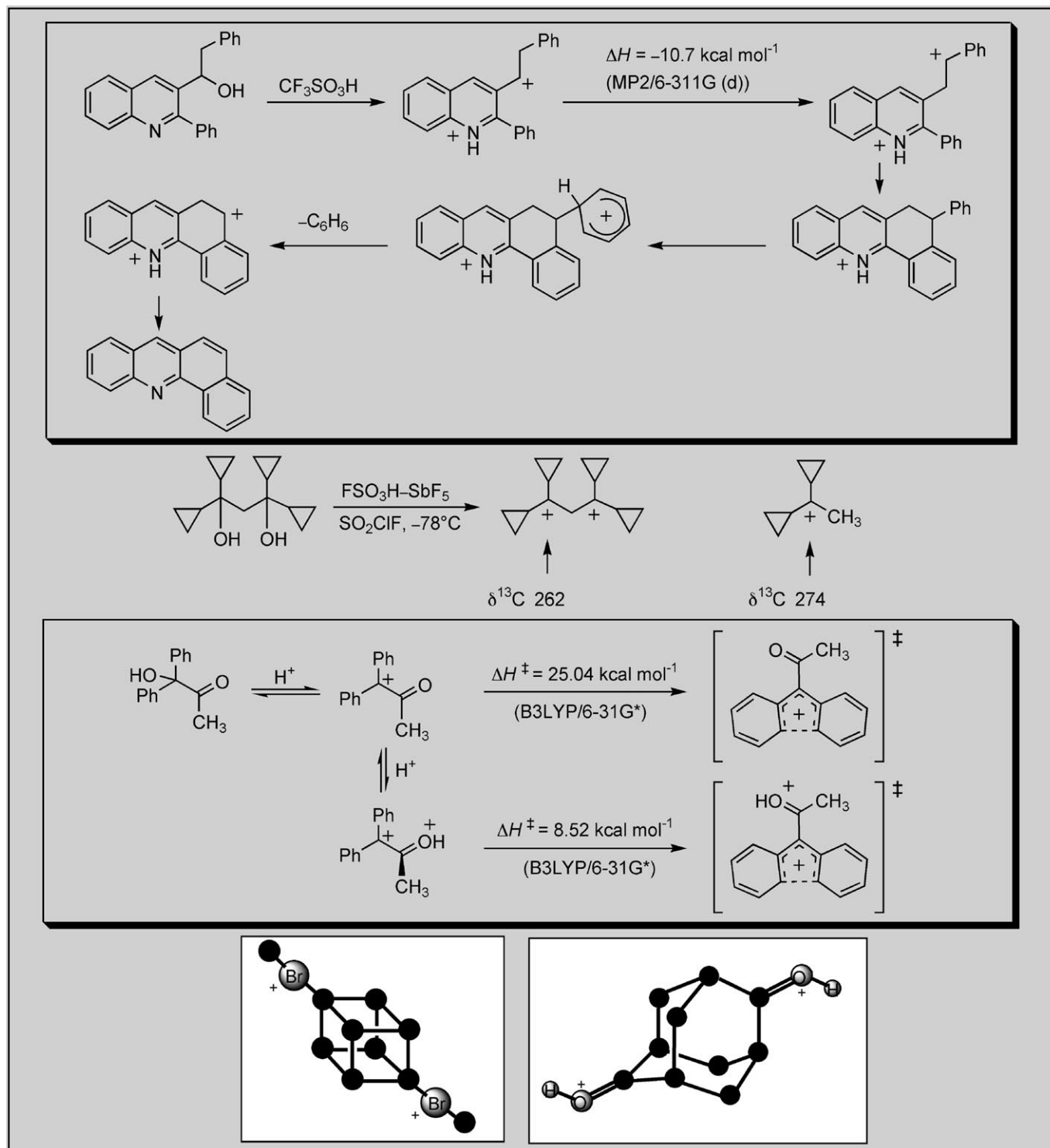# Superelectrophiles: Charge–Charge Repulsive Effects

Douglas A. Klumpp*[a]

Dedicated to Professor George A. Olah on the occasion of his 80th birthday

Abstract: Over the years, a significant number of di- and tricationic superelectrophiles have been studied. Many of these superelectrophiles exhibit charge–charge repulsive effects due to the interaction of the positive charges. Charge–charge repulsion can lead to novel molecular rearrangements, profoundly influence reactivities, and may significantly effect molecular structure.

Keywords: acidity · cations · Coulombic repulsion · electrostatic interactions · superelectrophiles

Introduction

During the 1960–70s, there were several reports of cationic electrophiles exhibiting increased reactivities in superacidic media. To account for the observed increasing electrophilic reactivities, Olah proposed the concept of superelectrophilic activation.[1] For the acetyl cation (**1**), superacidic media may interact with the non-bonding electron pairs, generating a protosolvated superelectrophile (**2**, Figure 1). In the limiting case, superelectrophilic activation may involve de facto dicationic superelectrophiles (i.e., **3**). Protosolvation of the acetyl cation produces an electrophile with increasing dicationic character and consequently superelectrophilic reactivity. Superelectrophilic activation is also observed with Lewis acid systems, for example producing the superelectrophile (**4** or **5**) by electrophilic solvation.[2]
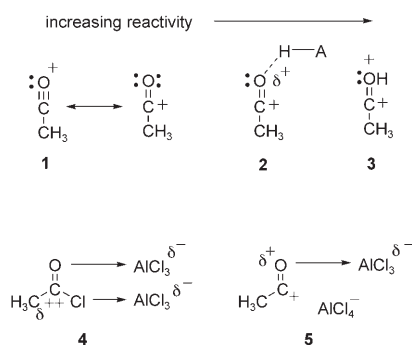

Figure 1. Acetyl cation **1** and its superelectrophilic derivatives **2**–**5**.

Superelectrophiles are organized according to their structures and the approximate distance between the charge centers (Table 1).[1e] The two basic categories, first proposed by

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Table 1. Categories of superelectrophiles with selected examples.

Olah, are the gitionic and distonic superelectrophiles. Gitionic (close) superelectrophiles are characterized by the charge centers being separated by no more than one carbon or heteroatom. They are further distinguished by the distance between charges, with geminal systems (**6**–**8**) having the charges located around a single atom, vicinal systems (**9**–**11**) being represented as 1,2-dications, and also with 1,3-dicationic systems (**12**–**14**). It is understood that various factors (including charge delocalization) makes such a classification approximate. For example in superelectrophilic oxonium ions such as diprotonated water **6**, calculations have shown that most of the positive charge resides on the hydrogen atoms.[3] Dications **10** and **12** also delocalize positive charge through resonance into the phenyl and cyclopropyl rings, respectively. Distonic (distant) superelectrophiles are characterized by structures having charges separated by 2 or more carbons or heteroatoms (i.e., **15**–**17**). The distonic superelectrophiles are distinguished from other types of onium dications, those in which the onium charge centers are isolated electrophilic sites. In such cases, the onium dications exhibit chemistry that is little different than monocationic electrophiles. Superelectrophiles may also involve hypervalent species, such as diprotonated methane (**8**) and butane (**15**) and the protosolvated *tert*-butyl cation (**11**).

The chemistry of superelectrophiles has been thoroughly reviewed several times.[1b–e] These earlier reviews provide overviews of this chemistry, including evidence for superelectrophiles, as well as summarizing their use in synthesis. Due to the dicationic nature of superelectrophiles (as well as the close proximity of the onium sites), it is expected that much of their chemistry will be controlled by Coulombic interactions. Electrostatic effects are well known for their influence on monocationic systems. For example, onium cations (ammonium, phosphonium, sulfonium, etc.) can significantly alter the acidities of adjacent groups and effect the preferred conformations of structures.[4] In the following concept article, the effects of Coulombic interactions and

their role in the chemistry of superelectrophiles will be examined.

Charge–Charge Repulsive Effects

Charge–charge repulsion and charge delocalization in superelectrophiles can have unusual effects in structure, bonding, and charge distributions. For example, the bishalonium ions (**19a,b**) from 1,4-dihalocubanes (**18a,b**) have been successfully prepared (Figure 2).[5] In contrast, the monohalonium
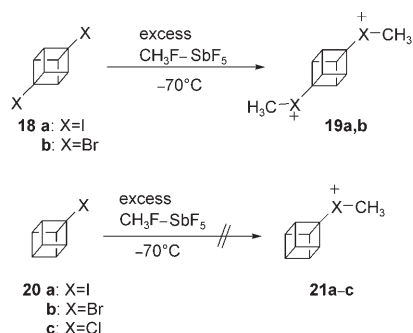
Figure 2. Cubyl halonium ions.

ions (**21a,b**) cannot be prepared using the same chemistry, but instead complex product mixtures are observed. It is suggested that the dicationic structures (**19a,b**) stabilize the cubyl framework towards ring-opening processes, including cleavage by superacid. The monocationic halonium ions (**2a–c**) do not possess this electrostatic stabilization of the cubyl cage. Another interesting system is the 1,4-bicyclo-[2.2.2]octanediyl dication (**25**, Figure 3).[6] Though efforts to
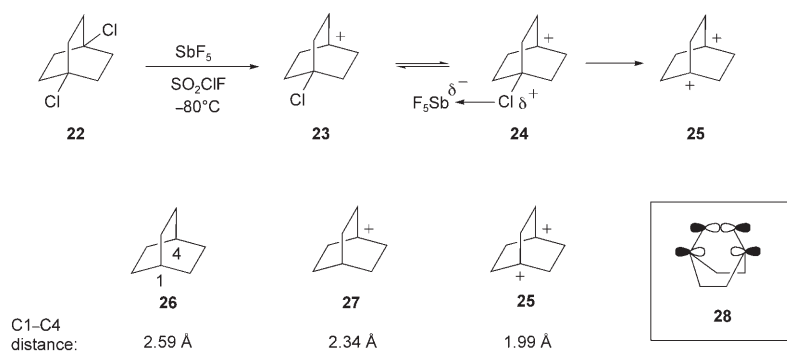
Figure 3. Bicyclo[2.2.2]octanediyl dication **25** and related structures.

observe dication **25** have not yet been successful, the superelectrophilic donor–acceptor complex **24** has been detected. MNDO calculations estimate the C1–C4 distance to be only 1.99 Å in **25**, considerably less than the C1–C4 distance in the parent hydrocarbon (**26**). Although charge–charge repulsion might be expected to increase the C1–C4 distance, this

does not occur. Extensive hydperconjugation with the adjacent methylene groups leads to the transfer of electron density to the carbocationic centers, resulting in symmetry allowed 1,4 bonding (i.e., **28**) and shortening of the C1–C4 distance.

In adamantane-based dications, adamanta-1,3-dimethyldiyl dication (**29**, a 1,5-dication) has been prepared in superacid (Figure 4) and observed by low temperature NMR
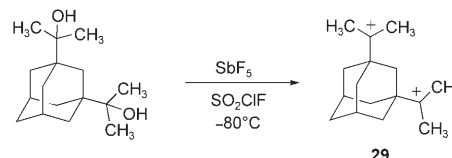
Figure 4. Preparation of adamanta-1,3-dimethyldiyl dication **29**.

spectroscopy.[7] The ^{13}C NMR data from dication (**29**) indicates that the positive charges are highly delocalized into the substituents and adamantyl cage. This is thought to be the result of the close proximity of the cationic charge centers. Similarly, the phenylene dication (**30**) was shown to have significantly deshielded methyl ^{13}C NMR signals compared to the analogous monocation **31** (the cumyl cation; Figure 5).[8]
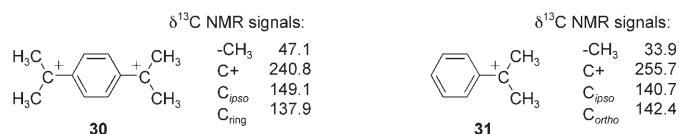
Figure 5. Comparison of dication **30** with the cumyl cation **31**.

This suggests a greater amount of hyperconjugation with the methyl groups in the **30**, a consequence of the charge–charge repulsion. In studies of diprotonated 2,6-adamantanedione (**32**), the carboxonium ^{13}C resonance is observed at δ 247.7, while the related monocationic species (**33**) exhibits a carboxonium ^{13}C resonance at δ 267.1 (Figure 6).[9] These results indicate an increasing importance of the car-
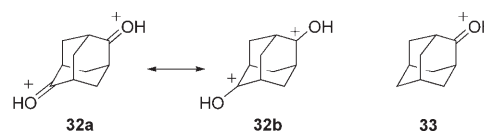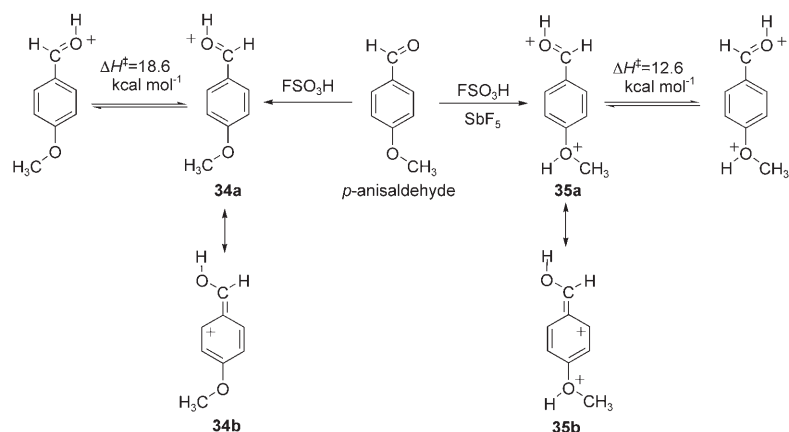
Figure 6. Protonated 2,6-adamantanedione and 2-adamantanone.

Figure 7. Protonation of *p*-anisaldehyde.

boxonium-type resonance structure (**32a**) due to the charge–charge repulsive effects. Using dynamic NMR techniques, a charge–charge repulsive interaction was shown to influence the rotational barrier in a superelectrophile (Figure 7).[10] In FSO$_3$H (H_o −15), *p*-anisaldehyde forms the carboxonium ion **34** and the rotational barrier was estimated to be 18.6 kcal mol^{-1}. In the stronger superacid FSO$_3$H/SbF$_5$ (H_o −20), the superelectrophile (**35**) is formed, and as a consequence, the rotational barrier decreases to 12.6 kcal mol^{-1}. This can be understood by considering the π-donation of the aryl ring, represented by resonance structures **34b** and **35b**. In the superelectrophile **35**, charge–charge repulsive effects tend to disfavor π-donation (and resonance form **35b**), leading to decreased double-bond character between the aryl ring and carboxonium group, and this influences the barrier to rotation.

The stability of aliphatic carbodications is significantly influenced by charge–charge repulsive effects. For example, long-lived aliphatic carbodications can be prepared (in the absence of electron donating groups) only if the charge bearing carbons are separated by at least two carbon atoms (Figure 8).[11] Ionization of compound **36** leads exclusively to the allyl monocation **38** rather than the 1,3-cabodication
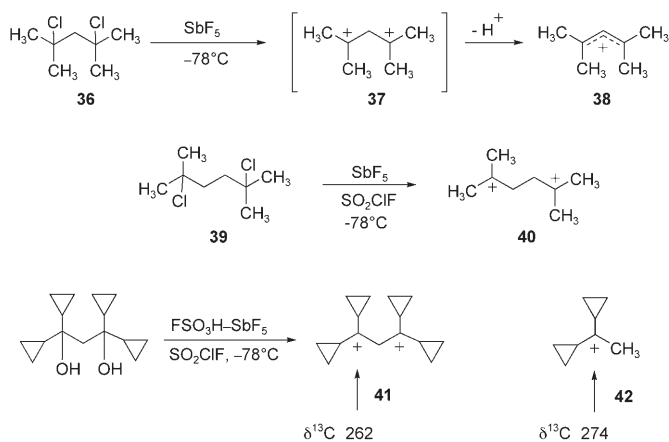
(**37**), while compound **39** provides the dication (**40**). A 1,3-dicarbocation has been prepared by utilization of stabilizing cyclopropyl groups (**41**).[12] When compared to the analogous monocation (**42**), it is seen that the carbenium centers are shifted significantly upfield in the dication **41**. This is attributed to more extensive delocalization of the positive charge into the cyclopropyl groups due to Coulombic repulsion.

Experimental and theoretical studies have demonstrated that charge–charge interactions can be significant in positional isomers of phenylenediyl dications and related systems. For example, the bis(1,3-dioxolanium) dications (**43**–**45**) are prepared by superacid-promoted reactions of the appropriate 2-methoxyethyl esters (Figure 9).[13] In calculations at the B3LYP/6-311*//B3LYP6-
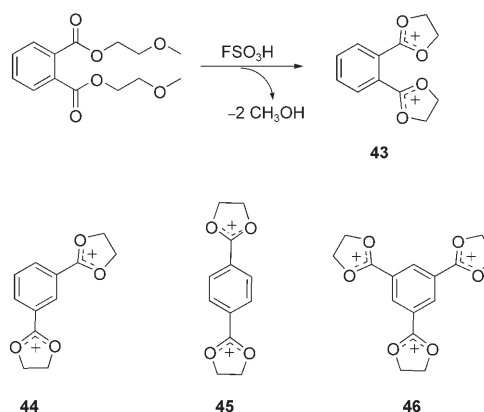
Figure 9. Studies of bis(1,3-dioxolanium) dications **43**–**45** and trication **46**.

31G* level, it was found that the energy of the *ortho* isomer is 15.0 kcal mol^{-1} higher in energy than the *para* and *meta* isomers. The destabilization of the *ortho* isomer is thought to be due to a combination of steric effects and charge–charge repulsive effects. When the tricationic species (**46**) is compared to the dications, NMR data indicates further electrostatic repulsive effects. The methylene carbons on the 1,3-dioxolanium rings are found at δ ^{13}C 77.5 for dication **44** and δ ^{13}C 86.9 for trication **46**. This increased deshielding on the trication is due to charge–charge repulsion leading to enhanced delocalization of the positive charge onto the ring oxygen atoms. As a result, the adjacent methylene carbons are deshieded. A series of phenyl-substituted phenylenediyl dications (**47**–**49**) were prepared in sulfuric acid solution and their pK_{R+} values were determined (Figure 10).[14] It was found that the pK_{R+} value for the *ortho*-substituted system
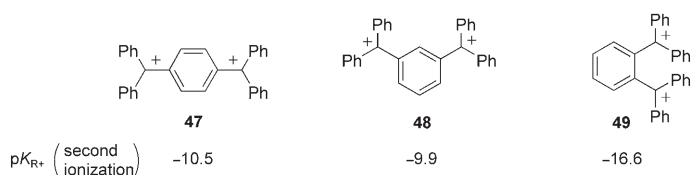

Figure 8. Preparations of carbodications.

Figure 10. Ionizations to phenylenediyl dications 47–49.

was significantly higher (more negative) than the isomeric dications. This was attributed to the close proximity of the charge centers.

In calorimetric studies of diketones, it was shown that the heats of diprotonation are related to the distance between the carboxonium ion centers.[15] In the case of γ-diketones, such as 2,5-hexanedione (50), the heats of diprotonation are found to be about 5 kcal mol^{-1} less that expected, when compared to the twice the heat of protonation of acetone and other monoketones (Figure 11). The decreased heat of diprotonation is a consequence of the Coulombic destabilization of the dicationic structure (51). With increasing separation of the carbonyl groups in the diketones (52, $n=3$), the heats of diprotonation are about equal to twice the

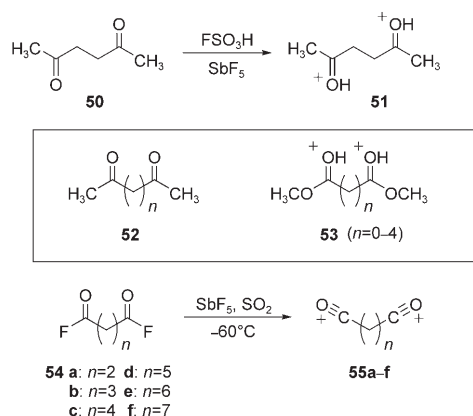Figure 11. Bis-carboxonium and bis-acyl dications 51, 53, 55.

heats of protonation of monoketones. Calorimetric studies reveal a similar trend with diprotonated diesters (53).[15] Charge–charge repulsive effects in 53 become negligible with separation of the carboxonium groups by three or more methylene units. Likewise, ionization of dicarboxylic acid fluorides (54) with SbF$_5$ may be accomplished in all cases except succinyl fluoride (54a), leading to the bis-acyl dications (55b–h, Figure 11).[15,16] The bis-acyl dications (55b–h) are capable of

reacting with benzene to give the respective diketone products. When the heats of ionization are measured, it was found that separation of the carboxylic acid fluoride groups by greater than three methylene units gives similar heats of ionization. Thus, the inability to prepare 55a and the decreased heat of ionization of 55b are consistent with charge–charge repulsive effects.

In 1,2-ethylene dications, charge delocalization has been studied by both experimental and theoretical methods (Figure 12). The ethylene dication (CH$_2$CH$_2^{2+}$, 56) has been observed in the gas phase and its structure studied by calculations.[17] Dication 56 is characterized by a structure with orthogonal vacant orbitals, allowing for delocalization of charge by hyperconjugation with the vicinal CH$_2$ groups. This leads to a relative short carbon-carbon bond length, estimated to be only 1.432 Å. With aryl-substitution, the 1,2-ethylene dications are sufficiently stable to be directly studied by NMR using stable ion conditions.[8] When compared to the olefin (57), the aryl ring carbons are significantly deshielded in the dication 58. This is consistent with separation of the positive charge through delocalization.

A number of superelectrophilic systems have been shown to undergo rearrangements that lead to greater distance between the charge centers. For example, the 1,5-manxyl dication 59 can be generated and it is found to be stable at −105 °C, but rearranges to dication 60 at −60 °C (Figure 13).[18,19] DFT calculations show that dication 60 is 26 kcal mol^{-1} more stable than 59, and rearrangement leads to an increased distance between the charge centers. Although both are formally 1,5-dications, the distance between the charge centers is 2.80 Å in the 1,5-manxyl dication (59) and 3.58 Å in dication 60. Efforts to ionize diol 61 to the 1,4-cyclohexyl dication (62) lead exclusively to dication 63.[20] This rearrangement is also driven by charge–charge repulsion.

It has been shown that superelectrophilic ring opening reactions may also be involve charge–charge separation (Figure 14). For example, reaction of the cyclopropane carboxylic acid (64) leads to product 66,[21] which arises from

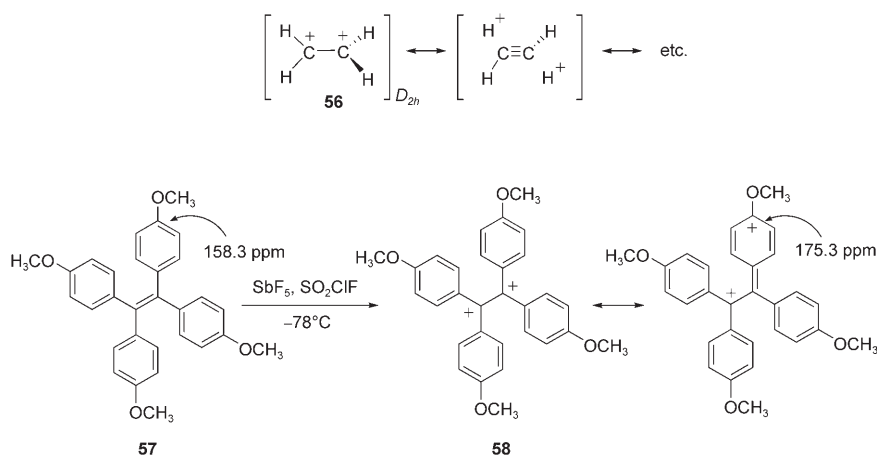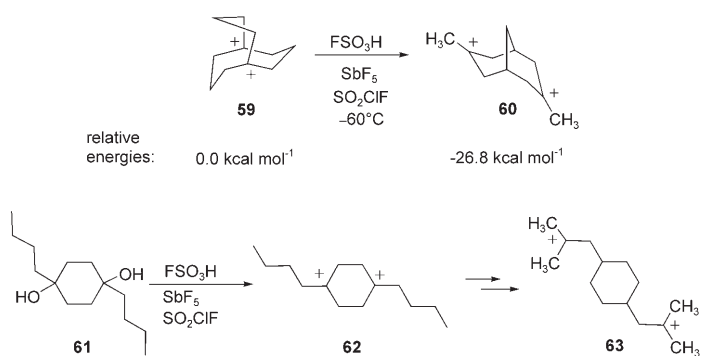Figure 12. 1,2-Ethylene dications 56 and 58.

Figure 13. Dicationic rearrangements.

protonation of the C1−C2 bond and formation of the super-electrophile (**65**). Subsequent reaction with benzene and cyclization give the tertralone **66**. Although protonation of the C2−C3 bond would also provide a benzylic-type carbo-cation (**67**), this intermediate is not formed due to Coulombic destabilization. In the super-acid-catalyzed reactions of oxa-zolines, diprotonation of the heterocycle gives the 1,3-dicat-ion (**68**) and ring opening leads to the distonic superelectro-phile (**69**, a 1,5-dication).[22] The charge-separated species is shown to be capable of reacting with benzene and dichloroben-zene. The isoxazolidine (**70**) un-dergoes a similar Lewis acid-promoted ring opening reaction to **72** and a Friedel–Crafts-type reaction with benzene.[23] Both the isoxazolidine and oxazoline ring opening are driven to some extent by charge–charge repul-sion.

Charge migration driven by charge–charge repulsion has also been observed on the side chains of pyridinium rings and other protonated *N*-heterocy-cles (Figure 15). For example, ionization of the alcohol **73** in superacid initially provides the 1,5-dication (**74**). Charge migra-tion leads to the 1,6-dication (**75**), which is trapped with ben-zene in high yield.[24] A similar charge migration is used in a superacid-promoted synthesis of aza-polycyclic aromatic com-pounds.[24] In the case of the quinoline **76**, ionization in

CF$_3$SO$_3$H initially provides the 1,4-dication (**77**). Charge mi-gration leads to **78** which undergoes cyclization and benzene elimination to provide benz[*c*]acridine (**79**) in reasonably good yield. Calculations estimate dication **78** to be about 10 kcal mol^{-1} more stable than dication **77**.[24b]

Varied onium dications have given products from charge migrations reactions. In the synthesis of the analgesic drug Butorphanol, a key step involves the ring expansion of the ammonium-carbodication (**80**), formally a distonic super-electrophile (Figure 16).[25] Despite the benzylic stabilization of the carbocationic center, charge–charge repulsive effects dominate and the ring expansion product (**81**) is formed. Further synthetic steps then provide the product Butorpha-nol. Reaction of the phosphonium salt (**82**) in superacid gives the 1,4-dication (**83**), which undergoes charge migra-tion to the 1,5-dication (**84**, Figure 17).[26] The resulting su-perelectrophile (**84**) reacts quantitatively with benzene.

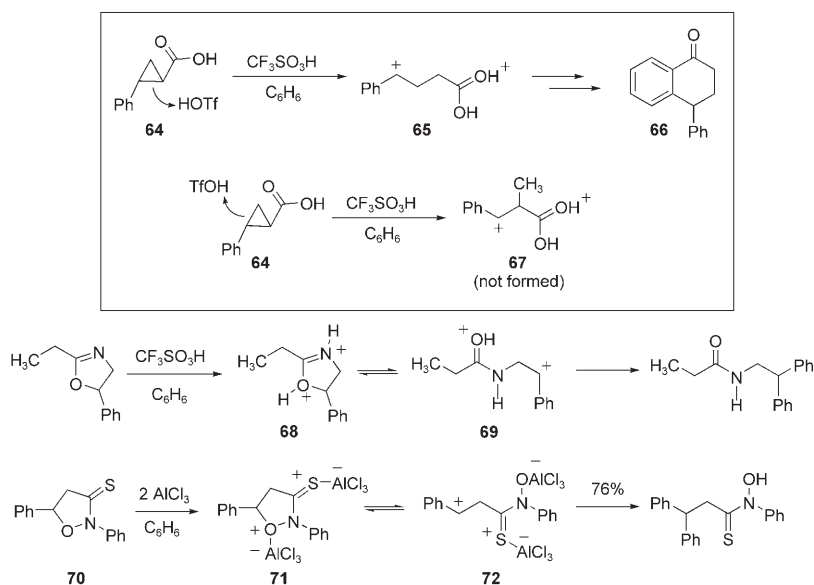

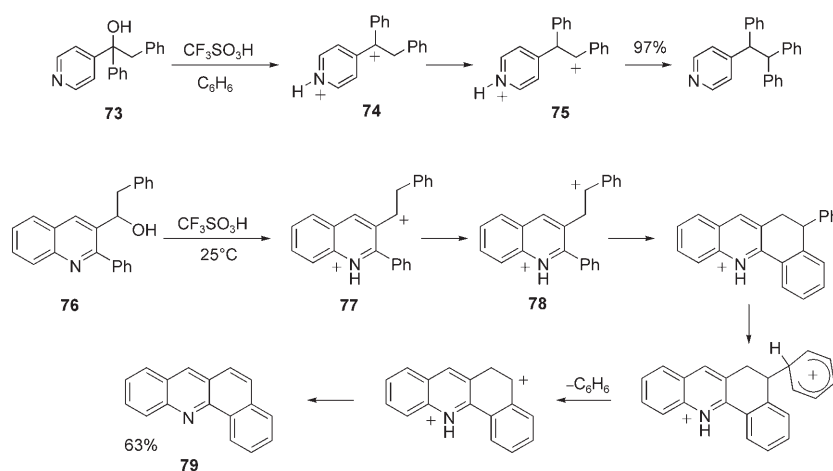Figure 14. Ring opening reactions involving superelectrophiles.
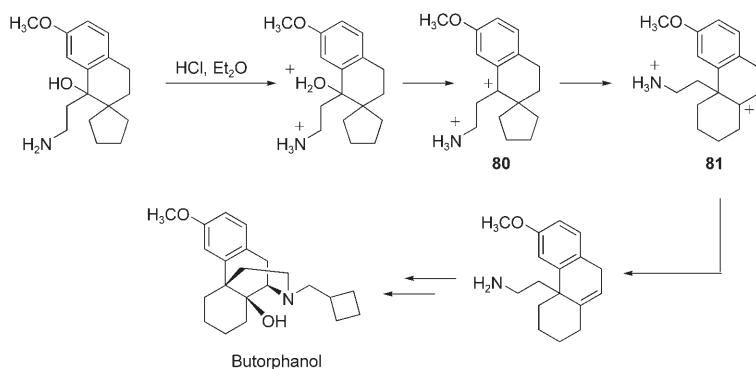

Figure 15. Charge migrations on heterocyclic side chains.
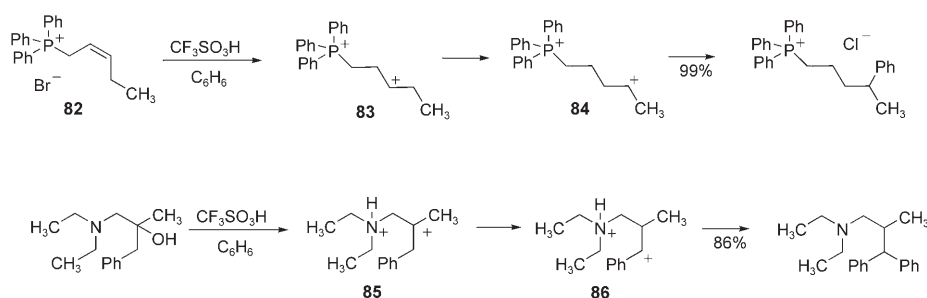
Figure 16. Preparation of *butorphanol*.

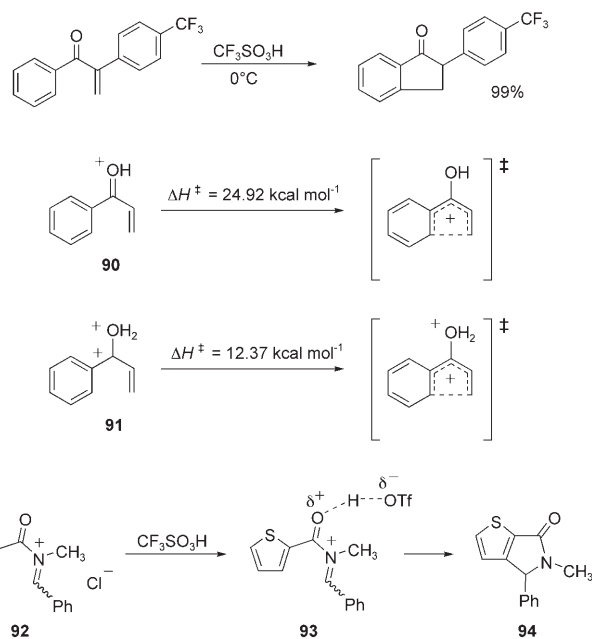Figure 17. Charge migration in onium dications **83** and **85**.

uct is found to be $16 \, \text{kcal mol}^{-1}$ lower in energy for the superelectrophillic cyclization. Charge–charge repulsion enhances the delocalization of positive charge into the phenyl rings, a necessary condition for the 4π electrocyclization. A similar result was obtained in a study of the Nazarov reaction (Scheme 2).[28] Examples of the Nazarov reaction gave increased yields and reaction rates with progressively stronger acids. Theoretical calculations done at the B3LYP/6-31G* level showed a significant decrease in the activation energy when the superelectrophile (**91**) was compared to the monoprotonated system (**90**). Again, charge–charge repulsion leads to a greater delocalization of positive charge and consequently the activation energy is lowered for the 4π electrocyclization. Recently, a similar mechanism was suggested in an aza-Nazarov reaction (Scheme 2).[29] It was suggested that protosolvation of the *N*-acyliminium ion (**92**) gives the superelectrophile (**93**) which undergoes cyclization to the heterocyclic product (**94**). Theoretical calculations likewise show that protosolvation leads to a dramatic lowering (ca.

Likewise, the amino alcohol provides dication (**85**) from superacid, and charge separation leads to the superelectrophile **86**, and product formation.[24]

The delocalization of positive charge in superelectrophiles has been shown to be important in concerted electrocyclization reactions. Shudo and Ohwada studied the superacid-promoted reactions of hydroxyketones such as **87** and formation of substituted fluorenes (Scheme 1).[27] With supporting evidence from kinetic and theoretical studies, it was proposed that superelectrophilic dications trigger the 4π electrocyclization. In comparing the monocation **88** with the dication **89**, the transition state leading to the cyclization product is found to be...

Scheme 1. Superelectrophilic electrocyclization.

Scheme 2. Superelectrophilic Nazarov and aza-Nazarov reactions.

Figure 18. Influence of protosolvation on stereomutation.

$12 \, \text{kcal} \, \text{mol}^{-1}$) of the activation energy to the cyclization. Delocalization of positive charge in a superelectrophile was also shown to increase the isomerization rate of an unsaturated carboxonium ion (**96**, Figure 18).[30] It was demonstrated that protosolvation of **97** leads to a significant increase in the rate of isomerization from **97** to **96**. This is understood as a consequence of the charge–charge separation and the greater importance of resonance form **98b**.

An interesting application of charge–charge repulsive effects has been in the remote functionalization of compounds. As a result of the tendency for charges to be separated, it has been observed in several studies that reactions producing cationic charge will occur at the site most distant from an existing onium charge center. For example, Olah and co-workers studied the protosolvation of the propionyl cation (**99**) and found that H/D exchange only occurred at the methyl carbon (Figure 19).[31] The selectivity of this exchange is explained by formation of the carbonium ion (**100**) at the methyl carbon, rather than the methylene carbon, in order to maximize charge separation. In the oxyfunctionalization of aldehydes and ketones, it was observed that compounds like cycloheptanone may be regioselectively converted to the diketone (**101**) by the reaction with ozone in FSO₃H/SbF₅ (Figure 20).[32] Exclusive formation of the 1,4-diketone **101** is understood as a result of maximum charge separation in the reaction. Oxy functionalization at the α- and β-carbons would require intermediates and/or transition states with more closely oriented charges. In a similar respect, pentanal gave the dicarbonyl product **103** in

good yield, however, butanal does not give the oxyfunctionalization product.[32] While the 1,5-dication (**102**) is apparently a viable superelectrophile, the 1,4-dication (**104**) does not form due to the more closely oriented charge centers. Electrostatically-controlled functionalizations are particularly efficient when the developing
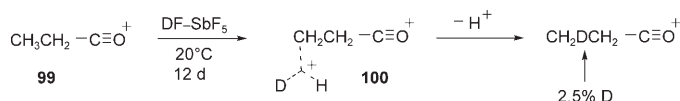
Figure 19. Protosolvation of the propionyl cation **99**.

charge center is relatively stable (i.e., tertiary carbocation), as demonstrated in the fluorination of amide **105** and the carboxylation of ketone **106** (Figure 21).[33, 34]

Other aspects of regioselectivity are influenced by charge–charge repulsive effects (Figure 22). In the reactions of 1,2,3,6-tetrahydropyridines, diprotonation leads to the charge-separated 1,4-dication **106**.[35] The less stable 1,3-di-
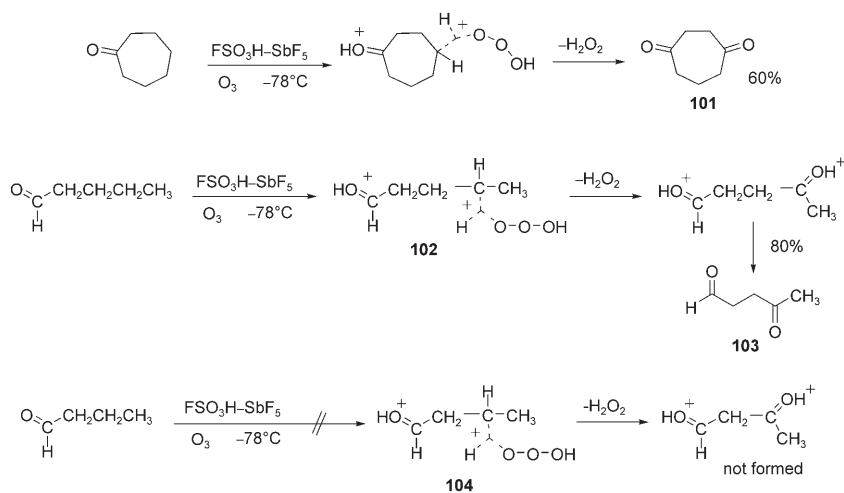

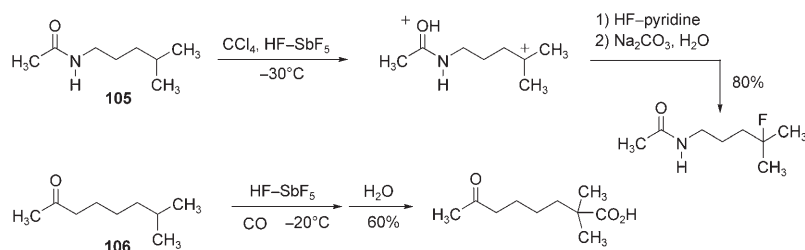Figure 20. Remote oxyfunctionalization involving superelectrophiles.

Figure 21. Remote functionalization involving carboxonium superelectrophiles.

cation **107** is not formed. With introduction of the methyl-substituent, the 1,3-dication **108** can be obtained. In this case, the increased stability of the tertiary carbocationic center in **108** compensates for the Coulombic destabilization in the 1,3-dication. The preference for charge-separated dications is important in the Grewe cyclization, chemistry that is useful in the preparation of morphine analogues.[36] Regioselective formation of the 1,4-dication (**109**) is critical to the success of this synthetic chemistry.

Another aspect of charge–charge repulsive effects has been described for intermolecular reactions of superelectrophiles. Vinyl-substituted *N*-heterocycles react in CF_3SO_3H to generate superelectrophiles (i.e., **111**) and react further with arene nucleophiles (Figure 23).[37] There is no oligomer or polymer formation from the vinylpyridine or other vinyl-substituted heterocycles. Similar chemistry has also been described with *N*-heterocyclic alkynes.[38] In contrast, CF_3SO_3H is known to be a good catalyst for the cationic polymerization of styrene.[39] Polymerization of vinylpyridine is inhibited by unfavorable electrostatic interaction, as cationic polymerization would require that dication **111** react with the vinyl group of **110**. Charge–charge repulsion essentially inhibits collisions between the dication **111** and monocation **110** and this prevents oligomerization and polymerization.

In general, superelectrophilic activation decreases with greater distance between the charge centers. Cinnamic acid (**112**) produces superelectrophile **113** in CF_3SO_3H which is capable of reacting with dichlorobenzene, however with greater distance between the carboxonium ion and carbocation centers, the superelectrophile **114** does not react with dichlorobenzene (Figure 24).[21]

Onium sites that are forced into close proximity due to a structural or conformational effect may demonstrate super-electrophilic character (Figure 25). For example, 1,8-bis(diphenylmethyl)naphthylene dication (**115**) and 1,1′-biphenyl-2,2′-diyl dications (**116**) are found to have a distance of 3.11 and 3.66 Å, respectively,

separating their carbocationic sites.[40,41] The close proximity of charges has been shown to effect their oxidation–reduction behavior, and in the case of **115**, its reactivity towards electron donors.

As noted above, closely-oriented charges can prevent the formation of superelectrophiles. This has been observed in a number of systems, including the previously described succinyl fluoride (**34a**) ionization to the bis-acyl dication. With bishalonium ions, Olah and co-workers observed that 1,3-dibromopropane may be dialkylated to give superelectrophile **117**, while the corresponding ion from 1,2-dibromoethane is only monoalkylated (**118**, Scheme 3).[42] Similarly, *p*-dibromobenzene forms the bishalonium ion (**119**), while the *meta* and *ortho* isomers only form the monoalkylated products (**120**).[42] Likewise, the halonium–oxonium dication (**121**) is
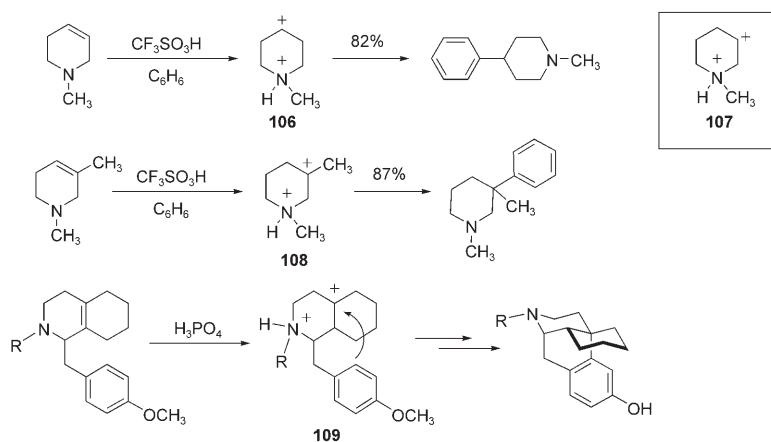

Figure 22. Superelectrophilic reactions of 1,2,3,6-tetrahydropyridines and the Grewe cyclization.
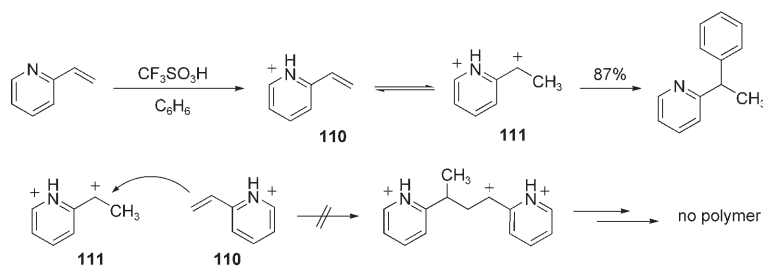

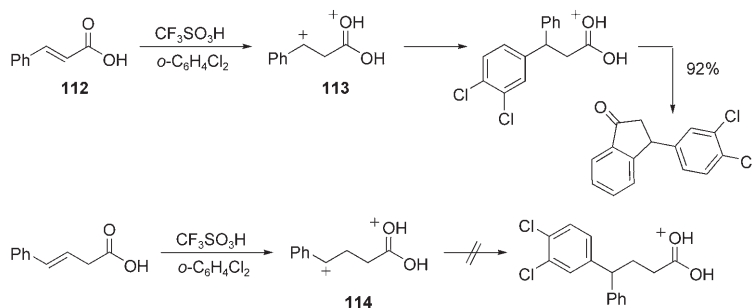Figure 23. Superacid-catalyzed reaction of 2-vinylpyridine.

Figure 24. Influence of distance on the reactivities of carboxonium-carbenium dications.
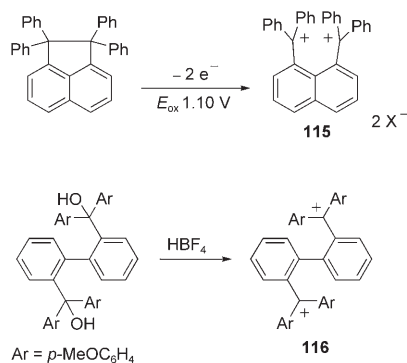
Figure 25. 1,8-Bis(diphenylmethyl)naphthylene and 1,1′-biphenyl-2,2′-diyl dications.
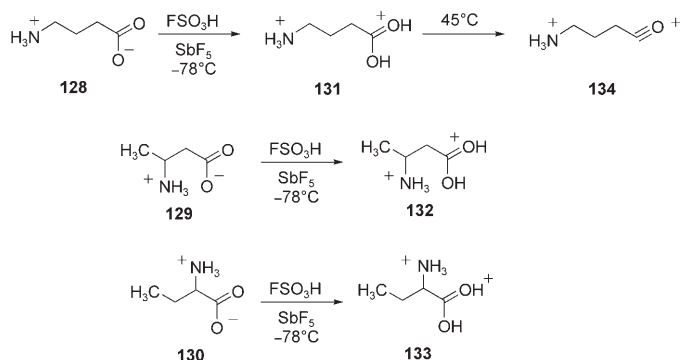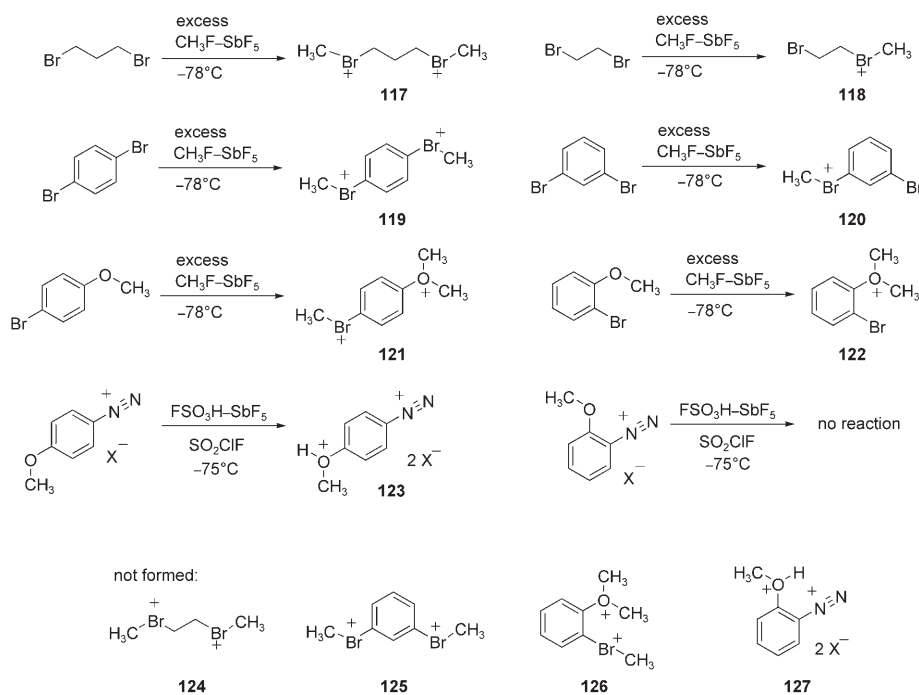

Figure 26. Ionization of aminobutyric acids **128–130**.

formed (accompanied by ca. 20% oxonium monocation) from *p*-bromoanisole, but not from the *m*- and *o*-bromoanisole.[43] The *p*-methoxybenzene diazonium salt is protonated (i.e., **123**) in FSO₃H/SbF₅, while *o*-methoxybenzene diazonium salt cannot be protonated.[44] These examples suggest a significant Coulombic destabilization in the structures **124**–**137**, when compared to the respective charge-separated dications (**117**, **119**, **121**, and **123**). A similar situation has also been described with a series of amino acids (Figure 26).[45] Ionization of aminobutyric acids (**128–130**) in FSO₃H-SbF₅ at low temperature gives the corresponding ammonium-carboxonium dications (**131–133**). When the solutions are warmed to 45°C, however, only the dication (**131**) from γ-aminobutyric acid (**128**) reacts further to yield the aminoacyl dication (**134**). With dications **132** and **133**, the ammoni-

um and carbonium groups are more closely-oriented, compared to **131**, and this prevents ionization to the acyl ions.

It is known from numerous gas-phase studies that multiply charged ions have a strong tendency to fragment into charge separated species. The driving force for these Coulombic explosions is of course the electrostatic repulsion arising from the multiple charge centers. The properties of multiply charged gas-phase ions, and their fragmentation reactions, have been described in several excellent reviews.[46,47] Both small molecular ions and larger ions derived from biomolecules are shown to undergo these (charge-separating) fragmentations in the gas-phase. Although little work has been done to study analogous processes involving superelectrophiles in the condensed phase, the same dynamics are likely important in this chemistry. That is to say, superelectrophilic reactions will tend to favor pathways that lead to charge-separated products. This usually involves loss of proton(s), as in the case of superelectrophile **135**, but may also involve loss of cationic atoms or fragments (Figure 27).[48] Superelectrophilic halogenation with *N*-halosuccinimides has been demonstrated in solution and also studied by theoretical methods. Increasing protosolvation leads to energetically more favorable cleavage to Cl⁺ (cp. **136** and **137**).[49] A similar case is seen in the isodesmic reaction of trichloromethyl cation (**138**) and the protosolvated superelectrophile (**139**) with propane (MP4-(STDQ)/6-31G*//MP2/6-31G* + ZPE level; Figure 28).[50] In accord with experimental observations, hydride transfer to the superelectrophile **139** provides

Scheme 3. Charge proximity influencing the stability of superelectrophiles.
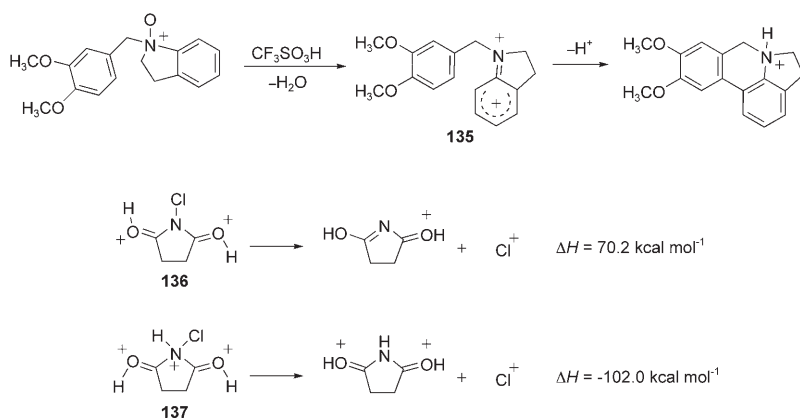
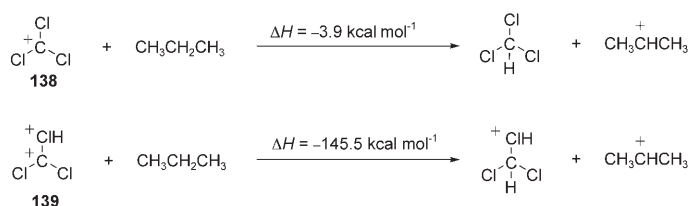Figure 27. Superelectrophilic reactions involving loss of H^+ and Cl^+.

Figure 28. Reactions of trichloromethyl cation and dication **138**–**139** with propane.

Conclusion

In summary, the study of super-electrophiles has revealed a number of trends with respect to charge–charge repulsion. In the chemical reactions of super-electrophiles, it has been observed that charge–charge repulsive effects will tend to favor reactions and reaction steps in which the charge centers separate. This can include actual charge migration, molecular rearrangement, or charge dispersal in a reaction intermediate (such as formation of a sigma complex with an arene). Charge–charge repulsive effects are well known as destabilizing forces in gas-phase ion chemistry, leading in some cases to "Coulombic explosion" of multiply charged ions. A similar situation occurs in condensed phase chemistry and superelectrophiles will tend to undergo reactions that involve loss of protons, hydronium ion, and other cationic fragments. Charge–charge interactions in superelectrophiles are strongly dependent on the distance between the interacting onium centers. Not surprisingly, the more closely spaced charge centers tend to possess greater superelectrophilic activation. This can lead to enhanced electrophilic reactivities, greater charge delocalizations, and even destabilization of these multiply charged structures. With increasing distance between the charge centers, the interaction of the onium centers decrease and their chemistry resembles that of isolated onium ions. If conformational or structural effects place the onium centers in close proximity however, superelectrophilic activation can dramatically increase. Charge–charge repulsive effects are clearly an important aspect in the chemistry of superelectrophiles. The structure–activity relationships in these systems are likely important to the chemistry of other multiply-charged structures, including biomolecules, catalytic systems, and gas-phase ions.

the 2-propyl cation (a charge-separated product) more favorably than does the monocationic electrophile (**138**). In a similar respect, charge separation can occur in reactions with arene nucleophiles. Calculations have shown a large energetic effect in the protosolvation of an *N*-acylium ion (**140**) and its reaction with benzene (Figure 29).[51] For the calculated gas-phase reactions (MP2/6-311+G(d) level), formation of the σ-complex **142** is found to be somewhat endothermic for the monocationic electrophile **140**, and strongly exothemic for the dicationic superlectrophile (**141**). The favorable energetics can be explained by the separation of charge in the σ-complex **143**, a process that is driven by charge–charge repulsion.
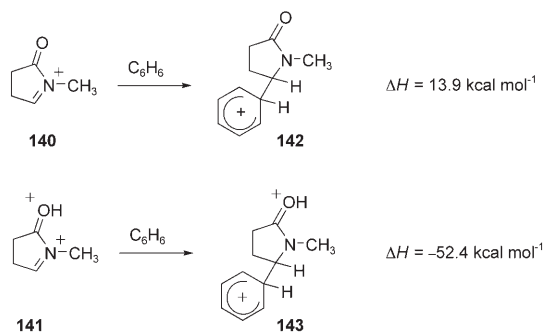
Figure 29. Reactions of *N*-acyliminium ion **140** and its superelectrophilic dication **141** with benzene, along with the calculated enthalpies of reaction.

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