39, 125877-46-5; 40, 125877-47-6; 41, 125877-48-7; 42, 125877-49-8; 43, 125877-50-1; 44, 125877-51-2; TBAF, 429-41-4; CsF, 13400-13-0; $TiCl_4$, 7550-45-0; $PhCH(OEt)_2$, 774-48-1; Ph_2CO, 119-61-9; *i*-PrCHO, 78-84-2; PhCHO, 100-52-7; PhCH=CHCHO, 104-55-2; PhCH=CHCOPh, 94-41-7; α,α'-dibromopentanone, 815-60-1; iron nonacarbonyl, 15321-51-4; diethyl ketone, 96-22-0; *N,N*-dimethylformamide, 68-12-2; 2'-methylchalcone, 13565-43-0; 4-methoxychalcone, 959-33-1; 4'-methoxychalcone, 959-23-9; 2-thenylideneacetophenone, 39511-11-0; 3-thenylideneacetophenone, 123293-65-2; 2-furfurylideneacetophenone, 39511-12-1.

Intramolecular 1,4-Dipolar Cycloaddition: A New Approach to the Assembly of Ring-Fused Heterocycles

K. T. Potts* and M. O. Dery[1]

Department of Chemistry, Rensselaer Polytechnic Institute, Troy, New York 12180

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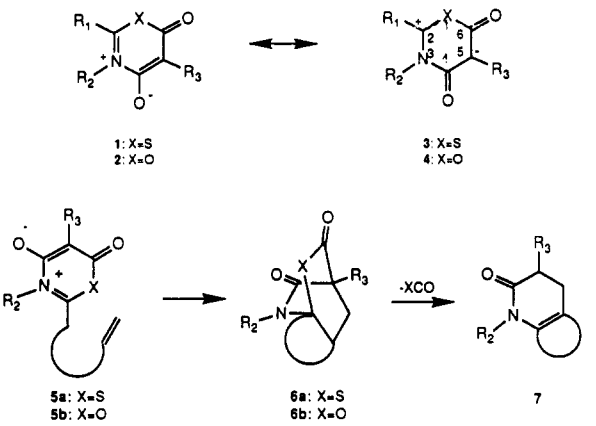
A new approach to ring-fused heterocycle construction involves facile intramolecular 1,4-dipolar cycloadditions with *anhydro*-4-hydroxy-6-oxo-1,3-thiazinium and -oxazinium hydroxides containing the dipolarophilic side chain (alkynes and alkenes) at the 2-position of the thiazinium and oxazinium nucleus and leads to benzo[*h*]-pyrano[4,3-*b*]pyridin-2(1*H*)-ones. The *anhydro*-4-hydroxy-6-oxo-1,3-oxazinium hydroxides were not isolated, being generated in situ from the appropriately substituted benzamides and substituted malonyl dichlorides. The oxazinium cycloadditions were characterized by their "one-pot" nature, the extreme ease with which they occurred, the high yields of pure products obtained, and their versatility. In both series alkenic side chains led to endo cycloadducts; methyl substitution on the alkene resulted in exo cycloadducts. Heating the thiazinium cycloadducts at 200 °C resulted in the loss of COS and rearrangement of the intermediate ylidic species to 3,4-dihydro-benzo[*h*]pyrano[4,3-*b*]pyridin-2(1*H*)-ones via a 1,5-H shift. Similarly, the oxazinium cycloadducts lost CO_2 at 80-200 °C, giving the pyridin-2(1*H*)-ones in excellent yields. With alkynic side chains the cycloadducts were not isolated. Cycloreversion occurred under these reaction conditions, giving benzo[*h*]pyrano[4,3-*b*]pyridin-2-(1*H*)-ones.

Intramolecular dipolar cycloadditions have found[2] widespread application in synthetic organic chemistry, and while intramolecular 1,3-dipolar cycloadditions are becoming well-established methods for the synthesis of ring-fused heterocyclic systems, there have been only a few reports[3] of intramolecular 1,4-dipolar cycloadditions in this important area of chemistry.

In this publication we describe the intramolecular 1,4-dipolar cycloaddition of *anhydro*-1,3-thiazinium hydroxides **1** and *anhydro*-1,3-oxazinium hydroxides **2**, both being cross-conjugated mesomeric betaines containing the elements of a 1,4-dipole as in **3** and **4**. Attachment of a suitable dipolarophilic side chain in the 2-position of **1** and **2** results in a system **5** which underwent intramolecular cycloaddition to a cycloadduct **6**, which, on heating, lost XCO, forming the ring-fused 2(1*H*)-pyridinone **7**.



I. Intramolecular Cycloadditions with *anhydro*-1,3-Thiazinium Hydroxides

Alkenic- and alkynic-substituted *anhydro*-4-hydroxy-6-oxo-2,3,5-trisubstituted-1,3-thiazinium hydroxides have been prepared and are described in Table I. Betaines **8**, **10**, **11**, **16**, **17**, and **25** were readily available by cyclocondensation of the appropriate thioamide[5] with (chlorocarbonyl)phenylketene, while the 5-unsubstituted betaines **29** and **30** were prepared from the appropriate thioamide and carbon suboxide.[6] These last two betaines were unstable and satisfactory analytical data could not be

(1) Abstracted from the Ph.D. Thesis of M.O.D., Rensselaer Polytechnic Institue, 1988. For preliminary communications describing part of this work, see: Potts, K. T.; Dery, M. O. *J. Chem. Soc., Chem. Commun.* **1986**, 563. Potts, K. T.; Dery, M. O.; Kullnig, R. K. *J. Chem. Soc. Chem. Commun.* **1987**, 840.

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(3) For related examples, see: (a) Padwa, A.; Carter, S. P.; Nimmesgern, H.; Stiell, P. D. *J. Am. Chem. Soc.* **1988**, *110*, 2894. (b) Sammes, P. G.; Watt, R. A. *J. Chem. Soc., Chem. Commun.* **1976**, *367*. (c) Joshi, R. A.; Street L. J. *J. Chem. Soc., Perkin Trans. 1* **1985**, 1725. (d) Gotthardt, H.; Blum, J. *Chem. Ber.* **1988**, *121*, 1579. (e) Gotthardt, H.; Flosbach, C. *Chem. Ber.* **1988**, *121*, 951. (f) Gotthardt, H.; Riegels, M. *Chem. Ber.* **1988**, *121*, 1143. (g) Sammes, P. G.; Watt, R. A. *J. Chem. Soc., Chem. Commun.* **1975**, *502*. (h) Rougeot, E.; Moskowitz, H.; Micocque, M. J. *J. Heterocycl. Chem.* **1983**, *20*, 1407. (i) Davies, L. B.; Greenburg, S. G.; Sammes, P. G. *J. Chem. Soc., Perkin Trans. 1* **1981**, 1909.

(4) Ollis, W. D.; Stanforth, S. P.; Ramsden, C. A. *Tetrahedron* **1985**, *41*, 2239.

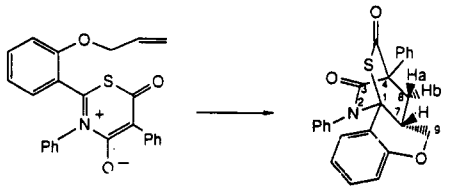
(5) Potts, K. T.; Dery, M. O.; Juzukonis, W. A. *J. Org. Chem.* **1989**, *54*, 1077.

(6) Murphy, P. Ph.D. Dissertation, Rensselaer Polytechnic Institute, 1987.

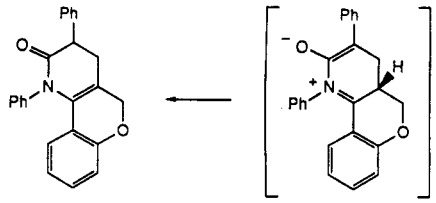
0022-3263/90/1955-2884$02.50/0

obtained. This family of betaines were highly colored and since their cycloadducts were usually colorless, visual monitoring of the progress of the cycloaddition was possible.

A. Cycloaddition with 2-(Allylic ether substituted)-*anhydro*-1,3-thiazinium Hydroxides. Heating *anhydro*-2-(2-(allyloxy)phenyl)-3,5-diphenyl-4-hydroxy-6-oxo-1,3-thiazinium hydroxide (8) under reflux in toluene for 3 h and concentration of the solvent under reduced pressure gave a colorless solid identified as the cycloadduct **9** (84%) principally from its ^{1}H NMR data. The stereochemical assignment was confirmed by single-crystal X-ray data.[7]



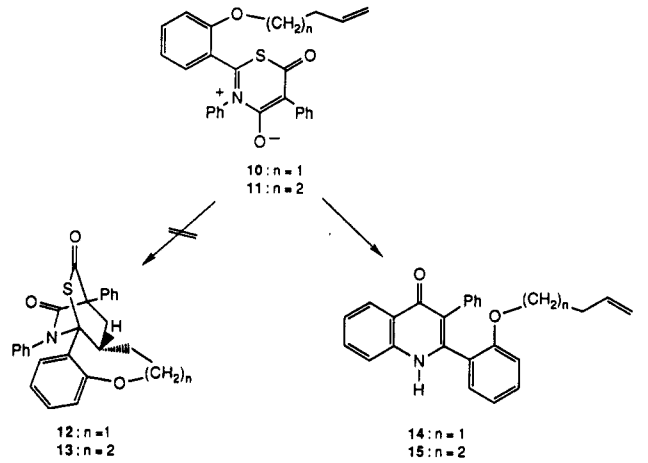
8 9



21 22

Relevant ^{1}H NMR data for cycloadduct **9** as well as for the other cycloadducts derived from the 1,3-thiazinium betaines are given in Table II. In general, the five chemical shifts corresponding to each of the five aliphatic protons were resolvable, with those for H_{8a} and H_7 being readily distinguishable and occurring as a large multiplet at ca. δ 3.23. The chemical shifts for the H_9 protons were downfield relative to the other aliphatic protons due to deshielding by the ether oxygen atom, and the exo protons were deshielded by the carbonyl sulfide bridge, their chemical shifts occurring downfield relative to those of the endo protons in these cycloadducts.

B. Variations in Dipolarophilic Chain Length. Increase in the dipolarophilic chain length over that present in the original betaine **8** resulted in betaines **10** (one additional CH_2 group) and **11** (two additional CH_2 groups). These betaines were more stable to thermal conditions than **8** and were recrystallized from hot acetone without undergoing change. When **10** and **11** were heated in dry toluene until the orange color of the betaine had disappeared, an extremely complex mixture of products was obtained. The ^{1}H NMR spectrum showed that the alkenic protons were unaffected, and the only isolable products were identified as the quinol-4-ones **14** (23%) and **15** (21%). These quinolones were formed via thermal rearrangement of the thiazinium betaine, this rearrangement having been observed in attempted intermolecular cycloadditions with this betaine family.[8] Dreiding models of **10** and **11** show that good overlap of the double bond and the 1,4-dipole in the transition state is inhibited by strain associated with ring size, with the rearrangement consequently being the preferred reaction pathway.



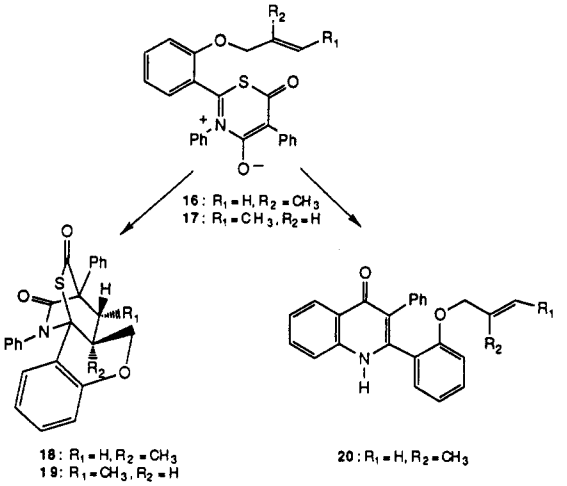
10: n = 1
11: n = 2

12: n = 1
13: n = 2

14: n = 1
15: n = 2

C. Cycloaddition with Methyl-Substituted Dipolarophiles. The methyl-substituted 1,3-thiazinium betaine **16** showed poor cycloaddition behavior. After the betaine **16** was refluxed in xylenes for 3 h, the colorless precipitate that formed was identified as the quinol-4-one **20** (23%). Concentration of the solvent under reduced pressure gave a complex residue that resisted separation. Its ^{1}H NMR (200 MHz) spectrum showed that only a trace amount of the cycloadduct **18** was present.

The poor cycloaddition behavior of the methallyl derivative **16**, compared to the simple allylic system **8**, is due to the steric interaction of the methyl group and the dipole system causing an unfavorable interaction in the parallel-plane transition state. This steric interaction was clearly evident in molecular models (Dreiding) of **16**, and the lack of good orbital overlap resulted in rearrangement rather than intramolecular cycloaddition being the favored reaction pathway. In contrast, when the methyl group was introduced at the terminal carbon of the allylic ether group as in the trans-methyl-substituted betaine **17**, cycloaddition occurred readily in refluxing toluene. A single product, identified as cycloadduct **19**, was obtained in 84% yield after purification. We attribute the difference in reactivity



16: R_1 = H, R_2 = CH_3
17: R_1 = CH_3, R_2 = H

18: R_1 = H, R_2 = CH_3
19: R_1 = CH_3, R_2 = H

20: R_1 = H, R_2 = CH_3

between **16** and **17** to steric reasons, and a similar result was observed by Grigg and co-workers,[9] who found that terminal methyl-substituted allylic ethers underwent

(7) Potts, K. T.; Dery, M. O. *J. Chem. Soc., Chem. Commun.* **1986**, 563.

(8) Potts, K. T.; Ehlinger, R.; Nichols, W. M. *J. Org. Chem.* **1975**, *40*, 2596.

(9) Armstrong, P.; Grigg, R.; Jordan, M. W.; Malone, J. F. *Tetrahedron* **1985**, *41*, 3547.

Table I. *anhydro*-2-[2-(Substituted-oxy)phenyl]-3,5-diphenyl-4-hydroxy-6-oxo-1,3-thiazinium Hydroxides

compd no.	mp,[a]	yield, %	cryst form/solvent	mol formula	anal. data[b] % C	% H	% N	[M+], % rel int	spectral data: IR (KBr), cm^{-1}	spectral data: ^{1}H NMR ($CDCl_3$), δ
8	184	46	orange prisms/ acetone	$C_{25}H_{19}NO_3S$	72.62 72.71	4.63 4.64	3.39 3.35	[M$^+$ + 1], 9	1655 (CO) 1600 (CO)	4.62 (s, 2, OCH_2), 5.44 (m, 2, $CHCH_2$), 6.06 (m, 1, $CHCH_2$), 6.70–7.80 (m, 14, aromatic)
10	172–174	52	orange prisms/ acetone	$C_{26}H_{21}NO_3S$	73.04 72.95	4.95 4.95	3.28 3.25	[M$^+$ + 1], 0.4	1655 (CO) 1600 (CO)	2.59 (m, 2, OCH_2CH_2), 4.09 (t, 2, OCH_2), 5.22 (m, 2, $CHCH_2$), 5.86 (m, 1, $CHCH_2$), 6.66–7.82 (m, 14, aromatic)
11	157–158	60	orange microneedles/ benzene	$C_{27}H_{23}NO_3S$	73.44 73.37	5.25 5.28	3.17 3.13	M$^+$, 0.8	1660 (CO) 1605 (CO)	1.94 (m, 2, CH_2), 2.24 (m, 2, CH_2), 3.94 (t, 2, OCH_2), 5.08 (m, 2, $CHCH_2$), 5.82 (m, 1, $CHCH_2$), 6.70–7.64 (m, 14, aromatic)
16	172–174	64	orange microprisms/ benzene	$C_{26}H_{21}NO_3S$	73.04 73.14	4.95 4.99	3.28 3.24	[M$^+$ + 1], 7	1660 (CO) 1605 (CO)	1.84 (s, 3, CH_3), 4.38 (s, 2, OCH_2), 5.06 (s, 2, CH_2), 6.70–7.64 (m, 14, aromatic)
17	178–181	62	orange prisms/ acetone	$C_{26}H_{21}NO_3S$	73.04 73.00	4.95 4.98	3.28 3.24	M$^+$, 2.3	1660 (CO) 1605 (CO)	1.81 (d, 3, J_{CH,CH_3} = 6.1 Hz, CH_3), 4.38 (br s, 2, OCH_2), 5.80 (m, 2, $J_{CH,CH}$ = 15.2 Hz, CHCH), 6.99–7.65 (m, 14, aromatic)
25	176–177	81	orange prisms/ benzene	$C_{25}H_{17}NO_3S$	72.98 72.88	4.16 4.20	3.40 3.37	[M$^+$ + 1], 7	2110 (C≡C) 1655 (CO) 1605 (CO)	2.60 (t, 1, CCH), 4.67 (d, 2, OCH_2), 7.65–6.85 (m, 14, aromatic)
29	105–107	79	yellow microneedles	$C_{19}H_{13}NO_3S$				[M$^+$ + 1], <1	2110 (C≡C) 1660 (CO) 1625 (CO)	2.56 (t, 1, CCH), 4.62 (d, 2, OCH_2), 5.48 (s, 1, H_5), 6.30–7.38 (m, 9, aromatic)
30	146–148	58	yellow microneedles	$C_{14}H_{11}NO_3S$				[M$^+$ + 1], <1	2105 (C≡C) 1620 (CO)	2.60 (t, 1, CCH), 3.58 (s, 3, NCH_3), 4.85 (d, 2, OCH_2), 5.46 (s, 1, H_5), 7.18–7.72 (m, 4, aromatic)

[a] All melted with decomposition. [b] Calculated values are listed first.

Table II. ^{1}H NMR Data (200 MHz, $CDCl_3$) for Cycloadducts

compd no.	chem shift, δ ($CDCl_3$) H_{8b}	H_{8a}	H_7	H_{9b}	H_{9a}	coupling constant, J (Hz) H_8 *gem*	H_{8b}, H_7	H_{8a}, H_7	H_{9b}, H_7	H_{9a}, H_7	H_9 *gem*
9	2.32	3.23[a]	3.30[a]	4.27	4.53	12.9	4.89	11.6	11.4	4.3	11.6
19		2.70	2.92	4.35	4.56			4.6	11.3	7.4	11.3
41	1.99	2.99		3.86	4.55	12.0	5.3	10.0	11.9	4.3	11.8
74	1.97		2.93–3.08	3.86	4.49		6.3		12.5	4.5	12.5
45	1.40	2.31	2.88	3.77	4.37	12.6	6.6	9.8	12.4	4.5	11.1
49	1.63	2.43	3.02	4.29	4.54	13.3	6.7	9.9	12.1	4.9	11.6
69a		2.48	2.64	3.95	4.51			5.8	11.9	4.5	12.2
69b		2.70	2.92	4.35	4.56			4.6	11.3	7.4	11.3

[a] H_{8a} and H_7 overlap.

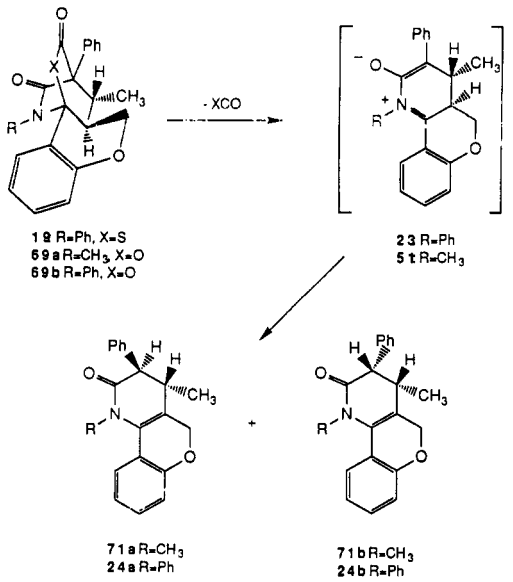
smooth intramolecular cycloaddition with azomethine ylides, whereas methallyl ether derivatives did not.

The structure of cycloadduct **19** was established by correlation of the chemical shifts and coupling constants of H_7, H_8, and H_9 with the corresponding protons in the established structure **9** (Table II). The absence of a chemical shift at δ 2.30, which would correspond to an endo H_8 in **19**, together with a chemical shift at δ 2.92 for H_7, which is upfield from δ_{H_7} = 3.30 for the exo proton of **9**, is consistent with H_7 having an endo configuration in **19**. The stereochemistry of the resultant cycloadduct from the trans amide **17** was different from that in the cycloadduct derived from the allylic system. Assuming that the electronic nature of the allylic and trans-methyl allylic systems is similar, this reversal in stereochemistry must be caused by a steric effect.

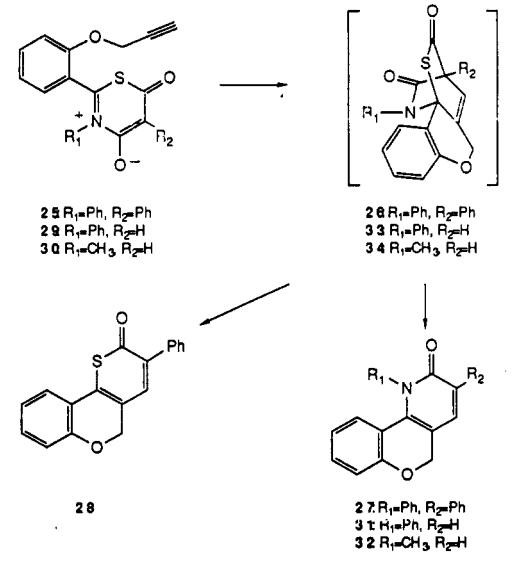
Heating cycloadduct **9** at or above its melting point (200 °C) resulted in the formation of a single product, verified by ^{1}H NMR and TLC data. The product's molecular weight corresponded to the loss of 60 amu (COS) from **9**, it had ν_{CONH} 1665 cm^{-1}, and its ^{1}H NMR spectrum indicated that the CH_2 protons adjacent to the ether linkage remained intact, exhibiting only geminal coupling; a two-proton doublet at δ 2.78 and a one-proton multiplet at δ 4.00 showing vicinal coupling were present and, on the basis of these spectral results and analytical data, this product was assigned structure **21**. The following series of reactions accounts for the formation of **21**; an initial loss of carbonyl sulfide from the cycloadduct **9** gave the nonisolable intermediate **22**, which then underwent a 1,5-sigmatropic H shift to **21** (Table III). Intermediates similar to **22** have been postulated in the photocyclization of dienamides[10] in which the 1,5-sigmatropic H shift was shown to occur with retention of configuration in aprotic solvents.[11] It has been shown that these intermediates can be long-lived and are capable of being protonated by protic solvents[12] and reduced by hydride reagents.[13]

Cycloadduct **19** also underwent rearrangement at elevated temperatures and was an ideal candidate to determine whether the 1,5-H shift occurred with retention of configuration. If such were the case, then the relative stereochemistry of the cycloadduct **19** would be transferred to the 3-position in the 2(1*H*)-dihydropyridinone **24**. This was not the case. Thermolysis of **19** produced a mixture of products, **24a** and **24b**, indicating that in this system the rearrangement occurred by an alternative process.

(10) For example, see: Campbell, A. L.; Lenz, G. R. *Synthesis* **1987**, 421. Bates, R. B., Kane, V. V.; Martin, A. R.; Mujumbar, R. B.; Ortege, R.; Hatanaka, Y.; San-nohe, K.; Kanaoka, Y. *J. Org. Chem.* **1987**, *52*, 3178.
(11) Lenz, G. R. *J. Org. Chem.* **1976**, *41*, 2201.
(12) Ninomoya, I.; Yamauchi, S.; Kiguchi, T.; Shinohara, A.; Naito, T. *J. Chem. Soc., Perkin Trans. 1*, **1974**, 1747.
(13) Kiguchi, T.; Hashimoto, C.; Naito, T.; Ninomoya, I. *Heterocycles* **1982**, *18*, 217.



D. Cycloaddition with Alkynic Dipolarophiles. The spatial requirements demonstrated above for reaction with alkenic dipolarophiles indicated that only betaines with four atoms between reactive centers in the dipolarophilic side chains, as in **25**, should be studied. Betaine **25** underwent smooth intramolecular cycloaddition at 110 °C over 90 min and, after reaction workup, the 2(1*H*)-pyridinone **27** was isolated as yellow, irregular prisms in 66% yield. Formation of **27** involved loss of carbonyl sulfide from the primary cycloadduct **26** and, although elimination of PhNCO is another conceivable reaction pathway, the thiapyranone **28** resulting from this process was not detected.

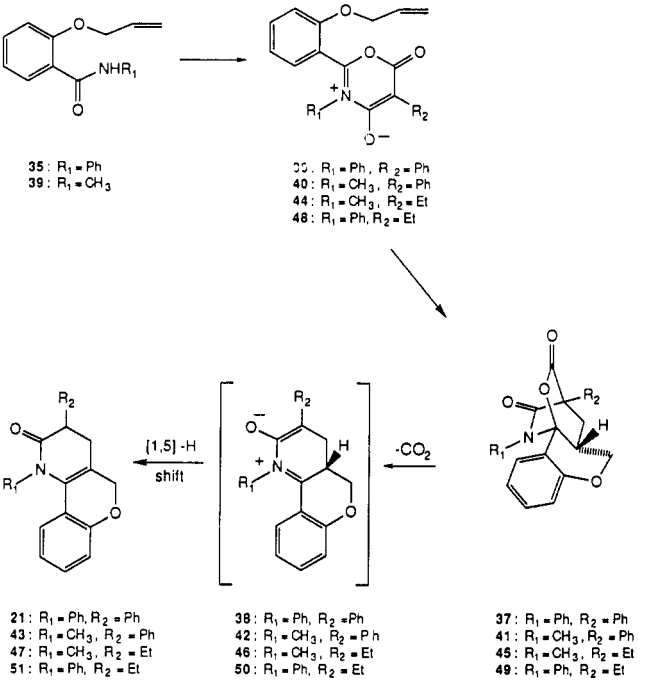


Betaines **29** and **30** were unstable to atmospheric moisture; the major products formed from the exposure of these betaines to the atmosphere were the thioamides. Thiazinium betaines are known[14] to undergo hydrolysis[15] to thioamides and malonic acids. However, when **29** or **30** was added rapidly to refluxing toluene, cycloaddition occurred in moderate to good yields: under these conditions the betaine **29** resulted in a vigorous reaction and, after loss of carbonyl sulfide from the initial cycloadduct, 1-phenyl-5*H*-benzo[*h*]pyrano[4,3-*b*]pyridin-2(1*H*)-one (**31**) was obtained (10%). Similarly, betaine **30** gave 1-methyl-5*H*-benzo[*h*]pyrano[4,3-*b*]pyridin-2(1*H*)-one (**32**) (66%).

II. Intramolecular Cycloadditions with Oxazinium Hydroxides

A. Cycloadditions with 2-Substituted Allyl Ether Derivatives. Our initial success with the *anhydro*-1,3-thiazinium hydroxides in intramolecular cycloadditions suggested an extention to *anhydro*-1,3-oxazinium hydroxides. The latter betaine system was found[16] to require high temperatures and prolonged reaction times for intermolecular cycloadditions with electron-deficient dipolarophiles; with electron-rich dipolarophiles cycloaddition occurred readily.[3e] It was thought that in these intramolecular cycloadditions the ease of attaining maximum orbital overlap would result in a facile cycloaddition, and our results with this betaine system are described below.

2-(Allyloxy)benzanilide[5] (**35**) and (chlorocarbonyl)phenylketene in benzene (Et_3N) at 55 °C resulted in a remarkably clean reaction mixture whose ^1H NMR spectrum showed that it was a mixture of the unreacted amide **35** and the tricyclic system **21**, previously obtained by extrusion of COS from the 1,3-thiazinium cycloadduct **9**.



The formation of **21** involved an initial ring closure of **35** to the 1,3-oxazinium betaine **36**, its conversion into the cycloadduct **37**, and loss of CO_2 from **37** under these reaction conditions, followed by rearrangement to the 2-(1*H*)-pyridinone **21**. ^1H NMR data (200 MHz) indicated that the conversion of **35** into **21** was quantitative. Neither of the intermediates **36** and **37** were observed in the crude reaction mixture, and formation of the betaine **36** was apparently the rate-controlling step, with the other processes leading to **21** being relatively facile. To enhance the initial ring closure of the amide to the betaine, the nucleophilicity of the precursor amide was increased by use of the *N*-methyl derivative **39**. 2-(Allyloxy)-*N*-methylbenzamide (**39**), with (chlorocarbonyl)phenylketene in boiling xylenes, resulted in a vigorous reaction. Concentration of the solvent gave a colorless solid which, after

(14) Friedrichsen, W.; Kappe, T.; Bottcher, A. *Heterocycles* **1982**, *19*, 1083.
(15) Kappe, T.; Golser, W. *Synthesis* **1972**, 312.
(16) For example, see: Friedrichsen, W.; Kujath, E.; Liebezeit, G. *Z. Naturforsch.* **1982**, *37b*, 222. Friedrichsen, W.; Kruger, C.; Kujath, E.; Liebezeit, G.; Mohr, S. *Tetrahedron Lett.* **1979**, 237.

Table III. 3,4-Dihydro-2(1*H*)-pyridinones and 2(1*H*)-Pyridinones Derived from Oxazinium and Thiazinium Betaines

compd no.	mp, °C	yield, %	cryst form/solvent	mol formula	anal. data[a] % C	% H	% N	[M⁺], % rel int	spectral data: IR (KBr), cm⁻¹	spectral data: ^{1}H NMR ($CDCl_3$), δ
21	150–152	A:[b] 8 C: 76	colorless microprisms/ ethanol	$C_{24}H_{19}NO_2$	81.56 81.44	5.42 5.46	3.96 3.92	[M⁺ + 1], 34	1665 (CO)	2.78 (t, 2, J_{H_3,H_4} = 7.8 Hz, H_4), 4.00 (m, 1, H_3), 4.71 (b q, 2, J_{gem} = 14.9 Hz, OCH_2), 6.45–7.38 (m, 14, aromatic)
24a	162–164	B: 8	colorless cubes/ *n*-pentane	$C_{25}H_{21}NO_2$	81.72 81.81	5.76 5.79	3.81 3.77	[M⁺ + 1], 100	1675 (CO)	1.14 (d, 3, CH_3), 2.49 (m, 1, H_4), 4.10 (d, 1, J_{H_3,H_4} = 5.3 Hz, H_3), 4.65 (d, 1, J_{gem} = 14.6 Hz, OCH_2), 4.87 (d, 1, OCH_2), 6.48–7.33 (m, 14, aromatic)
24b	164–166	B: 39	colorless prisms/ *n*-hexane	$C_{25}H_{21}NO_2$	81.72 81.63	5.76 5.77	3.81 3.80	[M⁺ + 1], 100	1675 (CO)	1.36 (d, 3, CH_3), 2.62 (m, 1, H_4), 3.85 (d, 1, J_{H_3,H_4} = 3.1 Hz, H_3), 4.51 (d, 1, J_{gem} = 14.7 Hz, OCH_2), 4.67 (d, 1, OCH_2), 6.52–7.34 (m, 14, aromatic)
43	169–171	A: 43 B: 85	colorless microprisms/ benzene	$C_{19}H_{17}NO_2$	78.33 78.12	5.88 5.93	4.81 4.76	[M⁺ + 1], 100	1655 (CO)	2.64 (m, 2, H_4), 3.30 (s, 3, NCH_3), 3.83 (t, J_{H_3,H_4} = 7.3 Hz, H_3), 4.59 (dd, 2, J_{gem} = 14.7 Hz, H_6), 6.93–7.36 (m, 9, aromatic)
71a	149–151	B: 11	colorless prisms/ *n*-pentane	$C_{20}H_{19}NO_2$	78.66 78.76	6.27 6.30	4.59 4.54	[M⁺ + 1], 100	1660 (CO)	1.03 (d, 3, CH_3), 2.64 (m, 1, H_4), 3.29 (s, 3, NCH_3), 3.89 (d, 2, J_{H_3,H_4} = 5.4 Hz, H_3), 4.54 (d, 1, OCH_2), 4.78 (d, 1, OCH_2), 6.99–7.36 (m, 9, aromatic)
71b	59–60 dec	B: 69	colorless microneedles/ *n*-hexane	$C_{20}H_{19}NO_2$	78.66 78.19	6.27 6.31	4.59 4.13	[M⁺ + 1], 100	1660 (CO)	1.24 (d, 2, CH_3), 2.32 (m, 1, H_4), 3.29 (s, 3, NCH_3), 3.69 (d, 1, J_{H_3,H_4} = 3.1 Hz, H_3), 4.48 (dd, 2, J_{gem} = 14.7 Hz, OCH_2), 6.90–7.25 (m, 9, aromatic)
76	156–157	B: 50	colorless needles/ benzene	$C_{19}H_{16}NO_2D$	78.06 78.10	6.20 6.00	4.79 4.76	M⁺, 100	1650 (CO)	2.64 (d, 1, H_4), 3.29 (s, 3, NCH_3), 3.84 (d, 1, J_{H_3,H_4} = 9.2 Hz, H_3), 4.50 (d, 1, J_{gem} = 14.7 Hz, OCH_2), 4.66 (d, 1, OCH_2), 6.92–7.32 (m, 9, aromatic)
61a	176–178	A: 20	colorless microprisms/ EtOAc	$C_{18}H_{15}NO_2$	77.96 78.06	5.45 5.49	5.05 5.04	[M⁺ + 1], 100	1655 (CO)	2.70 (d, 2, J_{H_3,H_4} = 8.0 Hz, H_4), 3.87 (t, 1, H_3), 4.79 (dd, 2, J_{gem} = 14.2 Hz, OCH_2), 6.85–7.55 (m, 10, aromatic)
51	95–96	A: quant B: 80	pale yellow microneedles/ *n*-hexane	$C_{20}H_{19}NO_2$				[M⁺ + 1], 100	1665 (CO)	1.05 (t, 3, CH_3), 1.55 (m, 1, CH_2CH_3), 2.00 (m, 1, CH_2CH_3), 2.31–2.60 (m, 3, H_3 and H_4), 4.75 (dd, 2, H_5), 6.42–7.35 (m, 9, aromatic)
47	104–106	A: quant B: 82	colorless microneedles/ *n*-hexane	$C_{15}H_{17}NO_2$	74.05 74.22	7.04 6.89	5.76 5.70	[M⁺ + 1], 100	1665 (CO)	0.97 (t, 3, CH_2CH_3), 1.45 (m, 1, CH_2CH_3), 1.89 (m, 1, CH_2CH_3), 2.18 (m, 2, H_3 and H_4), 3.21 (s, 3, NCH_3), 4.62 (dd, 2, H_5), 6.82–7.24 (m, 4, aromatic)
61b	160–162	A: quant	colorless microneedles/ methanol	$C_{14}H_{15}NO_2$	73.34 73.35	6.59 6.72	6.12 6.03	M⁺, 59	1655 (CO)	1.03 (t, 3, CH_3), 1.58 (m, 1, J_{CH_2,CH_3} = 6.6 Hz, J_{gem} = 13.9 Hz, CH_2), 1.97 (m, 1, J_{CH_2,CH_3} = 6.6 Hz, J_{CH_2,H_4} = 4.8 Hz, CH_2), 2.22 (m, 1, H_4), 2.45 (m, 2, H_4 and H_3), 4.79 (d, 2, OCH_2), 6.84–7.28 (m, 4, aromatic), 7.93 (s, 1, NH)
27	167–168	D: 66	yellow microneedles/ ethanol	$C_{24}H_{17}NO_2$	82.03 81.95	4.88 4.92	3.99 3.98	[M⁺ + 1], 100	1640 (CO)	4.95 (s, 2, OCH_2), 6.31–7.81 (m, 15, aromatic)
55a	144–145	A: 59	yellow needles/ methanol–diethyl ether	$C_{19}H_{15}NO_2$	78.87 78.81	5.23 5.25	4.84 4.78	[M⁺ + 1], 100	1615 (CO)	3.86 (s, 3, NCH_3), 4.87 (s, 2, OCH_2), 7.10–7.78 (m, 10, aromatic)
66a	258 dec	A: 35	yellow prisms/ EtOAc	$C_{18}H_{13}NO_2$	78.53 78.46	4.76 4.77	5.09 5.07	M⁺, 82	1605 (CO)	5.12 (s, 2, OCH_2), 7.02–7.79 (m, 10, aromatic)[c]
55b	187–188	A: 66	pale yellow prisms/ diethyl ether	$C_{20}H_{17}NO_2$	79.18 79.25	5.65 5.53	4.62 4.63	M⁺, 50	1635 (CO)	1.24 (t, 3, CH_2CH_3), 2.61 (q, 2, CH_2CH_3), 4.88 (s, 2, OCH_2), 6.30–7.46 (m, 9, aromatic)
55c	118–120	A: 83	pale yellow microneedles/ *n*-hexane	$C_{15}H_{15}NO_2$	74.67 74.49	6.27 6.40	5.80 5.67	M⁺, 100	1630 (CO)	1.20 (t, 3, CH_2CH_3), 2.60 (q, 2, CH_2CH_3), 3.80 (s, 1, NCH_3), 4.80 (s, 2, OCH_2), 7.05–7.61 (m, 5, aromatic)
66b	208–211	A: 54	pale yellow prisms/ benzene	$C_{14}H_{13}NO_2$	73.99 73.85	5.77 5.85	6.16 6.12	M⁺, 89	1600 (CO)	1.20 (t, 3, CH_2CH_3), 2.66 (d, 2, CH_2CH_3), 5.16 (s, 2, OCH_2), 6.94–8.08 (m, 5, aromatic and NH)
31	192–194	D: 23	yellow needles/ hexane	$C_{18}H_{13}NO_2$	78.53 77.74	4.76 4.88	5.09 4.97	M⁺, 86	1650 (CO)	4.88 (s, 2, OCH_2), 6.26–7.68 (m, 11, aromatic)

Table III (Continued)

compd no.	mp, °C	yield, %	cryst form/solvent	mol formula	anal. data[a] % C	% H	% N	[M+], % rel int	spectral data IR (KBr), cm^{-1}	^{1}H NMR ($CDCl_3$), δ
32	100–102	D: 66	pale yellow needles/ methanol	$C_{13}H_{11}NO_2$	73.22 73.22	5.20 5.07	6.57 6.32	[M+ + 1], 100	1620 (CO)	3.78 (s, 3, NCH_3), 4.80 (s, 2, OCH_2), 6.54–7.68 (m, 6, aromatic)

[a] Calculated values are listed first. [b] Method of preparation: (A) preparation and in situ cycloaddition of an oxazinium hydroxide; (B) elimination of CO_2 from a 1:1 cycloadduct derived from an oxazinium hydroxide; (C) elimination of COS from a 1:1 cycloadduct derived from a thiazinium hydroxide; (D) cycloaddition of a thiazinium hydroxide. [c] Recorded in DMSO-d_6.

recrystallization, was identified as the tricyclic 2(1*H*)-pyridinone **43** (43%). This yield was a significant improvement over that obtained in the *N*-phenyl system and is quite remarkable when one considers the number of bonds (seven) undergoing transformation in this and related reactions.

Although simpler *anhydro*-6-hydroxy-4-oxo-1,3-oxazinium hydroxides have been isolated and fully characterized,[16] we were not able to isolate **36** and other members of this family. In our present systems the elevated temperatures needed to form the betaines resulted in cycloaddition. However, under relatively milder reaction conditions [(chlorocarbonyl)phenylketene, benzene at 50 °C, Et_3N], the initial cycloadduct **41** was obtained (44%), although attempts to isolate cycloadduct **37** failed. The cycloadduct **41** was thermally unstable, with recrystallization being performed at moderate temperatures to avoid decomposition. A ^{1}H NMR analysis of the crude reaction mixture showed that no other isomers of the cycloadduct **41** were present, and the material balance was accounted for by the presence of unreacted amide **39** and some of the tricyclic system **43**. When the cycloadduct **41** was heated overnight in boiling benzene, **43** was obtained exclusively in 85% yield. The structure of the cycloadduct **41** was established by correlation of its ^{1}H NMR spectrum (Table II) with that of the known compound **9**, and it was confirmed by single-crystal X-ray data.[17] Structure **41** is one of the rare examples in cycloaddition chemistry in which CO_2 is retained in the primary cycloadduct.

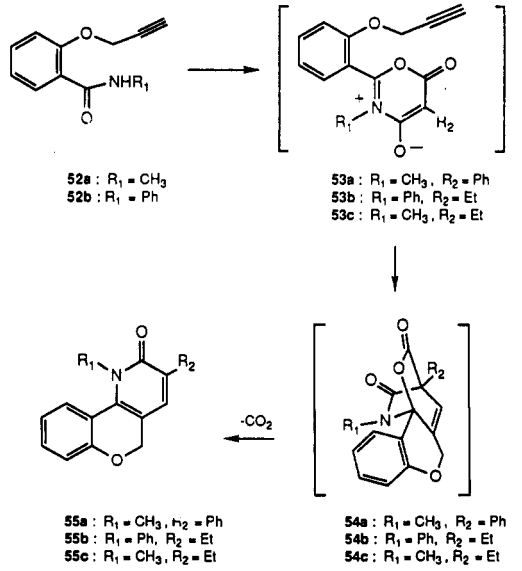
Use of ethylmalonyl dichloride as the 1,3-bielectrophile allowed the introduction of an alkyl substituent into the 3-position of the pyridinone system. When *N*-methyl-2-(allyloxy)benzamide (**39**) was treated with ethylmalonyl dichloride in refluxing xylenes, a vigorous reaction occurred. Concentration of the solvent under reduced pressure left a colorless solid whose ^{1}H NMR spectrum showed that the tricyclic system **47** was the exclusive product formed in this reaction. Isolation of **47** was difficult due to its inherent instability, and the analytical sample of **47** was prepared by thermolysis of the cycloadduct **45**.

Treatment of **39** with ethylmalonyl dichloride at 50 °C in benzene (Et_3N) gave the primary cycloadduct **45** exclusively in 55% yield. Material balance in the reaction was accounted for by the presence of **39** and some of the tricyclic product **47**. The cycloadduct **45** was thermally unstable and care had to be taken in purification to avoid decomposition. The structure of **45** was assigned by correlation of the chemical shifts and coupling constants of H_7, H_8, and H_9 with those of compound **41**. Heating **45** at 190 °C for 2 min caused rearrangement to the 2(1*H*)-pyridinone **47** in 82% yield.

2-(Allyloxy)benzanilide (**35**) and ethylmalonyl dichloride in refluxing xylenes gave an excellent yield of the tricyclic system **51**, which decomposed on attempted purification. This was avoided by isolation of the primary cycloadduct **49**, obtained exclusively (32%) from **35** and ethylmalonyl dichloride. The structure of **49** was determined on the basis of its characteristic ^{1}H NMR data, and, on heating to 190 °C for 2 min, rearrangement occurred to **51**.

This reaction sequence is analogous to that occurring with the 1,3-thiazinium betaines described above, but it offers several advantages such as the essentially quantitative nature of the overall conversion from **35** to **21**, milder reaction conditions, and a shorter reaction time. An additional advantage is the "one-pot" nature of the overall process; intermediates **36** and **37** were not isolated, being converted in situ into the cycloadducts, which also were not isolated, readily losing CO_2 to form the tricyclic pyridinones. 1,3-Bielectrophiles such as malonyl dichlorides are readily prepared, and considerable potential exists for the incorporation of a wide variety of groups into the 3-position of the pyridinone ring. Carbon suboxide and malonyl dichloride did not react with any of these amides, and the 3-unsubstituted pyridinones are best prepared from the *anhydro*-1,3-thiazinium hydroxides.

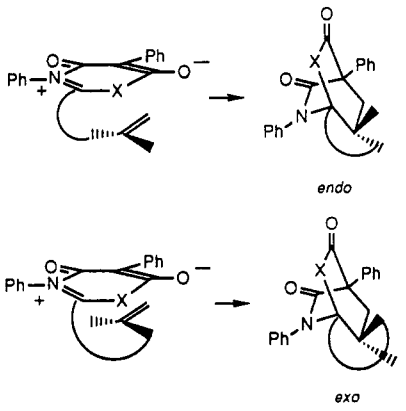
B. Intramolecular Cycloadditions with 2-Substituted Propargylic Ether Systems. Alkynic dipolarophiles[5] incorporated in the 2-position of the betaine underwent ready cycloaddition. The initial cycloadducts were never isolated, loss of carbon dioxide occurring under these reaction conditions to generate the 2(1*H*)-pyridinones directly, and both *N*-phenyl- and *N*-methyl-substituted betaines underwent cycloaddition to give good to excellent yields (59–83%) of the 2(1*H*)-pyridinones. Variation of the 3-substituent in the 2(1*H*)-pyridinones was possible by the use of (chlorocarbonyl)phenylketene or ethylmalonyl dichloride, resulting in good to excellent isolated yields of the pyridinones.



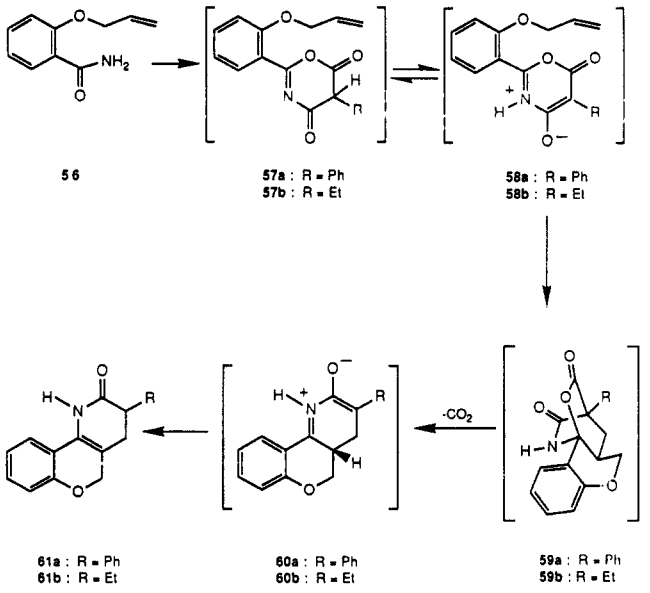
C. Cycloadditions with Betaines Derived from 2-(Allyloxy)benzamides. 2-(Allyloxy)benzamide (**56**) and

(17) Potts, K. T.; Dery, M. O.; Kullnig, R. K. *J. Chem. Soc., Chem. Commun.* **1987**, 840.

Scheme I

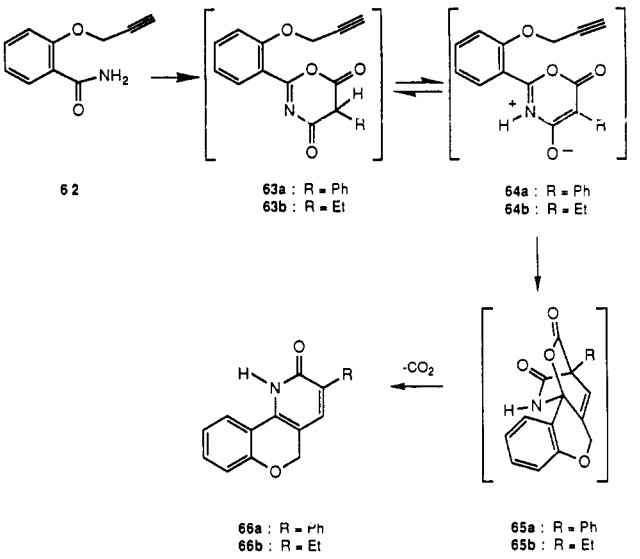


(chlorocarbonyl)phenylketene in refluxing xylenes gave the tricyclic system **61a** in 20% yield. The reaction was remarkably clean, with ^{1}H NMR analysis of the crude reaction mixture showing only the presence of the starting amide **56** and the pyridinone **61a**. The formation of **61a**



involved an initial tautomerization of the intermediate 1,3-oxazine-4,6-dione **57a** to the betaine **58a**, which then underwent cycloaddition to the cycloadduct **59a**. Loss of CO_2 resulted in **61a**. A similar reaction occurred between **56** and ethylmalonyl dichloride, giving **61b** in 99% yield. This type of tautomerism is believed to account for the cycloaddition behavior of several substituted pyrimidine-4,6-diones[18] and has been observed[19] in intermolecular cycloadditions involving oxazole derivatives and also with 3-hydroxypyrimidines.[20] An alternative mechanism involving a Diels–Alder cycloaddition to a tautomeric 4-hydroxy-1,3-oxazin-6-one is also possible.

A similar reaction occurred with 2-(propargyloxy)benzamide (**62**) and (chlorocarbonyl)phenylketene, resulting in the pyridinone **66a** (36%), and with ethylmalonyl dichloride **66b** (54%) was obtained. These reactions of benzamides demonstrate the general nature of this cycloaddition approach, which is unique in going from a substituted benzene to a tricyclic ricyclic system in what is essentially a "one-pot" reaction.



III. Stereochemical Aspects

A. Stereochemistry of the Cycloaddition Reaction. No definitive evidence is available[8] that establishes the concerted nature of 1,4-dipolar cycloadditions in general. The symmetry of the HOMO and LUMO shows[14] them to be suitable candidates for cycloaddition with 2π components. In these present cycloadditions the absence of stereoisomers in the initial cycloadducts suggests that there is no equilibrium between the initial cycloadduct and the betaine. The length of the dipolarophilic side chain is critical for the cycloaddition and regioisomers are not observed. Consequently, only two transition states need be considered for each 1,4-dipolar cycloadduct, with transition-state factors such as conformational practicality and steric demand most likely controlling the stereochemical outcome of the cycloaddition. A molecular model (Dreiding) shows parallel-plane approach can be achieved from a readily accessible conformation for both the exo and endo transition states (Scheme I) and both have approximately the same degree of steric demand.

Energy minimizations have found applications in other cycloaddition chemistry[21] but use of this approach[22] for the various intramolecular cycloadducts described above gave no clear-cut results. We believe that a complex balance of steric approach control and product development is operative in controlling the stereochemistry of these cycloadditions.

B. Stereochemistry of the 1,5-H Shift. The *trans*-olefinic amides[5] **67a** and **67b** and (chlorocarbonyl)-phenylketene in benzene/Et_3N at 55 °C gave the cycloadducts **69a** (28%) and **69b** (39%), and their structures were assigned on the basis of their characteristic ^{1}H NMR data, with no chemical shift being observed for an H_8 endo proton. A cycloadduct **19** with a structure similar to **69a** and **69b** was also isolated from the *trans*-olefinic betaine **17**.

Cycloadducts **69a** and **69b** were ideal candidates for determining the stereochemistry of the rearrangement in

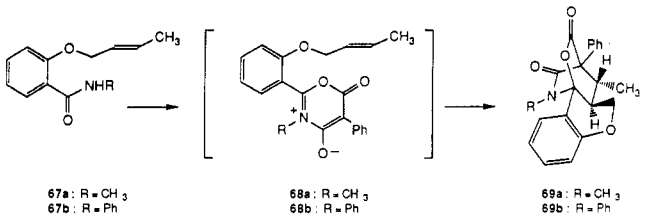
(18) For example, see: Sammes, P. G.; Brumridge, S. M.; Street, L. J. *J. Chem. Soc., Chem. Commun.* **1975**, 502. Davies, L. B.; Sammes, P. G.; Watt, R. A. *J. Chem. Soc., Chem. Commun.* **1977**, 663.

(19) Potts, K. T.; Marshall, J. *J. Chem. Soc., Chem. Commun.* **1972**, 1000.

(20) Banerji, T.; Dennis, N.; Katritzky, A. R. *J. Chem. Soc., Perkin Trans. 1* **1976**, 2334. Dennis, N.; Katritzky, A. R.; Parton, S. K. *J. Chem. Soc., Perkin Trans. 1* **1976**, 2285.

(21) For related examples, see: Brown, F. K.; Houk, K. N. *Tetrahedron Lett.* **1984**, 4609. Marshall, J. A.; Grote, J.; Andia, J. E. *J. Am. Chem. Soc.* **1987**, *109*, 1186. Wang, C. L.; Ripka, W. C.; Confalone, P. N. *Tetrahedron Lett.* **1984**, 4613.

(22) PC Model/MMX Software was used (Serena Software, Bloomington, IN).



67a: R = CH_3
67b: R = Ph

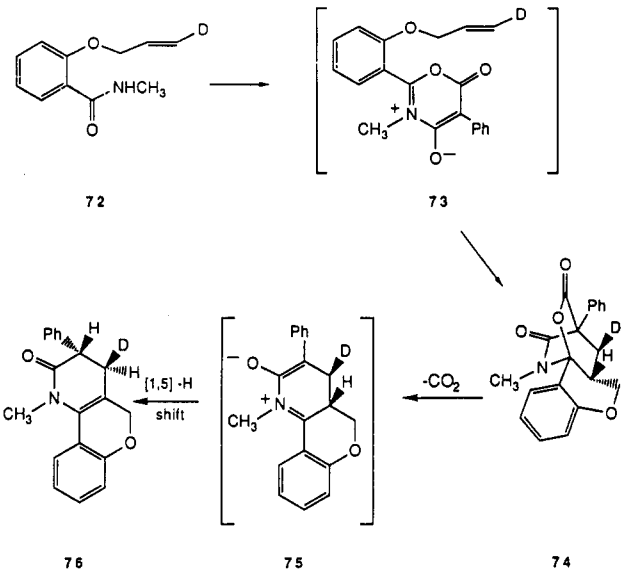
68a: R = CH_3
68b: R = Ph

69a: R = CH_3
69b: R = Ph

the 1,3-oxazinium cycloadducts, and thermolysis of **69a** and **69b** should each produce a single product if the stereochemistry of the 1,5-H shift were retained. This was not the case, however; heating cycloadducts **69a** and **69b** at 200 °C until the evolution of CO_2 had ceased produced mixtures of products. The diastereomers **24a** and **24b**, obtained from **69b**, were separated and fully characterized, and their ^1H NMR spectra showed that the relative ratio of product **24a** to **24b** was independent of the solvent used or the reaction temperature employed. These two products were not interconvertible. Similar results were obtained on heating the cycloadduct **69a**, a mixture of diastereomers **71a** and **71b** (1.0:4.7) resulting. The major isomer **71b** was thermally unstable and on heating for extended periods deep-seated decomposition occurred, resulting in a complex mixture of products. It was also sensitive to silica gel chromatography, undergoing decomposition if allowed to remain in contact with silica gel for extended periods. The **71a**:**71b** ratio observed was independent of the temperature or the solvent used in their preparation, and, for the highest conversion, the reaction should be carried out at high temperature utilizing a fast reaction time to avoid decomposition of the product **71b** which will occur at moderate temperature in solution before the decomposition of the 1:1 cycloadduct **69a** is completed. Heating a sample of **71a** for extended periods caused no change.

The structures of the diastereomers were assigned based on the characteristic[13,23] coupling constants of the H_3 and H_4 protons. The major isomers **24b** and **71b** showed J_{H_3,H_4} = 3.1 Hz, while the minor isomers **24a** and **71a** showed J_{H_3,H_4} = 5.3 and 5.4 Hz, respectively, consistent with protons in this type of trans relationship. Similar results have been observed in dienamide photochemistry. Kanaoka[24] and Ninomoya[12] independently showed that when intermediates such as **23** and **70** were relatively long-lived, protonation occurred and mixtures of isomers in which cis products predominated were obtained.

The two-step process in this sigmatropic 1,5-H shift is the result of the methyl group being on the same face as the migrating hydrogen; steric interaction prevents good orbital overlap, thus blocking a concerted process. Further evidence on this point was obtained by considering the rearrangement of the cycloadduct **74**, which is free from the steric constraints induced by the methyl group but has a reference point for determining the relative stereochemistry of the 1,5-H shift. This compound was synthesized from the reaction of (*E*)-3-deuterioallyl bromide, prepared from 3-deuteriopropargyl alcohol[25] by the procedure of McMichael,[26] with *N*-methylsalicylamide to give the labeled amide **72**. The conversion of **72** into the cycloadduct **74** with (chlorocarbonyl)phenylketene and triethylamine occurred in benzene at 50 °C. The cycloadduct **74** was thermally sensitive, and care had to be taken on reaction workup that decomposition did not occur. The structure of **74** was assigned on the basis of its ^1H NMR data, the chemical shift for an exo H_8 being absent in the spectrum of this cycloadduct. When a solution of **74** was refluxed overnight in benzene, a single product **76** was obtained. The structure of **76** was assigned based on the characteristic trans-coupling J_{H_3,H_4} = 9.2 Hz. In this instance the methyl group in the 4-position did not interfere with orbital overlap and the 1,5-H shift occurred with retention of stereochemistry.



72 73 76 75 74

Experimental Section[27]

General Procedure for the Preparation of *anhydro*-2-[2-(Substituted-oxy)phenyl]-3,5-diphenyl-6-hydroxy-4-oxo-4*H*-1,3-thiazinium Hydroxides 8, 10, 11, and 16. (Chlorocarbonyl)phenylketene (1 equiv) was added to a solution of the appropriate thioamide (1 equiv) in dry benzene. The reaction mixture was stirred for 4 h before Et_3N (1 equiv) was added, and stirring was then continued for an additional 4 h. The crude reaction mixture was filtered, the collected material was washed with benzene, and the filtrate was concentrated under reduced pressure, leaving an orange material that was recrystallized from an appropriate solvent.

Preparation of Precursor [2-(Substituted-oxy)phenyl]-amides 35, 39, 52a,b, 56, 62, 67a,b, and 72. Compounds **35**, **52a,b**, and **67b** were prepared as described previously.[5] The following were also prepared by this general method.

2-(Allyloxy)-*N*-methylbenzamide (39) crystallized from hot hexane as colorless needles: 90%, mp 41–42 °C; IR (KBr) 3350

(23) Ninomoya, I.; Naito, T.; Mori, T. *Tetrahedron Lett.* **1969**, 3643. Oppolzer, W.; Keller, K. *J. Am. Chem. Soc.* **1971**, *93*, 3836.
(24) Kanaoka, Y.; Itoh, K.; Hatanaka, Y.; Flippen, J. L.; Karle, I. L.; Witkop, B. *J. Org. Chem.* **1975**, *40*, 3001.
(25) Coufignal, R.; Gaudemar, M. *Bull. Soc. Chim. Fr.* **1969**, 3218.
(26) McMichael, K. D. *J. Am. Chem. Soc.* **1967**, *89*, 2943. Katzenwellenbogen, J. A.; Crumrine, A. L. *J. Am. Chem. Soc.* **1976**, *98*, 4925.

(27) Spectral characterizations were carried out on the following instruments: infrared spectra, Perkin-Elmer Model 298 or 337 grating infrared spectrophotometer; ^1H NMR spectra, Perkin-Elmer R600 or Varian XL-200 spectrometer with tetramethylsilane as an internal standard; ^{13}C NMR, Varian XL-200 spectrometer at 50.3 MHz with tetramethylsilane as an internal standard; mass spectra, Hewlett-Packard GC–MS system Model 5987A spectrometer. All melting points were determined in capillaries by using a Thomas-Hoover capillary melting point apparatus for samples melting below 200 °C or a Mel-Temp apparatus and are uncorrected. Evaporations were carried out under reduced pressure with a Büchi rotary evaporator. Microanalyses were performed by Atlantic Microlab, Inc., Atlanta, GA, or Robertson Laboratory, Inc., Madison, NJ. Anhydrous solvents were prepared as follows: tetrahydrofuran (THF), stored over potassium hydroxide, refluxed and distilled with either metallic potassium or sodium/benzophenone; dimethylformamide (DMF), acetonitrile, and methylene chloride, stored over 3-Å molecular sieves and decanted; toluene, benzene, hexane, xylenes, and diethyl ether, stored over metallic sodium for a minimum of 12 h and decanted. Nitrogen was dried by passage through an anhydrous calcium sulfate tower (7 × 50 cm). All reactions requiring anhydrous conditions were carried out under a positive pressure of dry nitrogen in a flame-dried apparatus. Separations were performed with silica gel or alumina gravity or flash columns, preparative thin-layer plates, or a Waters Prep 500A HPLC system.

(NH), 1615 (CO) cm^{-1}; ^1H NMR ($CDCl_3$) δ 3.02 (d, 3, NCH_3), 4.68 (d, 2, OCH_2), 5.41 (m, 2, $CHCH_2$), 6.10 (m, 1 CH), 7.92 (br s, 1, NH), 6.94–8.26 (m, 4, aromatic); mass spectrum (CI pos), [M^+ + 1] 192 (100%).

Anal. Calcd for $C_{11}H_{13}NO_2$: C, 69.09; H, 6.85; N, 7.33. Found: C, 69.04; H, 6.87; N, 7.27.

(*E*)-*N*-Methyl-2-[(1-deuterioallyl)oxy]benzamide (72) separated from *n*-hexane as colorless needles: 59%, mp 37–38 °C; IR (KBr) 1620 (CO) cm^{-1}; ^1H NMR ($CDCl_3$) δ 3.00 (d, 3, J_{NH,CH_3} = 4.9 Hz, CH_3), 4.68 (d, 2, J_{H,OCH_2} = 5.5 Hz, OCH_2), 5.40 (m, 1, CHCD*H*), 6.08 (m, 1, $J_{CH,CDH}$ = 17.6 Hz, *CH*CDH), 6.92–8.28 (m, 4, aromatic), 7.94 (br s, 1, NH); mass spectrum, M^+ 192 (4%).

Anal. Calcd for $C_{11}H_{12}DNO_2$: C, 68.73; H, 7.33; N, 7.29. Found: C, 68.84; H, 6.99; N, 7.21.

(*E*)-2-(Crotyloxy)-*N*-methylbenzamide (67a) was obtained as colorless prisms from *n*-hexane: 66%, mp 59–60 °C; IR (KBr) 1635 (CO) cm^{-1}; ^1H NMR ($CDCl_3$) δ 1.79 (d, 3, J_{CH,CH_3} = 6.1 Hz, CH_3), 3.00 (d, 3, J_{NH,CH_3} = 4.9 Hz, NCH_3), 4.60 (d, 2, J_{CH,OCH_2} = 5.4 Hz, OCH_2), 5.86 (m, 2, $J_{CH,CH}$ = 15.5 Hz, CHCH), 6.94–8.26 (m, 5, aromatic and NH); mass spectrum (CI pos), [M^+ + 1] 206 (7%).

Anal. Calcd for $C_{12}H_{15}NO_2$: C, 70.22; H, 7.37; N, 6.82. Found: C, 70.30; H, 7.42; N, 6.78.

2-(Allyloxy)benzamide (56) gave colorless prisms from ethyl acetate: 93%, mp 86–87 °C (lit.[28] mp 88 °C); IR (KBr) 1620 (CO) cm^{-1}; ^1H NMR ($CDCl_3$) δ 4.70 (d, 2, OCH_2), 5.40 (m, 2, $CHCH_2$), 6.09 (m, 1, CH), 6.41 (s, 1, NH), 7.00–8.25 (m, 4, aromatic), 7.82 (s, 1, NH); mass spectrum (CI pos), [M^+ + 1] 178 (100%).

2-(Propargyloxy)benzamide (62) crystallized from methanol as colorless needles: 90%, mp 148–149 °C (lit.[29] mp 150–151 °C); IR (KBr) 2100 (C≡C), 1655 (CO) cm^{-1}; ^1H NMR ($CDCl_3$) δ 2.61 (t, 1, CC≡H), 4.85 (d, 2, OCH_2), 6.03 (br s, 1, NH), 7.05–8.26 (m, 5, aromatic and NH); mass spectrum (CI pos), [M^+ + 1] 176 (100%).

Preparation of (*E*)-*anhydro*-2-[2-(Crotyloxy)phenyl]-3,5-diphenyl-6-hydroxy-4-oxo-4*H*-1,3-thiazinium Hydroxide (17). A solution of (*E*)-2-(crotyloxy)thiobenzanilide (1.72 g, 6.10 mmol) in dry benzene was treated with (chlorocarbonyl)-phenylketene (1.10 g, 6.10 mmol) and stirred overnight. The separated material was collected, washed with benzene, and then recrystallized from acetone from which it separated as orange prisms: 1.60 g (62%), mp 178–181 °C.

Preparation of *anhydro*-3,5-Diphenyl-6-hydroxy-4-oxo-2-[2-(propargyloxy)phenyl]-4*H*-1,3-thiazinium Hydroxide (25). A solution of (chlorocarbonyl)phenylketene (0.88 g, 4.9 mmol) in dry benzene (40 mL) was treated dropwise with a solution of 2-(propargyloxy)thiobenzanilide (1.30 g, 4.90 mmol) in dry benzene (20 mL), and after 2 h Et_3N (0.49 g, 4.9 mmol) was added and stirring maintained overnight. The reaction mixture was filtered, the collected material was washed with benzene, and the filtrate was concentrated under reduced pressure to an orange residue. This residue was dissolved in a minimum volume of methylene chloride, and distilled water was added to give two layers. The organic phase was separated, dried (Na_2SO_4), and evaporated, leaving an orange solid that crystallized from *n*-hexane as bright orange prisms: 0.82 g (81%), mp 176–177 °C dec.

General Procedure for the Preparation of *anhydro*-6-Hydroxy-4-oxo-2-[2-(substituted-oxy)phenyl]-4*H*-1,3-thiazinium Hydroxides 29 and 30. A solution of carbon suboxide (95 mL/0.031 M, 2.94 mmol) in diethyl ether (100 mL) was prepared and added slowly to a solution of the appropriate thioamide (2.94 mmol) in diethyl ether (75 mL) stirred at 0 °C. On final addition of the carbon suboxide the ice bath was removed, and the temperature of the reaction mixture was allowed to rise to room temperature. The reaction mixture was stirred for an additional 36 h, during which time yellow microneedles formed; these were collected by filtration, washed with diethyl ether, dried, and used without further purification. The composition of *anhydro*-6-hydroxy-3-methyl-4-oxo-2-[2-(propargyloxy)phenyl]-4*H*-1,3-thiazinium hydroxide (**30**) was confirmed by high-resolution mass spectroscopy: calculated for $C_{14}H_{11}NO_3S$, M^+ 273.0460, found M^+ 273.0460 (ΔM^+ <1 ppm).

General Procedure for the Preparation of the Cycloadducts 9 and 19 Derived from *anhydro*-2-[2-(Allyloxy)-phenyl]-3,5-diphenyl-6-hydroxy-4-oxo-4*H*-1,3-thiazinium Hydroxide (8) and (*E*)-*anhydro*-2-[2-(Crotyloxy)phenyl]-3,5-diphenyl-6-hydroxy-4-oxo-4*H*-1,3-thiazinium Hydroxide (17). A solution of the appropriate *anhydro*-3,5-diphenyl-6-hydroxy-4-oxo-[2-(substituted-oxy)phenyl]-4*H*-1,3-thiazinium hydroxide in dry toluene was stirred and heated under reflux for 3 h. Removal of the solvent left a colorless solid, which was recrystallized from ethanol. The cycloadduct **9** was obtained as colorless plates: 1.24 g (83%), mp 198–200 °C dec; IR (KBr) 1660 (CO) cm^{-1}; ^1H NMR ($CDCl_3$) δ 2.22 (dd, 1, $J_{H_{8gem}}$ = 12.9 Hz, J_{H_{8b},H_7} = 4.9 Hz, H_{8b}), 3.23 (m, 2, J_{H_{8a},H_7} = 11.6 Hz, H_{8a} and H_7), 4.27 (m, 1, $J_{H_{8gem}}$ = 11.6 Hz, J_{H_{9b},H_7} = 11.4 Hz, H_{9b}), 4.53 (dd, 1, J_{H_{8a},H_7} = 4.3 Hz, H_{9a}), 6.50–7.50 (m, 14, aromatic); mass spectrum (CI pos) [M^+ + 1] 414 (25%), 354 (100%) {[M^+ + 1] – COS}.

Anal. Calcd for $C_{25}H_{19}NO_3S$: C, 72.62; H, 4.63; N, 3.39. Found: C, 72.61; H, 4.67; N, 3.36.

The cycloadduct **19** formed colorless needles (ethanol): 0.84 g (84%), mp 194–196 °C dec; IR (KBr) 1650 (CO) cm^{-1}; ^1H NMR ($CDCl_3$) δ 1.42 (d, 3, J_{CH_3,H_8} = 6.8 Hz, CH_3), 2.70 (m, 1, J_{H_8,H_7} = 4.6 Hz, H_8), 2.92 (m, 1, H_7), 4.35 (t, 1, $J_{H_{9gem}}$ = 11.3 Hz, J_{H_{9b},H_7} = 10.9 Hz, H_{9b}), 4.56 (dd, 1, J_{H_{9a},H_7} = 7.4 Hz, H_{9a}), 6.55–7.44 (m, 14, aromatic); mass spectrum (EI) M^+ 428 (59%), 396 (24%) [M^+ – S], 368 (100%) [M^+ – COS].

Anal. Calcd for $C_{26}H_{21}NO_3S$: C, 73.04; H, 4.95; N, 3.28. Found: C, 73.11; H, 4.98; N, 3.23.

General Procedure for the Preparation of 3-Phenyl-2-[2-(substituted-oxy)phenyl]-4(1*H*)-quinolones 14, 15, and 20. A solution of the appropriate *anhydro*-3,5-diphenyl-6-hydroxy-4-oxo-2-[2-(substituted-oxy)diphenyl]-4*H*-1,3-thiazinium hydroxide in dry toluene was stirred and heated under reflux overnight. The reaction mixture was cooled to room temperature and filtered, and the collected material was washed with toluene and recrystallized from an appropriate solvent. Quinolone **14** separated from chloroform–*n*-hexane as colorless needles: 0.05 g (23%), mp 262–263 °C; IR (KBr) 1615 (CO) cm^{-1}; ^1H NMR (DMSO-d_6) δ 2.34 (m, 2, OCH_2CH_2), 3.92 (t, 2, OCH_2), 4.96 (m, 2, $CHCH_2$), 5.74 (m, 1, CH), 6.83–8.18 (m, 13, aromatic), 11.77 (s, 1, NH); mass spectrum (CI pos), [M^+ + 1] 368 (100%).

Anal. Calcd for $C_{25}H_{21}NO_2$: C, 81.72; H, 5.76; N, 3.81. Found: C, 81.52; H, 5.91; N, 3.71.

Quinolone **15** crystallized from chloroform–*n*-hexane as colorless needles: 0.18 g (21%), mp 252–254 °C; IR (KBr) 1620 (CO) cm^{-1}; ^1H NMR ($CDCl_3$) δ 1.79 (m, 2, CH_2), 2.09 (m, 2, OCH_2CH_2), 3.91 (t, 2, OCH_2), 4.94 (m, 2, $CHCH_2$), 5.73 (m, 1, CH), 6.48–8.40 (m, 13, aromatic), 8.61 (s, 1, NH); mass spectrum (CI pos), [M^+ + 1] 382 (100%).

Anal. Calcd for $C_{26}H_{23}NO_2$: C, 81.86; H, 6.08; N, 3.67. Found: C, 81.73; H, 6.12; N, 3.63.

Quinolone **20** separated from dichloromethane as colorless microneedles: 0.10 g (23%), mp 259–260 °C; IR (KBr) 1600 (CO) cm^{-1}; ^1H NMR ($CDCl_3$) δ 1.70 (s, 3, CH_3), 4.35 (s, 2, OCH_2), 4.92 (d, 2, CH_2), 6.75–8.43 (m, 13, aromatic) 8.49 (s, 1 NH); mass spectrum (CI pos), [M^+ + 1] 368 (100%).

Anal. Calcd for $C_{25}H_{21}NO_2$: C, 81.72; H, 5.76; N, 3.81. Found: C, 81.52; H, 5.82; N, 3.77.

3,4-Dihydro-1,3-diphenyl-5*H*-benzo[*h*]pyrano[4,3-*b*]-pyridin-2(1*H*)-one (21). The cycloadduct **9** obtained from *anhydro*-2-[2-(allyloxy)phenyl]-3,5-diphenyl-6-hydroxy-4-oxo-4*H*-1,3-thiazinium hydroxide (**8**) (1.0 g, 2.4 mmol) was heated at 200 °C until the evolution of carbonyl sulfide could no longer be detected. The residue crystallized on standing, and recrystallization from methanol gave colorless plates: 0.65 g (76%), mp 150–152 °C.

Diastereoisomers of 3,4-Dihydro-1,3-diphenyl-4-methylbenzo[*h*]pyrano[4,3-*b*]pyridin-2(1*H*)-one (24a,b). The cycloadduct **19** obtained from (*E*)-*anhydro*-2-[2-(crotyloxy)-phenyl]-3,5-diphenyl-6-hydroxy-4-oxo-4*H*-1,3-oxazinium hydroxide (0.15 g, 0.36 mmol) was heated under partial vacuum (30 mm) at 190 °C until the evolution of CO_2 had ceased. The cooled residue was dissolved in ethyl acetate and purified by preparative chromatography (silica gel, eluted with a mobile phase containing 85% *n*-hexane–15% ethyl acetate, four developments being necessary to obtain complete separation). The trans isomer eluted

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first and formed colorless cubes from *n*-pentane: 0.01 g (8%), mp 162–164 °C.

The cis isomer eluted second and formed colorless microprisms from *n*-hexane: 0.05 g (39%), mp 164–166 °C.

Preparation of 1,3-Diphenyl-5*H*-benzo[*h*]pyrano[4,3-*b*]-pyridin-2(1*H*)-one (27). A solution of *anhydro*-3,5-diphenyl-6-hydroxy-4-oxo-2-[2-(propargyloxy)phenyl]-4*H*-1,3-thiazinium hydroxide (**25**) (0.75 g, 1.82 mmol) in dry toluene (30 mL) was stirred and heated at 105 °C for 1.5 h. Removal of the solvent under reduced pressure gave a yellow solid that formed yellow microneedles from ethanol: 0.42 g (66%), mp 167–168 °C.

1-Phenyl-5*H*-benzo[*h*]pyrano[4,3-*b*]pyridin-2(1*H*)-one (31). *anhydro*-6-Hydroxy-4-oxo-3-phenyl-2-[2-(propargyloxy)-phenyl]-4*H*-1,3-thiazinium hydroxide (**29**) (0.36 g, 1.1 mmol) was added quickly to refluxing toluene. After the mixture was stirred and heated under reflux for 90 min, the oil bath was removed and the reaction mixture allowed to cool. The solvent was decanted from a small amount of intractable tarry material and concentrated under reduced pressure to give a brown oil. Column chromatography (silica gel, eluted with ethyl acetate, the first band being collected and the resultant material chromatographed again using the same procedure) of this material gave an orange oil which was a mixture of 2-(propargyloxy)thiobenzanilide and the desired cycloadduct **31**. Separation of these compounds was accomplished by preparative plate chromatography (silica gel, eluted with a mobile phase containing 60% ethyl acetate–40% *n*-hexane). The first fraction contained thioamide which formed yellow prisms from *n*-hexane: 0.06 g (21%), mp 69–70 °C. This material was identical in all respects with an authentic sample. The second fraction contained the desired cycloadduct **31**, which was isolated as hygroscopic, pale yellow needles by recrystallization from *n*-hexane: 0.03 g (10%), mp 192–194 °C.

1-Methyl-5*H*-benzo[*h*]pyrano[4,3-*b*]pyridin-2(1*H*)-one (32). *anhydro*-6-Hydroxy-3-methyl-4-oxo-2-[2-(propargyloxy)-phenyl]-4*H*-1,3-thiazinium hydroxide (**30**) (0.45 g, 1.65 mmol) was added quickly to boiling toluene (50 mL). A vigorous reaction occurred, during which the color of the resultant solution changed from orange to dark brown. After refluxing for 20 min, the reaction mixture was cooled and the solvent concentrated under reduced pressure to a brown oil. Purification of this material by column chromatography (silica gel, eluted with a solution containing 50% ethyl acetate–50% dichloromethane) gave an initial yellow fraction which was concentrated to a yellow oil. This material crystallized from *n*-hexane as yellow microneedles: 0.23 g (66%), mp 100–102 °C.

General Procedure for the Preparation of Cycloadducts 41, 69a,b, and 74 Derived from *anhydro*-6-Hydroxy-3-methyl-4-oxo-5-phenyl-2-[2-(substituted-oxy)phenyl]-4*H*-1,3-oxazinium Hydroxides. A solution of the appropriate amide (7.0 mmol) in dry benzene (40 mL) was stirred at 45 °C. (Chlorocarbonyl)phenylketene (7.0 mmol) in benzene (10 mL) was added to this solution, and stirring was continued for 10 min before Et_3N (7.0 mmol) was added. The reaction mixture was stirred for 1 h, cooled, and filtered, and the collected material was washed with benzene. The benzene filtrate was concentrated under reduced pressure to a brown oil which crystallized from an appropriate solvent. Cycloadduct **41** crystallized from methylene chloride–diethyl ether as colorless prisms: 44%, mp 154–155 °C dec; IR (KBr) 1685, 1765 (CO) cm^{-1}; ^1H NMR ($CDCl_3$) δ 1.99 (dd, 1, J_{gem} = 12.0 Hz, $J_{H_7,H_{8b}}$ = 5.3 Hz, H_{8b}), 2.81 (s, 3, NCH_3), 2.99 (m, 2, $J_{H_7,H_{8a}}$ = 10.0 Hz, H_7, H_{8a}), 3.86 (t, 1, J_{gem} = 11.8 Hz, $J_{H_7,H_{9b}}$ = 11.92 Hz, H_{9b}), 4.55 (dd, 1, $J_{H_7,H_{9a}}$ = 4.3 Hz, H_{9a}), 6.99–7.74 (m, 9, aromatic); mass spectrum CI (pos), $[M^+ + 1]$ 336 (3%), 292 (100%) $[M^+ + 1 - CO_2]$.

Anal. Calcd for $C_{20}H_{17}NO_4$: C, 71.63; H, 5.12; N, 4.17. Found: C, 71.51; H, 5.13; N, 4.13.

Cycloadduct **69a** crystallized from methylene chloride–diethyl ether, forming colorless microneedles: 39%, mp 192 °C dec; IR (KBr) 1760, 1680 (CO) cm^{-1}; ^1H NMR ($CDCl_3$) δ 1.21 (d, 3, J_{H_8,CH_3} = 6.7 Hz, CH_3), 2.48 (m, 1, J_{H_7,H_8} = 5.8 Hz, H_8), 2.64 (m, 1 H_7), 2.78 (s, 3, NCH_3), 3.95 (t, 1, J_{H_9,H_7} = 12.2 Hz, J_{gem} = 11.9 Hz, H_9), 4.51 (dd, 1, J_{H_9,H_7} = 4.5 Hz, H_9), 6.96–7.65 (m, 9, aromatic); mass spectrum (CI pos), $[M^+ + 1]$ 350 (1.7%), 306 (5%) $\{[M^+ + 1] - CO_2\}$.

Anal. Calcd for $C_{21}H_{19}NO_4$: C, 72.19; H, 5.48; N, 4.01. Found: C, 72.23; H, 5.49; N, 3.97.

Cycloadduct **69b** crystallized from diethyl ether, affording colorless prisms: 28%, mp 168 °C dec; IR (KBr) 1695, 1765 (CO) cm^{-1}; ^1H NMR ($CDCl_3$) δ 1.24 (d, 3, J_{CH_3,H_8} = 6.7 Hz, CH_3), 2.64 (m, 1, J_{H_8,H_7} = 6.1 Hz, H_8), 2.70 (m, 1, H_7), 4.47 (t, 1, J_{H_{9b},H_7} = 13.3 Hz, H_{9b}), 4.66 (dd, 1, J_{H_{9a},H_7} = 7.1 Hz, J_{gem} = 11.3 Hz, H_{9a}), 6.66–7.77 (m, 14, aromatic); mass spectrum (CI pos), $[M^+ + 1]$ 412 (100%).

Anal. Calcd for $C_{26}H_{21}NO_4$: C, 75.90; H, 5.15; N, 3.40. Found: C, 76.02; H, 5.19; N, 3.36.

Cycloadduct **74** crystallized from diethyl ether as colorless microneedles and decomposed on attempted further purification: 44%, mp 146–148 °C; IR (KBr) 1760, 1660 (CO) cm^{-1}; ^1H NMR ($CDCl_3$) δ 1.97 (d, 1, J_{H_{8b},H_7} = 6.3 Hz, H_{8b}), 2.82 (s, 3, NCH_3), 2.93–3.08 (m, 1, H_7), 3.86 (t, 1, J_{gem} = 11.6 Hz, J_{H_{9b},H_7} = 12.5 Hz, H_{9b}), 4.49 (dd, 1, J_{H_{9a},H_7} = 4.5 Hz, H_{9a}), 6.97–7.66 (m, 9, aromatic); mass spectrum (EI), M^+ 336 (1%), 292 (65%) $[M^+ - CO_2]$, 264 (57%) $[M^+ - CO_2 - CO]$, 118 (100%) $[C_8H_6O]$; high-resolution mass spectrum, calculated for $C_{20}H_{16}DNO_4$, M^+ 336.1220, found M^+ 336.1214 (ΔM^+ 2 ppm).

General Procedure for the Preparation of Cycloadducts 45 and 49 from *anhydro*-2-[2-(Allyloxy)phenyl]-5-ethyl-6-hydroxy-3-substituted-4*H*-1,3-oxazinium Hydroxide (68a,b). A solution of the appropriate amide (4.0 mmol) and Et_3N (8.0 mmol) in benzene (50 mL) was stirred at 50 °C. Ethylmalonyl dichloride (4.0 mmol) was added and after 1 h, the reaction mixture was cooled, the separated materials were removed by filtration, and the filtrate was concentrated under reduced pressure, leaving a tan solid. Recrystallization of this material from methanol gave colorless needles of **45**: 30%, mp 162–163 °C; IR (KBr) 1655, 1675 (CO) cm^{-1}; ^1H NMR ($CDCl_3$) δ 1.19 (t, 3, J_{CH_3,CH_2} = 7.5 Hz, CH_2CH_3), 1.63 (dd, 2, $J_{H_{8gem}}$ = 13.3 Hz, J_{H_{8b},H_7} = 6.7 Hz, H_{8b}), 2.12 (q, 2, CH_2CH_3), 2.43 (dd, 1, J_{H_{8a},H_7} = 9.9 Hz, H_{8a}), 3.02 (m, 1, H_7), 4.29 (t, 1, J_{H_{9b},H_7} = 12.1 Hz, $J_{H_{9gem}}$ = 11.6 Hz, H_{9b}), 4.54 (dd, 1, J_{H_{9a},H_7} = 4.9 Hz, H_{9a}), 6.62–7.26 (m, 9, aromatic); mass spectrum (CI pos), $[M^+ + 1]$ 350 (25%), 91 (100%) [PhN].

Anal. Calcd for $C_{21}H_{19}NO_4$: C, 72.19; H, 5.48; N, 4.01. Found: C, 71.99; H, 5.47; N, 3.90.

Cycloadduct **49** crystallized from methanol as colorless needles: 52%, mp 166–167 °C; IR (KBr) 1770, 1690 (CO) cm^{-1}; ^1H NMR ($CDCl_3$) δ 1.17 (t, 3, CH_2CH_3), 1.40 (dd, 1, $J_{H_{8b},H_{7a}}$ = 6.6 Hz, $J_{H_{8gem}}$ = 12.6 Hz, H_{8b}), 2.05 (q, 2, CH_2CH_3), 2.31 (dd, 1, $J_{H_7,H_{8a}}$ = 9.8 Hz, H_{8a}), 2.75 (s, 3, NCH_3), 2.88 (m, 1, H_7), 3.77 (t, 1, J_{H_{9b},H_7} = 12.4 Hz, $J_{H_{9gem}}$ = 11.1 Hz, H_{9b}), 4.37 (dd, 1, J_{H_{8a},H_7} = 4.5 Hz, H_{9a}), 6.93–7.57 (m, 9, aromatic); mass spectrum (CI pos), $[M^+ + 1]$ 288 (100%).

Anal. Calcd for $C_{16}H_{17}NO_4$: C, 66.89; H, 5.96; N, 4.88. Found: C, 66.96; H, 5.94; N, 4.75.

3,4-Dihydro-1,3-diphenyl-5*H*-benzo[*h*]pyrano[4,3-*b*]-pyridin-2(1*H*)-one (21). (Chlorocarbonyl)phenylketene (1.27 g, 7.0 mmol) was added dropwise to a solution of 2-(allyloxy)-benzanilide (1.78 g, 7.0 mmol) in dry benzene (50 mL) stirred at 55 °C. After 10 min Et_3N (0.71 g, 7.0 mmol) was added, and stirring was continued for an additional 1 h. The separated materials were removed by filtration and washed well with benzene. Concentration of the solvent under reduced pressure gave a red oil which crystallized from ethyl acetate at 0 °C. A final crystallization from ethanol afforded colorless plates: 0.21 g (8%), mp 149–150 °C.

1-Methyl-3-phenyl-5*H*-benzo[*h*]pyrano[4,3-*b*]pyridin-2-(1*H*)-one (43). Method A. (Chlorocarbonyl)phenylketene (0.70 g, 3.9 mmol) in benzene (10 mL) was added to a boiling solution of 2-(allyloxy)-*N*-methylbenzamide (0.74 g, 3.9 mmol) in xylenes (50 mL). After 10 min the reaction mixture was cooled and the solvent removed under reduced pressure to leave a colorless solid which formed colorless microprisms from benzene: 0.48 g (43%), mp 169–171 °C.

Method B. A solution of the cycloadduct **41** (0.75 g, 2.24 mmol) in dry benzene (50 mL) was stirred and heated under reflux for 24 h. The reaction mixture was cooled, and removal of the solvent left a colorless residue which separated from diethyl ether as colorless plates: 0.55 g (85%), mp 169–171 °C.

Diastereoisomers of 3,4-Dihydro-1,4-dimethyl-3-phenyl-5*H*-benzo[*h*]pyrano[4,3-*b*]pyridin-2(1*H*)-one (71a,b). The cycloadduct **69a** obtained from (*E*)-*anhydro*-2-[2-(crotyloxy)-phenyl]-6-hydroxy-3-methyl-4-oxo-5-phenyl-4*H*-1,3-oxazinium hydroxide (**68**) (0.30 g, 0.86 mmol) was heated at 200 °C until the

evolution of carbon dioxide was no longer observed. The residue was dissolved in dichloromethane and purified by preparative chromatography (silica gel, eluted with a mobile phase containing 90% *n*-hexane–10% ethyl acetate, three developments being necessary to obtain separation). The trans isomer **71a** eluted first and formed colorless prisms from pentane: 0.03 g (11%), mp 149–151 °C.

The second fraction was collected and concentrated under reduced pressure to give the cis-isomer **71b** as an unstable colorless oil: 0.18 g (69%).

4-Deuterio-3,4-dihydro-1-methyl-3-phenyl-5*H*-benzo[*h*]pyrano[4,3-*b*]pyridin-2(1*H*)-one (76). The cycloadduct **74** of *anhydro*-2-[2-[(1-deuterioallyl)oxy]phenyl]-6-hydroxy-3-methyl-4-oxo-5-phenyl-4*H*-1,3-oxazinium hydroxide (0.19 g, 0.56 mmol) was stirred and heated under reflux in benzene for 24 h. Concentration of the solvent under reduced pressure gave a brown oil which crystallized from methanol as colorless plates: 0.08 g (50%), mp 156–157 °C.

Preparation of 1*H*,4*H*-3-Phenylbenzo[*h*]pyrano[4,3-*b*]pyridin-2(1*H*)-one (61a). (Chlorocarbonyl)phenylketene (1.36 g, 7.5 mmol) in benzene (50 mL) was added to a boiling solution of 2-(allyloxy)benzamide (1.33 g, 7.5 mmol) in xylenes (50 mL). After 6 h the reaction mixture was cooled and a few milligrams of uncharacterizable material were removed by filtration. The filtrate was concentrated under reduced pressure to a brown oil which crystallized from diethyl ether–ethyl acetate. The crystalline material was collected, washed with ethyl acetate, and purified by preparative plate chromatography (silica gel, eluted with dichloromethane, four developments were necessary to obtain separation). The initial fraction was concentrated under reduced pressure, leaving a colorless residue which crystallized from ethyl acetate as colorless microprisms: 0.42 g (20%), mp 176–178 °C.

General Procedure for the Preparation 3,4-Dihydro-3-ethyl-1-phenyl-5*H*-benzo[*h*]pyrano[4,3-*b*]pyridin-2(1*H*)-one (51) and 3,4-Dihydro-3-ethyl-1-methyl-5*H*-benzo[*h*]pyrano[4,3-*b*]pyridin-2(1*H*)-one (47). The cycloadducts **45** and **49** of *anhydro*-2-[2-(allyloxy)phenyl]-5-ethyl-6-hydroxy-4-oxo-3-phenyl- and -3-methyl-4*H*-1,3-oxazinium hydroxides (**48** and **44**) were heated at 200 °C until the evolution of CO_2 was no longer detected. The resultant oily residue was heated with *n*-hexane, from which **51** crystallized on cooling as pale yellow microneedles: 0.20 g (77%), mp 96–68 °C.

Compound **47** also crystallized from *n*-hexane as colorless microneedles: 0.21 g (82%), mp 104–106 °C.

3,4-Dihydro-3-ethyl-5*H*-benzo[*h*]pyrano[4,3-*b*]pyridin-2(1*H*)-one (61b). A solution of 2-(allyloxy)benzamide (0.65 g, 3.7 mmol) in xylenes was stirred and heated under reflux. Ethylmalonyl dichloride was added dropwise to this solution and a vigorous reaction occurred. After the reaction mixture was heated overnight, the solvent was removed under reduced pressure, leaving a colorless solid which crystallized from methanol as colorless microneedles: 0.53 g (63%), mp 160–162 °C.

Preparation of 3-Phenyl-5*H*-benzo[*h*]pyrano[4,3-*b*]pyridin-2(1*H*)-one (66a). (Chlorocarbonyl)phenylketene (0.80 g, 4.4 mmol) was added to a boiling soluton of 2-(propargyloxy)benzamide (0.77 g, 4.4 mmol) in xylenes (50 mL). After 6 h the reaction mixture was cooled to 0 °C and filtered. Recrystallization of the collected product from ethyl acetate afforded yellow prisms: 0.44 g (36%), mp 258 °C dec.

General Procedure for the Preparation of 3-Ethyl-1-phenyl-5*H*-benzo[*h*]pyrano[4,3-*b*]pyridin-2(1*H*)-one (55b) and 3-Ethyl-1-methyl-5*H*-benzo[*h*]pyrano[4,3-*b*]pyridin-2-(1*H*)-one (55c). A solution of the appropriate amide (3.25 mmol) and benzene (50 mL) was stirred and heated under reflux. Ethylmalonyl dichloride (3.2 mmol) was added to this solution and a vigorous reaction occurred. After heating for 90 min, the reaction mixture was cooled and the solvent removed under reduced pressure to give a yellow solid. Recrystallization of this material from diethyl ether gave pale yellow microprisms of **55b**: 66%, mp 187–188 °C.

Recrystallization of **55c** from *n*-hexane gave pale yellow microneedles: 83%, mp 118–119 °C.

3-Ethyl-5*H*-benzo[*h*]pyrano[4,3-*b*]pyridin-2(1*H*)-one (66b). A solution of 2-(propargyloxy)benzamide (0.64 g, 3.67 mmol) and toluene (50 mL) was stirred and heated under reflux. Ethylmalonyl dichloride (0.62 g, 3.67 mmol) was added to this solution and heating continued for 4 h. After cooling overnight (0 °C), the precipitated materials were removed by filtration. Concentration of the filtrate under reduced pressure gave a brown oil which crystallized from methanol as pale yellow microneedles. The combined solids were recrystallized from benzene, forming pale yellow prisms: 0.45 g (54%), mp 208–211 °C.

1-Methyl-3-phenyl-5*H*-benzo[*h*]pyrano[4,3-*b*]pyridin-2(1*H*)-one (55a). A solution of *N*-methyl-2-(propargyloxy)-benzamide (0.64 g, 3.4 mmol) in dry benzene (50 mL) was stirred at 50 °C. (Chlorocarbonyl)phenylketene (0.68 g, 3.8 mmol) was added to this solution and stirring continued for 20 min before Et_3N (0.34 g, 3.4 mmol) was added. The reaction mixture was stirred for 1 h, cooled, and filtered, and the filter cake was washed with benzene (5 mL). The solvent was concentrated under reduced pressure, leaving an orange residue which crystallized from ether–methanol as yellow needles: 0.57 g (59%), mp 144–145 °C.

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