Convenient Synthesis of C_2-Symmetric Diazepinium Salts Derived from 1,1'-Binaphthyl-2,2'-Diamine.

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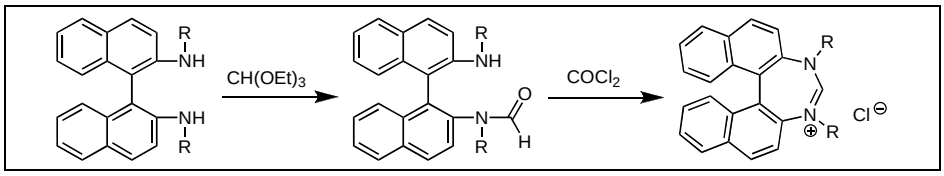

New C_2-symmetric atropisomeric diazepinium salts were prepared utilizing Vilsmeier-Haack activation of corresponding formamide precursors by phosgene solution in toluene. The structures of these substances were verified by X-ray diffraction.

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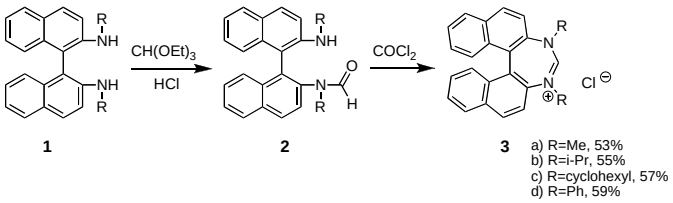
INTRODUCTION

N-heterocyclic carbenes (NHCs) have been introduced by our group as an important class of spectator ligands in homogeneous catalysis [1]. In our studies toward utilization of these ligands in asymmetric catalysis we envisioned that compounds incorporating binaphthyl framework within the carbene backbone may achieve the most promising results. Preparation of NHCs is best achieved by deprotonation of corresponding amidinium salts. We hence required access to a wide range of diazepinium salts **3**. Preparation of one compound of this class (with R being neopentyl) was already reported in the literature by condensation of corresponding amine with triethyl ortoformate [2].

RESULTS AND DISCUSSION

Our initial synthetic attempts were also directed toward condensation of wider range of previously reported *sec*-amines with triethyl orthoformate. However all our efforts were unsuccessful when a variety of known protocols were used. In all cases only formylation products (**2**) were isolated, Scheme 1.



Scheme 1. Synthesis of diazepinium salts.

Vilsmeier-Haack chemistry has been widely used for the preparation of N,N,N',N'-tetraalkylformamidinium salts. [3] However the preparation of diazepinium salts by this method was in our hands severely complicated by subsequent work-up. Because of the counter-ion mixtures (*e.g.*, $PO_2Cl_2^-$, as well as Cl^-) the salts could be isolated only in very low yields as low-melting waxy solids. As an alternative to $POCl_3$, phosgene was found to be sufficiently electophilic for our purposes. Indeed we were able to isolate the corresponding diazepinium salts (**3**) in good yields after very simple and convenient workup, Scheme 1. Products from phosgene reactions are colourless crystalline solids as opposed to dark intractable waxes typically formed in the corresponding $POCl_3$ reactions.

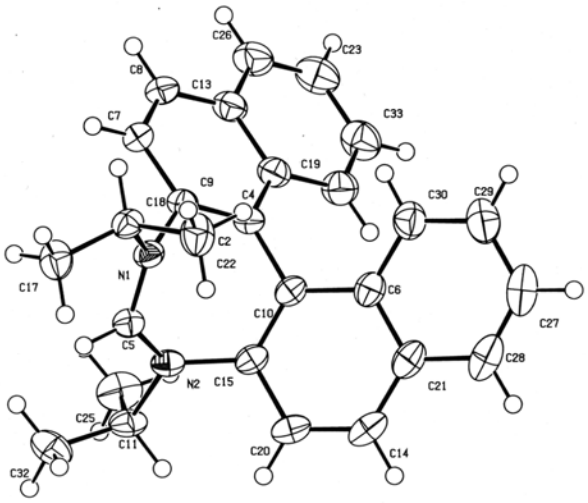


Figure 1. ORTEP diagram for the cationic part of **3b·PF$_6$**. Thermal ellipsoids are drawn at 50% probability level. All hydrogen atoms are placed in ideal positions (riding model). The anion is disordered over two positions.

Crystals suitable for the X-ray diffraction studies were obtained after anion exchange for hexafluorophosphate by layering of THF solution of **3b·PF$_6$** with pentane, Figure 1. The diazepinium salt **3b·PF$_6$** exhibits axial dissymmetry arising from torsion twist of the binaphthyl substituent. The torsion angle α between the two naphthyl

planes in **3b·PF$_6$** is 53.4º. Selected bond lengths and angles are given in the Table 1.

Table 1

Selected Bond Lengths and Angles for **3b·PF$_6$**

Bond Lengths (Å)		Bond Angles (deg)	
C5-N1	1.3187(17)	N1-C5-N2	123.33(13)
C5-N2	1.3258(18)	C5-N1-C18	121.91(12)
N1-C18	1.5007(18)	C5-N2-C11	120.43(13)
N2-C15	1.4509(19)	C15-C10-C2-C18	53.4(2)
C2-C10	1.4859(19)		
C9-C2	1.365(2)		
C10-C15	1.374(2)		

Table 2

Crystallographic data for **3b·PF$_6$**

	3b·PF$_6$
Formula	$C_{27}H_{27}N_2PF_6$
Fw	524.48
color / habit	Colorless / plate
cryst dimensions (mm^3)	0.05 × 0.15 × 0.15
cryst syst	Monoclinic
space group	$P2_1/c$ (no. 14)
a, Å	14.9265(1)
b, Å	12.0779(1)
c, Å	14.5726(1)
β, deg	105.2587(3)
V, Å^3	2534. 55(3)
Z	4
T, K	173
D_{calcd}, g cm^{-3}	1.754
μ, mm^{-1}	0.285
F(000)	1364
θ range, deg	2.20 – 27.54
Index ranges (h, k, l)	±19, ±15, ±18
no. of rflns collected	11363
no. of indep rflns / R_{int}	5828 / 0.017
no. of obsd rflns ($I>2\sigma(I)$)	4672
no. of data/restraints/params	5828 / 0 / 392
$R1$ / $wR2$ ($I>2\sigma(I)$) [a]	0.0456 / 0.1050
$R1$ / $wR2$ (all data) [a]	0.0608 / 0.1131
GOF (on F^2) [a]	1.036
Largest diff peak and hole (e Å^{-3})	+0.34 / -0.31

a) $R1 = \Sigma(||F_o|-|F_c||)/\Sigma|F_o|$; $wR2 = \{\Sigma[w(F_o^2-F_c^2)^2]/\Sigma[w(F_o^2)^2]\}^{1/2}$; $GOF = \{\Sigma[w(F_o^2-F_c^2)^2]/(n-p)\}^{1/2}$

The simple preparative access to the C_2-symmetric diazepinium salts **3** holds promise to make them useful organocatalysts and important starting materials for the preparation of chiral NHC-metal complexes [6]. Studies in this direction are underway.

ACKNOWLEDGEMENT

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EXPERIMENTAL

General Procedure for the Preparation of Formylation Products (2). A mixture of corresponding amine hydrochloride (4.53 mmol) and 30 ml of triethyl orthoformate and 2 drops of 96% formic acid was heated (100 ºC) for 72 h. The excess of triethyl orthoformate was removed *in vacuo* and the residue was purified by flash chromatography on silica gel with EtOAc/Hexan 1:2 as eluent. Analytically pure material was obtained by subsequent recrystallization out of THF.

***N*-Methyl-*N*-(1-(2-(methylamino)naphthalen-1-yl)naphthalen-2-yl)formamide (2a).** This compound was obtained as colourless crystals, mp. 131-132°; Yield 1.31 g (85%); IR ν_{max} (KBr)/cm^{-1} 3402, 2954, 1680, 1594, 1392, 1267, 1178, 813, 765, 741; ^{1}H NMR ($CDCl_3$): δ 8.21 (s, 1H), 7.65 (d, 2H, J = 8.7 Hz), 7.44 (m, 4H), 7.33 (t, 2H, J = 8.6 Hz), 7.15 (t, 2H, J = 8.6 Hz), 6.95 (d, 2H, J = 8.7 Hz), 2.86 (s, 3H), 2.78 (s, 3H), 1.96 (br, 1H); ^{13}C NMR ($CDCl_3$): δ 159.22, 139.13, 134.31, 134.18, 134.12, 133.08, 132.52, 131.64, 131.32, 129.95, 128.81, 128.63, 128.15, 128.00, 127.83, 127.69, 127.43, 127.13, 126.00, 125.89, 124.45, 30.41, 29.96; ms m/z 340.2 (M$^+$, 100%), 325.1 (M$^+$-Me, 34%), 310.1 (M$^+$-2Me, 16%). *Anal.* Calcd for $C_{23}H_{20}N_2O$: C, 81.15; H, 5.92; N, 8.23. Found C, 81.29; H, 6.12; N, 7.95.

***N*-Isopropyl-*N*-(1-(2-(isopropylamino)naphthalen-1-yl)-naphthalen-2-yl)formamide (2b).** This compound was obtained as colourless prisms, mp. 105-106 º; Yield 1.29 g (72%); ^{1}H NMR ($CDCl_3$): δ 8.66 (d, 1H, J = 9.2 Hz), 8.37 (s, 1H), 8.16 (d, 1H, J = 8.8 Hz), 8.10 (d, 1H, J = 8.8 Hz), 8.04-7.99 (m, 2H), 7.62-7.54 (m, 2H), 7.44 (d, 1H, J = 8.4 Hz), 7.37-7.31 (m, 2H), 7.00 (d, 2H, J = 8.8 Hz), 3.24 (sept, 1H, J = 6.8 Hz), 2.85 (sept, 1H, J = 6.6 Hz), 1.79 (br, 1H), 1.25 (d, 3H, J = 6.8 Hz), 1.13 (d, 3H, J = 6.8 Hz), 1.09 (d, 3H, J = 6.6 Hz), 0.58 (d, 3H, J = 6.6 Hz); ^{13}C NMR ($CDCl_3$): δ 165.16, 138.34, 133.72, 133.12, 133.08, 133.01, 132.94, 131.83, 130.62, 129.67, 128.93, 128.89, 128.45, 128.06, 127.91, 127.64, 127.54, 127.22, 126.06, 125.98, 124.56, 54.81, 54.04, 23.75, 22.19, 20.04, 17.61; IR ν_{max} (KBr)/cm^{-1} 3398, 2967, 1668, 1597, 1502, 1424, 1384, 1285, 1175, 812, 771, 748; ms m/z 396.2 (M$^+$, 100%), 353.2 (M$^+$-*i*Pr, 30%), 310.1 (M$^+$-2*i*Pr, 12%). *Anal.* Calcd for $C_{27}H_{28}N_2O$: C, 81.78; H, 7.12; N, 7.06. Found C, 81.56; H, 6.84; N, 6.77.

***N*-cyclohexyl-*N*-(1-(2-(cyclohexylamino)naphthalen-1-yl)naphthalen-2-yl)formamide (2c).** This compound was obtained as colourless crystals, mp. 111-112 º; Yield 1.64 g (76%); ^{1}H NMR ($CDCl_3$): δ 8.12 (s, 1H), 7.65-7.60 (m, 4H), 7. 57 (t, 2H, J = 8.5Hz), 7.39 (t, 2H, J = 8.6 Hz), 7.09 (t, 2H, J = 8.6 Hz), 6.87 (d, 2H, J = 8.6 Hz), 3.58 (m, 1H), 3.39 (m, 1H), 1.67 (br, 1H), 1.58-1.31 (m, 8H), 1.14 -1.02 (m, 12H); ^{13}C NMR ($CDCl_3$): δ 163.45, 142.78, 139.32, 134.46, 133.21, 133.12, 132.26, 130.78, 130.42, 129.99, 129.76, 129.54, 129.12, 128.67, 128.34, 127.99, 127.82, 127.00, 126.31, 116.13, 115.98, 53.97, 53.82, 34.92, 34.67, 27.61, 27.14, 21.43, 21.02; IR ν_{max} (KBr)/cm^{-1} 3381, 2962, 1672, 1603, 1493, 1442, 1392, 1275, 1166, 809, 786, 759; ms m/z 476.3 (M$^+$, 100%), 393.2 (M$^+$-hexyl, 41%), 310.1 (M$^+$-2hexyl, 9%). *Anal.* Calcd for $C_{33}H_{36}N_2O$: C, 83.15; H, 7.61; N, 5.88. Found C, 83.21; H, 7.82; N, 5.59.

***N*-phenyl-*N*-(1-(2-(phenylamino)naphthalen-1-yl)naphthalen-2-yl)formamide (2d).** This compound was obtained as yellow solid, mp. 103-104 º; Yield 1.36 g (64%); ^{1}H NMR ($CDCl_3$): δ 8.31 (s, 1H), 7.65-7.44 (m, 8H), 7.33-7.23 (m, 4H), 7.05-7.17 (m, 5H), 6.95 (d, 2H, J = 8.7 Hz), 6.85 (m, 3H), 2.15 (br, 1H); ^{13}C NMR ($CDCl_3$): δ 161.12, 141.73, 141.42, 141.34, 140.21, 139.02, 138.67, 138.43, 138.10, 137.95, 137.21, 137.00, 136.81, 136.54, 135.76, 135.35, 134.92, 131.34, 131.02, 130.26, 130.11, 129.63, 128.67, 128.16, 127.92, 127.53, 127.29, 117.72, 116.45; IR ν_{max} (KBr)/cm^{-1} 3351, 2923, 1651, 1612, 1521, 1467, 1417,

1256, 1153, 832, 793, 752, 749; ms m/z 464.2 (M^+, 100%), 387.2 (M^+-Ph, 50%), 310.1 (M^+-2Ph, 23%). *Anal.* Calcd for $C_{33}H_{24}N_2O$: C, 85.32; H, 5.21; N, 6.03. Found C, 85.83; H, 5.01; N, 6.46.

General Procedure for the Preparation of Diazepinium Salts (3). A solution of phosgene in toluene (4.3 ml, 0.082 mmol, ~20%) was added dropwise to a toluene solution (170 ml) of **2** (6.63 mmol). After stirring the reaction mixture at rt for 5 hr, a white precipitate formed. This was filtered off, washed with a small quantity of toluene (30 ml) and dried *in vacuo*.

3,5-Dimethyl-5*H*-5-aza-3-azonia-cyclohepta[2,1-*a*;3,4-*a*']dinaphthalene chloride (3a). Mp. 198-199 °; Yield 1.20 g (53%); ^{1}H NMR ($CDCl_3$): δ 8.05 (d, 2H, J = 8.8 Hz), 7.96 (d, 2H, J = 7.6 Hz), 7.93 (s, 1H), 7.52 (t, 2H, J = 8.4 Hz), 7.42 (d, 2H, J = 8.8 Hz), 7.34 (t, 2H, J = 7.6Hz), 7.16 (d, 2H, J = 8.8 Hz), 2.79 (s, 6H); ^{13}C NMR ($CDCl_3$): δ 162.96, 138.56, 134.12, 132.40, 130.92, 128.98, 128.71, 127.99, 126.74, 126.37, 124.48, 33.01; IR ν_{max} (KBr)/cm^{-1} 2924, 2859, 1681, 1316, 828, 753; ms m/z 341.2 (M^+-Cl+H_2O, 100%), 323.2 (M^+-Cl, 5%); 310.2 (M^+-Cl-CH, 34%), 280.0 (M^+-2CH_3-CH, 28%). *Anal.* Calcd for $C_{24}H_{19}N_2Cl$: C, 76.98; H, 5.34; N, 7.81. Found C, 77.09; H, 5.65; N, 7.93.

3,5-Diisopropyl-5*H*-5-aza-3-azonia-cyclohepta[2,1-*a*;3,4-*a*']-dinaphtalene chloride (3b). Mp. 164-165°; Yield 1.62 g (55%); For X-ray crystallography and elemental analysis a small sample of this substance was converted into its PF_6^- salt using standard procedure. ^{1}H NMR ($CDCl_3$): δ 10.33 (s, 1H), 8.03 (d, 2H, J = 9.2 Hz), 7.95 (d, 2H, J = 13.2 Hz), 7.59-7.53 (m, 4H), 7.29 (2H, t, J = 7.2 Hz), 7.09 (d, 2H, J = 8.8 Hz), 4.87 (sept, 2H, J = 6.8 Hz), 1.83 (d, 6H, J = 6.8 Hz), 1.37 (d, 6H, J = 6.8 Hz); ^{13}C NMR ($CDCl_3$): δ 172.78, 145.56, 132.81, 131.59, 131.00, 128.59, 128.19, 127.72, 127.64, 126.75, 120.78, 56.49, 24.07, 20.37; IR ν_{max} (KBr)/cm^{-1} 2924, 2859, 1681, 1503, 1316, 828, 753; m/z 379.2 (M^+-Cl, 100%), 336.2 (M^+-Cl-*i*Pr, 5%), 293.2 (M^+-Cl-2*i*Pr, 17%). *Anal.* Calcd for PF_6-salt: $C_{27}H_{27}F_6N_2P$: C, 61.83; H, 5.19; N, 5.34. Found C, 61.83; H, 5.19; N, 5.29.

3,5-Cyclohexyl-5*H*-5-aza-3-azonia-cyclohepta[2,1-*a*;3,4-*a*']dinaphthalene chloride (3d). Mp. 161-162°; Yield 1.86 g (57%); ^{1}H NMR ($CDCl_3$): δ 9.84 (s, 1H), 8.37 (d, 2H, J = 8.9 Hz), 8.04 (m, 2H), 7.89-7.75 (m, 4H), 7.63 (d, 2H, J = 9.1 Hz), 7.16 (d, 2H, J = 7.4 Hz), 4.32 (m, 2H), 2.03-1.85 (m, 16H), 1.48-1.36 (m, 4H); ^{13}C NMR ($CDCl_3$): δ 170.87, 146.12, 133.98, 132.47, 131.86, 130.53, 130.24, 128.11, 127.27, 126.00, 123.18, 64.15, 32.67, 30.72, 28.83; IR ν_{max} (KBr)/cm^{-1} 2942, 2860, 1673, 1496, 1309, 834, 749; m/z 459.3 (M^+-Cl, 100%), 376.2 (M^+-Cl-hexyl, 43%), 293.2 (M^+-Cl-2hexyl, 9%). *Anal.* Calcd for $C_{33}H_{35}N_2Cl$: C, 80.06; H, 7.13; N, 5.66. Found C, 80.39; H, 7.04; N, 6.02.

3,5-Phenyl-5*H*-5-aza-3-azonia-cyclohepta[2,1-*a*;3,4-*a*']dinaphtalene chloride (3d). Mp. 178-179°; Yield 1.89 g (59%); ^{1}H NMR ($CDCl_3$): δ 10.26 (s, 1H), 8.47-8.31 (m, 6H), 8.24-8.02 (m, 2H), 7.86-7.65 (m, 6H), 7.53-7.43 (m, 4H), 7.35-7.21 (m, 4H); ^{13}C NMR ($CDCl_3$): δ 175.13, 152.02, 147.64, 145.79, 137.30, 136.27, 135.28, 135.10, 133.92, 133.82, 133.75, 131.94, 131.63, 131.22, 130.93; IR ν_{max} (KBr)/cm^{-1} 2950, 2883, 1651, 1497, 1405, 778, 759, 738; ms m/z 465.2 (M^+-Cl+H_2O, 100%), 382.2 (M^+-Cl, 7%), 434.2 (M^+-Cl-CH, 34%), 293.1 (M+-Cl-2Ph, 16%). *Anal.* Calcd for $C_{33}H_{23}N_2Cl$: C, 82.06; H, 4.80; N, 5.80. Found C, 82.42; H, 4.71; N, 5.66.

Structural Determination of 3b·PF_6. Crystal data and details of the structure determination are presented in Table 2. Suitable single crystals for the X-ray diffraction study were grown from THF/pentane. A clear colourless plate was stored under perfluorinated ether, transferred in a Lindemann capillary, fixed, and sealed. Preliminary examination and data collection were carried out on an area detecting system (NONIUS, MACH3, κ–CCD) at the window of a rotating anode (NONIUS, FR951) and graphite monochromated Mo-K_α radiation (λ = 0.71073 Å). The unit cell parameters were obtained by full-matrix least-squares refinement of 6111 reflections. Data collection were performed at 173 K (OXFORD CRYOSYSTEMS) within a θ-range of 2.20°< θ < 27.54°. Measured with nine data sets in rotation scan modus with $Dj/D\omega$ = 1.0°. A total number of 11363 intensities were integrated. Raw data were corrected for Lorentz, polarization, and, arising from the scaling procedure, for latent decay and absorption effects. After merging [R_{int} = 0.017] a sum of 5828 (all data) and 4672 [$I>2s(I)$], respectively, remained and all data were used. The structure was solved by a combination of direct methods and difference Fourier syntheses. All non-hydrogen atoms were refined with anisotropic displacement parameters. All hydrogen atoms were placed in ideal positions (riding model). Full-matrix least-squares refinements with 392 parameters were carried out by minimizing $Sw(F_o^2-F_c^2)^2$ with the SHELXL-97 weighting scheme and stopped at shift/err < 0.001. The final residual electron density maps showed no remarkable features. Neutral atom scattering factors for all atoms and anomalous dispersion corrections for the non-hydrogen atoms were taken from *International Tables for Crystallography*. All calculations were performed on an Intel Pentium II PC, with the STRUX-V system, including the programs PLATON, SIR92, and SHELXL-97 [4]. The anion PF_6^- is disordered over two positions.

Detailed X-ray crystallographic data (excluding structure actors) for the structure in this paper have been deposited with the Cambridge Crystallographic Data Centre as supplementary publication number CCDC 297301. Copies of the data can be obtained, free of charge, on application to CCDC, 12 Union Road, Cambridge CB2 1EZ, UK [fax: +44(0)-1223-336033 or e-mail: deposit@ccdc.cam.ac.uk].

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