Preparation and Conversion of *N*-Halomethylpyridinium Halides. Comparison with Related Compounds†

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N-Halomethylpyridinium halides **1a**−**f** (X-$CH_2Py^+X^-$, X = Cl, Br) have been synthesized from a three-component reaction mixture containing a thionyl halide **5**, formaldehyde (**6**), and a pyridine **7**. The salts **1a**−**f** react readily with a variety of heterocyclic nucleophiles to yield (in general, nonsymmetrical) 1,1-bis(heteroarylium)methyl salts **2ea**−**hb**, (pathway a). The use of trichloroacetaldehyde (**9**) instead of formaldehyde in this three-component reaction leads to a salt **10** in which one of the CH_2-hydrogens was replaced by the electron-withdrawing CCl_3 substituent. This changes the standard reaction pathway a of **1** in solution toward nucleophiles completely: the chlorinated *N*-vinylpyridinium salts **11** and **12** were formed after the reaction of **10** with pyridine or triphenylphosphane. These are useful intermediates for the synthesis of new *N*- and 4-substituted 1,4-dihydropyridines **13**−**15** as could be demonstrated for compound **11**. To explain the reactivity pattern of compounds **1** and **10** and the related structures (MeO-CH_2Py^+, **16**, and Me_3SiO-CH_2Py^+, **17**) we calculated, using ab initio and DFT methods, reaction pathways a and b, both in the gas phase and in solution using ammonia as a model nucleophile. For all of these compounds, pyridine displacement (pathway b) dominates in the gas phase. As an example the energy gap between these two transition states for **1a** turns out to be relatively small (11.6 kcal/mol in favor of pathway b, TS2). Solvation effects can therefore stabilize the corresponding transition state TS1 more effectively. In a MeCN solution, TS1 is 1.6 kcal/mol less energetic than TS2.

Introduction

Pyridinium salts with an α-halogen atom in the *N*-substituent had already been described in the thirties.[1−3] Presumably because of the poor yields obtained in these first synthetic approaches, they received little further attention.[4−6]

Almost a decade ago, we reported the first preparation of *N*-(1-bromo- and chloro-alkyl)heteroarylium salts **1** (Figure 1) by means of a three-component reaction consisting of an *N*-heteroaromatic compound such as pyridine (or pyridine derivatives such as isoquinoline, etc.), an aldehyde, and thionyl chloride or bromide.[7−9] This very convenient method has provoked significant interest in such compounds and has led to many interesting applications in synthesis.

These salts **1** have been reacted, in many cases in situ, with a variety of nucleophiles. Systematic investigation has yielded many useful products such as novel sulfonato-pyridinium betaines **2a**, phosphonato-pyridinium salts **2b**, geminal substituted bisonium salts such as the phosphonium/pyridinium species **2c**, and the bis(heteroarylium) compounds **2d**.

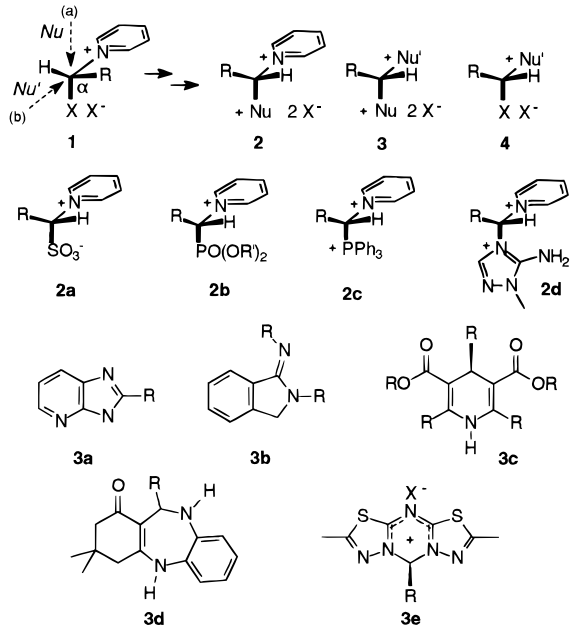

Figure 1. Reaction products **2**−**4** of *N*-(1-haloalkyl)-pyridinium salts **1**, R = alkyl, aryl.

Furthermore, one can synthesize five-, six- and seven-membered ring systems **3a**−**d**, as well as novel imines,

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† Dedicated to Professor Dr. Dirk Walther (Jena, Germany) on the occasion of his 60th birthday.

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from **1**. Recently, these salts **1** have been used as precursors for the synthesis of other *N*-(1-alkyl/aryl/azolyl)methyl pyridinium salts.[7,8,10−14] Tricyclic (5/6/5) salts **3e** can also be generated from **1**.[15] In general, all of these structures can be interpreted to be representatives of compounds in which the heteroarylium moiety *remains* in the molecule after the nucleophilic attack (e.g., **2a**−**d**, pathway a) or of those in which that moiety was *substituted* by a second nucleophile (pathway b). Product examples of the latter are the heterocycles **3a**−**e**.

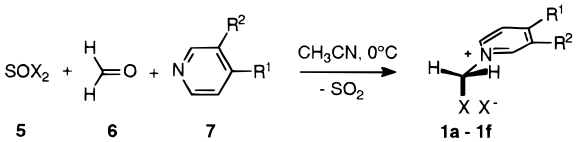
Although there are many synthetic applications for the pyridinium salts **1** (with R = aryl, alkyl), not much is known about the parent halides **1** with R = H. In addition, nothing is known about the salts **1a**−**f** or other examples of **1** in which R is a strongly electron-withdrawing substituent (Figure 1). A general synthesis for compounds of this type or structural/reactivity studies have not been reported.

We partially fill this void with this paper, in which we report a general synthetic method which leads to **1a**−**f**. We also report the first results of investigations which explain the structure and reactivity patterns of these new compounds. It is noteworthy that such α-halogen substituted *N*-methylpyridinium salts could be of preparative interest as starting compounds for the synthesis of a variety of heterocyclic bisonium methanes. These compounds could possibly be employed as biologically active substances.[6−16]

The success of the syntheses reported here depends on the feasibility of both the nucleophilic substitution pathways a and b, Figure 1. They can be controlled by varying the properties of the heteroarylium moiety, the substituent R, and to a minor extent, by the nature of the C-bonded halogen. In this context, the salt **1a** appears to be an especially useful model compound: it is easily accessible in excellent yields, and its molecular size allows high-level MO calculations**.**

Computational Methods. Ab initio and DFT calculations were performed using the Gaussian 94 suite of programs.[17] Molecular geometries for the species **1a** were optimized at the Hartree−Fock (HF), second-order perturbation (MP2),[18] and density functional (B3LYP) levels of theory using the 6-311+G*[19−24] basis set. All other geometries were optimized at the HF/6-31+G* or the B3LYP/6-31+G* level of theory. The Onsager method,[25] as implemented in Gaussian 94, was used to estimate solvation effects (the dielectric constant of the polar solvent MeCN (35.9) was employed) at the HF/6-31+G* level. The HF results were compared with semiempirical calculations using the AM1[26] and PM3[27] parameter set, as implemented in MOPAC93.[28] Solvation effects were carried out at the semiempirical level using the COSMO (Conducter-like Screening Model) method,[29] which is also available in specially compiled MOPAC93 versions (keywords: EPS = 35.9, TS (for transition states), PRECISE, NSPA = 0).[30] All local minima and transition-state structures found were verified by calculations of analytical force constants. These frequencies were also used to compute the zero-point energies (ZPE).

Scheme 1. *N*-Halomethylpyridinium Salts 1a−f from a Thionyl Halide 5, Formaldehyde (6), and a Pyridine 7



7, 1	R^1	R^2	X	1a - f [%]
a	H	H	Cl	90
b	H	H	Br	73
c	$N(CH_3)_2$	H	Cl	78
d	CN	H	Cl	30
e	H	CN	Cl	77
f	H	CO_2CH_3	Cl	86

Results and Discussion

1-Chloromethylpyridinium Chloride (1a). The *N*-monohalomethyl pyridinium halides **1a**−**f** (Scheme 1) were synthesized in yields of up to 90% by treating a mixture of an equimolar amount of **5** (X = Br, Cl) and the corresponding pyridine **7a**−**f** with gaseous formaldehyde (**6**) in CH_2Cl_2 or MeCN at 0 °C. The formaldehyde was generated externally from paraformaldehyde in a special apparatus (see the Experimental Section).

Compound **1a** was isolated from the reaction mixture of the three-component reaction and then recrystallized from methanol/acetone to give large (3 mm/3 mm) colorless prisms which were suitable for X-ray analysis (Figure 2).[31]

It is notable that pyridine itself does not react at atmospheric pressure with dichloromethane to form the salt **1a.** Under higher pressures, only *N*,*N*′-methylenebis(pyridinium) dichloride was formed.[4] The iodide Cl-CH_2-Py^+I^- (and from that the chloride **1a** via anion

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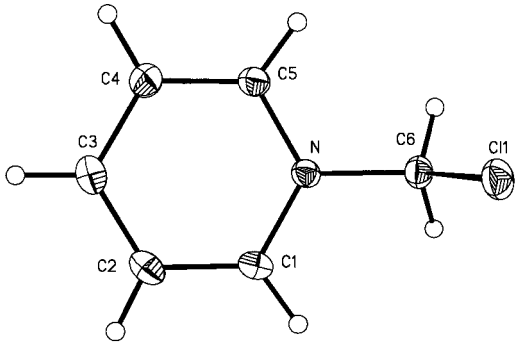

Figure 2. Crystal structure of **1a**. Bond lengths [pm] and angles [deg]: Cl(1)−C(6) 178.17(11), N−C(1) 135.21(14), C(1)−C(2) 137.70(16), C(2)−C(3) 138.88(18), C(3)−C(4) 138.86(17), C(4)−C(5) 137.46(16); C(5)−N−C(1) 121.87(9), C(1)−N−C(6) 119.31(9), N−C(6)−Cl(1) 109.17(8).

exchange) has been synthesized from Cl-CH_2-I by C. H. Calderon et al. However, neither spectroscopic or analytical data nor yield have been published.[6]

1-Bromomethylpyridinium Bromide (1b). Dibromomethane and pyridine have been reacted, giving exclusively *N*,*N*′-methylene-bis(pyridinium) dibromide.[4] The partial formation of **1b** was induced by suitable pressure reactions (solvent-free, molar ratio 2:1). In this reaction,[14] **1b** was neither isolated nor characterized by spectroscopic or other methods. Attempts to use Br-CH_2-I for the synthesis of **1b**, although conceivable, have not been reported. Application of our three-component reaction (thionyl bromide, formaldehyde, and pyridine) to this problem leads to **1b** with an isolated yield of 73%.

Structures. The C(6)−N bond length (or Cα−N^+, which is the notation used in this paper throughout) in **1a** (146.5 pm, Figure 2) appears not to be affected by the electronic influence of the Cl atom. It is almost identical to the corresponding bond length in the *N*-methylpyridinium cation (146.0 pm)[32] and is somewhat shorter than the corresponding bond in either the *N*-(1-chlorobenzyl)-pyridinium chloride **1** (R = Ph, 150.0 pm[33]) or the *N*-(1-sulfonatoalkyl)pyridinium betaine **2a** (R = 4-MeC_6H_4, 149.1 pm[34]). In contrast to these minor changes, the Cα-Cl bond lengths (178 pm) are almost identical to those in the haloalkylpyridinium salts **1**. Ab initio calculations on several levels of theory, as well as the inexpensive semiempirical methods (PM3, AM1), show acceptable overall agreement with the X-ray structural data (Table 1). The dihedral angle Cl−C(6)−N−C(1) (X-ray: 86.97°) indicates that the cation **1a** exhibits only a small deviation from ideal C_s symmetry.

To gain further insight into the structural properties of such compounds, we extended the calculations to the cations of **10** (Cl-CH(CCl_3)-), **16** (MeO-CH_2-), and **17** (Me_3SiO-CH_2-) and the methylpyridinium cation of **1** (R = X = H).

The calculated Cα−N^+ bond lengths (Table 2) of these pyridinium salts (as well as the bond orders BO and the reaction energies ΔH_R for a hypothetical dissociation to give the corresponding carbenium ion **18** and pyridines **7**, vide infra and Scheme 3) indicate that these bonds are significantly weakened in case of **16** (Cα−N^+ 153.5 pm, BO 0.82) and **17** (Cα−N^+ 152.3 pm, BO 0.85), as compared with the analogous bond in **1a** (Cα−N^+ 148.6 pm, BO 0.91) and the methylpyridinium cation (Cα−N^+ 148.6 pm, BO 0.91). The electron withdrawing CCl_3 substituent in **10** (Cα−N^+ 149.4 pm, BO 0.90) does not, as expected, cause such an effect. The background of this bond-lengthening effect can be found in the influence of the negative hyperconjugation or *bond/no-bond resonance* which depends on the extent of the interaction of the oxygen lone pair (n_O) with the antibonding Cα−N^+-σ bond (σ^*_{C-N}).[35]

Reactivity. The ab initio calculations led us to the interpretation that the oxygen-substituted compounds **16** and **17** should be much better candidates for nucleophilic substitution reactions that follow pathway b than the halo salts belonging to the **1a**−**f** family. The properties of the CCl_3-substituted cation of **10** should reveal more similarities with that of **1a** than with either **16** or **17**.

This interpretation is based on the structural and electronic properties of the pyridinium cations themselves. More reliable results could, however, be obtained by the calculation of relative activation barriers for the competing substitution reactions, especially if solvent effects are included in the calculations. To assess the reliability of actual methods as applied to the model systems in solution, we calculated the a and b gas-phase pathways (HF/6-31+G*//6-31+G*) and their counterparts in MeCN solution (vide supra) of the cations of **1a**, **16**, and **17**. We chose ammonia as a standard nucleophile. The results (Tables 3 and 4) indicate that all three cations prefer pathway b via TS2 in the gas phase. The activation barrier for the Cl displacement from **1a** is much smaller (+11.6 kcal/mol, relative to the alternative route b, Figure 1) than that for OMe- (**16**, +72.8 kcal/mol) or $OSiMe_3$-substitution (**17**, +69.2 kcal/mol). The same results are also found by comparing activation energies based on the separated reactants (≡0.0 kcal): pyridine substitution via TS2 requires significantly more energy for **1a** (32.8 kcal/mol) than for either **16** (15.1 kcal/mol) or **17** (14.8 kcal/mol). The activation barrier of route a which leads to TS1 is much smaller for **1a** (+44.4 kcal/mol) as compared with the values for **16** (+87.9 kcal/mol) and **17** (+83.9 kcal/mol).

We simulated both of these substitution pathways in MeCN solution using the Onsager model, Tables 3 and 4. Pathway a with substitution of Cl now appears to be energetically favored by 1.6 kcal/mol as compared with the pyridine substitution (pathway b). We then performed the similar TS1/TS2 calculations (Figure 3) for the OMe (**16**) and $OSiMe_3$ (**17**) cations. TS1 of both **16** and **17** remains significantly disfavored (+66.9 and +46.6 kcal/mol, respectively), thus indicating that pathway b should be preferred in MeCN. These findings are in complete agreement with our experimental observations.

Compound **16** has not yet been synthesized. However, we have a large body of synthetic data for nucleophilic substitution reactions with derivatives of **17** (synthesized

(31) Further details of the crystal structure investigations are available on request from the Cambridge Crystallographic Data Center, 12 Union Road, Cambridge CB2 1EZ, U.K., on quoting the depository number CCDC 104031(**1a**), CCDC 104032 (**2ha**), CCDC 104033 (**12**), and CCDC 104034 (**14**), the names of the authors, and the journal citation.

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Table 1. Structural Data of the 1-Chloromethylpyridinium Cation of 1a[a]

method	C(1)−Cl [pm]	C(6)−N [pm]	C(1)−N [pm]	C(1)−C(2) [pm]	C(2)−C(3) [pm]	ClC(6)NC(1) [deg]
PM3	177.2	148.9	137.7	139.1	139.6	88.5
AM1	174.6	146.6	137.1	139.9	140.0	89.4
RHF/6-311+G*//RHF/6-311+G*	176.4	146.9	134.1	137.0	138.8	88.76
RMP2/6-311+G*//RMP2/6-311+G*	175.7	147.9	135.5	138.9	139.8	89.17
RBP86/6-311+G*//RBP86/6-311+G*	178.4	148.6	136.4	138.8	140.2	88.69
RB3LYP/6-311+G*//RB3LYP/6-311+G*	178.1	147.9	135.5	138.0	139.5	88.78
X-ray	178.2(11)	146.5(14)	135.2(14)	137.7(16)	138.9(18)	86.97

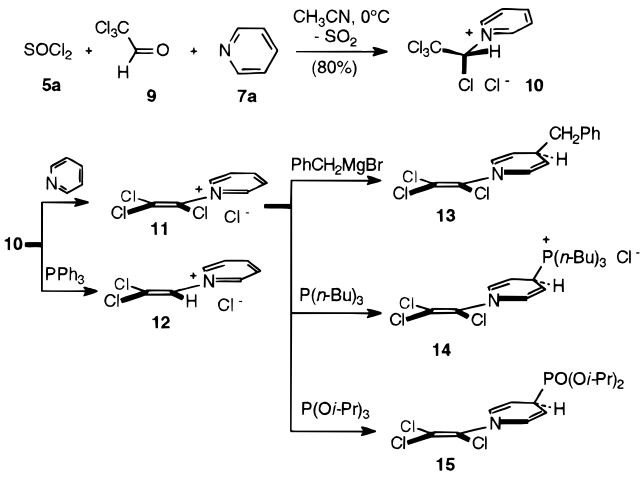
[a] For numbering, see Figure 2.

Table 2. Cations of 1, 1a, 10, 16, and 17. Cα−N^+ Bond Lengths (BL), Bond Orders (BO),[a] and Dissociation Energies (ΔH_R)[b]

molecule	BL [pm]	BO	ΔH_R [kcal/mol]
1[c]	148.6	0.91	120.95
1a	148.1	0.91	87.54
10	149.4	0.90	59.58
16	153.5	0.82	54.16
17	152.3	0.85	44.47

[a] From Natural Populations Analysis (NPA).[47] [b] RB3LYP/6-31+G* results; ΔH_R includes a zero-point energy correction with the scaling factor 0.98. [c] The parent 1-methylpyridinium cation, R = X = H, Figure 1.

Scheme 2. Some Aspects of the Chemistry of *N*-(1,2,2,2-Tetrachloroethyl)-pyridinium Chloride (10)



from aliphatic and aromatic aldehydes, pyridine, and trimethylsilyl triflate[36]). All of these results reveal that the exclusive preference of pathway b is the most important property of **17** (and presumably of **16** as well).

For the sake of completeness, we include semiempirical solvation calculations based on the Conductor-like Screening Model (COSMO) in implanted MOPAC. The results are promising but seem to overestimate the effect of the solvent significantly (Table 3).

Experimental Application. We found, in agreement with our calculational results, that a variety of heterocyclic nucleophiles (e.g., **7** and **8**) react with **1** to yield the geminal bis(heteroarylium) salts **2** (Scheme 4). For example, the chloride **1a** reacts with the heterocycles **7c**, **7g**, and **8a** to give *N*-(heteroarylium methyl)pyridinium dichlorides **2ea**, **2eb**, and **2fa** under mild conditions (room temperature) in excellent yields. In the case of the ambident triazole **8b** and the electrophile **1a**, we found

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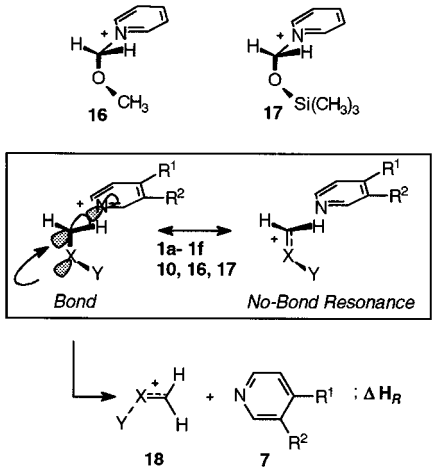
Scheme 3. Resonance Structures and Dissociation Energies of a Hypothetical Dissociation Reaction



the same highly selective alkylation (N4 of **8b** is attacked under formation of **2g**) as has been previously observed for *N*-(1-chloro*benzyl*)pyridinium chloride.[8] In general, the reaction rate decreases if the substituent R in **1** (Figure 1) is replaced by hydrogen when working under identical conditions. As a typical example, the reaction with **8b** in MeCN is almost complete after 8 h at room temperature when R = Ph and X = Cl. Under the same experimental conditions, the yield of **2g** does not exceed 20% but may be increased by heating under reflux (21 h, yield 92%). A substitution of the pyridine moiety under formation of species such as **3** (Nu = Nu′ = **8b**$^+$) was neither observed under our standard conditions nor obtained if either a double molar amount of **8b** was used or the more reactive bromine **1b** was used instead of **1a**. This is in contrast with the behavior of the pair of reactants *N*-[1-bromo-(4-methylphenyl)methyl]pyridinium bromide[9]/2 × **8b** from which the corresponding structure **3** (the bis[4-(5-amino-1-methyl-1*H*-1,2,4-triazolium)(4-methylphenyl)] methane) was isolated in 64% yield.[15] This comparison demonstrates that not only pathway a but also the consecutive second substitution reaction (pathway b) of the 1-halomethyl*pyridinium* salts **1a** and **1b** are more complicated as based on the properties of the aforementioned salts **1** with R = alkyl, aryl. This is further supported from the results of the reaction of **1a**/**1b** with 2 moles of the (ambident) nucleophile **8c**, a thiadiazole. Compound **1** (with R = alkyl, aryl, X = Cl, Br) reacts with **8c** via the corresponding structure **3** (Nu = Nu′ = **8c**$^+$) to give tricyclic 5/6/5 structures **3e**. However, in the case of **1a**/**1b**, only monosubstitution of Cα-bonded Cl or Br was observed to yield the related compounds **2ha** and **2hb**. A geminal bis(thiadiazolium) salt was not formed. The synthesis of 5/6/5 heterocycle **3e** (Figure 1, R = H) from **1a** or **1b** therefore appears to

Table 3. Transition Structures and ab Initio[a] and Semiempirical Gas-Phase and Solvation Calculations.[b,c] Alternative Pathways a via TS1 and b via TS2 for Nucleophilic Substitution Reactions. Model Nucleophile, NH_3

	energy[a] (ZPE)[e]		AM1[b]		PM3[b]	
structure[d]	gas phase	in MeCN[c]	gas phase	in MeCN[c]	gas phase	in MeCN[c]
TS1(**1a**)	−801.119 28 (107.48)	−801.144 75 (106.92)	229.0	142.7	224.7	147.8
TS2(**1a**)	−801.135 38 (105.82)	−801.140 42 (105.64)	209.4	159.5	209.9	159.7
Δ*E* TS1(**1a**)−TS2(**1a**)[d,e]	+11.58	−1.58	+19.6	−16.8	+14.8	−11.9
TS1(**16**)	−456.044 63 (134.54)	−456.060 55 (134.29)	217.6	136.7	217.4	142.4
TS2(**16**)	−456.159 34 (133.57)	−456.165 53 (133.20)	152.9	104.6	165.4	117.0
Δ*E* TS1(**16**)−TS2(**16**)[d,e]	+72.84	+66.85	+64.7	+32.1	+52.0	+25.4
TS1(**17**)	−824.297 50 (183.64)	−824.336 01 (182.77)	167.6	92.8	153.6	81.6
TS2(**17**)	−824.405 54 (182.04)	−824.408 52 (181.56)	82.1	41.4	72.8	31.9
Δ*E* TS1(**17**)−TS2(**17**)[d,e]	+69.16	+46.58	+85.5	+51.4	+80.8	+49.7

[a] RHF/6-31+G*//RHF/6-31+G* results, energies in au. [b] Energies in kcal/mol. [c] Ab initio, simulating MeCN (Onsager model); semiempirical, COSMO model, MOPAPC 93 keywords NSPA = 60, EPS = 35.9, TS, PRECISE. [d] All structures, number of imaginary frequencies = 1. For ab initio calculations, relative energies are ZPE-corrected (scaling factor, 0.89). [e] Zero Point Energy (kcal/mol).

Table 4. Activation Energies for the Nucleophilic Reaction of NH_3 with the Pyridinium Salts 1a, 16, and 17, Alternative Pathways a and b

	activation energy[a]	
structure	via TS1	via TS2
1a	+44.42 [+31.62][b]	+32.84 [+33.20]
16	+87.89 [+79.94]	+15.05 [+13.09]
17	+83.94 [+65.04]	+14.78 [+18.47]

[a] In kcal/mol from RHF/6-31+G*//RHF/6-31+G* optimizations. Separated reactants ≡ 0 kcal/mol. Relative energies are ZPE-corrected (scaling factor, 0.89). [b] Gas-phase calculations [in brackets], simulation of the MeCN solution. Compare Figure 1 and Table 3.

be almost impossible under moderate reaction conditions.[15] Only after a reaction time of 50 h at 80 °C was a minor amount (∼10%) of compound **3e** (R = H), along with other products, detected in the ^{1}H NMR of the crude reaction mixture.

More uncomplicated substitution reactions are possible at room temperature in MeCN between halomethylpyridinium derivatives such as **1d** (R^1 = CN, R^2 = H), **1e** (R^1 = H, R^2 = CN), or **1f** (R^1 = H, R^2 = CO_2Me) and 1-methylimidazole (**8a**). This reaction lead to the mixed bisonium compounds **2fa**−**2fg** in excellent yields. Interestingly enough, the 4-cyano substituted salt **1d** reacts with some other heterocyclic nucleophiles, for instance **7c** and **8c**, to yield a complex mixture of products. ^{1}H NMR and CI MS spectra of the reaction mixtures show the simultaneous formation of the *substitution products* ***2***, ***3***, *and* ***4*** *from both pathways a and b*. Two typical examples: **1d** reacts with **7c** to give **2fa** and, after substitution of the 4-cyanyopyridine **7d**, a mixture of both products **3a** and **4a** (Nu′ = Nu = **7c**, X = Cl). Reactants **8c** and **1d** yield the compound mixture **2ha**, **3b**, and **4b** (Nu′ = Nu = **8c**, X = Cl). Attempts to isolate these products have not yet been successful. Although the 4-cyano group weakens the Cα−N^+ bond, the feasibility of reactions due to pathway b increases only to a minor extent. The preference of pathway a reactions remains the dominant property of salts **1a**−**f**.

The new mixed bisonium salts **2** (Scheme 4) were characterized by NMR spectroscopic methods, massspectroscopy, and elemental analyses (see the Experimental Section). The exchange of the covalently bonded halogen atom in **1** with the heterocyclic nitrogen nucleophiles **7** and **8** causes downfield chemical shifts of the methylene signals of about 0.4−0.9 ppm. In addition, the ^{1}H and ^{13}C NMR signals of the pyridinium CH units in the product salts **2** do not differ significantly from those of the parent salt **1a**. We therefore conclude that the electron acceptor properties of the Cα-bound chlorine and the incoming heteroarylium moieties are similar.

Regioselectivity. The reaction of **1a** with the nucleophiles **8b** and **8c** occurs in all cases at nitrogen ring atoms which are adjacent to the amino groups (N4 in **8b**, N3 in **8c**). This highly selective attack parallels the increasing negative charges at the competitive nitrogen centers in **8b** and **8c**[8,15] and follows the decreasing activation barrier for the alkylation of these nitrogen centers. These results are comparable to those previously observed for protonation reactions at either the N4 atom in **8b**[37,38] or the N3 atom in **8c**.[39] The formation of **2g** and **2ha** was also confirmed by means of NMR and IR spectroscopy; the characteristic NH_2 singlets are shifted significantly downfield (δ 9.86 ppm (**2g**) and 11.76 ppm (**2ha**)). This proves beyond doubt that primary amino groups are present and indicates, in agreement with the IR spectra, the presence of amino triazolium or amino thiadiazolium units. The structure of **2ha** was confirmed by X-ray analysis (Figure 4). As compared with **1a**, substitution of the C-bound Cl atom causes a slight elongation of the Cα−N^+ (pyridine) bond length (**1a**, 146.5(14); **2ha**, 149.4(2) pm).[31]

We then completed our experimental study on Cα substituent effects by synthesizing and investigating *N*-(1,2,2,2-tetrachloroethyl)pyridinium chloride (**10**). The synthesis of **10** follows our standard three-component reaction in which thionyl chloride (**5a**), trichloroacetaldehyde (**9**), and pyridine (**7a**) were reacted at 0 °C in MeCN to give this salt in excellent yield (Scheme 2).

As might be expected, the CCl_3 group causes significant downfield shifts in both the ^{1}H and ^{13}C NMR spectra, thus indicating interesting properties of the central CHCl group.

Compound **10** was then reacted with 1 equiv of the ambident nucleophile **8b** at room temperature. Interestingly enough, neither substitution pathway a nor b were observed. This salt prefers an alternative route. The triazole derivative functions as a base and, after the elimination of HCl, the *N*-(trichloroethenyl)pyridinium chloride (**11**) was isolated. We improved this synthesis by using pyridine as a base and EtOH as the solvent. Again, the Cl substitution (pathway a) was not possible. We tried further nucleophiles which we have previously successfully applied, e.g., triphenylphosphane, which in

(37) Barlin, G. B.; Batterham, T. J. *J. Chem. Soc.* (B) **1967**, 516.
(38) Lynch, D. E.; Smith, G. *Acta Crystallogr.* **1994**, *C50*, 129.
(39) Antolini, L.; Cornia, A.; Fabretti, A. C.; Malavasi, W. *J. Crystallogr. Spectrosc. Res.* **1993**, *23*, 967.

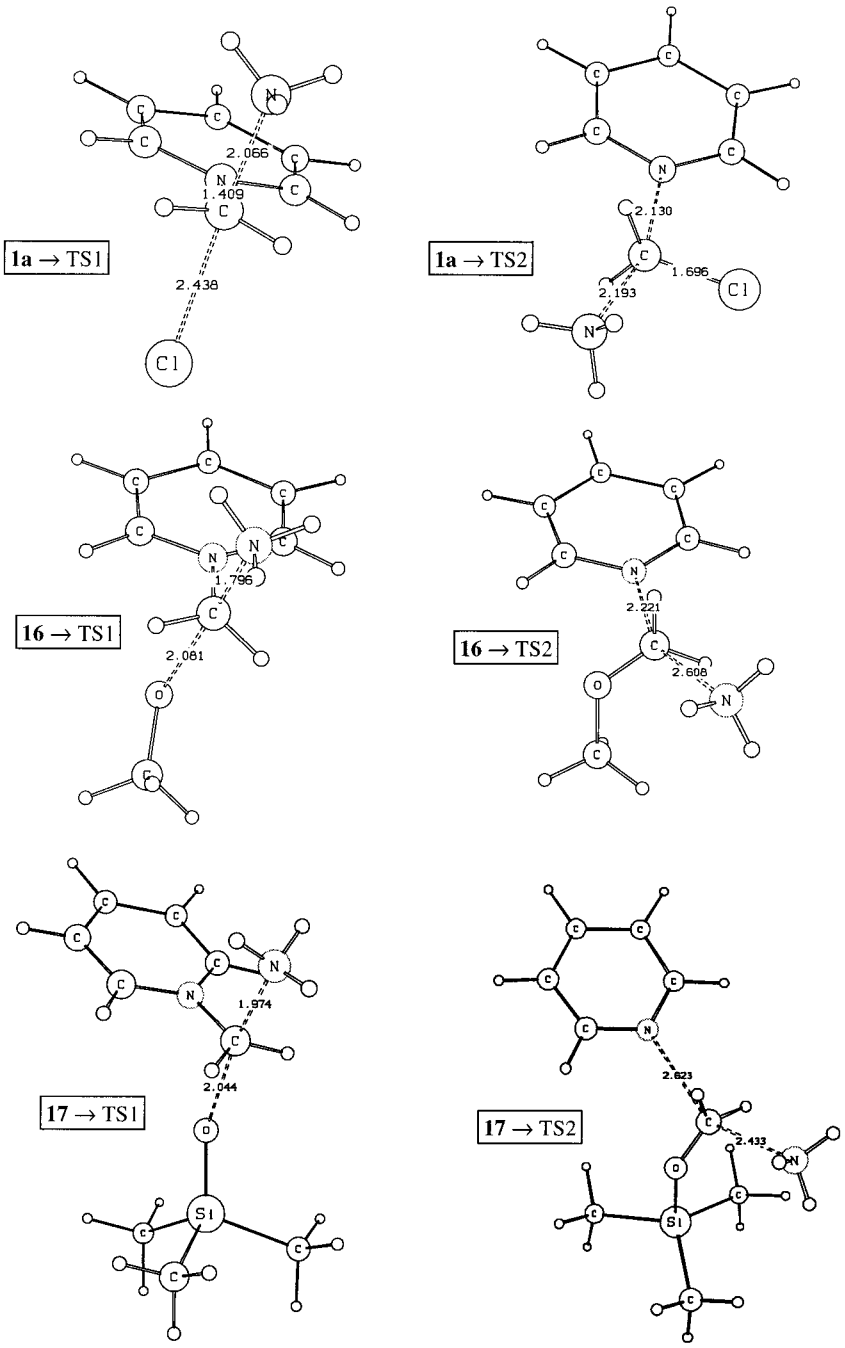


Figure 3. Ab initio (RHF/6-31+G*) transition structures (application of the Onsager method) for pathways a and b of nucleophilic substitution reactions of pyridinium salts **1** in MeCN using ammonia as a model nucleophile (TS1, pathway a; TS2, pathway b; see Figure 1).

the case of **1** with R = Ph substitutes the Cl atom to give **2c** (cf. ref 7, Figure 1). Surprisingly, the application of PPh_3 initiated a very effective dehalogenation with formation of the *N*-(2,2-dichloroethenyl)pyridinium chloride (**12**). The phosphonium/pyridinium dication was not formed.

Both of these novel chloroethenyl-pyridinium compounds **11** and **12** were analyzed by spectroscopic means (^{1}H and ^{13}C NMR, IR, MS). The structure of **12** has been further confirmed by X-ray analysis (Figure 5).[31]

Interestingly enough, the reaction of **11** with tri-*n*-butylphosphane results in the formation of the C4 addition product, *i.e.*, the phosphonium salt **14** (91%). The isomeric C2-product was not observed. The X-ray structure of **14** (Figure 6) reveals a remarkably short C(vinyl)−N^+ bond length (139.3(5) pm).

It is noteworthy that nucleophilic reactions at the C atoms in the pyridinium moiety cannot be performed with "normal" *N*-substituted pyridinium salts. Activation of the C4 position needs, in general, very strong electron-withdrawing *N*-substituents, e.g., the CF_3SO_2 group.[40,41] The trichlorovinyl group fulfills this condition and allows further related reactions, e.g., with Grignard reagents and trialkyl phosphites to give the *N*-(trichlorovinyl)-4-phenylmethyl- or 4-phoshonato-1,4-dihydropyridines (**13**) (74% yield) and (**15**) (80%), respectively. Compound **13**

(40) Anders, E.; Markus, F. *Tetrahedron Lett.* **1987**, *28*, 2675.
(41) Anders, E.; Markus, F. *Chem. Ber.* **1989**, *122*, 113.

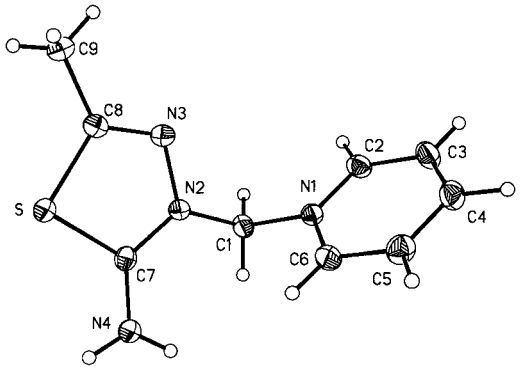


Figure 4. Crystal structure of **2ha**. Selected bond lengths [pm] and bond angles [deg]: N(1)−C(1) 149.4(2), N(2)−C(1) 144.5(2), C(1)−H(1A) 101(2), C(1)−H(1B) 0.95(2); N(1)−C(1)−H(1A) 108.5(10), N(1)−C(1)−H(1B) 106.4(11), N(2)−C(1)−H(1A) 108.7(10), N(2)−C(1)−H(1B) 109.9(10), C(6)−N(1)−C(1) 119.07(13), C(7)−N(2)−C(1) 126.63(14), C(2)−N(1)−C(1) 119.28-(13).

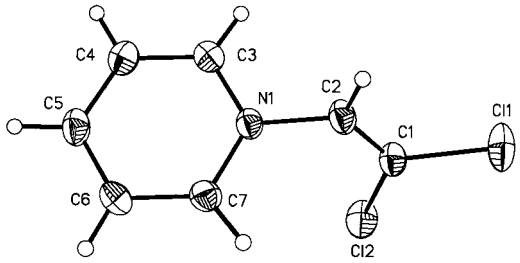
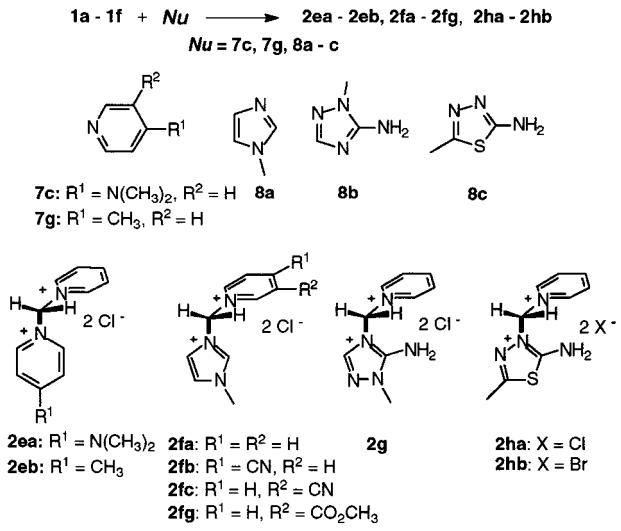


Figure 5. Crystal structure of **12.** Selected bond lengths [pm] and bond angles [deg]: C1(1)−C(1) 171.9(2), Cl(2)−C(1) 170.9-(2), C(1)−C(2) 131.2(3), C(2)−N(1) 144.4(2), N(1)−C(3) 134.7-(2), N(1)−C(7) 135.0(2); C(2)−C(1)−Cl(2) 126.1(2), C(2)−C(1)−Cl(1) 119.4(2), Cl(2)−C(1)−Cl(1) 114.52(11), C(1)−C(2)−H(2) 123(2), C(1)−C(2)−N(1) 122.1(2).

Scheme 4. Substitution Reactions of *N*-Halomethylpyridinium Salts 1a−f with Heterocyclic Nucleophiles 7 and 8



is very sensitive toward oxygen and should be handled under N_2. An alternative formation of an inamine caused by a dehalogenation comparable to the reaction of polyhaloenamines with lithium or magnesium alkyl compounds[42,43] was not observed.

(42) Ficini, J.; Barbara, C. *Bull. Soc. Chim. Fr.* **1964**, 871.

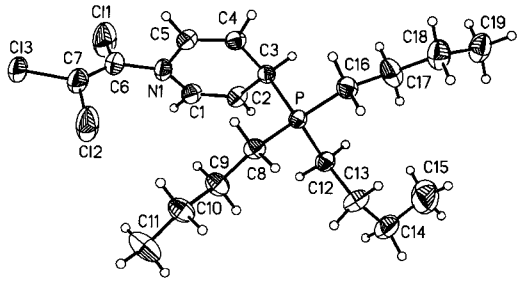


Figure 6. Crystal structure of **14**. Selected bond lengths [pm] and bond angles [deg]: N(1)−C(6) 1393(5), N(1)−C(1) 139.6-(5), N(1)−C(5) 140.5(5), C(1)−C(2) 131.8(5), C(2)−C(3) 150.2-(5), C(3)−P(1) 183.3(3), C(6)−C(7) 128.4(7), C(6)−Cl(1) 188.8-(9), C(7)−Cl(3) 171.0(4), C(7)−Cl(2) 173.2(8); C(6)−N(1)−C(1) 119.9(3), N(1)−C(6)−Cl(1) 114.5(4), C(7)−C(6)−N(1) 126.4(5), C(6)−C(7)−Cl(3) 125.9(4), P(1)−C(3)−H(3) 104(2).

Conclusion

These investigations show that the reactivity pattern of heteroarylium cations such as **1**, **10**, **16**, and **17** is determined by the increasing importance of the negative hyperconjugation due to the $n_X/\sigma^*_{C-N^+}$ interaction in the X-Cα-Py$^+$ moiety. This effect causes dramatic changes in the energy gaps between the two transition states TS1 and TS2 in the gas phase. TS1 and TS2 correspond to the two alternative nucleophilic substitution pathways a and b. In solution, small energy gaps between TS1 and TS2 may change their sign and value. Whereas the substitution of pyridine (pathway b) is the general pathway in the gas phase, the behavior of **1** changes in MeCN, with pathway a becoming dominant. The Onsager method appears to be a useful tool to estimate the relative energy changes, whereas the semiempirical COSMO method seems to overestimate solvation effects.

The influence of substituents at the pyridinium ring may increase or decrease the TS1/TS2 gap. This allows, to a minor extent, a remote control of the reaction pathways.

Experimental Section

General Methods. Melting points (uncorrected) were obtaining using a Lindstrom copper block apparatus. Reagents of commercial quality were purified by common methods. 5-Amino-1-methyl-1*H*-1,2,4-triazole was prepared according to the literature.[44] NMR spectra were obtained at 250 or 400 MHz and 62.5 or 100 MHz, for proton and carbon, respectively. For ^{1}H and ^{13}C NMR, DMSO-d_6 (H $\delta = 2.49$, C $\delta = 39.5$) was used as solvent, and TMS was used as internal standard.

Crystal Structure Analysis of 1a, 2ha, 12, and 14. Data Collection. The intensity data for the compounds were collected on a diffractometer using graphite-monochromated Mo Kα radiation. Data were corrected for Lorentz and polarization effects but not for absorption.

Structure Solution and Refinement. The structures were solved by direct methods (SHELXS[45]) and refined by full-matrix least-squares techniques against Fo^2 (SHELXL-97[46]).

The hydrogen atoms were located by difference Fourier synthesis and refined isotropically. All non-hydrogen atoms were refined anisotropically.

(43) Ficini, J.; Barbara, C. *Bull. Soc. Chim. Fr.* **1965**, 2787.
(44) Barascut, J.-L.; Claramunt, R.-M.; Elguero, J. *Bull. Soc. Chim. Fr.* **1973**, 1849.
(45) Sheldrick, G. M. *Acta Crystallogr. Sect. A* **1990**, *46*, 467−473.
(46) Sheldrick, G. M. *SHELXL-97*; University of Göttingen: Germany, 1997.
(47) Reed, A. E.; Curtiss, L. A.; Weinhold, F. *Chem. Rev.* **1988**, *88*, 899.

Crystal data for 1a:[31] $[C_6H_7ClN]^+Cl^-$, $M_r = 164.03$ g mol^{-1}, colorless prism, size 0.40 × 0.38 × 0.36 mm^3, orthorhombic, space group *Pbca*, $a = 8.353(2)$, $b = 10.780(2)$, $c = 16.262(3)$ Å, $V = 1464.3(5)$ Å^3, $T = -90$ °C, $Z = 8$, $\rho_{calcd} = 1.488$ g cm^{-3}, μ (Mo Kα) = 7.92 cm^{-1}, F(000) = 672, 2538 reflections in h(−12/0), k(−16/0), l(0/24), measured in the range $2.50° \le \Theta \le 31.96°$, 2538 independent reflections, 2219 reflections with $F_o > 4\sigma(F_o)$, 111 parameters, $R1_{obs} = 0.027$, $wR^2_{obs} = 0.072$, $R1_{all} = 0.036$, $wR^2_{all} = 0.079$, GOOF = 1.141, largest difference peak and hole 0.457 / −0.232 e Å^{-3}.

Crystal data for 2ha:[31] $[C_9H_{12}N_4OS]^{2+}2Cl^-\cdot H_2O$, $M_r = 297.20$ g mol^{-1}, colorless prism, size 0.32 × 0.30 × 0.20 mm^3, monoclinic, space group $P2_1/c$, $a = 11.7095(4)$, $b = 8.8223(3)$, $c = 13.9315(4)$ Å, $\beta = 111.243(2)°$, $V = 1341.40(8)$ Å^3, $T = -90$ °C, $Z = 4$, $\rho_{calcd} = 1.472$ g cm^{-3}, μ (Mo Kα) = 6.3 cm^{-1}, F(000) = 616, 3507 reflections in h(−13/12), k(−9/0), l(−15/15), measured in the range $2.79° \le \Theta \le 23.27°$, 1927 independent reflections, $R_{int} = 0.021$, 1767 reflections with $F_o > 4\sigma(F_o)$, 211 parameters, $R1_{obs} = 0.025$, $wR^2_{obs} = 0.078$, $R1_{all} = 0.032$, $wR^2_{all} = 0.120$, GOOF = 0.946, largest difference peak and hole 0.196/−0.231 e Å^{-3}.

Crystal data for 12:[31] $[C_7H_6Cl_2N]^+Cl^-$, $M_r = 210.48$ g mol^{-1}, colorless prism, size 0.39 × 0.32 × 0.28 mm^3, orthorhombic, space group *Pbca*, $a = 7.996(2)$, $b = 12.548(2)$, $c = 18.035(2)$ Å, $V = 1809.5(6)$ Å^3, $T = -90$ °C, $Z = 8$, $\rho_{calcd} = 1.545$ g cm^{-3}, μ (Mo Kα) = 9.45 cm^{-1}, F(000) = 848, 1833 reflections in h(0/9), k(−15/0), l(0/22), measured in the range $2.26° \le \Theta \le 26.32°$, 1833 independent reflections, 1673 reflections with $F_o > 4\sigma(F_o)$, 124 parameters, $R1_{obs} = 0.032$, $wR^2_{obs} = 0.085$, $R1_{all} = 0.043$, $wR^2_{all} = 0.102$, GOOF = 1.106, largest difference peak and hole 0.203/−0.426 e Å^{-3}.

Crystal data for 14:[31] $[C_{19}H_{32}Cl_3NP]^+Cl^-\cdot CH_2Cl_2$, $M_r = 532.15$ g mol^{-1}, colorless prism, size 0.42 × 0.32 × 0.21 mm^3, monoclinic, space group *C*2/*c*, $a = 24.284(2)$, $b = 8.352(2)$, $c = 27.685(4)$ Å, $\beta = 106.78(1)°$, $V = 5376(2)$ Å^3, $T = -90$ °C, $Z = 8$, $\rho_{calcd} = 1.315$ g cm^{-3}, μ (Mo Kα) = 7.07 cm^{-1}, F(000) = 2224, 4651 reflections in h(−28/27), k(−9/0), l(0/32), measured in the range $2.59° \le \Theta \le 24.67°$, 4543 independent reflections, $R_{int} = 0.013$, 3774 reflections with $F_o > 4\sigma(F_o)$, 334 parameters, $R1_{obs} = 0.061$, $wR^2_{obs} = 0.162$, $R1_{all} = 0.075$, $wR^2_{all} = 0.188$, GOOF = 1.091, largest difference peak and hole 1.088/−0.806 e Å^{-3}.

General Procedure for the Synthesis of *N*−Monohalomethylpyridinium Halides 1a−f. To a stirred solution of 0.1 mol of **5** (X = Br, Cl) in dichloromethane (150 mL) or MeCN (150 mL) was added 0.1 mol of **7a**−**f** at 0 °C under an atmosphere of argon. Gaseous **6** was generated by heating of paraformaldehyde in a separate flask equipped with a short wide tube. The formaldehyde was then immediately introduced into the reaction mixture for a period of 15 min. The mixture was slightly concentrated, and then the resulting precipitate was filtered off under vacuum and extracted with 100 mL of acetone/methanol (1:1) at 60 °C. Paraformaldehyde formed again was separated by filtration. The filtrate was evaporated, and the residue was recrystallized from MeCN.

1-Chloromethylpyridinium chloride (1a): mp 172 °C; ^{1}H NMR (DMSO-d_6) δ 6.74 (s, 2H), 8.30 (t, 2H), 8.79 (t, 1H), 9.50 (d, 2H, $J = 6.3$ Hz); ^{13}C NMR (DMSO-d_6) δ 64.1, 128.7, 145.5, 148.3; FAB MS *m*/*z* 128 (100) for $C_6H_7ClN^+$. Anal. Calcd for $C_6H_7Cl_2N$: C, 43.93; H, 4.30; Cl, 43.23; N, 8.54. Found: C, 43.80; H, 4.59; Cl, 42.52; N, 8.53.

1-Bromomethylpyridinium bromide (1b): mp 215 °C (dec); ^{1}H NMR (DMSO-d_6) δ 6.57 (s, 2H), 8.26 (t, 2H), 8.76 (t, 1H), 9.34 (d, 2H, $J = 6.4$ Hz); ^{13}C NMR (DMSO-d_6) δ 50.7, 128.8, 145.3, 148.0; CI MS *m*/*z* 172 (71) for $C_6H_7BrN^+$. Anal. Calcd for $C_6H_7Br_2N$: C, 28.49; H, 2.79; Br, 63.18; N, 5.54. Found: C, 28.49; H, 2.83; Br, 62.51; N, 5.58.

1-Chloromethyl-4-dimethylaminopyridinium chloride (1c): mp 236 °C (dec); ^{1}H NMR (DMSO-d_6) δ 3.24 (s, 6H), 6.25 (s, 2H), 7.13 (d, 2H, $J = 7.9$ Hz), 8.52 (d, 2H, $J = 8.0$ Hz); ^{13}C NMR (DMSO-d_6) δ 40.2, 62.4, 108.3, 141.8, 156.5; FAB MS *m*/*z* 171 (100) for $C_8H_{12}ClN_2^+$. Anal. Calcd for $C_8H_{12}Cl_2N_2$: C, 46.40; H, 5.84; Cl, 34.24; N, 13.53. Found: C, 46.20; H, 5.96; Cl, 33.56; N, 13.31.

1-Chloromethyl-4-cyanopyridinium chloride (1d): mp 182 °C (dec); IR (KBr) CN inactive; ^{1}H NMR (DMSO-d_6) δ 6.82 (s, 2H), 8.86 (d, 2H, $J = 6.8$ Hz), 9.85 (d, 2H, $J = 6.7$ Hz); ^{13}C NMR (DMSO-d_6) δ 64.4, 114.6, 129.1, 131.6, 146.8; FAB MS *m*/*z* 153 (60) for $C_7H_6ClN_2^+$. Anal. Calcd for $C_7H_6Cl_2N_2$: C, 44.47; H, 3.20; Cl 37.51, N 14.82. Found: C, 44.35; H, 3.21; Cl, 36.80; N, 14.83.

1-Chloromethyl-3-cyanopyridinium chloride (1e): mp 179 °C (dec); IR (KBr) 2245 cm^{-1}; ^{1}H NMR (DMSO-d_6) δ 6.79 (s, 2H), 8.50 (t, 1H), 9.27 (d, 1H, $J = 8.2$ Hz), 9.81 (d, 1H, $J = 6.3$ Hz), 10.41 (s, 1H); ^{13}C NMR (DMSO-d_6) δ 64.2, 113.1, 113.6, 129.0, 148.7, 149.8, 151.0; FAB MS *m*/*z* 153 (40) for $C_7H_6ClN_2^+$. Anal. Calcd for $C_7H_6Cl_2N_2$: C, 44.47; H, 3.20; Cl, 37.51; N, 14.82. Found: C, 43.87; H, 3.44; Cl, 37.06; N, 15.03.

1-Chloromethyl-3-methoxycarbonylpyridinium chloride (1f): oil; IR (film) 1738 cm^{-1}; ^{1}H NMR (DMSO-d_6) δ 3.98 (s, 3H), 6.83 (s, 2H), 8.44 (t, 1H), 9.14 (d, 2H, $J = 8.2$ Hz), 9.74 (d, 2H, $J = 6.3$ Hz), 10.03 (s, 1H); ^{13}C NMR (DMSO-d_6) δ 53.6, 64.2, 129.1, 130.2, 146.5, 147.7, 148.6, 161.8; FAB MS *m*/*z* 186 (35) for $C_8H_9ClNO_2^+$.

General Procedure for the Synthesis of Bis(heteroarylium)methanes 2. A solution of 5 mmol of a nitrogen nucleophile (**7c, 7g, 8a**−**c** in MeCN (10 mL)) was added to a suspension of 5 mmol of pyridinium salt **1** in MeCN (40 mL). The mixture was then stirred at room temperature for 15 h. The precipitate was filtered off and recrystallized from MeOH/*tert*-butyl methyl ether.

1-[(4-*N*,*N*-Dimethylaminopyridinium)methyl]pyridinium dichloride (2ea): 90%; mp 236 °C; IR (KBr) 3372 cm^{-1}; ^{1}H NMR (DMSO-d_6) δ 3.22 (s, 6H), 7.17 (d, 2H, $J = 7.9$ Hz), 7.21 (s, 2H), 8.28 (t, 2H), 8.74 (t, 1H), 9.05 (d, 2H, $J = 7.8$ Hz), 9.80 (d, 2H, $J = 6.0$ Hz); ^{13}C NMR (DMSO-d_6) δ 40.1, 73.2, 108.2, 128.5, 142.1, 145.0, 148.0, 156.6; FAB MS *m*/*z* 214 (31) for $C_{13}H_{16}N_3^+$. Anal. Calcd for $C_{13}H_{17}Cl_2N_3\cdot H_2O$: C, 51.33; H, 6.30; Cl, 23.31; N, 13.81. Found: C, 52.02; H, 6.29; Cl, 23.17; N, 13.56.

1-[(4-Methylpyridinium)methyl]pyridinium dichloride (2eb): 77%; mp 211 °C; ^{1}H NMR (DMSO-d_6) δ 2.64 (s, 3H), 7.57 (s, 2H), 8.14 (d, 2H, $J = 6.5$ Hz), 8.30 (t, 2H), 8.76 (t, 1H), 9.72 (d, 2H, $J = 6.6$ Hz), 9.88 (d, 2H, $J = 5.7$ Hz); ^{13}C NMR (DMSO-d_6) δ 21.8, 75.0, 128.5, 128.9, 144.8, 145.9, 148.5, 162.5; FAB MS *m*/*z* 221 (62) for $C_{12}H_{14}ClN_2^+$, 185 (8) for $C_{12}H_3N_2^+$. Anal. Calcd for $C_{12}H_{14}Cl_2N_2\cdot H_2O$: C, 54.39; H, 5.32; Cl, 26.74; N, 10.56. Found: C, 54.14, H, 5.67, Cl, 24.46, N, 10.58.

1-[(1-Methylimidazol-3-ylium)methyl]pyridinium dichloride (2fa): 56%; mp 253 °C; IR (KBr) 3412 cm^{-1}; ^{1}H NMR (DMSO-d_6) δ 3.34 (s, 3H), 7.26 (s, 2H), 7.81 (s, 1H), 8.29 (t, 2H), 8.38 (s, 1H), 8.75 (t, 1H), 9.70 (d, 2H, $J = 5.8$ Hz), 9.98 (s, 1H); ^{13}C NMR (DMSO-d_6) δ 36.2, 66.9, 122.2, 124.3, 128.3, 138.9, 145.3, 148.1; FAB MS *m*/*z* 210 (20) for $C_{10}H_{13}ClN_3^+$, 174 (91) for $C_{10}H_{12}N_3^+$. Anal. Calcd for $C_{10}H_{13}Cl_2N_3\cdot H_2O$: C, 45.47; H, 5.72; Cl, 26.84; N; 15.91. Found: C, 45.50; H, 5.63; Cl, 26.75; N, 16.00.

1-[(5-Amino-1-methyl-1*H*-1,2,4-triazol-4-ylium)methyl]pyridinium dichloride (2g): 92% (reaction was carried out at 80 °C, 21 h), mp 255 °C (dec); IR (KBr) 3453, 1684, 1576 cm^{-1}; ^{1}H NMR (DMSO-d_6) δ 3.64 (s, 3H), 7.13 (s, 2H), 8.31 (t, 2H), 8.74 (t, 1H), 9.03 (s, 1H), 9.58 (d, 2H, $J = 5.7$ Hz), 9.86 (s, 2H); ^{13}C NMR (DMSO-d_6) δ 35.1, 63.6, 128.1, 138.9, 144.7, 147.8, 149.5; CI MS *m*/*z* 190 (10) for $C_9H_{12}N_5^+$. Anal. Calcd for $C_9H_{13}Cl_2N_5$: C, 41.24; H, 5.00; Cl, 27.05; N, 26.72. Found: C, 41.32; H; 5.04; Cl, 27.04; N, 26.59.

1-[(2-Amino-5-methyl-1,3,4-thiadiazol-3-ylium)methyl]pyridinium dichloride (2ha): 65%, mp 179−182 °C (dec); IR (ATR) 3449, 3401, 1634 cm^{-1}; ^{1}H NMR (DMSO-d_6) δ 2.50 (s, 3H), 7.24 (s, 2H), 8.26 (t, 2H), 8.72 (t, 1H), 9.40 (d, 2H, $J = 5.8$ Hz), 11.76 (s, 2H); ^{13}C NMR (DMSO-d_6) δ 16.1, 68.3, 128.3, 145.2, 148.0, 155.9, 169.6. FAB MS *m*/*z* 207 (31) for $C_9H_{11}N_4S^+$. Anal. Calcd for $C_9H_{12}Cl_2N_4S$: C, 38.72; H, 4.33; Cl, 25.40; N, 20.07; S, 11.48. Found: C, 38.31; H, 4.45; Cl, 24.01; N, 19.34: S, 11.85.

1-[(2-Amino-5-methyl-1,3,4-thiadiazol-3-ylium)methyl]pyridinium dibromide (2hb): 62%, mp 200−202 °C; IR (ATR) 3447, 3400, 1635 cm^{-1}; ^{1}H NMR (DMSO-d_6) δ 2.50 (s,

3H), 6.95 (s, 2H), 8.28 (t, 2H), 8.76 (t, 1H), 9.23 (d, 2H, $J = 6.0$ Hz), 10.80 (s, 2H); ^{13}C NMR (DMSO-d_6) δ 16.2, 68.4, 128.3, 144.98, 148.1, 156.0, 169.7; FAB MS *m/z* 208 (33) for $C_9H_{12}N_4S^+$. Anal. Calcd for $C_9H_{12}Br_2N_4S$: C, 29.37; H, 3.29; Br, 43.42; N, 15.22; S; 8.71. Found: C, 29.38; H, 3.29; Br, 42.83; N, 15.49; S, 8.75.

4-Cyano-1-[(1-methylimidazol-3-ylium)methyl]pyridinium dichloride (2fb): 89%, mp 212−213 °C; IR (KBr) CN inactive; ^{1}H NMR (DMSO-d_6) δ 3.89 (s, 3H), 7.40 (s, 2H), 7.82 (s, 1H), 8.44 (s, 1H), 8.87 (d, 2H, $J = 6.8$ Hz), 10.06 (s, 1H), 10.11 (d, 2H, $J = 6.9$ Hz); ^{13}C NMR (DMSO-d_6) δ 36.2, 67.1, 114.6, 122.4, 124.2, 128.8, 131.2, 139.1, 146.9; FAB MS *m/z* 200 (39) for $C_{11}H_{12}N_4^+$. Anal. Calcd for $C_{11}H_{12}Cl_2N_4$: C, 48.78; H, 4.46; Cl, 26.15; N, 20.66. Found: C, 48.57; H, 4.64; Cl, 25.79; N, 20.45.

3-Cyano-1-[(1-methylimidazol-3-ylium)methyl]pyridinium dichloride (2fc): 93%, mp 185 °C; IR (KBr) 2250 cm^{-1}; ^{1}H NMR (DMSO-d_6) δ 3.90 (s, 3H), 7.37 (s, 2H), 7.65 (s, 1H), 8.45 (s, 1H), 8.50 (t, 1H), 9.24 (d, 1H, $J = 8.2$ Hz), 10.07 (d, 1H, $J = 7.9$ Hz), 10.11 (s, 1H), 10.57 (s, 1H); ^{13}C NMR (DMSO-d_6) δ 36.2, 66.8, 112.6, 113.6, 122.5, 124.1, 128.6, 139.2, 148.8, 149.8, 150.8; FAB MS *m/z* 235 (36) for $C_{11}H_{12}ClN_4^+$. Anal. Calcd for $C_{11}H_{12}Cl_2N_4$: C, 48.73; H, 4.46; Cl, 26.15; N, 20.66. Found: C, 48.23; H, 4.50; Cl, 26.21; N, 20.44.

3-Methoxycarbonyl-1-[(1-methylimidazol-3-ylium)-methyl]pyridinium dichloride (2fg): 84%, mp 152 °C; IR (KBr) 1728 cm^{-1}; ^{1}H NMR (DMSO-d_6) δ 3.89 (s, 3H), 3.98 (s, 3H), 7.42 (s, 2H), 7.85 (s, 1H), 8.41 (t, 1H), 8.45 (s, 1H), 9.11 (d, 1H, $J = 8.1$ Hz), 10.03 (d, 1H, $J = 5.5$ Hz), 10.09 (s, 1H), 10.23 (s, 1H); ^{13}C NMR (DMSO-d_6) δ 36.2, 53.6, 66.9, 122.3, 124.2, 128.7, 129.8, 139.0, 147.0, 147.5, 148.5, 161.9; CI MS *m/z* 232 (3) for $C_{12}H_{14}N_3O_2^+$. Anal. Calcd for $C_{12}H_{15}Cl_2N_3O_2\cdot H_2O$: C, 44.73; H, 5.32; Cl, 22.01; N, 13.04. Found: C, 44.82; H, 5.47; Cl, 20.77; N, 12.97.

***N*-(1,2,2,2-Tetrachloroethyl)pyridinium Chloride (10).** To a solution of **5a** (36.3 g, 305 mmol) in MeCN (70 mL) was added **7a** (24.1 g, 305 mmol) in MeCN (40 mL) at O °C. To this mixture was slowly added a solution of trichloroacetaldehyde (**9**) (44.2 g, 300 mmol) in MeCN (40 mL) in a dropwise manner; the reaction temperature is not to go beyond 5 °C. The reaction mixture was stirred for 2 h at room temperature. The precipitate was filtered off by suction and twice washed with MeCN. Compound **10** can be recrystallized from EtOH: 80%, mp 223 °C (dec); ^{1}H NMR (DMSO-d_6) δ 8.40 (t, 2H), 8.84 (s, 1H), 8.95 (t, 1H), 9.68 (d, 2H $J = 6.0$ Hz); ^{13}C NMR (DMSO-d_6) δ 82.7, 96.2, 128.6, 145.2, 151.0; CI MS *m/z* 244 (10) for $C_7H_6Cl_4N^+$, 208 (100) for $C_7H_5Cl_3N^+$. Anal. Calcd for $C_7H_6Cl_5N$: C, 29.88; H, 2.15, Cl, 62.99, N, 4.98. Found: C, 29.62; H, 2.35; Cl, 60.78; N, 5.18.

***N*-(Trichloroethenyl)pyridinium Chloride (11).** Compound **7a** (1.58 g, 20 mmol) was added to a suspension of **10** (2.81 g, 10 mmol) in EtOH (10 mL) at room temperature. The mixture was stirred for 20 h at room temperature in the course of which a yellow solution was formed. The solvent was removed under reduced pressure, and the residue was treated with dichloromethane and then refluxed with acetone. The crystalline material was filtered off and dried in vacuo: 71%, mp 261 °C (dec); IR (KBr) 1648 cm^{-1}; ^{1}H NMR (DMSO-d_6) δ 8.50 (t, 2H), 8.99 (t, 1H), 9.66 (d, 2H, $J = 6.5$ Hz); ^{13}C NMR (DMSO-d_6) δ 125.8, 127.0, 129.6, 146.1, 150.6; CI MS *m/z* 208 (100) for $C_7H_5Cl_3N^+$. Anal. Calcd for $C_7H_5Cl_4N$: C, 34.58, H, 2.07; Cl, 57.58, N 5.76. Found: C, 34.24; H, 2.25; Cl, 57.49; N, 5.81.

***N*-(2,2-Dichloroethenyl)pyridinium Chloride (12).** To a suspension of **10** (8.46 g, 30 mmol) in dichloromethane (90 mL) was added triphenylphosphane (8.65 g, 33 mmol). The mixture was stirred for 48 h at room temperature, evaporated to a third of the volume, and then cooled to O °C. The precipitate was filtered off and washed with cold dichloromethane: 68%, mp 165 °C; IR (KBr) 1639 cm^{-1}; ^{1}H NMR (DMSO-d_6) δ 8.36 (t, 2H), 8.55 (s, 1H), 8.81 (t, 1H), 9.26 (d, 2H, J ($H = 6.0$ Hz); ^{13}C NMR (DMSO-d_6) δ 128.0, 128.2, 130.1, 145.2, 148.2; CI MS *m/z* 174 (100) for $C_7H_6Cl_2N^+$. Anal. Calcd for $C_7H_6Cl_3N$: C, 39.93; H, 2.87; Cl, 50.54; N, 6.65. Found: C, 39.80; H, 2.88; Cl, 50.14; N, 6.36.

4-Phenylmethyl-1-trichloroethenyl-1,4-dihydropyridine (13). To a suspension of **11** (1.23 g, 5 mmol) in diethyl ether (10 mL) was added a solution of $PhCH_2MgBr$ (1.25 molar, 4 mL) in diethyl ether under argon at −78 °C, and the mixture was stirred for 1 h. The reaction mixture was allowed to warm to room temperature in the course of 5 h and then extracted with 5% aqueous sodium hydrogen carbonate (10 mL). The organic layer was separated, dried (Na_2SO_4), and passed through a silica gel column. Evaporation of solvent gave 0.82 g (73%) of crystalline **13**, which is sensitive to oxygen and was contaminated by 20% benzenemethanol: IR (CCl_4) 1680, 1625, 1603 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 2.72 (d, 2H, $J = 7.0$ Hz), 3.26 (m, 1H), 4.72 (m, 2H), 5.90 (d, 2H, $J = 14.5$ Hz), 7.16−7.23 (m, 5H); ^{13}C NMR ($CDCl_3$) δ 34.2, 45.8, 106.9, 115.7, 126.1, 126.7, 128.2, 129.5, 131.7, 138.7; CI MS *m/z* 300 (98) for $C_{14}H_{13}Cl_3N^+$, 264 (100) for $C_{14}H_{12}Cl_2N^+$, 208 (97) for $C_7H_5Cl_3N^+$, 129 (68) for $C_2Cl_3^+$.

4-Tri-*n*-butyl-phosphonium-1-trichloroethenyl-1,4-dihydropyridine Chloride (14). To a suspension of **11 (**1.23 g, 5 mmol) in dichloromethane (5 mL) was added tri-*n*-butylphosphane (1.01 g, 5 mmol) at 0 °C under an atmosphere of argon. An intense yellow color developed immediately. The clear solution was stirred at room temperature for 1 h, followed by the addition of *tert*-butyl methyl ether (5 mL). This mixture was filtered off under vacuum using silica gel. The solution was evaporated to half of the volume, and 20 mL of *tert*-butyl methyl ether was again added. The precipitate was filtered off and dried in vacuo: 91%, mp 92 °C (dec); IR (KBr) 1606, 1612, 1683 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 0.91 (t, 9H), 1.51 (m, 12H), 2.41 (m, 6H), 4.84 (m, 2H), 5.22 (m, 1H), 6.16 (d, 2H $J = 12.7$ Hz); ^{13}C NMR ($CDCl_3$) δ 13.5, 17.1 (d, $J = 43.5$ Hz), 24.0, 31.6 (d, $J = 47.0$ Hz), 95.8 (d, $J = 5.2$ Hz), 118.7, 130.1, 132.0 (d, $J = 6.8$ Hz); ^{31}P NMR ($CDCl_3$) δ 31.1; FAB MS *m/z* 410 (16) for $C_{19}H_{32}Cl_3NP^+$, 208 (100) for $C_7H_5Cl_3N^+$. Anal. Calcd for $C_{19}H_{32}Cl_4NP$: C, 51.02; H, 7.21; N, 3.13; Cl, 31.71. Found C, 50.61; H, 7.22; N, 3.11; Cl, 30.64.

4-(Di-2-propoxy)phosphoryl-1-trichloroethenyl-1,4-dihydropyridine (15). To a stirred suspension of **11** (1.35 g, 5.5 mmol) in dichloromethane (20 mL) was added tri-2-propyl phosphite (1.25 g, 6 mmol) at −78 °C under an atmosphere of argon. After 2 h, the mixture was allowed to warm to room temperature. The solvent was evaporated in vacuo to dryness, and the residue was purified by column chromatography (silica gel 60, 0.063−0.2 mm, EtOAc): 80%, mp 78 °C (dec); IR (ATR) 1607, 1623, 1685 cm $^{-1}$; ^{1}H NMR ($CDCl_3$) δ 1.29 (d, 12H), 3.37 (t, 1H, ^1J(P,H) = 27.43 Hz), 4.68 (m, 2H), 4.76 (m, 2H, ^2J(P,H) = 10.46 Hz), 5.59 (d, 2H, ^3J(P,H) = 6.97 Hz); ^{13}C NMR ($CDCl_3$) δ 24.0, 33.6 (d, J(C,P) = 149.9 Hz), 70.8 (d, J(C,P) = 7.55 Hz), 99.4 (d, J(C,P) = 9.75 Hz), 116.6, 128.7 (d, J(C,P) = 9.37 Hz), 131.1; EI MS *m/z* 373 (4) for $C_{13}H_{19}Cl_3NO_3P^+$, 208 (100) for $C_7H_5Cl_3N^+$. Anal. Calcd for $C_{13}H_{19}Cl_3NO_3P$: C, 41.68; H, 5.11; N, 3.74; Cl, 28.39. Found: C, 42.18; H, 5.51; N, 3.73; Cl, 27.60.

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