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N-Acetoxyammonium Ions – Reactive Intermediates in the Polonovski Reaction

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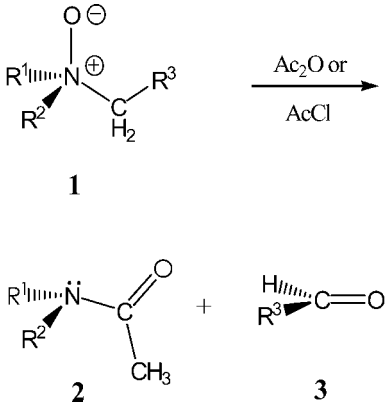
Dedicated to Theodor Wieland in memoriam

Keywords: *N*-Acetoxyammonium salts / Polonovski reaction / Density functional calculations / Elimination reactions

We have synthesized the *N*-acetoxyammonium salts **5**, **7**, **8**, **9** and **10** with different counterions (Cl^-, Br^-, ClO_4^-, BF_4^-, FSO_3^-) as models for the initially formed reactive intermediate in the Polonovski reaction. The perchlorates can be isolated in pure state. The geometries, relative stabilities and ^1H and ^{13}C chemical shifts of the *N*-acetoxyammonium ions were calculated by DFT methods on the levels B3LYP/6-311+G(2d,p) and B3LYP/TZVP. Further, the elimination reactions of the *N*-acetoxyammonium salts yielding the corresponding immonium salts were studied. The immonium salts were also characterized.

Introduction

The reaction of tertiary amine oxides **1** with acetic anhydride or acetyl chloride, in which one of the alkyl groups attached to the nitrogen is cleaved and the corresponding *N*,*N*-disubstituted acetamide **2** and the aldehyde **3** are generated, is known as Polonovski reaction.[1]



1 **2** **3**

Due to the fact that the Polonovski reaction is catalyzed by bases, Huisgen and co-workers[2] proposed the following mechanism for this reaction (Figure 1). *N*-Acetoxyammonium salts are postulated as the first intermediates in the Polonovski reaction of tertiary amine oxides.

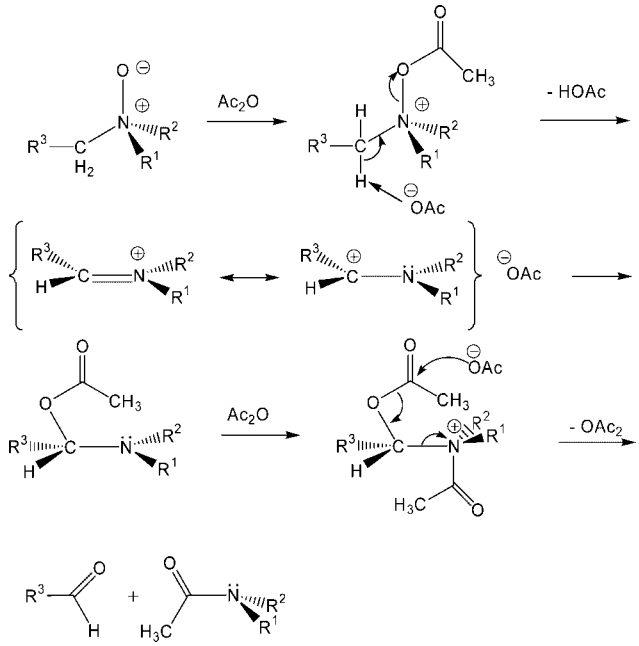


Figure 1. Huisgen mechanism of the Polonovski reaction.

By treatment of quinuclidine *N*-oxide with *p*-$MeC_6H_4SO_2Cl$ and $SbCl_5$ in $CHCl_3$ Huisgen and Kolbeck[3] isolated the stable salt **4**. The salt **4** is thermally stable so that radical intermediates can be excluded in the Polonovski reaction. However, the *N*-acetoxyammonium salt **4** cannot form an immonium salt with bases since this would break the Bredt rule. The ^1H NMR spectrum of the *N*-acetoxyammonium salt **5c** was recorded by Michelot[4] after the reaction of

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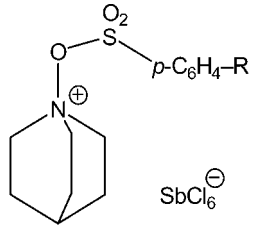
acetylperchlorate with *N*,*N*,*N*-trimethylamine oxide. Jessop and Lindsay Smith[5] were able to isolate the *N*-acetoxyammonium salts **6** and perform studies on reactions with base.



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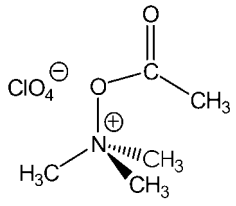
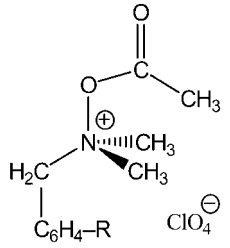


5c



R = (*para*) H, Cl, NO_2

6a,**b**,**c**

Computational Methods

For all calculations in this work we used the density-functional program packages provided by the Gaussian 03 suite of programs.[6] The employed density functional is the hybrid functional B3LYP, as implemented in Gaussian 03. For the calculations of the geometries and energies we used the 6-311+G(2d,p) basis set, which puts two d-functions on heavy atoms (plus diffuse functions), and one *p*-function on hydrogens and in some cases the contracted Gaussian basis sets of triple zeta valence TZVP.[7] For the calculation of the NMR chemical shifts we employed the GIAO method, using the 6-311+G(2d,p) and TZVP basis sets. The relative stabilities of the *N*-acetoxyammonium ions are determined by isodesmic reactions.[8]

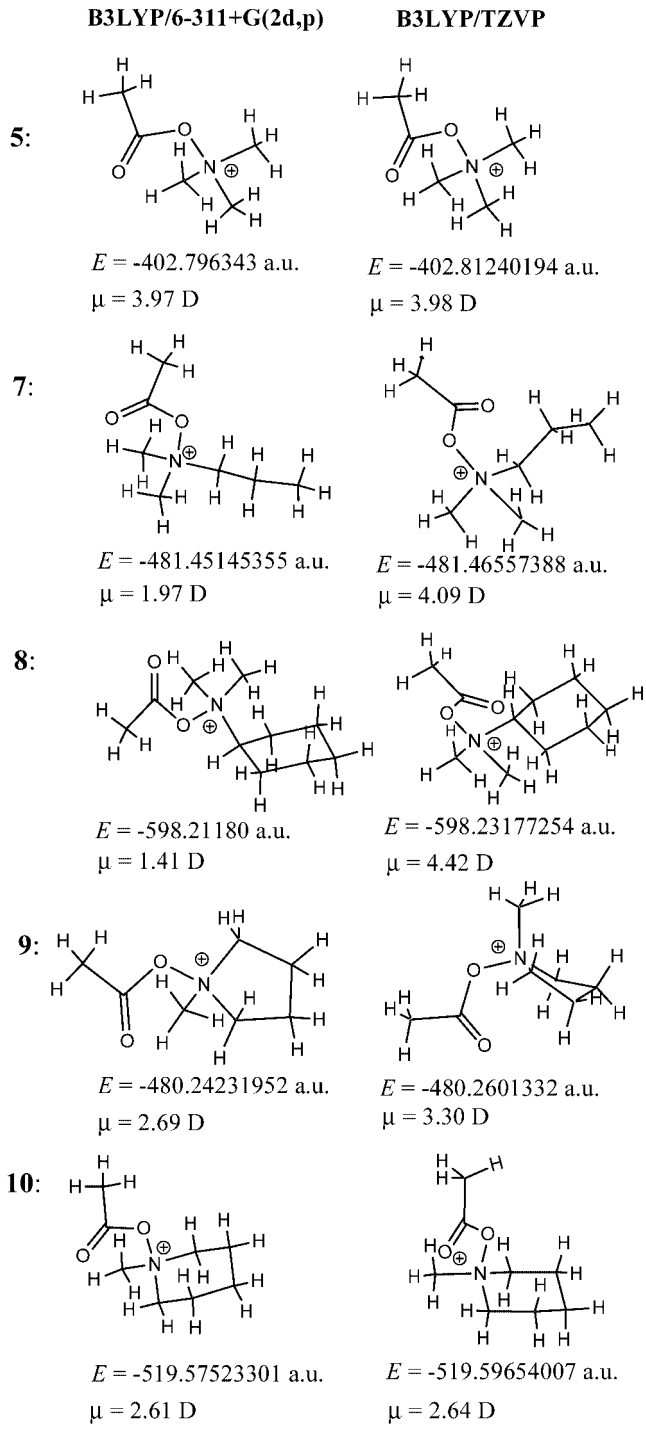
Results and Discussion

As a result of our systematic study we were able to synthesize the *N*-acetoxyammonium ions **5**, **7**, **8**, **9** and **10** with the following counterions: chloride, bromide and perchlorate. In addition to this **5**, **8**, **10** with the counterion fluoroborate, **5** with the counterion hexafluoroantimonate and **5**, **8** and **10** with the counterion fluorosulfonate.

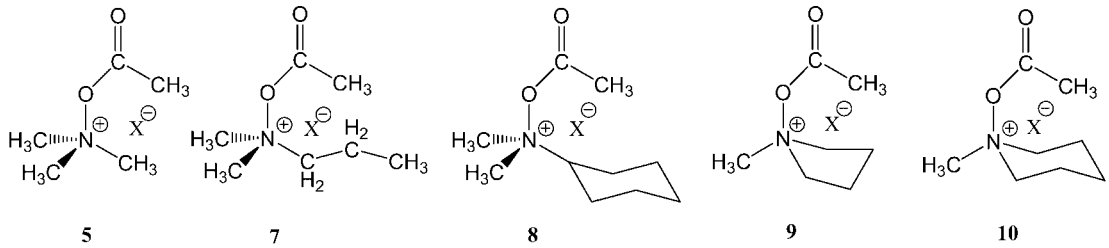
The geometries, energies and dipole moments of the *N*-acetoxyammonium ions were determined by DFT calculations (Scheme 1).

The relative stabilities of the *N*-acetoxyammonium ions were determined by isodesmic reactions (Scheme 2).[8]

For the synthesis of the *N*-acetoxyammonium salts we started out from the anhydrous amine oxides **11a**–**e**. Trimethylamine oxide **11a** reacts with acetyl chloride or acetyl bromide in dichloromethane at –78 °C to form *N*-acetoxy-*N*,*N*,*N*-trimethylammonium chloride **5a** und bromide **5b**. The two salts precipitate as fine crystalline salts. The salts were characterized by NMR spectroscopy. On warming up the salts in solution they are converted into the corresponding *N*,*N*-dimethylimmonium halides, the second reactive intermediate in the Huisgen mechanism. The *N*-acetoxyammonium halides **7a**,**b**–**10a**,**b** can also be produced at –78 °C.

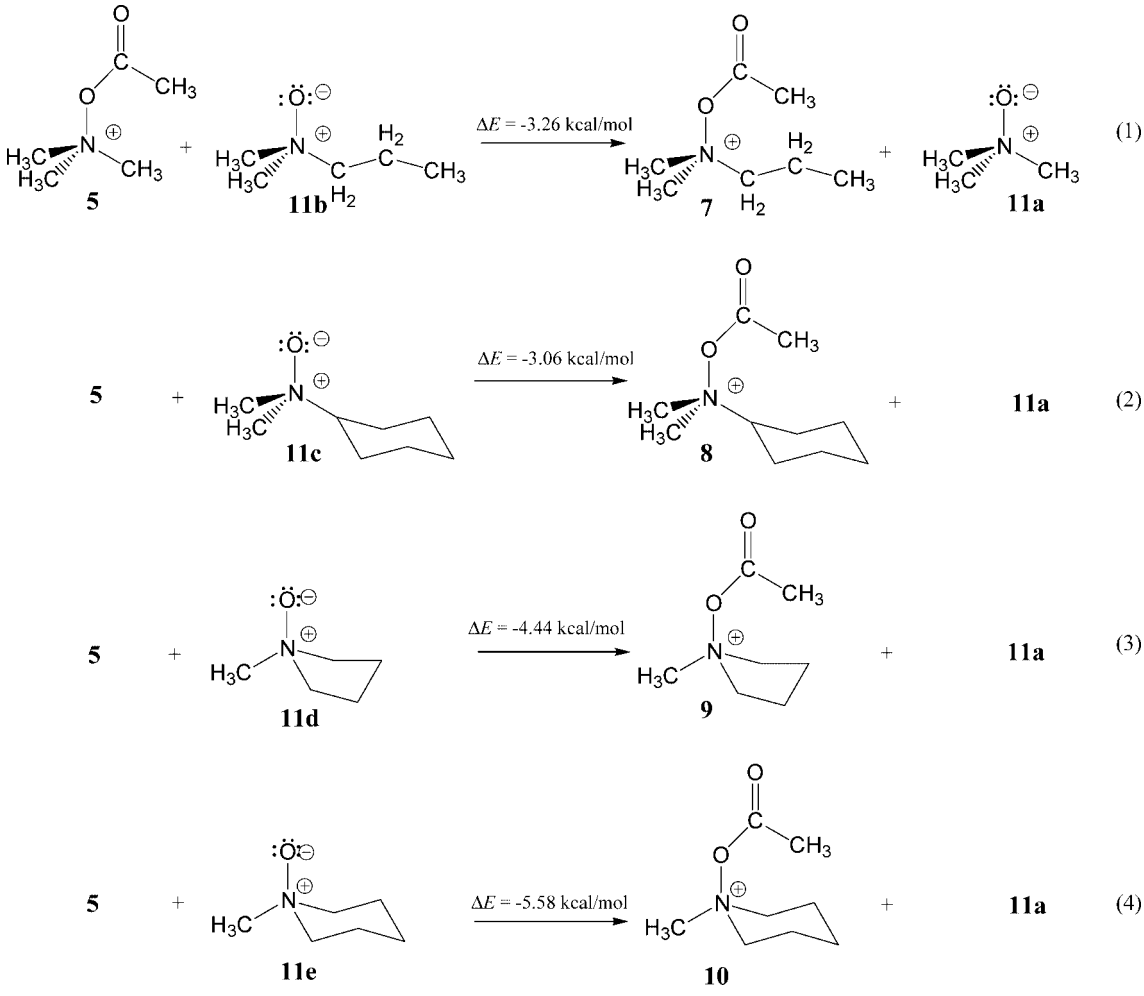


Scheme 1. Calculated geometries, energies and dipole moments of the *N*-acetoxyammonium ions present in the salts **5**, **7**, **8**, **9** and **10** synthesized in this work.



5 **7** **8** **9** **10**

5, 7–10	a	b	c	–	5, 8, 10	d	e	5f
X	Cl	Br	ClO_4	–	X	BF_4	FSO_3	X = SbF_6



(1) **5** + **11b** → **7** + **11a**

(2) **5** + **11c** → **8** + **11a**

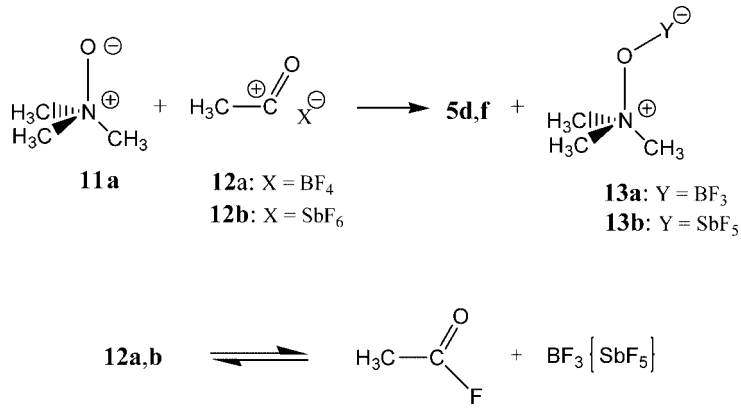
(3) **5** + **11d** → **9** + **11a**

(4) **5** + **11e** → **10** + **11a**

Scheme 2. Relative stabilities of the *N*-acetoxyammonium ions **5**, **7**, **8**, **9** and **10** as determined by isodesmic reactions – level B3LYP/6-311+G(2d,p). The energies are corrected by B3LYP/6-311+G(2d,p) zero-point energies.

They are sufficiently soluble in dichloromethane at this temperature and can be precipitated by addition of diethyl ether. The salts **5a**,**b**, **7a**,**b**, **8a**,**b**, **9a**,**b** and **10a**,**b** were characterized by NMR spectroscopy at –78 °C. The salts **7a**,**b**–**10a**,**b** are much more thermolabile than the salts **5a**,**b** and can even explode on rapid warming. By slow warming they are converted into the most stable immonium salt, in accordance with the Saytzeff rule. For this reason the *N*-acetoxyammonium halides produced by this way are always contaminated with the corresponding immonium halide.

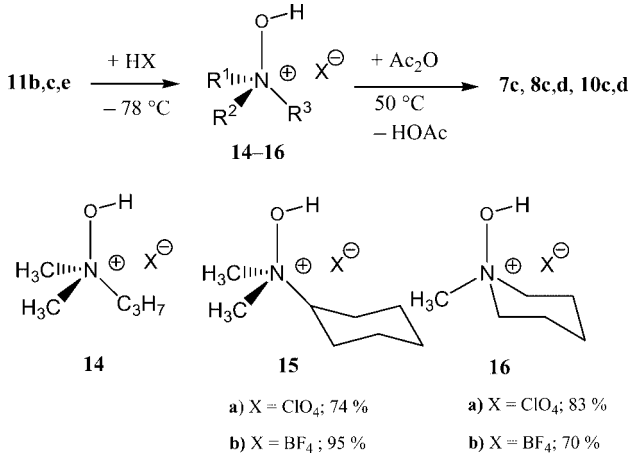
Since chloride and bromide ions are sufficiently basic to induce the elimination of acetic acid from the *N*-acetoxyammonium ions, we synthesized in the course of our studies *N*-acetoxyammonium salts containing low-basicity counterions.



Scheme 3. *N*-Acetoxyammoium salts **5d** and **5f**, synthesized by the reaction of trimethylamine oxide with acylium salts.

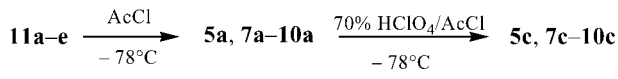
The reaction of trimethylamine oxide **11a** with the acylium salts **12a** and **12b** has not proved to be ideal. During the reaction of the acylium salt **12a** with the amine oxide **11a** *N*-acetoxyammonium fluoroborate **5d** and 10 mol-% of the BF_3 adduct **13a** is formed. In the reaction of acylium salt **12b** with **11a** even 50 mol-% of the SbF_5 adduct **13b** is formed. Addition of twelve equivalents of acetyl fluoride to the reaction mixture of trimethylamine oxide **11a** with **12a** yields the *N*-acetoxyammonium fluoroborate in pure form. By this method the crystalline salt **5d** can be prepared in 74% yield (Scheme 3).

For the preparation of *N*-acetoxyammonium perchlorates we have developed two methods: the first one starts with the protonation of the amine oxides with strong acids (70% $HClO_4$ in acetic anhydride; in some cases also 54% ethereal HBF_4) to form the corresponding *N*-hydroxyammonium salts. After warming up to room temperature and addition of diethyl ether the products separate as oils that crystallize after a while. The *N*-hydroxyammonium salts are very hygroscopic and can be converted into the corresponding *N*-acetoxyammonium salts by treatment with acetic anhydride for 5 d at 50 °C (Scheme 4).



Scheme 4. *N*-Acetoxyammonium perchlorates and fluoroborates from *N*-oxides **11b**,**c**,**e** and strong acids HBF_4 or $HClO_4$ followed by reaction with acetic anhydride.

Our second synthetic method provides better yields and analytical reagent grade perchlorates **5c**, **7c**–**10c**. In the first step the anhydrous amine oxides **11a**–**e** are treated with acetyl chloride at –78 °C (Scheme 5). In the second step a –78 °C cold mixture of 70% perchloric acid and acetyl chloride is added and the mixture allowed to react for 15 min. We have also prepared the fluorosulfonates of acetoxyammonium ions in a similar reaction. For example, the *N*-acetoxyammonium fluorosulfonates **5e** (91.5%), **8e** (23%) and **10e** (42%) could be synthesized.



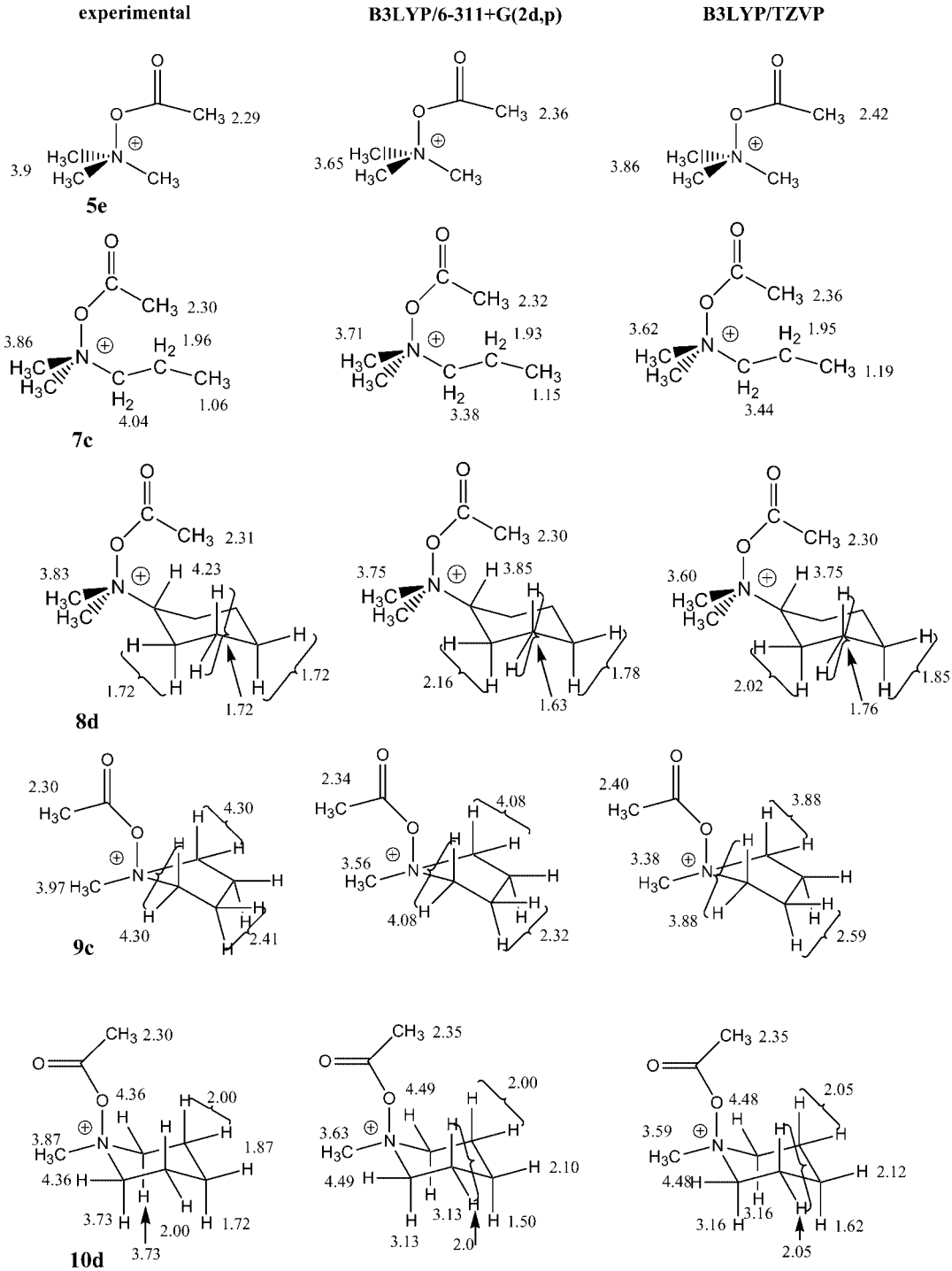
Scheme 5. *N*-Acetoxyammonium perchlorates from amine oxides, acetyl chloride and perchloric acid.

We have studied the spectroscopic behaviour of the pure salts **5c**, **7c**–**10c**. For all salts the carbonyl signal for the acetoxy group is observed in the IR spectrum at 1805 cm^{-1}. The NMR spectra of the perchlorates **5c**, **7c**, **8c**, **9c** and **10c** were recorded (δ values are given for solutions in nitromethane, chloroform or dichloromethane, depending on the solubility of the salts). The calculated ^1H and ^{13}C values of the *N*-acetoxyammonium ions are in good agreement with the experimental ones (see Schemes 6 and 7).

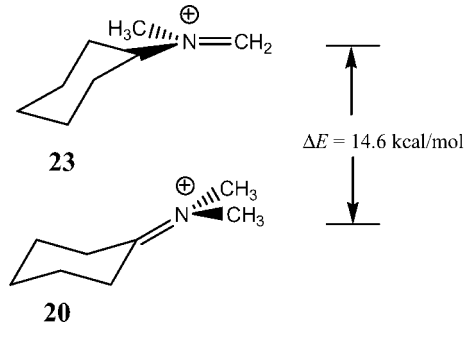
As mentioned before, on warming the *N*-acetoxyammonium halides **5a**,**b** and **7a**,**b**–**10a**,**b** are converted into the corresponding immonium salts (Schemes 8 and 9). Since the crystallization of the immonium halides is difficult and the noncyclic immonium halides are sensitive to hydrolysis they are converted into the perchlorates by treatment with a mixture of 70% $HClO_4$/acetyl chloride. The perchlorates are easier to crystallize and are not sensitive to hydrolysis.

According to our calculations on the level B3LYP/6-311+G(2d,p) the immonium ion **20** is by 14.6 kcal/mol more stable than the methylene immonium ion **23**.

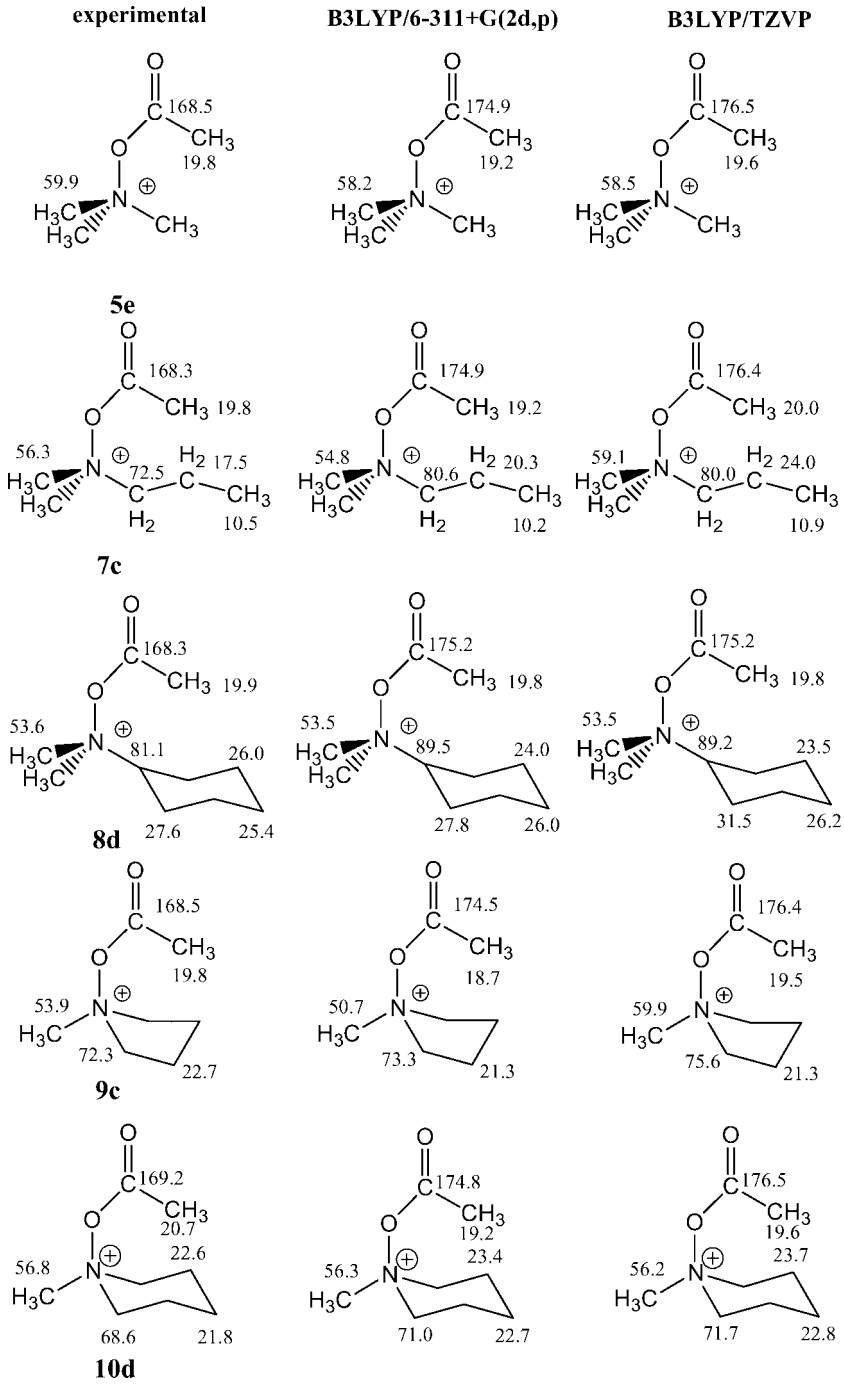
Michelot[4] has studied the Polonovski reaction of amine oxides with acetic anhydride and trifluoroacetic anhydride.



Scheme 6. Experimental and calculated ^{1}H chemical shifts of the *N*-acetoxyammonium perchlorates.

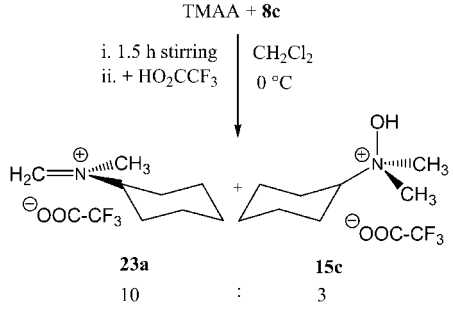


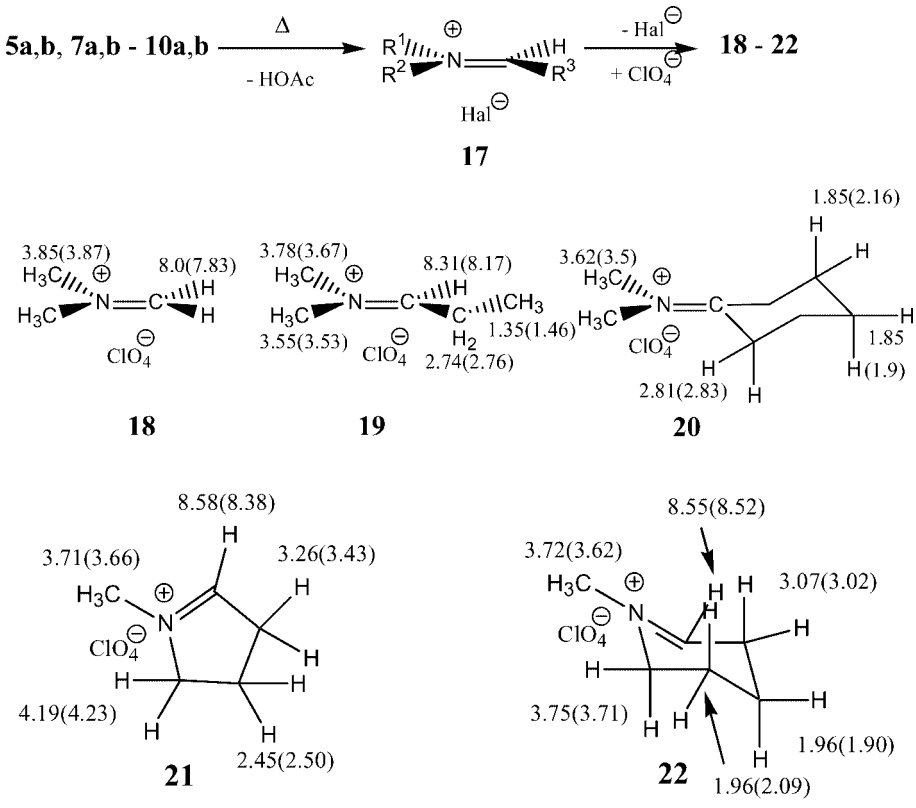
In the context of these studies he also employed the *N*-oxide **11c**. In the reaction of **11c** with acetic anhydride the only product obtained was *N*-methyl-*N*-cyclohexylacetamide, which was formed via the immonium ion **23**. When trifluoroacetic anhydride was used as reagent, the trifluoroacetate ion – being less basic than the acetate ion – gave a mixture of 2,2,2-trifluoro-*N*,*N*-dimethylacetamide (39%) and *N*-cyclohexyl-2,2,2-trifluoro-*N*-methylacetamide (61%), formed via **20** and **23**. With the even weaker basic chloride ion or bromide ion we found that only the immo-



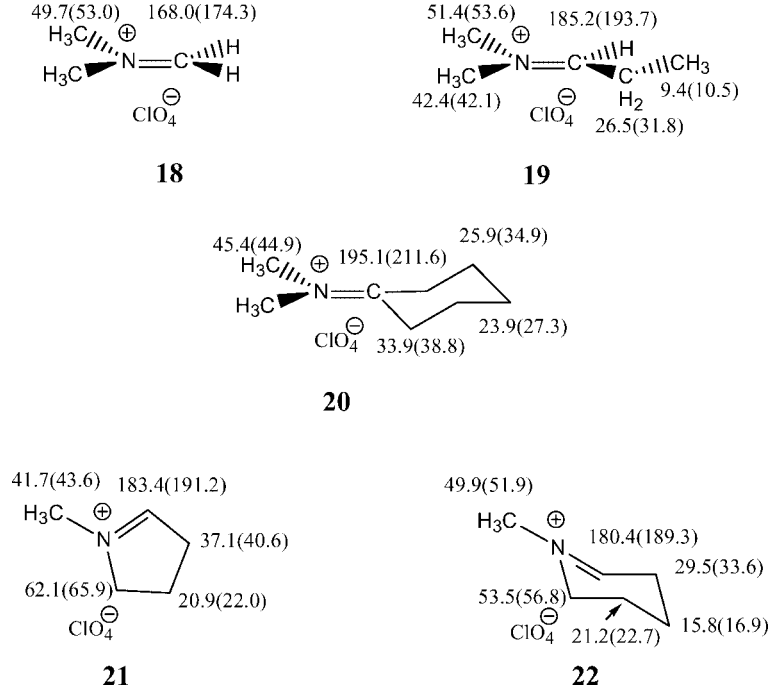
Scheme 7. Experimental and calculated ^{13}C chemical shifts of the *N*-acetoxyammonium perchlorates.

nium ion **20** is formed. To confirm that the basicity of the base determines the course of the elimination we treated *N*-acetoxyammonium perchlorate (**8c**) with tetramethylammonium acetate (TMAA) by adding a solution of **8c** in dichloromethane dropwise to a solution of TMAA at 0 °C. On acidification with trifluoroacetic acid the only immonium salt which is observed in this reaction sequence is **23a** together with some *N*-hydroxyammonium salt **15c**. This is a further proof for the assumption that the basicity of the counterion determines the type of elimination.





Scheme 8. Immonium perchlorates **18**–**22** from *N*-acetoxyammonium halides **5a**,**b**, **7a**,**b**–**10a**,**b**. Experimental and on the level B3LYP/6-311+G(2d,p) calculated (in parenthese) ^{1}H chemical shifts.



Scheme 9. ^{13}C chemical shifts of the immonium perchlorates **18**–**22**, calculated shifts in parenthese.

Conclusions

In the Huisgen mechanism for the Polonovski reaction, *N*-acetoxyammonium salts are postulated as the initially formed reactive intermediates. In this work we were able to observe and isolate the *N*-acetoxyammonium salts **5**, **7**–**10** by the reaction of anhydrous amine oxides **11a**–**e** with acetyl chloride under various conditions, and characterize them by chemical and spectroscopic methods. The geome-

tries and energies of the *N*-acetoxyammonium ions **5**, **7**–**10** were determined by DFT calculations. The calculated chemical shifts of the *N*-acetoxyammonium ions **5**, **7**–**10** are in good agreement with the experimental values and offer a good proof for the reliability of our DFT calculations. We have demonstrated that the course of the elimination reaction of the *N*-acetoxyammonium salts to give the corresponding immonium salts depends on the basicity of the counterion. For the demethylation of tertiary amines, acetic anhydride is most suited in the Polonovski reaction.

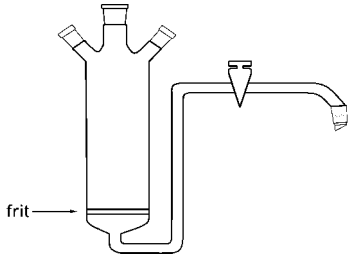
Experimental Section

General: Hydrolysis-sensitive or hygroscopic substances were handled and stored in a dry nitrogen atmosphere. The nitrogen was dried with Sicapent™ (Merck). All apparatus were dried by heating and evacuation and ventilation with dried nitrogen. All reactions were carried out under a weak excess pressure of nitrogen. Manipulations with the substances sensitive to moisture were carried out in a glove box. IR Spectroscopy: Grating Spectrometer Beckman IR-8. NMR: Bruker WH90 and Bruker WH300. MS: Varian match CH5, ionizing energy 70 eV.

Reagents and Solvents: Methylene chloride and carbon tetrachloride were heated at reflux with P_2O_5 for 5 h and then distilled. This was followed by the addition of potassium carbonate activated at 100 °C and distillation using a 30-cm Vigreux column. The dried solvent was kept over molecular sieves (4 Å, type 514, purchased from C. Roth, Karlsruhe, Germany). Chloroform was filtered prior to use over a column with Al_2O_3 (bas. I, Woelm), 40 g for each 100 mL. In order to remove peroxides, diethyl ether was filtered through a column fitted with Al_2O_3 (bas. I, Woelm), 100 g for 1000 mL. Directly before use the so treated diethyl ether was heated for 1 h over $LiAlH_4$ and then distilled. Nitromethane (puriss., C. Roth), acetic acid (p.a., Merck), acetic anhydride ("rein", Riedel-de Haën), acetyl chloride (p.a., Merck), acetyl bromide was prepared by a known method,[9] trifluoroacetic acid ("zur Synthese", Merck-Schuchardt).

The following amine oxides were prepared according to literature methods.[10,11] Trimethylamine oxide (**11a**) (CAS no. 1184-78-7), propyldimethylamine oxide (**11b**) (CAS no. 7311-26-4), cyclohexyldimethylamine oxide (**11c**) (CAS no. 17576-75-9), *N*-methylpyrrolidine oxide **11d** (CAS no. 7529-17-1), *N*-methylpiperidine oxide **11e** (CAS no. 17206-00-7).

All sensitive compounds were prepared in a frit equipment as shown.



Preparation of Anhydrous Amine Oxides: After the reaction of the amines with aqueous hydrogen peroxide solution the water of the reaction mixture was removed at temperatures below 50 °C by means of a rotary evaporator and the crude amine oxide was then dried in vacuo (10^{-2} Torr) for several hours over P_2O_5 at the same temperature. The resulting raw product was usually a viscous oil that still contained water and hydrogen peroxide. For drying purposes and destruction of residual hydrogen peroxide the raw product was taken up in dichloromethane and carefully mixed with powdered calcium hydride. The intense reaction of the calcium hydride with the water terminated after a few minutes. Then the reaction mixture was heated for one hour at reflux, and after cooling, filtered under suction, first over a D3 and secondly over a D4 frit. After removal of the solvent by distillation the anhydrous amine oxide remained as a crystalline product. The amine oxides are easily soluble in methanol, dichloromethane and chloroform.

Trimethylamine Oxide (11a): Colourless crystals. IR (CH_2Cl_2): $\tilde{\nu}$ = 3010, 2940, 2840, 1475, 1455, 1390, 1280, 1220, 936 cm^{-1}. ^1H NMR ($CDCl_3$, TMS): δ = 3.3 ppm.

Propyldimethylamine Oxide (11b): Colourless crystals. IR (CH_2Cl_2): $\tilde{\nu}$ = 3650, 3020, 2940, 2890, 2840, 2570, 2450, 2330, 1470, 1455, 1440, 1385, 1285, 1195, 1185, 1115, 1040, 960, 940, 910, 870 cm^{-1}. ^1H NMR ($CDCl_3$, TMS): δ = 3.16 (m, 2 H, 2× 1-H), 3.15 (s, 6 H, CH_3), 1.89 (m, 2 H, 2× 2-H), 0.98 t, 3 H; CH_3 propyl) ppm.

Cyclohexyldimethylamine Oxide (11c): Colourless crystals. IR (CH_2Cl_2): $\tilde{\nu}$ = 3020, 2940, 2860, 1470, 1450, 1370, 1265, 1235, 1090, 1050, 1020, 965, 900, 840, 815, 646 cm^{-1}. ^1H NMR ($CDCl_3$, TMS): δ = 3.11 (s, 6 H, CH_3), 3.04 (m, 1 H, 1-H_{cHex}), 2.43 (m, 2 H, 2-H_{eq}, 6-H_{eq}), 1.95 (m, 2 H, 2-H_{ax}, 6-H_{ax}), 1.41 (m, 6 H, 2× 3-H, 2× 4-H, 2× 5-H) ppm.

***N*-Methylpyrrolidine Oxide (11d):** Colourless crystals. IR (CH_2Cl_2): $\tilde{\nu}$ = 3020, 2940, 2860, 1465, 1450, 1390, 1370, 1350, 1267, 1180, 1160, 1020, 960, 905, 845, 815 cm^{-1}. ^1H NMR ($CDCl_3$, TMS): δ = 3.46 (m, 4 H, 2× 2-H, 2× 5-H), 3.37 (s, 3 H, CH_3), 2.45 (m, 2 H, 3-H_{cisO}, 4-H_{cisO}), 2.04 (m, 2 H, 3-H_{transO}, 4-H_{transO}) ppm.

***N*-Methylpiperidine Oxide (11e):** Colourless crystals. IR (CH_2Cl_2): $\tilde{\nu}$ = 3020, 2965, 2850, 2570, 2450, 2330, 1460, 1440, 1285, 1260, 1175, 1040, 1000, 960, 935, 845 cm^{-1}. ^1H NMR ($CDCl_3$, TMS): δ = 3.22 (s, 3 H, CH_3), 3.18 (m, 4 H, 2× 2-H, 2× 6-H), 2.27 (m, 2 H, 3-H_{ax}, 5-H_{ax}), 1.49 (m, 4 H, 2× 4-H, 3-H_{eq}, 5-H_{eq}) ppm.

Acetylium Salts: Acetylium tetrafluoroborate was prepared according to the description of Neuenschwander,[12] acetylium hexafluoroantimonate was prepared according to the description of Olah.[13]

Perchloric Acid/Acetyl Chloride Mixture: To aqueous perchloric acid (70 %, 5 mL) was carefully added excess acetyl chloride (13 mL) at room temperature. An intense reaction occurred with production of HCl. After the addition of all acetyl chloride the reaction mixture was boiled until all HCl was removed.

Synthesis of *N*-Acetoxyammonium Halides

Preparation of *N*-Acetoxy-*N*,*N*,*N*-trimethylammonium Chloride (5a): A solution of acetyl chloride (0.14 mol; 6.6 equiv.) in dichloromethane (10 mL) was cooled to –78 °C. To this vigorously stirred solution was slowly added dropwise a solution of anhydrous trimethylamine oxide (**11a**) (1.58 g, 0.0211 mol) in dichloromethane (20 mL), which was also cooled to –78 °C. After complete addition of the amine oxide solution, the reaction mixture was stirred for a further 15 min. *N*-Acetoxy-*N*,*N*,*N*-trimethylammonium chloride precipitated as colourless crystals. The precipitate was filtered by suction, washed twice with cooled dichloromethane and finally dried in vacuo (10^{-2} Torr) at –78 °C; yield 2.6 g (88 %).

In the preparation of the *N*-acetoxyammonium salts **7a**–**10a**, these salts were precipitated by addition of diethyl ether and washed with cold diethyl ether.

The *N*-acetoxyammonium halides were characterized by NMR spectroscopy (see the identical NMR spectra of the *N*-acetoxyammonium perchlorates **5c**, **7c**–**10c**.

Syntheses of *N*-Acetoxytrimethylammonium Salts by Reaction of Trimethylamine Oxide with Acylium Salts

Preparation of *N*-Acetoxy-*N*,*N*,*N*-trimethylammonium Tetrafluoroborate (5d): Acetylium tetrafluoroborate (5.19 g, 0.04 mol) was suspended at –78 °C in a mixture of dichloromethane (10 mL) and acetyl fluoride (7 mL). To the intensely stirred suspension was slowly added dropwise a solution at –78 °C of **11a** (3.0 g, 0.04 mol) in dichloromethane (20 mL). After all **11a** was added the mixture was stirred for a further 15 min, filtered under suction, washed twice with 20 mL of dichloromethane (at –78 °C), and dried in vacuo (10^{-2} Torr); yield 6.1 g (74%).

Preparation of *N*-Acetoxy-*N*,*N*,*N*-trimethylammonium Hexafluoroantimonate (5f): See procedure for **5d**. Starting material **12b** (3.93 g, 0.014 mol), **11a** (1.18 g, 0.016 mol); yield 4.0 g (80%).

The *N*-acetoxyammonium salts **5d** and **5f** were characterized by NMR spectroscopy (see the identical NMR spectrum of **5c**).

Synthesis of the *N*-Acetoxyammonium Salts 7c, 8c, 8d, 10c, 10d by Method 3. Reaction Sequence: Amine Oxide – *N*-Hydroxyammonium Salt – *N*-Acetoxyammonium Salt

Preparation of *N*-Hydroxyammonium Salts 14–16: The amine oxide was solved in dichloromethane (10 mL), the solution cooled to –78 °C, and the acid (HBF_4 or $HClO_4$) added slowly whilst stirring. The reaction mixture was warmed to room temperature. Thereupon the reaction solution was shaken vigorously with diethyl ether (100 mL). The product separated as colorless oil. The oil was shaken again with diethyl ether (100 mL), then separated and dried for about 24 h in vacuo (10^{-2} Torr) during which time crystallization of the oil occurred.

The hydroxyammonium salts form colourless, extremely hygroscopic crystals. **15** and **16** could be characterized by IR and ^{1}H-NMR spectroscopy.

15a (ClO_4^-): Starting material was **11c** (1.67 g, 0.0117 mol); yield of **15a** 2.1 g (74%). IR ($CHCl_3$): $\tilde{\nu}$ = 3400 (shoulder), 3050, 3015, 2940, 2860, 1510, 1470, 1445, 1405, 1375, 1350, 1330, 1275, 1255, 1225, 1090 (very intense signal; ClO_4^-), 960, 920, 895, 875, 840, 675, 615 cm^{-1}. ^{1}H NMR ($CDCl_3$, TMS): δ = 9.27 (broad, 1 H; OH), 3.51 (m, 1 H, 1-H), 3.4 (s, 6 H, CH_3), 2.44–1.0 (group of m, 10 H; 2× 2-H, 2× 3-H, 2× 4-H, 2× 5-H, 2× 6-H) ppm.

15b (BF_4^-): Starting material was **11c** (1.6 g, 0.0112 mol); yield of **15b** 2.5 g (95%). IR ($CHCl_3$): $\tilde{\nu}$ = 3500, 3250, 3030, 2940, 2860, 1510, 1470, 1440, 1405, 1375, 1350, 1330, 1275, 1225, 1070 (very intense signal; BF_4^-), 895, 840 cm^{-1}. ^{1}H NMR ($CDCl_3$, TMS): δ = 8.27 (broad, 1 H, OH), 3.51 (m, 1 H, 1-H), 3.4 (s, 6 H, CH_3), 2.44–1.0 (group of m, 10 H; 2× 2-H, 2× 3-H, 2× 4-H, 2× 5-H, 2× 6-H) ppm.

16a (ClO_4^-): Starting material was **11e** (2.7 g, 0.0234 mol); yield of **16a** 4.2 g (83%). IR (KBr): $\tilde{\nu}$ = 3400 (broad), 2850 (very broad signal), 1510, 1440, 1350, 1310, 1290, 1270, 1235, 1110 (very intense signal; ClO_4), 1000, 940, 930, 920, 865, 840, 685, 620 cm^{-1}. ^{1}H NMR ($CDCl_3$, TMS): δ = 8.84 (broad, 1 H; OH), 3.63 (m, 4 H, 2× 2-H, 2× 6-H), 3.5 (s, 3 H, CH_3), 1.35 (m, 6 H, 2× 3-H, 2× 4-H, 2× 5-H) ppm.

16b (BF_4^-): Starting material was **11e** (2.5 g, 0.0217 mol); yield of **16b** 3.1 g (70%). IR (KBr): $\tilde{\nu}$ = 3400 (broad), 2850 (very broad signal), 2520, 2440, 1515, 1470, 1440, 1345, 1315, 1295, 1270, 1235, 1085 (very intense signal; BF_4), 940, 930, 920, 865, 840, 770, 690 cm^{-1}. ^{1}H NMR ($CDCl_3$, TMS): δ = 8.29 (broad, 1 H; OH), 3.63 (m, 4 H, 2× 2-H, 2× 6-H), 3.5 (s, 3 H, CH_3), 1.35 (m, 6 H, 2× 3-H, 2× 4-H, 2× 5-H) ppm.

Transformation of *N*-Hydroxyammonium Salts into *N*-Acetoxyammonium Salts: The *N*-hydroxyammonium salt was solved in acetic anhydride (50 mL) and heated at 50 °C for 5 d whilst stirring. The reaction mixture turned reddish brown. It was then decanted into a frit equipment and cooled to –20 °C. On dropwise addition of ether (150 mL) brownish crystals separated. These crystals were washed twice with diethyl ether (2 × 50 mL) and recrystallized from chloroform. The *N*-acetoxyammonium salts were obtained as almost colourless crystals.

7c: Starting material was **11b** (1.25 g, 0.0121 mol); **14** not isolated; yield of **7c** 2.47 g (83%).

8c (ClO_4^-): Starting material was **15a** (3.34 g, 0.0137 mol); yield of **8c** 2.7 g (69%).

8d (BF_4^-): Starting material was **15b** (2.9 g, 0.0126 mol); yield of **8d** 2.5 g (73%).

10c (ClO_4^-): Starting material was **16a** (3.38 g, 0.0157 mol); yield of **10c** 2.6 g (64%).

10d (BF_4^-): Starting material was **16b** (2.27 g, 0.0111 mol); yield of **10d** 1.75 g (64%).

Preparation of *N*-Acetoxyammonium Perchlorates. Method 4: At first the corresponding amine oxide was converted into the *N*-acetoxyammonium chloride with an excess of acetyl chloride (see the previous description of the preparation of *N*-acetoxyammonium chlorides). Next was added at –78 °C the "perchloric acid/acetyl chloride mixture" (see above; 1.5 equiv.) and the reaction mixture was stirred for 15 min. In order to remove all the HCl formed during anion exchange, the reaction mixture was warmed with care and, at 10 Torr, two thirds of the solvent was distilled off and captured in a cold trap. To the remaining solution was added ether (50 mL) and the mixture was cooled to –78 °C. Upon shaking crystals separated which were washed twith ether (2 × 50 mL) and dried at 40 °C and 10^{-2} Torr. Recrystallization from acetyl chloride yielded colourless needles.

5c: Starting material **11a** (2.22 g, 0.0296 mol). **5c**: Colourless crystals, yield 6.13 g (95%). IR (KBr): $\tilde{\nu}$ = 3050, 1805, 1485, 1455, 1435, 1400, 1360, 1250, 1150, 1085, 1040, 995, 940, 900, 830, 750, 615 cm^{-1}. ^{1}H NMR (CD_3NO_2, TMS): δ = 3.9 (s, 9 H, N-CH_3), 2.29 (s, 3 H, OCOCH_3) ppm. ^{13}C NMR (CD_3NO_2, TMS): δ = 168.5 (*C*=O), 59.9 (N-*C*H_3), 19.8 (CO*C*H_3) ppm. $C_5H_{12}ClNO_6$ (217.60): calcd. C 27.6, H 5.56, N 6.44; found C 27.51, H 5.91, N 6.35.

7c: Starting material **11b** (1.48 g, 0.0144 mol). **7c**: Colourless crystals, yield 3.26 g (93%). IR (CH_2Cl_2): $\tilde{\nu}$ = 3050, 2975, 2940, 2880, 1805, 1680, 1470, 1450, 1390, 1365, 1250, 1140, 1085, 1000, 960, 945, 915, 880, 820, 780, 680, 615 cm^{-1}. ^{1}H NMR (CD_3NO_2, TMS): δ = 4.04 (m, 2 H, 2× 1-H), 3.86 (s, 6 H, N-CH_3), 2.30 (s, 3 H, CO-CH_3), 1.96 (m, 2 H, 2× 2-H), 1.06 (t, $^3J_{H,H}$ = 7.5 Hz, 3 H; CH_3) ppm. ^{13}C NMR (CD_3NO_2, TMS): δ = 168.3 (*C*=O), 72.5 (C-1), 56.3 (N-*C*H_3), 19.8 (CO-*C*H_3), 17.5 (C-2), 10.5 (*C*H_3) ppm. $C_7H_{16}ClNO_6$ (245.66): calcd. C 34.22, H 6.57, N 5.70; found C 34.02, H 6.70, N 5.64.

8c: Starting material **11c** (1.09 g, 0.0076 mol). **8c**: Colourless crystals, yield 2.0 g (92%). IR (CH_2Cl_2): $\tilde{\nu}$ = 3045, 2940, 2860, 1805, 1450, 1365, 1335, 1250, 1190, 1140, 1085, 990, 960, 930, 890, 870, 820, 680, 615 cm^{-1}. ^{1}H NMR (CD_2Cl_2, TMS): δ = 4.23 (m, 1 H, 1-H), 3.83 (s, 6 H, N-CH_3), 2.31 (s, 3 H, CO-CH_3), 1.72 (m, 10 H, 2× 2-H, 2× 3-H, 2× 4-H, 2× 5-H, 2× 6-H) ppm. ^{13}C NMR

(CD_3NO_2, TMS): δ = 168.3 (*C*=O), 81.1 (C-1), 53.6 (N-*C*H_3), 27.6 (C-2, C-6), 26.0 (C-3, C-5), 25.4 (C-4), 19.9 (*C*H_3) ppm. $C_{10}H_{20}ClNO_6$ (285.72): calcd. C 42.04, H 7.05, N 4.90; found C 42.39, H 7.48, N 4.92.

9c: Starting material **11d** (1.19 g, 0.0118 mol). **9c**: Colourless crystals, yield 2.43 g (85%). IR (CH_2Cl_2): $\tilde{\nu}$ = 3050, 2970, 1805, 1465, 1445, 1415, 1365, 1245, 1145, 1085, 995, 885, 835, 615 cm^{-1}. ^1H NMR (CD_2Cl_2, TMS): δ = 4.30 (m, 4 H, 2× 2-H, 2× 5-H), 3.97 (s, 3 H, N-CH_3), 2.41 (m, 4 H, 2× 3-H, 2× 4-H), 2.30 (s, 3 H, CO-CH_3) ppm. ^{13}C NMR ($CDCl_3$, TMS): δ = 168.5 (*C*=O), 72.3 (C-2, C-5), 53.9 (N-*C*H_3), 22.7 (C-3, C-4), 19.8 (*C*H_3) ppm. $C_7H_{14}ClNO_6$ (243.64): calcd. C 34.51, H 5.79, N 5.75; found C 34.48, H 6.09, N 5.63.

10c: Starting material **11e** (0.89 g, 0.0078 mol). **10c**: Colourless crystals, yield 1.9 g (96%). IR (CH_2Cl_2): $\tilde{\nu}$ = 3055, 2950, 2860, 1805, 1465, 1445, 1365, 1290, 1270, 1175, 1140, 1085, 1005, 985, 950, 920, 880, 845, 805, 615 cm^{-1}. ^1H NMR (CD_2Cl_2, TMS): δ = 4.36 (m, 2 H, 2-H_{eq}, 6-H_{eq}), 3.87 (s, 3 H, N-CH_3), 3.73 (m, 2 H, 2-H_{ax}, 6-H_{ax}), 2.30 (s, 3 H, CO-CH_3), 2.00 (m, 4 H, 2× 3-H, 2× 5-H), 1.87 (m, 1 H, 4-H_{eq}), 1.72 (m, 1 H, 4-H_{ax}) ppm. ^{13}C NMR (CD_3NO_2, TMS): δ = 169.2 (*C*=O), 68.6 (C-2, C-6), 56.8 (N-*C*H_3), 22.6 (C-3, C-5), 21.8 (C-4), 20.7 (CO-*C*H_3) ppm. $C_8H_{16}ClNO_6$ (257.67): calcd. C 37.29, H 6.26, N 5.44; found C 37.22, H 6.58, N 5.35.

***N*-Acetoxyammonium Fluorosulfonates**

"FSO_3H/Acetyl Chloride": FSO_3H/acetyl chloride = 1.5:1.0.

5e: Starting material **11a** (0.81 g, 0.011 mol), FSO_3H/acetyl chloride (4 mL). **5e**: Colourless crystals, yield 1.84 g (91%).

8e: Starting material **11c** (1.75 g, 0.0122 mol), FSO_3H/acetyl chloride (5 mL). **8e**: Colourless crystals, yield 0.81 g (23%).

10e: Starting material **11e** (2.32 g, 0.02 mol), FSO_3H/acetyl chloride (5 mL). **10e**: Colourless crystals, yield 2.3 g (42%).

The *N*-acetoxyammonium fluorosulfonates are less stable than the *N*-acetoxyammonium perchlorates.

Test of the Thermal Stability of 5c: A sample of **5c** (357 mg) was dissolved in acetic anhydride p.a. (10 mL) and heated to 100 °C for 9 h by stirring. The mixture became slightly yellow. The solution was then cooled to room temperature and ether was added dropwise until a slight turbidity appeared. Upon cooling to –20 °C the salt crystallized. The crystals were washed twice with diethyl ether (2 × 20 mL) and dried at 10^{-2} Torr and 40 °C. Recovered salt: 340 mg (95.3%). The ^1H NMR and IR spectra of the recovered salt were identical with the spectra of the original material.

Synthesis of the Immonium Salts 18–22: The *N*-acetoxyammonium chlorides were prepared at –78 °C as described above. Thereupon the mixture was warmed slowly to room temperature with stirring. Then the "perchloric acid/acetyl chloride mixture" (1.5 equiv.) was added dropwise, followed by stirring for 15 min. In order to remove all HCl formed during anion exchange, the reaction mixture was concentrated by distilling two thirds of the solvent at 10 Torr into a cold trap. To the remaining solution was added diethyl ether (50 mL) and the mixture was shaken. The immonium salts **18** and **19** were precipitated immediately in crystalline form and **20**, **21**, **22** separated as oils. **18** and **19** were washed twice with diethyl ether (2 × 20 mL) and dried in vacuo (10^{-2} Torr) at room temp. The oily products were intensely shaken twice with diethyl ether (2 × 50 mL), the ether decanted, the residue dried at 10^{-2} Torr, then taken up in acetyl chloride (5 mL), warmed to 40 °C by stirring for 15 min, and then cooled to room temperature. On careful addition of diethyl ether the salts separated in crystalline form. They were washed twice with diethyl ether (2 × 20 mL) and dried at room temperature/10^{-2} Torr.

18: Starting material **11a** (2.48 g, 0.033 mol). **18**: Yellowish crystals (acetyl chloride), yield 4.7 g (90%). IR (Nujol): $\tilde{\nu}$ = 1705 (C=N^+) cm^{-1}. ^1H NMR ($CDCl_3$/CF_3CO_2H, TMS): δ = 8.00 (m, 2 H, N=CH_2), 3.85 (t, $^4J_{H,H}$ = 1.5 Hz, 6 H; N-CH_3) ppm. ^{13}C NMR (CD_3NO_2, TMS): δ = 168.0 (*C*H_2), 49.7 (*C*H_3) ppm. This salt could not be prepared in analytical reagent grade.

19: Starting material **11b** (0.93 g, 0.009 mol). **19**: Colourless crystals (acetic anhydride/diethyl ether), yield 1.3 g (77%). IR (CH_2Cl_2): $\tilde{\nu}$ = 1700 (C=N^+) cm^{-1}. ^1H NMR (CD_2Cl_2, TMS): δ = 8.31 (m, 1 H, 1-H), 3.78 (d, $^4J_{H,H}$ = 1.25 Hz, 3 H; N-CH_3{*cis* to 1-H}), 3.55 (d, $^4J_{H,H}$ = 1.0 Hz, 3 H; N-CH_3{*trans* to 1-H}), 2.74 (quin., $^3J_{H,H}$ = 7.5 Hz, 2 H; 2× 2-H), 1.35 (t, $^3J_{H,H}$ = 7.5 Hz, 3 H; CH_3) ppm. ^{13}C NMR (CD_3NO_2, TMS): δ = 185.2 (C-1), 51.4 (N-*C*H_3{*cis* to 1-H}), 42.4 (N-*C*H_3{*trans* to 1-H}), 26.5 (C-2), 9.4 (*C*H_3) ppm. $C_5H_{12}ClNO_4$ (185.61): calcd. C 32.36, H 6.52, N 7.55; found C 31.87, H 6.73, N 7.32.

20: Starting material **11c** (0.77 g, 0.0054 mol). **20**: Colourless crystals (acetyl chloride), yield 1.1 g (91%). IR (CH_2Cl_2): $\tilde{\nu}$ = 1660 (C=N^+) cm^{-1}. ^1H NMR ($CDCl_3$/CF_3CO_2H, TMS): δ = 3.62 (s, 6 H, 2× N-CH_3), 2.81 (m, 4 H, 2× 2-H, 2× 6-H), 1.85 (m, 6 H, 2× 3-H, 2× 4-H, 2× 5-H) ppm. ^{13}C NMR (CD_3NO_2, TMS): δ = 195.1 (C-1), 45.4 (2× N-*C*H_3), 33.9 (C-2, C-6), 25.9 (C-3, C-5), 23.9 (C-4) ppm. $C_8H_{16}ClNO_4$ (225.67): calcd. C 42.58, H 7.15, N 6.21; found C 42.19, H 7.34, N 6.17.

21: Starting material **11d** (0.85 g, 0.0084 mol). **21**: Colourless crystals (acetic anhydride/diethyl ether), yield 1.33 g (86%). IR (CH_2Cl_2): $\tilde{\nu}$ = 1710 (C=N^+) cm^{-1}. ^1H NMR (CD_2Cl_2, TMS): δ = 8.58 (q, $^4J_{H,H}$ = 1.7 Hz, 1 H; 2-*H*), 4.19 (t, $^3J_{H,H}$ = 4 Hz, 2 H; 2× 5-H), 3.71 (d, $^4J_{H,H}$ = 1.7 Hz, 3 H; N-CH_3), 3.26 (m, 2 H, 2× 3-H), 2.45 (qui, $^3J_{H,H}$ = 4 Hz, 2 H; 2× 4-H) ppm. ^{13}C NMR (CD_3NO_2, TMS): δ = 183.4 (C-2), 62.1 (C-5), 41.7 (N-*C*H_3), 37.1 (C-3), 20.9 (C-4) ppm. $C_5H_{10}ClNO_4$ (183.59): calcd. C 32.71, H 5.49, N 7.63; found C 32.0, H 5.42. N 7.37.

22: Starting material **11e** (1.17 g, 0.01 mol). **22**: Colourless crystals (acetyl chloride), yield 1.56 g (77%). IR (CH_2Cl_2): $\tilde{\nu}$ = 1695 (C=N^+) cm^{-1}. ^1H NMR ($CDCl_3$/CF_3-CO_2H, TMS): δ = 8.55 (m, 1 H, 2-*H*), 3.75 (m, 2 H, 2× 6-H), 3.72 (s, 3 H, N-CH_3), 3.07 (m, 2 H, 2× 3-H), 1.96 (m, 4 H, 2× 4-H, 2× 5-H) ppm. ^{13}C NMR (CD_3NO_2, TMS): δ = 180.4 (C-2), 53.5 (C-6), 49.9 (N-*C*H_3), 29.5 (C-3), 21.2 (C-5), 15.8 (C-4) ppm. $C_6H_{12}ClNO_4$ (197.62): calcd. C 36.47, H 6.12, N 7.09; found C 36.08, H 6.39, N 6.87.

Reaction of 8c with Tetramethylammonium Acetate (TMAA): A solution of **TMAA** (0.932 g, 0.007 mol) in chloroform (10 mL) was placed in a frit equipment, cooled to 0 °C and a solution of **8c** (0.69 g, 0.0024 mol) in dichloromethane (10 mL), also cooled to 0 °C, was slowly added dropwise. The reaction mixture was stirred for 90 min. During the reaction tetramethylammonium perchlorate precipitated in crystalline form. The excess of **TMAA** was precipitated by addition of ether. The solvent was removed in vacuo (10 Torr) from the filtrate at room temp. The remaining oil was dissolved in trifluoroacetic acid and analyzed by ^1H NMR spectroscopy. The reaction mixture contained two products **23a** and **15c** (ratio 10:3). **23a**: δ = 8.06 (N=CH_2), 3.77 (N-CH_3). **15c**: δ = 3.4 (N-CH_3) ppm.

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