rhombic crystals gave the spectrum normally given by needles—in other words, by the β form! From 30 samples of **2** prepared at different times, three samples gave the spectrum corresponding to the α form. All attempts to recrystallize these samples of the α form have invariably given the β form. We have normally been unable to determine which form we have either by observation of the solid with the unaided eye or with a microscope.

Registry No.—**2**, 2041-14-7; **2** (*N*-benzoyl), 35045-99-9.

The Stereochemistry of Aziridine Ring Expansion Reactions with Sulfur Nucleophiles to Give Thiazolidines and 2-Amino-2-thiazolines

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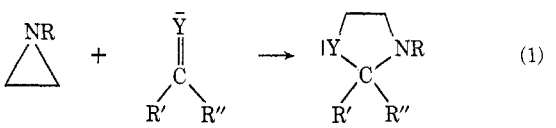
The ring enlargement reactions of aziridines with thiocyanic acid and acetone plus hydrogen sulfide to 2-amino-2-thiazolines **2** and 2,2-dimethylthiazolidines **9** proceed 100% stereospecifically with Walden inversion; for example *cis*- and *trans*-2,3-dimethylaziridine, **11** and **12**, with thiocyanic acid gave exclusively *trans*- and *cis*-2-amino-4,5-dimethyl-2-thiazoline, **13** and **14**, respectively. For the 2-amino-2-thiazolines **2** it was shown by means of ir and nmr spectra, that the tautomeric equilibrium between the forms with exocyclic and endocyclic double bond (eq 5) lies completely toward the 2-amino form **19a** with endocyclic double bond.

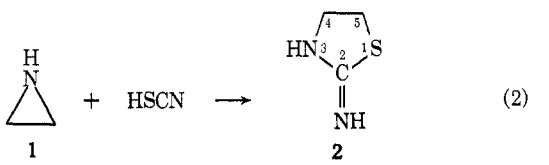
Aziridines can be ring expanded with suitable reagents according to the following general scheme (eq 1).[1]



(1)

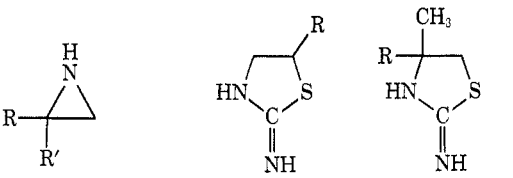
The reagent attacking the aziridine must have a multiple bond attached to an atom Y possessing a free electron pair. Only reactions in which the aziridine reacts under carbon–nitrogen cleavage (rather than carbon–carbon cleavage) are considered here. The ring expansion of aziridines with aldehydes,[2] aldehydes and ketones in the presence of H_2S,[2b,3-6] carbon disulfide,[1,7-10] xanthates,[1] isocyanates,[1] alkali thiocyanate or thiocyanic acid,[8,10,11] organic isothiocyanates,[1] thioacetamide,[1] and nitriles[1] have been reported. Many of these reactions proceed under acid catalysis which facilitates the opening of the aziridine ring.

Additions of Thiocyanic Acid to Give 2-Iminothiazolidines.—Gabriel and Colman discovered the reaction of aziridines (**1**) with thiocyanic acid to give 2-iminothiazolidines[8] according to eq 2. From phenylaziridine (**3a**)



(2)

in the presence of HCl they obtained 2-imino-5-phenylthiazolidine (**4a**). Earley, *et al.*, investigated in detail

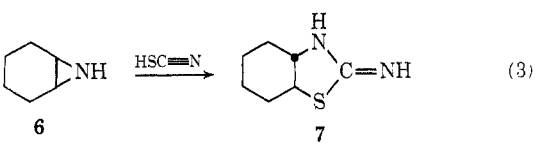


3a, R = C_6H_5; R′ = H
b, R = C_2H_5; R′ = H
c, R = CH_3; R′ = CH_3
d, R = CH_3; R′ = H

4a, R = C_6H_5
b, R = CH_3

5a, R = H
b, R = CH_3

the mechanism and kinetics of the addition of potassium thiocyanate to four aziridines, aziridine (**1**) itself, 2-ethylaziridine (**3b**), 2,2-dimethylaziridine (**3c**), and *N*-(*n*-butyl)aziridine and obtained in all cases the corresponding 2-iminothiazolidines.[11] From 2,2-dimethylaziridine (**3c**) they obtained 2-imino-4,4-dimethylthiazolidine (**5b**) by attack of the thiocyanate ion at the primary carbon atom of the aziridine ring. Finally, Mousseron, *et al.*, reported the addition of thiocyanic acid to *cis*-cyclohexenimine (**6**) to give the trans-fused thiazolidine **7** (eq 3).[10] The latter is



(3)

the only example where the stereochemistry of the reaction has been mentioned at all.

Additions of Aldehydes and Ketones in the Presence of Hydrogen Sulfide to Give 2-Alkyl- and 2,2-Dialkylthiazolidines.—Bestian[3] has shown that aziridine (**1**) treated with hydrogen sulfide in the presence of an aldehyde or ketone **8** gives a thiazolidine **9** according to eq 4; for example, the addition of hydrogen sulfide to

(1) P. E. Fanta in "Heterocyclic Compounds with Three- and Four-Membered Rings," Part 1, A. Weissberger, Ed., Interscience, New York, N. Y., 1964, pp 524–575. H. Bestian in "Methoden der Organischen Chemie," Vol. 11/2, Houben-Weyl, George Thieme Verlag, Stuttgart, 1958, p 223 ff; O. C. Dermer and G. E. Ham, "Ethylenimine and Other Aziridines," Academic Press, New York, N. Y., 1969, Chapter 3; J. McCormick, R. I. Kaplan, and B. J. Stormer, *Can. J. Chem.*, **49**, 699 (1971).

(2) (a) J. B. Doughty, C. L. Lazzell, and A. R. Collett, *J. Amer. Chem. Soc.*, **72**, 2866 (1950). (b) See, however, R. Tondeur, R. Sion, and E. Doray, *Bull. Soc. Chim. Fr.*, 2493 (1964).

(3) (a) H. Bestian, *Justus Liebigs Ann. Chem.*, **566**, 210 (1950); (b) H. Bestian (I. G. Farbenindusttie A.-G.), German Patent 747,733 (1939) [*Chem. Zentralbl.*, **I**, 952 (1945)].

(4) G. Drehfahl and M. Huebner, *J. Prakt. Chem.*, (4) **23**, 149 (1964); R. G. Kostyanovskii, *Dokl. Akad. Nauk SSSR*, **135**, 853 (1960) [*Chem. Abstr.*, **55**, 12380 (1961)]; F. Asinger, *Monatsh. Chem.*, **99**, 2090 (1968).

(5) J. Metzger and J.-L. Larice, *Bull. Soc. Chim. Fr.*, 575 (1965).

(6) J.-L. Larice, J. Roggero, and J. Metzger, *ibid.*, 3637 (1967).

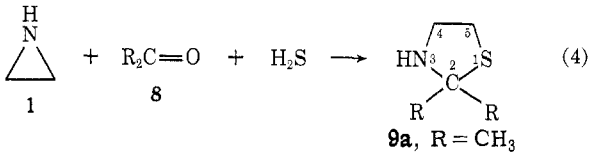
(7) S. Gabriel and H. Ohle, *Chem. Ber.*, **50**, 804 (1917).

(8) S. Gabriel and J. Colman, *ibid.*, **47**, 1866 (1914).

(9) T. A. Foglia, L. M. Gregory, G. Maerker, and S. F. Osman, *J. Org. Chem.*, **36**, 1068 (1971), and references cited therein.

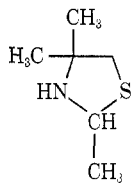
(10) M. Mousseron, F. Winternitz, and R. Dennilauer, *C. R. Acad. Sci.*, **239**, 278 (1954); F. Winternitz, M. Mousseron, and R. Dennilauer, *Bull. Soc. Chim. Fr.*, **382**, 1228 (1956).

(11) J. E. Earley, O. E. O'Rourke, L. B. Clapp, J. O. Edwards, and B. C. Lawes, *J. Amer. Chem. Soc.*, **80**, 3458 (1958).



1 + $R_2C{=}O$ (8) + H_2S → **9a**, R = CH_3 (4)

aziridine (**1**) in the presence of acetone gives 2,2-dimethylthiazolidine (**9a**). Larice, Roggero, and Metzger investigated the similar reaction of 2,2-dimethylaziridine (**3c**) with acetaldehyde in the presence of hydrogen sulfide and found the product to be 2,4,4-trimethylthiazolidine (**10**), *i.e.*, attack of the



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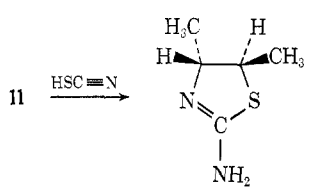
nucleophile took place exclusively at the less substituted primary carbon atom.[6]

Although numerous other authors and patents have used this reaction, no investigation of the stereochemistry of the reaction has been reported.

Results

Addition of Thiocyanic Acid.—When *cis*-2,3-dimethylaziridine (**11**) was treated with thiocyanic acid, *trans*-2-



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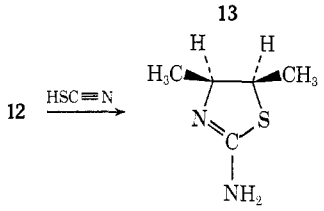


14

amino-4,5-dimethyl-2-thiazoline (**13**) was the only thiazoline isomer formed. Similarly, when *trans*-2,3-dimethylaziridine (**12**) was treated with thiocyanic acid, *cis*-2-amino-4,5-dimethyl-2-thiazoline (**14**) was the exclusive isomer formed. (The 2-amino-2-thiazoline structure is tautomeric with the 2-iminothiazolidine structure considered before, as will be discussed below, eq 5.) All preparative results are summarized in Table I.

Both the trans and cis isomers **13** and **14** were not previously reported in the literature. The stereospecificities of these two reactions was most easily determined by examination of the nmr spectra of the crude reaction products, especially in the region of the 4,5 methine protons (see Table II). The absence of any bands in the range of 4.10–4.30 ppm in the spectrum of the reaction product of the trans isomer **13** indicated the absence of the cis isomer **14**. Similarly, the absence of bands between 3.30 and 3.50 ppm in the

TABLE I

PRODUCTS OF RING EXPANSION REACTIONS OF AZIRIDINES WITH SULFUR NUCLEOPHILES

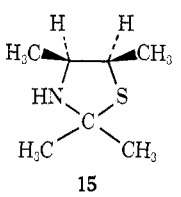
Aziridine	Nucleophile	Thiazolidine	% yield	Derivatives, mp, °C
11	Thiocyanic acid	**13**	73[a]	Picrate salt, 202–203
12	Thiocyanic acid	**14**	76[a]	Picrate salt, 201–202
3d	Thiocyanic acid	**5a**	79[a]	Oxalate salt, 227–230 Picrate salt, 236–239[c]
12	Hydrogen sulfide with acetone	**15**	15[b]	
3d	Hydrogen sulfide with acetone	**16**	24.2[b]	

[a] Crude weight yield of product. [b] Yield after one distillation. [c] Lit.[7] 230–244°, also depending on rate of heating.

spectrum of the reaction product of the cis isomer **14** showed the absence of the trans isomer **13**.

2-Methylaziridine (**3d**) after treatment with thiocyanic acid gave only one of the two possible constitutional 2-thiazoline isomers as indicated by the single methyl doublet appearing in the nmr spectrum of the raw reaction product. This isomer was identified as being 2-amino-4-methyl-2-thiazoline (**5a**) from the melting point of the picrate salt reported in literature by Gabriel and Ohle.[7,12] These authors had obtained the compound from the reaction of 2-amino-1-bromopropane with thiocyanic acid.

Addition of Acetone in the Presence of Hydrogen Sulfide.—Acetone was added in the presence of hydrogen sulfide to *trans*-2,3-dimethylaziridine (**12**). The nmr spectrum of the crude reaction product indicated that *cis*-2,2,4,5-tetramethylthiazolidine (**15**) was the exclusive thiazolidine formed.



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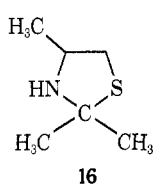


16

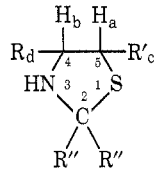
The addition of hydrogen sulfide to 2-methylaziridine (**3d**) in the presence of acetone gave a raw product in the nmr spectrum of which a single methyl doublet was observed, signifying that only one isomeric form was produced. On the base of the chemical shift of the 4- or 5-methyl group, the structure 2,2,4-trimethylthiazolidine (**16**) must be assigned to this product. This is in agreement with all other additions of sulfur nucleophiles to 2-alkylaziridines, specifically the addition of hydrogen sulfide in the presence of acetaldehyde to 2,2-dimethylaziridine (**3c**) to give solely 2,4,4-trimethylthiazolidine (**10**);[6] *i.e.*, nucleophilic attack takes place at the less substituted primary carbon atom. Compound **16** has been reported previously in the patent literature erroneously as 2,2,5-trimethylthiazolidine without proof of structure.[3b]

Nmr Spectra.—The nmr data of all thiazolidine deriv-

(12) The melting point of the picrate of the 4 isomer, 2-amino-4-methyl-2-thiazoline (**5a**), is 236–239°. (See Table I or Experimental Section for further comments.) The melting point of the picrate of the 5 isomer, 2-amino-5-methyl-2-thiazoline (**4b**), is 199–200°: P. Hirsch, *Chem. Ber.*, **23**, 965 (1890); also ref 7.

TABLE II

NMR DATA OF THIAZOLIDINES[a]



Compd	H_a (at C-5)	H_b (at C-4)	H_c (at C-5)	H_d (at C-4)	At C-2
14	3.86[b] (qu, J_{ac} = 6.5)	4.13[b,c] (qu, J_{bd} = 6.8)	1.24[b] (d, J_{ca} = 6.5)	1.30[b] (d, J_{db} = 6.8)	NH_2, 6.19 (s)
13	3.64[b] (qu, J_{ac} = 6.3)	3.73[b,c] (qu, J_{bd} = 6.0)	1.25 (d, J_{ca} = 6.3)	1.40 (d, J_{db} = 6.0)	NH_2, 6.02 (s)
5a (R′ = H cis to R)	3.43 (q, J_{ac} = 10.1, J_{ab} = 7.0)	4.25 (q,[c] J_{ba} = 7.0, J_{bc} = 7.8, J_{bd} = 6.5)	2.94 (q, J_{ca} = 10.1, J_{cb} = 7.8)	1.28 (d, J_{db} = 6.5)	NH_2, 4.81 (s)
15	4.49[b] (m)	4.60[b,c] (m)	1.09[b] (d, J_{ca} = 6.9)	1.16[b] (d, J_{db} = 5.7)	*cis*-CH_3, 1.53 (s) *trans*-CH_3, 1.67 (s)
16		3.05–3.75 (m, J_{bd} = 5.7)		1.35 (d, J_{db} = 5.7)	*cis*-CH_3, 1.55 (s) *trans*-CH_3, 1.66 (s)

[a] All spectra were determined in $CDCl_3$ solution; chemical shifts are in δ (ppm) (J in hertz) downfield from internal tetramethylsilane; s = singlet, d = doublet, q = quartet, qu = quintet, m = multiplet. [b] Overlapping peaks. [c] Predominant pattern in actually higher multiplet.

atives investigated are summarized in Table II. The 4- and 5-methyl groups and methine protons of the 4,5-dimethylthiazolidine derivatives were analyzed as A_3XYB_3 systems with $J_{AY} = J_{BX} = 0$. In all compounds studied, the 4-methine proton appears at lower field than the 5-methine proton by about 0.1–0.4 ppm. The differences are generally smaller for the 4- and 5-methyl groups although the 4-methyl group still appears at lower field than the 5-methyl group. This is in agreement with the general behavior of protons neighboring a saturated nitrogen atom[13,14] *vs.* a sulfur atom[15] and also with the assignment of thiazolidine derivatives given by all other authors.[9,16] The assignment is also supported, as will be discussed, by the coupling between the 4-methine proton and the neighboring N–H proton.

In practically all 4,5-dimethylthiazolidine derivatives examined the vicinal coupling constant between the 4- and 5-methine proton is very nearly of the same magnitude as the coupling constant between the methine protons and the corresponding geminal methyl groups. For this reason the 4- and 5-methine protons appear essentially as two quintets which frequently overlap partially.

Assignment of the Cis- or Trans Configuration.—The assignment of the cis or trans configuration with respect to the 4,5-methyl groups is based mainly on the comparison between the chemical shifts at the 4 and 5 positions. The 4- and 5-methyl groups in all compounds examined absorb at ~0.1 ppm higher field in the cis compounds than in the corresponding trans isomers. On the other hand, the 4- and 5-methine protons absorb at ~0.5 ppm lower field in the *cis*-thiazolidines than in the trans isomers. This effect can be attributed mainly to the diamagnetic anisotropy of the *C*-methyl bond and is found in many cis–trans isomer pairs of planar three- to five-membered-ring compounds.[17] A methyl group has the tendency to shield a neighboring substituent in the cis position and to deshield a neighboring substituent in trans orientation. Thus, two *trans*-4,5-methyl groups will mutually deshield each other so as to shift both methyl bands to lower field. At the same time the 4 and 5 protons will be shielded by the neighboring methyl groups and therefore shift upfield.[17]

Likewise, two *cis*-4,5-methyl groups will mutually shield each other causing the methyl bands to appear at higher field. The 4,5 protons will now be deshielded and therefore move to lower field.

The same effect results from the two protons. The diamagnetic anisotropy of carbon–hydrogen bond presently is assumed to be ~0.75 that of a carbon–carbon bond. This means that the effect of the carbon–hydrogen bonds opposes that of the methyl group, but cannot completely cancel it out.[18]

A more accurate treatment has to take into account the three C–H bonds of the methyl group as well as the rotation of the methyl group. This does not substantially change, however, the above conclusions.[19] A criterion frequently used for the assignment of the cis or trans configuration is based on the 4-H,5-H coupling constant. In three- to five-membered rings, which cannot deviate appreciably from planarity, cis proton coupling is generally larger than trans proton coupling, as expected from the Karplus rule.[14,20] Unfortunately this criterion is difficult to apply in the present case since in most compounds examined the multiplet pattern of the 4- and 5-methine protons is so complex that an accurate evaluation of the corresponding coupling constant is difficult. Probably the difference between the cis and trans vicinal coupling constant is much smaller in thiazolidine derivatives than in the 2-thiazoline or 2-oxazoline derivatives owing to the increased flexibility of the five-membered ring in the former.

The nmr spectrum of *cis*-2,2,4,5-tetramethylthiazolidine (**15**) clearly showed two distinct bands for the two methyl groups at carbon position two. The peak

(13) Protons neighboring an unsaturated nitrogen atom would be shifted downfield still further.

(14) L. M. Jackman and S. Sternhell, "Applications of Nuclear Magnetic Resonance Spectroscopy in Organic Chemistry," 2nd ed, Pergamon Press, Elmsford, N. Y., 1969.

(15) Reference 14, p 163.

(16) M. Chanon and J. Metzger, *Bull. Soc. Chim. Fr.*, 2855 (1968).

(17) Reference 14, p 234 ff.

(18) Reference 14, p 78 ff.

(19) J. Elguero and A. Fruchier, *Bull. Soc. Chim. Fr.*, 496 (1970).

(20) S. Sternhell, *Quart. Rev. Chem. Soc.*, **23**, 236 (1969); ref 14, p 286 ff.

TABLE III
IR DATA[a] FOR 2-AMINO-2-THIAZOLINES (CH_2Cl_2)

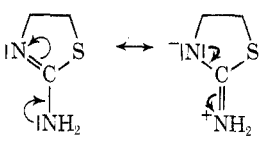
Compd	C=N[b]	C—N[c]	ν_a(N—H)	ν_s(N—H)	Other
5a	1645 (s)	1310 (m)	3510 (m)	3415	3110 (m), 2933 (m), 1595 (m), 1022 (m), 921 (S)
13	1639 (s)	1314 (m)	3509 (m)	3410	3100 (m), 2941 (m), 1595 (m), 1434 (m), 1019 (m), 1003 (m), 993 (m), 915 (m)
14	1647 (s)	1321 (m)	3520 (m)	3420 (m)	3110 (m), 2959 (m), 1595 (m), 1495 (m), 1443 (m), 1380 (m), 1063 (m), 1010 (m), 914 (m)

[a] In cm^{-1}. [b] Amidine I band. [c] Amidine III band.

at high field can be assigned to the group cis to the methyl groups at atoms 4 and 5, on the base of the shielding between *cis*-methyl groups discussed above, which applies to methyl groups in 1,3 position as well.[21]

Infrared Data of 2-Amino-2-thiazolines.—The important ir data of the 2-amino-2-thiazolines are summarized in Table III. All 2-amino-2-thiazolines show the C=N stretch (amide or amidine I band)[22] as a very strong band at 1640 cm^{-1} which is in the usual region of 1600–1640 cm^{-1} for 2-thiazoline and 2-amino-2-thiazoline derivatives.[23,24]

A medium to strong band around 1315 cm^{-1} may be assigned as mainly due to the C—N stretch (amidine III band). The band under consideration closely corresponds to the amide III band, which appears around 1290 cm^{-1}.[22] The higher frequency than that found for a typical C—N stretch (1220–1020 cm^{-1}) is, as in the amide III band, due to the resonance between forms **17** and **18**. Sharp and medium bands at

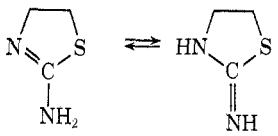


17 **18**

~3510 and 3420 cm^{-1} must be assigned to the asymmetric and symmetric N—H stretch of the amino group at C-2.[25,26] The medium to weak band around 3350 cm^{-1} is probably due to associated N—H.

Other medium to strong bands common in all 2-amino-2-thiazolines examined appear at ~3100, 1590, 1020, and 915 cm^{-1}. The band at ~3100 cm^{-1} has long been the subject of controversy in amides. The usual explanation for the band in amides is as a combination band between the N—H in-plane bending and the C=O stretching.[27] Bellamy has pointed out that this band persists in thiolactams with five- and six-membered rings although the explanation just mentioned is impossible.[28] The band at ~1590 cm^{-1} is usually assigned to the amino deformation $\delta(NH_2)$.[29]

2-Amino-2-thiazolines are basically capable of existing in two tautomeric forms (eq 5). The 2-amino-2-



(5)

19a **19b**

thiazoline form, **19a**, has an endocyclic double bond, whereas the other tautomer, the 2-iminothiazolidine, **19b**, possesses an exocyclic double bond.

The above ir data clearly show that the 2-amino-2-thiazoline tautomer **19a** with endocyclic double bond is the predominant, if not exclusive, form present. This is in agreement with the generalization that amino tautomers are always more stable than their imino tautomers[30] as well as with the behavior of the very similar equilibrium of 2-amino-2-oxazolines where also the endocyclic form has been found to be the predominant tautomer.[26] The exocyclic tautomer **19b** should not be present in the tautomeric equilibrium (eq 5) in a significant percentage, since all bands expected for this tautomer are absent in the ir spectrum. Thus no ν(C=N) band due to the exocyclic tautomer **19b** and no amide II band between 1500 and 1575 cm^{-1}, which the exocyclic tautomer **19b** as a secondary amide (amidine) should show, can be detected in the ir spectrum.

Discussion

Although all of the ring expansions of aziridines examined proceed identically with Walden inversion, the detailed mechanisms for the two reactions are different and so will be discussed in turn.

Formation of 2-Amino-2-thiazolines.—Mechanism 6, illustrated by the reaction of the *cis*-aziridine **11** to give the *trans*-2-thiazoline **13**, seems to account best for the observed results of the additions of thiocyanic acid to aziridines to give 2-amino-2-thiazolines.

Thus the reaction involves one inversion on opening of the protonated aziridine ring **20** by the thiocyanate ion to give the corresponding 2-aminothiocyanate **21** (threo depicted in mechanism 6). This is followed

(21) M. Anteunis and F. Alderweireldt, *Bull. Soc. Chim. Belg.*, **73**, 889, 903 (1964).

(22) L. J. Bellamy, "The Infra-red Spectra of Complex Molecules," Wiley, New York, N. Y., 1954; L. J. Bellamy, "Advances in Infrared Group Frequencies," Methuen, London, 1968.

(23) T. Nishiguchi, H. Tochio, A. Nabeya, and Y. Iwakura, *J. Amer. Chem. Soc.*, **91**, 5835, 5841 (1969).

(24) W. Otting and F. Drawert, *Chem. Ber.*, **88**, 1469 (1955); A. I. Myers, *J. Org. Chem.*, **24**, 1233 (1959); A. R. Katritzky and A. P. Ambler in "Physical Methods in Heterocyclic Chemistry," Vol. 2, A. R. Katritzky, Ed., Academic Press, New York, N. Y., 1963, p 161 ff.

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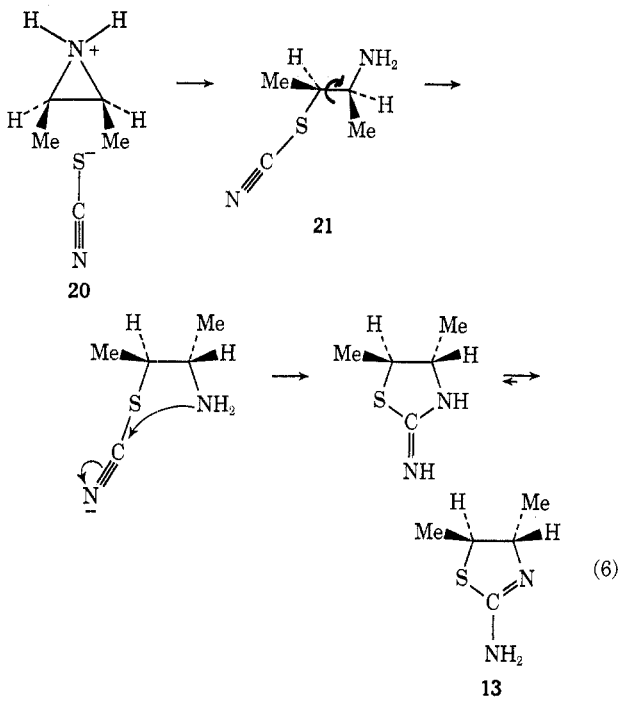
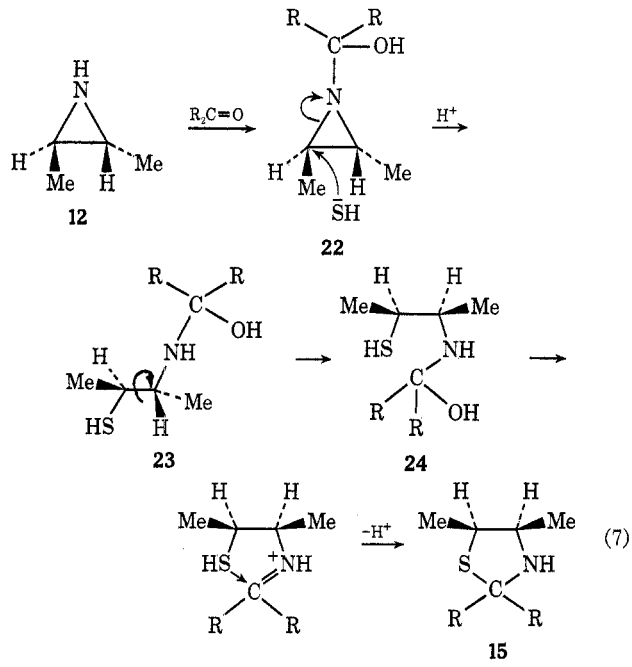


(6)

by rotation around the C—C bond of the former aziridine ring and ring closure to give, after several tautomerization steps, the 2-amino-2-thiazoline (**13** depicted in mechanism 6).

Formation of 2,2-Dialkylthiazolidines.—For the formation of thiazolidines by the ring expansion of N-unsubstituted aziridines with hydrogen sulfide in the presence of aldehydes and ketones, mechanism 7, illustrating the reaction of *trans*-2,3-dimethyaziridine (**12**) to give *cis*-2,2,4,5-tetramethylthiazolidine (**15**), seems to account best for the observed results. It has been well established that N-unsubstituted aziridines form hemiaminals of the type **22** with aldehydes and ketones.[2b,5,6] The mechanism then again involves one inversion on opening of this hemiaminal **22** to give the 2-aminothiol derivative **23** (erythro illustrated), followed by rotation around the C—C bond of the former aziridine ring and ring closure to give the final thiazolidine (*cis*-**15**, illustrated). It is known that the reaction under consideration also proceeds with N-substituted aziridines. Here the formation of the hemiaminal **22** is prevented, and the reaction is likely to proceed by the aziridine ring opening with SH^- to give the corresponding 2-aminothiol, which with acetone in turn then can form the hemiaminal **24** (with NR in place of NH).



(7)

The reactions of 2-methylaziridine (**3d**) with all sulfur nucleophiles led exclusively to the corresponding 4-methylthiazolidine derivatives, indicating that the attack at the primary carbon atom is favored over attack at the secondary carbon atom. This is, of course, in agreement for the SN2 mechanism postulated for all reactions.

Experimental Section

General Procedures.—All ir spectra were taken on Perkin-Elmer Model 137 and Perkin-Elmer Model 225 spectrophotometers. Nmr spectra were taken on a Varian A-60 nmr spectrometer. Deuterated chloroform was used as a solvent if not specified otherwise, with tetramethylsilane as an internal standard. Melting points were taken on a Fisher-Johns melting point apparatus and are corrected. Boiling points are not corrected.

The microanalyses were performed by the Hoffmann-La Roche Corp., Nutley, N. J., to whom we would like to extend our thanks.

cis- **and** *trans*-**dimethylaziridines, 11 and 12,** were synthesized according to the method given by Dickey and coworkers from the corresponding epoxybutanes.[31] On the base of nmr and ir spectra, both isomers were >99% stereochemically pure.

The epoxybutanes, *cis*- and *trans*-2,3-epoxybutane, were made by a method described by Winstein and Lucas, by the addition of HOBr to *trans*- and *cis*-2-butene, respectively, and elimination of HBr with aqueous NaOH.[32] *N*-Bromosuccinimide was used, however, in place of *N*-bromoacetamide.

2-Amino-4-methyl-2-thiazoline (5a).—2-Methylaziridine (**3d**, 0.20 g, 3.5 mmol) dissolved in 2 ml of ether was slowly added to an ether solution containing an excess of thiocyanic acid at 0°. Upon addition, the raw product settled out as an oil. After the mixture stood at room temperature for 24 hr, the ether was distilled off and the oil was taken up in chloroform and dried with potassium carbonate. After evaporation of the solvent, the crude product remained as a viscous liquid yielding 0.32 g (79%) of **19**, picrate mp 236–239° (lit.[7] mp 230–244°, also dependent on rate of heating), oxalate mp 227–230°.

Anal. Calcd for $C_{10}H_{11}N_5O_7S$: C, 34.79; H, 3.21; N, 20.28; S, 9.28. Found: C, 34.87; H, 3.18; N, 20.31; S, 9.13.

trans-**2-Amino-4,5-dimethyl-2-thiazoline (13)** was prepared from *cis*-2,3-dimethylaziridine (**11**) in 73% crude yield, using the same method as was used for compound **5a**, picrate mp 202–203°.

Anal. Calcd for $C_{11}H_{13}N_5O_7S$: C, 36.77; H, 3.65; N, 19.49; S, 8.92. Found: C, 36.51; H, 3.39; N, 19.48; S, 8.63.

cis-**2-Amino-4,5-dimethyl-2-thiazoline (14)** was prepared from *trans*-2,3-dimethylaziridine (**12**) in 76% crude yield using the same procedure as was used for compound **5a**, picrate mp 201–202°.

Anal. Calcd for $C_{11}H_{13}H_5O_7S$: C, 36.77; H, 3.65; N, 19.49; S, 8.92. Found: C, 36.98; H, 3.73; N, 19.55; S, 8.77.

cis-**2,2,4,5-Tetramethylthiazolidine (15)** was prepared from 0.467 g of *trans*-2,3-dimethylaziridine (**12**) in 2 ml of acetone through which hydrogen sulfide was bubbled in excess for 2 hr; then for an additional half hour hydrogen sulfide was added under slight overpressure. The solution was heated for 2 hr at 40°, then at 60° for 2 additional hr. After heating, any remaining solvent was removed at reduced pressure. Distillation of the raw product gave a 0.137-g (15%) yield: ir (CH_2Cl_2) 3340 (br), 2915 (m), 1453 (m), 1379 (m), 1361 (m), 1142 (m), 1116 (m), 812 cm^{-1} (s).

2,2,4-Trimethylthiazolidine (16) was prepared from 0.57 (10

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mmol) of 2-methylaziridine (**3d**) using the procedure given for **15**. Distillation at reduced pressure gave 0.316 g (24.2% yield): bp 59° (18 mm) [lit.[3b] bp 55° (13 mm)]; ir (CH_2Cl_2) 3350 (br), 2915 (m), 1458 (m), 1379 (m), 1364 (m), 1125 (s), 802 cm^{-1} (s).

Registry No.—**5a**, 35740-21-7; **5a** oxalate, 35740-22-8; **13**, 35740-69-3; **13** picrate, 35740-70-6; **14**, 35740-71-7; **14** picrate, 35740-72-8; **15**, 35740-73-9; **16**, 35740-23-9.

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The Reaction of Thiophene-3,4-dicarbonyl Chloride with Aluminum Chloride and Benzene

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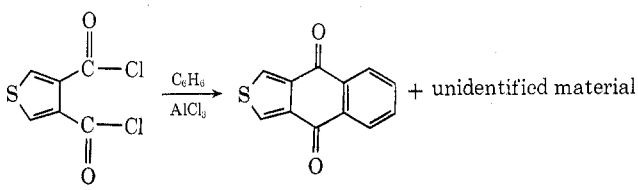
The reaction of thiophene-3,4-dicarbonyl chloride (1) with aluminum chloride and benzene has been shown to afford 4,9-dihydronaphtho[2,3-*c*]thiophene-4,9-dione (**2**), 1,1-diphenyl-1*H*,3*H*-thieno[3,4-*c*]furan-3-one (**14**), 3,4-dibenzoylthiophene (**15**), and 4-benzoylthiophene-3-carboxylic acid (**16**), depending upon the reaction conditions. These results contrast with literature reports of analogous reactions involving furan and pyrrole derivatives (**10** and **11**). A further example of a lactone derivative similar to **14** is seen in the treatment of 4-(α-hydroxybenzyl)-3-thiophenecarboxylic acid (**26**) with phosphorus pentachloride to give 1-phenyl-1*H*,3*H*-thieno-[3,4-*c*]furan-3-one (**28**).

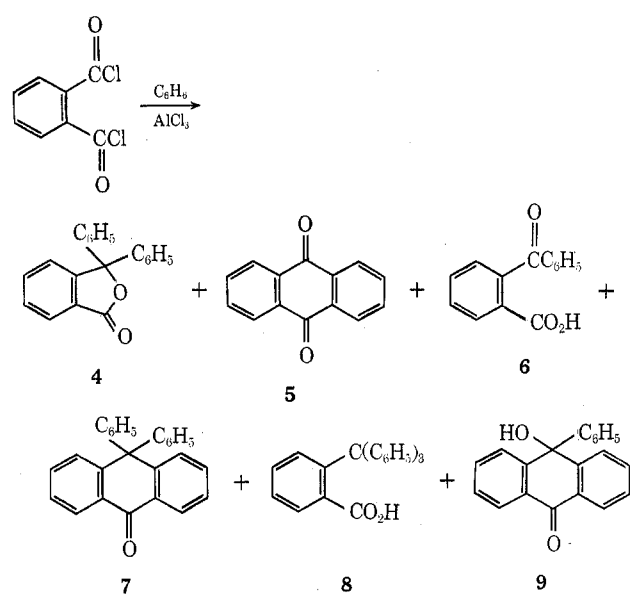
In an earlier report[1] concerning the synthesis of 4,9-dihydronaphtho[2,3-*c*]thiophene-4,9-dione (**2**), *via* the reaction of thiophene-3,4-dicarbonyl chloride (**1**) with



1 **2**

benzene and aluminum chloride, there was also isolated a second reaction product whose structure was not determined at that time.

The reaction of phthaloyl chloride (**3**) with benzene and aluminum chloride has been studied by several workers and shown to lead to the formation of as many

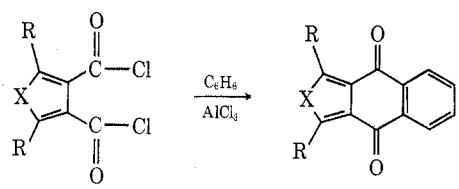


4 **5** **6**

7 **8** **9**

as six different products, **4**–**9**,[2] depending upon the reaction conditions.

There are a few reports in the literature concerning the acylation reactions of the heterocyclic analogs of phthaloyl chloride.[3] Nightingale and coworkers have studied the acylation reactions of the pyrrole derivative **10**[3b] and the analogous furan derivatives **11** with benzene.[3a,c] The only products isolated in each case



10, R = CH_3; X = *n*-C_4H_9N **12**, R = CH_3; X = *n*-C_4H_9N
11, R = CH_3, C_6H_5; X = O **13**, R = CH_3, C_6H_5; X = O

were cyclic diketones **12** and **13**. Attempts to acylate toluene with pyridine-2,3- and -3,4-dicarbonyl chlorides resulted in the formation of dark, intractable oils.[3e]

The unexpected isolation of a second product from the reaction of **1** with benzene and aluminum chloride motivated further study of this reaction. An investigation of this reaction involving the variation of quantities of reactants and reaction conditions was undertaken.

This study led not only to the isolation of **2**, but also to the isolation and characterization of 1,1-diphenyl-1*H*,3*H*-thieno[3,4-*c*]furan-3-one (**14**), 3,4-dibenzoylthiophene (**15**), and 4-benzoylthiophene-3-carboxylic acid (**16**). This appears to be the first report of the isolation of a heterocyclic analog of 3,3-diphenylphthalide (**4**) in an acylation reaction. The results of this investigation are summarized in Table I.

The 1:1 ratio of dicarbonyl chloride **1** to benzene (runs 1–3) appeared to favor the exclusive formation of the cyclic diketone **2**. Similar observations[2] had

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(3) (a) D. V. Nightingale and B. Sukornick, *J. Org. Chem.*, **24**, 497 (1959); (b) D. V. Nightingale and J. A. Gallagher, *ibid.*, **24**, 501 (1959); (c) D. V. Nightingale and H. L. Needles, *J. Heterocycl. Chem.*, **1**, 74 (1964).