5; they were reduced to dryness, extracted into heptane, filtered hot through Celite, and cooled. The resulting crystals (1.1 g, 37% yield) were contaminated with about 4% of 3. After five recrystallizations from heptane, analytically pure material was obtained as pale olive-green crystals: mp 98–99 °C; NMR ($CDCl_3$) δ 6.90–7.73 (m); UV (MeOH) 206, 276, 330 nm (log ε 4.42, 4.36, 4.11). Anal. Calcd for $C_{18}H_{12}S_3$: C, 66.63; H, 3.73; S, 29.64. Found: C, 66.79; H, 3.67; S, 29.85.

General Procedure for Photolysis of 1, 7, 9, and 11. A solution of 1.5 g of the pyrrole and 10–20 mg of I_2[27] in 500 mL of PhH was placed in a quartz vessel in a 350-nm Rayonet reactor and stirred magnetically while a slow stream of air was passed through the solution by means of a bubbler. Irradiation was continued until HPLC showed virtual disappearance of starting pyrrole. In all cases, a single product peak emerged on HPLC, but the mixture became turbid from the formation of intractable decomposition products over the course of the irradiation, which required 8–14 h. The reaction mixture was filtered through Celite and reduced to a black oil, which was exhaustively extracted with boiling heptane. The hot extracts were forced through a 2-cm layer of silica gel, whereupon the product crystallized in high purity on cooling or concentrating.

1-Methyl-2-phenyl-1*H*-dithieno[2,3-*e*:3′,2′-*g*]indole (2). From 1.5 g of 1 was obtained 0.6 g (40%) of 2, 98% pure by HPLC. Recrystallization from *n*-PrOH/MeCOEt (9:1) gave analytically pure colorless crystals: mp 131–133 °C; NMR ($CDCl_3$) δ 4.00 (s, 3 H, NMe), 6.77 (s, 1 H, 3-indole), 7.23–7.77 (m, 9 H); UV (MeOH) 204, 218, 277, 317 nm (log ε 4.47, 4.44, 4.55, 4.21); MS, *m/e* (relative intensity) 319 (M^+, 100). Anal. Calcd for $C_{19}H_{13}NS_2$: C, 71.44; H, 4.10; N, 4.39; S, 20.07. Found: C, 71.54; H, 4.01; N, 4.32; S, 20.32.

9-Methyl-8-phenyl-9*H*-dithieno[3,2-*e*:3′,2′-*g*]indole (8). From 1.5 g of 7 was obtained 0.4 g (28%) of 8, 98% pure by HPLC. Recrystallization from *n*-PrOH/MeCOEt (9:1) gave analytically pure colorless crystals: mp 152–153 °C; NMR ($CDCl_3$) δ 4.03 (s, 3 H, NMe), 6.88 (s, 1 H, 3-indole), 7.30–7.73 (m, 9 H); UV (MeOH) 205, 256, 278, 326 nm (log ε 4.58, 4.38, 4.43, 4.32), shoulder at 342 nm; MS, *m/e* (relative intensity) 319 (M^+, 100). Anal. Calcd as for 2. Found: C, 71.54; H, 4.11; N, 4.31; S, 20.34.

7-Methyl-8-phenyl-7*H*-dithieno[2,3-*e*:2′,3′-*g*]indole (10). From 1.5 g of 9 was obtained 0.7 g (47%) of 10, 99% pure by HPLC. Recrystallization gave analytically pure colorless crystals: mp 169–170 °C; NMR ($CDCl_3$) δ 3.98 (s, 3 H, NMe), 6.78 (s, 1 H, 3-indole), 7.26–7.90 (m, 9 H); UV (MeOH) 205, 237, 270, 312, 341 nm (log ε 4.42, 4.36, 4.67, 4.13, 4.02); MS, *m/e* (relative intensity) 319 (M^+, 100). Anal. Calcd as for 2. Found: C, 71.55; H. 4.04; N, 4.39; S, 20.35.

4-Methyl-5-phenyl-4*H*-dithieno[3,2-*e*:2′,3′-*g*]indole (12). From 1.5 g of 11 was obtained 0.5 g (33%) of 12 as yellow crystals of 98% purity. Several recrystallizations and filtrations through silica gel in hot heptane resulted in colorless crystals, mp 179–180 °C; however, a persistent cocrystallizing contaminant of <0.01% could be detected with HPLC. NMR ($CDCl_3$) δ 4.05 (s, 3 H, NMe), 6.88 (s, 1 H, 3-indole), 7.33–7.93 (m, 9 H); UV (MeOH) 209, 242, 292, 323, 336, 350 nm (log ε 4.45, 4.45, 4.24, 4.18, 4.22, 4.21, 4.18); MS, *m/e* (relative intensity) 319 (M^+, 100). Anal. Calcd as for 2. Found: C, 71.40; H, 4.02; N, 4.35; S, 20.21.

Attempted Photocyclization of 3 and 5. A dilute solution of 3 in PhH with I_2 showed no change by HPLC after 3 h in a 350-nm Rayonet reactor. A catalytic amount of I_2 was added to 0.426 g of 3 dissolved in 1.5 L of PhH, and the solution was irradiated with a 450-W Hanovia probe in a water-cooled quartz jacket. Within 20 min all of 3 had decomposed with no discrete product formation. Similarly, 5 in PhH with I_2 and a slow stream of air through a bubbler showed no change after irradiation in a 350- or 300-nm Rayonet reactor. During more than 6 h of exposure to a 450-W Hanovia probe in a quartz vessel, 0.414 g of 5 in 300 mL of PhH with 0.013 g of I_2 underwent slow decomposition to 25% of its initial concentration with no evidence of discrete product formation.

Single-Crystal X-ray Analysis of 2. The crystal structure of compound 2 was determined from three-dimensional X-ray diffraction data collected on an Enras-Nonius CAD4 four-circle diffractometer using copper radiation at room temperature. Lp and decay corrections were applied to the data; no absorption was done. The contour of the structure was solved by direct methods using the SDP program. Refinement of positional and anisotropic thermal parameters was carried out by full-matrix least-squares methods for all 22 non-hydrogen atoms; a final difference Fourier revealed no missing or misplaced electron density. Pertinent crystal, data collection, and refinement parameters are summarized in Table I (supplementary material).

Acknowledgment. We are grateful to Dr. Kurt L. Loening of Chemical Abstracts Service for help in assigning the systematic names to 2, 8, 10, and 12. D.M.P. gratefully acknowledges support from the Chicago Province Jesuit Graduate Scholarship Fund.

Supplementary Material Available: Crystallographic data, including Figure 1 and Table I, and tables of atomic positional and thermal parameters and bond angles for 2 (6 pages). Ordering information is given on any current masthead page.

(27) The amount of iodine was based on: (a) Wynberg, H.; Lehman, P. G. *Aust. J. Chem.* **1974**, *27*, 315–322. Increased amounts did not seem to improve yields or rates; see, however: (b) Sato, T.; Shimada, S.; Hata, K. *Bull. Chem. Soc. Jpn.* **1971**, *44*, 2484–2490.

Intramolecular [2 + 2] Cycloadditions of Ketene Iminium Salts to Carbon–Carbon Double Bonds

William T. Brady,* Yun-Seng F. Giang, Lingling Weng, and Mohammad M. Dad

Department of Chemistry, North Texas State University, Denton, Texas 76203

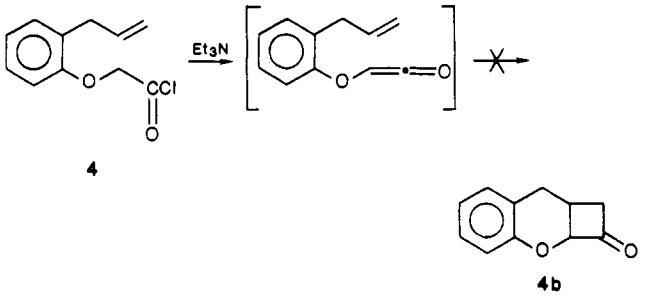
Received December 9, 1986

Intramolecular [2 + 2] cycloadditions of ketene iminium salts with carbon–carbon double bonds are compared with the corresponding intramolecular [2 + 2] ketene cycloadditions. The ketene cycloaddition process provides better yields than the ketene iminium salt method for ketoketenes. However, the aldoketene iminium salts give much better yields than the corresponding aldoketenes.

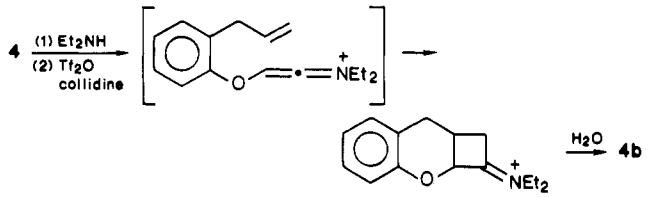
Several recent reports on the intramolecular [2 + 2] cycloaddition of ketenes and ketene iminium salts to carbon–carbon double bonds and carbonyl groups have demonstrated the power and versatility of these reactions

0022-3263/87/1952-2216$01.50/0

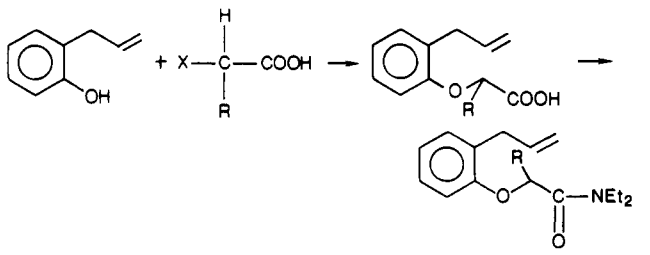
Scheme I



Scheme II



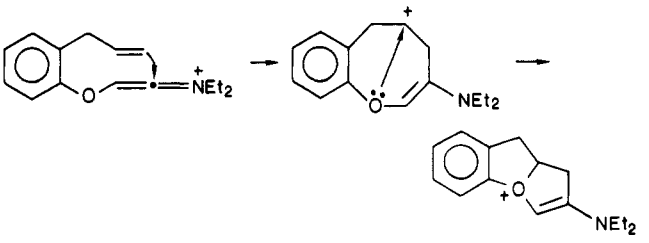
Scheme III



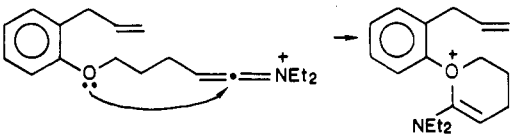
in the synthesis of polycyclic compounds.[1] Ketene iminium salts are more electrophilic than ketenes and will react with less nucleophilic olefins and do not undergo dimerization and oligomerization like many ketenes, particularly aldoketenes.[2] Therefore, since both ketenes and ketene iminium salts are readily obtained from the same acid halide, the intramolecular cycloaddition of ketene iminium salts should complement ketene cycloadditions. However, the use of ketene iminium salts instead of ketenes in intramolecular cycloadditions does have some limitations.[1c] In this paper we describe the intramolecular [2 + 2] cycloaddition of ketene iminium salts with carbon–carbon double bonds and compare these cycloadditions with the corresponding ketene cycloadditions.

We have attempted the intramolecular [2 + 2] cycloaddition of (*o*-allylphenoxy)ketene many times under a variety of reaction conditions but have not been able to isolate the cycloaddition product (Scheme I). It is well-known that aldoketenes are unstable and susceptible to dimerization and oligomerization, and evidence suggests that this was the fate of the aldoketene in this reaction. Conversely, the intramolecular [2 + 2] cycloaddition of the corresponding ketene iminium salt occurred in a 44% yield (entry 4 in Table I) (Scheme II). The inability of the ketene iminium salt to dimerize and the greater reactivity

Scheme IV



Scheme V



with the less nucleophilic carbon–carbon double bond are apparently responsible for this cycloaddition.

We have compared several other intramolecular ketene iminium salt cycloadditions with the corresponding intramolecular ketene cycloadditions as shown in Table I. In entries 1–7, the precursor amides were prepared from the appropriate phenols as illustrated with *o*-allylphenol (Scheme III). In entry 8, the precursor acid was prepared by the Wittig reaction of the appropriate keto acid. The amide in entry 9 was prepared by the addition of allylmagnesium bromide to cyclopentanone, subsequent reaction with chloroacetic acid, and finally preparation of the *N,N*-diethyl amide through the acid chloride.

An examination of the results presented in Table I clearly shows that for ketoketenes the ketene cycloaddition process provides better yields than the ketene iminium salt method, as indicated by entries 1–3. However, the ketene iminium salt method is much superior for the aldoketenes as illustrated with entries 4–9 in Table I. This difference is dramatic with entry 8, in which the aldoketene iminium salt, separated by a three-atom bridge, gives a 73% yield and the aldoketene gives only a 12% yield. However, it should be noted that entry 8 is not an alkoxyketene or alkoxyketene iminium salt but rather an alkylaldoketene which is less reactive than alkoxyketenes.

When the bridge between the ketene iminium salt function and the carbon–carbon double bond is increased from three- to seven-atom bridges (entries 4–7), a significant reduction in yield results. This is believed to be due to the possible competition between (a) the oxygen atom, (b) the double bond, and (c) the activated phenyl ring toward the electrophilic ketene iminium salt. The ability of the nucleophilic oxygen atom to become involved in the reaction has been previously demonstrated.[1c] Since the [2 + 2] cycloaddition of ketene iminium salts to the carbon–carbon double bond likely proceeds by a stepwise mechanism,[3] the ether oxygen atom of the (alkenyloxy)-ketene iminium salt may serve as a nucleophile to attack the positive-charged carbon in the initially formed intermediate to generate an oxonium salt if the bridge between the two reacting functional groups is no less than four atoms. Reaction of the carbocation with the activated benzene ring is another alternate pathway that would lead to reduced yields of the cycloaddition products. (Scheme IV).

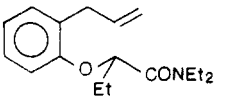
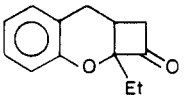
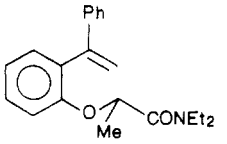
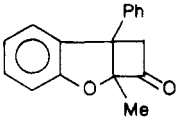
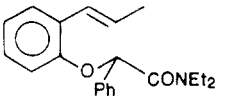
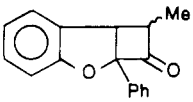
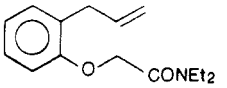
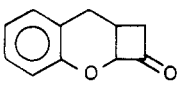
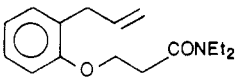
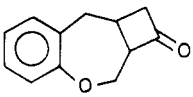
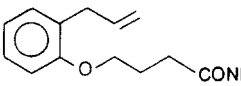
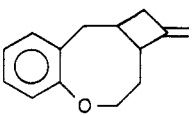
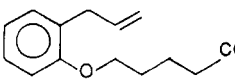
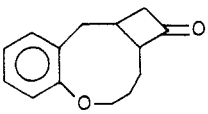
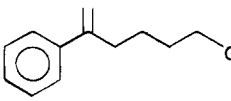
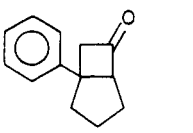
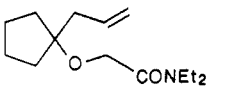
Entries 6 and 7 also provide another possibility for a facile cyclization without involvement of the olefin function, as illustrated with entry 7 (Scheme V).

(1) (a) Snider, B. B.; Hui, R. A. H. F.; Kulkarni, Y. S. *J. Am. Chem. Soc.* **1985**, *107*, 2194. (b) Marko, I.; Rosmans, B.; Hesbain-Frisque, A.; Dumas, S.; Ghosez, L.; Ernst, B.; Greuter, H. *Ibid.* **1985**, *107*, 2192. (c) Snider, B. B.; Hui, R. A. H. F. *J. Org. Chem.* **1985**, *50*, 5167. (d) Kulkarni, Y. S.; Snider, B. B. *Ibid.* **1985**, *50*, 2809. (e) Brady, W. T.; Giang, Y. F. *Ibid.* **1985**, *50*, 5177. (f) Corey, E. J.; Desol, M. C. *Tetrahedron Lett.* **1985**, *26*, 3535. (g) Kulkarni, Y. S.; Burbaum, B. W.; Snider, B. B. *Ibid.* **1985**, *26*, 5619. (h) Ghosez, L.; Marko, I.; Hesbain-Frisque, A. M. *Ibid.* **1986**, *27*, 5211. (i) Brady, W. T.; Giang, Y. G. *J. Org. Chem.* **1986**, *51*, 2145.

(2) (a) Ghosez, L.; Marchand-Brynaert, J. *Iminium Salts in Organic Chemistry*; Boohme, J., Viehe, H. G., Eds.; Wiley: New York, 1976; Part 1, pp 421–532. (b) Falmagne, J. B.; Escudero, J.; Taleb-Sahraoui, S.; Ghosez, L. *Angew. Chem., Int. Ed. Engl.* **1981**, *20*, 879.

(3) Saimoto, H.; Houge, C.; Hesbain-Frisque, A. M.; Mockel, A.; Ghosez, L. *Tetrahedron Lett.* **1983**, *24*, 2251.

Table I. Intramolecular [2 + 2] Cycloadditions of Ketene Iminium Salts

entry	amide (a)	cyclobutanone (b)	yield,[a] %
1			32 (49)
2			70 (84)
3			66 (85)
4			44 (0)
5			18 (0)
6			10 (0)
7			4
8			73 (12)
9			50

[a] The yields in parentheses were obtained by the corresponding ketene cycloadditions.

Experimental Section

^{1}H NMR spectra were recorded on a Perkin-Elmer R-24B nuclear magnetic resonance spectrometer, employing deuteriochloroform as the solvent with tetramethylsilane as the internal standard. The ^{13}C NMR spectra were obtained on a JEOL FX-90Q FT nuclear magnetic resonance spectrometer. The IR spectra were obtained on a Perkin-Elmer 1330 spectrometer. The GC/MS spectra were obtained on a Hewlett-Packard 5790A Series GC/mass spectrophotometer. All melting points were determined on a Thomas Hoover capillary melting point apparatus and, like boiling points, are uncorrected. Elemental analyses were carried out by Midwest Microlab, IN, and the high-resolution mass spectra were obtained at the Midwest Center for Mass Spectrometry, Department of Chemistry, University of Nebraska, Lincoln, NE.

Hexane, benzene, tetrahydrofuran, ether, and triethylamine were dried and purified by distillation from a sodium–potassium alloy under a nitrogen atmosphere prior to use. Collidine was distilled from CaH_2 and stored under nitrogen. Reagents were added via dried syringes through septa. Column chromatography was performed on Aldrich silica gel, 70–270 mesh. Preparative TLC separations were performed on Aldrich precoated TLC plates (250 m thick, 2–25 m silica gel on glass).

The intramolecular [2 + 2] ketene cycloadditions reported in Table I with the yield in parentheses were either previously reported or performed by the previously reported general procedure employing the appropriate precursor acids.[1e]

Precursor Acids. The precursor acids from which the amides in entries 1–3 in Table I were prepared have been previously reported by us.[1e] (*o*-Allylphenoxy)acetic acid was the precursor acid for the amide in entry 4 in Table I and was prepared by the literature procedure.[4] 6-Phenyl-6-heptenoic acid was the precursor acid for the amide in entry 8 in Table I and has been previously reported by us.[5]

3-(*o*-Allylphenoxy)propanoic Acid. To a solution of 10.9 g (0.1 mol) of 3-chloropropanoic acid in 20 mL of ice–water was added with cooling and stirring a solution of 4 g (0.1 mol) of NaOH in 20 mL of ice–water. The resulting cold solution was stirred for 20 min and added dropwise to a refluxing aqueous solution containing 0.09 mol of sodium *o*-allylphenolate (prepared from 12.1 g of *o*-allylphenol and 4 g of NaOH) and 30 mL of water. After the addition was completed, the reaction mixture was refluxed for an additional 15 h. Upon cooling, the aqueous solution was washed with three 20-mL portions of chloroform. The aqueous solution was then acidified to pH 1 with dilute HCl and extracted with three 30-mL portions of ether. The combined ether extracts were washed with water and brine, dried over anhydrous magnesium sulfate, and evaporated in vacuo. A 5.13-g (28%) portion of pure acid was obtained as white solid: mp 98–100 °C; IR ($CDCl_3$) 3060, 1710, 1638 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 10.53 (s, 1 H), 7.04–6.38 (m, 4 H), 6.22–5.65 (m, 1 H), 5.35–4.60 (m, 4 H), 3.56–3.27 (m, 4 H); ^{13}C NMR ($CDCl_3$) δ 177.3 (s), 156.1 (s), 137.8 (d), 129.8 (d), 128.3 (s), 127.0 (d), 120.4 (d), 114.8 (t), 111.3 (d), 64.5 (t), 41.8 (t), 34.0 (t).

(4) Corson, B. B.; Heintzelman, W. J.; Tiefenthal, H. E.; Nickels, J. E. *J. Org. Chem.* **1952**, *17*, 971.

(5) Brady, W. T.; Giang, Y. F.; Weng, L.; Ong, W.; Marchand, A. P.; Wu, A. submitted for publication in *J. Org. Chem.*

5-(*o*-Allylphenoxy)pentanoic Acid. A mixture of sodium *o*-allylphenolate (37 mmol, prepared from 5.1 g of *o*-allylphenol and 2.1 g of 60% sodium hydride in mineral oil) and 1,4-dibromobutane (24.2 g, 0.11 mol) in 30 mL of THF was refluxed for 8 h. The reaction mixture was cooled and filtered. The filtrate was evaporated and vacuum distilled to give 6.8 g [68%, bp 85–90 °C (0.03 mmHg)] of 1-allyl-2-(4-bromobutoxy)benzene. This bromo compound was reacted with potassium cyanide followed by a basic hydrolysis according to the standard literature procedure to give the crude acid.[6] A 4.4-g (75%) portion of the pure acid was obtained as a pale yellow oil via a silica gel column filtration: IR (neat) 3065, 1700, 1635 cm^{-1}; ^1H NMR ($CDCl_3$) δ 9.95 (s, 1 H), 7.18–5.46 (m, 5 H), 4.85 (s, 1 H), 4.63 (s, 1 H), 3.59–1.70 (m, 10 H); ^{13}C NMR ($CDCl_3$) δ 179.3 (s), 156.3 (s), 136.8 (d), 129.5 (d), 128.4 (s), 127.0 (d), 120.2 (d), 115.0 (t), 110.9 (d), 67.0 (t), 34.1 (t), 33.3 (t), 28.4 (t), 21.2 (t).

1-Allylcyclopentanol. This alcohol was prepared from allyl bromide and cyclopentanone by a standard Grignard reaction procedure in 75% distilled yield: bp 45–47 °C (2.5 mm); IR (neat) 3400, 3080, 1638 cm^{-1}; ^1H NMR ($CDCl_3$) δ 6.17–5.74 (m, 2 H), 5.22–4.98 (m, 2 H), 2.38–1.42 (m, 10 H); ^{13}C NMR ($CDCl_3$) δ 134.5 (d), 118.0 (t), 81.2 (s), 45.6 (t), 39.2 (t), 23.7 (t).

(1-Allylcyclopentoxy)acetic Acid. This acid was prepared from 1-allylcyclopentanol and bromoacetic acid by the procedure previously described for (*o*-alkenylphenoxy)acetic acids (method B)[1e] in 83% yield as a pale yellow oil: IR (neat) 3095, 1733, 1640 cm^{-1}; ^1H NMR ($CDCl_3$) δ 10.57 (s, 1 H), 5.68–5.92 (m, 1 H), 5.13 (m, 2 H), 4.05 (s, 2 H), 2.39 (d, 2 H, J = 6.4 Hz), 1.84–1.56 (m, 8 H); ^{13}C NMR ($CDCl_3$) δ 172.2 (s), 133.4 (d), 118.0 (t), 88.7 (s), 60.2 (t), 40.9 (t), 35.8 (t), 23.7 (t).

General Procedure for Unsaturated Amide Preparation. Method A. This method was used for the preparation of all unsaturated amides except for **6a** in Table I. The corresponding precursor unsaturated acids were treated with 5–8 equiv of oxalyl chloride in benzene at ambient temperature for 3–5 h. The excess oxalyl chloride was removed in vacuo, and the crude acid chloride was diluted with benzene. To the acid chloride solution was added slowly with stirring and cooling 3–4 equiv of diethylamine. The mixture was stirred overnight at ambient temperature. Upon filtration, the filtrate was evaporated and passed through a silica gel column by using 25% EtOAc–hexane as the eluent. Yields of 85–92% were obtained for this two-step transformation. The purities and structures of these unsaturated amides were determined by TLC (one spot), IR (strong amide I band at 1635–65 cm^{-1}), ^1H NMR, ^{13}C NMR (the two ethyl groups on the nitrogen atom show four decoupled peaks), and GC/MS.

Method B. This method was used for the preparation of unsaturated amide **6a** in Table I. To a solution of 10 g (73 mmol) of *o*-allylphenol in 60 mL of dry THF was added 3.37 g (80 mmol) of 60% NaH in mineral oil, and the solution was stirred for 20 min under nitrogen. An 8.88-g (50 mmol) portion of *N,N*-diethyl-γ-chlorobutyramide was added, and the reaction mixture was refluxed overnight. Upon cooling, 100 mL of dry hexane was added and stirred for 10 min. The salt was filtered and the filtrate evaporated. The excess *o*-allylphenol was removed by vacuum distillation. The crude **6a** was further purified by column chromatography on silica gel (15% EtOAc–hexane) to give 9.5 g (69%) of pure **6a**: IR (neat) 3075, 1638 cm^{-1}; ^1H NMR ($CDCl_3$) δ 7.23–6.56 (m, 4 H), 6.18–5.67 (m, 2 H), 5.15–4.84 (m, 3 H), 3.98 (t, J = 5.6 Hz, 2 H), 3.36 (q, J = 5.7 Hz, 4 H), 2.61–1.92 (m, 4 H), 1.12 (t, J = 7.2 Hz, 6 H); ^{13}C NMR ($CDCl_3$) δ 171.1 (s), 156.3 (s), 136.8 (d), 129.5 (d), 128.2 (s), 127.1 (d), 120.2 (d), 114.8 (t), 111.0 (d), 66.9 (t), 41.6 (t), 39.9 (t), 34.2 (t), 29.2 (t), 25.0 (t), 14.1 (q), 12.9 (q).

General Procedures for Intramolecular [2 + 2] Cycloadditions of Ketene Iminium Salts to Carbon–Carbon Double Bonds. All ketene Iminium salts were prepared and reacted by a previously reported procedure as described below for 1b.[1c] All crude hydrolyzed cycloadducts were routinely chromatographed three times; the first column chromatography on 70–270-mesh silica gel gave spectroscopically pure products, which were mostly yellow oils. The analytical samples were obtained by preparative TLC (30% EtOAc–hexane as the developing solvent) followed by another column chromatography on silica gel (4–12% EtOAc–hexane). The yields were based on the initially obtained spectroscopically pure products. A good yield was not obtained for **8b** until 5% aqueous NaOH was added to the two-phase hydrolyzing mixture (the methylene chloride was displaced by benzene). However, 5% aqueous NaOH would destroy such cycloadducts as **9b** at ambient temperature.

1-Ethyl-2-oxa-3,4-benzobicyclo[4.2.0]octan-8-one (1b). To a solution of **1a** (1.36 g, 4.95 mmol) in 80 mL of dry benzene under N_2 was added 0.74 mL (1.05 equiv) of collidine, and the solution was heated at reflux. A solution of 1.02 mL (1.1 equiv) of triflic anhydride (trifluoromethanesulfonic anhydride, Tf_2O) in 15 mL of dry benzene was added over 30 min via a syringe. An orange to brownish oil gradually formed and separated. The solution was heated at reflux for 2 h, cooled to 25 °C, and evaporated in vacuo. The residual oil was washed with ether and then taken up in 50 mL of CH_2Cl_2 and 50 mL of water. The two-phase mixture was stirred for 24 h at room temperature, and the methylene chloride was removed in vacuo at 10 °C to leave a yellow aqueous layer containing brownish gum, which was extracted with three 40-mL portions of CCl_4. The combined CCl_4 extracts were washed with water and brine, and the combined aqueous layers were extracted with two 20-mL portions of CH_2Cl_2. The combined CH_2Cl_2 extracts were washed with water and brine. The two fractions were combined and passed through a silica gel column. A 317-mg (32% yield) portion of **1b** was obtained. The spectra of **1b** were identical with those of the authentic sample.

1-Methyl-5-phenyl-2-oxa-3,4-benzobicyclo[3.2.0]heptan-7-one (2b). A 401-mg (70% yield) portion of **2b** was obtained from 738 mg of **2a**. The **2b** was spectroscopically identical with an authentic sample.[1e]

6-Methyl-1-phenyl-2-oxa-3,4-benzobicyclo[3.2.0]heptan-7-one (3b). A 469-mg (66% yield) portion of **3b** was obtained from 922 mg of **3a**. The melting point and spectra were identical with those of an authentic sample.[1e]

2-Oxa-3,4-benzobicyclo[4.2.0]octan-8-one (4b). A 0.95-g (44% yield) portion of oil was obtained from 3.06 g of **4a**: IR (neat) 1786 cm^{-1}; ^1H NMR ($CDCl_3$) δ 7.19–6.74 (m, 4 H), 3.21–2.16 (m, 6 H); ^{13}C NMR ($CDCl_3$) δ 205.8 (s), 154.0 (s), 129.1 (d), 127.5 (d), 123.1 (s), 121.9 (d), 117.0 (d), 85.3 (d), 48.0 (t), 27.8 (t), 26.2 (d); GC/MS (70 eV), m/e (relative intensity) 174.1 (molecular ion, 0.8), 146.0 (1.6), 145.0 (11.7), 132.0 (62.0), 131.0 (100.0), 77.0 (11.8).

Anal. Calcd for $C_{11}H_{10}O_2$: C, 75.84; H, 5.79. Found: C, 75.70; H, 5.73.

3-Oxa-4,5-benzobicyclo[5.2.0]nonan-9-one (5b). A 62-mg (18% yield) portion of oil was obtained from 479 mg of **5a**: IR ($CDCl_3$) 1777 cm^{-1}; ^1H NMR ($CDCl_3$) δ 7.09–6.87 (m, 4 H), 3.08–2.16 (m, 8 H); ^{13}C NMR ($CDCl_3$) δ 206.1 (s), 153.8 (s), 130.3 (d), 28.8 (d), 124.5 (s), 120.7 (d), 118.2 (d), 84.2 (t), 53.1 (d), 49.2 (t), 29.0 (t), 27.8 (d).

Anal. Calcd for $C_{12}H_{12}O_2$: C, 76.57; H, 6.43. Found: C, 76.19; H, 6.28.

4-Oxa-5,6-benzobicyclo[6.2.0]decan-10-one (6b). A 96-mg (10% yield) portion of oil was obtained from 1.31 g of **6a**: IR ($CDCl_3$) 1775 cm^{-1}; ^1H NMR ($CDCl_3$) δ 7.32–6.97 (m, 4 H), 3.35–2.21 (m, 10 H); ^{13}C NMR ($CDCl_3$) δ 209.1 (s), 155.9 (s), 129.9 (d), 129.2 (d), 127.1 (s), 120.5 (d), 115.0 (d), 66.3 (t), 64.7 (t), 62.9 (d), 62.5 (d), 50.4 (t), 50.0 (t), 36.5 (t), 35.6 (t), 31.5 (t), 31.3 (t), 28.7 (d), 28.5 (d).

Anal. Calcd for $C_{13}H_{14}O_2$: C, 77.20; H, 6.98. Found: C, 76.99; H, 7.06.

5-Oxa-6,7-benzobicyclo[7.2.0]undecan-11-one (7b). A 55-mg (4% yield) portion of oil was obtained from 1.84 g of **7a**: IR ($CDCl_3$) 1774 cm^{-1}; ^1H NMR ($CDCl_3$) δ 7.27–6.90 (m, 4 H), 3.28–2.20 (m, 12 H); ^{13}C NMR ($CDCl_3$) δ 208.7 (s), 156.1 (s), 133.8 (d), 129.7 (d), 127.5 (s), 120.8 (d), 115.3 (d), 63.8 (t), 63.3 (t), 61.4 (d), 61.0 (d), 50.7 (t), 50.3 (t), 35.9 (t), 35.4 (t), 32.5 (t), 32.3 (t), 31.7 (t), 31.5 (t), 29.3 (d), 29.0 (d).

Anal. Calcd for $C_{14}H_{16}O_2$: C, 77.78; H, 7.41. Found: C, 77.8; H, 7.40.

1-Phenylbicyclo[3.2.0]heptan-6-one (8b). A 68-mg (73% yield) portion of oil was obtained from 130 mg of **8a** by using normal hydrolysis followed by basic hydrolysis: IR ($CDCl_3$) 1778 cm^{-1}; ^1H NMR ($CDCl_3$) δ 7.35–6.88 (m, 5 H), 3.91–2.69 (m, 3 H), 2.28–1.20 (m, 6 H); ^{13}C NMR ($CDCl_3$) δ 212.2 (s), 147.1 (s), 128.4 (d), 126.0 (d), 125.7 (d), 67.0 (d), 57.6 (t), 45.2 (s), 42.6 (t), 30.8

(6) Harrison, G. C.; Diehl, H. *Organic Syntheses*; Wiley: New York, 1955; Vol. 3, p 372.

(t), 26.3 (t); GC/MS (70 eV), *m/e* (relative intensity) 159.0 (2.3), 158.0 (molecular ion – [CO], 18.5), 145.1 (10.9), 144.1 (molecular ion – [H_2C=C=O], 100.0), 129.1 (79.2), 115.1 (39.1); high-resolution mass spectrometry, calcd for $C_{13}H_{14}O$ M_r 186.1045, found M_r 186.1034.

2-Oxa-3-tetramethylenebicyclo[3.2.0]heptan-7-one (9b). A 117-mg (50% yield) portion of **9b** was obtained from 338 mg of **9a** as a pale yellow oil: IR (neat) 1786 cm^{-1}; ^1H NMR ($CDCl_3$) δ 4.10 (m, 1 H), 3.50 (m, 2 H), 2.44–0.92 (m, 11 H); ^{13}C NMR ($CDCl_3$) δ 212.1 (s), 96.5 (s), 93.7 (d), 50.0 (t), 42.3 (d), 39.4 (t, 2 C), 31.5 (t), 24.8 (t), 23.7 (t); GC/MS (70 eV), *m/e* (relative intensity) 139.00 (0.5), 138.10 (molecular ion – [CO], 5.1), 124.00 (molecular ion – [H_2C=C=O], 23.9), 120.10 (10.6), 109.10 (16.0), 95.00 (21.1), 81.00 (23.9), 67.00 (100.0), 55.00 (22.5), 41.00 (39.5), 39.00 (43.0); high-resolution mass spectrometry, calcd for $C_{10}H_{14}O_2$ M_r 166.0994, found M_r 166.0993.

Acknowledgment. We are grateful to the Robert A. Welch Foundation for support of this work.

Registry No. 1 (acid), 6839-30-1; **1a**, 6839-43-6; **1b**, 99477-39-1; 2 (acid), 99477-30-2; **2a**, 107770-73-0; **2b**, 99477-37-9; 3 (acid), 997477-28-8; **3a**, 107770-74-1; **3b**, 99477-35-7; 4 (acid), 6627-85-6; **4a**, 107770-75-2; **4b**, 107770-80-9; 5 (acid), 107770-68-3; **5a**, 107770-76-3; **5b**, 107770-81-0; **6a**, 107770-72-9; **6b**, 107770-82-1; 7 (acid), 107770-69-4; **7a**, 107770-77-4; **7b**, 107770-83-2; 8 (acid), 39764-82-4; **8a**, 107770-78-5; **8b**, 39764-85-7; 9 (acid), 107770-71-8; **9a**, 107770-79-6; **9b**, 107770-84-3; $Cl(CH_2)_2CO_2H$, 107-94-8; 2-$HOC_6H_4CH_2CH$=CH_2, 1745-81-9; $Br(CH_2)_4Br$, 110-52-1; 2-H_2C=$CHCH_2C_6H_4O(DcH_2)_4Br$, 107770-70-7; $BrCH_2CH$=CH_2, 106-95-6; $BrCH_2CO_2H$, 79-08-3; Et_2NH, 109-89-7; Cl-$(CH_2)_3CONEt_2$, 56794-28-6; cyclopentanone, 120-92-3; 1-allylcyclopentanol, 36399-21-0.

Cyclocondensation Reactions of 3-Amino-2-hydrazino-4(3*H*)-pyrimidinones.[1,2] Formation of 1,2,4-Triazolo[4,3-*a*]pyrimidines and Pyrimido[1,2-*b*][1,2,4,5]tetrazines

Panayota Bitha,* Joseph J. Hlavka, and Yang-i Lin

American Cyanamid Company, Medical Research Division, Lederle Laboratories, Pearl River, New York 10965

Received May 8, 1986

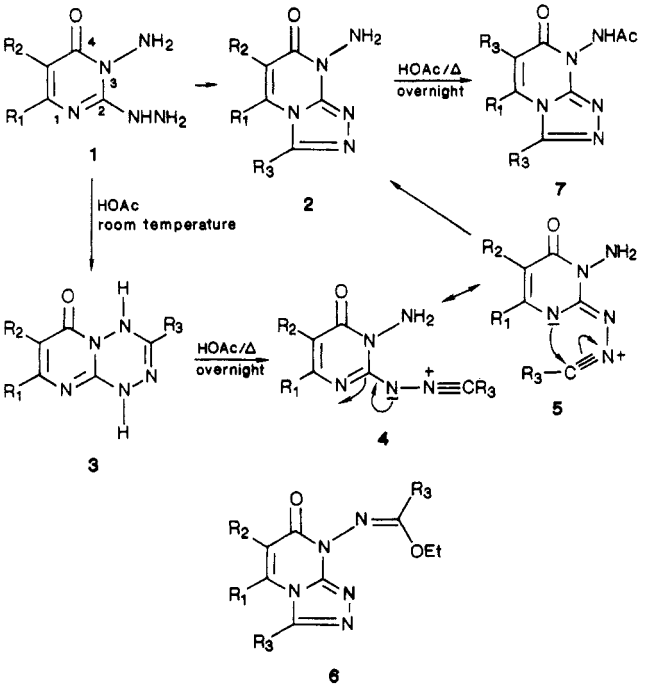
3-Amino-2-hydrazino-4(3*H*)-pyrimidinones **1**, derived from diaminoguanidine and β-keto esters,[1,2] react readily with ortho esters in hot acetic acid or butanol to give 1,2,4-triazolo[4,3-*a*]pyrimidin-7(8*H*)-ones **2**. In acetic acid at room temperature, **1** reacts with ortho esters, dimethylformamide dimethyl acetal, and diethoxymethyl acetate to form **2** and 6*H*-pyrimido[1,2-*b*][1,2,4,5]tetrazin-6-ones **3**. The latter ring system undergoes a thermal, acid-catalyzed, rearrangement to **2**.

Adjacent amino and hydrazino functional groups in a heterocyclic system provide many opportunities for the elaboration of additional ring systems. This synthetic strategy provides a route to ring-fused systems containing nitrogen at the ring-junction when an *N*-amino group is utilized. We now wish to describe our results utilizing 3-amino-2-hydrazino-4(3*H*)-pyrimidinones **1**, previously prepared[1,2] in our laboratory from diaminoguanidine and substituted β-keto esters, as a route to 1,2,4-triazolo[4,3-*a*]pyrimidin-7(8*H*)-ones **2** and 6*H*-pyrimido[1,2-*b*]-[1,2,4,5]tetrazin-6-ones **3**, which can now be readily prepared with a variety of substituents.

Reaction of **1** with ortho esters may occur in three ways: reaction with the *N*-NH_2 group or the $NHNH_2$ group to give the corresponding imino ethers, cyclocondensation at N-1 to give a 1,2,4-triazole system, or cyclocondensation between the *N*-NH_2 and the $NHNH_2$ groups to afford a 1,4-dihydrotetrazine derivative. Reaction of **1** with ortho esters in boiling butanol overnight or glacial acetic acid for 30 min gave only one product, identified as an 8-amino-1,2,4-triazolo[4,3-*a*]pyrimidin-7(8*H*)-one derivative **2**, in 50–75% yields. When the refluxing in acetic acid continued overnight, the acetamido derivative **7** was obtained.

Although the ^1H NMR data (Table I) were consistent with the assigned structure, they could not be considered conclusive. The structure **2c** (R_1 = R_3 = CH_3, R_2 = H) was finally determined by a single-crystal X-ray analysis[3] (supplementary material). Reaction of **1** with ortho esters, dimethylformamide dimethyl acetal, or diethoxymethyl acetate in glacial acetic acid at room temperature led to a mixture, readily separable by crystallization, of **2** and a second product **3** identified as a pyrimido[1,2-*b*][1,2,4,5]-tetrazin-6-one derivative (supplementary material) (Scheme I). The NMR spectra of the ring-fused tetrazines **3** show two NH signals at δ 9.3–9.8 (Table II), and they

Scheme I



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(3) X-ray work was performed by the crystallographic staff of Molecular Structure Corporation: Dr. M. W. Extine, R. A. Meisner, Dr. J. M. Troup, and B. B. Warrington, College Station, TX.

0022-3263/87/1952-2220$01.50/0