The Reaction of Dienes with Chlorosulfonyl Isocyanate[1]

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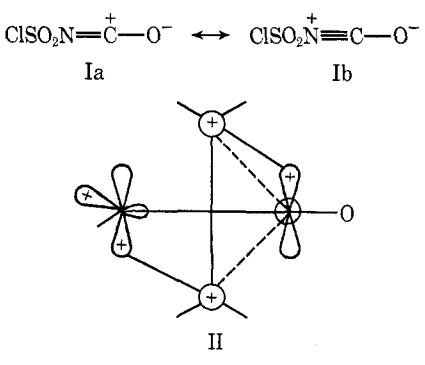
Chlorosulfonyl isocyanate (CSI) may play an antarafacial role as the $_{\pi}2_a$ component in concerted reactions with $_{\pi}2_s$ systems. It does so in additions at low temperature to such conjugated dienes as 1,3-butadiene, isoprene, 2,3-dimethyl-1,3-butadiene, the *cis,trans*-1,3-pentadiene mixture, and *trans*-1,3- and *trans,trans*-2,4-hexadiene. The β-lactam products are Markovnikov-oriented 1,2-cycloadducts in which CSI has added to the terminal double bond. In no instance was the symmetry-allowed $_{\pi}4_s + _{\pi}2_s$ reaction observed. These initially formed *N*-chlorosulfonyl-β-lactams thermally rearrange to N- and O-1,4 cycloadducts. Alternative stepwise and concerted mechanisms are proffered. Alkaline hydrolysis of the *N*-chlorosulfonyl-β-lactams in acetone-water conventionally afford NH 2-azetidinones. In methanol, solvent participation in the alkaline hydrolysis led to ring cleavage and the formation of bis esters of β-amino(*N*-sulfonic acid)carboxylic acids. Since both hydrolytic processes probably commence by displacement of Cl^- by OH^-, the intermediate sulfonic acid must be trapped by the methanol as the sulfonate ester. In the nmr spectra of 2-azetidinones, four-bond coupling was observed between NH and C-3 protons. In 4-substituted 2-azetidinones, the magnitude of J was largest to the C-3 proton trans to the C-4 substituent, while, in 4,4-disubstituted 2-azetidinones, the C-3 proton trans to the larger substituent at C-4 has the greater J value and also appears further downfield than the cis proton.

Among the compelling pieces of evidence for the (near) concerted, thermally allowed $_{\pi}2_a + _{\pi}2_s$[3] cycloaddition of chlorosulfonyl isocyanate (CSI) to certain unsaturated systems[4] is the formation of 1,2 cycloadducts between CSI and conjugated dienes.[5]

The polar chlorosulfonyl group attached to the cumulative double bond in CSI enhances the reactivity of the isocyanate group such that the carbon atom is strongly electrophilic.[6] Thus CSI should be just as favorably constituted as ketenes to play an antarafacial role as the $_{\pi}2_a$ component in concerted reactions with $_{\pi}2_s$ systems. Valence bond structure Ia does suggest vinylium ylide properties and the relevant orbital diagram II depicts the two additional bonding interactions between the π system and the low-lying $\pi^*_{C=O}$ orbital of CSI. These interactions may be weakened to the extent of the contribution of Ib where the N lone pair of electrons has been delocalized into this unoccupied orbital. In molecular orbital terms this would lower the electrophilic activity of CSI and its capacity to act as a $_{\pi}2_a$ component. The participation of CSI as a $_{\pi}2_s$ component is not facilitated, however, by the orthogonal $\pi_{C=O}$ system on the one side and probably not by the tetrahedral $d\text{–}p_{\pi SO_2Cl}$ system on the other. Thus, in the reaction between CSI and 1,3-dienes, the symmetry-allowed $_{\pi}4_s + _{\pi}2_s$ reaction was not observed.



In our initial communication,[5] we noted that the low temperature addition of CSI to 1,3-butadiene (**1**) and isoprene (**7**) afforded the 4-vinyl (**2**) and 4-methyl-4-vinyl (**8**) derivatives, respectively, of 1-chlorosulfonyl-2-azetidinone (*N*-chlorosulfonyl-β-lactams) (Scheme I). Benzenethiol–pyridine reduction and/or alkaline hydrolysis in acetone converted **2** and **8** to the more stable 4-vinyl- (**3**) and 4-methyl-4-vinyl-2-azetidinone (**9**), respectively.

Catalytic hydrogenation of **3** and **9** afforded β-lactams 4-ethyl- (**6**) and 4-ethyl-4-methyl-2-azetidinone (**12**), respectively. The latter were prepared independently *via* CSI cycloaddition to 1-butene (**4**) and 2-methyl-1-butene (**10**), respectively, followed by benzenethiol–pyridine reduction of the intermediate 1-chlorosulfonyl-2-azetidinones **5** and **11**.

Similar results from two independent groups appeared shortly thereafter,[7,8] and we followed with a possible mechanistic rationale for both the near-concerted cycloaddition process and the subsequent thermal 1,2 → 1,4 rearrangement of the initial 1-chlorosulfonyl-2-azetidinone adduct.[6]

In this concluding paper, we report on (1) CSI addition to dienes 2,3-dimethyl-1,3-butadiene (**13**), the *cis,trans*-1,3-pentadiene mixture (**19**), *trans*-1,3- (**25**), *cis,trans*-1,4- (**31**), and *trans,trans*-2,4-hexadiene (**34**); (2) long-range coupling constants in 2-azetidinones; (3) thermal rearrangement of 1-chlorosulfonyl-4-methyl-4-vinyl- (**8**) and 1 chlorosulfonyl-4-methyl-4-isopropenyl-2-azetidinone (**14**); (4) methanolysis of 1-chlorosulfonyl-

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(2) NASA Predoctoral Research Trainee, 1966–1969; taken entirely from the Ph.D. Thesis of W. C. Meyer, Fordham University, N. Y., 1970.

(3) R. B. Woodward and R. Hoffmann, *Angew. Chem., Int. Ed. Engl.*, **8**, 781 (1969).

(4) Other data in support of the one-step process include (a) the stereospecificity of CSI cycloadditions [E. J. Moriconi and J. F. Kelly, *Tetrahedron Lett.*, 1435 (1968); H. Bestian, H. Biener, K. Clauss, and H. Heyn, *Justus Liebigs Ann. Chem.*, **718**, 94 (1968)]; (b) the total retention of stereochemistry in thermal cycloreversion of β lactams to olefins *via* the $_{\sigma}2_s + _{\sigma}2_a$ route [L. A. Paquette, M. J. Wyvratt, and G. R. Allen, Jr., *J. Amer. Chem. Soc.*, **92**, 1763 (1970)]; (c) the lack of rearrangement [E. J. Moriconi and W. C. Crawford, *J. Org. Chem.*, **33**, 370 (1968)] and kinetics [E. J. Moriconi, R. Spaar, and R. Britt, IUPAC Symposium "Cycloaddition Reactions," Munich, Sept 7–10, 1970] of cycloaddition of CSI to norbornene and norbornadiene; and (d) the dominant steric control exerted by the dimethyl substituents in 7,7-dimethylnorbornene such that it fails to form a cycloadduct with CSI [ref 4c and H. C. Brown and J. H. Kawakami, *J. Amer. Chem. Soc.*, **92**, 201 (1970); H. C. Brown and K. T. Liu, *ibid.*, **92**, 3502 (1970); H. C. Brown, J. H. Kawakami, and S. Ikegami, *ibid.*, **92**, 6914 (1970)].

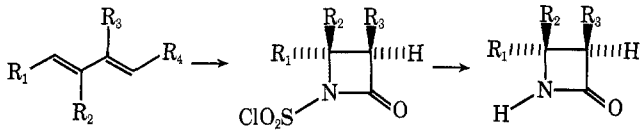
(5) E. J. Moriconi and W. C. Meyer, *Tetrahedron Lett.*, 3823 (1968).

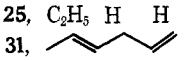
(6) E. J. Moriconi, "Mechanisms of Reactions of Sulfur Compounds," Vol. 3, Intra-Science Research Foundation, Santa Monica, Calif., 1968, p 131.

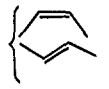
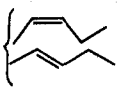
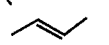
(7) Th. Haug, F. Lohse, K. Metzger, and H. Batzer, *Helv. Chim. Acta*, **51**, 2069 (1968).

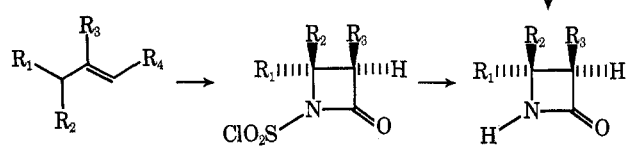
(8) P. Goebel and K. Clauss, *Justus Liebigs Ann. Chem.*, **722**, 122 (1969).

SCHEME I



	R_1	R_2	R_3	R_4
1,	H	H	H	H
7,	H	H	CH_3	H
13,	H	CH_3	CH_3	H
19,	CH_3	H	H	H
25,	C_2H_5	H	H	H
31,				
34,	CH_3	H	H	CH_3

	R_1	R_2	R_3	
2,		H	H,	3
8,		CH_3	H,	9
14,		CH_3	H,	15
20,		H	H,	21
26,		H	H,	27
32,		H	H,	33
35,		H	CH_3,	36



	R_1	R_2	R_3	R_4
4,	CH_3	H	H	H
10,	CH_3	H	CH_3	H
16,	CH_3	CH_3	CH_3	H
22,	C_2H_5	H	H	H
28,	C_3H_7	H	H	H
37,	C_2H_5	H	H	CH_3

	R_1	R_2	R_3	
5,	C_2H_5	H	H,	6
11,	C_2H_5	CH_3	H,	12
17,	i-C_3H_7	CH_3	H,	18
23,	n-C_3H_7	H	H,	24
29,	n-C_4H_9	H	H,	30
38,	n-C_3H_7	H	CH_3,	40
39,	CH_3	H	n-C_3H_7,	41

2-azetidinones; and (5) possible mechanisms for the rearrangement, methanolysis, and imino ether solvolysis reactions.

CSI Addition to Dienes.—The addition of CSI to dienes **13**, **19**, **25**, **31**, and **34** at 0–10° afforded the following 1-chlorosulfonyl-2-azetidinones, respectively: 4-methyl-4-isopropenyl- (**14**), *cis,trans*-4-prop-1-enyl mixture (**20**), 4-but-1-enyl- (**26**), *cis,trans*-4-but-2-enyl- (**32**), and 3-methyl-4-prop-1-enyl- (**35**). In general, these β-lactam-*N*-sulfonyl chlorides were unstable at room temperature and were base hydrolyzed or reduced with benzenethiol–pyridine to the more stable 2-azetidinones, respectively: **15** (57%), **21** (30%), **27** (24%), **33** (27%), and **36** (41%). Proof of structure of **15**, **21**, **27**, **33**, and **36** was achieved by catalytic hydrogenation, respectively, to 4-methyl-4-isopropyl-2-azetidinone (**18**), 4-propyl-2-azetidinone (**24**), 4-butyl-2-azetidinone (**30**), **30**, and 3-methyl-4-propyl-2-azetidinone (**40**). Each of these NH β-lactams in turn was independently prepared by the following sequence of reactions: (1) cycloaddition of CSI to 2,3-dimethyl-1-butene (**16**), 1-pentene (**22**), 1-hexene (**28**), and *trans*-2-hexene (**37**) afforded the following 1-chlorosulfonyl-2-azetidinones, respectively—4-methyl-4-isopropyl- (**17**), 4-propyl- (**23**), 4-butyl- (**29**), and a mixture of 3-methyl-4-propyl- (**38**) and 4-methyl-3-propyl- (**39**); (2) alkaline hydrolysis of these *N*-chlorosulfonyl derivatives in acetone afforded **18**, **24**, **30**, and a mixture of **40** and 4-methyl-3-propyl-2-azetidinone (**41**).

Conjugated dienes **1**, **13**, and **34** are symmetrically substituted and only one Markovnikov-oriented CSI 1,2-cycloaddition product is possible in each case. With unsymmetrical, conjugated dienes **19** and **25**, CSI addition at either the terminal or internal double bond would give rise to similarly stabilized secondary allylic carbonium ions,[9] and a mixture of cycloaddition products is possible in both cases. However, **19** led only to **20**, and **25** solely to **26**, and in each case the CSI added, in Markovnikov orientation, to the terminal double bond.

The nmr of β-lactam **21** contained two distinct multiplets arising from eight-line patterns in the range δ 4.50–4.22 and 4.12–3.88 (ratio 44:56, respectively) which integrated for a total of one proton assigned to the CHNH of a cis,trans mixture. The methyl resonance appeared as a doublet (J = 5.0 Hz) while the two vinyl protons gave rise to a complex multiplet (δ 6.05–5.22). The ring methylene protons appeared as an overlap of two similar AB patterns due to the cis,trans mixture. The nmr of its hydrogenation product, **24** was considerably simplified. *n*-Propyl resonances appeared in place of the vinyl and methyl signals. The ring methylene protons now gave rise to a single AB pattern further split into four, while the two CHNH multiplets now appeared as a single multiplet at δ 3.70–3.34.

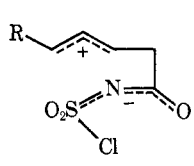
Similarly, β-lactam **27** displayed the expected multiplets for vinyl and methyl protons while the CHNH proton appeared as a doublet of triplets at δ 3.97 due to the similarity of vinyl (J = 5.00 Hz) and cis (J = 5.02 Hz) coupling constants. The hydrogenation of **27** to **30** was evidenced in the nmr spectrum by the disappearance of the vinyl resonance and an increase in the integration of alkyl methylene protons.

The cis,trans mixture of nonconjugated diene **31** afforded ultimately 4-but-2-enyl-2-azetidinone (**33**) as a 5:1 cis,trans mixture in which CSI had also added solely to the terminal double bond.

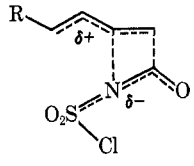
Since Hoffmann and Diehr[10] did not assign a specific structure to their 2,4-hexadiene–CSI cycloadduct, we also examined the reaction between the trans,trans isomer **34** and CSI. Benzenethiol–pyridine reduction of the initial 1-chlorosulfonyl-2-azetidinone product **35** afforded only *trans*-3-methyl-4-prop-1-enyl-2-azetidinone (**36**).[11] As noted, catalytic hydrogenation of **36** led to **40**. An alternative synthesis of **40** was achieved by the cycloaddition of CSI to 2-hexene (**37**). The expected 1-chlorosulfonyl-2-azetidinone product mixture (**38** + **39**) was hydrolyzed; analysis of the product nmr ratio indicated at 2:1 mixture of **40** and its isomer **41**.

Nmr Spectra and Long-Range Coupling of 2-Azeti-

(9) These appear either as a dipolar intermediate (*e.g.*, III) in a stepwise addition or as polar transition state (*e.g.*, IV) in a near-concerted process.



III



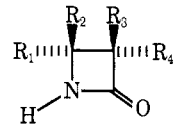
IV

(10) H. Hoffmann and H. J. Diehr, *Tetrahedron Lett.*, 1875 (1963).

(11) In the nmr, the CHNH proton of this stereospecific cis-cycloaddition product appeared as a doublet of doublets centered at δ 3.65 while the CHCO proton appeared as a quartet at δ 2.77 further split in four. Both multiplets gave a C_{H_3}–C_{H_4} coupling constant of J = 2.0 Hz (*cf.* Table I).

TABLE I

LONG-RANGE COUPLING CONSTANTS OF 2-AZETIDINONES



Compd	Registry no.	R_1	R_2	R_3	R_4	$J_{1,3}$[a]	$J_{1,4}$[a]
3		H	CH_2=CH	H	H	1.20	1.95
6		H	C_2H_5	H	H	1.24	1.90
9		CH_3	CH_2=CH	H	H	1.50[b]	
15		CH_3	CH_2=C(CH_3)	H	H	1.20[b]	
18		CH_3	$(CH_3)_2C$	H	H	1.50	1.75
21		H	CH_3CH=CH	H	H	1.24	1.88
24		H	*n*-C_3H_7	H	H	1.30	1.98
27		H	CH_3CH_2CH=CH	H	H	1.05	1.80
30		H	*n*-C_4H_9	H	H	1.10	1.80
33		H	CH_3CH=$CHCH_2$	H	H	1.10	1.70
36		H	CH_3CH=CH	CH_3	H	0.95	2.0
40		H	*n*-C_3H_7	CH_3	H	1.0	2.0
	7486-92-2	H	*i*-C_3H_7	H	H	1.16	1.95
	5661-55-2	H[c]	C_6H_5	H	H	0.9	2.4
		H[d]	C_6H_5	H	H	1.00	2.08
	30217-38-0	CH_3	$(CH_3)_3C$	H	H	1.10	1.80
	16934-12-6	H	C_6H_5	CH_3	H		2.0
	16934-13-7	H	C_6H_5	H	CH_3	0.7	
	16934-14-8	H	C_2H_5	C_2H_5	H		1.50
	16934-15-9	H	C_2H_5	H	C_2H_5	1.00	

[a] All constants were measured using first-order analysis. Those reported in hundredths were measured to ±0.02; those reported in tenths were measured to ±0.05. [b] R_3 and R_4 appear as a single doublet. [c] Data from ref 13. [d] Our data.

dinones.—The nmr spectrum of **3** appears in Figure 1 and is illustrative of the 2-azetidinones obtained from the cycloaddition of CSI to conjugated dienes.

The most notable feature of the spectrum is the AB pattern at δ 3.35–2.46 (H_{3a}, H_{3b}) which is further split by protons H_1 and H_4. The assignment of the downfield proton to H_{3b} was unequivocal, based on the magnitudes of J_{34} coupling (J_{3b4} = 5.10, J_{3a3} = 2.80 Hz).[12]

The magnitude of the J_{13} coupling constants are worthy of note. Resolvable and highly stereospecific five-bond coupling has been observed in N-substituted 2-azetidinones between the C-3 protons and the protons on the NCH_3 or $NCH_2C_6H_5$ substituents.[13] In each case the coupling was greatest to the C-3 proton cis to the ring substituent on C-4. The lone anomaly seemed to be 4-phenyl-2-azetidinone where the coupling is greatest to the proton trans to the C-4 phenyl group. The data in Table I suggest that this is a general rule to which all 2-azetidinones adhere. In addition, examination of 4,4-disubstituted 2-azetidinones, where the C-3 protons are an AB pattern, show that the proton trans to the larger substituent at C-4 consistently has a greater long-range coupling constant and likewise appears further downfield than the cis proton.

The multiplet at δ 4.25–3.92 has the expected chemical shift for, and is assigned to, protons α to the NHCOR group. The vinyl protons appear as a second-order ABX pattern where the X portion (H_5) is further split into the observed eight peaks by H_4. The broad multiplet centered at δ 7.6 has the typical chemical shift for an NH proton but its multiplicity is unusual.[14]

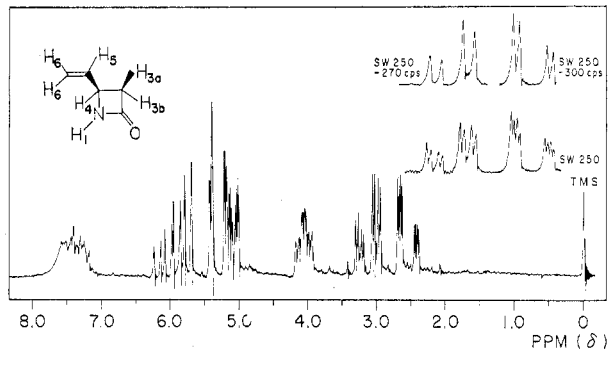


Figure 1.—Nmr spectrum of 4-vinyl-2-azetidinone (**3**); decoupling of the AB pattern to the NH proton at δ 7.5 is shown at the upper right.

Rearrangement of *N*-Chlorosulfonyl-β-lactams (Scheme II).—*N*-Chlorosulfonyl-β-lactams **8, 14, 20,** and **26** thermally rearrange to N and O 1,4-cycloadducts, the expected products of the symmetry-allowed $_\pi4_s + _\pi2_s$ process between 1,3-dienes and CSI. Of these, the rearrangement of **8** and **14** were studied in detail.

Warming an ethereal solution of **8** to 40° for 1 hr led to the isomeric 6-chlorosulfonylimino-5,6-dihydro-4-methyl-2*H*-pyran (**42**).[15] Although this relatively un-

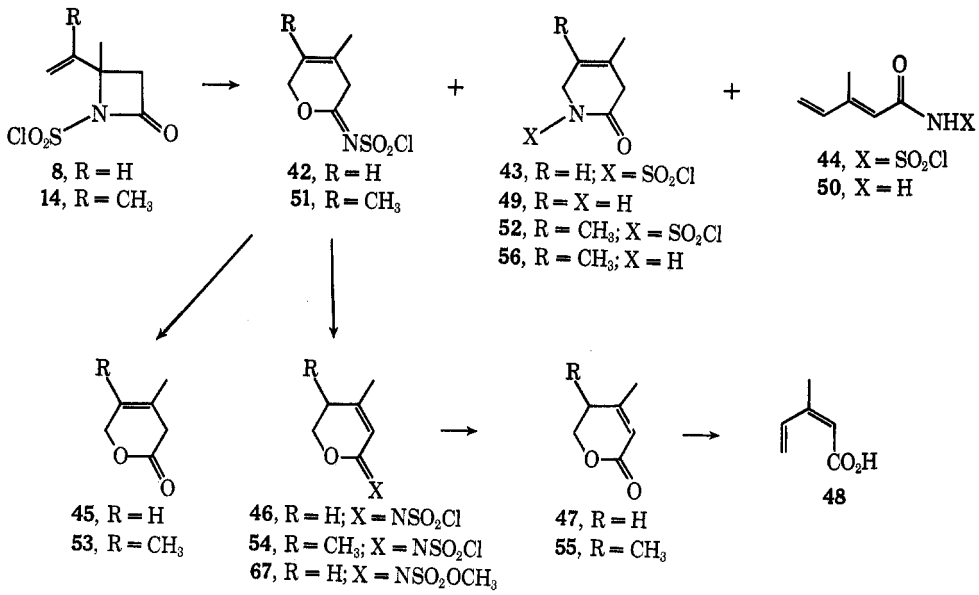
(12) Since the substituents on the 2-azetidinone ring are held in fixed geometry, application of the Karplus equation shows that cis protons (dihedral angle 0°) have greater coupling constants than trans (dihedral angle 120°). Decoupling experiments with the NH proton and measurement of the two J_{34} coupling constants therefore afforded unequivocal assignments.

(13) K. D. Barrow and T. M. Spotswood, *Tetrahedron Lett.*, 3325 (1965).

(14) The NH proton in 2-azetidinones is usually a very broad (½ width = 15–40 Hz) mound with no observable multiplicity.

(15) In our original communication,[5] this compound was assigned the structure of the N-cyclized adduct **43**. In a later paper, this was corrected to the O-cyclized adduct **42**.[6] One of the more cogent reasons for preferring **42** to **43** was the absence of any peak in its mass spectrum due to the loss of CO from its molecular ion or from one of its fragments. The hydrolysis product **49** of N-cyclized adduct **43** was subsequently isolated from a tarry still pot residue.

SCHEME II



stable 1,4 cycloadduct could not be isolated even after extended cooling at −65°, its presence was demonstrated by hydrolysis to 3,6-dihydro-4-methyl-2*H*-pyran-2-one (**45**, 31% overall yield).[16] Refluxing the ethereal solution of **42** an additional 4–5 hr isomerized it to the conjugated isomer 6-chlorosulfonylimino-3,6-dihydro-4-methyl-2*H*-pyran (**46**, 41%).[17] Solvolysis of **46** in methanol quantitatively converted it to the known δ lactone, 5,6-dihydro-4-methyl-2*H*-pyran-2-one (**47**), careful hydrolysis of which afforded 3-methyl-*cis*-2,4-pentadienoic acid (**48**).[18]

Treatment of **7** with CSI in refluxing ether led to the identical and sequential reaction product mixture as in the thermal rearrangement of **8** and could be monitored by ir. Thus the β-lactam carbonyl peak of **8** appeared initially, followed successively by the appearance of the imino-*N*-chlorosulfonyl band of **42** and then its conjugated isomer **46**. Prolonged heating completely converted **42** to **46**, accompanied by the total disappearance of the β-lactam carbonyl of **8**.

In just such a direct run, hydrolytic work-up led to an oil (51%) which was vacuum distilled to provide lactone **47**. An nmr taken of the red oil prior to distillation indicated that it consisted of a mixture of the conjugated lactone **47** and 3,6-dihydro-4-methyl-2(1*H*)-pyridone (**49**, *via* hydrolysis of the *N*-chlorosulfonyl-γ-lactam precursor **43**) in a ratio of 3:2. Freezing the oil at −15° for several weeks followed by filtration and sublimation ultimately afforded pure **49**.[19]

When several reaction mixtures from the rearrangement of **8** were extracted with water, varying amounts (0–35%) of 3-methyl-2,4-pentadieneamide (**50**, *via* hydrolysis of the *N*-chlorosulfonyl precursor **44**) could be isolated.

1-Chlorosulfonyl-2-azetidinone (**14**) rearranged in a manner quite similar to **8** and could be monitored by ir and nmr to follow the formation of 6-chlorosulfonylimino-5,6-dihydro-3,4-dimethyl-2*H*-pyran (**51**) and 1-chlorosulfonyl-3,6-dihydro-4,5-dimethyl-2-pyridone (**52**), and thermal isomerization of the former to 6-chlorosulfonylimino-3,6-dihydro-3,4-dimethyl-2*H*-pyran (**54**). Of these, **54**, 3,6-dihydro-4,5-dimethyl-2*H*-pyran-2-one (**53**), 3,6-dihydro-4,5-dimethyl-2(1*H*)-pyridone (**56**), and 5,6-dihydro-4,5-dimethyl-2*H*-pyran-2-one (**55**) were isolated. The latter three are hydrolysis products of **51**, **52**, and **54**, respectively. The formation of an open-chain amide, similar to **44**, was not observed.

Mechanism of Rearrangement.—We[6] and others[7,8] have suggested that the thermal rearrangement could reasonably proceed in stepwise fashion to both 6-chlorosulfonylimino-2*H*-pyrans (**42**, **51**) and 1-chlorosulfonyl-3,6-dihydro-2-pyridones (**43**, **52**) *via* the ring-opened dipolar intermediate III.[9] There is an alternative, much less probable, concerted pathway (Scheme III) involving a sequence of symmetry-allowed changes which could occur after enolization of **8** to azetine V:[20] (1) 4-electron conrotatory electrocyclic ring opening to VI in which a rotation about C–C bond (a) permits coexistence of conformers VIa and VIb; (2) 1,3-sigmatropic H shift in VIb would lead to VII; (3) 6-electron disrotatory electrocyclization of VIa and VII would afford, respectively, VIII and IX. 1,3-Sigmatropic H shifts in VIa, VIII, and IX would lead to the observed products **44**, **43**, and **42**, respectively.

Solvent Effects in Hydrolysis of *N*-Chlorosulfonyl Derivatives (Scheme IV).—Alkaline hydrolysis in acetone–water[21a] as solvent for representative *N*-chlo-

(16) The ir of **45** displayed a C=O band at 1749 cm^{-1} (5.72 μ) and no NH absorption. The two CH_2 groups appear at δ 4.76 (m, OCH_2) and 2.89 (s, CH_2CO) and were not coupled.

(17) The ir of **46** displayed both a conjugated diene (1635 cm^{-1}, 6.12 μ) and imine absorption (1527 cm^{-1}, 6.55 μ). The nmr spectrum showed the two CH_2 groups as triplets coupled to each other. Their chemical shifts indicated one to be allylic and the other to be adjacent to the electronegative O moiety. The uv demonstrated a conjugated species, λ_{max}^{EtOH} 255 mμ (ε 16,000).

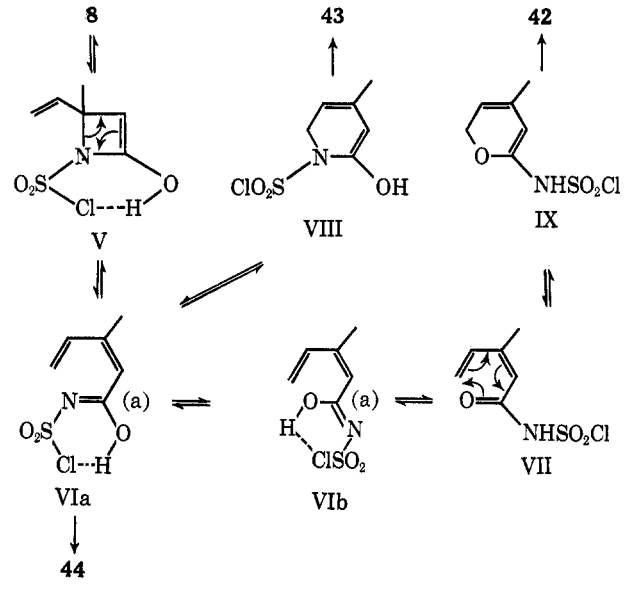
(18) J. W. Cornforth, R. H. Cornforth, G. Popjak, and I. Y. Gore, *Biochem. J.*, **69**, 146 (1958).

(19) The ir (KBr) of **49** exhibited absorption bands at 3180 (3.15 μ) (NH) and 1655 cm^{-1} (6.04 μ) (C=O); the nmr gave the expected NH and CH_3 resonances, but the vinyl and methylene protons appeared as extremely broad (1/2 width = 15–25 Hz), poorly resolved singlets or multiplets, resembling almost mounds. A D_2O wash removed the NH peak and sharpened the vinyl and CH_2ND peaks into clearly resolved multiplets.

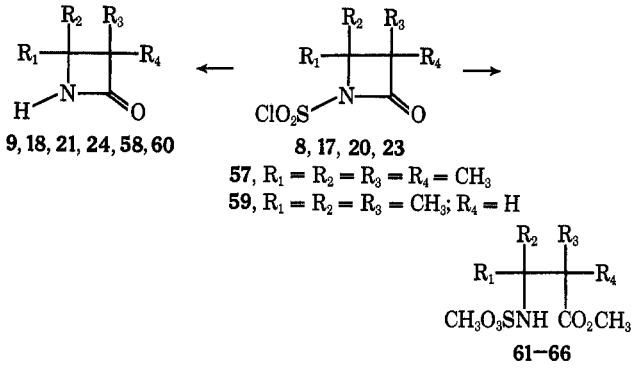
(20) The formation of V would be enhanced as a consequence of the intramolecular H bond to the chlorine atom.

(21) (a) R. Graf, *Justus Liebigs Ann. Chem.*, **661**, 111 (1963); *Org. Syn.*, **46**, 51 (1966). (b) R. Graf, German Patent 950,912, Farbwerke Hochst AG (1954); *Chem. Zentr.*, 4531 (1957).

SCHEME III



SCHEME IV



rosulfonyl-2-azetidinones **8, 17, 20, 23,** 1-chlorosulfonyl-3,3,4,4-tetramethyl- (**57**),[22] and 3,4,4-trimethyl-2-azetidinone (**59**)[22] afforded the expected NH 2-azetidinones **9, 18, 21, 24, 58,**[22] and **60**,[22] respectively. When the solvent was changed to methanol, its participation in the alkaline hydrolysis of these same 1-chlorosulfonyl-2-azetidinones led to the formation of bis esters of β-amino-(*N*-sulfonic acid)carboxylic acids **61–66**, respectively.[21,23] Clearly the presence of solvent–reactant methanol diverted the reaction to give the ring-opened bis ester rather than the unsubstituted 2-azetidinones.

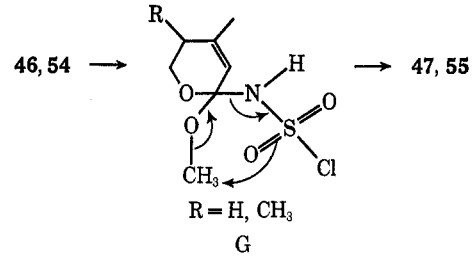
Conventional hydrolysis of *N*-chlorosulfonyl derivatives with base or base in acetone therefore probably involve initial displacement of Cl^- by OH^- (A → B, Scheme V), followed by desulfonation to C. In methanol, sulfonic acid B is trapped as the sulfonate ester D. Since D can no longer lose SO_3, the slower, nucleophilic attack of OH^- at the carbonyl site leads to ring-opened carboxylic acid E.[24] Solvolysis and esterification by methanol completes the reaction to the observed bis ester F.

(22) E. J. Moriconi, J. F. Kelly, and R. A. Salomone, *J. Org. Chem.*, **33**, 3348 (1968); E. J. Moriconi and J. F. Kelly, *ibid.*, **33**, 3036 (1968).

(23) Hydrolysis of these 1-chlorosulfonyl-2-azetidinones with NaOH–CH_3OH in Et_2O or NaOH–CH_3OH in acetone also afforded bis esters, while refluxing in CH_3OH led only to recovery of starting material.

(24) Possibly the electron-withdrawing *N* sulfonate ester group inductively enhances the electron deficiency at the carbonyl site and lowers the E_{act} for nucleophilic attack.

Solvent effects were also observed in the hydrolysis–solvolysis of imino ethers **46** and **54**. As noted, methanolysis of **46** and **54**, followed by aqueous work-up, quantitatively converted them to the conjugated δ lactones **47** and **55** (Scheme II). In addition, treatment of **46** with base in methanol or acetone led to lactone **47** and 3,6-dihydro-6-methoxysulfonylimino-4-methyl-2*H*-pyran (**67**) in ratios of 1:1 and 1:9, respectively. Inexplicably, similar treatment of **54** afforded only the lactone **55**. Sulfonate ester **67** was unresponsive to methanol, while aqueous base converted it to **47**. The results suggest that the methanolysis of **46** and **54** proceeds *via* the intermediacy of G followed by subsequent rearrangement to their respective δ lactones **47** and **55**. The fragmentation product was isolated after aqueous work-up as chlorosulfamic acid.

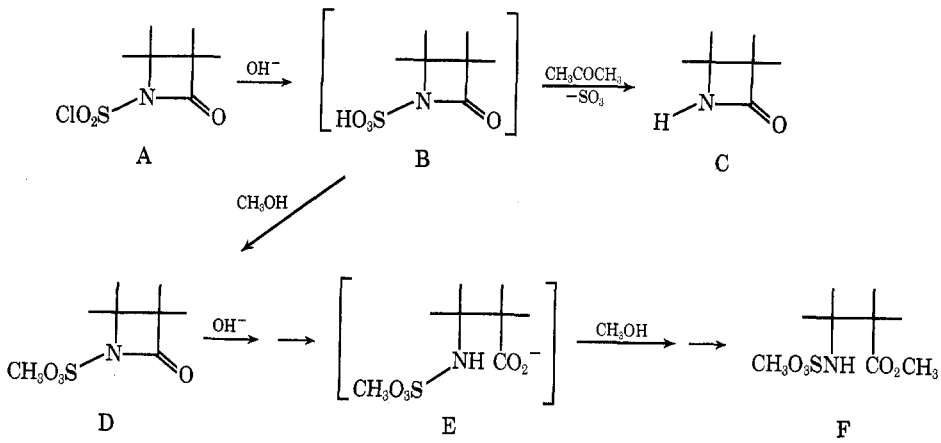


Experimental Section[25]

4-Vinyl-2-azetidinone (3) from 1,3-Butadiene (1).—To 25 ml of **1**, condensed in a flask equipped with a Dry Ice–acetone condenser and protected from moisture, was added 28.3 g (0.20 mol) of CSI in 100 ml of absolute ether. The resulting mixture was allowed to warm and reflux at ambient temperature. At night the reaction was cooled, stoppered, and stored in a freezer at −10°. This daily refluxing schedule was maintained for 6 days. The reaction mixture was then washed with 50 ml of water, and the residual ethereal solution of **1-chlorosulfonyl-4-vinyl-2-azetidinone (2)** [ir (neat) 5.5 μ (C=O)] was immediately reduced. To a cooled (−30°) solution of **2** was added benzenethiol (22 g, 0.20 mol) and to this mixture was added pyridine (9.5 g, 0.12 mol) in 50 ml of absolute ether. To maintain the temperature at −30° required 20–30 min for the pyridine addition, whereupon the solution was allowed to warm and remain at room temperature. To the two-phase reaction mixture was added 100 ml of ether and 100 ml of H_2O. The ether layer was separated, dried (Na_2SO_4), filtered, and allowed to evaporate. Fifty milliliters of methanol was then added to the resulting mixture of yellow crystals and orange oil to precipitate the diphenyl disulfide. Successive solvent volume reduction and cooling (−50°) produced several additional crops of diphenyl disulfide which were filtered (*ca.* 90% of this by-product could be removed in this manner). Distillation of the resulting yellow-orange solution using a short-path, microapparatus (with heated head to avoid refluxing and to distill volatile products as quickly as possible) gave crude **3** (2.1 g, 11%), bp 60–110° (0.5 mm). A second distillation afforded pure **3** as a colorless liquid: bp 67–68° (0.3 mm); ir (neat) 3250 (3.08) (NH) and 1745 cm^{-1} (5.73 μ) (C=O); nmr (Figure 1) (CCl_4) δ 7.6 (mound, 1, NH), 6.36–5.68 (m, 1, J_{3-4} = 6.1 Hz, CH=C),

(25) All boiling points are uncorrected. Melting points were determined on a Mel-Temp apparatus and are corrected. Microanalyses were done by the Schwarzkopf Microanalytical Laboratory, Woodside, N. Y. Infrared spectra were obtained on a Perkin-Elmer 337 spectrophotometer; ultraviolet spectra were obtained on a Cary 15. Nmr spectra were taken on a Varian A-60A; chemical shifts are reported in parts per million (δ) downfield from TMS as an internal standard. Spectra obtained in DMSO-d_6 use the DOH peak as an internal standard. All vpc analyses were done on a Perkin-Elmer 880; compounds containing an NSO_2Cl group were run on a 6 ft × 1/8 in. column of 3% Apiezon L grease; all other compounds were run on a standard 6 ft × 1/8 in. column of 10% SE-30, both on Chromosorb W, 60–80 mesh, AW-DMCS. Preparative gc were run on a Perkin-Elmer F21 with a 20 ft × 3/8 in. o.d. column of 20% SE-30 on 60–80 mesh Chromosorb W, AW-DMCS. All olefins, dienes, and common chemicals were purchased from various common laboratory suppliers. The CSI was obtained from the American Hoechst Corp. and was used without further purification.

SCHEME V



5.45–5.00 (m, 2, $=CH_2$), 4.25–3.92 (m, 1, CHNH), 3.35–2.92 ($^1/_2$ AB pattern further split in four by C-4 H and NH, 1, J_{cis} = 5.10, J_{gem} = 14.7, J_{NH} = 1.95 Hz, CHCO trans to vinyl), 2.72–2.46 ($^1/_2$ AB pattern further split in four by C_4H and NH, 1, J_{trans} = 2.80, J_{gem} = 14.7, J_{NH} = 1.20 Hz, CHCO cis to vinyl).

Anal. Calcd for C_5H_7NO: C, 61.83; H, 7.27; N, 14.23. Found: C, 61.81; H, 7.44; N, 14.52.

4-Methyl-4-vinyl-2-azetidinone (9) from Isoprene (7).—Diene **7** (27.2 g, 0.40 mol) was added dropwise (*via* an equal pressure addition funnel and reflux condenser protected from moisture) at −10° to a stirred solution of 56.6 g (0.040 mol) of CSI in 100 ml of absolute ether. After maintaining the reaction temperature at *−10 to 0° for an additional 30 min, the solution was cooled to* −65° and allowed to stand for another 30 min. The precipitate was quickly filtered and washed with very cold ether to give 67 g (80%) of off-white **1-chlorosulfonyl-4-methyl-4-vinyl-2-azetidinone (8)**: mp 28–30°; ir (KBr) 1815 cm^{-1} (5.51 μ) (C=O); nmr ($CDCl_3$) δ 6.49–6.04 (four peaks, 1, $CH=CH_2$), 5.62–5.42 (four peaks, 2, $=CH_2$), 3.23 (s, 2, CH_2), and 1.90 (s, 3, CH_3). Further purification of **8** led to decomposition; so it was hydrolyzed to the more stable **9** in the following manner. To a cooled (0–10°) stirred solution of 21 g (0.10 mol) of **8** in 150 ml of acetone was added 5 *N* NaOH until basic to pH paper. Upon successive addition of 50 ml of ether and sufficient water until both phases were clear, the layers were separated, and the aqueous layer was successively extracted with three 50-ml portions of ether and four 75-ml portions of CH_2Cl_2. The combined organic extracts were dried ($MgSO_4$), filtered, and reduced in volume to an orange oil which was vacuum distilled to give **9** (8.1 g, 0.073 mol, 73%): bp 62–63° (0.2 mm); ir (neat) 3230 (3.10) (NH) and 1750 cm^{-1} (5.71 μ) (C=O); nmr (CCl_4) δ 7.8 (mound, 1, NH), 6.35–5.83 (four peaks, 1, $CH=CH_2$), 5.45–4.94 (m, 2, $=CH_2$), 2.72 (d, 2, J_{NH} = 1.50 Hz, CH_2CO), and 1.48 (s, 3, CH_3).

Anal. Calcd for C_6H_9NO: C, 64.84; H, 8.16; N, 12.60. Found: C, 64.94; H, 8.12; N, 12.83.

4-Methyl-4-isopropenyl-2-azetidinone (15) from 2,3-Dimethyl-1,3-butadiene (13).—A solution of CSI (28.3 g, 0.20 mol) in 20 ml of ether was added dropwise (*via* an equal pressure funnel) at −65° to a stirred solution of 16.4 g (0.20 mol) of **13**. The reaction temperature was slowly permitted to rise to −10° and maintained there for 1 hr. Crystallization was induced by lowering the temperature to −65° for 30 min. The white **1-chlorosulfonyl-4-methyl-4-isopropenyl-2-azetidinone (14**, 38.1 g, 0.166 mol, 84%) which precipitated was filtered and washed with cold ether: mp 38–40°; ir (KBr) 3220 (3.11) (NH), 1810 cm^{-1} (5.53 μ) (C=O); nmr ($CDCl_3$) δ 5.30 (s, 1, vinyl H cis to CH_3) 5.20 (s with fine splitting, 1, vinyl H trans to CH_3), 3.22 (AB pattern, 2, J_{AB} = 17 Hz, $\Delta\delta$ = 3 Hz, CH_2), 1.98 (s, 3, CH_3CNR), 1.93 (s, with fine coupling 3, $CH_3C=$).

Alkaline hydrolysis of **14** (22.4 g, 0.10 mol) in 150 ml of acetone in a manner similar to **8** afforded **15** (8.5 g, 0.068 mol, 68%): bp 78° (0.2 mm); ir (neat) 1750 cm^{-1} (5.71 μ); nmr (CCl_4) δ 7.95 (mound, 1, NH), 4.95, (s, with fine splitting, 1, J = 0.65 Hz, vinyl H cis to CH_3), 4.80 (s, with fine splitting, 1, J = 1.40 Hz, vinyl H trans to CH_3), 2.73 (d, 2, J_{NH} = 1.20 Hz, CH_2), 1.80 (s with fine splitting, 3, $CH_3C=$), 1.50 (s, 3 CH_3CHN).

Anal. Calcd for $C_7H_{11}NO$: C, 67.17; H, 8.86; N, 11.19. Found: C, 67.27; H, 9.11; 11.50.

***cis,trans*-4-Prop-1-enyl-2-azetidinone Mixture (21) from *cis,trans*-1,3-Pentadiene Mixture (19).**—A solution of CSI (42.0 g, 0.30 mol) in 25 ml absolute ether was added dropwise in the usual manner at −10° to a stirred solution of 20.2 g (0.30 mol) of **19** in 75 ml of absolute ether and maintained at −10 to 0° for an additional 3 hr. The reaction was then cooled to −70° and allowed to stand overnight at this temperature. Usually crystallization occurred; however, occasionally scratching or seeding was required to induce crystallization. The crystals of **1-chlorosulfonyl-*cis,trans*-prop-1-enyl-2-azetidinone (20)** [ir (CCl_4) 1818 cm^{-1} (5.50 μ) (C=O)] which melt well below 0° were rapidly filtered in a sintered glass filter previously cooled in a Dry Ice–acetone bath. As soon as most of the ether had been removed, the soft mass was quickly placed into 150 ml of acetone and hydrolyzed in a manner similar to **8**. Azetidinone mixture **21**, bp 82–83° (0.3 mm), was obtained in 10.9-g (0.091 mol, 30%) yield: ir (neat) 3220 (3.11) (NH) and 1750 cm^{-1} (5.71 μ) (C=O); nmr (CCl_4) δ 7.52 (mound, 1, NH), 6.05–5.22 (m, 2, CH=CH) 4.50–4.22 and 4.12–3.88 (two multiplets in a ratio of 44:56 respectively, 1, CHNH both cis and trans to CH_3), 3.32–2.30 (complex AB pattern resulting from the overlap of two AB patterns further split in four, 2, CH_2 from both cis and trans double bond), 1.70 (d, 3, J = 5.00 Hz, CH_3).

Anal. Calcd for C_6H_9NO: C, 64.84; H, 8.16; N, 12.60. Found: C, 64.82; H, 8.07; N, 12.28.

4-But-1-enyl-2-azetidinone (27) from *trans*-1,3-Hexadiene (25).—A solution of 28.3 g (0.20 mol) of CSI was added dropwise to a stirred solution of 16.4 g (0.20 mol) of **25** at −10°, followed by stirring from −10 to 10° for 2 hr (or until the ir isocyanate peak disappeared). The usual work-up led to an ethereal solution of **4-but-1-enyl-1-chlorosulfonyl-2-azetidinone (26)** [ir (neat) 5.50 μ (C=O)]. Benzenethiol–pyridine reduction and work-up (similar to that of **2**) afforded initially crude **27** (6.0 g, 0.048 mol, 24%) at 80–102° (0.4 mm). Pure **27** was obtained in a final distillation 78–80° (0.1 mm): ir (neat) 3240 (3.09) (NH) and 1750 cm^{-1} (5.71 μ) (C=O); nmr ($CDCl_3$) δ 7.54 (mound, 1, NH), 6.00–5.20 (m, 2, CH=CH), 3.97 (doublet of triplet, 1, J_{vinyl} = 5.0, J_{trans} = 2.50, J_{cis} = 5.02 Hz, CHNH), 3.24–2.85 ($^1/_2$ AB pattern further split in four, 1, J_{NH} = 1.80, J_{gem} = 14.4, J_{cis} = 5.02 Hz, CHCO trans to substituent), 2.60–2.30 ($^1/_2$ AB pattern further split in four, 1, J_{gem} = 14.4, J_{NH} = 1.05, J_{trans} = 2.50 Hz, CHCO cis to substituent), 2.24–1.76 (m, 2, $CH_2C=$), 0.94 (t, 3, J = 7.2 Hz, CH_3).

Anal. Calcd for $C_7H_{11}NO$: C, 67.16; H, 8.86; N, 11.19. Found: C, 67.29; H, 9.08; N, 11.47.

4-But-2-enyl-2-azetidinone (33) from *cis,trans*-1,4-Hexadiene (31).—A mixture of 9.0 g (0.11 mol) of **31** and 17.0 g (0.12 mol) of CSI in 100 ml of absolute ether was stirred overnight at room temperature. The reaction mixture was then poured over 15 g of cracked ice. The ether layer was separated, dried ($MgSO_4$), and filtered to yield an ethereal solution of ***cis,trans*-4-but-2-enyl 1-chlorosulfonyl-2-azetidinone (32)** [ir (neat) 5.5 μ (C=O)]. Benzenethiol–pyridine reduction and work-up afforded 3.7 g (0.03 mol, 27%) of **33**, bp 72–93° (0.3 mm). A final distillation at 62–63° (0.05 mm) afforded pure **33** as a 6:1 cis–trans mixture (vpc): ir (neat) 3250 (3.08) (NH) and 1755 cm^{-1} (5.70 μ) (C=O); nmr (neat) δ 7.62 (s, 1, NH), 5.90–5.00 (m, 2, CH=CH), 3.74–3.28 (m, 1, CHNH), 3.14–2.72 ($^1/_2$ AB pattern further split in four, 1, J_{gem} = 14.2, J_{cis} = 4.50, J_{NH} = 1.70 Hz,

CHCO trans to substituent), 2.62–2.20 (1/2 AB pattern further split in four, 1, J_{trans} = 2.20, J_{NH} = 1.10 Hz, CHCO cis to substituent), 2.50–2.04 (m, 2, CH_2C=), 1.64 (d, of which upfield half showed fine splitting, 3, J = 4 Hz, CH_3).

Anal. Calcd for $C_7H_{11}NO$: C, 67.17; H, 8.86; N, 11.19. Found: C, 66.89; H, 9.08; N, 10.87.

3-Methyl-4-prop-1-enyl-2-azetidinone (36) from *trans,trans*-2,4-Hexadiene (34).—A solution of 28.3 g (0.20 mol) of CSI in 100 ml of absolute ether was added dropwise to a stirred solution of 16.4 g (0.20 mol) of **34** at −10°. Reaction time and work-up were the same as with **26**. The ethereal solution of **1-chlorosulfonyl-3-methyl-4-prop-1-enyl-2-azetidinone (35)** [ir 5.50 μ (C=O)] was reduced with benzenethiol–pyridine in a manner similar to **2**. Successive distillations at 81–116° (0.5 mm) and 81–84° (0.3 mm) gave 10.2 g (0.082 mol, 41%) of **36**. An analytical sample of **36**, bp 67–69° (0.2 mm), had the following spectral properties: ir (neat) 3220 (3.11) (NH) and 1740 cm^{-1} (5.75 μ) (C=O); nmr (CCl_4) δ 7.65 (s, 1, NH), 6.10–5.35 (m, 2, CH=CH), 3.65 (two d, 1, J_{vinyl} = 5.0, J_{trans} = 2.0 Hz, CHNH), 2.77 (quartet split further in four, 1, J_{CH_3} = 7.6, J_{trans} = 2.0, J_{NH} = 0.95 Hz, CHCO), 1.73 (d, 3, J = 5.2 Hz, CH_3C=), 1.24 (d, 3, J = 7.6 Hz, CH_3CO).

Anal. Calcd for $C_7H_{11}NO$: C, 67.16; H, 8.86; N, 11.19. Found: C, 67.29; H, 8.95; N, 11.06.

Catalytic Reduction of 2-Azetidinones.—The general procedure used was as follows. A solution of the 2-azetidinone in absolute ethanol was hydrogenated in a Parr shaker at 50 psi using Pd/C as catalyst. The mixture was then filtered and the solvent removed *in vacuo*. The resulting oil was purified by vacuum distillation. Reaction time and catalyst concentration are parenthetically noted.

4-Vinyl-2-azetidinone (3, 1.0 g, 0.010 mol) (3 days, 30% Pd/C) gave **4-ethyl-2-azetidinone (6**, 90%): bp 66–67° (0.3 mm); ir (neat) 3230 (3.10) (NH) and 1748 cm^{-1} (5.72 μ) (C=O); nmr (CCl_4) δ 7.7 (mound, 1, NH), 3.69–3.31 (m, 1, CHNH), 3.16–2.76 (1/2 AB pattern further split by C-4 H and NH, 1, J_{cis} = 4.80, J_{gem} = 14.4, J_{NH} = 1.90 Hz, CHCO), 2.60–2.23 (1/2 AB pattern finely split by C-4 H and NH, 1, J_{trans} = 2.42, J_{gem} = 14.4, J_{NH} = 1.24 Hz, CHCO), 1.88–1.32 (m, 2, CH_2CH_3), 0.92 (t, 3, J = 7 Hz, CH_2CH_3).

Anal. Calcd for C_5H_9NO: C, 60.58; H, 9.15; N, 14.13. Found: C, 60.40; H, 9.29; N, 13.85.

4-Methyl-4-vinyl-2-azetidinone (9, 2.0 g, 0.018 mol) (3 days, 10% Pd/C) gave **4-ethyl-4-methyl-2-azetidinone (12**, 89%): bp 71–72° (0.2 mm); ir (neat) 3225 (3.10) (NH) and 1745 cm^{-1} (5.73 μ) (C=O); nmr (CCl_4) δ 7.66 (mound, 1, NH), 2.58 (d, 2, J_{NH} = 1.0 Hz, CH_2CO), 1.89–1.46 (m, 2, CH_2CH_3), 1.37 (s, 3, CH_3CNH), 0.95 (t, 3, J = 7 Hz, CH_2CH_3).

Anal. Calcd for $C_6H_{11}NO$: C, 63.68; H, 9.80; N, 12.38. Found: C, 63.36; H, 9.80; N, 12.52.

4-Methyl-4-isopropenyl-2-azetidinone (15, 3.0 g, 0.024 mol) (24 hr, 10% Pd/C) gave **4-methyl-4-isopropyl-2-azetidinone (18**, 88%): bp 84–85° (0.3 mm); ir (neat) 3215 (3.11) (NH) and 1748 cm^{-1} (5.72 μ) (C=O); nmr (CCl_4) δ 7.90 (mound, 1, NH), 2.97 (AB pattern split in two by NH, J_{AB} = 15.0, $J_{A\text{-}NH}$ = 1.50, $J_{B\text{-}NH}$ = 1.75 Hz, CH_2), 1.85 (septuplet, 1, J = 7.0 Hz, CH), 1.30 (s, 3, CH_3), 0.95 (d, 3, J = 7.00 Hz, one of the isopropyl methyls), 0.93 (d, 3, J = 7.00 Hz, the remaining is propyl methyl).

Anal. Calcd for $C_7H_{13}NO$: C, 66.10; H, 10.30; N, 11.02. Found: C, 65.85; H, 10.24; N, 11.19.

***cis,trans*-4-Prop-1-enyl-2-azetidinone (21**, 3.0 g, 0.027 mol) (24 hr, 10% Pd/C) gave **4-propyl-2-azetidinone (24**, 80%): bp 76–76.5° (0.4 mm); ir (neat) 3245 (3.08) (NH) and 1745 cm^{-1} (5.73 μ) (C=O); nmr (CCl_4) δ 7.7 (mound, 1, NH), 3.70–3.34 (m, 1, CH), 3.15–2.75 (1/2 AB pattern further split in four by C-4 H and NH, 1, J_{gem} = 14.2, J_{cis} = 4.6, J_{NH} = 1.98 Hz, CHCO), 2.60–2.22 (1/2 AB pattern further split in four by NH and C-4 H, 1, J_{gem} = 14.2, J_{trans} = 2.5, J_{NH} = 1.30 Hz, CHCO), 1.78–1.12 (m, 4, CH_2CH_2), 1.12–0.70 (m, 3, CH_3).

Anal. Calcd for $C_6H_{11}NO$: C, 63.69; H, 9.80; N, 12.38. Found: C, 63.42; H, 9.99; N, 11.98.

4-But-1-enyl-2-azetidinone (27, 2.0 g, 0.016 mol) (24 hr, 10% Pd/C) gave **4-butyl-2-azetidinone (30**, 80%): bp 82–84° (0.2 mm); ir (neat) 3250 (3.08) (NH) and 1745 cm^{-1} (5.73 μ) (C=O); nmr (CCl_4) δ 7.63 (s, 1, NH), 3.65–3.12 (m, 1, CHNH), 3.10–2.74 (1/2 AB pattern further split in four, 1, J_{gem} = 14.3, J_{NH} = 1.80, J_{cis} = 4.80 Hz, CHCO), 2.55–2.20 (1/2 AB pattern further split in four, 1, J_{gem} = 14.3, J_{NH} = 1.10, J_{trans} = 2.40 Hz, CHCO), 1.80–0.70 [m, 9, $(CH_2)_3CH_3$].

Anal. Calcd for $C_7H_{13}NO$: C, 66.10; H, 10.30; N, 11.02. Found: C, 66.00; H, 10.13; N, 10.96.

***cis,trans*-4-But-2-enyl-2-azetidinone (33**, 2.0 g, 0.016 mol) (24 hr, 10% Pd/C) also gave **30**, bp 81–83° (0.2 mm), in 80% yield.

3-Methyl-4-prop-1-enyl-2-azetidinone (36, 3.0 g, 0.024 mol) (24 hr, 10% Pd/C) gave **3-methyl-4-propyl-2-azetidinone (40**, 90%): bp 74–75° (0.2 mm); ir (neat) 3250 (3.08) (NH) and 1748 cm^{-1} (5.72 μ) (C=O); nmr (CCl_4) δ 7.84 (s, 1, NH), 3.18 (triplet of doublets, 1, J_{trans} = 2.0, J_{CH_2} = 6.2 Hz, CHNH), 2.68 (quartet further split in four by NH and C-4 H, 1, J_{trans} = 2.0, J_{NH} = 1.0, J_{CH_3} = 7.5 Hz, CHCO), 1.23 (d, 3, J = 7.5 Hz, CH_3CH), 1.70–0.80 (m, 7, $CH_2CH_2CH_3$).

Anal. Calcd for $C_7H_{13}NO$: C, 66.10; H, 10.30; N, 11.02. Found: C, 66.14; H, 10.48; N, 10.87.

Reaction of Olefins with CSI.—**1-Butene (4**, 14.6 g, 0.26 mol) on treatment with CSI (36.8 g, 0.26 mol) in absolute ether in a manner similar to the reaction between **1** and CSI afforded **1-chlorosulfonyl-4-ethyl-2-azetidinone (5)** as an orange oil [ir (neat) 5.5 μ (C=O)]. Sodium hydroxide (5 *N*) was added dropwise to a stirred solution of **5** in 150 ml of acetone at 0–10° to pH 8. Ether (50 ml) and sufficient water for clear separation were successively added. The layers were separated, and the aqueous phase was extracted with three 50-ml portions of ether and four 75-ml portions of CH_2Cl_2. The combined organic extracts were dried ($MgSO_4$) and reduced *in vacuo* to an orange oil which was vacuum distilled to give **6** (1.1 g, 0.013 mol, 5%), bp 63–65° (0.2 mm).

2-Methyl-1-butene (10, 14 g, 0.20 mol) and 28.3 g (0.20 mol) of CSI (4 hr, room temperature) in 100 ml of absolute ether gave **1-chlorosulfonyl-4-ethyl-4-methyl-2-azetidinone (11)** as an oil [ir (neat) 5.5 μ (C=O)] which was hydrolyzed to **12** (9.3 g, 0.082 mol, 41%), bp 72–75° (0.3 mm).

2,3-Dimethyl-2-butene (16, 16.8 g, 0.20 mol) in 100 ml of absolute ether and CSI (28.3 g, 0.20 mol) in 30 ml of absolute ether (3 hr, 0°) gave **1-chlorosulfonyl-4-methyl-4-isopropyl-2-azetidinone (17)** as an oil [ir (neat) 5.5 μ (C=O)] which was hydrolyzed to **18** (14.6 g, 0.114 mol, 57%), bp 89–91° (0.5 mm).

1-Pentene (22, 21.4 g, 0.30 mol) and CSI (42.5 g, 0.30 mol) in 100 ml of CH_2Cl_2 (72 hr, room temperature) ultimately gave **1-chlorosulfonyl-4-propyl-2-azetidinone (23)** as an oil [ir (neat) 5.5 μ (C=O)] after quenching the reaction over cracked ice. Hydrolysis of **23** afforded **24** (12.1 g, 0.107 mol, 36%), bp 81–83° (0.5 mm).

1-Hexene (28, 16.8 g, 0.20 mol) in 100 ml of nitromethane and CSI (28.3 g, 0.20 mol) (24 hr, room temperature) gave **4-butyl-1-chlorosulfonyl-2-azetidinone (29)** as a red oil [ir (neat) 5.5 μ (C=O)]. Hydrolysis of **29** afforded **30** (4.7 g, 0.044 mol, 22%), bp 77–79° (0.2 mm).

***trans*-2-Hexene (37**, 16.8 g, 0.20 mol) and CSI 28.3 g (0.20 mol) in 100 ml of CH_2Cl_2 (1 week, room temperature) gave a mixture of **1-chlorosulfonyl-3-methyl-4-propyl- (38)** and **4-methyl-3-propyl-2-azetidinone (39)** [ir (neat) 5.5 μ (C=O)]. Hydrolysis of the mixture afforded a 2:1 mixture of **40** and **4-methyl-3-propyl-2-azetidinone (41)** (11.5 g, 0.09 mol, 64%): bp 75–77° (0.3 mm): ir (neat) 3250 (3.08) (NH) and 1748 cm^{-1} (5.72 μ) (C=O); nmr (CCl_4) δ 7.65 and 7.50 (two s in a ratio of 2:1, total of 1, NH), 3.56–2.50 (m, total of 1, CHNH), 2.90–2.35 (m, total of 1, CHCO), 1.22 and 1.29 (two d in a ratio of 2:1, total of 3, J = 7.2 and 6.0 Hz, respectively, CH_3CH), 1.80–0.80 (m, 7, $CH_3CH_2CH_2$).

Anal. Calcd for $C_7H_{13}NO$ (mixture): C, 66.10; H, 10.30; N, 11.02. Found: C, 65.82; H, 10.25; N, 10.64.

3,6-Dihydro-4-methyl-2*H*-pyran-2-one (45).—CSI (28.3 g, 0.20 mol) in 150 ml of absolute ether was added slowly to **7** (13.6 g, 0.20 mol) with stirring at ambient temperature. At the end of the first 30 min and at 15-min intervals, the ir spectrum was scanned in the C=O region. When the β-lactam carbonyl (5.5 μ) of **8** had virtually disappeared (usually 95% by 1–2 hr) and with the concomitant appearance of the imino absorption (~6 μ) of the unstable **6-chlorosulfonylimino-5,6-dihydro-4-methyl-2*H*-pyran (42)**, hydrolysis of the reaction mixture was effected with a saturated NaOH solution in methanol. Hydrolysis and work-up were similar to that of **5**. Two successive vacuum distillations of the residual yellow oil gave **45** (7.0 g, 0.063 mol, 31%), bp 68–70° (0.3 mm). To remove the last of isomeric coproduct **47**, **45** was purified by preparative vpc using a 12 ft × 0.5 in. o.d. stainless steel column of 15% SE-30 on 60–80 Chromosorb W: ir (neat) 1749 cm^{-1} (5.72 μ) (C=O); nmr (CCl_4) δ 5.62 (m, 1, =CH), 4.76 (m, 2, OCH_2), 2.89 (s with fine splitting, 2, CH_2CO), 1.78 (s, with fine splitting, 3, CH_3).

Anal. Calcd for $C_6H_8O_2$: C, 64.27; H, 8.16. Found: C, 64.34; H, 8.24.

6-Chlorosulfonylimino-3,6-dihydro-4-methyl-2*H*-pyran (46).—CSI (56.6 g, 0.40 mol) in 300 ml of absolute ether was added slowly to **7** (27.2 g, 0.40 mol) with stirring and the whole mixture was refluxed 6 hr. The reaction mixture was then cooled to −65° and maintained at this temperature for 1 hr. If no precipitate had formed, shaking or scratching was all that was necessary. The precipitate was filtered and washed with cold ether to give light orange **46** (34.3 g, 0.164 mol, 41%). Two recrystallizations from CH_2Cl_2–ether afforded analytically pure **46**: mp 81–82°; ir (KBr) 1635 cm^{-1} (6.12 μ) (C=N); uv max (EtOH) 255 mμ (ϵ 16,000); nmr ($CDCl_3$) δ 6.06 (s with fine splitting, 1, J = ~1.3 Hz, =CH), 4.68 (t, 2, J = 6.7 Hz, CH_2O), 2.63 (t, 2, J = 6.7 Hz, $=CH_2$), 2.17 (s, 3, CH_3).

Anal Calcd for $C_6H_8NO_3SCl$: C, 34.37; H, 3.84; N, 6.68. Found: C, 34.41; H, 3.91; N, 6.84.

5,6-Dihydro-4-methyl-2*H*-pyran-2-one (47).—A solution of **46** (20.9 g, 0.10 mol) in 25 ml of absolute methanol was refluxed (steam bath) for 5 min. After solvent stripping *in vacuo*, 25 ml of H_2O was added, and the whole extracted with six 25-ml portions of CH_2Cl_2. The combined extracts were dried ($MgSO_4$), reduced in volume *in vacuo*, and vacuum distilled to give **47** (11.0 g, 0.0984 mol, 98%): bp 71–72° (0.2 mm); ir (neat) 1725 cm^{-1} (5.80 μ) (C=O); uv max (EtOH) 215 mμ (ϵ 5600) [lit.[18] uv max (EtOH) 214 mμ (ϵ 8000)]; nmr (CCl_4) δ 5.65 (q, 1, J = 1.4 Hz, =CH), 4.28 (t, 2, J = 6.2 Hz, $=CCH_2$), 2.48 (t, 2, J = 6.2 Hz, CH_2O).

Anal. Calcd for $C_6H_8O_2$: C, 64.27; H, 7.19; O, 28.54. Found: C, 64.21; H, 7.20; O, 28.55.

δ lactone **47** could be prepared directly (overall yield 30%) by refluxing equimolar amounts of **7** and CSI in absolute ether for 6 hr, followed by alkaline hydrolysis and work-up similar to that on **5**.

***cis*-3-Methyl-2,4-pentadienoic Acid (48).**—δ lactone **47** (1.30 g, 0.116 mol) in 4 ml of ether was added slowly to a stirred, ice bath cooled solution of *tert*-BuOK (1.30 g, 0.0116 mol) in 10 ml of *tert*-BuOH and 4 ml of ether. The resulting precipitate was filtered, washed with ether, and air-dried to yield 1.70 g (0.0113 mol, 97%) of **potassium 3-methyl-*cis*-2,4-pentadienoate**: mp 380–385° dec; ir (KBr) 1690 (5.92) (C=O) and 1590 cm^{-1} (6.29 μ) (C=C). This material was dissolved in 10 ml of H_2O and acidified to pH 3 with dilute H_2SO_4. The precipitate was filtered, washed with ice-water, and air-dried to yield **48** (1.05 g, 9.4 mmol, 83%). One recrystallization from pentane afforded analytically pure **48**: mp 63.5–65° (lit.[18] mp 66–67°); ir (KBr) 1640 (6.10) (C=O), 1585 (6.31), and 1550 cm^{-1} (6.45 μ) (C=C); uv max (EtOH) 248 mμ (ϵ 13,500) [lit.[18] 250 mμ (ϵ 17,000)]; nmr ($CDCl_3$) δ 11.76 (s, 1, CO_2H), 8.03–7.55 (four peaks, 1, **CH**=CH_2), 5.75–5.32 (m, 3, remaining vinyl H), 2.04 (s with fine splitting, 3, CH_3).

Anal. Calcd for $C_6H_8O_2$: C, 64.27; H, 7.19. Found: C, 64.25; H, 7.05.

3,6-Dihydro-4-methyl-2(1*H*)-pyridone (49).—Diene **7** (13.6 g, 0.20 mol) was added dropwise to a solution of CSI (28.3 g, 0.20 mol) in 100 ml of absolute ether under the usual conditions and the whole mixture refluxed 6 hr. The solvent was then removed in a rotary evaporator and the residual red oil was dissolved in 150 ml of acetone and hydrolyzed (0–10°) with 5 *N* NaOH to pH 8. The acetone layer was separated, and the aqueous layer repeatedly extracted with acetone until only an orange pasty mass remained. The combined acetone extracts were dried (Na_2SO_4), filtered, and reduced in volume to an oil. The latter was dissolved in 150 ml of CH_2Cl_2, redried ($MgSO_4$), and filtered, and the solvent was removed *in vacuo* to yield 11.4 g of an oil. An nmr of this material integrated for a 2:3 mixture of **47** and **49**, the latter clearly a hydrolysis product of **1-chlorosulfonyl-3,6-dihydro-4-methyl-2(1*H*)-pyridone (43)**. γ lactam **49** crystallized from the mixture after 2 weeks standing in a freezer (−15°). It was filtered, washed with pentane, and sublimed at 60–70° (0.4 mm) to yield analytically pure **49**: mp 88–91°;[19] nmr ($CDCl_3$) δ 8.25 (mound, 1, NH), 5.46 (very broad s, 1, CH=), 3.92 (very broad s with some fine splitting, 2, CH_2NH), 2.78 (m, 2, CH_2CO), 1.85 (s with fine splitting, 3, CH_3). After a D_2O wash, the peaks at 5.46 and 3.92 became sharper and more clearly defined multiplets.

Anal. Calcd for C_6H_9NO: C, 64.84; H, 8.16; N, 12.60. Found: C, 65.08; H, 8.27; N, 12.23.

3-Methyl-2,4-pentadieneamide (50).—Equimolar amounts (0.20 mol) of CSI and **7** in ether were refluxed for 6 hr under the usual conditions. The cooled solution was extracted with 50 ml of H_2O, and the separated aqueous phase was hydrolyzed to pH 9 with a 50% NaOH solution. This solution was then extracted with three 50-ml portions of $CHCl_3$. The combined extracts were dried ($MgSO_4$) and filtered and the solvent was removed *in vacuo* to yield 3.2 g (0.029 mol, 14.5%) of **50**, undoubtedly a hydrolysis product of the unstable precursor ***N*-chlorosulfonyl-3-methyl-2,4-pentadieneamide (44)**. Amide **50** was purified by sublimation at 50° (0.3 mm): mp 80–82°; ir (KBr) 3370 and 3170 (NH_2), 1650 with shoulders at 1615 and 1590 cm^{-1} (C=O); uv max (EtOH) 251 mμ (ϵ 11,200); nmr ($CDCl_3$) δ 8.04–7.56 (four peaks, 1, CH_2=**CH**), 7.0–5.5 (mound, 2, NH_2), 5.76–5.05 (m, 3, remaining vinyl H), 1.95 (d, 3, J = ~1.5 Hz, CH_3).

Anal. Calcd for C_6H_9NO: C, 64.84; H, 8.16; N, 12.60. Found: C, 64.57; H, 7.97; N, 12.28.

3,6-Dihydro-6-methoxysulfonylimino-4-methyl-2*H*-pyran (67).—A saturated solution of NaOH in CH_3OH was added to a cooled solution of **46** (16.0 g, 0.076 mol) in 100 ml of acetone to pH 9. Sufficient H_2O was added to dissolve the solids or to clear any dispersions. This mixture was extracted once with 50 ml of ether, and the water layer then was separated and further extracted with five 50-ml portions of CH_2Cl_2. The combined organic extracts were dried ($MgSO_4$), filtered, and reduced in volume to yield a residual yellow oil which solidified to give a 1:7 mixture of lactone **47** and **67** (10.8 g, 0.053 mol, 70%). Separation of the sulfonate ester **67** was effected by fractional crystallization from CH_2Cl_2–hexane: mp 80.5–82°; uv max (EtOH) 244 mμ (ϵ 15,500); ir (KBr) 1650 (6.06) (C=N) and 1585 cm^{-1} (6.31 μ) (C=C); nmr ($CDCl_3$) δ 6.02 (broad s, 1, =CH), 4.50 (t, 2, J = 6.5 Hz, CH_2O), 3.89 (s, 3, OCH_3), 2.42 (t, 2, J = 6.5 Hz, $=CCH_2$), 2.08 (s, with fine splitting, 3, CH_3).

Anal. Calcd for $C_7H_{11}NO_4S$: C, 40.97; H, 5.40; N, 6.83; mol wt, 205. Found: C, 41.15; H, 5.32; N, 6.89; *m/e* 205.[26]

3,6-Dihydro-4,5-dimethyl-2*H*-pyran-2-one (53).—In a manner similar to the preparation of **42** and its hydrolysis to **45**, unstable **6-chlorosulfonylimino-5,6-dihydro-3,4-dimethyl-2*H*-pyran (51)** was obtained as one of the three products resulting from the reaction between equimolar (0.20 mol) quantities of **13** and CSI. Hydrolysis of **51** in this mixture afforded **53** as an oil (9.3 g, 0.074 mol, 37%): bp 76–78° (0.3 mm); ir (neat) 1720 cm^{-1} (5.81 μ) (C=O); nmr (neat) δ 4.60 (broad s with fine splitting, 2, CH_2O), 2.90 (broad s with fine splitting, 2, CH_2CO), 1.66 (broad s with fine splitting, 6, CH_3).

Anal. Calcd for $C_7H_{10}O_2$: C, 66.64; H, 7.99. Found: C, 66.42; H, 7.96.

6-Chlorosulfonylimino-3,6-dihydro-3,4-dimethyl-2*H*-pyran (54).—***N*-Chlorosulfonyl-2-azetidinone (14,** 44.6 g, 0.20 mol) in a capped jar was allowed to stand at ambient temperature for 48 hr. Rearrangement product **54** (22.8 g, 0.102 mol, 51%) was thus obtained as white crystals: mp 78–79° (from CH_2Cl_2–ether): ir (KBr) 1635 (6.12) (C=N) and 1545 cm^{-1} (6.47 μ) (C=C); uv max (EtOH) 257 mμ (ϵ 10,000); nmr ($CDCl_3$) δ 6.02 (s with fine splitting, 1, =CH), 4.52 (seven peaks arising from an AB pattern further split in two, in which the center two lines overlap, 2, J_{gem} = 11.5 Hz, CH_2), 3.0–2.4 (m, 1, CH), 2.16 (d, 3, J = 1 Hz, CH_3C=), 1.24 (d, 3, J = 7.0 Hz, CH_3CH).

Anal. Calcd for $C_7H_{10}NO_3SCl$: C, 38.15; H, 4.57; N, 6.36; mol wt, 223. Found: C, 37.86; H, 4.20; N, 6.08; *m/e* 223.[26]

5,6-Dihydro-4,5-dimethyl-2*H*-pyran-2-one (55).—A solution of **54** (11.2 g, 0.050 mol) in 30 ml of absolute methanol was refluxed for 10 min. After addition of 20 ml of H_2O, the solution was extracted with four 50-ml portions of CH_2Cl_2. The combined extracts were dried ($MgSO_4$) and filtered, and the solvent was removed *in vacuo*. The residual oil was fractionally distilled to give **55** (5.8 g, 0.046 mol, 92%): bp 67–70° (0.05 mm); ir (neat) 1725 cm^{-1} (5.80 μ) (C=O); uv max (EtOH) 216 mμ (ϵ 6500); nmr ($CDCl_3$) δ 5.61 (s with fine splitting, 1, =CH), 4.15 (AB pattern further split in two, 2, J_{gem} = ~11.5, J = 4.5, Hz $\Delta\delta$ = ~18 Hz, CH_2), 2.65–2.20 (m, 1, CH), 1.96 (d, 3, J = 1 Hz, CH_3C=), 1.16 (d, 3, J = 7.0 Hz, CH_3CH).

Anal. Calcd for $C_7H_{10}O_2$: C, 66.64; H, 7.99. Found: C, 66.59; H, 7.87.

3,6-Dihydro-4,5-dimethyl-2(1*H*)-pyridone (56).—Equimolar amounts (0.20 mol) of **13** and CSI in ether were refluxed for 6 hr under the usual conditions. The cooled solution containing

(26) We are grateful to Dr. Ramon A. Solomone for the mass spectrum of this compound and its interpretation, and to the facilities of the National Institute of Health sponsored (FR 00317) Mass Spectrometry Center at the Massachusetts Institute of Technology.

1-chlorosulfonyl-3,5-dihydro-4,5-dimethyl-2-pyridone (**52**) was hydrolyzed and worked up in a manner similar to **43** → **49**. γ lactam **56** crystallized from the hydrolysis mixture after 2 weeks standing in a freezer (−15°). Several sublimations at 80° (0.3 mm) afforded analytically pure **56**: mp 96–98°; ir (KBr) 1325 (7.55) and 1660 cm^{-1} (6.02 μ) (C=O); nmr ($CDCl_3$) δ 8.65 (mound, 1, NH), 3.87 (mound, 2, CH_2NH), 2.89 (mound, 2, CH_2CO), 1.67 (s, 6, CH_3). Unlike lactam **49**, the signals did not sharpen up after a D_2O wash.

Anal. Calcd for $C_7H_{11}NO$: C, 67.17; H, 8.86; N, 11.19. Found: C, 66.76; H, 8.81; N, 10.94.

With the isolation and identification of lactones **53** and **55** and lactam **56**, it was possible to run a material balance on the reaction between CSI and **13** to form **14** and its thermal rearrangement to **51**, **52**, and **54**. Thus on a 0.20 *M* scale, the reaction between CSI and **13** afforded a mixture of **51**, **52**, and **54** which was hydrolyzed to give 17.7 g (0.140 mol based on an average mol wt 126 (70% conversion) of an oil containing **53**, **56**, and **55**, respectively, in a ratio (nmr) of 8:24:38.

Alkaline Hydrolysis of *N*-Chlorosulfonyl-2-azetidinones in Methanol.—The general procedure used was as follows. A solution of the *N*-chlorosulfonyl-2-azetidinone in ether was treated with a saturated solution of NaOH in CH_3OH to pH 9 at 5–20°. Sufficient water was added to clarify the reaction mixture which was then extracted with five 50-ml portions of ether. The combined extracts were dried ($MgSO_4$) and filtered and the solvent was removed *in vacuo* to give the bis esters of β-amino(*N*-sulfonic acid)carboxylic acids of nmr purity.

Methyl 3-methoxysulfonylamino-3,4-dimethylpent-4-enoate (**61**) was obtained from **8** as a red oil (64%): ir (neat) 3300 (NH) and 1735 cm^{-1} (C=O); nmr ($CDCl_3$) δ 6.20 (s, 1, NH), 6.31–5.83 (four peaks, 1, CH=), 5.43–5.00 (four peaks, 2, CH_2=), 3.77 and 3.65 (two s, each 3, SO_3CH_3 and CO_2CH_3), 2.76 (s, 2, CH_2), 1.52 (s, 3, CH_3).

Methyl 3-methoxysulfonylamino-3,4-dimethylpentanoate (**62**) was obtained from **17** as a light yellow oil (72%): bp 135–140° (0.2 mm); ir (neat) 3300 (NH) and 1735 cm^{-1} (C=O); nmr ($CDCl_3$) δ 5.67 (s, 1, NH), 3.77 and 3.66 (two s, each 3, SO_3CH_3 and CO_2CH_3), 2.66 (AB pattern, 2, J_{gem} = ~16 Hz, CH_2), 2.15 (heptet, 1, *J* = 7.0 Hz, CH), 1.31 (s, 3, CH_3), 0.96 and 0.90 [two d, 6, *J* = 7.0 Hz, $CH(CH_3)_2$].

Methyl 3-methoxysulfonylaminohex-4-enoate (**63**) was obtained from **20** as an orange–red oil (46%): ir (neat) 3275 (NH) and 1730 cm^{-1} (C=O); nmr ($CDCl_3$) δ 6.34 (mound, 1, NH), 5.73–5.45 (m, 2, CH=CH), 4.40–3.92 (m, 1, CH), 3.72 and 3.64 (two s, each 3, SO_3CH_3 and CO_2CH_3), 2.56 (d, 2, *J* = 6.5 Hz, CH_2), 1.68 (d, 3, *J* = 5.0 Hz, CH_3).

Methyl 3-methoxysulfonylaminohexanoate (**64**) was obtained from **23** as an orange oil (36%): ir (neat) 3290 (NH) and 1735 cm^{-1} (C=O); nmr ($CDCl_3$) δ 5.98 (mound, 1, NH), 3.96–3.52 (m, 1, buried under the methyl singlets, CH), 3.78 and 3.68 (two s, each 3, SO_3CH_3 and CO_2CH_3), 2.62 (d, 2, *J* = 6.0 Hz, CH_2), 1.73–0.73 [m, 9, $(CH_2)_3CH_3$].

Methyl 3-methoxysulfonylamino-2,3-dimethylbutanoate (**65**) was obtained from **57**[22] as an orange oil (66%): bp 128–136° (0.5 mm); ir (neat) 3300 (NH) and 1730 cm^{-1} (C=O); nmr ($CDCl_3$) δ 5.78 (mound, 1, NH), 3.76 and 3.68 (two s, each 3, SO_3CH_3 and CO_2CH_3), 2.72 (q, 1, *J* = 7.0 Hz, CH), 1.36 [s, 6, $(CH_3)_2C$], 1.22 (d, 3, *J* = 7.0 Hz, CH_3).

Methyl 3-methoxysulfonylamino-2,2,3-trimethylbutanoate (**66**) was obtained from **59**[22] as a yellow oil (74%): ir (neat) 3280 (NH) and 1715 cm^{-1} (C=O); nmr ($CDCl_3$) δ 6.12 (mound, 1, NH), 3.76 and 3.71 (two s, each 3, SO_3CH_3 and CO_2CH_3), 1.34 [s, 6, $(CH_3)_2CNHSO_3$], 1.24 [s, 6, $(CH_3)_2CCO_2$].

Registry No.—**3**, 7486-94-4; **6**, 5303-67-3; **8**, 20012-93-5; **9**, 20012-94-6; **12**, 20361-37-9; **14**, 30217-24-4; **15**, 30217-25-5; **18**, 30217-26-6; *cis*-**21**, 22970-43-0; *trans*-**21**, 22970-42-9; **24**, 22937-03-7; **27**, 30217-74-4; **30**, 30217-27-7; *cis*-**33**, 30288-16-5; *trans*-**33**, 30217-75-5; **36**, 30217-76-6; **40**, 22038-80-8; **41**, 22038-79-5; **45**, 10021-22-4; **46**, 30217-28-8; **47**, 2381-87-5; **48**, 30288-18-7; **49**, 20967-57-1; **50**, 30288-19-8; **53**, 22937-02-6; **54**, 30217-32-4; **55**, 30217-33-5; **56**, 30288-20-1; **61**, 30288-21-1; **62**, 30288-22-3; **63**, 30217-34-6; **64**, 30299-80-0; **65**, 30354-61-1; **66**, 30288-23-4; **67**, 30217-35-7; CSI, 1189-71-5; potassium 3-methyl-*cis*-2,4-pentadienoate, 30217-83-5.

Steric Effects of Vicinal Substituents on Redox Equilibria in Quinonoid Compounds

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The redox potentials of a series of methyl-substituted quinones and hydroquinones having *p*-tolylthio substituents were determined polarographically in 50% methanol at pH 5.37. The substituent effects are not additive, as shown by a break in the plot of $E_{1/2}$ *vs.* $\Sigma\sigma_{p\text{-Me}}$ (summation of Hammett σ-para constants of methyl). The break occurs with those compounds in which the *p*-tolylthio group is flanked by a methyl group, giving half-wave potentials which are more positive than predicted. The fact that the quinone sulfides are more easily reduced than expected suggests steric inhibition of the mesomeric effect of the arylthio substituent. Substituents that show strong electron-withdrawing inductive effects (*e.g.*, phenylsulfonyl and 1-phenyl-5-tetrazolylthio) fail to show a similar break in the linear free-energy relationship. Small, but significant, deviations from strict additivity for certain quinone–hydroquinone couples illustrate that subtle electronic and steric effects can be identified when an internally consistent series of polarographic measurements is obtained.

It is well established that the electronic and steric requirements of substituents attached to quinone and hydroquinone rings have important effects on the observed reduction and oxidation potentials.[1] In preparative organic chemistry, the nature of the substituent determines the oxidation state of the product when nucleophiles are added to quinones (eq 1 and 2).[2,3] Thus, when N = $PhNH_2$ and R = H, the substituted hydroquinone (HQ_2) formed initially is oxidized by unreacted Q, and further addition can occur.[2] When N = $PhSO_2H$, no cross oxidation occurs and HQ_2 is isolated.[3]

Addition of thiophenol (N = PhSH) to 1,4-benzoquinone gives the cross-oxidized product Q_2 (R = H).[4,5] In contrast, we find that addition of *p*-toluenethiol to di- and trimethyl-1,4-benzoquinones gives good yields of the *p*-tolylhydroquinone sulfides (HQ_2). Therefore, the presence and number of other substituents in the

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