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From uncharged to decacationic molecules: syntheses and spectroscopic properties of heteroarenium-substituted pyridines

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Nucleophilic substitutions on pentachloropyridine with 4-(dimethylamino)pyridine, 4-aminopyridine, and 4-(pyrrolidin-1-yl)pyridine give mono-, tri- and pentacationic pyridine-hetarenium salts. The mono-, tri- and pentacationic 4-aminopyridine derivatives can be deprotonated to neutral compounds in solution, or protonated to di-, hexa- and decacationic pyridine derivatives, respectively. Successive substitutions with different heteroaromatic nucleophiles give pyridines with two distinct types of heteroarenium substituents.

Introduction

Di- and morefold positively charged heteroaromatics are interesting compounds both from a biological and chemical point of view. Thus, salts of cationic alkaloids possessing the pyridinium, quinolinium, and isoquinolinium ring, respectively, are widespread in nature,[1] among them dicationic species such as tubocurarine[2] and cyclostellettamine.[3] Oligomeric pyridinium alkaloids were identified as multicationic molecules from natural sources.[4] In organic synthesis and material sciences, heteroarenium substituents have been used to stabilize reactive anionic species such as pyrimidinium-olates,[5,6] pyrimidinium-aminides,[7] pyridinium-4-olates,[8] uracilates,[9] or the allyl anion.[10] Recently, we described DMAP-activated pyridines which undergo substitution reactions with oxygen and sulfur nucleophiles. By this method a broad variety of new highly substituted and hitherto unavailable pyridine ethers[11] and pyridine thioethers[12] were prepared regioselectively. Activation by heteroarenium substituents overcomes the severe limitations of substitution reactions on chloropyridines which—even under vigorous reaction conditions—almost never[13] lead to more than disubstituted pyridines.[14] On the other hand, ring closure reactions starting from acyclic starting materials (*Hantzsch* synthesis,[15] *Kröhnke* synthesis,[16] gas phase reactions of aldehydes and ketones with amines[17]), electrocyclic ring closure reactions,[18] ring transformations,[19] cycloadditions,[20] directed metalations,[21] and transition-metal catalyzed reactions[22] proved to be unsuited for the preparation of highly substituted pyridines due to limited substitution patterns of the starting materials.[23] Recently, an approach to highly functionalized pyridines starting from fluoropyridines was described.[24]

We report here reactions starting from pentachloropyridine leading to mono, tris- and pentakis-heteroarenium substituted pyridines with two or three different types of heteroaromatic substituents. Depending on the conditions and the substitution pattern, these molecules can be uncharged, or mono- to decacationic. The general substitution patterns of these molecules are exemplified by **I–III** in Fig. 1.

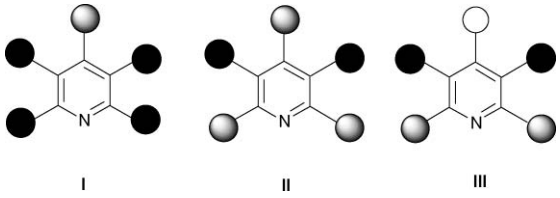
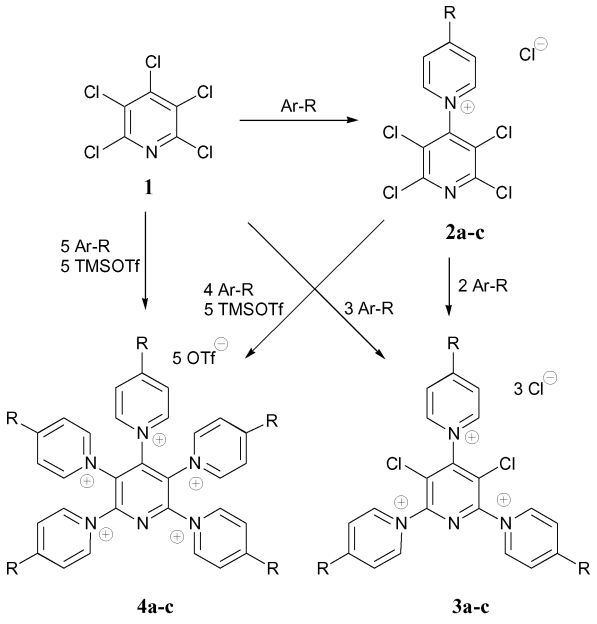


Fig. 1

Results and discussion

Pentachloropyridine **1** reacts with one equivalent of nucleophilic heteroaromatics such as 4-(dimethylamino)pyridine (DMAP), 4-aminopyridine, and 4-(pyrrolidin-1-yl)pyridine to afford the (2,3,5,6-tetrachloropyridin-4-yl)heteroarenium chlorides **2a–c**, respectively. The reaction conditions strongly depend on the heteroaromatic used. Thus, 4-(dimethylamino)pyridine requires 1,2-dichlorobenzene as solvent and a reaction temperature of 80 °C to give **2a** as an essentially colourless solid in quantitative yield (Scheme 1). By contrast, room temperature



	R =
2a, 3a, 4a	—$N(CH_3)_2$
2b, 3b, 4b	—NH_2
2c, 3c, 4c	—N

Scheme 1

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proved to give the best yields of the 4-aminopyridinium salt **2b** and the 4-(pyrrolidin-1-yl)pyridinium salt **2c**, respectively. The substitution at C-4 of **2a,b,c** was unambiguously proved by three signals of the tetrachloropyridine at $\delta = 145.7 \pm 0.1$ ppm, 128.8 ± 0.1 ppm and 146.7 ± 0.1 ppm in the ^{13}C NMR spectra which can be assigned to C-2, C-3, and C-4, respectively. The pyridinium nitrogen atom of **2a** gives a resonance frequency at $\delta = -220.5$ ppm in ^{15}N NMR spectroscopy.

Suitable single crystals of the 4-(pyrrolidin-1-yl)pyridine derivative **2c** were obtained by slow evaporation of a concentrated solution in H_2O–EtOH–HBF_4 (50% in H_2O) = 1 : 1 : 1. The molecular structure and the crystallographic numbering are shown in Fig. 2. The compound crystallizes monoclinic and adopts a twisted conformation with a dihedral angle C3–C4–N7–C8 of 111.26(17)°. The corresponding C4–N7 bond distance (crystallographic numbering) is 143.0(2) pm which corresponds to a long C(sp^2)–N bond. The dihedral angle C11–C10–N13–C14, describing the torsion between the pyridinium and the pyrrolidine ring is 172.37(16)°. The pyrrolidine ring is joined to the pyridinium ring by a shortened C–N bond, the bond length of which was determined to be 132.1(2) pm. Bond distances of C8–C9 = 135.1(2) pm and C11–C12 = 135.5(2) pm do not hint at a quinoidal character of the pyridinium substituent.

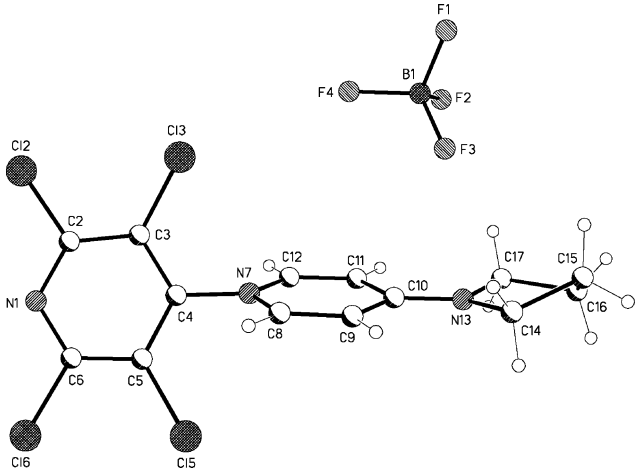
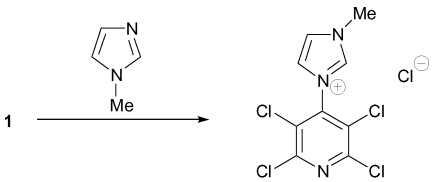


Fig. 2

Threefold substitution on pentachloropyridine **1** with the heteroaromatics required temperatures between 120 °C and 130 °C to give the tricationic species **3a–c** as yellow solids in quantitative yields, respectively (Scheme 1). Alternatively, the 4-(dimethylamino)pyridinium salt **3a** and the 4-(pyrrolidin-1-yl)pyridinium salt **3c** are available from **2a** and **2c**, respectively, on addition of two equivalents of heteroaromatic as indicated in Scheme 1. However, the limited solubility of the 4-aminopyridine derivative prevented us from converting **2b** into **3b**. C-2, C-3, and C-4 of the central pyridine ring appear at 145.9 ± 0.6 ppm, 126.4 ± 0.7 ppm, and 146.9 ± 0.8 ppm in the ^{13}C NMR spectra depending on the substituent. In the electrospray ionisation mass spectra (ESIMS), the peaks of M^{3+} and $[M^{3+} + n\ Cl^-]^{(3-n)+}$ can be detected. Thus, the ESI mass spectrum of **3b** displays a prominent peak of M^{3+} at m/z 142.2 u and of $[M + Cl]^{2+}$ at $m/z = 231.4$ u spraying a sample from methanol at 0 V fragmentor voltage.

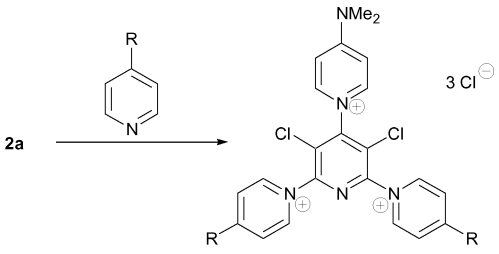
Interception of the leaving group chloride by TMSOTf during the nucleophilic substitution of heteroaromatics on pentachloropyridine **1** in refluxing 1,2-dichlorobenzene results in the formation of the pentacationic molecules **4a–c** as pentakis(triflates) in 73–80% yield (Scheme 1). Similar to the formation of the tricationic species, the pentacations **4a** and **4c** are also available starting from the monocations **2a** and **2c**, respectively. Three distinct types of pyridinium substituents in a 2 : 2 : 1 ratio are detectable in ^1H NMR spectroscopy. The nitrogen atom of **4a** gives resonance frequencies at $\delta = -214.4$ ppm, -220.5 ppm, and -224.3 ppm in the ^{15}N NMR spectra. No mono-, di-, or tricationic species were isolated when the reaction was conducted in the presence of TMSOTf, although these products were formed—as already mentioned—in good to excellent yields without this intercepting agent. C-2/6 of the central pyridine ring appears at 147.4 ± 0.6 ppm, C-3/5 at 128.0 ± 1.1 ppm, and C-4 at lowest field, between 146.6 ppm and 149.0 ppm. The reactions shown in Scheme 1 are not reversible. After heating samples of the salts in 1,2-dichlorobenzene at reflux temperature for 4 h, the starting materials were recovered quantitatively, respectively.

1-Methylimidazole as the heteroaromatic nucleophile gave the monocationic imidazolium salt **5** in low yield (Scheme 2). Attempts to synthesize tri- and pentacationic molecules, however, failed under the applied reaction conditions.



Scheme 2

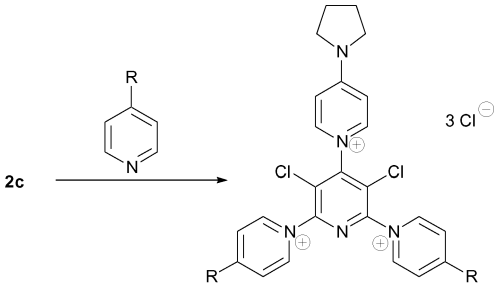
Encouraged by the observations that some heteroarenium-substituted pyridines can be converted into others, and that these substitutions are not reversible, we focused our interest on mixed trications as exemplified by structure **III** in Fig. 1. Indeed, starting from the 4-(dimethylamino)pyridinium substituted salt **2a**, two different heteroarenium substituents can be joined to C-2 and C-6. Thus, the mixed pyridinium salts **6** and **7** were available (Scheme 3).



6: R = NH_2 (83%)
7: R = pyrrolidin-1-yl (54%)

Scheme 3

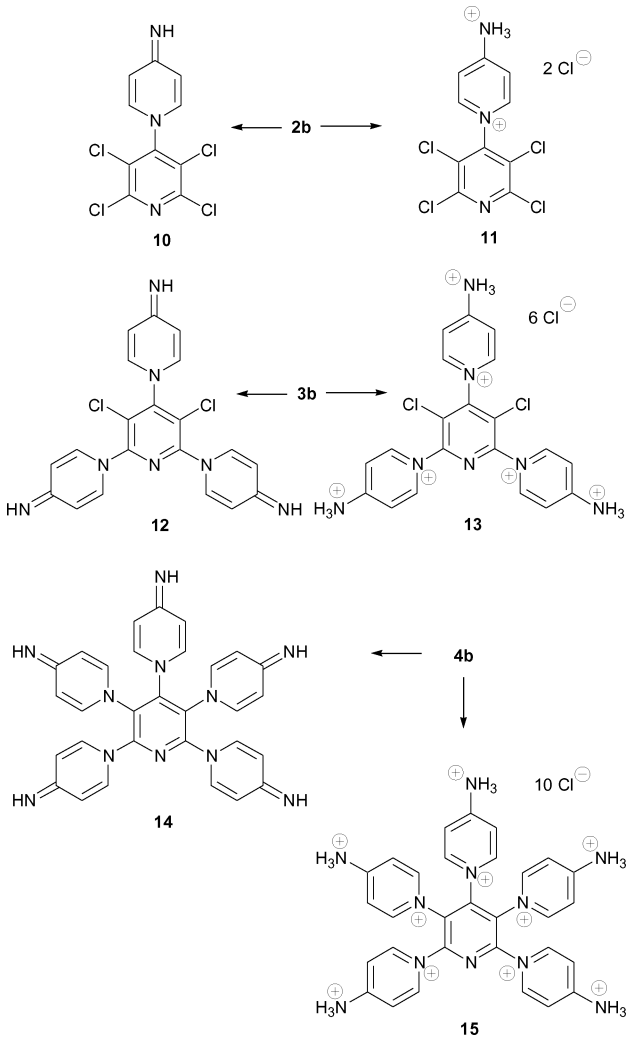
Likewise, the 4-(pyrrolidin-1-yl)pyridinium derivative **2c** reacts to form **8** and **9** in good yields (Scheme 4). Again, the limited solubility of **2b** prevented us from synthesizing the corresponding 4-(4-aminopyridinium) substituted species.



8: R = NH_2 (95%)
9: R = NMe_2 (64%)

Scheme 4

The amino group of the 4-aminopyridinium substituent gives rise to some acid–base reactions. We therefore focused our attention on deprotonations and protonations of the amino group of **2b**, **3b**, and **4b**. Thus, the yellowish coloured imines **10**, **12**, and **14** precipitate from concentrated aqueous or methanolic solutions of **2b**, **3b**, and **4b** on addition of aqueous sodium hydroxide (Scheme 5). These compounds decompose even under an inert atmosphere to red oils, and this instability prevented us from a complete characterization. However, acidification of the freshly prepared imines gives the starting materials in quantitative yields.



Scheme 5

In ESI-mass spectrometry, **10** and **12** sprayed from methanol give peaks at $m/z = 310$ u $[MH]^+$ and 425 u $[MH]^+$, respectively. Compound **14** was sprayed from a methanol–water–formic acid mixture due to its limited solubility and displayed peaks of partially protonated species at $m/z = 181$ u $[M + 3H]^{3+}$, 136 u $[M + 4H]^{4+}$ and 109 u $[M + 5H]^{5+}$. In the crude ^{13}C NMR spectra taken in DMSO-d_6, the imine carbon appears at $\delta = 153.2 \pm 1.0$ ppm, the enamine carbon atoms at $\delta = 107.8 \pm 1.0$ ppm, and the α-carbon atoms at 148.5 ± 0.9 ppm. In the ^1H NMR in DMSO-d_6, all compounds have doublets of doublets at 7.95–8.15 ppm and additional doublets of doublets at 6.44–6.65 ppm. The protons of the imino groups gave broad peaks at approximately 6 ppm. New absorption bands at 3426 cm^{-1} and 1646 cm^{-1} were observable in the IR spectra on conversion of the salts into the imines.

On deprotonation in DMSO-d_6 with KO^{t}Bu, the chemical shifts of the α- and γ-carbon atoms of the 4-aminopyridine resonance frequencies of **2b**, **3b**, and **4b** change considerably, whereas the signals of the β-carbon atoms as well as of the chloropyridine rings of **2b** and **3b** and the central pyridine of **4b** remain essentially unchanged. The NMR titration of monocation **2b** is shown in Fig. 3.

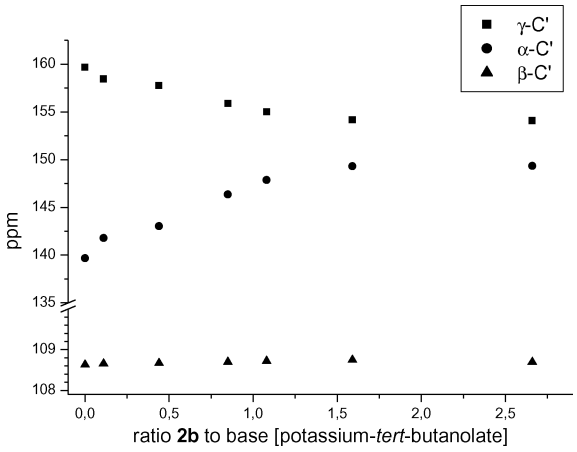


Fig. 3

The salts **2b**, **3b**, and **4b** can also be protonated with concentrated hydrochloric acid in solution to a dication **11**, a hexacation **13**, and a decacation **15**, respectively (Scheme 5), which precipitated on concentrating the solutions *in vacuo* as colourless to pale yellowish solids which rapidly lose HCl on standing. Correspondingly, solutions of **2b**, **3b**, and **4b** in water are basic and this behaviour is analogous to some literature-known 4-aminopyridinium salts.[25–27] The dicationic molecule **11** was detected at $m/z = 155.49$ u ($z = 2$) in ESI mass spectrometry, whereas the detection of hexa- and decacationic species under these conditions seemingly is beyond the scope of this spectrometric method.

Results of a titration of 100 mL of a 0.04 M solution of the salts **11**, **13**, and **15** in water with 0.04 M NaOH are shown in Fig. 4. The pK_a values of these salts, which are strongly acidic in solution, are about 2. Addition of one, three, and five equivalents of base gives the starting materials **2b**, **3b**, and **4b** in quantitative yields, respectively. The salts **11**, **13**, and **15** can be deprotonated by 2, 6 and 10 equivalents of base to the aforementioned imines **10**, **12**, and **14**. In NMR titrations, the resonance frequencies of the chloropyridine moiety of **11** and **13**, and of the central pyridine ring of **15** remain virtually unchanged. These findings provide evidence for the amino groups as protonation sites. Obviously, no protonation of the pyridine nitrogen atom occurs under these conditions.

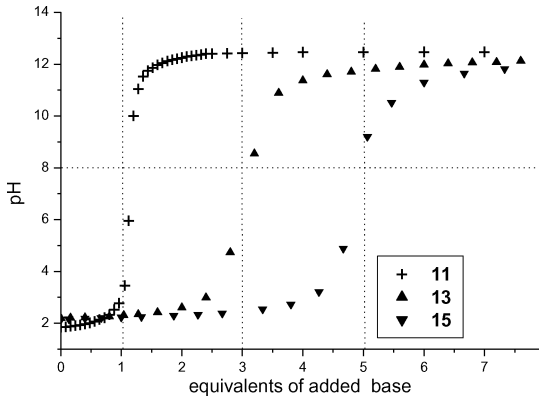


Fig. 4

In summary, we present the synthetic potential of penta-chloropyridine towards heteroaromatic nitrogen nucleophiles which enables the synthesis of highly functionalized

oligocationic pyridines bearing up to ten positive charges within a common π-electron system.

Experimental

General remarks

The ^{1}H and ^{13}C NMR spectra were recorded on Bruker Digital FT–NMR Avance 400 and Avance DPX 200 spectrometers. Multiplicities are described by using the following abbreviations: s = singlet, d = doublet, m = multiplet. FT-IR spectra were obtained on a Bruker Vektor 22 in the range of 400 to 4000 cm^{-1} (2.5% pellets in KBr). ^{15}N NMR spectra: reference $MeNO_2$. The electrospray ionisation mass spectra (ESIMS) were measured with an Agilent LCMSD Series HP1100 with APIES. Samples were sprayed from methanol at 0 V fragmentor voltage. Melting points are uncorrected.

Crystal structure determination of 2c (tetrafluoroborate)

Crystal data. $C_{14}H_{12}BCl_4F_4N_3$, $[(C_{14}H_{12}N_3Cl_4) + (BF_4)]$, $M = 450.88$, monoclinic, $a = 7.7703(1)$ Å, $b = 20.6759(3)$ Å, $c = 11.1315(2)$ Å, $\beta = 95.594(1)°$, $U = 1779.85(5)$ Å^3, $T = 123(2)$ K, space group $P2(1)/c$ (no. 14), $Z = 4$, $\mu(Mo–K_\alpha) = 0.708$ mm^{-1}, 11708 reflections measured, 3989 unique ($R_{int} = 0.0372$) which were used in all calculations. The final $wR(F^2)$ was 0.0831 (all data) with $R_1 = 0.032$ for $I > 3\sigma(I)$.†

General procedure for the synthesis of the 1-(2,3,5,6-tetrachloropyridin-4-yl)hetarenium chlorides 2a, 2b, 2c, and 5

A solution of pentachloropyridine **1** (2.51 g, 10.0 mmol) and the heteroaromatic [4-(dimethylamino)pyridine (1.22 g, 10.0 mmol); 4-aminopyridine (0.94 g, 10.0 mmol); 1-methylimidazole (0.82 g, 10.0 mmol) and 4-(pyrrolidin-1-yl)-pyridine (1.48 g, 10.0 mmol), respectively] in 100 mL of solvent was stirred as described below. The precipitates were filtered off, washed with ethyl acetate and dried *in vacuo*.

1-(4-Dimethylamino)-[2,3,5,6-tetrachloropyridin-4-yl]-pyridinium chloride (2a). After 3 h in 1,2-dichlorobenzene at 80 °C, the salt (3.74 g) was obtained as a colourless solid in quantitative yield, mp 242 °C. (Found: C, 38.04; H, 3.12; N, 10.98. $C_{12}H_{10}Cl_5N_3$ requires C, 38.59; H, 2.70; N, 11.25%; δ_H 8.36 (d, $^3J = 7.8$ Hz, 2H; α-H), 7.42 (d, $^3J = 7.8$ Hz, 2H; β-H), 3.34 (s, 6H; NMe_2); δ_C 156.4, 146.7, 145.7 (2C), 140.6 (2C), 128.8 (2C), 108.6 (2C), 40.0 (2C); δ_N −220.5 ($C_5H_4N(NMe_2)$), −274.9 ($C_5H_4N(NMe_2)$; the signal of the N-atom of the tetrachloropyridine could not be detected; ν_{max} (KBr)/cm^{-1}: 3423, 3027, 1651, 1583, 1538, 1412, 1334, 1219, 1070, 850; m/z (ESI) = 338.1 ([M − Cl]$^+$, 100).

1-(4-Amino)-[2,3,5,6-tetrachloropyridin-4-yl]-pyridinium chloride (2b). After 48 h in ethyl acetate at rt, the salt was obtained as a pale yellow solid in 85% yield (2.94 g), mp 172 °C. (Found: 307.9321. $C_{10}H_6N_3Cl_4^+$ requires 307.9316); δ_H 9.62 (NH_2), 8.30 (d, $^3J = 7.2$ Hz, 2H; α-H), 7.29 (d, $^3J = 7.2$ Hz, 2H; β-H); δ_C 160.1, 146.8, 145.8 (2C), 141.6 (2C), 128.9 (2C), 110.0 (2C) ppm; ν_{max} (KBr)/cm^{-1}: 3424, 1654, 1530, 1401, 1331, 1202, 1173, 843; m/z (ESI) = 310 ([M − Cl]$^+$, 82).

1-(4-Pyrrolidino)-[2,3,5,6-tetrachloropyridin-4-yl]-pyridinium chloride (2c). After 24 h at rt in 1,2-dichlorobenzene, the salt was obtained as a pale yellow solid in 95% yield (3.80 g), mp 196 °C. (Found: 361.9802. $C_{14}H_{12}N_3Cl_4^+$ requires 361.9660); δ_H 8.41 (d, $^3J = 7.5$ Hz, 2H; α-H), 7.29 (d, $^3J = 7.5$ Hz, 2H; β-H), 3.67 (s, 4H), 2.05 (s, 4H) ppm; δ_C 153.5, 146.8, 145.8 (2C), 140.6 (2C), 128.8 (2C), 109.3 (2C), 49.2 (2C), 24.5 (2C) ppm; ν_{max} (KBr)/cm^{-1}: 3417, 2976, 1649, 1574, 1552, 1438, 1383, 1333, 1218, 1174, 1068; m/z (ESI) = 364 ([M − Cl]$^+$, 100).

† CCDC reference number 278514. See http://dx.doi.org/10.1039/b510627c for crystallographic data in CIF or other electronic format.

1-(3-Methyl)-[2,3,5,6-tetrachloropyridin-4-yl]-imidazolium chloride (5). After 24 h in ethyl acetate at 60 °C, the salt was obtained as a white solid in 10% yield (0.33 g), mp 62 °C. (Found: 295.9328. $C_9H_6N_3Cl_4^+$ requires 295.9316); δ_H 9.99 (s, 1H; 2-H), 8.27 (s, 1H; 5-H), 8.17 (s, 1H; 4-H), 4.11 (s, 3H; Me) ppm; δ_C 145.7 (2C), 141.9, 138.0, 128.8 (2C), 125.3, 122.9, 36.8 ppm; ν_{max} (KBr)/cm^{-1}: 3418, 3087, 2855, 1585, 1544, 1441, 1383, 1241, 1156, 1123, 1087, 1023; m/z (ESI) = 298 ([M − Cl]$^+$, 38).

General procedure for the synthesis of the 1,1′,1″-(3,5-dichloropyridin-2,4,6-triyl)-trisheteroarenium trichlorides 3a, 3b, and 3c

A solution of pentachloropyridine (2.51 g, 10.0 mmol) and the corresponding heteroaromatic [4-(dimethylamino)pyridine (3.66 g, 30.0 mmol); 4-aminopyridine (2.82 g, 30.0 mmol); 4-(pyrrolidin-1-yl)-pyridine (4.44 g, 30.0 mmol), respectively] in 200 mL of solvent was stirred as described below. The products precipitated on cooling, were filtered off, washed with ethyl acetate and dried *in vacuo*.

1,1′,1″-Tris[4-dimethylamino-(3,5-dichloropyridine-2,4,6-triyl)-pyridinium] trichloride (3a). After 3 h in 1,2-dichlorobenzene at 120 °C, the trication was isolated as a pale yellow solid in quantitative yield (6.15 g), mp 281 °C. (Found: C, 47.77; H, 5.24; N, 14.42. $C_{26}H_{30}Cl_5N_7O_2{\cdot}2H_2O$ requires: C, 47.76; H, 5.24; N, 15.00%). δ_H 9.00 (d, $^3J = 8.2$ Hz, 4H; α-H, α-pyridinium), 8.96 (d, $^3J = 8.1$ Hz, 2H; α-H, γ-pyridinium), 7.53 (d, $^3J = 8.1$ Hz, 2H; β-H, γ-pyridinium), 7.37 (d, $^3J = 8.2$ Hz, 4H; β-H, α-pyridinium), 3.38 (s, 18H; Me) ppm; δ_C 156.7 (2C), 156.6, 147.2, 146.3 (2C), 140.8 (2C), 140.7 (4C), 127.0 (2C), 108.6 (2C), 107.8 (4C), 40.6 (6C) ppm. No ^{15}N NMR resonance frequencies of the central pyridine and the 4-pyridinium substituent were found; ν_{max} (KBr)/cm^{-1}: 3051, 1648, 1583, 1560, 1403, 1225, 1170, 832; m/z (ESI) = 582 ([M − Cl]$^+$, 10).

1,1′,1″-Tris[4-amino-(3,5-dichloropyridine-2,4,6-triyl)pyridinium] trichloride (3b). After 1 h in DMF at 120 °C, the trication was isolated as a yellow solid in quantitative yield (5.34 g), mp 110 °C; in order to obtain a non-hygroscopic material for CHN analyses, the tetraphenylborate was prepared by anion exchange with excess $NaBPh_4$ in EtOAc: (Found: C, 80.28; H, 6.10; N, 7.08. $C_{92}H_{78}B_3Cl_2N_7$ requires: C, 79.78; H, 5.68; N, 7.08%). δ_H 9.63 (s, 2H; γ-NH_2), 9.59 (s, 4H; α-NH_2), 8.72 (d, $^3J = 7.6$ Hz, 4H; α-H, α-pyridinium), 8.53 (d, $^3J = 7.5$ Hz, 2H; α-H, γ-pyridinium), 7.31 (d, $^3J = 7.5$ Hz, 2H; β-H, γ-pyridinium), 7.20 (d, $^3J = 7.6$ Hz, 4H; β-H, α-pyridinium) ppm; δ_C 160.3 (2C), 160.2, 147.7, 146.5 (2C), 141.6 (br, 6C), 126.9 (2C), 110.2 (2C), 109.3 (4C) ppm; ν_{max} (KBr)/cm^{-1}: 3314, 3089, 1653, 1530, 1401, 1197, 1166, 843; m/z (ESI) = 142.2 ([M^{3+}], 80), 231.4 [M + Cl]$^{2+}$.

1,1′,1″-Tris[4-pyrrolidino-(3,5-dichloropyridine-2,4,6-triyl)-pyridinium] trichloride (3c). After 2 h in DMF at 120 °C, the trication was isolated as a strongly hygroscopic yellow solid in quantitative yield (6.96 g), mp 115 °C. (Found: C, 49.12; H, 4.81. $C_{32}H_{36}Cl_5N_7{\cdot}4H_2O$ requires: C, 50.04; H, 5.77%). δ_H 8.64 (d, $^3J = 7.5$ Hz, 4H; α-H, α-pyridinium), 8.46 (d, $^3J = 7.5$ Hz, 2H; α-H, γ-pyridinium), 7.19 (d, $^3J = 7.5$ Hz, 2H; β-H, γ-pyridinium), 7.08 (d, $^3J = 7.5$ Hz, 4H; β-H, α-pyridinium), 3.63 (s, br 12H), 2.02 (s, br, 12H) ppm; δ_C 152.2 (2C), 152.1, 146.1, 145.3 (2C), 139.1 (2C), 139.0 (4C), 125.7 (2C), 107.7 (2C), 106.9 (4C), 47.8 (6C), 23.1 (6C) ppm; ν_{max} (KBr)/cm^{-1}: 3418, 3046, 2873, 1696, 1560, 1433, 1401, 1533, 1218, 1175, 828.

General procedure for the syntheses of the 1,1′,1″,1‴,1⁗-pentakis-(pyridine-2,3,4,5,6-pentyl)heteroarenium pentakis(trifluoromethylsulfonate)s 4a, 4b and 4c

A solution of pentachloropyridine (2.51 g, 10.0 mmol), the corresponding heteroaromatic [4-(dimethylamino)pyridine (6.1 g,

50.0 mmol); 4-aminopyridine (4.7 g, 50.0 mmol)]; 4-(pyrrolidin-1-yl)-pyridine (7.41 g, 50.0 mmol)] and trimethylsilyl trifluoromethansulfonate (TMSOTf; 12.22 g, 55.0 mmol) in 200 mL of 1,2-dichlorobenzene was heated at reflux temperature under an inert atmosphere. The products precipitated from the solution after approximately one hour. After cooling, the solid was filtered off, washed with ethyl acetate and dried *in vacuo*.

1,1′,1″,1‴,1⁗-Pentakis[4-dimethylamino-(2,3,4,5,6-pentyl)pyridinium] pentakis(trifluoromethylsulfonate) (4a). The pentacation was isolated as a pale grey solid (11.44 g; 80%), mp 218 °C. (Found: C, 35.84; H, 3.46; N, 9.95. $C_{45}H_{50}F_{15}N_{11}O_{15}S_5$ requires C, 37.79; H, 3.52; N, 10.77%). δ_H 8.53 (d, $^3J = 8.0$ Hz, 4H; α-H, α-pyridinium), 8.26 (d, $^3J = 8.0$ Hz, 4H; α-H, β-pyridinium), 8.08 (d, $^3J = 7.8$ Hz, 2H; α-H, γ-pyridinium), 7.50 (d, $^3J = 7,8$ Hz, 2H; β-H, γ-pyridinium), 7.35 (d, $^3J = 8.0$ Hz, 8H; β-H, α-H, β-pyridinium), 3.38 (s, 6H; CH_3, γ-pyridinium), 3.37 (s, 12H; CH_3), 3.35 (s, 12H; CH_3) ppm; δ_C 156.9, 156.7 (2C), 156.5 (2C), 147.9, 146.7 (2C), 140.2 (2C), 140.1 (4C), 139.0 (4C), 130.1 (CF_3), 126.9 (2C), 123.7 (CF_3), 117.3 (CF_3), 110.9 (CF_3), 108.9 (2C), 107.9 (4C), 106.9 (4C), 40.5 (br, 8C), 39.5 (2C) ppm; δ_N −214.4 (2N), −220.5 (2N), −224.3, −268.2 (2N), −270.6, −292.1 (2N) ppm; no signal of the central pyridine was detected; ν_{max} (KBr)/cm^{-1}: 3272, 3095, 1651, 1567, 1407, 1273, 1222, 1158, 1031, 834, 804, 638.

1,1′,1″,1‴,1⁗-Pentakis[4-amino-(pyridine-2,3,4,5,6-pentyl)-pyridinium] pentakis(trifluoromethylsulfonate) (4b). The pentacation was isolated as a yellow solid (9.60 g; 75%), mp 147 °C. (Found C, 69.13; H, 5.05. $C_{106}H_{90}F_6N_9O_6S_2{\cdot}2H_2O$ requires: C, 69.48; H, 5.17%). δ_H 9.38 (s, br, 2H; γ-NH_2), 9.31 (s, br, 4H; β-NH_2), 9.19 (s, br, 4H; α-NH_2), 8.46 (d, $^3J = 6.3$ Hz, 4H; α-H, α-pyridinium), 8.03 (m, 4H; α-H, β-pyridinium), 7.82 (m, 2H; α-H, γ-pyridinium), 7.04 (m, 2H; β-H, γ-pyridinium), 6.94 (d, $^3J = 6.3$ Hz, 4H; β-H, α-pyridinium), 6.60 (m, 4H; β-H, β-pyridinium); δ_C 160.3, 159,8 (br, 4C), 149.0, 147.5 (2C), 141.6 (2C), 139.4 (br, 8C), 130.1 (CF_3), 127.1 (2C), 123.7 (CF_3), 117.2 (CF_3), 110.9 (CF_3), 109.2 (2C), 108.6 (br, 8C) ppm; ν_{max} (KBr)/cm^{-1}: 3358, 3241, 2989, 1661, 1537, 1256, 1204, 1171, 1030.

1,1′,1″,1‴,1⁗-Pentakis[4-pyrrolidino-(pyridine-2,3,4,5,6-pentyl)-pyridinium] pentakis(trifluoromethylsulfonate) (4c). The pentacation was isolated as a yellow solid (12.48 g; 73%), mp 305 °C. (Found: C: 36.76; H: 5.21; N: 17.43. $C_{17}H_{18}Cl_5N_7{\cdot}3.5H_2O$ requires: C: 36.42; H, 4.49; N, 17.49%). δ_H 8.20 (d, $^3J = 7.3$ Hz, 4H; α-H, α-pyridinium), 8.02 (d, $^3J = 7.2$ Hz, 4H; α-H, β-pyridinium), 7.86 (d, $^3J = 7.3$ Hz, 2H; α-H, γ-pyridinium), 7.24 (d, $^3J = 7.3$ Hz, 2H; β-H, γ-pyridinium), 7.11 (d, $^3J = 7.2$ Hz, 8H; β-H, α-H, β-pyridinium), 3.66 (s, br, 4H; α-H, γ-pyrrolidine), 3.63 (s, br, 8H; α-H, β-pyrrolidine), 3.59 (s, br, 8H; α-H, α-pyrrolidine), 2.03 (s, br, 20H; β-H, pyrrolidine) ppm; δ_C 153.5 (2C), 152.9, 152.8, 148.0, 146.6 (2C), 139.8 (4C), 139.5 (2C), 138.8 (4C), 130.1 (CF_3), 129.1 (2C), 123.6 (CF_3), 117.2 (CF_3), 110.8 (br, 5C; CF_3 and 2C), 110.5 (4C), 108.6 (4C), 49.5 (br, 10C), 24.4 (br, 10C) ppm; ν_{max} (KBr)/cm^{-1}: 3096, 3066, 1652, 1586, 1449, 1357, 1260, 1223, 1172, 1031, 828, 638.

General procedure for the synthesis of the trications 6–9

Solutions of the monocationic species [3.46 g (10.0 mmol) of **2a**; 4.00 g (10.0 mmol) of **2b**] and 4-(dimethylamino)pyridine (2.44 g, 20.0 mmol), 4-aminopyridine (1.88 g, 20.0 mmol), 4-(pyrrolidin-1-yl)-pyridine (2.96 g, 20.0 mmol), respectively, were suspended in 250 mL of DMF and then heated at 100 °C with vigorous stirring. After three hours, the solution was cooled to room temperature and treated with 250 mL of ethyl acetate. The resulting precipitate was filtered off, washed with petrol ether and dried *in vacuo*.

1,1′-Bis[4-amino-(3,5-dichloro-4-(4-dimethylamino)pyridinio-pyridine-2,6-diyl)pyridinium] trichloride (6). The trication was isolated as a yellow solid (4.66 g; 83%), mp 208 °C. (Found: C, 42.42; H, 4.89; N, 13.58. $C_{22}H_{22}Cl_5N_7{\cdot}4H_2O$ requires C, 41.69; H, 4.77; N, 15.47%). δ_H 9.44 (s, br, 4H; NH_2), 8.71 (m, 4H; α-H, α-pyridinium), 8.51 (d, $^3J = 7.1$ Hz, 2H; α-H, γ-pyridinium), 7.45 (d, $^3J = 7.1$ Hz, 2H; β-H, γ-pyridinium), 7.16 (m, 4H; β-H, α-pyridinium), 3.35 (s, 6H; CH_3) ppm; δ_C 160.2 (2C), 156.6, 147.4, 146.5 (2C), 141.7 (4C), 140.6 (2C), 127.0 (2C), 109.3 (4C), 108.6 (2C), 40.5 (4C) ppm; ν_{max} (KBr)/cm^{-1}: 3418, 3085, 1650, 1532, 1401, 1200, 1170.

1,1′-Bis[4-pyrrolidino-(3,5-dichloro-4-(4-dimethylamino)pyridinio-pyridine-2,6-diyl)pyridinium] trichloride (7). This compound was isolated as a strongly hygroscopic yellow solid (3.61 g; 54%), mp 108 °C. (Found: C, 46.38; H, 5.04. $C_{30}H_{34}Cl_5N_7{\cdot}6H_2O$ requires: C, 46.31; H, 5.96%). δ_H 8.96 (d, $^3J = 7.5$ Hz, 4H; α-H, α-pyridinium), 8.89 (d, $^3J = 7.5$ Hz, 2H; α-H, γ-pyridinium), 7.33 (d, $^3J = 7.5$ Hz, 2H; β-H, γ-pyridinium), 7.18 (d, $^3J = 7.5$ Hz, 4H; β-H, α-pyridinium), 3.67 (s, br, 8H; α-H, pyrrolidine), 3.41 (s, 6H; CH_3), 2.04 (s, br, 8H; β-H, pyrrolidine) ppm; δ_C 156.6, 153.7 (2C), 147.3, 146.4 (2C), 140.8 (4C), 140.7 (2C), 127.1 (2C), 108.5 (br, 6C), 49.3 (2C), 40.6 (4C), 24.5 (2C) ppm; ν_{max} (KBr)/cm^{-1}: 3418, 3051, 1648, 1562, 1438, 1402, 1350, 1218, 1173, 827.

1,1′-Bis[4-amino-(3,5-dichloro-4-(pyrrolidino)pyridinio-pyridine-2,6-diyl)pyridinium] trichloride (8). This compound was isolated as a yellow solid (5.57 g; 95%), mp 185 °C. (Found: C, 45.23; H, 5.08; N, 15.67. $C_{24}H_{24}Cl_5N_7{\cdot}3H_2O$ requires: C, 44.91; H, 4.71; N, 15.28%). δ_H 9.60 (s, br, 4H; NH_2), 8.74 (m, 4H; α-H, α-pyridinium), 8.54 (m, 2H; α-H, γ-pyridinium), 7.31 (m, 2H; β-H, γ-pyridinium), 7.20 (m, 4H; β-H, α-pyridinium), 3.67 (s, br, 4H; α-pyrrolidine), 2.03 (s, br, 4H; β-pyrrolidine) ppm; δ_C 160.3 (2C), 153.6, 147.5, 146.5 (2C), 141.6 (br, 6C), 126.6 (2C), 109.2 (br, 6C), 49.3 (2C), 24.5 (2C) ppm; ν_{max} (KBr)/cm^{-1}: 3406, 3091, 1651, 1561, 1531, 1200, 1172; m/z (ESI) = 514 (M − 2Cl$^-$, 10).

1,1′-Bis[4-(dimethylamino)-3,5-dichloro-4-(pyrrolidino)pyridinio-pyridine-2,6-diyl)pyridinium] trichloride (9). This compound was isolated as a yellow solid (4.12 g; 64%), mp 122 °C. (Found: C, 46.34; H, 5.77; N, 13.39. $C_{28}H_{32}Cl_5N_7{\cdot}4.5H_2O$ requires: C, 46.39; H, 5.70; N, 13.52%). δ_H 8.96 (d, $^3J = 8.0$ Hz, 4H; α-H, α-pyridinium), 8.91 (d, $^3J = 7.7$ Hz, 2H; α-H, γ-pyridinium), 7.34 (d, $^3J = 8.0$ Hz, 4H; β-H, α-pyridinium), 7.33 (d, $^3J = 7.7$ Hz, 2H; β-H, γ-pyridinium), 3.68 (s, br, 4H; α-H, pyrrolidine), 3.43 (s, 12H; CH_3), 2.04 (s, br, 4H; β-H, pyrrolidine) ppm; δ_C 156.7 (2C), 153.6, 147.2, 146.3 (2C), 140.7 (br, 6C), 127.1 (2C), 109.3 (2C), 107.8 (4C), 49.3 (2C), 40.6 (4C), 24.5 (2C) ppm; ν_{max} (KBr)/cm^{-1}: 3419, 3061, 1649, 1563, 1403, 1221, 1172, 827. m/z (ESI) = 605 (M − 2Cl$^-$, 10).

General procedure for the formation of the imines 10, 12 and 14 by deprotonation of 2b, 3b and 4b

1-(4-Amino)-[2,3,5,6-tetrachloropyridin-4-yl]-pyridinium chloride **2b** (3.45 g, 10 mmol), 1,1′,1″-tris[4-amino-(3,5-dichloropyridine-2,4,6-triyl)pyridinium] trichloride **3b** (5.34 g, 10 mmol), or 1,1′,1″,1‴,1⁗-pentakis[4-amino-(pyridine-2,3,4,5,6-pentyl)-pyridinium] pentakis(trifluoromethylsulfonate) **4b** (12.8 g, 10 mmol) were dissolved in 50 mL water, respectively. Under vigorous stirring, 5 N aqueous sodium hydroxide was added dropwise until yellowish solids precipitated. After filtration, the solids were washed twice with diethyl ether. The colour of the yellow solids turned to red on storage due to decomposition.

2,3,5,6-Tetrachloro-4-[(1*H*-pyridin-4-ylidenamine)-1-yl]-pyridine (10). This compound is red in colour and decomposes rapidly, mp 267 °C. $\delta_H = 7.95$ (dd, $^5J = 1.5$ Hz, $^3J = 4.8$ Hz, 2H; β-H), 6.46 (dd, $^5J = 1.5$ Hz, $^3J = 4.8$ Hz, 2H; α-H), 6.03 (s, 1H; N*H*) ppm; δ_C = 160.9, 154.2, 149.3, 139.0, 110.2, 108.8 ppm; m/z (ESI) = 310 ([M + H]$^+$, 15); ν_{max} (KBr)/cm^{-1}: 3426, 1646. Protonation reconstitutes **2b** quantitatively.

3,5-Dichloro-2,4,6-tris[(1*H*-pyridin-4-ylidenamine)-1-yl]-pyridine (12). This compound was isolated as a yellow solid which rapidly decomposes on storage, mp 307 °C. δ_H = 8.05 (dd, ^5J = 1.5 Hz, ^3J = 4.8 Hz, 2H; β-H), 6.56 (dd, ^5J = 1.5 Hz, ^3J = 4.8 Hz, 2H; α-H), 6.03 (s, 1H; N*H*) ppm; no ^{13}C NMR was taken due to the limited solubility; *m*/*z* (ESI) = 425 (M + H)$^+$; ν_{max} (KBr)/cm^{-1}: 3437, 1650. Protonation reconstitutes **3b** quantitatively.

2,3,4,5,6-Pentakis[(1*H*-pyridin-4-ylidenamine)-1-yl]-pyridine (14). This compound was isolated as a yellow solid which rapidly decomposes on storage, mp 217 °C. δ_H = 8.15 (dd, ^5J = 1.5 Hz, ^3J = 4.8 Hz, 2H; β-H), 6.65 (dd, ^5J = 1.5 Hz, ^3J = 4.8 Hz, 2H; α-H), 5.95 (s, 1H; N*H*) ppm; no ^{13}C NMR was taken due to the limited solubility; *m*/*z* (ESI; MeOH, H_2O, HCOOH): 182, [M + 3H]$^{3+}$, 137 [M + 4H]$^{4+}$ and 109 [M + 5H]$^{5+}$. ν_{max} (KBr)/cm^{-1}: 3439, 1649. Protonation reconstitutes **4b** quantitatively.

General procedure for the synthesis of the salts 11, 13 and 15 by protonation of 2b, 3b and 4b

1-(4-Amino)-[2,3,5,6-tetrachloropyridin-4-yl]-pyridinium chloride **2b** (3.45 g, 10 mmol), 1,1′,1″-tris[4-amino-(3,5-dichloropyridine-2,4,6-triyl)pyridinium] trichloride **3b** (5.34 g, 10 mmol), or 1,1′,1″,1‴,1⁗-pentakis[4-amino-(pyridine-2,3,4,5,6-pentyl)-pyridinium] pentakis(trifluoromethylsulfonate) **4b** (12.8 g, 10 mmol) were dissolved in 50 mL of concentrated hydrochloric acid. On slow concentration of the solutions *in vacuo*, the compounds precipitated. The solids were filtered off and dried in a desiccator.

1-(4-Ammonium)-[2,3,5,6-tetrachloropyridin-4-yl]-pyridinium dichloride (11). This compound was isolated as a colourless solid in quantitative yield. δ_H (D_2O) 9.43 (NH_2), 8.23 (d, ^3J = 7.4 Hz, 2H; α-H), 7.22 (d, ^3J = 7.4 Hz, 2H; β-H); δ_C 160.0, 146.8, 145.8 (2C), 141.7 (2C), 128.9 (2C), 110.1 (2C); ν_{max} (KBr)/cm^{-1}: 3009, 1654, 1403, 1312; *m*/*z* (ESI) = 155.49 (M^{2+}). Deprotonation reconstitutes **2b** quantitatively.

1,1′,1″-Tris[4-ammonium-(3,5-dichloropyridine-2,4,6-triyl)pyridinium] hexachloride (13). This compound was isolated as a pale yellow solid which rapidly loses HCl on storage. δ_H (D_2O) 9.46 (s, 2H; γ-H_2), 9.39 (s, 4H; α-H_2), 8.64 (d, ^3J = 7.6 Hz, 4H; α-H, α-pyridinium), 8.41 (d, ^3J = 7.5 Hz, 2H; α-H, γ-pyridinium), 7.27 (d, ^3J = 7.5 Hz, 2H; β-H, γ-pyridinium), 7.16 (d, ^3J = 7.6 Hz, 4H; β-H, α-pyridinium) ppm; δ_C 160.3 (2C), 160.2, 147.8, 146.6 (2C), 141.6 (br, 6C), 126.9 (2C), 110.3 (2C), 109.4 (4C) ppm; ν_{max} (KBr)/cm^{-1}: 2777, 2259, 1656, 1541. Deprotonation reconstitutes **3b** quantitatively.

1,1′,1″,1‴,1⁗-Pentakis[4-ammonium-(pyridine-2,3,4,5,6-pentyl)pyridinium] decachloride (15). This compound was isolated as a yellowish, unstable solid. δ_H (D_2O) 9.47 (s, br, 10H; NH_2), 8.69 (d, ^3J = 6.3 Hz, 4H; α-H, α-pyridinium), 8.20 (m, 4H; α-H, β-pyridinium), 8.09 (m, 2H; α-H, γ-pyridinium), 7.28 (m, 2H; β-H, γ-pyridinium), 7.15 (d, ^3J = 6.3 Hz, 4H; β-H, α-pyridinium), 6.83 (d, ^3J = 6.9 Hz, 4H; β-H, β-pyridinium) ppm. Due to limited solubility, no ^{13}C NMR spectra could be obtained. ν_{max} (KBr)/cm^{-1}: 1656, 1534, 1256, 1203. Deprotonation reconstitutes **4b** quantitatively.

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