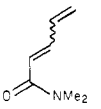
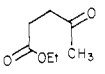
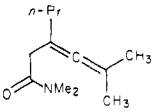
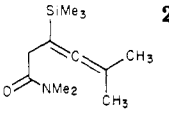
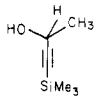
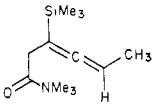
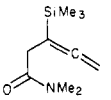
Infrared spectra were obtained with a Perkin-Elmer 257 grating instrument, nuclear magnetic resonance (NMR) spectra with a Varian A-60 spectrometer, and mass spectra with a Hitachi Perkin-Elmer Model RMU-6D spectrometer at 40 eV. Melting points were determined on a Thomas-Hoover melting point apparatus and are uncorrected.

Microanalyses were performed by Schwarzkopf Microanalytical Laboratory, Inc.

Reaction with DMA-DEA. Procedure A. The propargyl alcohol and excess DMA-DEA were stirred at elevated temperature for several hours (see Tables I and II). The reaction mixture was concentrated and the residue distilled. Yields are reported in Tables I and II; physical constants for the products are reported in the Experimental Section.

Procedure B. The propargyl alcohol and excess DMA-DEA were stirred at elevated temperatures for several hours (see Tables I and II). Then the mixture was cooled to room temperature and placed on a column containing 60 g of silica gel (Baker, 60–200

Table II. Reactions of Propargyl Alcohols with DMA-DEA

alcohol (amt)	products (% yield)	procedure	DMA-DEA	temp, °C	time, h
15 (937 mg)	18, 19 (74, combined)	A	5 mL	120	4
15 (500 mg)	 20 (73)	B	5 mL	120	3
 21 (506 mg)	 22 (23)  23 (7)	B	5 mL	95	2
 24 (507 mg)	 25 (21)  26 (4)	B	5 mL	95	2
 27[9,10] (1.05 g)	 28 (81)	B	5 mL	reflux	2
 29[7] (616 mg)	 30 (59) 20 (15)	D[a]	840 mg	145	36
 31[7,11] (500 mg)	 32 (86)	E	740 mg	reflux	28
 33[12] (450 mg)	 34 (80)	E	790 mg	reflux	24

[a] See the Experimental Section.

mesh) which had been shaken with 6.0 mL of water. The column was eluted with 100 mL of chloroform, 100 mL of 1% methanol/chloroform, and, if necessary, 100 mL of 2% methanol/chloroform. The appropriate chromatography fraction was concentrated and the residue distilled. Yields are reported in Tables I and II; physical constants for products are reported below.

Procedure C. See the Experimental Section for **10** and **11**.

Procedure D. See the Experimental Section for **30** and **20**.

Procedure E. A solution of the propargyl alcohol and 1.4–1.8 equiv of DMA-DEA in 10 mL of xylene was stirred at reflux for several hours (see Table II). Then the solution was allowed to cool to room temperature, washed twice with water, and dried over magnesium sulfate.

Reactions with DMF-DEA. Procedure F. The propargyl alcohol and a catalytic amount of pivalic acid were added to a solution of ethanol and DMF-DEA, and the resulting solution was stirred at elevated temperature for many hours.

Procedure G. See the Experimental Section for **48**.

Procedure H. See the Experimental Section for **52**.

Procedure I. The propargyl alcohol and 1.1–2.1 equiv of DEA-DEA were dissolved in xylene, and the reaction mixture was stirred under a Dean–Stark trap at elevated temperatures for 1 h or more. The reaction mixture was cooled and chromatographed on silica gel with ether/hexane (1:1–1:2). The appropriate fraction(s) was (were) dried ($MgSO_4$) and concentrated.

Procedure J. The propargyl alcohol and 1.5–2.0 equiv of DEF-DEA were dissolved in *o*-dichlorobenzene. The mixture was stirred under a Dean–Stark trap at elevated temperatures. *o*-Dichlorobenzene was removed by distillation, and the residue was eluted from silica gel with an ether/hexane mixture. The eluant was dried and concentrated.

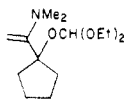
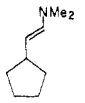
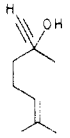
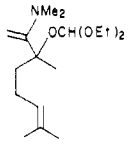
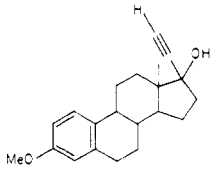
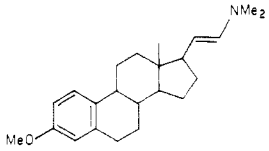
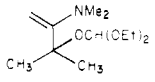
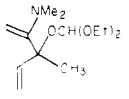
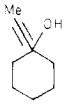
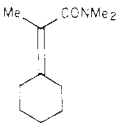
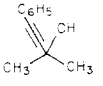
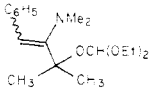
Ethyl 6-(Dimethylamino)-5-methyl-4,6-heptadienoate (4). See Table I. Distillation provided 1.67 g (72%) of **4**: bp 79–84 °C (0.6 mm); NMR ($CDCl_3$) δ 1.24 (t, J = 7 Hz, 3 H) 1.78 (s, 3 H), 2.48 (m containing s at 2.52, 10 H), 3.69 (s, 1 H), 3.89 (s, 1 H), 4.12 (q, J = 7 Hz, 2 H), 4.77–5.25 (small signals, impurity or isomer), 5.58 (m, 1 H), 6.50–7.33 (small signals, impurity or isomer); IR ($CHCl_3$) 1725, 1665, 1370, 1165 cm^{-1}.

Ethyl 5-Methyl-6-oxo-4-heptenoate (5).[17] See Table I. Distillation provided 0.993 g (69%) of **5**: bp 105–110 °C (1.7 mm); NMR ($CDCl_3$) δ 1.25 (t, J = 7 Hz, 3 H) 1.78 (s, 3 H), 2.27 (s, 3 H), 2.5–2.9 (m, 4 H) 4.12 (q, J = 7 Hz, 2 H), 6.60 (t, J = 6 Hz, 1 H); IR ($CHCl_3$) 1730, 1665, 1370, 1165 cm^{-1}; UV ($CHCl_3$) λ 237 nm (ε 7.9×10^3). Anal. Calcd for $C_{10}H_{16}O_3$: C, 65.19; H, 8.76. Found: C, 65.09; H, 8.65.

3-Methyl-1-octen-4-yn-3-ol (6). To 0.15 g of ferric nitrate in 400 mL of liquid ammonia was added 12.5 g (0.54 mol) of sodium (one piece at a time!). To the gray mixture was added a solution of 34 g of pentyne (0.5 mol, Farchan) in 30 mL of THF dropwise.

(17) Authentic material was prepared for comparison from ethyl 4-oxobutyrate [E. R. H. Jones, J. B. Jones, L. Skattebol, and M. C. Whiting, *J. Chem. Soc.*, 3489 (1960)] by the method of H. J. Bestmann and B. Arnason, *Chem. Ber.*, **95**, 1513 (1962).

Table III. Reaction of Propargyl Alcohols with DMF-DEA

alcohol (amt)	products (% yield)	procedure	DMF-DEA (mL)/ EtOH (mL)/ pivalic acid (mg)	temp, °C	time, h
35 (971 mg)	38 (47), 40 (42)	F	5/1/20	120	40
 41 (903 mg)	 42 (46)  43 (22)	F	5/1/18	120	40
 44 (763 mg)	 45 (40)  46 (24)	F	3.5/1/19	125	38
 47	 48	G[a,b]			
15 (969 mg)	 49 (51)	F	5/1/21	120	4
29 (1.76 g)	49 (40)	F	3/1	reflux	64
1 (923 mg)	 50 (50)	F	3/1.5/7	125	36
 51[10] (1.40 g)	 52 (60)	H[a]			
 53[10,14] (1.00 g)	 54 (55)	F	1.5/1/32	145	90

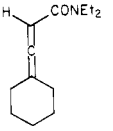
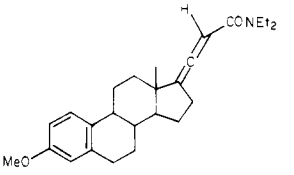
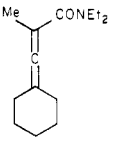
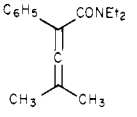
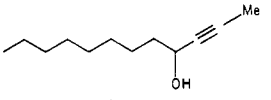
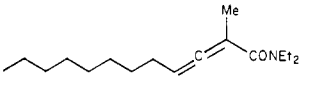
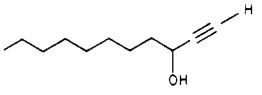
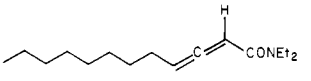
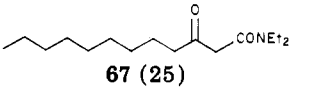
[a] See the experimental procedure. [b] Alternatively, the reaction mixture could be filtered through wet silica gel to give *trans*-3-methoxy-19-norpregna-1,3,5(10),17(20)-tetraen-21-al: mp 166–168 °C (lit.[13] mp 175–177 °C); 97% yield.

The mixture was stirred approximately 15 min. To the mixture was added dropwise a solution of 7.74 g (0.11 mol) of methyl vinyl ketone in 80 mL of dry ether. After the addition (0.5 h), the mixture was stirred for 2 h. To the mixture was added *slowly* 35 g of ammonium chloride. Ammonia was allowed to evaporate, and 200 mL of ether was added. The mixture was poured into 750 mL of water overlaid with ether. The ether layer was washed with brine, dried, and concentrated. Distillation afforded 5.66 g (36%) of alcohol **6**: bp 92–98 °C (28 mm); NMR ($CDCl_3$) δ 0.98 (t, J = 7 Hz, 3 H), 1.50 (s and m, 5 H) 2.18 (t, J = 7 Hz, 2 H) 2.81 (br s, 1 H), 5.56 (m, 3 H); IR ($CHCl_3$) 3600, 3420, 2240, 1330, 910 cm^{-1}.

***N,N*-Dimethyl-5-methyl-4-decen-6-ynamide (7, 8).** See Table I. Kugelrohr distillation provided 58% of a mixture, [bp 120 °C (1 mm)] of *cis*- and *trans*-*N,N*-dimethyl-5-methyl-4-decen-6-ynamide. Gas chromatography on column B indicated 47% of one isomer and 11% of the other. Preparative gas chromatography gave two isomers. The major product was assigned the *Z* geometry (**7**): NMR ($CDCl_3$) δ 1.00 (t, J = 7 Hz, 3 H), 1.12–1.92 (m, 2 H), 1.92 (s, 3 H), 1.98–2.65 (m, 6 H), 2.96 (s, 3 H), 3.03 (s, 3 H), 5.66 (t, J = 6.5 Hz, 1 H); IR ($CHCl_3$) 1630, 1400, 1265, 1140 cm^{-1}. Anal. Calcd for $C_{13}H_{21}NO$: C, 75.31; H, 10.21; N, 6.76. Found: C, 74.98; H, 10.39; N, 6.80. The minor product was assigned the *E* geometry (**8**): NMR ($CDCl_3$) δ 0.96 (t, J = 7 Hz, 3 H), 1.18–1.88 (m, 5 H), 1.82 (s, 3 H), 2.06–2.52 (m, 6 H), 2.99 (s, 3 H), 3.03 (s, 3 H), 5.77 (m, 1 H); IR ($CHCl_3$) 1630, 1390, 1140 cm^{-1}.

3-Methyl-5-(trimethylsilyl)-1-penten-4-yn-3-ol (9). The method of Shostakovskii et al.[7] for C-silylation of ethynyl carbinols was modified. Thus, to a solution of ethylmagnesium bromide (from 20 g of magnesium and 88 g of ethyl bromide in 220 mL of ether) at 0 °C was added dropwise a solution of 13.1 g of 3-methyl-1-penten-4-yn-3-ol (Fluka, AG) in 200 mL of ether. After 48 h, 0.35 g of cuprous chloride (freshly prepared) and 0.66 g of mercurous chloride were added. The mixture was cooled to room temperature and poured *slowly* into 800 mL of ice-cold 10% HCl. The mixture was extracted twice with ether. The ether solution was washed twice with water and once with saturated sodium chloride and dried (magnesium sulfate). Distillation provided 18.5 g (81%) of alcohol **9**: bp 62–63 °C (20 mm); NMR ($CHCl_3$) δ 0.17 (s, 9 H), 1.50 (s, 3 H), 2.76 (s, 1 H), 4.91–6.23 (m, 3 H); IR ($CHCl_3$) 2150, 1310, 1240, 935 cm^{-1}. Anal. Calcd for $C_9H_{16}OSi$:

Table IV. Reactions of Propargyl Alcohols with DEF-DEA

alcohol (amt)	products (% yield)	procedure	DEF-DEA/xylene/ *o*-dichlorobenzene	temp, °C	time, h
35 (527 mg)	 59 (50)	I	833 mg/ 20 mL/0	reflux	1.5
47 (895 mg)	 60 (61)	I	557 mg/ 30 mL/0	140	3
51 (707 mg)	 61 (92)	J	1.80 g/0/15 mL	140 170	1 0.5
53 (809 mg)	 62 (84)	I	1.2 mL/ 20 mL/0	138	0.5
 63 (1.06 g)	 64 (93)	J	1.06 g/0/15 mL	140 175	0.5 1
 65 (747 mg)	 66 (29) +  67 (25)	I	903 mg/ 15 mL/0	140	6

C, 64.22; H, 9.58. Found: C, 64.19; H, 9.49.

***N*,*N*-Dimethyl-5-methyl-7-(trimethylsilyl)-4-hepten-6-ynamide (10) and *N*,*N*-Dimethyl-5-methyl-3-(trimethylsilyl)-3,4,6-heptatrienamide (11).** A solution of 0.496 g (2.95 mmol) of 3-methyl-5-(trimethylsilyl)penten-4-yn-3-ol (**9**), 0.557 g (3.46 mmol) of DMA-DEA, and 10 mL of benzene was heated in a sealed tube at 165 °C for 40 h. The isolated solution was washed with 5% HCl, 10% sodium bicarbonate, water, and brine and dried. Evaporation of solvent followed by Kugelrohr distillation provided 0.319 g (46%) of a mixture [bp 95 °C (1 mm)] of **10** and **11** (ratio 4.7:1). Preparative gas chromatography on column B resulted in separation of the two. For **10**: NMR ($CDCl_3$) δ 0.20 (s, 9 H), 1.83 (d, J = 1.0 Hz, 3 H), 2.52 (br s, 4 H), 2.95 (s, 3 H), 3.01 (s, 3 H), 5.83 (m, 1 H); IR ($CHCl_3$) 2140, 1630, 1400, 1250, 1135 cm^{-1}; mass spectrum, m/e (M^+) 237. Anal. Calcd for $C_{13}H_{23}NOSi$: C, 65.76; H, 9.76; N, 5.90. Found: C, 65.34; H, 9.68; N, 5.9. For **11**: NMR ($CDCl_3$) δ 0.12 (s, 9 H), 1.77 (s, 3 H), 2.90 (s, 3 H), 3.00 (s, 3 H), 3.98 (s, 2 H), 4.76–5.13 (m, 2 H); IR ($CHCl_3$) 1920, 1625, 830 cm^{-1}.

1-Penten-4-yn-3-ol (12). The procedure of Lespieau and Lombard[8] was modified by the use of THF as the solvent and applied to 40.5 g (0.722 mol) of acrolein. After the reaction mixture was quenched and extracted, the solvent was removed by distillation through a 40-cm Vigreux column. Distillation provided 25.1 g (42%) of 1-penten-4-yn-3-ol: bp 67–72 °C (60 mm) NMR ($CDCl_3$) δ 2.61 (d, J = 2.5 Hz, 1 H), 3.95 (br s, 1 H), 4.89 (br s, 1 H), 5.08–6.33 (m, 3 H); IR ($CHCl_3$) 3610, 925 cm^{-1}.

***N*,*N*-Dimethyl-*trans*-4-hepten-6-ynamide (13) and Ethyl *trans*-6-Oxo-4-heptenoate (14).** See Table I. Kugelrohr distillation provided 1.66 g of material, bp 110 °C (0.8 mm). Analytical and preparative GC on column B indicated several products, including 21.5% (overall) of **13**: NMR ($CDCl_3$) δ 2.43 (m, 4 H), 2.78 (d, J = 2 Hz, 1 H), 2.97 (s, 3 H), 3.01 (s, 3 H), 5.49 (d, J = 16 Hz, 1 H), 6.32 (dm, J = 16 Hz, 1 H); IR ($CHCl_3$) 2100, 1635, 1400, 950 cm^{-1}. It also included 7% (overall) of **14**: NMR ($CDCl_3$) δ 1.27 (t, J = 7 Hz, 3 H), 2.25 (s, 3 H), 2.53 (m, 4 H), 4.17 (q, J = 7 Hz, 2 H), 6.10 (unsym d, J = 16 Hz, 1 H), 6.83 (unsym dm, J = 16 Hz, 1 H); IR ($CDCl_3$) 1730, 1675, 1630, 1365, 910 cm^{-1}.

Ethyl 4-(Dimethylamino)-5-methyl-4-hexenoate (18) and Ethyl 4-Ethoxy-5-methyl-4-hexenoate (19). See Table II. Distillation provided 1.65 g (approximately 74%) of a mixture, [bp 95.2–101.5 °C (3 mm)] of what appeared by NMR to be a mixture of enamines **18** and enol ether **19**: NMR ($CDCl_3$) δ 1.05–1.65 (m), 2.48 (s), 2.77 (s), 3.58 (q, J = 7 Hz), 4.17 (q, J = 7 Hz).

Ethyl 5-Methyl-4-oxohexanoate (20).[18] See Table II. Distillation [bp 84 °C (1.5 mm)] gave 0.750 g (73%) of keto ester **20**: NMR ($CDCl_3$) δ 1.12 (d, J = 7 Hz, 6 H), 1.25 (t, J = 7 Hz, 3 H), 2.68 (m, 5 H), 4.14 (q, J = 7 Hz, 2 H).

***N*,*N*-Dimethyl-2,4-hexadienamide (22) and Ethyl 4-Oxohexanoate (23).** See Table II. Evaporation of solvent followed by Kugelrohr distillation provided 2.64 g of material, bp 105 °C (0.5 mm). Analytical and preparative GC on column B indicated

(18) Authentic material was prepared for comparison from the corresponding acid [H. Scheibler and M. Schmidt, *Chem. Ber.*, 54, 139 (1921)].
(19) H. Meerwein, et al., *Justus Liebigs Ann. Chem.*, 641, 1 (1961).

23% (overall) of *N,N*-dimethyl-2,4-hexadienamide (**22**) and 6.7% (overall) of ethyl 4-oxohexanoate (**23**). For **22**: NMR ($CDCl_3$) δ 1.88 (d, J = 6 Hz, 3 H), 3.06 (s, 6 H), 5.84–6.50 (m, 3 H), 7.28–7.90 (m, 1 H); IR ($CHCl_3$) 1650, 1620, 1590, 1390, 1130 cm^{-1}. For **23**: NMR ($CDCl_3$) δ 1.08 (t, J = 7 Hz, 3 H), 1.26 (t, J = 7 Hz, 3 H), 2.62 (complex m, 6 H), 4.16 (q, J = 7 Hz, 2H); IR ($CHCl_3$) 1710–1740, 1380, 1175, 1115 cm^{-1}.

***N,N*-Dimethyl-2,4-pentadienamide (25) and Ethyl 4-Oxopentanoate (26).** See Table II. Kugelrohr distillation provided 2.84 g of material, bp 120 °C (1 mm). Analytical and preparative GC on column B indicated a 21.5% (overall) yield of *N,N*-dimethyl-2,4-pentadienamide (**25**) [NMR ($CDCl_3$) δ 3.07 (s, 6 H) 5.27–5.77 (m, 2 H), 6.17–7.53 (m, 3 H); IR ($CHCl_3$) 1653, 1616, 1396, 1135 cm^{-1}] and a 4.2% (overall) yield of ethyl 4-oxopentanoate. In another experiment the minor component (**26**) was isolated by preparative GC and shown to be identical with commercial ethyl levulinate.

2-Methyl-3-heptyn-2-ol (27). The procedure of Fleck and Kmiecik[10] afforded a quantitative yield of 2-methyl-3-heptyn-2-ol: bp 73–81 °C (20 mm); NMR ($CDCl_3$) δ 0.92 (t, J = 7 Hz, 3 H), 1.42 (s + m, 8 H), 2.10 (t, J = 7 Hz, 2 H), 3.02 (br s, 1 H); IR ($CHCl_3$) 3370, 2870, 2230, 1165, 945 cm^{-1}.

***N,N*-Dimethyl-5-methyl-3-propyl-3,4-hexadienamide (28).** See Table II. Kugelrohr distillation provided 2.77 g of material, bp 110 °C (1 mm). Analytical gas chromatography on column A indicated an overall yield of 81% of **28**: NMR ($CDCl_3$) δ 0.91 (t, J = 7 Hz, 3 H), 1.08–2.23 (s + m, 10 H), 2.91 (s, 3 H), 2.97 (s, 2 H), 3.01 (s, 3 H); IR ($CHCl_3$) 1630, 1445, 1395, 1120 cm^{-1}. Anal. Calcd for $C_{12}H_{21}NO$: C, 73.80; H, 10.84. Found: C, 73.90; H, 10.88.

***N,N*-Dimethyl-5-methyl-3-(trimethylsilyl)-3,4-hexadienamide (30).** See Table II. Kugelrohr distillation provided 0.747 g of material, bp 105 °C (0.7 mm); gas chromatography of this product indicated 70% of one component. Preparative gas chromatography of this component afforded clean allene **30**: NMR ($CDCl_3$) δ 0.08 (s, 9 H), 1.63 (s, 6 H), 2.89 (s, 3 H), 2.96 (s, 5 H); IR ($CHCl_3$) 1940, 1630, 1390, 1240 cm^{-1}.

***N,N*-Dimethyl-3-(trimethylsilyl)-3,4-hexadienamide (32).** See Table II. Kugelrohr distillation provided 6.36 g (86%) of **32**: bp 90 °C (2 mm); NMR ($CDCl_3$) δ 0.10 (s, 9 H), 1.61 (d, J = 7 Hz, 3 H), 2.98 (m, 8 H), 4.87 (br s, 1 H); IR ($CDCl_3$) 2930, 1900, 1640, 1400, 1245, 840 cm^{-1}. Anal. Calcd for $C_{11}H_{21}NOSi$: C, 62.48; H, 10.01. Found: C, 62.37; H, 9.96.

***N,N*-Dimethyl-3-(trimethylsilyl)-3,4-pentadienamide (34).** See Table II. Kugelrohr distillation provided 0.522 g (80%) of **34**: bp 100 °C (4 mm) NMR ($CDCl_3$) δ 0.12 (s, 9 H), 2.95 and 3.02 (2 s, 8 H), 4.42 (m, 2 H); IR ($CHCl_3$) 1940, 1640, 1400, 1250 cm^{-1}. Anal. Calcd for $C_{10}H_{19}NOSi$: C, 60.86; H, 9.70. Found: C, 61.21; H, 9.66.

1-(Diethoxymethoxy)-*N,N*-dimethyl-α-methylenecyclohexanemethanamine (38) and 2-(1-Cyclohexen-1-yl)-*N,N*-dimethylethenamine (40). See Table III. Fractional distillation provided 0.701 g of a colorless liquid [bp 81–98 °C (0.7 mm)] which was shown by NMR to be a 3:1 mixture **40** and **38**; the second fraction [bp 101–104 °C (6.7 mm)] afforded 0.682 g of clean enamine orthoformate **38**: bp 104–106 °C (0.7 mm); NMR ($CDCl_3$) δ 1.17 (t, J = 7 Hz, 6 H), 1.0–2.05 (m, 10 H), 2.65 (s, 6 H), 3.56 (q, J = 7 Hz, 4 H), 4.20 (s, 1 H), 4.35 (s, 1 H), 5.30 (s, 1 H); IR ($CHCl_3$) 1590, 1445, 1055 cm^{-1}. In a separate experiment, dienamine **40** was isolated by distillation and characterized: NMR ($CDCl_3$) δ 1.00–2.30 (2 br m, 8 H), 2.65 (s, 6 H), 5.00 (d, J = 14 Hz, 1 H), 5.39 (t, J = 3.5 Hz, 1 H), 6.12 (d, J = 14 Hz, 1 H); IR ($CHCl_3$) 1635, 1615, 1340, 1070, 925 cm^{-1}.

1-(Diethoxymethoxy)-*N,N*-dimethyl-α-methylenecyclopentanemethanamine (42) and 2-(1-Cyclopenten-1-yl)-*N,N*-dimethylethenamine (43). See Table III. Distillation provided two fractions: 0.342 g of material [bp 73–90 °C (1.5 mm); 29% **42** and 71% **43** by GC] and 0.872 g of clean **42**: bp 100–107 °C (1.5 mm); NMR ($CDCl_3$) δ 1.12 (t, J = 7 Hz, 6 H), 1.45–2.48 (m, 8 H), 2.67 (s, 6 H), 3.58 (q, J = 7 Hz, 4 H), 3.86 (s, 1 H), 4.13 (s, 1 H), 5.27 (s, 1 H); IR ($CHCl_3$) 1600, 1350, 1050 cm^{-1}. In another run, careful distillation provided clean dienamine **43**: NMR ($CDCl_3$) δ 1.42–2.7 (m, 6 H), 2.68 (s, 6 H), 5.18 (d, J = 14 Hz, 1 H), 5.3 (s, 1 H), 6.12 (d, J = 14 Hz, 1 H); IR ($CHCl_3$) 1640, 1610, 1340, 1080 cm^{-1}.

3-(Diethoxymethoxy)-3,7-dimethyl-2-(dimethylamino)-1,7-octadiene (45) and 3,7-Dimethyl-1-(dimethylamino)-1,3,6-octatriene (46). See Table III. Distillation of the reaction mixture (0.04 mm) afforded two fractions: 213 mg (24%) of dienamine **46** and 614 mg (40.0%) of enamine orthoformate **45**: NMR ($CDCl_3$) δ 1.18 (t, J = 7 Hz, 6 H), 1.45 (s, 3 H), 1.68 (m, 10 H), 2.71 (s, 6 H), 3.60 (q, J = 7 Hz, 4 H), 4.14 (s, 1 H), 4.37 (s, 1 H), 5.15 (br s, 1 H), 5.37 (s, 1 H).

17-[2-(Dimethylamino)ethylenyl]-3-methoxy-19-norpregna-1,3,5(10),16-tetraene (48). A mixture of 0.455 g (1.44 mmol) of 17-(α-ethynyl)estradiol 3-methyl ether (Sigma), 0.5 mL of ethanol, 9 mg of pivalic acid, and 5 mL of DMF-DEA was heated at 120–125 °C for 9 h under nitrogen. the solvent was evaporated at 40 °C (5 mm). The last traces of solvent were removed at room temperature (1 mm for 12 h) to provide dienamine **48**: NMR ($CDCl_3$) δ 0.88 (s, 3 H), 2.69 (s, 6 H), 3.75 (s, 3 H), 4.77 (d, J = 14 Hz, 1 H), 5.33 (m, 1 H), 6.56 (d, J = 14 Hz, 1 H), 6.63 (s, 1 H), 7.18 (br d, 1 H); IR ($CHCl_3$) 1640, 1615, 1500, 1050 cm^{-1}.

2-(Diethoxymethoxy)-3-(dimethylamino)-2-methyl-3-butene (49). (a) From Alcohol 15. See Table III. Distillation provided 1.37 g (52%) of **49**: bp 79–84 °C (1.25 mm); NMR ($CDCl_3$) δ 1.17 (t, J = 7 Hz, 6 H), 1.48 (s, 6 H), 2.65 (s, 6 H), 3.60 (q, J = 7 Hz, 4 H), 4.00 (s, 1 H), 4.28 (s, 1 H), 5.28 (s, 1 H); IR ($CHCl_3$) 1595, 1380, 1340, 1140, 1030 cm^{-1}.

(b) From Alcohol 29. Distillation provided 1.25 g (41%) enamine orthoformate **49**, bp 97–102 °C (8.4 mm); the analytical data were as above.

3-(Diethoxymethoxy)-3-methyl-2-(dimethylamino)-1,4-pentadiene (50). See Table III. Distillation at 55–65 °C (0.25–0.3 mm) afforded 1.16 g (50%) of enamine orthoformate **50**: NMR ($CDCl_3$) δ 1.28 (t, J = 7 Hz, 6 H), 1.52 (s, 3 H), 2.68 (s, 6 H), 3.63 (q, J = 7 Hz, 4 H), 3.95 (s, 1 H), 4.22 (s, 1 H), 5.2 (overlapping m, 2 H), 6.1 (m, 1 H).

3-Cyclohexylidene-*N,N*-dimethyl-2-methyl-2-propenamide (52). A solution of 1.40 g (10.1 mmol) of 1-propynyl-1-cyclohexanol, 3 mL (22.6 mmol) of DMF-DMA, and 10 mL toluene was stirred under nitrogen at an oil bath temperature at 140 °C for 4 h. A Dean–Stark trap was employed to remove MeOH by distillation. The mixture was allowed to cool to room temperature, and toluene was evaporated. Distillation over a short path provided 0.164 g (12%) of recovered alcohol **51** [bp 50 °C (0.65 mm)] along with 1.40 g (72%) of allenic amide **52**: bp 93 °C (0.6 mm); NMR ($CDCl_3$) δ 1.39–1.82 (br s, 6 H), 1.90 (s, 3 H), 2.00–2.35 (br s, 4 H), 3.07 (s, 6 H); IR (neat) 1955, 1625, 1495 cm^{-1}. Anal. Calcd for $C_{12}H_{19}NO$: C, 74.56; H, 9.90; N, 7.24. Found: C, 74.65; H, 9.99; N, 7.07.

1-Phenyl-2-(dimethylamino)-3-(diethoxymethoxy)-3-methylbutene (54). See Table III. Distillation provided 1.06 g (55%) of enamine orthoformate **54**: bp 109–112 °C (0.13 mm); NMR ($CDCl_3$) δ 1.20 (t, J = 7.5 Hz, 6 H), 1.53 (s, 6 H), 2.68 (s, 6 H) 3.63 (q, J = 7.5 Hz, 4 H), 5.38 (s, 1 H), 6.01 (s, 1 H), 7.24 (s, 5 H); IR (neat) 1660, 1610 cm^{-1}.

***N,N*-Dimethylbenzamide Diethyl Acetal.** To 111 mL (0.88 mol) of boron trifluoride in 500 mL of anhydrous ether was added dropwise 52.8 mL (0.67 mol) of epichlorohydrin over 1 h. After complete addition the solution was stirred at reflux for 1 h. Solvent was decanted and the slurry cooled in a water bath. To the slurry was added at once 100 g (0.67 mol) of solid *N,N*-dimethylbenzamide (Eastman). Reaction was complete within minutes. The lower layer of the resulting solution was added dropwise to a solution of sodium ethoxide in ethanol (from 23 g of sodium in 450 mL of absolute ethanol). The sodium fluoroborate was removed by filtration, and the filtrate was concentrated. The residue was distilled to provide 96 g (64%) of *N,N*-dimethylbenzamide diethyl acetal: bp 138–140 °C (36 mm); NMR ($CDCl_3$) δ 1.25 (t, J = 7 Hz, 6 H), 2.15 (s, 6 H), 3.53 (q, J = 7 Hz, 4 H), 7.38 (s, 5 H); IR (film) 1450, 1280, 1230, 1150 cm^{-1}.

1-Acetyl-1-cyclohexanol (58). A solution of 1.34 g of *N,N*-dimethylbenzamide diethyl acetal, 0.437 g (3.5 mmol) of 1-ethynyl-1-cyclohexanol, and 1 mL of anhydrous ethanol was stirred at 100 °C for 24 h. The mixture was allowed to cool to room temperature and treated with 10 mL ethanol, 10 mL water, and a catalytic amount of *p*-toluenesulfonic acid. The solution was stirred at reflux for 4 h and allowed to cool to room temperature. The mixture was then treated with 2 g of sodium hydroxide and stirred at reflux for an additional 4 h. The mixture was allowed to cool to room temperature, poured into 30 mL of brine, and

extracted with three 50-mL portions of ether. The solvent was evaporated, and the residue was eluted from a column containing 50 g of silica gel by hexane/ether (4:1). The eluant was dried (magnesium sulfate) and concentrated. Kugelrohr distillation provided 0.322 g (63%) of 1-acetyl-1-cyclohexanol: bp 119–121 °C (46 mm); NMR ($CDCl_3$) δ 2.23 (s, 3 H), 3.59 (br s, 1 H); IR (film) 3430, 1700, 1450, 1150 cm^{-1}.

3-Cyclohexylidene-*N*,*N*-diethyl-2-propenamide (59). See Table IV. Kugelrohr distillation provided 0.45 g (50%) of allenic amide **59**: bp 153–155 °C (0.35 mm); NMR ($CDCl_3$) δ 1.17 (t, J = 7 Hz, 6 H), 1.43–1.93 (br s, 6 H), 2.05–2.5 (br s, 4 H), 3.42 (q, J = 7 Hz, 4 H), 5.75 (m, 1 H); IR (neat) 2900, 1950, 1600, 1420 cm^{-1}. Anal. Calcd for $C_{13}H_{21}NO$: C, 75.36; H, 10.14; N, 6.76. Found: C, 75.21; H, 10.16; N, 6.71.

***N*,*N*-Diethyl-3-methoxy-19-norpregna-1,3,5(10),17(20),20-pentaene-21-carboxamide (60).** See Table IV. The residual solid was crystallized from hexanes to provide 0.669 g (61%) of allenic amide **60**: bp 103–104 °C; NMR ($CDCl_3$) δ 1.03 (s, 3 H), 1.18 (t, J = 8 Hz, 6 H), 1.3–3.05 (complicated m, 18 H), 3.45 (q, J = 8 Hz, 4 H), 3.78 (s, 3 H), 5.98 (t, J = 4 Hz, 1 H), 6.75 (d, J = 3 Hz, 2 H), 7.25 (d, J = 1.5 Hz, 1 H); IR ($CHCl_3$) 2920, 1955, 1605 cm^{-1}. Anal. Calcd for $C_{26}H_{35}NO_2$: C, 79.13; H, 8.90; N, 3.56. Found: C, 78.88; H, 8.99; N, 3.51.

3-Cyclohexylidene-*N*,*N*-diethyl-2-methyl-2-propenamide (61). See Table IV. Kugelrohr distillation provided 1.04 g (92%) of allenic amide **61**: bp 120 °C (1.1 mm); NMR ($CDCl_3$) δ 1.12 (t, J = 7 Hz, 6 H), 1.40–1.80 (br s, 6 H), 1.90 (s, 3 H), 1.97–2.33 (br s, 4 H), 3.46 (q, J = 7 Hz, 4 H); IR ($CHCl_3$) 1950, 1605, 1445, 1405 cm^{-1}. Anal. Calcd for $C_{14}H_{23}NO$: C, 76.01; H, 10.40; N, 6.33. Found: C, 75.98; H, 10.42; N, 6.22.

***N*,*N*-Diethyl-2-phenyl-4-methyl-2,3-pentadienamide (62).** See Table IV. The residue solidified upon standing to provide 1.03 g (84%) of allenic amide **62**: bp 46–47.5 °C; NMR ($CDCl_3$) δ 1.17 (poorly resolved t, 6 H), 1.86 (s, 6 H), 3.48 (poorly resolved q, 4 H), 7.32 (s, 5 H); IR ($CHCl_3$) 1950, 1610, 1430, 1275 cm^{-1}. Anal. Calcd for $C_{16}H_{21}NO$: C, 79.10; H, 8.64; N, 5.76. Found: C, 78.81; H, 8.78; N, 5.87.

2-Dodecyn-4-ol (63). The Grignard method of Fleck and Kmiecik[10] was applied to 9.92 g (6.9 mmol) of nonanal. Distillation provided 8.71 g (68%) of alcohol **63**: bp 72 °C (0.07 mm) NMR ($CDCl_3$) δ 0.90 (t, J = 5 Hz, 3 H), 1.12–1.8 (br s, 14 H), 1.85 (d, J = 2.5 Hz, 3 H), 2.33 (br s, 1 H), 4.36 (unresolved, 1 H); IR (neat) 3340, 2200, 1450 cm^{-1}.

***N*,*N*-Diethyl-2-methyl-2,3-dodecadienamide (64).** See Table IV. Kugelrohr distillation provided 1.43 g (93%) of allenic amide **64**: bp 144 °C (0.50 mm); NMR ($CDCl_3$) δ 0.89 (t, J = 4.5 Hz, 3 H), 1.15 (t, J = 7.5 Hz, 6 H), 1.18–1.67 (br s, 12 H), 1.88 (d, J = 3 Hz, 3 H), 1.98 (unresolved, 2 H), 3.38 (q, J = 7.5 Hz, 4 H), 5.23 (t, J = 3 Hz, 1 H); IR (neat) 1960, 1625, 1450 cm^{-1}. Anal. Calcd for $C_{17}H_{31}NO$: C, 76.99; H, 11.69; N, 5.28. Found: C, 76.80; H, 11.69; N, 5.03.

***N*,*N*-Diethyl-2,3-dodecadienamide (66) and *N*,*N*-Diethyl-3-oxolauramide (67).** See Table IV. Each fraction was dried and concentrated. Kugelrohr distillation of the first fraction provided 0.319 g (25%) of β-keto amide **67**: bp 149 °C (0.26 mm); NMR ($CDCl_3$) δ 0.88 (t, J = 4 Hz, 3 H), 1.12 (2 t, J = 7 Hz, 6 H), 1.15–2.2 (br s, 14 H), 2.58 (t, J = 6.5 Hz, 2 H), 3.37 (2 q, J = 7 Hz, 4 H), 3.48 (s, 2 H), 5.08 (s, vinyl proton from enol form), 14.9 (br s, hydroxyl proton from enol form); IR (neat) 1715, 1625, 1585, 1450 cm^{-1}. Anal. Calcd for $C_{16}H_{31}NO_2$: C, 71.37; H, 11.52; N, 5.16. Found: C, 71.32; H, 11.51; N, 5.27. Kugelrohr distillation of the second fraction provided 0.326 g (29%) of the allenic amide: bp 147 °C (0.27 mm); NMR ($CDCl_3$) δ 0.89 (t, J = 4.5 Hz, 3 H), 1.18 (t, J = 7 Hz, 6 H), 1.2–1.8 (br s, 12 H), 1.95–2.4 (v br, 2 H), 3.38 (q, J = 7 Hz, 4 H), 5.4–6.0 (m, 2 H); IR (neat) 1955, 1625, 1440 cm^{-1}. Anal. Calcd for $C_{16}H_{29}NO$: C, 76.49; H, 11.55; N, 5.56. Found: C, 76.76; H, 11.43; N, 5.32.

***N*,*N*-Diethyl-3-oxolauramide (67) from *N*,*N*-Diethyl-2,3-dodecadienamide (65).** A solution of 42 mg (0.167 mmol) of allenamide **65**, 1 mL of absolute EtOH, and 1 mL of xylene was heated at an oil bath temperature of 140 °C under nitrogen for 12 h. The solution was allowed to cool to room temperature, and the solvent was removed. The residue was placed on a preparative thin-layer chromatography plate (silica); a 1:1 mixture of hexanes and ether was used to elute the plate. Kugelrohr distillation of the recovered material material provided 19 mg (42%) of β-keto amide **67**, identical in all respects to the product described above.

4-Iodo-2-methyl-5,5-pentamethylene-2(5*H*)-furanone (68). To a solution containing 2.02 g of iodine, 10 mL water, and 10 mL THF was added 0.586 g (26.5 mmol) of allenamide **61** at 0 °C, and the solution was stirred for 1 h. The mixture was extracted with chloroform, and the resulting solution was decolorized over 2 g of sodium sulfite and cooled in an ice bath. Two crops of crystals were isolated and combined in 10 mL of THF and 10 mL of water. The mixture was heated and allowed to reflux for 24 h. The solution was allowed to cool to room temperature and extracted with chloroform. This solution was dried and concentrated. The resulting solid was recrystallized from hexanes to provide 0.377 g (49%) of butenolide **68**: bp 159–162 °C; NMR ($CDCl_3$) δ 1.28–2.07 (br s, 10 H), 1.92 (s, 3 H); IR (KBr) 1730, 1630^{-1}. Anal. Calcd for $C_{10}H_{13}IO_2$: C, 41.09; H, 4.45; I, 43.46. Found: C, 40.83; H, 4.33; I, 43.13.

3-Methyl-5,5-pentamethylene-2(5*H*)-furanone (69). A solution of 0.800 g (3.62 mmol) of allenamide **61**, 8 mL of 98–100% formic acid, and 2 mL of water was heated at reflux for 12 h under nitrogen. The solution was allowed to cool to room temperature and extracted with ether. The ether solution was washed with water, dried, and concentrated. The residue was placed on a column containing 100 g of silica gel. Elution by a 1:1 mixture of hexanes and ether gave several fractions which were combined, dried, and concentrated. The residue solidified upon standing to provide 0.446 g (74%) of butenolide **69**: bp 64–67 °C; NMR ($CDCl_3$) δ 1.67 (br s, 10 H), 1.90 (d, J = 1.5 Hz, 3 H), 7.07 (q, J = 1.5 Hz, 1 H); IR (KBr) 1745, 1650, 1430 cm^{-1}. Anal. Calcd for $C_{10}H_{14}O_2$: C, 72.28; H, 8.43. Found: C, 72.02; H, 8.71.

***N*,*N*-Diethyl-3-(1-cyclohexen-1-yl)-2-methyl-2-propenamide (70).** A solution of 1.125 g (5.1 mmol) of amide **61** in 10 mL of 98–100% of formic acid was stirred at reflux under nitrogen for 4.5 h. The mixture was allowed to cool to room temperature and poured into 75 mL of water. Neutralization with bicarbonate was followed by extraction with ether. The ether solution was concentrated, and the residue was placed on a column containing 100 g of silica gel. Elution with a 2:1 mixture of benzene and ethyl acetate, drying, concentration, and Kugelrohr distillation provided 0.556 g (49%) of dienamide **70**: bp 131 °C (0.25 mm); NMR ($CDCl_3$) δ 1.15 (t, J = 7 Hz, 6 H), 1.35–2.35 (br s, 8 H), 2.00 (s, 3 H), 3.40 (q, J = 7 Hz, 4 H), 5.58–5.90 (m, overlapping br s, 2 H); IR (neat) 1620, 1425 cm^{-1}. Anal. Calcd for $C_{14}H_{23}NO$: C, 76.01; H, 10.40; N, 6.33. Found: C, 75.86; H, 10.66; N, 6.15.

***N*,*N*-Diethyl-2,3-dimethyl-3-dodecenamide (71).** To a solution of 0.503 g (1.89 mmol) of dienamide **64** in 50 mL of anhydrous THF under nitrogen and cooled in a water bath was slowly added 1 mL of 2.9 M (2.9 mmol) methylmagnesium chloride (Aldrich) in THF. The solution was stirred at room temperature for 2 h and poured into 50 mL of water. The solution was extracted with ether several times, and the combined ether solution was dried (magnesium sulfate) and concentrated. The residue was placed on a column containing 100 g of silica gel. Elution with a 2:1 mixture of hexanes and ether, drying (magnesium sulfate), concentration, and Kugelrohr distillation provided 0.282 g (53%) of amide **71**: bp 153 °C (0.75 mm); NMR ($CDCl_3$) δ 0.88–1.3 (m, 24 H), 1.62 (d, J = 1.5 Hz, 3 H), 2.0 (br, 3 H) 3.38 (m, 4 H), 5.17 (br t, J = 7 Hz, 1 H); IR (neat) 1645, 1430, 1385, 1260, 1235 cm^{-1}. Anal. Calcd for $C_{18}H_{35}NO$: C, 76.86; H, 12.45; N, 4.98. Found: C, 76.84; H, 12.69; N, 4.89.

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57502-92-8; **7**, 79972-40-0; **8**, 79972-41-1; **9**, 50516-66-0; **10**, 57502-95-1; **11**, 57502-96-2; **12**, 14304-27-9; **13**, 79972-42-2; **14**, 57502-98-4; **15**, 115-19-5; **18**, 79972-43-3; **19**, 79972-44-4; **20**, 54857-48-6; **21**, 2028-63-9; **22**, 29334-61-0; **23**, 3249-33-0; **24**, 107-19-7; **25**, 59223-42-6; **26**, 539-88-8; **27**, 763-19-9; **28**, 79972-45-5; **29**, 5272-33-3; **30**, 79972-46-6; **31**, 2117-12-6; **32**, 79972-47-7; **33**, 5272-36-6; **34**, 79972-48-8; **35**, 78-27-3; **38**, 61065-26-7; **40**, 61065-23-4; **41**, 17356-19-3; **42**, 61065-27-8; **43**, 61065-24-5; **44**, 29171-20-8; **45**, 61096-15-9; **46**, 61096-16-0; **47**, 72-33-3; **48**, 61065-25-6; **49**, 79972-49-9; **50**, 61065-29-0; **51**, 697-37-0; **52**, 79972-50-2; **53**, 1719-19-3; **54**, 61065-28-9; **58**, 1123-27-9; **59**, 66617-41-2; **60**, 66617-42-3; **61**, 66617-44-5; **62**, 66617-43-4; **63**, 66617-39-8; **64**, 66617-45-6; **65**, 53735-49-2; **66**, 66617-46-7; **67**, 66617-47-8; **68**, 79972-51-3; **69**, 71127-55-4; **70**, 79972-52-4; **71**, 79972-53-5; DMA-DEA, 19429-85-7; DMF-DEA, 1188-33-6; DEF-DEA, 22630-13-3; pentyne, 627-19-0; methyl vinyl ketone, 78-94-4; acrolein, 107-02-8; *N,N*-dimethylbenzamide, 611-74-5; *N,N*-dimethylbenzamide diethyl acetal, 19429-87-9; *trans*-3-methoxy-19-norpregna-1,3,5(10),17(20)-tetraen-21-al, 16934-50-2.

Photolysis of Some Chlorinated Pyridazines[1]

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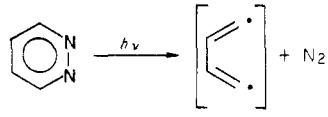
Photorearrangement of chlorinated pyridazines to chlorinated pyrazines proceeds with predictable regiocontrol if radical-stabilizing substituents are located at C_4 and C_5 of the pyridazine ring. Mechanistic studies imply that the chemistry originates from a reactive n,π^* singlet state. An activation barrier of ~4 kcal/mol is encountered as the excited state of tetrachloropyridazine rearranges to tetrachloropyrazine.

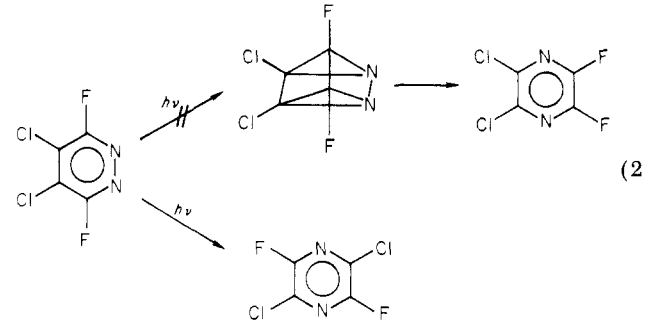
The photochemistry of chlorinated pyridazines is of interest for several reasons. Because they are isoelectronic with aryl chlorides, they may provide insight into the photoreactions of this important class of compounds. The two heteroatoms, however, provide access not only to the π,π^* excited states accessible to aryl halides but also to n,π^* excited states. It may be possible then to discover state-specific photoreactions in these molecules. For example, because of the low-lying n,π^* states, these molecules, in contrast to typical chlorinated benzenes,[2] may resist facile dechlorination; i.e., the lower lying singlet and triplet states are probably insufficiently energetic to induce dissociation of Ar–Cl.[3]

Since the ring system of pyridazines contains two adjacent nitrogen atoms, photoelimination of N_2, a common feature of the photochemical reactions of azines,[4] must be considered. Though correlation diagrams[5] indicate that the concerted loss of nitrogen from the planar lowest excited states of pyridazine (assumed to be planar) is orbital symmetry forbidden, gas-phase photolysis of pyridazine does generate nitrogen and, apparently, a C_4H_4 biradical,[6] (eq 1).



(1)

Lacking a convenient σ-dissociation pathway, chlorinated pyridazine excited states may undergo valence isomerization instead. Indeed, this process is well documented for the analogous fluorinated or perfluoroalkylated compounds.[7-13] The photorearrangement of tetrachloropyridazine to tetrachloropyrazine may well proceed through intermediate valence isomers. A double labeling experiment with 3,6-difluoro-4,5-dichloropyridazine had established, however, that a diazaprismane was not involved (eq 2).[13] In this paper we describe mechanistic



(2)

studies regarding the photorearrangement of chlorinated pyridazines and delineate the relationship between substitution pattern and the proclivity of a particular pyridazine to isomerize upon photoexcitation.

Results

Tetrachloropyridazine.[14] Because of its rearrangement efficiency, ready availability, and relatively low-lying

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(3) The bond dissociation energy of Ar–Cl is ~85–91 kcal/mol.[2a,b] From the absorption spectra, S_1 lies below 82 kcal/mol in tetrachloropyridazine.

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