1,3-Dipolar cycloaddition reactions of 2-(2′-thienyl)aziridines

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Received June 3, 1970

The 1,3-dipolar cycloaddition of 2-(2′-thienyl)aziridines to a series of acetylenic and heteromultiple dipolarophiles leading to a series of new linked heterocycles is described. The versatility of these reactions suggests a general synthetic route to linked heterocycles.

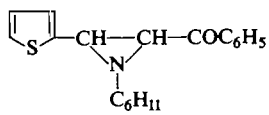
Canadian Journal of Chemistry, **48**, 3399 (1970)

We have recently described the preparation of the hitherto unknown 2-(2′-thienyl)aziridines (1) and have shown that, despite the lower resonance energy of the thiophene ring (20 kcal mole^{-1} (2)) compared with benzene, 2-(2′-thienyl)-3-aroylaziridines undergo thermal cleavage of the 2–3 bond of the aziridine ring to azomethine ylides at moderate temperatures. The transient dipoles could be trapped with olefinic dipolarophiles affording 2-(2′-thienyl)pyrrolidines.

We report the examination of 1,3-dipolar cycloadditions of 2-(2′-thienyl)aziridines to acetylenic and heteromultiple bonds as a first approach to a general synthesis of linked heterocycles.

(a) Acetylenic Dipolarophiles

Both *cis*- and *trans*-3-benzoyl-1-cyclohexyl-2-(2′-thienyl)aziridine (**1**) reacted with dimethyl



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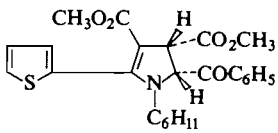
acetylenedicarboxylate to form a 1:1 adduct, the spectral data of which were consistent with the *cis*-2-pyrroline structure **2**, together with some of the pyrrole **3** (1). Heine *et al.* have shown that 3-pyrrolines are formed when 1,2,3-triphenylaziridine reacts with acetylenic esters (3) but Padwa and Hamilton isolated 2-pyrrolines like **2** when 3-aroylaziridines reacted with acetylenes (4). In the present work, addition of dimethyl acetylenedicarboxylate to 3-benzoyl-1-cyclohex-



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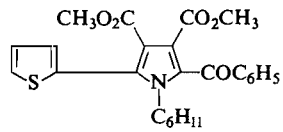
[1]NRCC Postdoctorate Fellow, 1969 to present.



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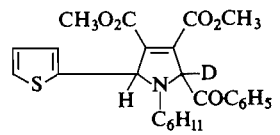
yl-3-deutero-2-(2′-thienyl)aziridine (91% deuterium incorporation) gave **5** in which both branches of the 12 Hz AB quartet due to the methine protons were diminished to an equal extent (20%). This discounts the *trans*-3-pyrroline structure **4** for the compound (which is in any case unlikely in view of the magnitude of the methine coupling) which would be expected to show one branch of the AB quartet diminished



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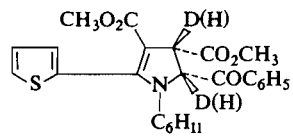

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in intensity. The observed scrambling of the deuterium label in **5** suggests its formation by rapid prototropy of the 3-pyrroline **4** the intermediacy of which in this type of reaction was previously suggested by Padwa and Hamilton (4). The extent of deuterium incorporation in 1,3 dipolar addition products of 3-deuterated aziridines with reactive dipolarophiles is normally about 70–80% (27). The observed 20% incorporation with the powerful acetylenic dipolarophiles attests to the lability of the methine protons in the intermediate **4**.

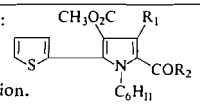
Similar 2-(2′-thienyl)pyrroles prepared in this way are listed in Tables 1 and 2. Addition of

TABLE 1

5-Aroyl (or acyl) -2-(2′-thienyl)pyrroles*

No.	R_1	R_2	Melting point (°C)	Yield (%)†	Found C	Found H	Found N	Found S	Found Molecular ion (mass spectrum)	Calculated C	Calculated H	Calculated N	Calculated S	Calculated Molecular ion (mass spectrum)
a	CH_3CO_2	*m*-$NO_2C_6H_4$	161–162	32	60.58	4.88	5.47	6.16	496.1302	60.47	4.87	5.64	6.46	496.1304
b	CH_3CO_2	*p*-$CH_3C_6H_4$	194–195	53	66.65	5.75	2.90	6.92	465.1606	67.05	5.85	3.01	6.89	465.1610
c	CH_3CO_2	*p*-$CH_3OC_6H_4$	176–177	65	64.64	5.63	2.86	6.77	481.1557	64.85	5.65	2.91	6.66	481.1559
d	H	C_6H_5	179–180	32	70.08	5.89	3.63	8.14	393.1397	70.20	5.89	3.56	8.13	393.1398
e	H	*m*-$NO_2C_6H_4$	178–179	25	62.92	5.15	6.23	7.20	438.1807	62.70	5.49	6.36	7.28	438.1803
f	H	*p*-$CH_3C_6H_4$	177–179	26	70.97	6.19	3.71	7.95	407.1556	70.74	6.18	3.44	7.87	407.1555
g	H	*p*-$CH_3OC_6H_4$	157–158	39	68.55	6.46	3.24	7.68	423.1500	68.08	5.95	3.31	7.57	423.1505
h	H	2-Naphthyl	158–160	36	72.98	5.69	3.29	7.07	443.1540	73.10	5.68	3.16	7.23	443.1555

*Compounds of structure:



†Yield after recrystallization.

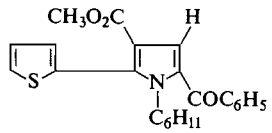
TABLE 2

Spectroscopic properties of 5-aroyl (or acyl) -2-(2′-thienyl)-pyrroles

No.	Infrared spectrum $CHCl_3$ (C=O)	Nuclear magnetic resonance spectrum ($CDCl_3$)δ: Aryl, thienyl, and (—CH=) protons	3-Carboxy methyl protons	4-Carboxy methyl protons	Aroyl substituent	*N*-Substituent	Absorption spectrum* ($CHCl_3$) λ_{max}	log ε
a	1677 1719	7.09–9.0(7H)m	3.65(3H)s	3.35(3H)s		3.7–4.2(1H)m 0.3–2.2(10H)m	314	3.52
b	1663 1720	7.0–8.0(7H)m	3.65(3H)S	3.33(3H)S	2.41(3H)s	0.3–2.2(10H)m 3.6–4.3(1H)m	264 310(sh)	4.34 3.38
c	1659 1721	6.7–8.1(7H)m	3.65(3H)s	3.38(3H)s	3.86(3H)s	0.5–2.3(10H)m 3.5–4.3(1H)m	293	4.32
d	1637 1705	7.0–8.0(9H)m	3.58(3H)s	—	—	0.5–2.6(10H)m 4.0–4.5(1H)m	303	4.21
e	1646 1715	7.0–8.7(8H)m	3.65(3H)s	—	—	0.6–2.8(10H)m 3.8–4.7(1H)m	308	4.19
f	1637 1707	7.0–8.1(8H)m	3.65(3H)s	—	2.46(3H)s	0.7–2.6(10H)m 3.9–4.6(1H)m	305	4.24
g	1637 1708	6.7–8.1(8H)m	3.64(3H)s	—	3.89(3H)s	0.6–2.8(10H)m 3.9–4.6(1H)m	308	4.35
h	1640 1711	7.0–8.5(10H)m	3.65(3H)s	—	—	0.6–2.8(10H)m 3.9–4.7(1H)m	311 293	4.29 4.22

*Absorption spectrum of compound $R_1 = CO_2CH_3$, $R_2 = C_6H_5$ previously reported (1) was λ_{max}: 250 (log ε 4.38), 300 mμ (sh) (log ε 3.80).

methyl propiolate to **1** gave only the 2-(2′-thienyl)-pyrrole **6**, evidently in this case the intermediate pyrroline was readily dehydrogenated by atmospheric oxygen. In contrast 1,2,3-triphenylaziridine afforded the 3-pyrroline **7** which showed a



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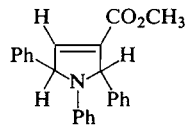

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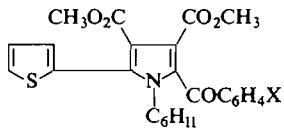
singlet for the methine protons, and no allylic coupling as was observed in the analogous compound prepared with ethyl propiolate by Heine *et al.* (3).

The orientation of addition in the case of **6** is based on the following evidence. The n.m.r. line positions of the carbomethoxy groups in the series of 2-(2′-thienyl)pyrroles **8** fall into two groups at 3.65 and 3.28–3.38 δ. By comparison



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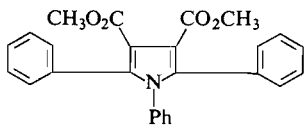
X	δ(CO$_2$CH$_3$)	
H	3.65	3.28
p-CH$_3$	3.65	3.33
p-CH$_3$O	3.65	3.38



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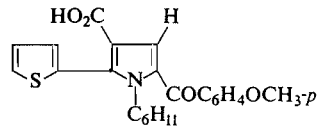
δ(CO$_2$CH$_3$) 3.69

in **9** in which the carbomethoxy groups are necessarily adjacent to an aromatic ring the line position was 3.69 δ, which allows the assignment of ester methyl groups in **8** as 3.65 (4-ester) and 3.28–3.38 δ (3-ester). It has been demonstrated that the ring current in thiophen does not differ significantly from that in benzene despite the observed differences in resonance energy (5).

Since the prepared series of adducts of 2-(2′-thienyl) aziridines with methyl propiolate all showed a carbomethoxy singlet at 3.65 δ they were accordingly assigned structure **6**. Careful examination of the i.r. spectrum of the acid **10** in carbon tetrachloride at different concentrations showed no evidence of *intra*-molecular hydrogen



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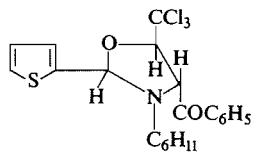
bonding such as might have been expected had the reverse mode of addition been adopted (6). The conclusions reached above with respect to the orientation of the addition of methyl propiolate in **6** are in agreement with studies of the addition of olefinic dipolarophiles to 2-(2′-thienyl)aziridines in which bulky addends were found to adopt positions remote from the 3-aroyl group which presumably exerts greater steric hindrance than does the 2-(2′-thienyl) group in this type of addition (1).

(b) Carbonyl Dipolarophiles

The 2-(2′-thienyl)aziridine **1** reacted readily with chloral in benzene to give the 2-(2′-thienyl)-oxazolidine **11**. The orientation of the 1,3-dipolar



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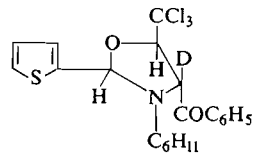

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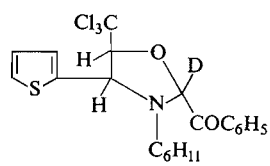
cycloaddition to the carbon bond was proven by a parallel reaction with 3-benzoyl-1-cyclohexyl-3-deutero-2-(2′-thienyl)aziridine (91% deuterium) to give **12**, the n.m.r. spectrum of which confirmed specific deuterium labelling (77%) at the 4-oxazolidine position by the modified AB quartet due to the *trans* 4,5-protons. This experiment disposes of the product of the alternative mode of addition, *i.e.* structure **13**. The method used to



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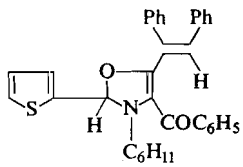
assign the full stereochemistry to oxazolidine structures obtained from analogous 2-aryl-3-aroylaziridines has been reported elsewhere (7).

The 2-(2′-thienyl)aziridine, **1**, reacted readily with diphenylcyclopropenone to give a 1:1 adduct assigned the 2-(2′-thienyl)-4-oxazoline structure **14** on the basis of its dipolarophilic activity (8, 9). For example, treatment of **14** with



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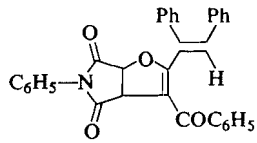

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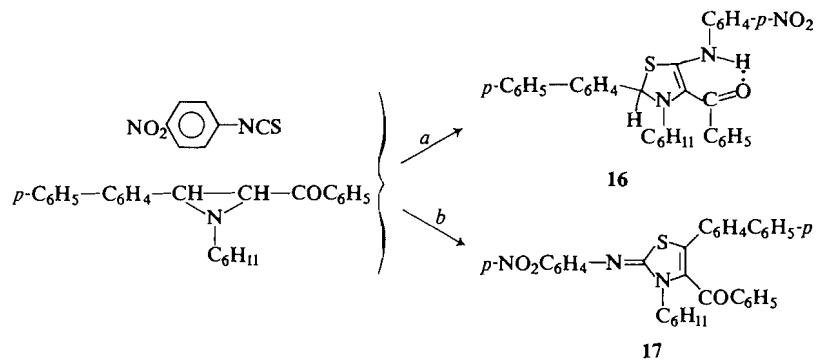
N-phenylmaleimide afforded the known dihydrofuran adduct **15** (9) in 82% yield with the expulsion of the 2-thiophen aldimine. The latter reaction shows that 4-oxazolines cleave thermally to 1,3-dipoles of the externally stabilized ketocarbene type even with a 2-substituent of substantially reduced resonance energy compared with an aryl group.

(c) Aryl Isothiocyanates as Dipolarophiles

We have reported that 3-aroyl-2-arylaziridines react with aryl isothiocyanates to form (*a*) 4-aroyl-5-arylamino-4-thiazolines, **16**, by 1,3-dipolar cycloaddition to the C=S bond followed by tautomerization and/or (*b*) 2-arylimino-4-aroyl-4-thiazolines **17** (10) (Scheme 1).

The novelty of this reaction and the observed marked dependence of the course of the reaction on the nature of the substituents both at the 1 and 2 positions of the aziridine ring demanded further investigation.

The 2-(2′-thienyl)aziridines bearing an *N*-cyclohexyl substituent reacted with a series of aryl isothiocyanates to give, after chromatography on alumina, 2-(2′-thienyl)-4-thiazolines and 2-arylimino-4-(2′-thienyl)-4-thiazolines ex-



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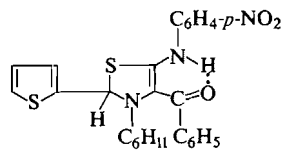
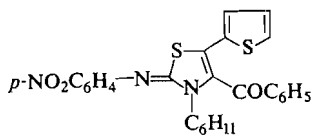
SCHEME 1

emplified by **18** and **19** respectively. In this set of reactions compounds of type *A* were by far the major products.



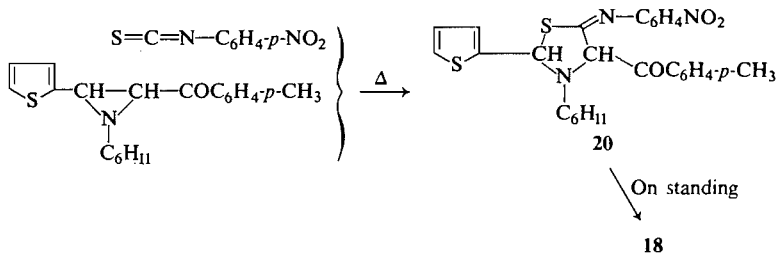
Type *A* **18**



Type *B* **19**

The previously postulated initial product of 1,3-dipolar cycloaddition (10) was frequently detected in this series of reactions as an extremely labile species **20** before chromatographic separation of *A* and *B*. (Scheme 2). Compound **20** and similar structures tautomerized completely to the stable form **18** upon attempted chromatographic purification on neutral alumina or merely on standing in $CDCl_3$ solution so that the progress of this tautomerization could be followed by n.m.r. (see Fig. 1).

It was observed in this series that smaller *N*-substituents *e.g.* isopropyl instead of cyclohexyl lead to the exclusive formation of thiazolines of type *B*, regardless of solvent type. This result, which parallels that observed previously with 3-aroyl-2-arylaziridines, may now be given



SCHEME 2

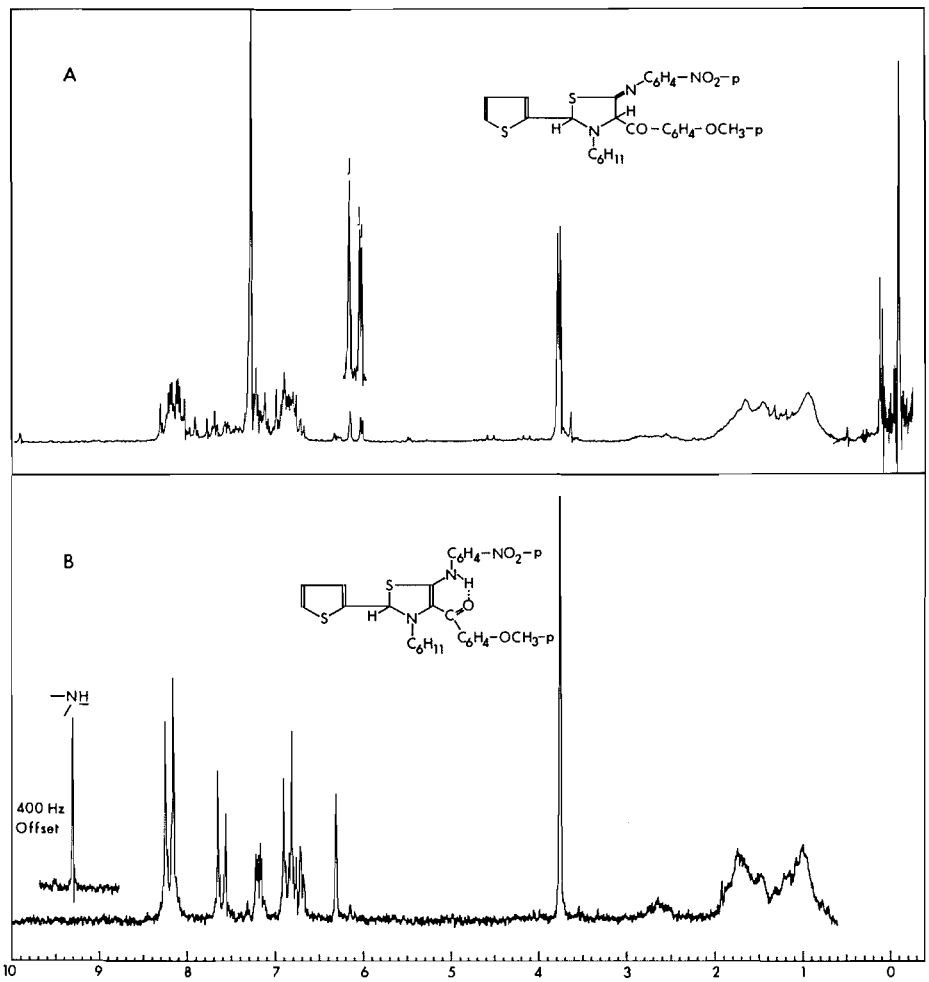
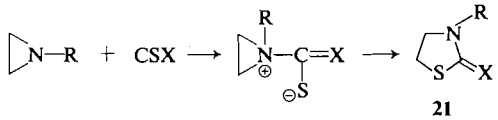


FIG. 1. The n.m.r. spectrum at 100 MHz of (A) labile intermediate in the reaction of 3-*p*-anisoyl-1-cyclohexyl-2-(2′-thienyl)aziridine with *p*-nitrophenyliso-thiocyanate. (B) 4-*p*-anisoyl-3-cyclohexyl-5-*p*-nitrophenyl-amino-2-(2′-thienyl)-4-thiazoline.

a plausible interpretation. Professor Stamm informed us that he has observed a similar tendency towards increased yield in the reaction of aziridines with carbon disulfide to form thiazolidin-2-thiones with smaller *N*-substituents (11) (Scheme 3). Steric hindrance to quaternization of the aziridine nitrogen when R is larger than CH_3 will tend to favor the competing 1,3-dipolar cycloaddition as observed when N is cyclohexyl for example.

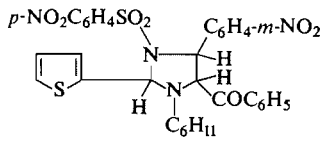


X = N—Ar (10)
X = S (11)

SCHEME 3

(d) Sulfonylimines as Dipolarophiles

The 2-(2′-thienyl)aziridine **1** reacted readily with *N*-(*m*-nitrobenzal)-*p*-nitrobenzene sulfonamide (12, 13) to give the thienyl imidazolidine **22** in 90% yield. A control reaction with the



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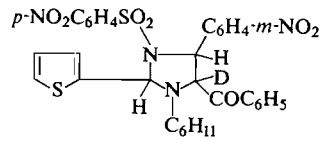

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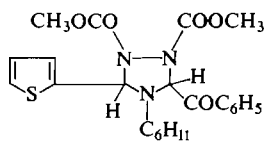
corresponding specifically 3-deuterated thienylaziridine afforded **23** in 94% yield, the n.m.r. spectrum of which confirmed the orientation of addition of the dipolarophile.

(e) Methyl Azodicarboxylate as Dipolarophile

The aziridine **1** added readily to methyl azodicarboxylate (3) in benzene to give the triazolidine **24** in 65% yield.



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Inspection of the literature of heterocyclic chemistry reveals that many naturally occurring and synthetic compounds in which heterocycles are linked directly together often have valuable applications in agriculture and pharmacology. The representative examples shown in Chart 1 have been cast in a perhaps unfamiliar form to bring out this feature.

While specific syntheses have been developed for particular compounds and some of their analogues, no attempt at a general synthesis of linked heterocycles has been made hitherto. A general route to linked heterocycles would also be useful for studies of comparative reactivity in substitution reactions.

The demonstrated versatility and synthetic utility of 1,3-dipolar cycloadditions of substituted 3-aroylaziridines to heteromultiple bonds illustrated above suggests the general synthetic scheme (Scheme 4) for the formation of a wide variety of otherwise inaccessible linked heterocycles.

This approach has the advantages of (*i*) versatility, (*ii*) availability of starting materials, (*iii*) generally good yields, (*iv*) predictability of full stereochemistry of the new heterocyclic ring from considerations of the Woodward–Hoffmann rules to ring opening (in the case of aziridines (22) and oxiranes (23, 24)), and (*v*) a wide variety of substituents in the products.

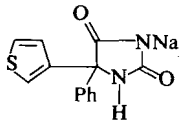
In view of the recent demonstration of photolytic cleavage of epoxides to carbonyl ylides (23, 24), the application of epoxides in Scheme 4 is under examination.

Experimental

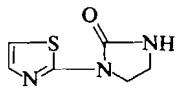
Melting points were determined on a Fisher–Johns apparatus and are uncorrected. The i.r. spectra were recorded on a Perkin–Elmer model 421 spectrophotometer, and only the principal, sharply defined peaks are reported. The n.m.r. spectra were recorded on Varian A-60 and A-100 analytical spectrometers. The spectra were measured on approximately 10–15% (w/v) solutions in $CDCl_3$, with tetramethylsilane as a standard. Line positions are reported in p.p.m. from the reference. Absorption spectra were recorded in 'spectro'-grade solvents on a Beckman DB recording spectrophotometer. Mass spectra were determined on an Associated Electrical Industries MS-9 double focusing high resolution mass spectrometer. The ionization energy, in general, was 70 eV. Peak measurements were made by comparison with perfluorotributylamine at a resolving power of 15 000. Kieselgel DF-5 (Camag, Switzerland) and Eastman Kodak precoated sheets were used for t.l.c. Microanalyses were carried out by Dr. C. Daesslé, Organic Microanalysis Ltd., Montreal, Quebec and by Mrs. D. Mahlow of this department.

General Preparation of 2-(2′-Thienyl)aziridines

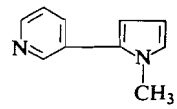
The details of the method of preparation of most of the 2-(2′-thienyl)aziridines employed in this paper have been given elsewhere (1). One new aziridine was prepared, the physical and spectroscopic data of which follow.



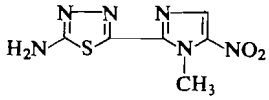
Sodium phethenylate
(anticonvulsant) (14)



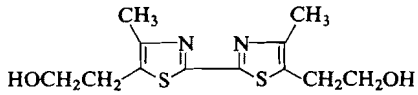
Niridazole
(schistomicidal amebicidal) (15)



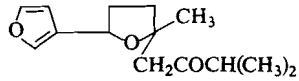
β-Nicotyrine
(insecticide) (16)



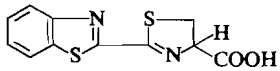
(Antimicrobial agent)
(17)



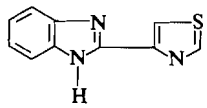
Vitachrome
(18)



Furacin
(antibacterial) (19)

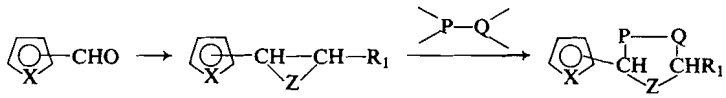


Luciferin
(20)



Thibendazole (21)
(Vermifuge)

CHART 1



X = O; S; NR; —C=N—
Z = NR; NAr; O
P—Q = C=C; C≡C; O=C, S=C, N=C; N≡C; N=N
R_1 = COAr; COR; CO_2R; C≡N; Ar

SCHEME 4

1,2-Dibromo-1-(β-naphthoyl)-2-(2′-thienyl)ethylene

1,2-Dibromo-1-(β-naphthoyl)-2-(2′-thienyl)ethylene was prepared from 1-(β-naphthoyl)-2-(2′-thienyl)ethylene (25) by bromination in chloroform in 91% yield, m.p. 132–133°.

Anal. Calcd. for $C_{17}H_{12}BrOS$: C, 48.12; H, 2.85; Br, 37.68; S, 7.56. Found: C, 48.17; H, 2.87; Br, 37.39; S, 7.54.

The i.r. spectrum $\nu_{max}(CHCl_3)$: 1686 cm^{-1} (C=O). The n.m.r. spectrum δ TMS ($(CD_3)SO$): AB quartet centered at 6.28 and 6.81, J = 10.5 Hz (2H, 1, 2-protons); 7.5–8.5 (10H, multiplet, thienyl and naphthyl protons).

1-Cyclohexyl-3-(β-napthoyl)-2-(2′-thienyl)aziridine

This aziridine was prepared in the manner previously described (1) in 91% yield, m.p. 103–105° (*cis* and *trans* mixture).

Anal. Calcd. for $C_{23}H_{23}NSO$: C, 76.42, H, 6.41; N, 3.88; S, 8.87. Found: C, 76.65; H, 6.12; N, 3.72; S, 8.79.

The i.r. spectrum: $\nu_{max}(CHCl_3)$: 1663 cm^{-1} (C=O). The n.m.r. spectrum δ TMS ($CDCl_3$): 0.3–2.9 (11H, multiplet, cyclohexyl protons); 3.35 and 3.81 (2H, singlets, *cis* and *trans* 2,3-protons); 6.8–8.3 (10H, multiplet, thienyl and naphthyl protons).

Addition of 2-(2′-Thienyl)aziridines to Acetylenic Dipolarophiles

The additions of aziridines to dimethyl acetylenedicarboxylate and to methyl propiolate were carried out in the manner described in the following representative examples. Thereafter the analytical and spectral data on new thienyl pyrroles are summarized in Tables 1 and 2.

1-Cyclohexyl-3,4-dicarbomethoxy-5-(4-methoxybenzoyl)-2-(2′-thienyl)-2-pyrroline

A solution of 0.683 g (2 mmoles) of 1-cyclohexyl-3-(*p*-methoxybenzoyl-2-(2′-thienyl)aziridine and 0.286 g (2 mmoles) of dimethyl acetylenedicarboxylate in 30 ml dry benzene was refluxed for 5 h under nitrogen. The solution was concentrated to *ca.* 10 ml and subjected to chromatography on alumina (BDH). Elution with benzene

followed by benzene–ether (3:1) gave one main fraction. Evaporation of solvent gave a yellow oil, trituration of which with hexane gave a pale yellow crystalline solid which was recrystallized with ether–hexane (m.p. 160–162°) 0.543 g (56% yield).

Anal. Calcd. for $C_{26}H_{29}NSO_6$ (mol. wt. 483.1716): C, 64.59; H, 6.05; N, 2.90; S, 6.63. Found: ((mass spectrum) 483.1710) C, 64.57; H, 5.64; N, 2.95; S, 6.60.

The i.r. spectrum $\nu_{max}(CHCl_3)$: 1666 (aryl C=O), 1727 cm^{-1} (ester C=O). The n.m.r. spectrum δ TMS ($CDCl_3$): 0.6–2.2 (10H, multiplet, cyclohexyl protons); 2.6–3.2 (1H, multiplet, CH—N); 3.39 (3H, singlet, ester methyl protons); 3.45 (3H, singlet, ester methyl protons) 3.92 (3H, singlet, methoxyl protons); AB quartet centered at 4.34 and 5.56 (2H, J = 12 Hz, 4,5-protons); 6.8–8.5 (7H, multiplet, thienyl and aryl protons). Absorption spectrum λ_{max}(EtOH): 224 (log ε 4.26); 293 mμ (log ε 4.34).

1-Cyclohexyl-3,4-dicarbomethoxy-5-(4′-methylbenzoyl)-2-(2′-thienyl)-2-pyrroline

A solution of 0.650 g (2 mmoles) of 1-cyclohexyl-3-(*p*-methylbenzoyl)-2-(2′-thienyl)aziridine and 0.286 g (2 mmoles) of dimethyl acetylenedicarboxylate in 50 ml dry benzene was refluxed for 5 h under nitrogen and worked-up exactly as described above to give the 2-pyrroline, m.p. 143–146 °C, 0.478 g (51% yield).

Anal. Calcd. for $C_{26}H_{29}NSO_5$ (mol. wt. 467.1767): C, 66.82; H, 6.18; N, 2.91; S, 6.80. Found ((mass spectrum) 467.1762): C, 66.77; H, 6.25; N, 3.00; S, 6.80.

The i.r. spectrum $\nu_{max}(CHCl_3)$: 1675 (aryl C=O), 1732 cm^{-1} (ester C=O). The n.m.r. spectrum δ TMS ($CDCl_3$): 0.6–2.2 (10H, multiplet, cyclohexyl protons); 2.44 (3H, singlet, methylprotons); 3.39 (3H, singlet, ester methyl protons); 3.43 (3H, singlet, ester methyl protons); AB quartet centered at 4.39 and 5.56 (2H, J = 12.5 Hz, 4,5 protons); 6.8–8.4 (7H, multiplet, thienyl and aryl protons). Absorption spectrum λ_{max}(EtOH): 210 (log ε 4.13) 265 mμ (log ε 4.26).

Similar reaction of 1-cyclohexyl-3-(*p*-methoxybenzoyl)-2-(2′-thienyl)aziridine or 1-cyclohexyl-3-(*p*-methylbenzoyl)-2-(2′-thienyl)aziridine with 10 equiv. of dimethyl acetylenedicarboxylate afforded only the corresponding pyrroles and not the 2-pyrrolines. In the reaction of 1-cyclohexyl-3-(*m*-nitrobenzoyl)-2-(2′-thienyl)aziridine with only 1 equiv. of dimethyl acetylenedicarboxylate only the pyrrole was obtained directly.

Reaction of 3-Benzoyl-1-cyclohexyl-3-deutero-2-(2′-thienyl)aziridine with Dimethyl Acetylenedicarboxylate

The reaction between 0.933 g (3 mmoles) of 3-benzoyl-1-cyclohexyl-3-deutero-2-(2′-thienyl)aziridine (prepared according to a previously described procedure and containing *ca.* 91% deuterium incorporation by n.m.r. integration) and 0.426 g (3 mmoles) of dimethyl acetylenedicarboxylate was carried out in the manner described above, the product subjected to chromatography on alumina to yield (*a*) 5-benzoyl-3,4-dicarbomethoxy-1-cyclohexyl-2-(2′-thienyl)pyrrole, m.p. 158–160° (petroleum ether) 0.246 g (18% yield) and (*b*) 5-benzoyl-3,4-dicarbomethoxy-5-deutero-2-(2′-thienyl)-2-pyrroline, m.p. 140–141° (petroleum ether) 0.52 g (38% yield). The analytical and spectroscopic data on the labelled pyrroline were identical with that of the corresponding protium compound with the exception of the n.m.r. intensities of the methine protons which confirm equal labelling at the 4 and 5 positions. The n.m.r. spectrum δ TMS ($CDCl_3$): 0.5–2.0 (10H, multiplet, cyclohexyl protons); 2.5–3.3 (1H, multiplet CHN); 3.37 (3H, singlet, $COOCH_3$); 3.41 (3H, singlet $COOCH_3$); AB quartet centered at 4.34 and 5.52 (1.81H, J = 12 Hz, 4,5-protons); 6.8–8.4 (8H, multiplet aromatic protons).

Dehydrogenation of Pyrrolines to Pyrroles with Tetrachloro-1,4-benzoquinone

(a) 1-Cyclohexyl-3,4-dicarbomethoxy-5-(p-methoxybenzoyl)-2-(2′-thienyl)pyrrole

A mixture of 0.292 g (0.5 mmoles) of 1-cyclohexyl-3,4-dicarbomethoxy-5-(*p*-methoxybenzoyl)-2-(2′-thienyl)-2-pyrroline and 0.615 g (2.5 mmoles) of tetrachloro-1,4-benzoquinone in 20 ml dry chlorobenzene was heated under reflux with stirring for 4 days. The reaction mixture was cooled and 200 ml ether was added. The solution was washed with 4% aqueous sodium hydroxide solution containing 1% sodium bisulfite and then washed with water. The organic layer was dried ($MgSO_4$) and evaporation of the solvents gave a pale green solid which was recrystallized from ether–hexane, m.p. 176–177°, 0.103 g (43% yield). This compound was identical in all respects with the compound which was obtained by the reaction of 1-cyclohexyl-3-(*p*-methoxybenzoyl)-2-(2′-thienyl)aziridine with 10 equiv. of dimethyl acetylenedicarboxylate (Table 1).

(b) 1-Cyclohexyl-3,4-dicarbomethoxy-5-(p-methylbenzoyl)-2-(2′-thienyl)pyrrole

A mixture of 0.936 g (2 mmoles) of 1-cyclohexyl-3,4-dicarbomethoxy-5-(*p*-methylbenzoyl)-2-(2′-thienyl)-2-pyrroline and 2.460 g (0.01 mole) of tetrachloro-1,4-benzoquinone in 50 ml dry chlorobenzene was refluxed with stirring for 4 days. The mixture was worked-up exactly in the same manner as above, m.p. 194–195° (ethyl acetate – hexane), 0.288 g (31% yield). This compound was identical in all respects with the product which was obtained by reaction of the corresponding aziridine with 10 equiv. of dimethyl acetylenedicarboxylate (see Tables 1 and 2).

3,4-Dicarbomethoxy-1,2,5-triphenyl-3-pyrroline and 3,4-Dicarbomethoxy-1,2,5-triphenylpyrrole

These compounds had been prepared by Heine and Peavy (26) but the n.m.r. line positions required for the present studies had not been reported. Therefore the pyrrole was prepared by the procedures described above and then dehydrogenated with tetrachloro-1,4-benzoquinone.

(a) 3,4-Dicarbomethoxy-1,2,5-triphenyl-3-pyrroline

Melting point 158–159° (ethyl acetate – hexane), 93% yield.

Anal. Calcd. for $C_{26}H_{23}NO_4$ (mol. wt. 413.1627): C, 75.51; H, 5.61; N, 3.39. Found ((mass spectrum) 413.1623): C, 75.60; H, 5.75; N, 3.40.

The i.r. spectrum $\nu_{max}(CHCl_3)$: 1723 cm^{-1} (ester C=O). The n.m.r. spectrum δ TMS ($CDCl_3$): 3.60 (6H, singlet, ester methyl protons); 6.23 (2H, singlet, 2,5-protons); 6.1–7.5 (15H, multiplet, aryl protons).

(b) 3,4-Dicarbomethoxy-1,2,5-triphenylpyrrole

Melting point 196–197° (ethyl acetate – hexane).

Anal. Calcd. for $C_{26}H_{21}NO_4$ (mol. wt. 411.1471):

C, 75.92; H, 5.15; N, 3.41. Found ((mass spectrum) 411.1468); C, 75.68; H, 5.17; N, 3.69.

The i.r. spectrum $\nu_{max}(CHCl_3)$: 1717 cm^{-1} (ester C=O). The n.m.r. spectrum δ TMS ($CDCl_3$): 3.69, (6H, singlet, ester methyl protons); 6.7–7.4 (15H, multiplet, aryl protons). Absorption spectrum $\lambda_{max}(CHCl_3)$: 277 mμ (log ε 4.18).

Reaction of 1,2,3-Triphenylaziridine with Methyl Propiolate

A solution of 1.626 g (6 mmoles) of 1,2,3-triphenylaziridine and 0.504 g (6 mmoles) of methyl propiolate in 50 ml toluene was heated under reflux for 24 h. Evaporation of the solvent gave 3-carbomethoxy-1,2,5-triphenyl-3-pyrroline as a white solid, m.p. 195–196° (ethyl acetate – hexane), 1.391 g (65% yield).

Anal. Calcd. for $C_{24}H_{21}NO_2$ (mol. wt. 355.1573): C, 81.11; H, 5.96; N, 3.94. Found ((mass spectrum) 355.1573): C, 81.16; H, 5.92; N, 4.25.

The i.r. spectrum $\nu_{max}(CHCl_3)$: 1724 cm^{-1} (ester C=O). The n.m.r. spectrum δ TMS ($CDCl_3$): 3.63 (3H, singlet, ester methyl protons); 6.13 (2H, singlet, 2,5-protons); 6.3–7.7 (16H, multiplet, aromatic protons). Absorption spectrum $\lambda_{max}(CHCl_3)$: 298 mμ (log ε 3.34).

Dehydrogenation of 3-Carbomethoxy-1,2,5-triphenyl-3-pyrroline with Tetrachloro-1,4-benzoquinone

A solution of 0.710 g (2 mmoles) of 3-carbomethoxy-1,2,5-triphenyl-3-pyrroline and 0.984 g (4 mmoles) of tetrachloro-1,4-benzoquinone in 25 ml of *p*-xylene was heated under reflux for 8 h. The reaction mixture was worked-up as described above affording 3-carbomethoxy-1,2,5-triphenylpyrrole, m.p. 152–153° (ethyl acetate – hexane), 0.583 g (83% yield).

Anal. Calcd. for $C_{24}H_{19}NO_2$ (mol. wt. 353.1416): C, 81.56; H, 5.42; N, 3.96. Found ((mass spectrum) 353.1415): C, 82.06; H, 5.36; N, 3.88.

The i.r. spectrum $\nu_{max}(CHCl_3)$: 1702 cm^{-1} (ester C=O). The n.m.r. spectrum δ TMS ($CDCl_3$): 3.69 (3H, singlet, ester methyl protons); 6.8–7.4 (16H, multiplet aryl protons). Absorption spectrum $\lambda_{max}(CHCl_3)$: 279 mμ (log ε 4.26).

Hydrolysis of 3-Carbomethoxy-1-cyclohexyl-5-p-methoxybenzoyl-2-(2′-thienyl)pyrrole to 1-Cyclohexyl-3-carboxy-5-p-methoxybenzoyl-2-(2′-thienyl)pyrrole

A solution of 0.212 g (5 mmoles) of 3-carbomethoxy-1-cyclohexyl-5-*p*-methoxybenzoyl-2-(2′-thienyl)pyrrole and 155 mg (3.9 mmoles) of sodium hydroxide in 25 ml of 95% dimethylsulfoxide was heated to about 80° with stirring for 3 h. The solution was diluted with water and made slightly acidic with hydrochloric acid. A white crystalline solid precipitated and was collected and dried, m.p. 220–222°, 0.181 g (88% yield).

Anal. Calcd. for $C_{23}H_{23}NSO_4$ (mol. wt. 409.1348): C, 67.47; H, 5.66; N, 3.42; S, 7.83. Found ((mass spectrum) 409.1346): C, 67.26; H, 5.52; N, 3.59; S, 7.92.

The i.r. spectrum $\nu_{max}(CCl_3)$: 3000 (OH, *intermolecular hydrogen bonding, vide infra*), 1638 (aryl C=O), 1679 cm^{-1} (carboxyl C=O dimer). The n.m.r. spectrum δ TMS ($CDCl_3$): 0.5–2.7 (10H, multiplet, cyclohexyl protons); 3.88 (3H, singlet, methoxyl protons); 3.9–4.5 (1H, multiplet CHN): 6.8–8.0 (8H, multiplet, aromatic protons); 10.73 (1H, singlet, exchangeable with D_2O, carboxyl proton).

Examination of the i.r. spectrum at three different concentrations showed no evidence for the presence of *intra*-molecular hydrogen bonding but showed a free OH bond at 3428 cm^{-1} at high dilution which adopted a value of *ca.* 3000 cm^{-1} under conditions at which intermolecular hydrogen bonding was appreciable.

Reaction of 3-Benzoyl-1-cyclohexyl-2-(2′-thienyl)aziridine with Chloral

A solution of 0.933 g (3 mmoles) of 3-benzoyl-1-cyclohexyl-2-(2′-thienyl)aziridine and 0.442 g (3 mmoles) of chloral in 50 ml dry benzene was heated under reflux for 5 h. Evaporation of solvent gave a dark red oil which was subjected to chromatography on alumina (BDH). Elution with benzene gave one fraction. Evaporation of solvent and trituration of the residual oil with hexane gave 4-benzoyl-3-cyclohexyl-2-(2′-thienyl)-5-trichloromethyloxazolidine as a yellow solid, m.p. 88–90° (ether–hexane), 0.605 g (45% yield).

Anal. Calcd. for $C_{21}H_{22}NSCl_3O_2$: C, 54.96; H, 4.83; N, 3.05; S, 6.99; Cl, 23.18. Found: C, 54.84; H, 4.72; N, 2.89; S, 7.04; Cl, 23.46.

The i.r. spectrum $\nu_{max}(CHCl_3)$: 1677 cm^{-1} (aryl C=O). The n.m.r. spectrum δ TMS ($CDCl_3$): 0.3–3.0 (11H, multiplet, cyclohexyl and $\diagdown$CH—N$\diagup$ protons); 4.81 (1H, doublet, J = 4 Hz 5-proton); 5.31 (1H, doublet, J = 4 Hz, 4-proton); 6.61 (1H, singlet 2-proton); 6.8–8.4 (8H, multiplet, thienyl and aryl protons).

Reaction of 3-Benzoyl-1-cyclohexyl-3-deutero-2-(2′-thienyl)aziridine with Chloral

A mixture of 0.933 g (3 mmoles) of 3-benzoyl-1-cyclohexyl-3-deutero-2-(2′-thienyl)aziridine (91% D incorporation) and 0.442 g (3 mmoles) of chloral in 50 ml dry benzene was heated under reflux for 3 h. The reaction mixture worked-up exactly as described above affording 4-benzoyl-3-cyclohexyl-5-deutero-2-(2′-thienyl)-5-trichloromethyloxazolidine, m.p. 89–90°, 0.687 g (51% yield).

The n.mr. spectrum δ TMS ($CDCl_3$): 0.2–3.0 (11H, multiplet, cyclohexyl protons); 4.81 (1H, singlet, 5-proton); 5.31 (0.23H, doublet, 4-proton); 6.61 (1H, singlet, 2-proton); 6.8–8.4 (8H, multiplet, thienyl and phenyl protons).

By this experiment the orientation of the 1,3-dipolar addition of the chloral was confirmed.

Reaction of 3-Benzoyl-1-cyclohexyl-2-(2′-thienyl)-aziridine with Diphenylcyclopropenone

A solution of 0.933 g (3 mmoles) of 3-benzoyl-1-cyclohexyl-2-(2′-thienyl)aziridine and 0.620 g (3 mmoles) of diphenylcyclopropenone in 50 ml dry benzene was heated under reflux for 12 h. Evaporation of the solvent gave a yellow oil which was subjected to chromatography on alumina. Elution with benzene gave one fraction. Evaporation of solvent and trituration with hexane gave 4-benzoyl-3-cyclohexyl-5-(*cis*-1,2-diphenylvinyl)-2-(2′-thienyl)-4-oxazoline as a white solid, m.p. 108–110° (ether–hexane), 1.01 g (65% yield).

Anal. Calcd. for $C_{34}H_{31}NSO_2$ (mol. wt. 517): C, 78.87; H, 6.05; N, 2.71; S, 6.19. Found: ((mass spectrum) 517): C, 79.49; H, 6.47; N, 2.52; S, 6.15.

The i.r. spectrum $\nu_{max}(CHCl_3)$: 1715 cm^{-1} (aryl C=O). The n.m.r. spectrum δ TMS ($CDCl_3$): 0.3–2.2 (10H, multiplet, cyclohexyl protons); 2.5–3.2 (1H, multiplet,

TABLE 3

4-Aroyl-5-arylamino-2-(2′-thienyl)-4-thiazolines*

					Found					Calculated				
No.	R_4	R_5	Melting point (°C)	Yield† (%)	C	H	N	S	Molecular ion (mass spectrum)	C	H	N	S	Molecular ion (mass spectrum)
i	C_6H_5	*p*-$NO_2C_6H_4$	176–177	43	63.70	5.17	8.27	13.10	491.1338	63.52	5.13	8.55	13.05	491.1337
j	*p*-$CH_3C_6H_4$	*p*-$NO_2C_6H_4$	112	35	63.95	5.28	8.33	12.07	505.1496	64.13	5.38	8.31	12.68	505.1494
k	*p*-$CH_3OC_6H_4$	*p*-$NO_2C_6H_4$	193	61	62.55	5.25	7.92	12.45	521.1444	62.17	5.22	8.06	12.30	521.1443
l	2-Naphthyl	*p*-$NO_2C_6H_4$	125	64	66.54	5.14	7.88	11.51	541.1489	66.51	5.03	7.76	11.84	541.1494
m	*m*-$NO_2C_6H_4$	*p*-$NO_2C_6H_4$	184	42	58.16	4.60	10.19	11.62	536.1187	58.18	4.51	10.44	11.95	536.1189
n	C_6H_5	1-Naphthyl	163	12	—	—	5.84	13.29	496.1645	—	—	5.65	12.92	496.1643
o	*p*-$C_6H_5C_6H_4$	2-Naphthyl	174	15	—	—	5.01	11.19	572.1960	—	—	4.89	11.20	572.1956

*Compounds of structure:

†Yield after recrystallization.

TABLE 4

Spectroscopic properties of 4-aroyl-5-arylamino-2-(2′-thienyl)-4-thiazolines

	Infrared spectrum ($CHCl_3$)		Nuclear magnetic resonance spectrum ($CDCl_3$)δ					Absorption spectrum ($CHCl_3$)	
No.	N—H Bonded	C=O	Aryl protons	2-Proton	*N*-Alkyl groups	Aryl methyl	Chelated N—H	λ_{max} (mμ)	log ε
i	3050 br	1607 (s)	6.8–8.4 (12H) m	6.42 (1H) s	0.6–3.2 (11H) m C_6H_{11}		13.36 (1H) s	437 371 275	4.06 4.12 4.09
	3050 br	1599 (s)	6.7–8.4 (11H) m	6.43 (1H) s	0.5–2.2 (10H) m 2.3–3.0 (1H) m C_6H_{11}	2.40 (3H) s	13.38 (1H) s	440 370 281	4.12 4.03 4.15
k	3050 br	1607 (s)	6.6–8.4 (11H) m	6.40 (1H) s	0.5–2.3 (10H) m 2.3–3.0 (1H) m C_6H_{11}	3.86 (3H) s	13.43 (1H) s	450 371 292	4.19 4.09 4.11
	3050 br	1608 (s)	6.6–8.6 (14H) m	6.44 (1H) s	0.5–2.2 (10H) m 2.3–2.9 (1H) m	—	13.36 (1H) s	454 363 297	4.17 4.08 4.19
m	3050	1610 (sh)	6.8–8.6 (11H) m	6.30 (1H) s	0.5–2.9 (11H) m	—	13.66 (1H) s	462 320	4.23 4.05
n	3050	1610 (s)	6.6–8.5 (15H) m	6.42 (1H) s	0.5–3.0 (11H) m	—	13.35 (1H) s	428 280	3.80 4.16
o	3050 br	1606	6.6–8.5 (19H) m	6.44 (1H) s	0.5–2.3 (10 H) m 2.4–3.1 (1H) m	—	13.30 (1H) s	426 373 285	4.23 4.09 4.39

CH—N<): 5.15 (1H, singlet, 2-proton); 6.8–8.1 (15H, multiplet, aryl and vinyl protons).

Reaction of 4-Benzoyl-3-cyclohexyl-5-(cis-1,2-diphenylvinyl)-2-(2′-thienyl)-4-oxazoline with N-Phenylmaleimide

A solution of 0.259 g (5 mmoles) of 4-benzoyl-3-cyclohexyl-5-(*cis*-1,2-diphenylvinyl)-2-(2′-thienyl)-4-oxazoline and 0.10 g (5.8 mmoles) of *N*-phenylmaleimide in 25 ml of dry toluene was heated under reflux for 25 h. Evaporation of the solvent afforded an oil which was subjected to chromatography on alumina (BDH) with benzene as eluant affording one fraction. Evaporation of the solvent gave 3-benzoyl-2-(*cis*-1,2-diphenylvinyl)-6-phenyl-4,8-dihydrofurano-[4,5-*c*]-pyrrolin-2,5-dione, m.p. 220–224° (lit. m.p. 222–224° (9)), 0.24 g (82% yield). This compound was identical in all respects with that obtained by reaction of 4-benzoyl-3-cyclohexyl-5-(*cis*-1,2-diphenylvinyl)-2-phenyl-4-oxazoline with *N*-phenylmaleimide.

Reaction of 2-(2′-Thienyl)aziridines with Aryl Isothiocyanate.

General Method

The method is exemplified by two reactions in which the products were respectively a 5-arylamino-4-thiazoline and a 2-arylimino-4-thiazoline.

(a) Reaction of 3-Benzoyl-1-cyclohexyl-2-(2′-thienyl)-aziridine with p-Nitrophenyl Isothiocyanate

A solution of 0.933 g (3 mmoles) 3-benzoyl-1-cyclohexyl-2-(2′-thienyl)aziridine and 0.540 g (3 mmoles) of *p*-nitrophenylisothiocyanate in 50 ml of dry benzene was heated under reflux for 5 h under nitrogen. The solution was concentrated *in vacuo* to *ca.* 10 ml and chromatographed on grade 1 alumina (BDH). Elution with benzene afforded one main fraction which upon evaporation afforded 4-benzoyl-3-cyclohexyl-5-*p*-nitrophenylamino-2-(2′-thienyl)-4-thiazoline as orange crystals, m.p. 176–177° (ethyl acetate), 0.633 g (43% yield after recrystallization). Full details on this and other analogous 5-arylamino-2-(2′-thienyl)-4-thiazolines are summarized in Tables 3 and 4.

(b) Reaction of 1-Isopropyl-3-phenylbenzoyl-2-(2′-thienyl)aziridine with p-Nitrophenyl Isothiocyanate

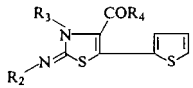
A solution of 0.695 g (2 mmoles) of 1-isopropyl-3-*p*-phenylbenzoyl-2-(2′-thienyl)aziridine and 0.360 g (2 mmoles) of *p*-nitrophenyl isothiocyanate in 50 ml of dry benzene was heated under reflux for 5 h under nitrogen. The solvent was evaporated and the residual red oil was chromatographed on alumina with elution by benzene followed by chloroform, which gave one main fraction. Evaporation of solvent gave an orange oil, which by trituration with ethyl acetate gave 3-cyclohexyl-

TABLE 5

4-Aroyl-2-arylimino-5-(2′-thienyl)-4-thiazolines*

						Found					Calculated				
No.	R_2	R_3	R_4	Melting point (°C)	Yield (%)†	C	H	N	S	Molecular ion (mass spectrum)	C	H	N	S	Molecular ion (mass spectrum)
p	*p*-$NO_2C_6H_4$	C_6H_{11}	*p*-$CH_3C_6H_4$	107	33	63.74	5.05	8.50	12.87	503.1337	64.39	5.00	8.34	12.74	503.1336
q	*m*-$NO_2C_6H_4$	C_6H_{11}	*p*-$CH_3C_6H_4$	180	49	64.58	5.07	8.43	12.67	503.1338	64.39	5.00	8.34	12.74	503.1338
r	*p*-$NO_2C_6H_4$	$(CH_3)_2CH$	*p*-$C_6H_5C_6H_4$	254	32	66.37	4.28	7.84	11.90	525.1183	66.25	4.41	8.00	12.20	525.1181

*Compounds of structure:



†Yield after recrystallization.

TABLE 6

Spectroscopic properties of 4-aroyl-2-arylimino-5-(2′-thienyl)-4-thiazolines

				Infrared spectrum ($CHCl_3$)		Nuclear magnetic resonance spectrum δ($CDCl_3$)			Absorption spectrum	
No.	R_2	R_3	R_4	C=O	C=N	Aryl protons	Aryl methyl	*N*-Alkyl groups	λ_{max} (mμ)	log ε
p	*p*-$NO_2C_6H_4$	C_6H_{11}	*p*-$CH_3C_6H_4$	1607	1597	6.8–8.3 (11H)m	2.38 (3H)s	0.5–2.5 (10H)m	425	3.73
								3.8–4.5 (1H)m	346	3.71
									264	4.49
q	*m*-$NO_2C_6H_4$	C_6H_{11}	*p*-$CH_3C_6H_4$	1608(s)	1598(s)	6.7–8.3 (11H)m	2.37 (3H)s	0.5–2.5 (10H)m	415	3.45
								3.9–4.6 (1H)m	345	3.55
									257	4.45
r	*p*-$NO_2C_6H_4$	$(CH_3)_2CH$	*p*-$C_6H_5C_6H_4$	1619(s)	1603(s)	6.9–8.4 (16H)m	—	1.62(6H)d	431	3.82
								4.4–5.1 (1H)m	339	3.81
									271	4.48

2-*p*-nitrophenylimino-4-*p*-phenylbenzoyl-5-(2′-thienyl)-4-thiazoline as a yellow solid, m.p. 254–255°, 0.334 g (32% yield).

Anal. Calcd. for $C_{29}H_{23}N_3S_2O_3$·(mol. wt. 525.1181); C, 66.25; H, 4.41; N, 8.00; S, 12.20. Found: ((mass spectrum) 525.1183): C, 66.37; H, 4.28; N, 7.84; S, 11.90.

The i.r. spectrum $\nu_{max}(CHCl_3)$: 1619 (C=O), 1603 (C=N). The n.m.r. spectrum δ TMS ($CDCl_3$): 1.62 (6H, doublet, isopropyl-methyl protons); 4.5–5.1 (1H, multiplet, isopropyl methine proton); 6.9–8.4 (16H, multiplet, thienyl and aryl protons). The analytical and spectral data on other 4-aroyl-2-arylimino-5-(2′-thienyl)-4-thiazolines are summarized in Tables 5 and 6.

Reaction of 2-(2′-thienyl)aziridine with N-(m-nitrobenzal)-p-nitrobenzenesulfonamide

A mixture of 0.933 g (3 mmoles) of 3-benzoyl-1-cyclohexyl-2-(2′-thienyl)aziridine and 1.005 g (3 mmoles) of *N*-(*m*-nitrobenzoyl)-*p*-nitrobenzenesulfonamide (27) in 50 ml of dry benzene was heated under reflux for 3 h. Evaporation of the solvent gave 5-benzoyl-1-cyclohexyl-3-(*N*-*p*-nitrobenzenesulfonyl)-4-*m*-nitrophenyl-2-(2-thienyl)imidazolidine as a pale yellow solid, m.p. 180–181° (ethyl acetate – hexane), 1.73 g (89% yield).

Anal. Calcd. for $C_{32}H_{30}N_4S_2O_7$: C, 59.43; H, 4.68; N, 8.66; S, 9.92. Found: C, 59.79; H, 4.67; N, 8.43; S, 9.79.

The i.r. spectrum $\nu_{max}(CHCl_3)$: 1690 (aryl C=O). The n.m.r. spectrum δ TMS ($(CD_3)_2SO$): 0.4–2.0 (10H, multiplet, cyclohexyl protons); 5.16 (1H, singlet, 4-proton, see below); 5.24 (1H, singlet, 5-proton); 6.48 (1H, singlet, 2-proton); 7.0–8.7 (16H, multiplet, thienyl and aryl protons).

Mass spectrum Calcd. for $C_{26}H_{23}N_3S$ (imidazole fragment ion): 457.1460. Found: 457.1464.

Reaction of 3-Benzoyl-1-cyclohexyl-3-deutero-2-(2′-thienyl)aziridine with N-(m-Nitrobenzal)-p-nitrobenzenesulfonamide

A mixture of 0.933 g (3 mmoles) of 3-benzoyl-1-cyclohexyl-3-deutero-2-(2′-thienyl)aziridine (91% deuterium incorporation) and 1.006 g (3 mmoles of *N*-(*m*-nitrobenzal)-*p*-nitrobenzenesulfonamide in 50 ml of dry benzene was refluxed for 3 h. Evaporation of the benzene gave the product as a pale yellow solid which was recrystallized from ethyl acetate – hexane, m.p. 180–181°, 1.833 g (94% yield).

The n.m.r. spectrum δ TMS ($(CD_3)_2SO$): 0.4–2.0 (10H, cyclohexyl protons); 5.16 (1H, singlet, 4-proton); 5.24 (0.3H, singlet, 5-proton); 6.48 (1H, singlet, 2-proton); 7.0–8.7 (16H, multiplet, thienyl and aryl protons).

Examination of the n.m.r. spectrum thus showed the position and extent of deuterium incorporation and confirmed the orientation of the 1,3-dipolar cycloaddition.

Reaction of 2-(2′-Thienyl)aziridines with Dimethyl Azodicarboxylate

(i) 5-Benzoyl-4-cyclohexyl-1,2-dicarbomethoxy-3-(2′-thienyl)-1,2,4-triazolidine

A solution of 0.933 g (3 mmoles) of 3-benzoyl-1-cyclohexyl-2-(2′-thienyl)aziridine and 0.438 g (3 mmoles) of dimethyl azodicarboxylate in 50 ml of dry benzene was heated under reflux for 5 h. The solution was concentrated to 10 ml and chromatographed on alumina (BDH) with elution by benzene, which gave one fraction. Evaporation of the solvent gave 5-benzoyl-4-cyclohexyl-1,2-dicarbomethoxy-3-(2′-thienyl)-1,2,4-triazolidine as a white solid, m.p. 141–142° (dec.) (ether–hexane), 0.887 g (65% yield).

Anal. Calcd. for $C_{23}H_{27}SN_3O_5$: C, 60.37; H, 5.95; N, 9.19; S, 7.01. Found: C, 60.33; H, 5.78; N, 8.82; S, 6.97.

The i.r. spectrum $\nu_{max}(CHCl_3)$: 1684 (aryl C=O), 1717 cm^{-1} (ester C=O). The n.m.r. spectrum δ TMS ($CDCl_3$): 0.5–2.0 (10H, cyclohexyl protons); 2.8–3.3 (1H, multiplet >N—CH—cyclohexyl proton); 3.66 and 3.71 (6H, singlets, ester methyl protons); 6.37 (1H, singlet, 5-proton); 6.58 (1H, singlet, 3 proton); 6.8–8.2 (8H, multiplet, thienyl and phenyl protons).

(ii) 4-Cyclohexyl-1,2-dicarbomethoxy-5-β-naphthoyl-3-(2′-thienyl)-1,2,4-triazoline

A solution of 1.807 g (5 mmoles) of 1-cyclohexyl-3-β-naphthoyl-2-(2′-thienyl)aziridine and 0.731 g (5 mmoles) of dimethyl azodicarboxylate in 50 ml of dry benzene was heated under reflux for 3 h. The reaction mixture was worked-up as described above affording the product as a white solid, m.p. 86° (dec.) (pentane), 2.08 g (82% yield).

Anal. Calcd. for $C_{27}H_{29}N_3SO_5$: C, 63.89; H, 5.76; N, 8.28; S, 6.32. Found: C, 63.91; H, 5.70; N, 8.20; S, 6.24.

The i.r. spectrum $\nu_{max}(CHCl_3)$: 1680 (aryl C=O), 1717 cm^{-1} (ester C=O). The n.m.r. spectrum δ TMS ($CDCl_3$): 0.5–2.2 (10H, multiplet, cyclohexyl protons); 2.8–3.3 (1H, cyclohexyl CH—N proton); 3.64 and 3.73 (6H, singlets, ester methyl protons); 6.43 (1H, singlet, 5-proton); 6.76 (1H, singlet, 3-proton); 6.8–8.3 (10H, multiplet, thienyl and aryl protons).

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