Rotational Equilibria in 1,2,6-Trisubstituted Pyridinium Cations and Reactions of 2-Isopropylpyrylium Cations

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2-Isopropyl-6-phenyl- and 2,6-diisopropyl-pyridiniums with bulky 1-substituents show temperature-variable NMR spectra which are interpreted in terms of restricted rotation. 2-Isopropyl-4,6-diphenylpyrylium can be deprotonated at the isopropyl group to give an anhydro base which forms new pyryliums with electrophiles.

INTRODUCTION

Vicinal trisubstituted benzenes show interesting kinetic and equilibrium rotational behaviour[1–3] owing to the occurrence of buttressing and gear effects.[4] This is particularly pronounced for 'Janus-like'[5] unsymmetrical susbtituents, such as isopropyl. Since 1,2,6-trisubstituted pyridinium cations are readily available from pyrylium cations and primary amines,[6] we have investigated compounds containing α-isopropyl groups. In contrast to extensive work covering α-aryl-, α-primary alkyl- and α-*tert*-butyl-pyryliums and -pyridiniums,[6] relatively few reports have appeared on such derivatives containing α-*sec*-alkyl groups. We expected that α-*iso*-propylpyryliums could show interesting properties, in that deprotonation should give fully substituted anhydro bases. Further, in the corresponding pyridiniums, 2-isopropyl groups could have special effects on the reactivity of adjacent *N*-substituents.

RESULTS AND DISCUSSION

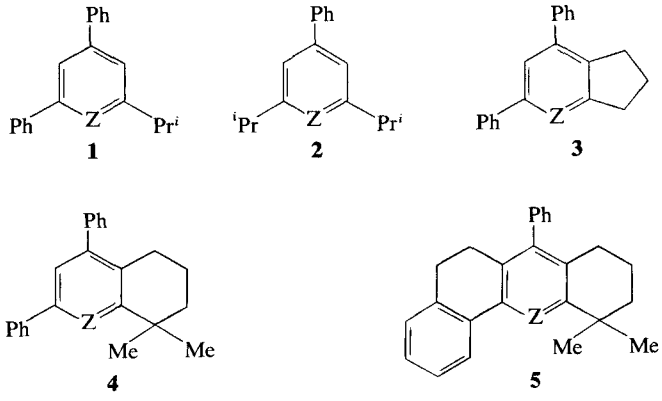
Preparation of compounds

4,6-Diphenyl-2-isopropylpyrylium (**1A**) was previously reported as the tetrachloroferrate ($FeCl_4^-$).[7] Cation **1A** was prepared as the tetrafluoroborate from dypnone and isobutyryl chloride; BF_3 was found to be a better condensing agent than the $FeCl_3$ previously used.[7] 4-Phenyl-2,6-diisopropylpyrylium salts, **2A**, were previously unknown; the tetrafluoroborate was prepared from isobutyryl chloride and α-methylstyrene by a method similar to that previously used to make 4-methyl-2,6-diisopropylpyrylium tetrafluoroborate.[8] 2,4-Diphenyl-6,7-dihydro-5*H*-cyclopenta[*b*]pyrylium tetrafluoroborate (**3A**)[9] was prepared from the corresponding diketone and BF_3 with chalcone as a hydride acceptor; this improved the previously reported yield.[9] The 8,8-dimethylchromylium tetrafluoroborate **4A** was prepared from the appropriate chalcone and acetophenone using trityl tetrafluoroborate (for previous use of trityl tetrafluoroborate as a hydride acceptor, see Ref. 10). The new 11,11-dimethylxanthylium triflate, **5A**, was obtained similarly, using triflic acid as a cyclizing agent (cf. Ref. 11).

The pyryliums were converted by ammonia into the corresponding pyridines (**1B**, **3B–5B**) (Table 1) and by primary amines into a series of pyridinium salts **6–10** (Tables 2–4), as expected. Primary alkyl-primary amines reacted readily to give the pyridinium salts in high yields. Secondary alkyl-primary amines and aromatic amines, owing to their steric crowding or lower nucleophilicity, necessitated longer reaction time or the use of acid catalyst, and the yields were generally lower.

Reactions at α-isopropyl groups

4,6-Diphenyl-2-isopropylidene-2*H*-pyran (**11**) was isolated as an unstable bright red solid by the reaction of the corresponding pyrylium, **1A**, with KOBu^t. The corresponding 4-substituted pyran, **12**, has been previously reported[13] and is considerably more stable. A known analogue of **11** is stabilized by ring fusion.[14]



Series **A**, Z = O$^+$; **B**, Z = N

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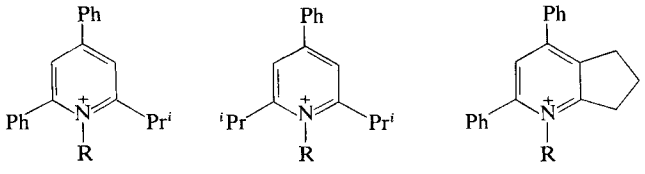
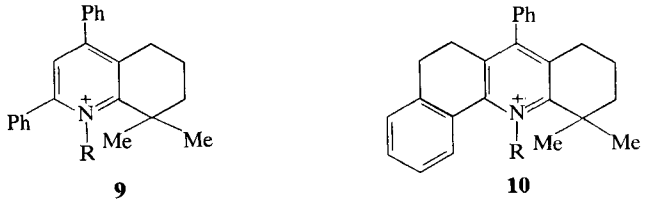
Table 1. Pyridines and pyridinium tetrafluoroborates 1B, 3B–5B

Compound No.	Method[a]	Yield (%)	M.p. (°C)	Cryst. form	Cryst. solv.	Found (%) C	H	N	Molecular formula	Required (%) C	H	H
1B	I	99	208–210	Needles	EtOH	66.5	5.4	3.9	$C_{20}H_{20}BF_4N$	66.5	5.6	3.9
3B	II	95	142–145[b]	Prisms	EtOH–H_2O	—	—	—	—	—	—	—
4B	II	94	209–211	Prisms	EtOH	68.8	6.0	3.5	$C_{23}H_{23}BF_4N$	68.8	6.5	3.5
5B	II	80	135–137	Microcrystalline	EtOH–H_2O	88.4	7.4	4.1	$C_{25}H_{25}N$	88.4	7.4	4.1

[a] See Experimental.
[b] Lit.[12] m.p. 144–146 °C.



6 **7** **8**



9 **10**

a **b** **c** **d** **e** **f** **g** **h** **i**

R = Me, Et, ^{n}Pr, ^{i}Pr, ^{n}Bu, ^{s}Bu, Ph, $PhCH_2$, 3-Me-2-pyridyl,

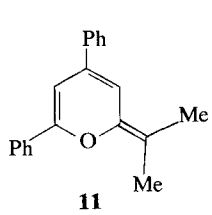
j **k** **l**

CH(Me)Ph, mesityl, CH(Me)^{i}Pr

chloride (see Table 8). The structures of all these new pyryliums were confirmed by elemental analysis and by their ^{1}H NMR spectra (Table 9); in all the compounds the geminal dimethyl group formed a 6H singlet at δ 1.9–1.6. Other CH_2 or CH_3 groups of the 2-substituent absorbed as expected, and the 1H doublet for H-5 was clearly seen on the edge of the aromatic multiplet at δ 8.6–8.4.

Several attempts were made to extend reactions of the type mentioned above to effect deprotonation of α-isopropylpyridiniums **6a**, **6g** to methine bases of type **14**, followed by capture with an electrophile E to form a new pyridinium **15**, but they all failed.[15] Examination of models disclosed considerable steric hindrance between the *N*-substituent in **14** and one of the methyl groups in the stabilized planar form; it is known that exhaustive methylation of the *C*-methyl groups in 1,2,6-trimethylpyridinium cation is difficult.[16,17]

The pyran **11** reacted with HBF_4 to reform pyrylium **1A** as expected. A variety of other electrophilic reagents also reacted with the anhydro base **11** to give new pyryliums **13**; these included methyl iodide, acetyl chloride, two α-haloketones and a vinylogous acid



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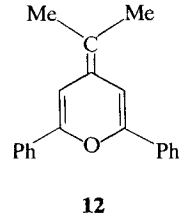

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Table 2. 1-Substituted-4,6-diphenyl-2-isopropylpyridinium tetrafluoroborates, 6a–k

Compound No.	1-Substituent	Method[a]	Time (h)	Yield (%)	M.p. (°C)	Cryst. form[c]	Found (%) C	H	N	Molecular formula	Required (%) C	H	N
6a	Methyl	II	10	98	188–190	Prisms	67.3	5.8	3.7	$C_{21}H_{22}BF_4N$	67.2	5.9	3.7
6b	Ethyl	II	10	77	112–114	Prisms	67.8	6.3	3.6	$C_{22}H_{24}BF_4N$	67.9	6.2	3.6
6c	*n*-Propyl	I	4	100	143–144	Prisms	68.3	6.8	3.5	$C_{23}H_{26}BF_4N$	68.0	6.6	3.5
6d	Isopropyl	II	12	82	198–200	Prisms	68.2	6.4	3.4	$C_{23}H_{26}BF_4N$	68.0	6.6	3.5
6e	*n*-Butyl	I	4	100	129–130	Microcrystalline	69.2	6.7	3.4	$C_{24}H_{28}BF_4N$	69.1	6.8	3.4
6f	*sec*-Butyl	I	24	53	174–175	Needles	69.1	6.6	3.3	$C_{24}H_{28}BF_4N$	69.1	6.8	3.4
6g	Phenyl	II	7[b]	96	195–197	Prisms	71.7	5.5	3.1	$C_{26}H_{24}BF_4N$	71.4	5.5	3.2
6h	Benzyl	II	10	95	105–107	Needles	71.8	6.2	3.0	$C_{27}H_{26}BF_4N$	71.8	5.8	3.1
6i	3-Methyl-2-pyridyl	II	20	32	165–167	Prisms	68.8	5.6	6.1	$C_{26}H_{25}BF_4N_2$	69.0	5.5	6.2
6j	1-Phenylethyl	II	48	47	229–231	Needles	72.0	6.1	3.0	$C_{28}H_{28}BF_4N$	71.9	6.1	3.0
6k	Mesityl	I	72[b]	15	210–212	Plates	72.6	6.3	2.9	$C_{29}H_{30}BF_4N$	72.7	6.3	2.9

[a] See Experimental.
[b] Reflux.
[c] From ethanol.

Table 3. 1-Substituted-2,6-diisopropyl-4-phenylpyridinium tetrafluoroborates, 7a–j

Compound No.	1-Substituent	Method[a]	Time (h)	Yield (%)	M.p. (°C)	Cryst. form[b]	Found (%) C	H	N	Molecular formula	Required (%) C	H	N
7a	Methyl	II	10	100	158–160	Plates	63.0	7.1	4.1	$C_{18}H_{24}BF_4N$	63.4	7.1	4.1
7b	Ethyl	I	10	94	147.5–148.5	Prisms	64.2	7.2	3.9	$C_{19}H_{26}BF_4N$	64.2	7.4	3.9
7c	*n*-Propyl	I	4	82	150–151	Prisms	64.9	7.4	3.8	$C_{20}H_{28}BF_4N$	65.1	7.6	3.8
7d	Isopropyl	II	12	90	210–212	Needles	64.8	7.4	3.8	$C_{20}H_{28}BF_4N$	65.1	7.6	3.8
7e	*n*-Butyl	I	6	70	197–198	Microcrystalline	65.7	8.1	3.6	$C_{21}H_{30}BF_4N$	65.8	7.9	3.6
7f	*sec*-Butyl	I	24	70	165.5–166.5	Prisms	65.9	7.8	3.6	$C_{21}H_{30}BF_4N$	65.8	7.9	3.6
7g	Phenyl	II	12	92	303 (d)	Plates	68.4	6.5	3.4	$C_{23}H_{26}BF_4N$	68.0	6.6	3.5
7h	Benzyl	II	10	96	230–231	Prisms	68.9	6.9	3.3	$C_{24}H_{28}BF_4N$	69.1	6.8	3.4
7i	3-Methyl-2-pyridyl	II	48	76	240–241	Prisms	66.1	6.5	6.5	$C_{23}H_{27}BF_4N_2$	66.0	6.5	6.7
7j	1-Phenylethyl	II	72	42	133–135	Prisms	69.5	7.0	3.2	$C_{25}H_{30}BF_4N$	69.6	7.0	3.2

[a] See Experimental.
[b] From ethanol.

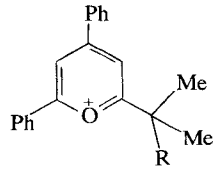
Table 4. Miscellaneous pyridinium tetrafluoroborates, 8–10

Compound No.	*N*-Substituent	Method	Time (h)	Yield (%)	M.p. (°C)	Cryst. form[a]	Found (%) C	H	N	Molecular formula	Required (%) C	H	N
8d	Isopropyl	II	70	64	140–141	Plates	68.9	6.1	3.4	$C_{23}H_{24}BF_4N$	68.8	6.0	3.5
8j	1-Phenylethyl	II	72	65	150–152	Prisms	72.5	5.7	3.0	$C_{28}H_{26}BF_4N$	72.2	5.7	3.1
8l	2-(3-Methyl)butyl	II	120	38	173–175	Sticks	69.9	6.6	3.2	$C_{25}H_{28}BF_4N$	69.9	6.6	3.3
9a	Methyl	I	7	45	208–210	Prisms	69.5	6.4	3.3	$C_{24}H_{26}BF_4N$	64.9	6.3	3.4
9g	Phenyl	I	11	40	240–242	Prisms	72.9	5.9	2.9	$C_{29}H_{28}BF_4N$	73.0	5.9	2.9
10a	Methyl	II	35	80[b]	184–186	Sticks	64.4	5.7	2.8	$C_{27}H_{28}F_3NO_3S$	64.4	5.6	2.8
10h	Benzyl	II	48	65[b]	144–146	Needles	68.0	5.7	2.4	$C_{33}H_{32}F_3NO_3S$	68.4	5.6	2.4

[a] From ethanol.
[b] As trifluoromethanesulphonate.

Reaction of the *N*-substituent group

In view of the resistance of the α-isopropylpyridiniums to deprotonation at the 2-isopropyl group, we attempted deprotonation at the 1′-carbon of the *N*-substituent. When compound **6a** (0.133 mol) was kept in DMSO-d_6 with D_2O (4 mol) and NaOH (0.044 mol), the *N*-methyl signal disappeared in 1.5 min showing H–D exchange; the isopropyl signals remained unchanged. However, several attempts at preparative reactions with strong bases followed by electrophiles failed to give well defined products.[15]



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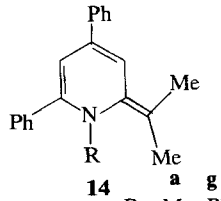
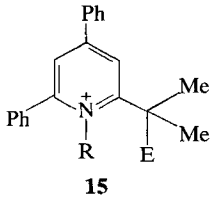
a **b** **c**
R = Me, MeCO, $PhCOCH_2$,

d **e**
4-Br-$C_6H_4COCH_2$, PhCOCH=CH



14 **a** **g**
R = Me, Ph



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^{1}H NMR spectra of 4,6-diphenyl-2-isopropyl- and 4-phenyl-2,6-diisopropylpyridinium tetrafluoroborates

In the ^{1}H NMR spectra of pyridinium salts **6a–k** and **7a–j** (Tables 5 and 6, respectively) the aromatic protons on the heterocyclic and phenyl rings resonate as complex multiplets at δ 8.45–6.75. The protons α- to the nitrogen in the *N*-substituents are deshielded by the adjacent positively charged nitrogen and appear at δ 6.60–4.07; the β- and γ-hydrogens, experiencing less deshielding from the ring, resonate upfield at δ 2.4–0.75, all with the expected multiplicities and coupling constants.[18] The terminal δ-hydrogens in the case of the *n*-butyl group give a distorted triplet at δ 0.7. The isopropyl groups show the methyl doublet at δ 1.60–0.75 and the methine septet at δ 3.83–2.50 [$J(vic) = 6.5–7.1$ Hz].

The isopropyl group patterns were, however, more complex for the *N*-α-phenylethyl (**6j, 7j**) and *N*-(3-methyl-2-pyridyl) (**6i, 7i**) compounds. In **6i, 6j** (Table 5) and **7i** (Table 6) the isopropyl group displays two different methyl signals, whereas in **7j** three methyl peaks are found with two septets for the CH group. These phenomena are due to restricted rotation.

The first example of the existence of two methyl doublets for isopropylpyridinium cations was reported by Balaban[19] for the 4,6-dimethyl-2-isopropyl-1-*o*-tolylpyridinium, which shows the phenomenon at 20 °C, in contrast to the 1-*m*-tolyl analogue which shows no splitting even at −60 °C. The Rumanian group has also investigated rotational barriers in 1-substituted 2,4,6-triphenylpyridinium cations;[20] the

Table 5. ^{1}H NMR spectra[a] of 1-substituted-4,6-diphenyl-2-isopropylpyridinium tetrafluoroborates 6a–k

		1-Substituent																
		Aromatic multiplet		α-CH				Other protons				ω-CH				2-Isopropyl		
Compound No.	1-Substituent	H	δ	H	δ	m	J(Hz)	H	δ	m	J(Hz)	H	δ	m	J(Hz)	CH_3 (6H, d)	J(Hz)	CH (sept.)
—	Hydrogen	12	8.25–7.15		—				—				—			1.35	7.0	3.15
6a	Methyl[b]	12	8.05–7.30	3	4.07	s	—		—				—			1.54	6.9	3.65
6b	Ethyl	12	8.00–7.25	2	4.45	q	7.0		—			3	1.25	t	7.2	1.46	7.0	3.53
6c	*n*-Propyl	12	8.25–7.10	2	4.40	t	7.8	2	2.20–1.65	m	—	3	0.75	t	6.6	1.55	6.8	3.60
6d	Isopropyl	12	8.05–7.20	1	5.20	sep	6.6		—			6	1.70	d	6.6	1.57	7.0	3.83
6e	*n*-Butyl	12	8.10–7.15	2	4.45	t	7.8	4	3.80–3.30	m	—	3	0.70	t	6.0	1.55	6.9	3.58
6f	*sec*-Butyl	12	8.10–7.20	1	4.85	m	—	2	2.30–1.85	m	7.0	3	0.75	t	6.8	1.55	6.7	3.75
								3	1.75	d								
6g	Phenyl	17	8.10–7.10		—				—[c]				—[c]			1.32	7.0	2.90
6h	Benzyl	17	8.20–6.75	2	5.85	s	—		—				—			1.35	6.9	3.45
6i	3-Methyl-2-pyridyl	15	8.25–7.15		—				—			3	2.60	s	—	1.47	6.9[d]	2.85
																1.60	7.0	
6j	1-Phenylethyl	17	7.45–6.95	1	6.25	q	7.2	3	2.15	d	7.2		—			0.75	6.5[d]	3.50
																1.47	6.7	
6k	Mesityl	14	8.45–7.00		—			6	2.00	s	—	3	2.30	s	—	1.45	7.1	2.90

[a] In $CDCl_3$ with $(CH_3)_4Si$ as internal standard.
[b] In $CDCl_3$–CF_3CO_2H.
[c] In aromatic multiplet.
[d] See Discussion.

barriers found were all greater than in the corresponding mesitylene derivatives, owing to a shorter C—N bond. ^{1}H NMR spectra of other compounds described in this paper are collected in Table 7; these spectra support the structural assignments made. In **8l**, the isopropyl methyl carbons appear as two doublets due to the adjacent asymmetric carbon atom.

Variable-temperature NMR spectra

The ^{1}H NMR spectrum of 1-(3-methyl-2-pyridyl)-4,6-diphenyl-2-isopropylpyridinium tetrafluoroborate (**6i**) at 23 °C (Table 5) shows similar behaviour—a septet at δ 2.85 and two methyl doublets at δ 1.60 and 1.47 [$J(vic)$ = 7.0 and 6.9 Hz, respectively]. On heating, the two doublets broadened at 76 °C and coalesced at 106 °C into a single doublet at δ 1.5.

1-(3-Methyl-2-pyridyl)-4-phenyl-2,6-diisopropylpyridinium tetrafluoroborate (**7i**) shows a similar ^{1}H NMR spectrum—two methyl doublets for the isopropyls at δ 1.30 and 1.45 [$J(vic)$ = 6.8 and 6.7 Hz, respectively] (Table 6). Heating a solution of **7i** in DMSO caused no observable change: the energy barrier to rotation is evidently higher than in **6i**.

Table 6. ^{1}H NMR spectra[a] of 1-substituted-2,6-diisopropyl-4-phenylpyridinium tetrafluoroborates, 7a–j

		1-Substituent																
		Aromatic multiplet		α-CH				Other protons				ω-CH				2,6-Isopropyl		
Compound No.	1-Substituent	H	δ	H	δ	m	J(Hz)	H	δ	m	J(Hz)	H	δ	m	J(Hz)	CH_3 (6H, d)	J(Hz)	CH (sep)
—	[b]	7	7.85–7.10		—				—				—			1.30	6.9	3.07
7a	Methyl	7	8.00–7.40	3	4.25	s	—		—				—			1.45	6.9	3.65
7b	Ethyl	7	8.00–7.45	2	4.70	q	7.0		—			3	1.60	t	7.2	1.55	6.8	3.60
7c	*n*-Propyl	7	7.95–7.40	2	4.50	t	9.0	2	2.30–1.80	m	—	3	1.10	t	7.2	1.45	6.8	3.50
7d	Isopropyl	7	7.90–7.20	1	5.65	sep	6.6		—			6	1.85	d	6.6	1.55	6.7	3.80
7e	*n*-Butyl	7	7.85–7.35	2	4.60	t	7.0	4	2.10–1.65	m	—	3	1.00	t	6.0	1.52	6.9	3.53
7f	*s*-Butyl	7	7.90–7.20	1	5.25	t	6.0	2	2.40–1.90	m	—	3	1.00	t	6.9	1.52	6.8	3.75
								3	1.83	d	7.0							
7g	Phenyl	12	7.95–7.25		—				—				—			1.27	6.9	2.75
7h	Benzyl	12	8.00–6.85	2	5.97	s	—		—				—			1.37	7.0	3.40
7i	3-Methyl-2-pyridyl	10	8.25–7.40		—				—			3	2.65	s	—	1.30 1.45	6.8[c] 6.7	2.50
7j	1-Phenylethyl	12	8.45–7.20	1	6.90	q	6.6	3	2.25	d	6.6		—			0.80[c] 1.45 1.70	[d]	3.50 4.00

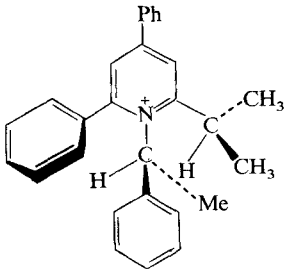
[a] In $CDCl_3$ with $(CH_3)_4Si$ as internal standard.
[b] 4-Phenyl-2,6-diisopropylpyridine.
[c] See Discussion.
[d] Broad.

Table 7. ^{1}H NMR[a] of miscellaneous pyridiniums and pyridines

Compound No.	N-substituent	Aromatic multiplet H	Aromatic multiplet δ	N-substituent H	N-substituent δ	N-substituent m	N-substituent J	gem. diMe (6H, s)	Methylene multiplet H	Methylene multiplet δ
8d	Isopropyl	11	7.70–7.30	1	5.10	sep	6.6	—	4	3.80–3.00
				6	1.60	d	6.6	—	2	2.60–2.10
8j	CH(Me)Ph	16	7.80–7.00	1	6.20	q	7.0	—	4	3.60–2.95
				3	2.10	d	7.0	—	2	2.35–1.95
8l	CH(Me)^{i}Pr	11	7.80–7.30	1	4.55–4.49	m	—	—	4	3.80–3.00
				1	2.42	m	—			
				3	1.77	d	6.8[b]		2	2.60–2.00
				3	0.90	d	6.3[b]			
				3	0.68	d	6.3[b]			
4B	—	11	7.90–7.00		—			1.4	2	2.80–2.40
									4	2.10–1.20
9a	Me	11	7.80–7.30	3	4.20	s	—	1.8	2	3.05–2.65
									4	2.15–1.80
9g	Ph	16	7.90–7.00		[c]			1.2	2	3.20–2.80
									4	2.10–1.60
5B	—	9	7.70–7.00		—			1.45	10	2.90–1.50
10a	Me	9	8.00–7.10	3	4.50	s	—	1.7	10	3.00–1.80
10h	$PhCH_2$	14	8.30–6.90	2	6.40	s	—	1.9	10	2.80–1.70

[a] In $CDCl_3$ with $(CH_3)_4Si$ as internal standard.
[b] See Discussion.
[c] In the aromatics.

1-(1-Phenylethyl)-4,6-diphenyl-2-isopropylpyridinium tetrafluoroborate (**6j**) also shows in the ^{1}H NMR spectrum (Table 5) at 23 °C a methine septet at δ 3.5, and two well separated methyl doublets at δ 1.47 and 0.75 [$J(vic) = 6.7$ and 6.5 Hz], as well as the signals for the *N*-α-phenylethyl group. The preferred spatial arrangement of the adjacent bulky substituents will be as shown in **16**, so that the methine proton of the *N*-substituent lies in the same plane as the pyridinium ring with the methyl and phenyl groups above and below. Similarly, the methine proton of the isopropyl group lies in the same plane as the pyridinium ring with the two methyl groups above and below. One of the methyl groups of the isopropyl moiety is considerably shielded by the magnetic anisotropy of the phenyl ring,[18] and thus resonates at higher field than the other methyl group. We attempted to induce faster rotation by heating **6j** in $CDCl_3$ solution. At 52 °C the three doublets (one from N—CHMePH, two from 2-$CHMe_2$) collapsed into a single doublet. However, this doublet remained unchanged on cooling. Further, a series of peaks related to an AMX spin system[21] were seen in the spectrum and, evidently, irreversible formation of styrene and 4,6-diphenyl-2-isopropylpyridine had occurred. Recently,[22,23] similar loss of the *N*-substituent was observed in the reaction of 2,4,6-triphenylpyrylium tetrafluoroborate with α-methylbenzylamine, at 20 °C in dichloromethane. The expected pyridinium salt dissociated *in situ* to 2,4,6-triphenylpyridine, and the carbocation $PhCH^+Me$ could be trapped by nucleophiles.



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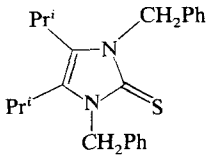

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Heating the pyridinium salt **6j** in acetonitrile-d_3 up to 64 °C caused neither coalescence nor elimination of the *N*-substituent. Apparently, the barrier to rotation around the N(sp^2)—C(sp^3) bond is too high to show coalescence. Further, the solvent evidently plays a role in the elimination of the *N*-substituent as styrene.

Table 8. Preparation of pyrylium salts 13 from the anhydro base 11

Compound No.	Electrophile	Substituent (R)	Yield (%)	M.p. (°C)	Cryst. form	Found (%) C	Found (%) H	Molecular formula	Required (%) C	Required (%) H
13a	MeI	Me	55	260–262	Yellow needles	66.9	5.6	$C_{21}H_{21}BF_4O$	67.0	5.6
13b	MeCOCl	MeCO	42	192–194	Yellow prisms		[a]	$C_{22}H_{21}BF_4O_2$		
13c	$PhCOCH_2Br$	$PhCOCH_2$	31	191–194	Yellow needles	69.8	5.3	$C_{28}H_{25}BF_4O_2$	70.0	5.2
13d	$4\text{-}BrC_6H_4COCH_2Br$	$4\text{-}BrC_6H_4COCH_2$	50	213–215	Yellow prisms	60.0	4.4	$C_{28}H_{24}BBrF_4O_2$	60.1	4.3[b]
13e	PhCOCH=CHCl	PhCOCH=CH	28	166–168	Yellow needles	70.7	5.1	$C_{29}H_{25}BF_4O_2$	70.7	5.1

[a] *m/e*: (M^+—MeCO, 100%).
[b] Br: found, 14.1; required, 14.3%.

Table 9. ^{1}H NMR spectra[a] of 2-substituted-4,6-diphenylpyryliums

Compound No.	Substituent (R)	Geminal diMe (6H, s)	Other 2-substituted protons (s)		H-5 (1H, d)		Other aromatic protons (multiplet)	
			H	δ	δ	J	H	δ
13a	Me	1.60	3	1.60	8.40	2.0	11	8.20–7.40
13b	MeCO	1.95	3	2.20	8.50	2.0	11	8.30–7.50
13c	$PhCOCH_2$	1.85	2	3.90	8.50	2.0	16	8.30–7.30
13d	$4\text{-}BrC_6H_4COCH_2$	1.80	2	3.95	8.50	2.0	15	8.30–7.50
13e	PhCOCH=CH	1.90	[b]		8.60	2.0	18	8.30–7.30

[a] In $CDCl_3$–CF_3COOH (5:1) with $(CH_3)_4Si$ as internal standard.
[b] Appears in the aromatic multiplet.

In the 300 MHz ^{1}H NMR spectrum of 1-(1-phenylethyl)-4-phenyl-2,6-diisopropylpyridinium tetrafluoroborate (**7j**) at 25 °C (Table 6), the methyl groups of the isopropyl substituents resonate as three broad singlets; the peaks at δ 0.8 and 1.45 integrate for three protons each, and that at δ 1.7 integrates for six protons. The methyl protons of the *N*-(1-phenylethyl) group appear as a doublet at δ 2.3 [$J(vic) = 6.6$ Hz]. The methine protons of the isopropyl substituents give two broad peaks at δ 3.5 and 4.0. The methine proton of the *N*-(1-phenylethyl) group resonates as a quartet at δ 6.9. The aromatic protons appear as a complex multiplet at δ 8.45–7.2, in which the most downfield singlet at δ 8.4 belongs to the β-protons of the pyridinium ring.[24]

At −20 °C the signals due to the methyl protons of the two isopropyl groups sharpen and split; the two most shielded signals at δ 0.8 and 1.45 become two sharp doublets [$J(vic) = 6.6$ Hz], while the signal at δ 1.7 splits to two narrowly separated doublets [$J(vic) = 6.6$ Hz]. Thus, all the four methyl groups of the two isopropyl substituents are non-equivalent, owing both to the presence of the bulky *N*-(1-phenylethyl) substituent which possesses an asymmetric centre and to the restricted rotation around the N(sp^2)—C(sp^3) bond as well as the C—C bonds. At −20 °C, the methine isopropyl signals split into two multiplets at δ 4.0 and 3.5. However, the doublet at δ 2.3 and the quartet at δ 6.9, due to the methyl and methine protons, respectively, of the *N*-(1-phenylethyl) group are unchanged by lowering the temperature. The most deshielded aromatic peak at δ 8.4, which is due to the β-protons of the pyridinium ring, also becomes sharper on cooling.

Decoupling experiments were carried out at −20 °C. Irradiation of the doublet at δ 2.3 collapsed the quartet at δ 6.9 into a singlet; this confirms that this doublet is due to the methyl and the quartet is due to the methine of the *N*-(1-phenylethyl) group. Irradiating the most deshielded septet at δ 4.0 collapsed the two doublets at δ 1.75 and 1.70 (which are the most deshielded of the four doublets attributable to the isopropyl methyls) into two singlets. This shows that the septet at δ 4.0 and the doublets at δ 1.75 and 1.70 belong to the same isopropyl group. Further, irradiating the septet at δ 3.5 collapsed the doublets at δ 1.45 and 0.8 into two singlets, showing that these peaks are due to the same isopropyl group. The most shielded doublet at δ 0.8 belongs to a methyl group which lies above the plane of the phenyl ring of the *N*-(1-phenylethyl) substituent and, thus, owing to the anisotropy of the phenyl ring[18] is considerably shielded (cf. the shielding observed in the ^{1}H NMR spectrum of 1-(1-phenylethyl)-4,6-diphenyl-2-isopropylpyridinium tetrafluoroborate (**6j**).

On heating, the signals due to the methyl and methine protons of the isopropyl groups broaden further. At 60 °C, the two peaks due to the isopropyl methine protons are no longer discernible and the methyl signals show extreme broadening. However, the pyridinium β-proton signal (at δ 8.4) becomes sharper on heating. As the temperature increases, the rotation around the N(sp^2)–C(sp^3) bond becomes faster, and the rate of the exchange is such that the protons of the two isopropyl groups experience an averaged environment and, thus, resonate as very broad peaks (coalescence). The two β-protons of the pyridinium ring, as the temperature and the rate of rotation increase, experience averaged environments and collapse to a singlet. However, even when fast rotation of each of the 1-, 2- and 6-substituents is achieved, the chiral center of the 1-substituent is retained and the diastereotopic nature of the isopropyl methyl groups is expected to be observed.

Prolonged heating of **7j** in DMSO-d_6 results in the loss of the *N*-1-(phenylethyl) substituent as styrene and the formation of 4-phenyl-2,6-diisopropylpyridine, as observed for *N*-(1-phenylethyl)-4,6-diphenyl-2-isopropylpyridinium tetrafluoroborate (**6j**).

In the 25 MHz ^{13}C NMR spectrum of **7j** at 23 °C the four methyl carbon atoms of the isopropyl substituents give two broad peaks at δ 23.2 and 21.7, while the methyl carbon atom of the *N*-substituent resonates upfield at δ 18.6 (all quartets in the off-resonance spectrum). The methine carbon atoms of the isopropyl groups appear as a sharp signal at δ 32.3, while the methine carbon atom of the 1-phenylethyl group resonates downfield at δ 60.9 (both doublets in the off-resonance spectrum). At −40 °C, the signals at δ 23.0 and 21.7 split into four sharp singlets which correspond to the four diastereotopic methyl carbon atoms of the isopropyl substituents. The other aliphatic peaks show no change.

The 75 MHz ^{13}C spectrum, at 24 °C, displays four signals for the methyl carbon atoms of the isopropyl groups which on cooling to −20 °C become sharper but on heating to 50 °C collapse into two broad peaks. Dramatic changes occur in some of the aromatic signals. Four broad peaks at δ 166.2, 163.5, 123.0 and 120.4 in the spectrum at 24 °C on cooling to −20 °C

Table 10. Rotational barriers for coalescence data

Compound No.	Substituents 6	1	2	Spectrum	Coalescence process observed	Solvent	T (°C)	$\Delta\nu$ (Hz)	$\Delta G^{\neq}$ (kcal)
6i	Ph	3-Me-2-Py	*i*-Pr	^{1}H	Me of *i*-Pr	DMSO	82±5	13	18.5±0.3
7i	*i*-Pr	3-Me-2-Py	*i*-Pr	^{1}H	Me of *i*-Pr	DMSO	>106	20	>20
6j	Ph	CHMePh	*i*-Pr	^{1}H	Me of *i*-Pr	DMSO	>52	16	>16
7j	*i*-Pr	CHMePh	*i*-Pr	^{1}H	Me of *i*-Pr	DMSO	35	219	14.2±0.3
				^{1}H	Me of *i*-Pr	Acetone	12	195	13.7±0.3
				^{13}C	Me of *i*-Pr	$CDCl_3$	50	50	15.9±0.3
				^{13}C	2,6-C of ring	$CDCl_3$	50	207	15.0±0.3
				^{13}C	3,5-C of ring	$CDCl_3$	50	199	15.0±0.3

become four sharp singlets; on heating to 50 °C, however, they become so broad, owing to fast exchange, that they are no longer discernible. Off-resonance studies showed that the two peaks at low field, at δ 166.2 and 163.5, are due to quaternary carbon atoms which we assign to the α-carbon atoms of the pyridinium ring;[25–27] the other two peaks, at δ 123.0 and 120.4, are due to methine carbon atoms which are the β-carbon atoms of the pyridinium ring.[25–27] The unusual long-range effect of the isopropyl group on the ^{13}C chemical shifts[1] must also be considered.

These ^{13}C NMR studies revealed non-equivalence of the methyl carbon atoms of the isopropyl substituents (but not that of the methine carbon atoms) and of the α- and β-carbon atoms of the pyridinium ring.

Rotational energy barriers

The energy barriers calculated for the coalescence data are collected in Table 10. There has recently been considerable interest in rotational barriers in isopropyl compounds, for example in *N,N*-diisopropylamides.[4b] In 2-isopropylmesitylene, the barrier to Ar-Pr^i rotation is 13.1 kcal mol^{-1}.[1]

For compounds **6i** and **7i**, the processes observed are clearly the rotation of the N—C bond joining the two rings (rotation about the C-2—*i*-Pr bond would not result in methyl group non-equivalence): the situation is similar to 2,4,6-triisopropylbenzophenone, for which the barrier to the Ar—COPh rotation is 16.2 kcal mol^{-1}.[2]

In 1,3-dibenzyl-4,5-diisopropylimidazoline-2-thione (**17**), exchange of the two isopropyl groups between geared conformations shows a barrier to rotation of 11.5 kcal mol^{-1}: two other barriers at 10.6 and 8.5 kcal mol^{-1} arise from rotation of the two benzyl groups.[5] A similar situation is expected for **7j**: here rotation of the phenylethyl group about the N—C bond will be sufficient to cause equivalence of the αα′ and ββ′ carbon atoms; the barrier found here is 15.0 kcal mol^{-1}. A significantly higher barrier of 15.9 kcal mol^{-1} is found for coalescence of the methyl groups, for which rotation of the isopropyl groups about the C—C bond must also occur. The barrier for rotation around the C-2—isopropyl bond can only be observed in the ^{13}C NMR spectrum; for the barrier to rotation about the N—CHMePh bond considerable variation with solvent is found.

EXPERIMENTAL

Melting points were determined with a Reichert or Kofler type hot-stage apparatus and are uncorrected. IR spectra were recorded on Perkin-Elmer 297 or 283B spectrophotometers. The 60 MHz ^{1}H NMR spectra were recorded on Perkin-Elmer R12, Varian A60-A, Jeol JNM-PMX 60 and Varian EM 360 L spectrometers; 100 MHz ^{1}H and 25 MHz ^{13}C NMR spectra were recorded in $CDCl_3$ on a Jeol FX 100 spectrometer equipped with a variable-temperature controller. The 300 MHz ^{1}H and 75 MHz ^{13}C NMR spectra were recorded on a Nicolet NT-300 spectrometer, operating at a field of 7 tesla, equipped with a variable-temperature controller.

4,6-Diphenyl-2-isopropylpyrylium tetrafluoroborate (1A)

Dypnone (12 g, 54 mmol), isobutyryl chloride (12 ml, 108 mmol) and boron trifluoride dietherate (27 ml of 47% solution, 89 mmol) were heated at 100 °C for 2 h. Diethyl ether (500 ml) precipitated the *pyrylium* **1A** from the reaction mixture; recrystallization from methanol gave bright yellow needles (8.0 g, 41%), m.p. 244–246 °C. Analysis: calculated, C 66.3, H 5.3; found, C 66.1, H 5.1%. ν_{max} ($CHBr_3$) 1630, 1600, 1520 cm^{-1}; δ(CF_3COOH), 1.60 (d, *J* 6 Hz, 6H), 3.6 (sept, 1H), 8.6–7.6 (m, 12 H).

4-Phenyl-2,6-diisopropylpyrylium tetrafluoroborate (2A)

α-Methylstyrene (2.5 g, 0.021 mol) was added slowly at 0 °C, with stirring, to anhydrous aluminum chloride (2.8 g, 0.021 mol) in isobutyryl chloride (4.5 g, 0.042 mol). After 24 h at 23 °C, ice (50 g) and 2 N HCl (50 ml) were added and impurities were extracted with diethyl ether (100 ml). Fluoroboric acid (5 ml of a 40% aqueous solution) was added and the mixture extracted with dichloromethane (200 ml). The dry ($MgSO_4$) extracts were evaporated (to 15 mmHg, 50 °C). Diethyl ether was added to the residue to give *pyrylium* **2A**, which recrystallized from methanol as creamy flakes (1.0 g, 15%), m.p. 179–181 °C. Analysis: calculated, C 62.2, H 6.4; found, C 62.2, H 6.4%. ν_{max} ($CHBr_3$) 1645, 1600 and 1530 cm^{-1}; δ

($CDCl_3$) 1.45 (d, J 6 Hz, 12 H), 3.5 (sept. 2 H), 7.3–8.3 (m, 7 H).

2,4-Diphenyl-6,7-dihydro-5*H*-cyclopenta[*b*]pyrylium tetrafluoroborate (3A)

3-(Cyclopentan-2-one)-1,3-diphenylpropane-1-one[28] (4.0 g, 13.7 mmol), benzylideneacetophenone (2.85 g, 13.7 mmol) and boron trifluoride etherate (3.5 ml of a 47% solution in diethyl ether, 11.5 mmol) were heated at 100 °C for 2 h. Diethyl ether (90 ml) was added to give the *pyrylium* **3A** as purple–brown prisms (4.1 g, 84%), m.p. 224–227 °C (lit.[9] m.p., 226–228 °C) Analysis: calculated, C 66.7, H 4.8; found, C 66.9, H 4.8%. ν_{max} ($CHBr_3$) 1615, 1500, 1465 cm^{-1}; δ (CF_3COOH) 2.55 (m, 2 H), 3.5 (m, 4 H), 7.6–8.4 (m, 11 H).

8,8-Dimethyl-2,4-diphenyl-5,6,7,8-tetrahydrochromylium tetrafluoroborate (4A)

2,2-Dimethyl-6-benzylidenecyclohexanone (2.5 g, 0.12 mol)[29], acetophenone (0.7 g, 0.006 mol) and trityl fluoroborate (2 g, 0.006 mol) were heated at 100 °C for 1 h. Ethanol (5 ml) and fluoroboric acid (0.5 ml of a 48% aqueous solution) were added and the mixture heated at 100 °C for 5 min. Diethyl ether (100 ml) gave the *chromylium* **4A**, which crystallized from ethanol as yellow prisms (1.0 g, 42%), m.p. 198–200 °C. Analysis: calculated, C 68.2, H 5.8; found, C 68.6, H 5.8%. ν_{max} ($CHBr_3$) 1615, 1580, 1500, 1470 cm^{-1}; $\delta(CDCl_3)$ 1.6 (s, 6 H), 1.5–2.1 (m, 4 H), 2.85 (m, 2 H), 7.4–8.15 (m, 11 H).

11,11-Dimethyl-7-phenyl-5,6,8,9,10,11-hexahydrobenzo[*c*]xanthylium triflate (5A)

2,2-Dimethyl-6-benzylidenecyclohexanone (3.0 g, 0.014 mol),[29] α-tetralone (1.02 g, 0.007 mol) and triflic acid (1.06 g, 0.63 ml) were heated at 100 °C for 2 h. Acetone (5 ml) and diethyl ether (100 ml) were added to give the *xanthylium* **5A** as bright yellow needles (2.9 g, 85%), m.p. 267–270 °C. Analysis: calculated, C 63.7, H 5.1; found, C 63.6, H 5.1%. ν_{max} ($CHBr_3$) 1610, 1570, 1480 cm^{-1}; $\delta(CDCl_3$–CF_3COOH, 1:1) 1.65 (s, 6 H), 1.7–3.2 (m, 10 H), 7.2–8.25 (m, 9 H).

General procedure for the preparation of pyridines

Method I. Ammonia gas was passed for 1 h into the pyrylium (1.0 g) in dichloromethane (40 ml) at 25 °C. The mixture was stirred at 23 °C for 5 h. Removal of solvent gave the pyridine.

Method II. The pyrylium (1.0 g), ammonium acetate (0.5 g) and ethanol (30 ml) were refluxed for 2 h. Water (60 ml) was added to give the pyridine. Details are given in Table 1.

General procedure for the preparation of pyridinium salts.

Method I. The appropriate amine (1 equiv.), triethylamine (0.3 g), acetic acid (0.2 g) and the pyrylium salt (1.0 g) were stirred in dichloromethane (40 ml) and dried over molecular sieves 3Å at 23 °C for 4–72 h. The solvent was removed and diethyl ether (50 ml) added to give the pyridinium salts.

Method II As in method I, except that 2 equiv. of primary amine but no triethylamine or acetic acid were used. Details are given in Tables 2–4.

4,6-Diphenyl-2-isopropylidene-2*H*-pyran (11)

2-Isopropyl-4,6-diphenylpyrylium tetrafluoroborate (4.2 g, 11.6 mmol), potassium *tert*-butoxide (2.6 g, 23.2 mmol) and *tert*-butanol (80 ml) were refluxed for 11 h. Hot water was added slowly at 90 °C until the solution became cloudy. After 12 h at 23 °C the pyran was filtered off and washed with water, to give pyran **11** as red needles (2.1 g, 66%) which decomposed rapidly on standing; ν_{max} ($CHBr_3$) 2920 m, 1650 m, 1630 s, 1066 m, 1490 s, 1450 s, 1370 m, 1260 m, 1200 m, 1110 s, 1030 w, 840 m, 760 vs; ^1H NMR $\delta(CDCl_3)$ 1.70 (s, 3 H), 1.75 (s, 3 H), 6.0 (d, 1 H), 6.3 (d, 1 H), 7.0–7.5 (m, 10 H). ^{13}C NMR $\delta(CDCl_3)$ 17.2 (q), 17.7 (q), 98.0 (d), 113.9 (d).

General method for preparation of functionalized pyrylium salts from 4,6-diphenyl-2-isopropylidene-2*H*-pyran (11) (pyryliums 13).

4,6-Diphenyl-2-isopropylidene-2*H*-pyran (1.0 g, 3.65 mmol) and the appropriate electrophile (3.65 mmol) were heated at reflux in anhydrous dichloromethane (20 ml) for 24 h. Diethyl ether (50 ml) was added to give the pyrylium salt. This was dissolved in ethanol, and HBF_4 (1 ml of a 48% solution) was added before heating at reflux for 5 min. Cooling gave the corresponding pyrylium tetrafluoroborates as yellow solids. Pyrylium **13a** was prepared using excess of methyl iodide as solvent and heating at reflux for 24 h. Pyrylium **13b** was prepared from acetyl chloride (4 equiv.) and $BF_3 \cdot Et_2O$ (0.5 g) by stirring at 23 °C for 4 h (details are given in Table 8).

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