1,3-Dipolar Character of Six-membered Aromatic Rings. Part 34.[1] The Search for Superior 1-Substituents to Facilitate Cycloadditions of 3-Oxidopyridinium

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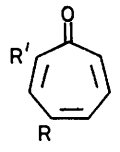
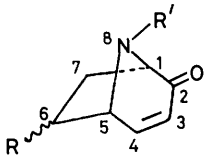
Cycloaddition products have been prepared from 3-hydroxypyridinium betaines containing *N*-carbamoyl, *N*-phenylthiomethyl, *N*-thiadiazoyl, *N*-benzylideneamino-, and *N*-4-pyridyl substituents.

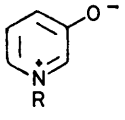
TROPONES [2] (1) and tropolones [2] (2) are produced by the Hofmann degradation of the methiodides of azabicyclo-[3.2.1]octenones (3) synthesised [3] by 1,3-dipolar cycloaddition between 1-methyl-3-oxidopyridinium (6) and numerous dipolarophiles. Extension of this tropone synthesis to more readily available *N*-phenyl cycloadducts is made difficult because methylation of the *N*-phenyl adducts (to give quaternary ammonium salts) requires [4] 'magic methyl'.[5] Ideally we require *N*-substituents which are easy to place on the starting 3-hydroxypyridines, activate the ring to give good yields of cycloadducts, and are then easy to remove. We now describe experiments directed towards these aims.



(1) R′ = NMe_2
(2) R′ = OH



(3) R′ = Me
(4) R′ = $CH_2CH_2CO_2Me$; R = CO_2Me
(5) R = CN; R^1 = H



(6) R = Me
(7) R = $CONMe_2$
(8) R = CH_2SPh
(9) R = CH_2SO_2Ph
(10) R = 3-Phenyl-1,2,4-thiadiazol-5-yl
(11) R = H

N-Carbamoyl Substituents.—Our previous attempts to use RCO substituents failed [6] because of the instability of *N*-carbonylpyridinium salts. However, Johnson and Rumon [7] have shown that pyridine reacts with *NN*-dimethylcarbamoyl chloride in hydroxylic solvents (*e.g.* MeOH, EtOH) to yield 1-(*NN*-dimethylcarbamoyl)-pyridinium chloride (12) which is stable in these solvents, although rapidly decomposed in non-hydroxylic solvents. We successfully allowed 3-hydroxypyridine to react with *NN*-dimethylcarbamoyl chloride in MeOH to yield 1-(*NN*-dimethylcarbamoyl)-3-hydroxypyridinium chloride (13) [urea [8] ν(C=O) 1 660 cm^{-1}] which with acrylonitrile and triethylamine yields the expected stereoisomeric cycloadducts (18) and (21) *via* the transient betaine, 1-(*NN*-dimethylcarbamoyl)-3-oxidopyridinium (7).

Both cycloadducts show αβ-unsaturated carbonyl stretching at 1 690 and 1 720 cm^{-1} characteristic [9] of this class of adducts. The structures and stereochemistry of both adducts were determined by n.m.r. spectroscopy (Table). In both cases, the 1-H signal appears as a doublet ($J_{1,7\text{-}exo}$ 8.0—9.0 Hz) broadened by long-range coupling ($J_{1,3}$ 1.0 Hz) and that of 5-H as a doublet ($J_{4,5}$ 5.0 Hz) for the *exo*-isomer (18) and a double doublet ($J_{4,5}$ 4.0, $J_{5,6\text{-}exo}$ 7.0 Hz) for the *endo*-isomer (21).

No reaction occurred between the betaine (7) and styrene. With methyl acrylate, the previously reported [10] 2 : 1 adducts (4) derived from 3-hydroxypyridine were obtained. Attempted hydrolysis of the cycloaducts (18) and (21) failed to yield the desired nor-adduct (5); in view of this further work with carbamoyl as a substituent was abandoned.

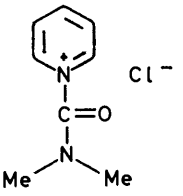
Phenylthiomethyl and Related Substituents.—Pyridine is readily quaternised by chloromethyl phenyl sulphide [11] to yield the sulphide chloride (25). The corresponding perchlorate salt (26) was oxidised to the sulphone perchlorate (27), m.p. 202—204 °C. Quaternisation of 1-phenylthiomethylpyridinium perchlorate (26) with methyl iodide in the presence of silver perchlorate–acetonitrile complex [12] produced the diperchlorate (28), m.p. 158—160 °C. Arylsulphonylmethylpyridinium salts have recently been described by Abramovitch.[13]

We reasoned that a CH_2SPh substituent would be easy to remove. Chloromethyl phenyl sulphide with 3-hydroxypyridine gave the quaternary salt (15) (*cf.* ref. 14) which reacted with methyl acrylate in the presence of NEt_3 to yield the *exo*-adduct (19), m.p. 104—106 °C, *via* the betaine (8). The *exo*-configuration at C-6 was indicated by the n.m.r. spectrum (Table) which showed a doublet for 5-H ($J_{5,6}$ 0, $J_{4,5}$ 5.0 Hz). Spectral evidence indicated the formation of cycloadducts from the betaine (8) with acrylonitrile and styrene but these adducts were too unstable for isolation.

The sulphide chloride (15) was oxidised by peracetic acid to the sulphone chloride (16).[15] Treatment of (15) with sodium perchlorate followed by oxidation

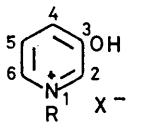
‡ Previously transliterated as Sabounji.

yielded the corresponding perchlorate salt (17), but neither the betaine (9) nor its cycloaddition products could be isolated. n-Butyl chloromethyl ether [16] also failed to react with 3-hydroxypyridine.

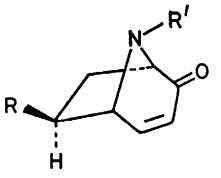


(12)

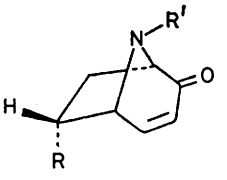
The betaine (10) was, therefore, generated *in situ* with 1 mol. equiv. excess of 3-hydroxypyridine. In the absence of the dipolarophile it dimerises as expected [20] to the *syn*-dimer (34) which was isolated as the ethyl ether (35) since ethanol added to the αβ-unsaturated double-bond (*cf.* ref. 20) during isolation and purification.



(13) R = $CONMe_2$; X = Cl
(14) R = 3-Phenyl-1,2,4-thiadiazol-5-yl; X = Cl
(15) R = CH_2SPh; X = Cl
(16) R = CH_2SO_2Ph; X = Cl
(17) R = CH_2SO_2Ph; X = ClO_4

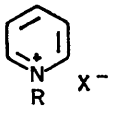


(18) R = CN; R′ = $CONMe_2$
(19) R = CO_2Me; R′ = CH_2SPh
(20) R = CO_2Me; R′ = 3-Phenyl-1,2,4-thiadiazol-5-yl



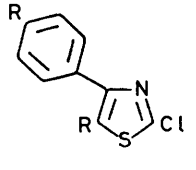
(21) R = CN; R′ = $CONMe_2$
(22) R = CN; R′ = 3-Phenyl-1,2,4-thiadiazol-5-yl
(23) R = CO_2Me; R′ = 3-Phenyl-1,2,4-thiadiazol-5-yl
(24) R = Ph; R′ = 3-Phenyl-1,2,4-thiadiazol-5-yl

N-Thiazolyl Substituents.—We next turned to an activated heterocyclic chloride containing sulphur in the ring, which we hoped eventually to remove by degradation with Raney nickel. 2-Chloro-4-phenyl-1,3-thiazole [17] (29) failed to yield the quaternary salt (31) with 3-hydroxypyridine. The unreactivity towards nucleophiles is consistent with a relatively high electron density [18] at C-2. To make C-2 of (29) more susceptible to nucleophilic attack, a nitro-group was introduced into (29); however, 2-chloro-5-nitro-4-(4-nitrophenyl)-1,3-thiazole [17] (30) also failed to produce the salt (32) with 3-hydroxypyridine.

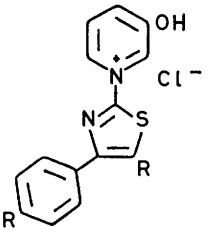


(25) R = CH_2SPh; X = Cl
(26) R = CH_2SPh; X = ClO_4
(27) R = CH_2SO_2Ph; X = ClO_4
(28) R = $CH_2-\overset{+}{S}(Me)-Ph$; X = $2ClO_4$

N-Thiadiazoyl Substituent.—5-Chloro-3-phenyl-1,2,4-thiadiazole [19] (33) with 3-hydroxypyridine gave a quaternary salt (14) which decomposed during work-up.



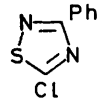
(29) R = H
(30) R = NO_2



(31) R = H
(32) R = NO_2

The i.r. spectrum of (35) exhibited a band at 1 740 cm^{-1} characteristic [20] of a saturated ketone and at 1 650 cm^{-1} for the enamine C=C. The n.m.r. spectrum confirms the structure of (35). In the olefinic region, the low field doublet at δ 6.50 was assigned to 4-H and irradiation at this frequency simplified the absorption of 5-H (δ 5.10). Irradiation of 5-H identified 6-H as the doublet of triplets at δ 3.15. The high-field nature of 6-H is characteristic of a *syn*-dimer,[20] while the W-type long-range coupling (2 Hz) between 2-H and 6-H is consistent with the *exo*-configuration for (35). The ethoxy-group at C-8 was identified by the high-field quartet and triplet at δ 3.60

and 1.00 respectively. The remaining high-field doublet (δ 2.60) and double doublet (δ 2.85) were assigned to the methylene protons, 9-H.



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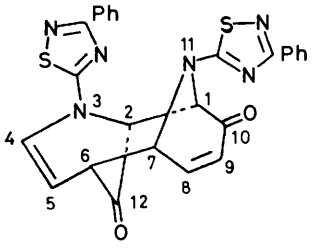

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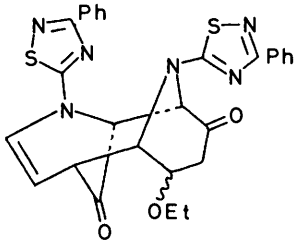
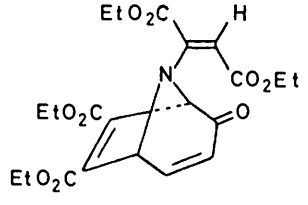


(35)

The *in situ*-generated betaine (10) underwent $4\pi + 2\pi$ thermal additions with acrylonitrile to yield the expected [21] *endo*-adduct (22) while with methyl acrylate both *exo*- and *endo*-adducts (20) and (23) were isolated. Styrene reacted with (10) to produce the single *endo*-adduct (24) as expected.[22] All four new adducts show characteristic αβ-unsaturated carbonyl stretching frequencies in their i.r. spectra. In the n.m.r. spectra (Table) of all four cycloadducts, the 1-H signal appears as a doublet ($J_{1,7\text{-}exo}$ 8.0 Hz) broadened by long-range coupling ($J_{1,3}$ 2.0 Hz) and that of 5-H as a doublet ($J_{4,5}$ 6.0 Hz) for the *exo*-isomer (20) but as a triplet ($J_{4,5}$ 6.0, $J_{5,6\text{-}exo}$ 6.0 Hz) for the *endo*-isomers (22)—(24).

N-Phenylmaleimide and diethyl acetylenedicarboxylate (DEAD) failed to react with the betaine (10). However in the case of DEAD, a 2 : 1 adduct (36), m.p. 287—288 °C, *m/e* 435 of 3-hydroxypyridine was isolated. The initial 1 : 1 adduct (37) evidently underwent [23] a Michael addition with a further mole of DEAD [*cf.* phthalazin-1(2*H*)-one [24]]. The i.r. spectrum shows the presence of an αβ-unsaturated ketone [ν(CO) 1 680 cm^{-1}] and ester [ν(CO) 1 730 cm^{-1}], while the n.m.r. spectrum (Table) shows the presence of four methyl groups at δ 1.30.



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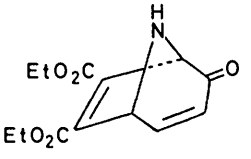
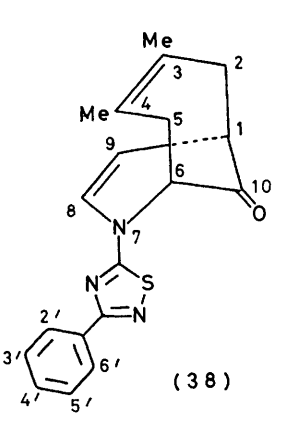


(37)

2,3-Dimethylbuta-1,3-diene reacted with the betaine (10) to yield a single isomer (38), m.p. 139—140 °C. The i.r. spectrum showed a saturated carbonyl [ν(C=O) 1 720 cm^{-1}] and enamine double-bond [ν(C=C–N) 1 650 cm^{-1}]. The n.m.r. spectrum (Table) demonstrated the *endo*-configuration (38) for the cycloadduct since the coupling ($J_{5\text{-}exo,6}$ 8 Hz) is characteristic [21] of *endo*-cycloadducts of this type having a dihedral angle ϕ 6-H, 5-*exo*-H ≈ 25°. The carbonyl stretching frequency of 1 720 cm^{-1} supports the *endo*-configuration since *exo*-adducts [21] absorb at 1 740 cm^{-1}. The initial $4\pi + 6\pi$ addition of the diene to the betaine (10) favours *exo*-addition to yield the *exo*-isomer (39) which undergoes a conformational flip to the thermodynamically more stable *endo*-isomer (38).[21]

Attempts to cleave the thiadiazole ring of the cycloadduct (24) by catalytic hydrogenolysis (Raney-Ni),[25] acid hydrolysis (HCl–EtOH), and by methylation (MeI and MeI–HI) [26] followed by Hofmann degradation were all unsuccessful.

3-*Hydroxypyridine* N-*Oxide*.—The *N*-oxide [27] (40) did not react with olefinic dipolarophiles. However, diethyl acetylenedicarboxylate readily reacts with the *N*-oxide to yield the isomeric mixture (44) and (45) (Scheme). The i.r. spectrum shows OH stretching at 3 535 (free OH) and 3 480 cm^{-1} (hydrogen bonded OH),



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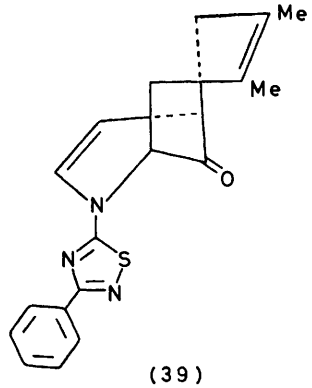


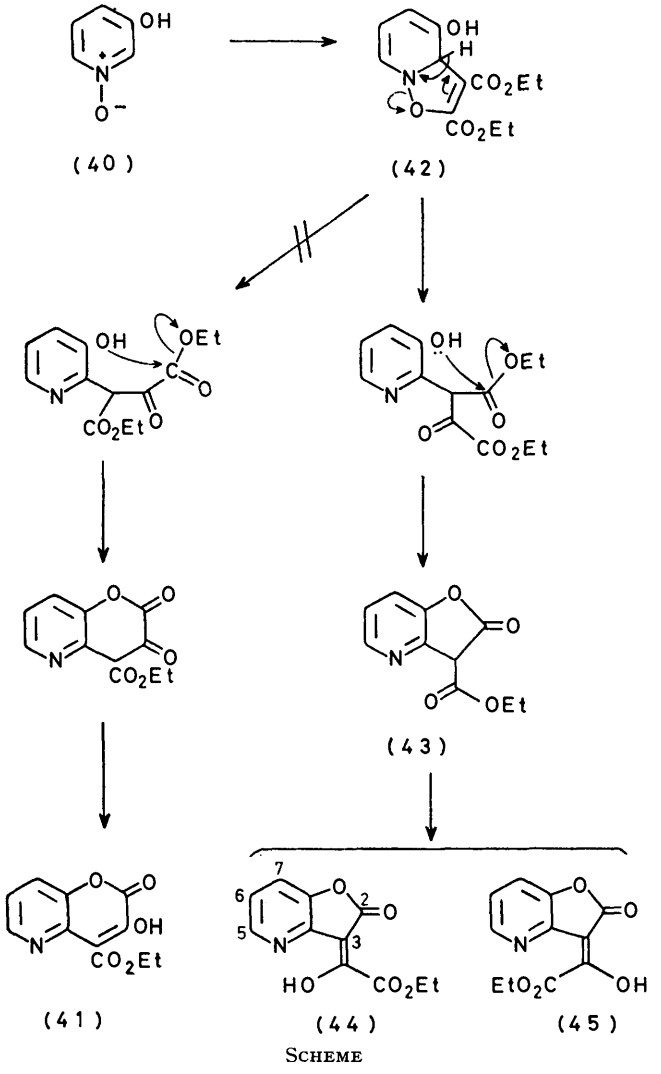
(39)

ester carbonyl stretching at 1 740 cm^{-1}, and a band at 1 770 cm^{-1} typical [28] of a γ-lactone carbonyl group. The n.m.r. spectrum supports the structure. The heteroaromatic protons, 5-H and 7-H, appear as double doublets at δ 7.65 and 8.20 respectively, while 6-H appears as a double doublet at δ 7.10. The ethoxy-group shows characteristic quartet and triplet at δ 4.40 and 1.35 respectively.

The isomers (44) and (45) are thought to arise *via* the initially formed cycloadduct (42) (*cf.* reaction of isoquinoline *N*-oxide and propiolic esters [29]). Ring-opening and rearomatisation followed by cyclisation and tautomeric equilibration *via* (43) lead to (44) and (45) (Scheme). The isomeric coumarin structure (41) is precluded in view of the absence of characteristic [2] coumarin-like absorption in the i.r. spectrum (*cf.* coumarin lactone ketone *ca.* 1 700 cm^{-1}).[30]

N-*Benzylidineamino-substituent*.—Numerous methods are available for the fission of the N–N bond of a hydr-

azino-group. We therefore turned to *N*-aminated pyridinium betaines. Amination of 3-hydroxypyridine



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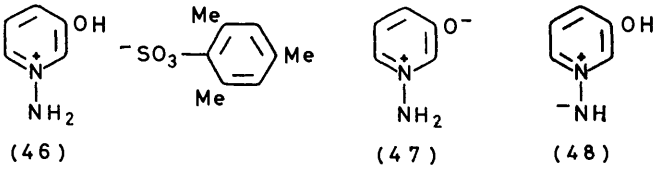
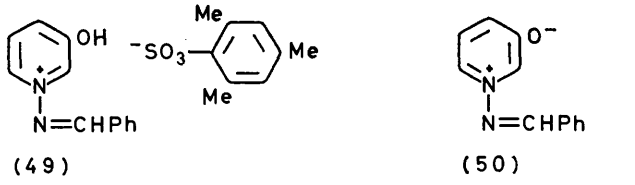
(*cf.* pyridine [31]) with *O*-mesitylenesulphonylhydroxylamine [32] readily produced 1-amino-3-hydroxypyridinium mesitylenesulphonate (46), m.p. 185—186 °C. 1-Amino-3-oxidopyridinium betaine (47) or its tautomer (48) (generated *in situ*) proved unreactive towards acrylate dipolarophiles. Activation of the heteroaromatic ring was achieved by converting the *N*-aminopyridinium salt (46) into the Schiff's base (49), m.p. 140—141 °C, with benzaldehyde.

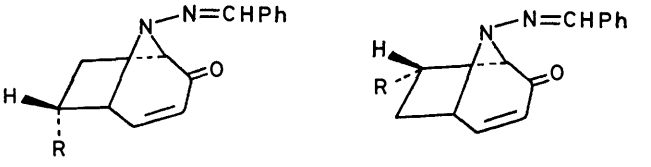
1-(*N*-Benzylidineamino)-3-oxidopyridinium (50) (generated *in situ*) underwent $4\pi + 2\pi$ thermal additions with acrylonitrile to yield the expected [21] 6-*endo*-adduct (51) together with the 7-*endo*-adduct (54) [*cf.* 1-(2,4-dinitrophenyl)-3-oxidopyridinium [9]]. Methyl acrylate and styrene both reacted with betaine (50) to produce single 6-*endo*-adducts (52) and (53) respectively. *N*-Phenylmaleimide yielded a mixture of the *endo*- and *exo*-cycloadducts (55) and (56). All six cycloadducts exhibited characteristic αβ-unsaturated carbonyl stretching frequencies in their i.r. spectra. In the n.m.r. spectra (Table) of all five *endo*-adducts, the 1-H signal appears as a doublet ($J_{1,7\text{-}exo}$ 7.0—8.0 Hz) and that of 5-H as a triplet ($J_{4,5}$ 5.0—6.0 Hz, $J_{5,6\text{-}exo}$ 6.0 Hz) while in the spectrum of the *exo*-dicarboximide (56) the 5-H signal exhibits a doublet ($J_{4,5}$ 5.0 Hz).

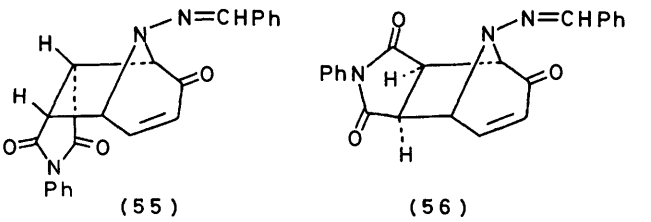
Work with the *N*-benzylidineamino-substituent was not pursued in view of the moderate yields and the multistep procedure needed to introduce and eliminate this substituent.

N-(*Tetrafluoropyridyl*) *Substituents.*—*N*-Aryl-3-oxidopyridinium betaines in which the rings assume coplanarity are highly reactive [33] towards dimerisation and cycloaddition. Strongly electron-withdrawing substituents *ortho* and *para* to the *N*-aryl group of *N*-aryl-3-oxidopyridinium betaines should [33] increase reactivity providing secondary steric effects are small. Fluorine is strongly electron-withdrawing [34] and has low volume.[35] Pentafluoropyridine is planar [36] and readily reacts [37] with nucleophiles at the 4-position. We find that 3-









hydroxypyridine with pentafluoropyridine gives the quaternary salt (57), m.p. 171—172 °C, but in low yield

(11%). Pentafluoropyridine and pyridine give [38] polypyridinium salts which may explain the poor yield. The i.r. spectrum of (57) showed fluorinated ring vibrations [36] (1 460 cm^{-1}) and C–F stretching [36] (970 and 980 cm^{-1}).

N-(4-*Pyridyl*) *Substituent.*—Schmid and Wolkoff [39]

Proton n.m.r. spectra (δ values) of cycloadducts [ab]

Chemical shifts

Proton(s)	(18)	(19)	(20)	(21)	(22)	(23)	(24)	(36)	(38)
1	3.88—4.02 [c]	3.80 [c]	4.65 [c]	3.77 [c]	4.53 [c]	4.55 [c]	4.51 [c]	4.85 [c]	3.35 [d]
2-*endo*									2.30 [d]
2-*exo*									2.30 [d]
3	6.16 [e]	6.05 [e]	6.00 [e]	6.06 [e]	6.23 [e]	6.10 [e]	5.94 [e]	5.65 [e]	
4	7.20 [e]	6.94 [e]		6.98 [e]		7.20 [e]	6.69 [e]	7.30 [e]	
5	3.88—4.02 [c]	4.45 [c]	5.15 [c]	4.17 [e]	5.13 [f]	5.10 [f]	4.91 [f]	4.85 [c]	
5-*endo*									3.35 [d]
5-*exo*									2.30 [d]
6									4.75 [c]
6-*endo*	3.56 [e]		3.75 [e]						
6-*exo*				2.44—3.14	3.50 [g]	3.70 [g]	3.93 [g]		
7-*endo*	2.10 [e]	1.86 [e]	2.15 [e]	2.09 [e]	2.17 [e]	2.25 [e]	1.98 [e]		
7-*exo*	2.42—3.12	2.88 [g]	3.00 [g]	2.44—3.14	2.98 [g]	2.80 [g]	2.87 [g]		
8									6.55 [e]
9									4.90 [e]

Proton(s)	(51)	(52)	(53)	(54)	(55)	(56)	(60)	(61)	(62)
1	4.38	4.40 [e]	4.56 [e]	4.55 [e]	4.82 [e]	4.73 [e]	4.30 [e]	4.42 [e]	5.20 [e]
3	6.25 [e]	6.00 [e]	6.10 [e]	6.20 [e]	6.22 [e]	6.07 [e]	5.77 [e]	5.82 [e]	6.13
4	7.53 [e]	7.03 [e]	6.70 [e]	7.52 [e]	7.62 [e]	7.52 [e]	6.94 [e]	6.55 [e]	7.26 [e]
5	4.70 [f]	4.77 [f]	4.80 [f]	4.54 [f]	5.16 [e]	5.06 [f]	4.77 [f]	4.73 [f]	5.47 [f]
6-*endo*				2.20 [e]		3.78 [e]			
6-*exo*	3.50 [h]	3.62 [h]	4.06 [h]	2.76 [g]	4.20 [e]		3.53 [h]	3.86 [h]	4.30 [e]
7-*endo*	2.00 [e]	2.10 [e]	2.05 [e]			3.50 [e]	2.02 [e]	2.12 [e]	
7-*exo*	2.86 [g]	2.67 [g]	2.92 [g]	3.60 [g]	4.24 [f]		2.60 [g]	2.80 [g]	3.32 [e]

Proton(s)	(18)	(19)	(20)	(21)	(22)	(23)	(24)	(36)	(38)
2′			8.20 [i]		8.15 [i]	8.20 [i]	8.05 [i]		8.20 [i]
3′			7.30 [i]		7.40 [i]	7.45 [i]	7.25 [i]		7.40 [i]
4′			7.30 [i]		7.40 [i]	7.45 [i]	7.25 [i]		7.40 [i]
5′			7.30 [i]		7.40 [i]	7.45 [i]	7.25 [i]		7.40 [i]
6′			8.20 [i]		8.15 [i]	8.20 [i]	8.05 [i]		8.20 [i]
CH_2		4.12 [e]						4.30 [i]	
CH_3-C								1.30 [i]	1.60 [j]
									1.70 [j]
CH_3N	3.04 [j]			2.84 [j]					
CH_3-O		3.65 [j]	3.75 [j]			3.70 [j]			
RC*H*=CR_2								7.30 [j]	
C_6H_5		7.07—7.48 [i]					7.25 [i]		

Proton(s)	(51)	(52)	(53)	(54)	(55)	(56)	(60)	(61)	(62)
2′							6.38 [e]	6.42 [e]	6.86 [e]
3′							8.08 [e]	8.08 [e]	8.18 [e]
4′									
5′							8.08 [e]	8.08 [e]	8.18 [e]
6′							6.38 [e]	6.42 [e]	6.86 [e]
CH_3-O		3.68 [j]					3.53 [j]		
–N=C*H*	7.77 [j]	7.64 [j]	7.66 [j]	7.84 [j]	7.76 [j]	7.77 [j]			
C_6H_5	7.16—7.68 [d]	7.40 [d]	7.08—7.70 [d]	7.16—7.80 [d]	6.80—7.68 [d]	7.06—7.58 [d]		7.12 [d]	7.26 [d]

Coupling constants (Hz)

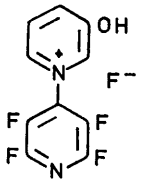
Coupling	(18)	(19)	(20)	(21)	(22)	(23)	(24)	(36)	(38)
1,3	1.0	1.5	2.0	1.0	2.0	2.0	2.0	2.0	
1,7-*exo*	8.0	9.0	8.0	9.0	8.0	8.0	8.0		
3,4	10.0	10.0	10.0	13.0	10.0	10.0	10.0	10.0	
4,5	5.0	5.0	6.0	4.0	6.0	6.0	6.0	8.0	
5,6-*exo*				7.0	6.0	6.0	6.0		
5-*exo*, 6									8.0
6-*endo*,7-*endo*	9.0		10.0						
6-*endo*, 7-*exo*			8.0						
6-*exo*, 7-*endo*				4.0	8.0	8.0	8.0		
6-*exo*, 7-*exo*				11.0	10.0	10.0	10.0		
6,8									2.0

[a] Me_4Si as internal standard. [b] In $CDCl_3$. [c] Doublet. [d] Complex. [e] Double doublet. [f] Triplet. [g] Quartet of doublets. [h] Doublet of triplets. [i] Multiplet. [j] Singlet.

TABLE (*Continued*)

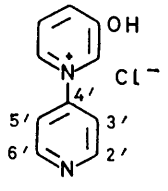
Coupling constants (Hz) Coupling	(51)	(52)	(53)	(54)	(55)	(56)	(60)	(61)	(62)
1,3	1.0	1.0	1.0	1.0	1.5	1.5	1.0	1.0	1.0
1,7-*exo*	8.0	8.0	8.0	7.0	8.0		8.0	8.0	8.0
3,4	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
4,5	6.0	6.0	6.0	5.0	5.0	5.0	5.0	4.0	6.0
5,6-*exo*	6.0	6.0	6.0	6.0	6.0		6.0	6.0	6.0
6-*endo*, 6-*exo*				13.0					
6-*endo*, 7-*endo*						8.0			
6-*endo*, 7-*exo*				4.0					
6-*exo*, 7-*endo*	6.0	6.0	6.0				7.0	6.0	10.0
6-*exo*, 7-*exo*	10.0	10.0	10.0	10.0	8.0		10.0	10.0	
7-*endo*, 7-*exo*	14.0	14.0	14.0				14.0	16.0	
2′,3′							5.0	6.0	6.0
5′,6′							5.0	6.0	6.0

have shown that 4-pyridyloxy-ethers are readily cleaved (*via* their *N*-methyl quaternary salts) under essentially neutral conditions. Therefore we decided to prepare the

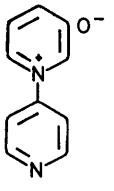


(57)

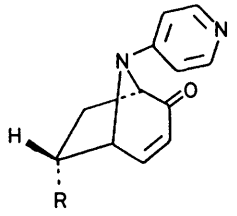
corresponding *N*-(4-pyridyl) cycloadducts. 3-Hydroxypyridine with 4-chloropyridine readily afforded the



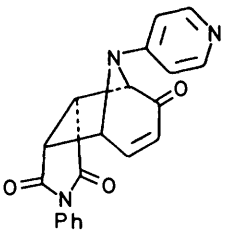
(58)



(59)



(60) R = CO_2Me
(61) R = Ph



(62)

quaternary salt (58) as colourless needles, m.p. 226—227 °C. 3-Oxido-1-(4-pyridyl)pyridinium (59) generated *in situ* underwent $4\pi + 2\pi$ thermal additions with methyl acrylate, styrene, and *N*-phenylmaleimide to yield single *endo*-cycloadducts (60), (61), and (62) respectively. The i.r. spectra of all three adducts exhibit αβ-unsaturated carbonyl stretching frequencies. The n.m.r. spectra (Table) of all three adducts are indicative of *endo*-adducts for which the signals of 1-H and 5-H appear as a doublet and a triplet respectively. The signals for the 4-pyridyl protons are characteristic of an A_2B_2 system. The 4-pyridyl group as *N*-substituent offers considerable promise and further work is planned.

General Conclusions.—With one possible exception, none of the *N*-substituents reported in this paper fulfils all the aims of being easy to put on, highly activating towards cycloaddition, and easy to remove. However, the 4-pyridyl group, and certain other groups with which we are now working do show considerable promise for a general route for the preparation of tropones and tropolones.

EXPERIMENTAL

The m.p.s were determined with a Reichert apparatus. The spectra were recorded with a Perkin-Elmer 257 grating i.r. spectrophotometer, a Hitachi–Perkin-Elmer RMU-6E mass spectrometer, and a Varian HA-100 n.m.r. spectrometer. Compounds were purified until they were observed as single spots on t.l.c. using Kieselgel GF 254 (Type 60). Isomeric pairs of adducts were separated by preparative thick layer chromatography (prep. t.l.c.) using Kieselgel PF 254.

1-(NN-*Dimethylcarbamoyl*)-3-*hydroxypyridinium Chloride* (13).—3-Hydroxypyridine (0.96 g, 0.01 mol) and *NN*-dimethylcarbamoyl chloride (1.1 g, 0.01 mol) in MeOH (40 ml) were allowed to react at room temperature for 18 h. The solvent was evaporated *in vacuo* to yield the salt (13) as an oil (2.2 g) which was not further purified, $\nu_{max.}$ (neat) 3 500—3 350 (OH), 2 500, 1 730 (unchanged carbamoyl chloride, CO [40]), and 1 690 cm^{-1} (urea, CO).

8-(NN-*Dimethylcarbamoyl*)-2-*oxo*-8-*azabicyclo*[3.2.1]*oct*-3-*ene*-6-endo- *and* -exo-*carbonitrile* (21) *and* (18).—A solution of the salt (13) (2.2 g, 1.08 × 10^{-2} mol), acrylonitrile (15.3 g, 0.29 mol), and Et_3N (5.10 g, 7 ml, 0.05 mol) in $(CH_2)_4O$ (40 ml) were heated under reflux for 8 h. The reaction mixture was evaporated to dryness *in vacuo* to yield an oil which was further purified by prep. t.l.c. [light petroleum–EtOAc(1 : 1)]. The endo-*isomer* (21) (35 mg, 1.2%) was isolated as an oil (Found: C, 61.2; H, 5.9; N, 19.9. $C_{11}H_{13}N_3O_2$ requires C, 60.3; H, 5.9; N, 19.2%); $\nu_{max.}$ (film) 1 720 (ester, CO) and 1 690 cm^{-1} (αβ-unsat. ketone, CO); *m/e* 166.072 8 (19.33%, betaine, 166.16 calc.). The exo-*isomer* (18) (30 mg, 1.0%) was also obtained as a mobile oil [$\nu_{max.}$ (film) 1 720 (ester CO) and 1 690 cm^{-1} (α,β-unsat. ketone, CO] which was not further characterised. Preparative work on adducts (18) and (21) was halted in view of the recent disclosures * of the potent carcinogenic nature of *NN*-dimethylcarbamoyl chloride.

1-*Phenylthiomethylpyridinium Perchlorate* (26).—Chloromethyl phenyl sulphide (8.0 g, 5 × 10^{-2} mol) and pyridine (4.0 g, 5 × 10^{-2} mol) were heated on a steam-bath for 15

* By a circular dated 8th June, 1976, from Koch–Light Laboratories Ltd.

min. Anhydrous Et_2O was added and the precipitated 1-phenylthiomethylpyridinium chloride (25) collected. An aqueous solution of the chloride was treated with saturated sodium perchlorate to yield the *perchlorate salt* (26) (10.6 g, 70%) as white needles, m.p. 68—69 °C (Me_2CO–Et_2O) (Found: C, 48.0; H, 3.9; N, 4.2. $C_{12}H_{12}ClNO_4S$ requires C, 47.7; H, 4.0; N, 4.6%).

1-*Phenylsulphonylmethylpyridinium Perchlorate* (27).—1-Phenylthiomethylpyridinium perchlorate (26) (5.0 g, 1.65×10^{-2} mol) and H_2O_2 (15 g of 30%) in HOAc (15 ml) were set aside in the dark for 4 days. The white precipitate was collected and washed with water (20 ml) to give the *title compound* (27) (4.5 g, 81.4%) as white needles (EtOH), m.p. 202—204 °C (Found: C, 42.9; H, 3.8; N, 4.5. $C_{12}H_{12}ClNO_6S$ requires C, 43.2; H, 3.6; N, 4.2%).

(*Methylphenylsulphonio*)*methylpyridinium Diperchlorate* (28).—1-Phenylthiomethylpyridinium perchlorate (26) (5.0 g, 1.65×10^{-2} mol) in CH_2Cl_2 (20 ml) was treated with MeI (3.5 g, 2.4×10^{-2} mol) in the presence of silver perchlorate–acetonitrile complex [12] (1 : 4, 4.0 g). After 4 days, the precipitate of silver halide was filtered, washed with MeCN (10 ml) and discarded. The filtrate was evaporated to dryness under vacuum to yield the *diperchlorate* (28) (4.2 g, 60.9%) as colourless shining plates, m.p. 158—160 °C (Found: C, 37.4; H, 3.5; N, 3.2. $C_{13}H_{15}Cl_2NO_8S$ requires C, 37.5; H, 3.6; N, 3.4%).

Preparation of 3-*Hydroxy*-1-(*phenylthiomethyl*)*pyridinium Chloride* (15).—A solution of 3-hydroxypyridine (9.6 g, 0.1 mol) and chloromethyl phenyl sulphide (16 g, 0.1 mol) in MeCN (95 ml) was heated under reflux for 9 h. The precipitate when recrystallised from EtOH–EtOAc gave the *salt* (15) (20 g, 78.8%) as colourless needles, m.p. 171—172 °C (Found: C, 56.7; H, 5.0; Cl, 13.8; N, 5.5; S, 12.6. $C_{12}H_{12}ClNOS$ requires C, 56.8; H, 4.8; Cl, 13.9; N, 5.5; S, 12.6%); $\nu_{max.}$ (Nujol) 1 580 (Ph) and 1 640 cm^{-1} (C=C–N); $\delta(D_2O)$ 6.25 (2 H, s, CH_2), 7.85 (5 H, s, Ph), and 8.20—8.70 (4 H, complex, C_5H_4N).

3-*Hydroxy*-1-(*phenylsulphonylmethyl*)*pyridinium Chloride* (16).—A solution of 3-hydroxy-1-(phenylthiomethyl)pyridinium chloride (15) (5 g, 1.97 mol) in glacial HOAc (10 ml) was treated with H_2O_2 (30%, 15 ml) in glacial HOAc (15 ml) to give the *salt* (16) (5 g, 88.5%) as white needles, m.p. 242—244 °C (from EtOH–Et_2O) (Found: C, 50.4; H, 4.4; N, 4.9. $C_{12}H_{12}ClNO_3S$ requires C, 50.4; H, 4.2; N, 4.9%); $\nu_{max.}$ (Nujol) 1 320 (SO_2) and 1 150 cm^{-1}; $\delta(D_2O)$ 6.40 (2 H, s, CH_2), 7.90 (5 H, s, Ph), and 8.20—8.60 (4 H, complex, C_5H_4N).

3-*Hydroxy*-1-(*phenylsulphonylmethyl*)*pyridinium Perchlorate* (17).—An aqueous solution of 3-hydroxy-1-(phenylthiomethyl)pyridinium chloride (5 g, 1.97 mol) was treated with aqueous saturated $NaClO_4$. The semisolid precipitate (5 g) was collected and oxidised with H_2O_2 (30%, 15 ml) in glacial HOAc (15 ml). The white amorphous solid was further treated with aqueous saturated $NaClO_4$ to give the *perchlorate* (17) (5.2 g, 75.3%) as white prisms, m.p. 222—224 °C (from EtOH–Et_2O) (Found: C, 41.1; H, 3.6; N, 4.0. $C_{12}H_{12}ClNO_7S$ requires C, 41.2; H, 3.5; N, 4.0%); $\nu_{max.}$ (Nujol) 1 320 (SO_2) and 1 150 cm^{-1}; $\delta(D_2O)$ 6.40 (2 H, s, CH_2), 7.90 (5 H, s, Ph), and 8.20—8.60 (4 H, complex, C_5H_4N).

Methyl 2-*Oxo*-8-*phenylthiomethyl*-8-*azabicyclo*[3.2.1]*oct*-3-*ene*-6-exo-*carboxylate* (19).—A well-stirred suspension of 3-hydroxy-1-(phenylthiomethyl)pyridinium chloride (15) (5.0 g, 0.02 mol), methyl acrylate (30 ml), and quinol (0.1 g) was heated under reflux. Et_3N (5 ml) was added dropwise during 30 min. After 12 h, the mixture was cooled, filtered, and evaporated to dryness *in vacuo*. The residual oil when recrystallised gave the *carboxylate* (19) (0.213 g, 3.6%) as yellow prisms, m.p. 104—106 °C (EtOH) (Found: C, 63.1; H, 5.7; N, 4.6; S, 10.6. $C_{16}H_{17}NO_3S$ requires C, 63.4; H, 5.7; N, 4.6; S, 10.6%); $\nu_{max.}$ (Nujol) 1 675 (αβ-unsat. ketone, CO) and 1 730 cm^{-1} (ester, CO).

8-*Ethoxy*-3,11-*bis*-(3-*phenyl*-1,2,4-*thiadiazol*-5-*yl*)-3,11-*diazatricyclo*[5.3.1.$1^{2,6}$]*dodeca*-4-*ene*-10,12-*dione* (35).—5-Chloro-3-phenyl-1,2,4-thiadiazole (1 g, 0.005 mol) and 3-hydroxypyridine (0.96 g, 0.01 mol) in $(CH_2)_4O$ (50 ml) and EtOH (5 ml) were heated under reflux with stirring for 48 h. The reaction mixture when evaporated *in vacuo* yielded a residue which was purified by prep. t.l.c. (benzene–EtOAc 9 : 1). The dimer (35) (50 mg, 3.6%) was isolated as colourless prisms, m.p. 210—212 °C (EtOH) (Found: C, 60.7; H, 4.3; N, 14.9. $C_{28}H_{24}N_6O_3S_2$ requires C, 60.4; H, 4.4; N, 15.1%), $\nu_{max.}$ (Nujol) 1 740 (sat. ketone, CO) and 1 650 cm^{-1} (enamine, C=C); $\delta(CDCl_3)$ 1.00 (t, 3 H, Me, J_{CH_3,CH_2} 8 Hz), 2.60 (d, 1 H, 9a-H, $J_{9a,9b}$ 16 Hz), 2.85 (dd, 1 H, 9b-H, $J_{9b,8}$ 4 Hz), 3.15 (dt, 1 H, 6-H $J_{2,6} = J_{6,7} = 2$ Hz), 3.60 (q, 2 H, OCH_2), 4.80 (m, 4 H, 1-H, 2-H, 7-H, 8-H), 5.10 (dd, 1 H, 5-H, $J_{5,6}$ 6 Hz), 6.50 (d, 1 H, 4-H, $J_{4,5}$ 8 Hz), 7.40 (m, 3 H, 3′-H, 4′-H, 5′-H), 8.05 (m, 2 H, 2′-H, 6′-H), and 8.35 (m, 2 H, 2′-H, 6′-H); *m/e* 556.

2-*Oxo*-8-(3-*phenyl*-1,2,4-*thiadiazol*-5-*yl*)-8-*azabicyclo*[3.2.1]-*oct*-3-*ene*-6-endo-*carbonitrile* (22).—A solution of 3-hydroxypyridine (0.5 g, 0.005 mol), 5-chloro-3-phenyl-1,2,4-thiadiazole (0.5 g, 0.002 5 mol), and hydroquinone (0.1 g) in acrylonitrile (20 ml) was heated under reflux for 48 h. The reaction mixture was then evaporated *in vacuo* to yield a brown gum which was chromatographed (light petroleum–EtOAc, 4 : 1) to yield the *cycloadduct* (22) (0.1 g, 11%) as white prisms, m.p. 203—204 °C (EtOH) (Found: C, 62.2; H, 4.1; N, 18.4. $C_{16}H_{12}N_4OS$ requires C, 62.3; H, 3.9; N, 18.2%); $\nu_{max.}$ ($CHBr_3$) 1 680 (unsat. CO) and 1 600 cm^{-1} (C=C); $\lambda_{max.}$ (EtOH) 246 nm (log ε 4.45); *m/e* 308 (97%).

Methyl 2-*Oxo*-8-(3-*phenyl*-1,2,4-*thiadiazol*-5-*yl*)-8-*azabicyclo*[3.2.1]*oct*-3-*ene*-6-endo- *and* -6-exo-*carboxylate* (23) *and* (20).—A solution of 3-hydroxypyridine (0.5 g, 0.005 mol), 5-chloro-3-phenyl-1,2,4-thiadiazole, methyl acrylate (0.5 g, 0.002 5 mol) (15 ml), and hydroquinone (0.1 g) in $(CH_2)_4O$ (15 ml) was heated under reflux for 3 days. The reaction mixture was evaporated *in vacuo* to give a brown gum which was chromatographed (light petroleum–EtOAc, 4 : 1) to yield the endo-*adduct* (23) (0.14 g, 20%) as colourless needles, m.p. 170—171 °C (EtOH) (Found: C, 59.5; H, 4.6; N, 12.2. $C_{17}H_{15}N_3O_3S$ requires C, 59.8; H, 4.4; N, 12.3%); $\nu_{max.}$ ($CHBr_3$) 1 730 (ester CO) and 1 680 cm^{-1} (unsat. CO); $\lambda_{max.}$ (MeCN) 257 nm (log ε 4.69); *m/e* 341 (50%). The exo-*adduct* (20) (0.15 g, 20%) was isolated as colourless needles, m.p. 95—96 °C (EtOH) (Found: C, 59.7; H, 4.6; N. 12.2. $C_{17}H_{15}N_3O_3S$ requires C, 59.8; H, 4.4; N, 12.3%); $\nu_{max.}$ ($CHBr_3$) 1 740 (ester, CO) and 1 680 cm^{-1} (unsat. CO); $\lambda_{max.}$ (MeCN) 235 nm (log ε 4.45); *m/e* 341 (57%).

8-(3-*Phenyl*-1,2,4-*thiadiazol*-5-*yl*)-6-endo-*phenyl*-8-*azabicyclo*[3.2.1]*oct*-3-*en*-2-*one* (24).—A solution of 3-hydroxypyridine (1 g, 0.01 mol), 5-chloro-3-phenyl-1,2,4-thiadiazole (1 g, 0.005 mol), styrene (20 ml), and hydroquinone (0.1 g) was heated under reflux for 80 h. The reaction mixture was evaporated to dryness *in vacuo* to a brown gum from which the *cycloadduct* (24) (0.6 g, 50%) crystallised as prisms, m.p. 140—141 °C (EtOH) (Found: C, 70.4; H, 5.0; N, 11.4. $C_{21}H_{17}N_3OS$ requires C, 70.2; H, 4.8; N, 11.7%);

$\nu_{max.}$ ($CHBr_3$) 1 690 (unsat. CO) and 1 600 cm^{-1} (C=C); $\lambda_{max.}$ (EtOH) 247 nm (log ε 4.49); *m/e* 359 (22%).

Diethyl 8-(trans-1,2-*Bisethoxycarbonylvinyl*)-8-*azabicyclo*-[3.2.1]*octa*-3,6-*diene*-6,7-*dicarboxylate* (36).—A solution of 3-hydroxypyridine (0.5 g, 0.005 mol), 5-chloro-3-phenyl-1,2,4-thiadiazole (0.5 g, 0.002 5 mol), diethyl acetylenedicarboxylate (5 ml), and hydroquinone (0.1 g) was heated under reflux for 12 h. The red reaction mixture was evaporated *in vacuo* to give a brown gum. Unchanged acetylene was removed by chromatography over silica gel. Elution with light petroleum–EtOAc (1 : 1) followed by prep. t.l.c. (light petroleum–EtOAc, 1 : 1) gave the *cycloadduct* (36) (0.15 g, 12%) as red yellow prisms, m.p. 287—288 °C (EtOH) (Found: N, 3.3. $C_{21}H_{25}NO_9$ requires N, 3.2%); $\nu_{max.}$ ($CHBr_3$) 1 730 (ester CO) and 1 680 cm^{-1} (unsat. CO); *m/e* 435 (10%).

3,4-*Dimethyl*-7-(3-*phenyl*-1,2,4-*thiadiazol*-5-*yl*)-7-*aza*-*bicyclo*[4.3.1]*deca*-3,8-*dien*-10-*one* (38).—A solution of 3-hydroxypyridine (0.5 g, 0.005 mol), 5-chloro-3-phenyl-1,2,4-thiadiazole (0.5 g, 0.002 5 mol), 2,3-dimethylbuta-1,3-diene (5 ml), and hydroquinone (0.1 g) in $(CH_2)_4O$ (15 ml) was heated under reflux for 24 h. The reaction mixture was evaporated to dryness *in vacuo* to give a brown gum which was purified by prep. t.l.c. (light petroleum–EtOAc, 6 : 1) to give the *cycloadduct* (38) (0.2 g, 25%) as colourless prisms, m.p. 139—140 °C (EtOH) (Found: C, 67.4; H, 5.7; N, 12.4. $C_{19}H_{19}N_3OS$ requires C, 67.6; H, 5.7; N, 12.5%); $\nu_{max.}$ ($CHBr_3$) 1 720 (sat. CO) and 1 650 cm^{-1} (N–C=C); $\lambda_{max.}$ (MeCN) 257 nm (log ε 4.53); *m/e* 337 (45%).

Reaction of 3-*Hydroxypyridine* N-*Oxide with Diethyl Acetylenedicarboxylate*.—3-Hydroxypyridine *N*-oxide (0.5 g, 0.005 mol) and diethyl acetylenedicarboxylate (5 ml) in $(CH_2)_4O$ (15 ml) and chlorobenzene (15 ml) were heated under reflux for 24 h. The reaction mixture was evaporated to dryness *in vacuo*, and the residue washed with Et_2O (3 × 10 ml). The brown solid so obtained (0.5 g, 50%) was crystallised from EtOH to give *ethyl* 2-(2-*oxofuro*[3,2-b]-*pyridin*-3-*ylidene*)*glycolate* (44/45) as greenish yellow needles, m.p. 195—199 °C (Found: C, 56.1; H, 4.0; N, 5.8. $C_{11}H_9NO_5$ requires C, 56.2; H, 3.8; N, 6.0%); $\nu_{max.}$ ($CHBr_3$) 3 535 and 3 480 (O–H), 1 770 (lactone, C=O), and 1 740 cm^{-1} (ester, C=O); $\lambda_{max.}$ ($CHCl_3$) 375 (log ε 4.17) and 285 nm (4.08); δ($CDCl_3$) 8.20 (1 H, dd, 7-H, $J_{5,6}$ 6.0 Hz, $J_{5,7}$ 2.0 Hz), 7.65 (1 H, dd, 5-H, $J_{6,7}$ 8.0 Hz), 7.10 (1 H, dd, 6-H), 4.40 (2 H, q, CH_2, *J* 8.0 Hz), and 1.35 (3 H, t, Me) ; *m/e* 235 (21%).

1-*Amino*-3-*hydroxypyridinium Mesitylenesulphonate* (46).—3-Hydroxypyridine (1.6 g, 1.68 × 10^{-2} mol) was added to a solution of *O*-mesitylsulphonylhydroxylamine [32] (3.8 g, 1.78 × 10^{-2} mol) in CH_2Cl_2 and stirred for 4 min at room temp. Et_2O (30 ml) was added to precipitate the *mesitylene*-*sulphonate* (46) (2.5 g, 47.9%) as colourless needles, m.p. 185—186 °C (MeOH–EtOAc) (Found: C, 54.1; H, 5.9; N, 9.1; S, 10.4. $C_{14}H_{18}N_2O_4S$ requires C, 54.2; H, 5.8; N, 9.0; S, 10.3%); δ(D_2O) 2.12 (3 H, s, Me), 2.42 (6 H, s, Me), 6.92 (2 H, s, Ph), 7.68 (2 H, dd, 4'-, 5'-H), and 8.12 (2 H, dd, 2'-, 6'-H).

1-*Benzylidineamino*-3-*hydroxypyridinium Mesitylene*-*sulphonate* (49).—Benzaldehyde (2 ml, 0.02 mol) was added to a solution of 1-amino-3-hydroxypyridinium mesitylenesulphonate (46) (0.4 g, 1.36 × 10^{-3} mol) in EtOH (30 ml) and heated under reflux for 15 h. After evaporation and addition of Et_2O (10 ml), the *mesitylenesulphonate* (49) (0.49 g, 92%) was obtained as colourless needles, m.p. 140—141 °C (EtOH–Et_2O) (Found: C, 63.4; H, 5.5; N, 7.1; S. 8.0. $C_{21}H_{22}N_2O_4S$ requires C, 63.3; H, 5.5; N, 7.0; S, 8.0%); $\nu_{max.}$ (Nujol) 1 605 cm^{-1} (>C=N–); δ($CDCl_3$) 2.20 (3 H, s, Me), 2.64 (6 H, s, Me), 7.60 (2 H, m, 4'-,5'-H, and 9.50 (3 H, m, 2'-,6'-H, N=CH).

8-*Benzylideneamino*-2-*oxo*-8-*azabicyclo*[3.2.1]*oct*-3-*ene*-6-endo- *and* -7-endo-*carbonitrile* (51) *and* (54).—The mesitylenesulphonate salt (49) (0.4 g, 1.04 × 10^{-3} mol), quinol (15 mg), Et_3N (3 ml), and an excess of acrylonitrile (20 ml) were heated under reflux for 24 h. The solvent was evaporated *in vacuo* to yield a dark red oil which was triturated with EtOH (20 ml). The yellow precipitate (2 components by t.l.c.) was chromatographed on silica gel (light petroleum–EtOAc (1 : 1)]. The endo-6-*adduct* (51) [30 mg, 11.9%) was isolated as yellow needles (EtOH), m.p. 129—130 °C (EtOH) (Found: C, 71.8; H, 5.3; N, 16.4. $C_{15}H_{13}N_3O$ requires C, 71.7; H, 5.2; N, 16.7%); $\nu_{max.}$ (Nujol) 2 210 (–C≡N) and 1 680 cm^{-1} (αβ-unsat. ketone, CO).

The endo-7-*adduct* (54) (8 mg, 3.2%) crystallised as yellow needles, m.p. 166—168 °C (EtOH) (Found: C, 71.5; H, 5.4; N, 16.5%); $\nu_{max.}$ (Nujol) 2 210 (–C≡N) and 1 680 cm^{-1} (αβ-unsat. ketone, CO).

Methyl 8-*Benzylideneamino*-2-*oxo*-8-*azabicyclo*[3.2.1]*oct*-3-*ene*-6-endo-*carboxylate* (52).—The mesitylenesulphonate salt (49) (0.4 g, 1.04 × 10^{-3} mol), quinol (15 mg), Et_3N (3 ml), and methyl acrylate (8 ml) in MeCN (20 ml) were heated under reflux for 24 h. The solvent was evaporated to yield a yellow oil which crystallised from EtOH to give the endo-*adduct* (52) (60 mg, 21.0%) as needles (EtOH), m.p. 120—121 °C (Found: C, 67.4; H, 5.8; N, 9.8. $C_{16}H_{16}N_2O_3$ requires C, 67.6; H, 5.6; N, 9.8%); $\nu_{max.}$ (Nujol) 1 730 (sat. ester, CO) and 1 690 cm^{-1} (αβ-unsat. ketone, CO).

8-*Benzylideneamino*-2-*oxo*-6-endo-*phenyl*-8-*azabicyclo*-[3.2.1]*oct*-3-*en*-2-*one* (53).—The mesitylenesulphonate (49) (0.4 g, 1.04 × 10^{-3} mol), quinol (15 mg), Et_3N (3 ml), and styrene (2 ml) in MeCN (20 ml) were heated under reflux for 24 h. The solvent was evaporated *in vacuo* to yield the endo-*adduct* (53) (70 mg, 23.1%) as yellow needles, m.p. 133—134 °C (EtOH) (Found: C, 79.5; H, 5.9; N, 9.0. $C_{20}H_{18}N_2O$ requires C, 79.5; H, 6.0; N, 9.3%); $\nu_{max.}$ (Nujol) 1 690 (αβ-unsat. ketone, CO) and 1 600 cm^{-1} (arom. C=C).

8-*Benzylideneamino*-2-*oxo*-N-*phenyl*-8-*azabicyclo*[3.2.1]-*oct*-3-*ene*-6,7-endo- *and* 6,7-exo-*dicarboximide* (55) *and* (56).—The mesitylenetosylate salt (49) (0.4 g, 1.04 × 10^{-3} mol), *N*-phenylmaleimide (0.170 g, 0.001 mol), quinol (15 mg), and Et_3N (3 ml) in MeCN (20 ml) were heated under reflux for 24 h. The yellow residual solid (2 components by t.l.c.) was chromatographed on silica gel [light petroleum–EtOAc (1 : 1)]. The endo-*isomer* (55) (100 mg, 26.8%) was isolated as yellow needles, m.p. 204—206 °C (EtOH) (Found: C, 71.0; H, 4.7; N, 11.3. $C_{22}H_{17}N_3O_3$ requires C, 71.1; H, 4.6; N, 11.3%); $\nu_{max.}$ (Nujol) 1 700 (sat. imide, CO), 1 680 (αβ-unsat. ketone, CO), and 1 600 cm^{-1} (C=C, Ph).

The exo-*isomer* (56) (80 mg, 21.4%) crystallised as yellow needles (EtOH), m.p. 171—172 °C (Found: C, 71.0; H, 4.7; N, 11.1%); $\nu_{max.}$ (Nujol) 1 700 (sat. imide, CO), 1 680 (αβ-unsat. ketone, CO), and 1 600 cm^{-1} (C=C, Ph).

3-*Hydroxy*-1-(2,3,5,6-*tetrafluoro*-4-*pyridyl*)*pyridinium Fluoride* (57).—Pentafluoropyridine (1.69 g, 0.01 mol) was added dropwise to 3-hydroxypyridine (0.95 g, 0.01 mol) in $(CH_2)_4O$ (20 ml) and stirred for 2 days at room temp. The *fluoride* (57) (0.3 g, 11%) was obtained after washing with ether as a dark brown amorphous solid, m.p. 171—

172 °C (Found: C, 45.6; H, 2,2; F, 33.4; N, 10.3. $C_{10}H_5F_5N_2O$ requires C, 45.5; H, 1.9; F, 35.9; N, 10.6%); $\nu_{max.}$ (Nujol) 1 460, 980, and 970 cm^{-1}; $\delta(D_2O)$ 7.96 (2 H, s, 4'-,5'-H) and 8.22 (2 H, s, 2'-,6'-H).

3-Hydroxy-1-(4-pyridyl)pyridinium Chloride (58).— A solution of 3-hydroxypyridine (1 g, 0.01 mol) and 4-chloropyridine (1.14 g, 0.01 mol) in $(CH_2)_4O$ (10 ml) was heated under reflux for 4 days. The desired *chloride* (58) (1.9 g, 86.6%) was obtained as colourless needles, m.p. 226—227 °C (MeOH–EtOAc) (Found: C, 56.8; H, 4.4; N, 13.4; Cl, 16.9. $C_{10}H_9ClN_2O$ requires C, 57.5; H, 4.3; N, 13.4; Cl, 17.0%); $\nu_{max.}$ (Nujol) 2 800—2 500 (phenolic OH), 1 630 (C=C–N), and 1 590 cm^{-1} (C=C); $\delta(D_2O)$ 7.84 (2 H, dd, 3-,5-H), 8.08 (2 H, dd, 4'-,5'-H), 8.58 (2 H, dd, 2-,6-H), and 8.84 (2 H, dd, 2'-,6'-H).

Methyl 2-Oxo-8-(4-pyridyl)-8-azabicyclo[3.2.1]*oct-3-ene-6-endo-carboxylate* (60).—3-Hydroxy-1-(4-pyridyl)pyridinium chloride (58) (1 g, 0.005 mol), quinol (20 mg), Et_3N (3 ml), and methyl acrylate (10 ml) in MeCN (15 ml) were heated under reflux for 12 h. The solution was evaporated to dryness *in vacuo* to leave a yellow oil which was triturated with light petroleum (50 ml). The endo-*adduct* (60) (0.12 g, 9.7%) was obtained as yellow needles, m.p. 143—145 °C (EtOH–Et_2O) (Found: C, 65.2; H, 5.2; N, 10.6. $C_{14}H_{14}N_2O_3$ requires C, 65.1; H, 5.4; N, 10.8%); $\nu_{max.}$ (Nujol) 1 730 (ester, C=O) and 1 680 cm^{-1} (αβ-unsat. ketone, CO).

6-endo-Phenyl-8-(4-pyridyl)-8-azabicyclo[3.2.1]*oct-3-en-2-one* (61).—The chloride (58) (1 g, 0.005 mol), styrene (3 ml), quinol (20 mg), Et_3N (3 ml), and MeCN (20 ml) were heated under reflux for 12 h. The solution was evaporated *in vacuo* to yield a black solid residue. The endo-*adduct* (61) (0.27 g, 20.4%) was isolated as yellow needles, m.p. 195—197 °C (EtOH–Et_2O) (Found: C, 77.9; H, 5.8; N, 10.0. $C_8H_{16}N_2O$ requires C, 78.1; H, 5.8; N, 10.1%); $\nu_{max.}$ (Nujol) 1 680 (αβ-unsat. ketone, CO) and 1 600 cm^{-1} (C=C).

2-Oxo-N-phenyl-8-(4-pyridyl)-8-azabicyclo[3.2.1]*oct-3-ene-6,7-endo-dicarboximide* (62).—A well-stirred suspension of the chloride (58) (0.6 g, 2.8×10^{-3} mol), *N*-phenylmaleimide (0.5 g, 2.8×10^{-3} mol), and quinol (0.012 g) in MeCN (25 ml) was heated to reflux. Et_3N (3 ml) was added dropwise during 15 min. After 24 h, the solvent was removed *in vacuo* to leave a brown residue from which the endo-*adduct* (62) (80 mg, 8%) was isolated as yellow needles, m.p. 247—249 °C (EtOH) (Found: N, 12.4. $C_{20}H_{15}N_3O_3$ requires N, 12.2%); $\nu_{max.}$ (Nujol) 1 700 (amide, CO) and 1 680 cm^{-1} (αβ-unsat. ketone, CO).

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