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Preparation of New Nitrogen-Bridged Heterocycles. 36.[1)] Synthesis and Reaction of Dimethyl 4-Thia-1-azatetracyclo[5.4.0.0^{5,11}.0^{6,8}]undeca-2,9-diene-5,6-dicarboxylate Derivatives

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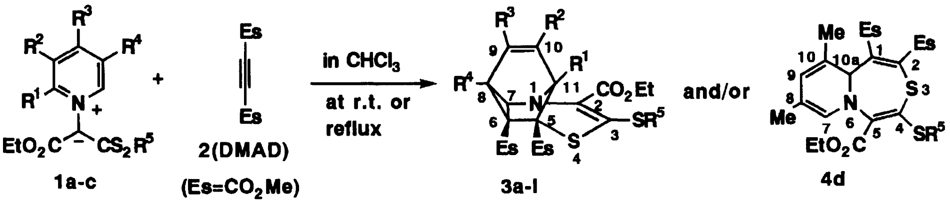
The title compounds, dimethyl 4-thia-1-azatetracyclo[5.4.0.0^{5,11}.0^{6,8}]undeca-2,9-diene-5,6-dicarboxylates, were prepared in low to moderate yields by the reactions of various 1-pyridinio[(thiocarbonyl)methylide]s and 3-(1-pyridinio)thiophene-2-thiolates with dimethyl acetylenedicarboxylate in chloroform or benzene at room temperature or at the elevated temperature. Some compounds could also be obtained by heating the corresponding dimethyl 10a*H*-pyrido[1,2-*d*][1,4]thiazepine-1,2-dicarboxylates once separated from the reaction of pyridinium ylides with the same reagent. These 4-thia-1-azatetracyclo[5.4.0.0^{5,11}.0^{6,8}]undeca-2,9-diene derivatives were smoothly thermolyzed in xylene at the reflux temperature to afford dimethyl phthalate and the corresponding thiazole derivatives in good yields. The structures of these 4-thia-1-azatetracyclo[5.4.0.0^{5,11}.0^{6,8}]undeca-2,9-dienes were mainly identified by their physical and spectral inspections together with mechanistic considerations, and confirmed finally by the X-ray analyses of two compounds.

In our previous papers,[1,2)] we have described first preparation of 10a*H*-pyrido[1,2-*d*][1,4]thiazepine derivatives from the reactions of 1-pyridinio[(thiocarbonyl)methylide]s having a cyano or a benzoyl group at the ylidic carbanion and 3-(1-pyridinio)thiophene-2-thiolates with dimethyl acetylenedicarboxylate (DMAD) in chloroform at room temperature. In our recent attempts to extend this reaction, however, we found that other pyridiniomethylides such as 1-pyridinio[[ethoxycarbonyl[(methylthio)thiocarbonyl]]methylide]s and 1-(2-methylpyridinio)[[cyano[(methylthio)thiocarbonyl]]methylide] reacted smoothly with the same reagent even at room temperature to afford quite different types of 1 : 1 adducts.[3)] Some spectral evidences for these products and the mechanistic consideration suggested that these products must be the intramolecular Diels–Alder type of adducts of 1,2-dimethyl 5-ethyl 4-methylthio-10a*H*-pyrido[1,2-*d*][1,4]thiazepine-1,2,5-tricarboxylates or dimethyl 5-cyano-7-methyl-4-(methylthio)-10a*H*-pyrido[1,2-*d*][1,4]thiazepine-1,2-dicarboxylate initially formed from the reactions of pyridinium ylides with DMAD. From this standpoint of view, we examined the reactions of some other 1-pyridinio[(thiocarbonyl)methylide]s with DMAD under more severe conditions and confirmed the formation of the same types of products. In this paper we wish to report the syntheses of title compounds, dimethyl 4-thia-1-azatetracyclo[5.4.0.0^{5,11}.0^{6,8}]undeca-2,9-diene-5,6-dicarboxylates, from the reactions of various 1-pyridinio[(thiocarbonyl)methylide]s with DMAD, and their thermolyses leading to the fragmentation to dimethyl phthalate and thiazole derivatives.

Results and Discussion

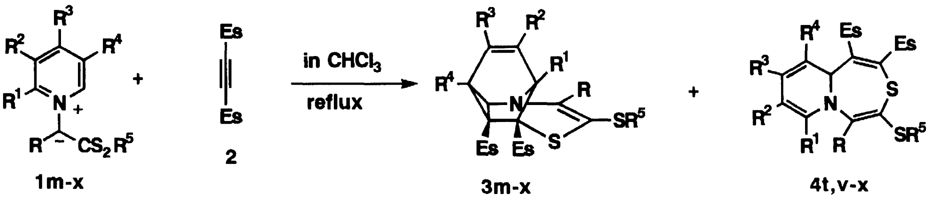
Preparations of Dimethyl 4-Thia-1-azatetracyclo[5.4.0.0^{5,11}.0^{6,8}]undeca-2,9-diene-5,6-dicarboxylates. In contrast with the formation of 10a*H*-pyrido[1,2-*d*][1,4]thiazepine derivatives from the reactions of 1-pyridinio[(thiocarbonyl)methylide]s having a cyano or benzoyl group at the ylidic carbanion with DMAD (**2**), the reactions of 1-pyridinio[[ethoxycarbonyl[(methylthio)thiocarbonyl)]]methylide]s **1a**—**c** with **2** in chloroform at room temperature did not give any colored product such as pyridothiazepine derivatives **4** at all as described earlier by us,[1,2)] but they afforded compound **3a**—**c** as colorless prisms in 51,46, and 38% yields, respectively. When these reactions were done in boiling chloroform, the yields for products **3a**—**c** increased to 71, 73, and 41%, respectively. On the other hand, the reaction of 1-(3,5-dimethylpyridinio)[[ethoxycarbonyl[(methylthio)thiocarbonyl)]]methylide] **1d** with **2** in boiling chloroform gave a mixture of **3d** (7%) and 5-ethyl 1,2-dimethyl 8,10-dimethyl-4-methylthio-10a*H*-pyrido[1,2-*d*][1,4]thiazepine-1,2,5-tricarboxylate **4d** (53%). Similarly, other 1-pyridinio[[ethoxycarbonyl[(substituted thiocarbonyl)]]methylide]s **1e**—**l** reacted with **2** in boiling chloroform to give the corresponding products **3e**—**l** in 14—40% yields, respectively (Scheme 1). Furthermore, 1-pyridinio[[cyano(substituted thiocarbonyl)]methylide]s **1m,o**—**s** and 1-pyridinio[[benzoyl(substituted thiocarbonyl)]methylide]s **1t**—**x**, which gave only 10a*H*-pyrido[1,2-*d*][1,4]thiazepine derivatives **4** at room temperature,[1)] also reacted with **2** in boiling chloroform to yield the corresponding compounds **3m,o**—**x** (4—59%) together with 10a*H*-pyrido[1,2-*d*][1,4]thiazepines **4t,v**—**x** (22—32%). Interestingly, 1-(2-methylpyridinio)[[cyano[(methylthio)thiocarbonyl]]methylide] **1n** afforded only product **3n** in 28% yield even at room temperature. These results are shown in Scheme 2.

Similarly, 3-(1-pyridinio)thiophene-2-thiolate derivatives **5a**—**g,i**, reacted with DMAD (**2**) in boiling chloroform or benzene to give the corresponding thiophene-fused adducts **6a**—**g,i** in 14—62% yields, respectively. On the other hand, the reaction of ylide **5h** with DMAD in boiling chloroform or benzene gave a complex mix-



1,3	R¹	R²	R³	R⁴	R⁵
a	H	H	H	H	Me
b	Me	H	H	H	Me
c	H	H	Me	H	Me
d	H	Me	H	Me	Me
e	H	H	H	H	Et
f	H	H	Me	H	Et
g	H	H	H	H	CH_2CO_2Et
h	Me	H	H	H	CH_2CO_2Et
i	H	H	Me	H	CH_2CO_2Et
j	H	Me	H	Me	CH_2CO_2Et
k	H	H	H	H	CH_2Ph
l	H	H	Me	H	CH_2Ph

Scheme 1.



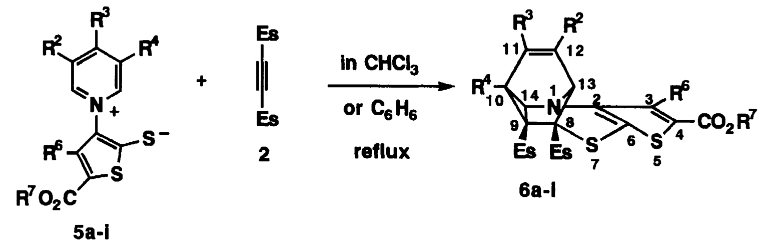
1,3,4	R¹	R²	R³	R⁴	R⁵	R
m	H	H	H	H	Me	CN
n	Me	H	H	H	Me	CN
o	H	H	Me	H	Me	CN
p	H	Me	H	Me	Me	CN
q	H	H	H	H	Et	CN
r	H	H	Me	H	Et	CN
s	H	Me	H	Me	Et	CN
t	H	H	H	H	Me	COPh
u	Me	H	H	H	Me	COPh
v	H	H	Me	H	Me	COPh
w	H	H	H	H	Et	COPh
x	H	H	Me	H	Et	COPh

Scheme 2.

ture and no significant product was isolated. The corresponding products **6h**, however, were obtained from **5h** and **2** in 28% yield by lowering the reaction temperature to 50 °C (Scheme 3).

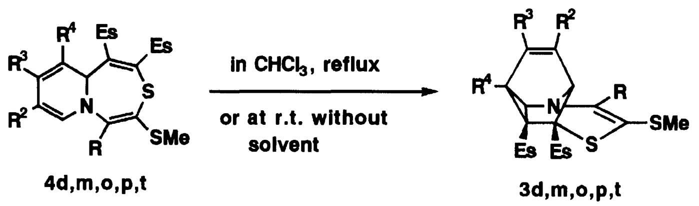
Compounds **3d,m,o,p,t** could also be obtained in good yields (65—79%) by heating the corresponding pyridothiazepines **4m,o** in chloroform for 4 h or by keeping **4d,p,t** in chloroform at room temperature for about 30 d. Similarly, adducts **6d,g** were formed in 64 and 51% yields from the reactions of 2-ethyl 5,6-dimethyl 1-methyl- **4y** and 1-phenyl-6a*H*-pyrido[1,2-*d*]thieno-[2′,3′-*b*][1,4]thiazepine-2,5,6-tricarboxylates **4z**1) in boiling chloroform (Scheme 4). These facts strongly suggested that 10a*H*-pyrido[1,2-*d*][1,4]thiazepine derivatives such as **4** are precursors for these compounds **3a**—**x** and **6a**—**i**.

The elemental analyses (see Experimental) and ^{1}H NMR spectra (Table 1) clearly showed that the products **3a**—**x** and **6a**—**i** are the 1 : 1 adducts between pyridinium ylides **1a**—**x** or pyridinium betaines **5a**—**i** and DMAD (**2**). Furthermore, the formation of the same adducts **3d,m,o,p,t** and **6d,g** from the corresponding 10a*H*-pyrido[1,2-*d*][1,4]thiazepines **4d,m,o,p,t** and 6a*H*-pyrido[1,2-*d*]thieno[2′,3′-*b*][1,4]thiazepines **4y,z** and the dramatic decrease of the number of the olefinic protons derived from the original pyridine ring in the ^{1}H NMR spectra suggested the possibility that compounds **3a**—**x** and **6a**—**i** are the intramolecular Diels–Alder type of adducts of the initially formed pyridothiazepine derivatives such as **4**. In the ^{1}H NMR spectra of adducts **3a**—**x** and **6a**—**i**, for example, the maximum numbers of the olefinic protons derived from the pyridine ring are 2, and this means that these adducts have a tetrahydropyridine moiety. Furthermore, the proton signals of the 2- and 5-methyl groups on the pyridine ring in starting 1-pyridinio[(thiocarbonyl)ylide]s **1b,d,h,j,n,p, s,u,v** and **5c,f,i** appeared in the range of δ=1.42—1.59 as a singlet, and the proton signals of the 2-, 5-, and

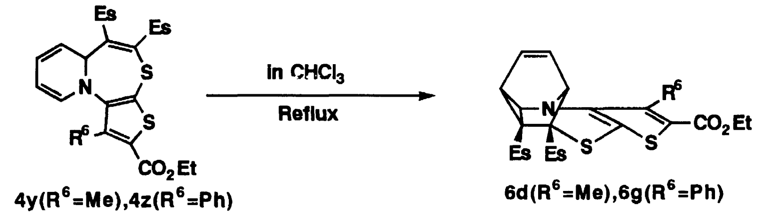


5,6	R²	R³	R⁴	R⁶	R⁷	5,6	R²	R³	R⁴	R⁶	R⁷
a	H	H	H	Me	Me	f	Me	H	Me	Me	Et
b	H	Me	H	Me	Me	g	H	H	H	Ph	Et
c	Me	H	Me	Me	Me	h	H	Me	H	Ph	Et
d	H	H	H	Me	Et	i	Me	H	Me	Ph	Et
e	H	Me	H	Me	Et						

Scheme 3.



3,4	R²	R³	R⁴	R	3,4	R²	R³	R⁴	R
d	Me	H	Me	CO₂Et	p	Me	H	Me	CN
m	H	H	H	CN	t	H	H	H	COPh
o	H	Me	H	CN					



Scheme 4.

6-positions appeared in the ranges of $\delta=3.60$—4.18, $\delta=2.36$—2.77, and $\delta=3.28$—3.77, respectively. These higher chemical shifts for the protons and the methyl protons indicated distinctly that they are on sp^3 hybridized carbons. On the other hand, the signals attributable to the protons and the methyl groups at the 3- and 4-positions on the pyridine ring appeared in lower regions ($\delta=5.55$—5.74 and $\delta=1.78$—1.97 respectively). From their chemical shifts and signal patterns we concluded that these molecules must have a 1,2,3,6-tetrahydropyridine moiety in their structures. Interestingly, a long-range coupling (1.0 Hz) between the 2- and 6-protons on this 1,2,3,6-tetrahydropyridine ring was observed. This long-range coupling should be a W-shaped one as seen in some cage compounds,[4] and, from the consideration of the conformation with Dreiding models, the appearance of such long range coupling could be understood. However, there is still the problem of which double bond in the 4,5-dihydro-1,4-thiazepine structure of primary compounds **4** acts as a 2π component in these intramolecular Diels–Alder type of reactions. This answer could also be obtained by considering normal electron demand (diene(HOMO)–olefin(LUMO)) in such a reaction[5] and in part by indicating an α,β-unsaturated cyano absorption band (2191—2211 cm^{-1}) in the IR spectra of compounds **3m**—**s**: the double bond which acts as the 2π component during these intramolecular Diels–Alder type of reactions must be the more electron-deficient one between the 6- and 7-positions rather than that between the 2- and 3-positions in the 4,5-dihydro-1,4-thiazepine structure.

To confirm our proposed structures and to obtain further structural data for these adducts **3a**—**x** and **6a**—**i**, we did X-ray structural analyses for two compounds, **3n** and **6b**. The crystal and structure analysis data as well as the selected bond lengths and angles for **3n**

Table 1. ^{1}H NMR Spectral Data for 4-Thia-1-azatetracyclo[$5.4.0.0^{5,11}.0^{6,8}$]undeca-2,9-dienes

Compd	δ (CDCl$_3$)										
No.a,b)	C-7	C-8	C-9	C-10	C-11	R^5 or R^6		CO$_2$Me		Others	
3a	3.58	2.66	5.7—6.4		3.88	2.43		3.66	3.66	1.29	3.9—4.4
	dd	brt	m		brd	s		s	s	t	m
3b	3.57	2.53	6.28	5.63	1.52	2.45		3.66	3.66	1.28	3.9—4.4
	d	brt	q	dd	s	s		s	s	t	m
3c	3.51	2.42	1.85	5.69	3.76	2.39		3.60	3.62	1.27	3.9—4.4
	dd	dd	d	brd	dd	s		s	s	t	m
3d	3.37	1.45	5.61	1.78	c)	2.40		3.69	3.69	1.29	3.9—4.4
	d	s	brs	d		s		s	s	t	m
3e	3.62	2.71	5.7—6.5		3.96	1.33	3.01	3.71	3.71	1.33	3.9—4.4
	dd	brt	m		brd	t	q	s	s	t	m
3f	3.56	2.44	1.89	5.65	3.79	1.29	2.94	3.60	3.62	1.29	3.9—4.4
	dd	dd	d	brd	dd	t	q	s	s	t	m
3g	3.62	2.67	5.7—6.4		3.81	3.65	1.30d)	3.69	3.69	1.30	3.9—4.4
	dd	brt	m		brd	s	t	s	s	t	m
3h	3.61	2.53	6.27	5.63	1.53	3.68	1.27d)	3.60	3.60	1.27	3.9—4.4
	d	brt	q	dd	s	s	t	s	s	t	m
3i	3.53	2.43	1.87	5.64	3.77	3.58	1.27d)	3.63	3.63	1.27	3.9—4.4
	dd	dd	d	brd	dd	s	t	s	s	t	m
3j	3.38	1.47	5.58	1.75	d)	3.60	1.29d)	3.60	3.60	1.29	3.9—4.4
	d	s	brs	d		s	t	s	s	t	m
3k	3.58	2.65	5.7—6.4		3.92	4.13	7.30	3.66	3.68	1.24	3.8—4.5
	dd	brt	m		brd	s	brs	s	s	t	m
3l	3.58	2.45	1.91	5.65	3.79	4.13	7.30	3.66	3.70	1.26	3.8—4.5
	dd	dd	d	brd	dd	s	brs	s	s	t	m
3m	c)	2.66	5.7—6.4		4.00	2.47		3.67	3.71		
		brt	m		brd	s		s	s		
3n	c)	2.56	6.26	5.61	1.59	2.48		3.65	3.69		
		brt	q	dd	s	s		s	s		
3o	c)	2.44	1.89	5.61	3.87	2.44		3.65	3.69		
		dd	d	brd	dd	s		s	s		
3p	3.50	1.45	5.64	1.81	3.80	2.47		3.72	3.72		
	d	s	brs	d	d	s		s	s		
3q	c)	2.75	5.7—6.5		3.88	1.34	3.01	3.70	3.75		
		brt	m		brd	t	q	s	s		
3r	c)	2.48	1.90	5.59	3.87	1.34	2.96	3.62	3.66		
		dd	d	brd	dd	t	q	s	s		
3s	3.77	1.44	5.61	1.79	3.60	1.30	2.92	3.70	3.70		
	d	s	brs	d	d	t	q	s	s		
3t	3.28	2.50	5.8—6.4		4.10	2.37		3.65	3.65	7.2—8.1	
	dd	brt	m		brd	s		s	s	m	
3u	3.40	2.43	6.21	5.66	1.68	2.43		3.64	3.64	7.2—8.1	
	d	brt	q	dd	s	s		s	s	m	
3v	3.45	2.38	1.87	5.74	4.06	2.40		3.69	3.69	7.2—8.1	
	dd	dd	d	brd	dd	s		s	s	m	
3w	3.54	2.59	5.8—6.4		4.18	1.27	2.92	3.69	3.69	7.2—8.1	
	dd	brt	m		brd	t	q	s	s	m	
3x	3.53	2.36	1.83	5.67	4.04	1.23	2.84	3.64	3.64	7.2—8.1	
	dd	brt	d	brd	dd	t	q	s	s	m	

and **6b** are summarized in Tables 2 and 3. Tables of the coordinates, bond lengths, bond and torsion angles, and F_o-F_c tables are deposited as Document No. 67028 at the Office of the Editor of Bull. Chem. Soc. Jpn. ORTEP drawings[6] for **3n** and **6b** are shown in Figs. 1 and 2. As might be expected from the Dreiding models for compounds **3a**—**x** and **6a**—**i** and was also demonstrated from the ORTEP figures for **3n** and **6b**, these molecules have very rigid and strained structures. In molecules **3n** and **6b**, significant extensions of some bond lengths were observed as the result. In particular, two bond lengths (f=1.533 Å and h=1.557 Å for **3n** and (f=1.564 Å and h=1.579 Å for **6b**, see Fig. 3 and Table 3) for the cyclopropane ring and the other one bond length (n=1.588 Å for **3n** and n=1.564 Å for **6b**) for the cyclohexene ring are considerably longer than those

Table 1. (Continued)

Compd No.[a,b]	C-7	C-8	C-9	C-10	C-11	R^5 or R^6	CO_2Me		Others	
6a	3.56	2.77	5.8—6.5		4.16	2.40	3.74	3.74	3.82	
	dd	brt	m		brd	s	s	s	s	
6b	3.52	2.55	1.97	5.72	4.00	2.39	3.70	3.70	3.79	
	dd	dd	d	brd	dd	s	s	s	s	
6c	3.30	1.47	5.67	1.83	3.93	2.37	3.72	3.72	3.80	
	d	s	brs	d	brs	s	s	s	s	
6d	3.56	2.78	5.8—6.5		4.17	2.38	3.70	3.70	1.33	4.28
	dd	brt	m		brd	s	s	s	t	q
6e	3.51	2.57	1.94	5.73	4.02	2.37	3.70	3.70	1.31	4.28
	dd	dd	d	brd	dd	s	s	s	t	q
6f	3.34	1.52	5.67	1.88	3.95	2.41	3.75	3.75	1.37	4.30
	d	s	brs	d	brs	s	s	s	t	q
6g	3.46	2.64	5.7—6.3		[c]	7.38	3.70	3.70	1.09	4.09
	dd	brt	m			brs	s	s	t	q
6h	3.50	2.46	1.87	5.69	[c]	7.39	3.76	3.76	1.12	4.17
	dd	dd	d	brd		brs	s	s	t	q
6i	3.28	1.42	5.55	1.80	4.01	7.40	3.77	3.77	1.15	4.12
	d	s	brs	d	brs	brs	s	s	t	q

δ ($CDCl_3$)

a) For the tetrahydropyridine moiety in compounds **6a**—**i**, the same numberings with that in thiophene-free compounds **3a**—**x** were used. b) The coupling constants are as follows: $J_{7,8}=7.0$, $J_{8,9}=6.5$, $J_{9,10}=8.5$, $J_{10,11}=7.0$, $J_{8,10}=2.0$, and $J_{7,11}=1.0$ Hz. c) Overlapped with the proton signals of the methoxycarbonyl group. d) Overlapped with the methylene proton signals of the ethoxycarbonyl group.

Table 2. Crystal and Structure Analysis Data Compounds **3n** and **6b**

	3n	**6b**
Formula	$C_{16}H_{16}N_2O_4S_2$	$C_{19}H_{19}NO_6S_2$
Formula weight	364.43	421.48
Crystal system	Orthorhombic	Triclinic
Space group	*Pbca*; $Z=8$	$P\bar{1}$; $Z=2$
Lattice parameter		
a/Å	13.748(5)	9.826(2)
b/Å	26.567(2)	13.674(2)
c/Å	9.033(2)	7.353(2)
α/°	90	104.51(2)
β/°	90	90.22(2)
γ/°	90	95.84(2)
V/Å^3	3300(1)	951.0(4)
D_{calcd}/g cm^3	1.467	1.472
Crystal size/mm^3	0.22×0.28×0.48	0.40×0.08×0.80
Diffractometer	Rigaku AFC5S	Rigaku AFC5S
Radiation	Mo$K\alpha$ (λ=0.71069 Å)	Mo$K\alpha$ (λ=0.71069 Å)
Monochromator	Graphite	Graphite
Scan type	ω	ω–2θ
2θ Max	55.0°	55.0°
Computer program	TEXSAN system[a]	TEXSAN system[a]
Structure solution	MITHRIL[b]	MITHRIL[b]
Hydrogen atom treatment	Observed, isotropic	Calculated, not refined
Refinement	Full-matrix, anisotropic	Full-matrix, anisotropic
Least-squares weight	$4F_o^2/\sigma^2(F_o^2)$	$4F_o^2/\sigma^2(F_o^2)$
No. of measurement ref.	Total: 4282	Total: 4608 Unique: 4352
No. of observations[c]	1970	3204
No. of variables	282	253
Residuals R;R_w	0.043; 0.047	0.067; 0.105
Max Shift/Error	0.00	0.49
$\Delta\rho_{max}$/e$^-$/Å^3	0.25	0.55

a) See Ref. 7. b) Direct methods, see Ref. 8. c) $I>3.00\sigma(I)$.

Table 3. Selected Bond Lengths and Bond Angles for Compounds **3n** and **6b** (esd's where given, are in parentheses)

	3n	**6b**		**3n**	**6b**
Bond lengths[a)]					
a	1.450(4)	1.453(6)	j	1.303(6)	1.313(7)
b	1.340(5)	1.352(7)	k	1.505(5)	1.504(7)
c	1.748(3)	1.750(5)	l	1.508(4)	1.487(6)
d	1.848(3)	1.857(5)	m	1.459(4)	1.459(6)
e	1.511(4)	1.491(7)	n	1.588(5)	1.564(7)
f	1.533(4)	1.564(7)	o	—	1.428(7)
g	1.504(5)	1.493(7)	p	—	1.378(7)
h	1.557(5)	1.579(6)	q	—	1.745(5)
i	1.457(6)	1.484(7)	r	—	1.730(5)
Bond angeles[a)]					
ab	124.1(3)	123.1(4)	gm	114.8(3)	114.9(4)
al	112.0(3)	110.3(4)	hi	118.1(3)	118.9(4)
am	108.3(3)	108.1(4)	ij	117.0(4)	114.8(4)
bc	123.4(3)	127.5(4)	jk	117.0(4)	115.8(4)
cd	101.0(1)	96.3(2)	kl	105.8(3)	108.4(4)
de	109.7(2)	113.4(3)	kn	109.2(3)	109.0(4)
dn	109.0(2)	118.7(3)	lm	104.4(2)	102.8(4)
ef	104.7(3)	104.3(4)	ln	100.2(3)	102.6(4)
eh	114.9(3)	111.9(4)	ao	—	121.8(4)
en	102.0(2)	102.6(4)	bo	—	114.9(4)
fg	61.7(2)	62.2(3)	br	—	111.6(4)
fh	58.3(2)	56.7(3)	cr	—	120.9(3)
fm	108.3(3)	107.9(4)	op	—	110.2(4)
gh	60.1(2)	61.1(3)	pq	—	112.6(4)
gi	116.6(3)	118.4(4)	qr	—	90.7(2)

a) For the alphabetical symbols of the bond lengths and angles, see Fig. 3.

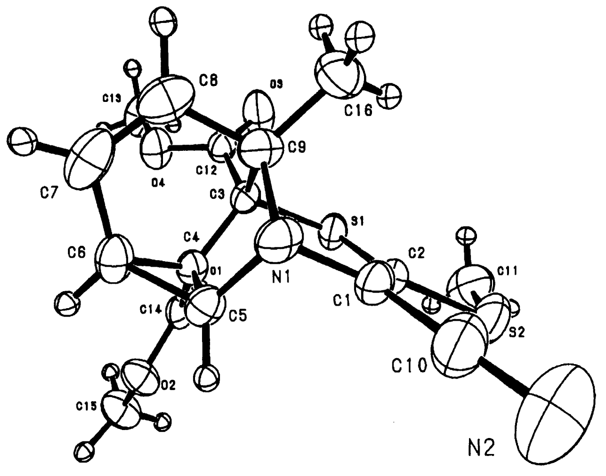


Fig. 1. ORTEP drawing of dimethyl 2-cyano-11-methyl-3-methylthio-4-thia-1-azatetracyclo[5.4.0.0^{5,11}.0^{6,8}]-undeca-2,9-diene-5,6-dicarboxylate (**3n**) showing the atom labeling scheme and 50% probability thermal ellipsoids.

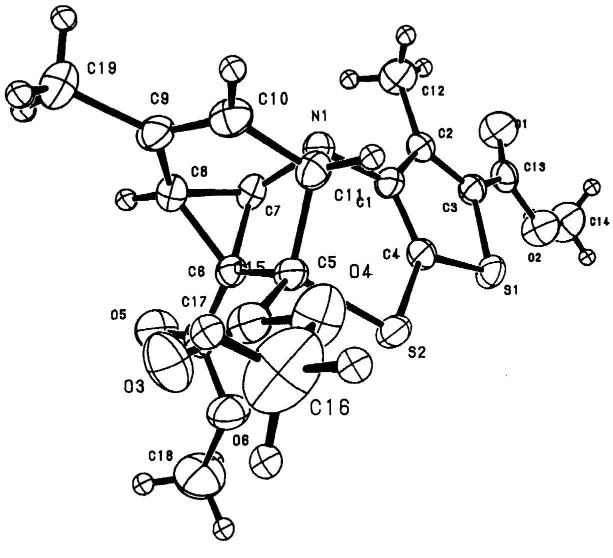


Fig. 2. ORTEP drawing of trimethyl 3,11-dimethyl-5,7-dithia-1-azapentacyclo[8.3.1.0^{2,6}.0^{8,13}.0^{9,14}]-tetradeca-2(6),3,11-triene-4,8,9-tricarboxylate (**6b**) showing the atom labeling scheme and 50% probability thermal ellipsoids.

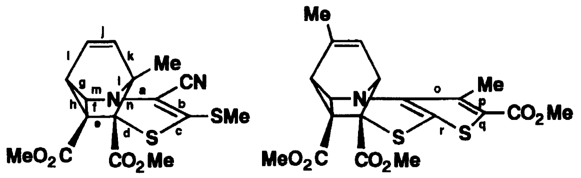
observed for usual cyclopropanes (1.512 Å) and cyclohexenes (1.52 Å).[9)] This large ring strain seems to make these compounds **3a**—**x** and **6a**—**i** thermally unstable and this must be a driving force for their subsequent ready fragmentation (see below).

Thermolysis of Adducts 3a,g,k,m,t. In the reactions of pyridinium ylides **1** or **5** with DMAD (**2**) in boiling chloroform, the prolonged reaction time resulted in a decrease of the yields for the intramolecular Diels–Alder type of adducts **3** and **6**. This strongly

Table 4. Some Data for Heterocage Compounds **3a**—**x** and **6a**—**i**

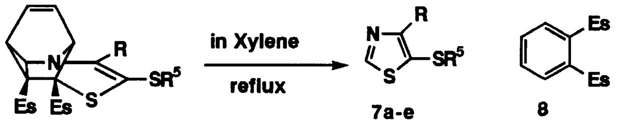
Compd[a] No	Ylide	Yield[b] %	Mp °C	ν(KBr) cm^{-1}				Formula[c]
3a	**1a**	71(51)	135—136	1721	1674			$C_{17}H_{19}NO_6S_2$
3b	**1b**	73(46)	125—126	1725	1674			$C_{18}H_{21}NO_6S_2$
3c	**1c**	41(38)	136—137	1748	1723	1680		$C_{18}H_{21}NO_6S_2$
3d	**1d**	7[d]	142—144	1752	1703	1678		$C_{19}H_{23}NO_6S_2$
3e	**1e**	40	104—106	1721	1676			$C_{18}H_{21}NO_6S_2$
3f	**1f**	20	133—134	1707	1682			$C_{19}H_{23}NO_6S_2$
3g	**1g**	22	122—124	1746	1723	1682		$C_{20}H_{23}NO_8S_2$
3h	**1h**	14	128—130	1742	1722	1680		$C_{21}H_{25}NO_8S_2$
3i	**1i**	25	133—134	1746	1713	1682		$C_{21}H_{25}NO_8S_2$
3j	**1j**	22	114—115	1748	1730	1711	1678	$C_{22}H_{27}NO_8S_2$
3k	**1k**	36	136—137	1738	1717	1667		$C_{23}H_{23}NO_6S_2$
3l	**1l**	39	134—135	1750	1719	1678		$C_{24}H_{25}NO_6S_2$
3m	**1m**	26	157—159	2203	1721			$C_{15}H_{14}N_2O_4S_2$
3n	**1n**	46(28)	128—130	2191	1721			$C_{16}H_{16}N_2O_4S_2$
3o	**1o**	59	137—139	2209	1746	1718		$C_{16}H_{16}N_2O_4S_2$
3p	**1p**	4	160—161	2195	1748	1713		$C_{17}H_{18}N_2O_4S_2$
3q	**1q**	30	123—124	2209	1750	1725		$C_{16}H_{16}N_2O_4S_2$
3r	**1r**	55	130—132	2211	1730			$C_{17}H_{18}N_2O_4S_2$
3s	**1s**	5	110—111	2209	1715			$C_{18}H_{20}N_2O_4S_2$
3t	**1t**	12[e]	151—152	1725	1707			$C_{21}H_{19}NO_5S_2$
3u	**1u**	6	160—161	1725	1707			$C_{22}H_{21}NO_5S_2$
3v	**1v**	7[f]	143—144	1752	1711			$C_{22}H_{21}NO_5S_2$
3w	**1w**	12[g]	122—124	1744	1711			$C_{22}H_{21}NO_5S_2$
3x	**1x**	9[h]	129—130	1750	1709			$C_{23}H_{23}NO_5S_2$
6a	**5a**	32	153—155	1745	1711			$C_{18}H_{17}NO_6S_2$
6b	**5b**	52	184—186	1741	1716			$C_{19}H_{19}NO_6S_2$
6c	**5c**	23[i]	134—136	1749	1718			$C_{20}H_{21}NO_6S_2$
6d	**5d**	62	148—150	1747	1701			$C_{19}H_{19}NO_6S_2$
6e	**5e**	14	165	1745	1711			$C_{20}H_{21}NO_6S_2$
6f	**5f**	22[i]	134—136	1753	1718			$C_{21}H_{23}NO_6S_2$
6g	**5g**	54	187—189	1750	1723	1707		$C_{24}H_{21}NO_6S_2$
6h	**5h**	28[j]	125—127	1747	1716			$C_{25}H_{23}NO_6S_2$
6i	**5i**	44[i]	165—167	1749	1718			$C_{26}H_{25}NO_6S_2$

a) Compounds **3a**—**s** and **6a**—**i** were obtained as colorless prisms, and **3t**—**x** as pale yellow needles. b) The yields in the parenthesis are those for the reactions at room temperature. c) Satisfactory elemental analyses (within ±0.3% for C, H, and N) were obtained for all compounds. d) Plus **4d** (53%). e) Plus **4t** (24%). f) Plus **4v** (32%). g) Plus **4w** (22%). h) Plus **4x** (30%). i) The reaction was done in boiling benzene. j) The reaction was done in benzene at about 50 °C.



3n **6b**

Fig. 3.



3a,g,k,m,t **7a-e** **8**

7	3	R	R^5
a	a	CO_2Et	Me
b	g	CO_2Et	CH_2CO_2Et
c	k	CO_2Et	CH_2Ph
d	m	CN	Me
e	t	COPh	Me

Scheme 5.

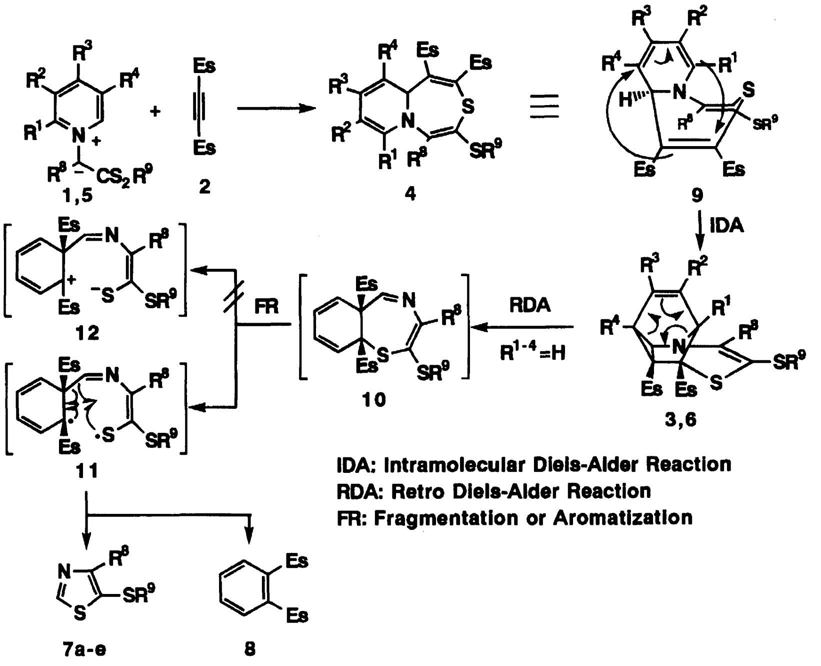
suggested the possibility of further thermolysis of these adducts once formed during these reactions. When adducts **3a,g,k,m,t** were heated in boiling xylene for 2 h and the resulting mixtures were separated in the usual manner, two types of fragments, 5-(alkylthio)thiazoles **7a**—**e** and dimethyl phthalate (**8**), were isolated in good yields (Scheme 5). The structures of **7a**—**e** were readily identified by the spectral and analytical data. Another product, **8**, was in complete accordance with the authentic dimethyl phthalate in all respects.

Reaction Mechanisms. Possible mechanisms are postulated in Scheme 6. Evidently, the formation

Table 5. Some Data for the Thermolyses of 4-Thia-1-azatetracyclo-[5.4.0.0^{5,11}.0^{6,8}]undeca-2,9-dienes

React.	Compd$^{a,b)}$ No.	Yield$^{c)}$ %	Mp °C	ν(KBr)/cm^{-1} CN	CO	Formula$^{d)}$
3a	**7a**	89(95)	60—61$^{e)}$		1701	$C_7H_9NO_2S_2$
3g	**7b**	85(96)	68—70		1736 1692	$C_{10}H_{13}NO_4S_2$
3k	**7c**	55(95)	57—58		1694	$C_{13}H_{13}NOS_2$
3m	**7d**	87(93)	176—178	2214		$C_5H_4N_2S_2$
3t	**7e**	62(62)	64—65		1615	$C_{11}H_9NOS_2$

a) All compounds **7a**—**e** were obtained as colorless prisms. b) The ^{1}H NMR spectra for these thiazole derivatives **7a**—**e** are as follows; **7a**, ^{1}H NMR ($CDCl_3$) δ=1.43 (3h, t, J=7.0 Hz, OCH_2CH_3), 2.62 (3H, s, SMe), 4.45 (2H, q, J=7.0 Hz, OCH_2CH_3), and 8.63 (1H, s, 2-H). **7b**, δ ($CDCl_3$)=1.27 and 1.42 (each 3H, t, J=7.0 Hz, $2\times OCH_2CH_3$), 3.78 (2H, s, SCH_2), 4.30 and 4.40 (each 2H, q, J=7.0 Hz, $2\times OCH_2CH_3$), 8.70 (1H, s, 2-H). **7c**, δ ($CDCl_3$)=2.71 (3H, s, SMe) and 8.81 (1H, s, 2-H). **7e**, δ ($CDCl_3$)=2.64 (3H, s, SMe), 7.3—8.5 (5H, m, Ph), and 8.71 (1H, s, 2-H). c) The yields in the parenthesis is for dimethyl phthalate **8**. d) Satisfactory elemental analyses (within ±0.3% for C, H, and N) were obtained for all compounds. e) Lit,[11] mp 57 °C.



Scheme 6.

of adducts **3a**—**x** and **6a**—**i** proceeds via the intervention of 10a*H*-pyrido[1,2-*d*][1,4]thiazepines such as **4**, which were formed first from the reaction of pyridinium ylides **1a**—**x** or **5a**—**i** with DMAD (**2**), as described in our preceding papers.[1,2] From the consideration of the stereochemistry for these intramolecular Diels–Alder type of reactions which lead to the corresponding adducts **3a**—**x** and **6a**—**i** and of the extremely smooth formation of 11-methyl derivatives **3b,n**, the transition state with conformations such as **9** in which there is no severe peri-interaction between the 5- and 7-positions in 10a*H*-pyrido[1,2-*d*][1,4]thiazepine structure **4**,[3] must be involved in these reactions. The retardation for this intramolecular Diels–Alder reaction of 8,10-dimethyl-10a*H*-pyrido[1,2-*d*][1,4]thiazepine **4d** can also be explained by the consideration of the peri-interaction between the 1-methoxycarbonyl (Es, see Scheme 6) and the 10-methyl group (R^4) in the same conformer **9**. On the other hand, the fragmentation of the adducts **3a, g,k,m,t** to 5-(alkylthio)thiazoles **7a**—**e** and dimethyl phthalate **8** may be curious as a glance. However, the rigid and strained structure of the adducts **3a**—**x** and the reversibility of Diels–Alder reaction immediately prompted us to postulate the intervention of an important intermediate, dimethyl 2-alkylthio-5a,9a-dihydrobenzo-1,4-thiazepine-5a,9a-dicarboxylate derivative **10**. This molecule **10** should be formed via the alternative retro Diels–Alder reaction of the adducts **3a,g,k,m,t** in which the C_1–C_{11} and C_7–C_8 single bonds are both broken with the movement of the C_9–C_{10} double bond. To lead to the final products **7** and **8** from the resulting dihydrobenzothiazepine derivatives **10**, the generation and fragmentation of a biradical intermediate **11** may be considered further, since concerted *cis*-1,2-elimination ($\sigma 2s+\sigma 2s$) is a thermally forbidden process.[10] A possible alternative intermediate, **12**, from **10** can be neglected because of its structure, which does not stabilize the cationic center.

Experimental

The melting points were measured with a Yanagimoto micromelting point apparatus and not corrected. Microanalyses were done on a Perkin–Elmer 2400 elemental analyzer. The ^{1}H NMR spectra (60 MHz) were measured with a Varian EM360A spectrometer in deuteriochloroform with tetramethylsilane used as an internal standard; the chemical shifts are expressed in δ values. The IR spectra were taken with a JASCO FT/IR-5300 infrared spectrophotometer.

Reactions of Pyridinium Ylides 1 and Betaines 5 with Dimethyl Acetylenedicarboxylate (2). General Method A. After a chloroform solution (50 ml) of pyridinium ylide or betaine (**1** or **5**, 5 mmol) and DMAD (**2**, 1 g, 7 mmol) was heated under reflux for 3—4.5 h, the resulting solution was concentrated under reduced pressure with a rotatory evaporator. The residual oil was separated by column chromatography on alumina (or silica gel when 10a*H*-Pyrido[1,2-*d*][1,4]thiazepine derivative **4** was also formed together with intramolecular Diels–Alder type of adduct **3** or **6**) using ether and then chloroform as eluents. The ether fractions involving pyridothiazepine **4** and the chloroform fractions involving the corresponding adduct **3** or **6** were collected, and the respective solutions were concentrated under reduced pressure. Recrystallizations of the respective residues from chloroform-hexane afforded the corresponding compounds **3a**—**x** or **6a,b,d,e,g** as colorless or pale yellow crystals and compounds **4d,t,v**—**x** as red crystals, respectively.

General Method B. Since the expected Diels–Alder adducts **6c,f,h,i** could not be obtained by general method A described above, the reactions of pyridinium betaines **5c, f,i** with **2** were done in boiling benzene for 4 h. Usual workup of the resulting reaction mixtures afforded the expected products **6c,f,i**. On the other hand, compound **6h** could be obtained only by the reaction of betaine **5h** with **2** in benzene at lower temperature (about 50 °C), while the reaction at the reflux temperature gave a complex mixture without the isolation of any significant product.

These results and some data are shown in Tables 1 and 4.

The structures of 10a*H*-pyrido[1,2-*d*][1,4]thiazepine derivatives **4m,t,v**—**x** were confirmed by comparisons with the authentic samples we described earlier.[1,2] Some spectral and analytical data of a new compound, 5-ethyl 1,2-dimethyl 8, 10-dimethyl-4-methylthio-10a*H*-pyrido[1,2-*d*][1,4]thiazepine-1,2,5-tricarboxylate (**4d**) are as follows; red prisms, mp 135—136 °C, ν (KBr) 1668 and 1720 (CO) cm^{-1}, ^{1}H NMR ($CDCl_3$) δ=1.33 (3H, t, J=7.0 Hz, OCH_2CH_3), 1.64 (3H, s, 8-Me), 1.86 (3H, s, 10-Me), 2.30 (3H, s, SMe), 3.61 (3H, s, OMe), 3.69 (3H, s, OMe), 4.19 (2H, q, J=7.0 Hz, OCH_2CH_3), 5.66 (2H, br s, 9- and 10a-H), and 5.78 (1H, s, 7-H). Anal. ($C_{19}H_{23}NO_6S_2$) C,H,N.

Transformations of 10a*H*-Pyrido[1,2-*d*][1,4]thiazepines 4d,m,o,p,t,y,z to Intramolecular Diels–Alder Type of Adducts 3d,m,o,p,t and 6d,g. When a chloroform solution (20 ml) of 10a*H*-pyrido[1,2-*d*][1,4]thiazepine (**4m,o,y,z**, 1 mmol), which was synthesized by the reaction of pyridinium ylide (**1m,o** or **5d,g**) and **2** in chloroform at room temperature,[1,2] was heated under reflux for 4 h in a water bath and the resulting reaction mixture was treated in a similar manner as described above, the same adduct **3m,o** or **6d,g** was obtained in 67, 71, 64, or 51% yield. However, similar treatment for compounds **4d,p,t** did not provide good results, because these transformations required a lot of reaction time and the prolonged reaction time caused these adducts **3d,p,t** to decompose smoothly. These compounds **4d,p,t** could be transformed to **3d,p,t** in 65, 66, and 79% yields respectively by keeping their chloroform solution at room temperature for about 30 d.

Thermolyses of Adducts 3,a,g,k,m,t. General Method. Dimethyl 4-thia-1-azatetracyclo[$5.4.0.0^{6,11}.0^{6,8}$]undeca-2,9-diene-6,7-dicarboxylate (**3**, 1 mmol) was dissolved in xylene (20 ml) and the resulting solution was heated under reflux for 2 h. The resulting mixture was then concentrated under reduced pressure and the residue was separated by column chromatography on alumina using hexane and ether as eluents. The hexane fraction involving dimethyl phthalate (**8**) were collected and the combined solution was concentrated under reduced pressure. The physical and spectral data for this residual oil were completely in accord with those for an authentic sample **8** in all respects. The ether including a thiazole derivative was similarly treated and recrystallization of the residue from ether-hexane gave the corresponding products **7a**—**e** as colorless crystals.

The melting point (60—61 °C) which was observed for known compound **7a** by us was consistant with that (57 °C) reported earlier.[11]

These results are summarized in Table 5.

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