α-Imino and α-Oximino Carbocations. A Comparison with α-Carbonyl and α-Thiocarbonyl Carbocations

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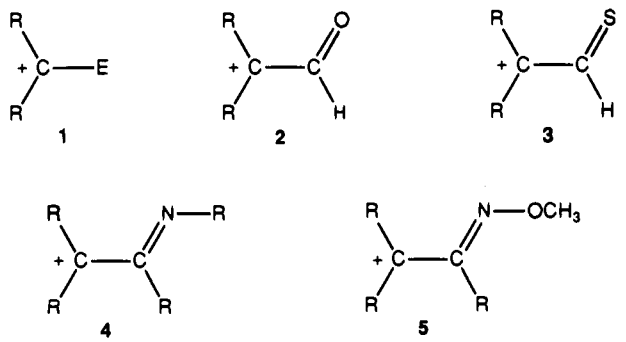
Abstract: The σ^+ values for the groups *m*-CH=N-*t*-Bu and *p*-CH=N-*t*-Bu have been determined to be 0.16 and 0.078, respectively. The CH=N-*t*-Bu group is therefore cation-destabilizing relative to hydrogen when placed in the meta position of a cumyl cation. Although the *p*-CH=N-*t*-Bu group is still cation-destabilizing, the effect is reduced by a competing resonance effect when the imino group is placed in the para position. However, when attached directly to a cationic center, this imino group enhances rates relative to α-H. This is interpreted in terms of a cation-stabilizing conjugative effect. The σ^+ value of the *p*-oximino group, *p*-CH=NOCH$_3$, is −0.03 and indicates that a cation-stabilizing conjugative effect can essentially offset the inductive effect of this electron-withdrawing substituent in a cumyl cation. However, when attached directly to a developing cationic center, this oximino group greatly enhances cation formation rates relative to hydrogen. This group is even more cation-stabilizing than the methyl group. Studies on systems of type ArCH(OMs)C(NOCH$_3$)Ph, where the oximino group can be syn or anti to the developing cationic center, indicate the existence of isomeric α-oximino cations, with the anti cations forming faster than the syn cations. Computational studies at the MP2/6-31G** level support the idea of extensive conjugative stabilization of α-oximino cations. Despite extensive mesomeric stabilization of α-oximimo cations, the primary cation $^+$CH$_2$CH=NOCH$_3$ cannot be solvolytically generated since nucleophilic solvent displacement processes dominate. Stabilities of a series of cations of type $^+$CH$_2$X, where X is a formal electron-withdrawing group, have been evaluated by *ab initio* methods. Isodesmic reactions indicate a stability order of α-CHNOCH$_3$ ~ CH=CH$_2$ > CHNHCH$_3$ > CHS > CHO ~ H > CN > NO$_2$.

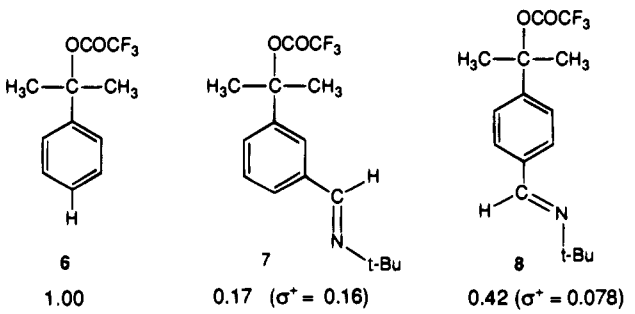
It is now well-established that carbocations substituted with formal electron-withdrawing groups are viable chemical entities. A variety of such intermediates of type **1** have been generated and studied in detail.[1] Over the years, we and others have been interested in the α-carbonyl cation **2** and the mode by which this cation receives stabilization.[2] In order to better understand the cation **2**, we have investigated the α-thiocarbonyl analog **3**.[3] The α-imino cation **4** and the α-oximino cation **5** are also intermediates related to the α-carbonyl cation. They are of



additional interest as synthetic equivalents of the α-carbonyl cation since hydrolysis of the imino group would regenerate a carbonyl-containing compound. While such intermediates have been generated in the past,[4] we wondered about their stability relative to carbonyl and thiocarbonyl analogs. We have therefore carried out solvolytic and computational studies in order to evaluate the ease of generation of α-imino and α-oximino cations and to determine their relative stabilities. Reported here are the results of these studies.

Results and Discussion

Solvolytic Studies. The initial task was to evaluate the electronic properties of the imino group. The σ^+ values of *m*- and *p*-CH=N-*t*-Bu were therefore determined from the solvolysis rate of the substituted cumyl trifluoroacetates **7** and **8**.[5] The



Relative Solvolysis Rates in CH$_3$OH

rate of methanolysis of the meta-substituted derivative **7** was 5.8 times slower than that of the unsubstituted cumyl trifluoroacetate **6**. This corresponds to a σ^+ value of 0.16 for

[⊗] Abstract published in *Advance ACS Abstracts*, February 15, 1995.

(1) Creary, X. *Chem. Rev.* **1991**, *91*, 1625.

(2) (a) Creary, X.; Hopkinson, A. C.; Lee-Ruff, E. *Advances in Carbocation Chemistry*; Creary, X., Ed.; JAI Press Inc.: Greenwich, CT, 1989; p 45. (b) Charpentier-Morize, M.; Bonnet-Delpon, D. In *Advances in Carbocation Chemistry*; Creary, X., Ed.; JAI Press Inc.: Greenwich, CT, 1989; p 219.

(3) (a) Creary, X.; Aldridge, T. E. *J. Org. Chem.* **1988**, *53*, 3888. (b) Creary, X. Aldridge, T. E. *Ibid.* **1991**, *56*, 4280. (c) Creary, X.; Hatoum, H.; Barton, A.; Aldridge, T. E. *J. Org. Chem.* **1992**, *57*, 1887.

(4) (a) DeKimpe, N.; Verhé, R.; DeBuyck, L.; Schamp, N.; Charpentier-Morize, M. *Tetrahedron Lett.* **1982**, *23*, 2853. (b) DeKimpe, N.; Verhé, R.; DeBuyck, L.; Schamp, N. *Can. J. Chem.* **1984**, *62*, 1812.

(5) Creary, X.; Wang, Y.-X. *J. Org. Chem.* **1992**, *57*, 4761.

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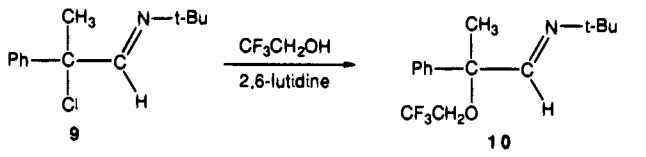
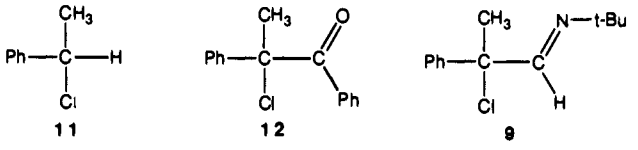
m-CH=N-*t*-Bu and is indicative of a small cation-destabilizing effect. The para-substituted derivative **8** is also less reactive than the unsubstituted analog **6**, but the rate-retarding effect of the *p*-CH=N-*t*-Bu group is only a factor of 2.4. This behavior is reminiscent of that of halogens in the para position of cumyl chlorides, where a cation-stabilizing resonance effect is superimposed on the cation-destabilizing inductive effect.[6] The net result is that *p*-halo substituents are less cation-destabilizing than their *m*-halo analogs. The same type of interplay of resonance and inductive effects appears to be operating in solvolyses of **7** and **8**, *i.e.*, a resonance effect in the cation derived from **8** could be partially offsetting the inductive effect of the imino group.

The effect of attaching this imino group directly to a carbocationic center was next evaluated in solvolysis of the chloride **9**. In the highly ionizing solvent trifluoroethanol, the simple substitution product **10** was formed and the rate of reaction was substantially greater than that of the carbonyl analog **12**. The solvolysis rate of **9** is even greater than that of



9 **10**

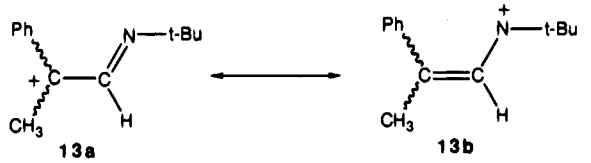


11 **12** **9**

1.00 0.012 13.4

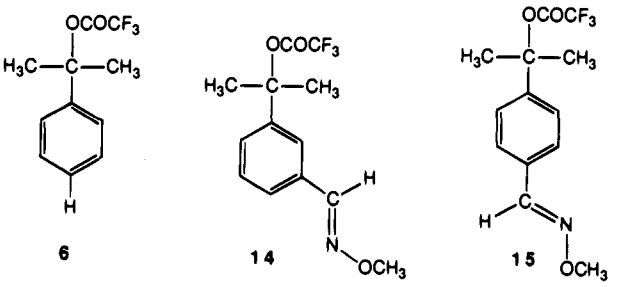
Relative Solvolysis Rates in CF_3CH_2OH

the α-H analog **11** even though the imino group is "electron-withdrawing" relative to hydrogen. The weakly cation-destabilizing effect of CH=N-*t*-Bu, when attached to the para position of a developing cumyl cation as in **8**, becomes a cation-stabilizing effect when directly attached to a developing cationic center as in **9**. On this basis, it is suggested that the contribution of form **13b** to the intermediate α-imino cation is substantial.



13a **13b**

In order to further support the importance of delocalization of charge onto nitrogen as in **13b**, attention was next focused on the *O*-methyloxime derivative, where the methoxy group serves as a probe for developing charge on nitrogen. Initial evaluation of the electronic properties of the oxime group $CH{=}NOCH_3$ revealed that this group in the meta position of an aromatic ring is electron-withdrawing with respect to hydrogen. The σ^+ value of *m*-$CH{=}NOCH_3$ (based on the solvolysis rate of **14**) is 0.15, and the σ_I value (based on the ^{19}F chemical shift of *m*-$FC_6H_4CHNOCH_3$)[7] is 0.14. However, the *p*-$CH{=}NOCH_3$ substituent ($\sigma^+ = -0.03$ based on the solvolysis rate of **15**) does not destabilize a cumyl cation relative to hydrogen. This is indicative of a cation-stabilizing resonance



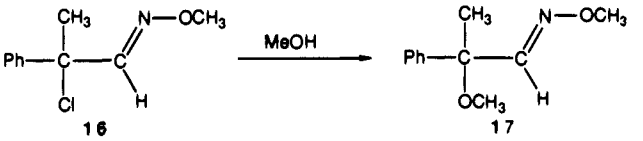
6 **14** **15**

1.00 0.20 (σ^+ = 0.15) 1.35 (σ^+ = -0.03)

Relative Solvolysis Rates

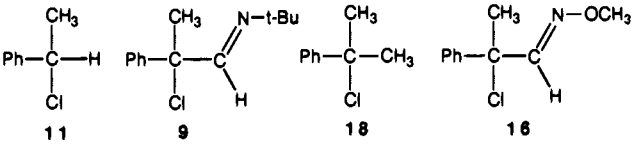
interaction which is strong enough to offset the electron-withdrawing inductive effect of this group.

When the $CH{=}NOCH_3$ substituent is placed directly on a developing cationic center, high reactivity is observed. The substrate **16** is too reactive for rates to be measured in trifluoroethanol. The half-life of **16** in the less highly ionizing solvent methanol is only 39 s, and the simple substitution product **17** is formed. A comparison of solvolysis rates of **16**



16 **17**

with those of model substrates shows that the group is quite stabilizing when placed directly on a cationic center. The rate of **16** is even greater than that of the tertiary α-CH_3 analog, cumyl chloride, **18**. It is suggested that charge delocalization

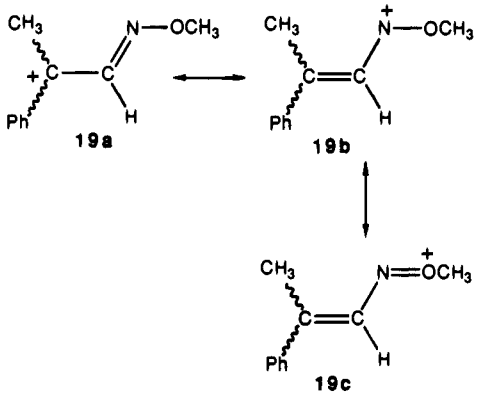


11 **9** **18** **16**

1.0 26 2.3×10^3 8.6×10^3

Relative Solvolysis Rates in CH_3OH

in the intermediate cation **19** is extensive and also involves delocalization onto oxygen as in **19c**.



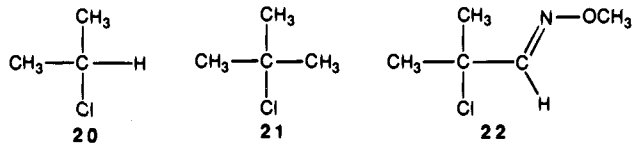
19a **19b** **19c**

The ability of α-$CH{=}NOCH_3$ to enhance solvolysis rates appears to be a function of stabilization demands. Trifluoroethanolysis of the chloride **22** gives the substitution product more than 10^7 times faster than does the α-H analog 2-propyl chloride,

(6) Brown, H. C.; Okamoto, Y.; Ham, G. *J. Am. Chem. Soc.* **1957**, *79*, 1906.

(7) The ^{19}F signal of *m*-$F\text{-}C_6H_4CHNOCH_3$ appears 0.412 ppm downfield from that of fluorobenzene. This corresponds to a σ_I value of 0.14. See: Taft, R. W.; Price, E.; Fox, I. R.; Lewis, I. C.; Andersen, K. K.; Davis, G. T. *J. Am. Chem. Soc.* **1963**, *85*, 709.

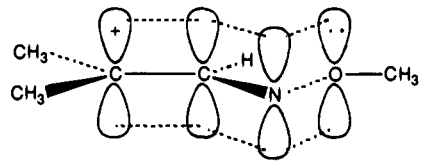
20.[8] This is also indicative of charge delocalization onto oxygen as represented by the ion **23**. The demand for α-$CHNOCH_3$



20 **21** **22**

1.0 6.9×10^6 6.9×10^7

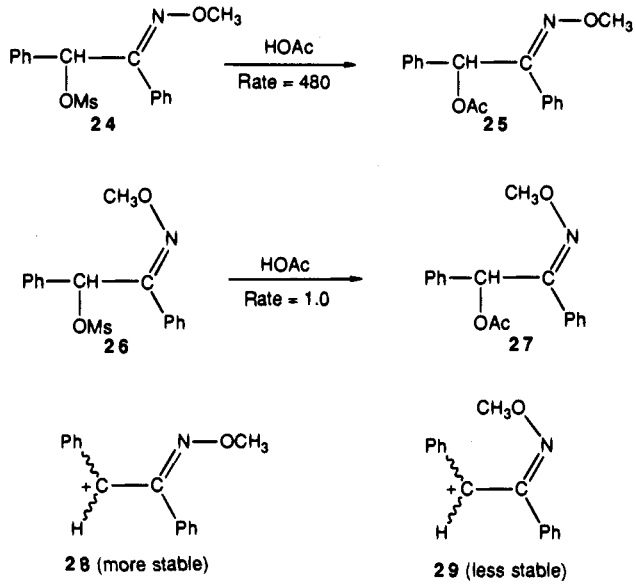
Relative Solvolysis Rates in CF_3CH_2OH



23

stabilization in **23** is even greater than in the benzylic cation **19**, and hence, greater rate enhancements (relative to α-H analogs) are observed.

The mesylates **24** and **26** react in acetic acid to give products **25** and **27**, respectively, where the stereochemistry of the oxime group is completely maintained. The rate of **24** is 480 times greater than that of the syn isomer **26**. These data are indicative of involvement of two distinct noninterconverting cations, **28** and **29**, in which conjugative stabilization in the anti cation **28** is greater than in **29**. Unfavorable steric factors may contribute

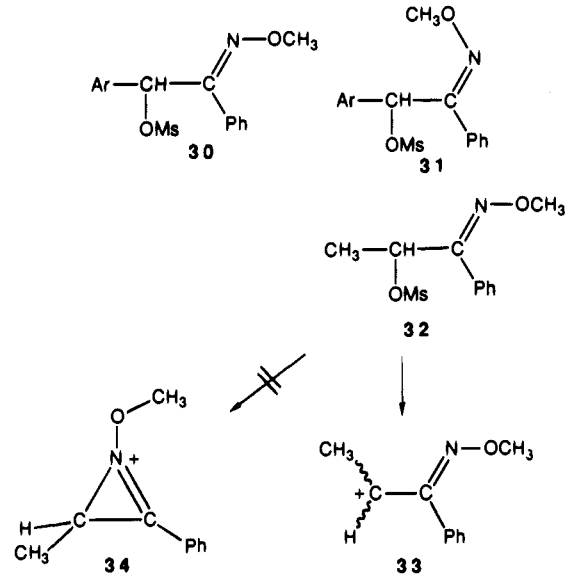


24 **25** **26** **27**

28 (more stable) **29** (less stable)

to the decreased stability of **29** relative to **28**.

A series of substituted mesylates **30** and **31** have also been prepared and reacted in acetic acid. All of these substrates cleanly give the simple acetate substitution products where the stereochemistry of the oxime group is maintained in the product. The *anti*-oximes **30** are all more reactive than the analogous syn isomers **31** as shown in Figure 1. We have employed the method developed by Peters[9] which allows incorporation of the secondary substrate **32** into a Hammett plot for **30**. The mesylate **32** ($\gamma^+ = 0.77$)[9] has been included in Figure 1 for the anti series, and the plot is still linear. This implies that the solvolytic mechanisms for **30** and **32** are similar. Consequently, there is *no change in mechanism* (from k_C to k_Δ) with the substrate **32**. Despite the increased demand for cation stabilization, cyclized cations such as **34** do not appear to be involved in any of these solvolyses.

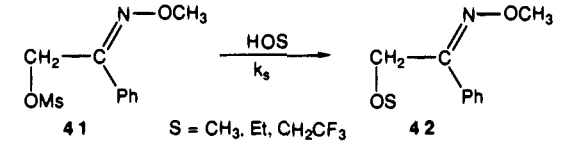


30 **31** **32** **34** **33**

Also of interest is the fact that the acetolysis rate of **32** is 380 times faster than that of the α-methyl analog, isopropyl mesylate. This again illustrates that the oximino group is more effective than methyl in cation stabilization. Previous rate enhancements relative to α-methyl were 3.7 and 9.9 in formation of the more stable tertiary benzylic cation **19** and the tertiary cation **23**. Increased electron demand results in a rate enhancement of 380 in the formation of less stable secondary cation **33**.

The norbornyl substrates **35** and **38** (Scheme 1) were next examined under solvolytic conditions. Trifluoroethanolyses of both of these substrates led to the *exo*-trifluoroethyl ether **36** as the major product, along with smaller amounts of the elimination product **37**. These products are consistent with the involvement of the open cation **39**. Solvolysis of **38** *via* a cyclic ion derived from a k_Δ process would lead to a retained product and not the inverted product **36**. No products of Wagner–Meerwein rearrangement are seen from either **35** or **38**, attesting to the cation-stabilizing influence of the $CHNOCH_3$ substituent. As before, the α-$CHNOCH_3$ substituent appears to be an even more cation-stabilizing group than α-CH_3 as revealed by comparison of the rate of **38** with that of the α-CH_3 analog **40**.

As a test of the limits of our ability to solvolytically generate α-$CHNOCH_3$-substituted cations, the mesylate **41** was prepared and solvolyzed in trifluoroethanol. The simple substution product **42** readily forms in this solvent at 70 °C. However,



41 S = CH_3, Et, CH_2CF_3 **42**

substitution occurs even more readily in ethanol or methanol, despite the fact that these solvents are less highly ionizing. On this basis, we conclude that the mesylate **41** is reacting by a k_s mechanism, in which solvent nucleophilicity is the most important factor in controlling rate. The primary α-$CHNOCH_3$

(8) The trifluoroethanolysis rate of 2-propyl chloride is estimated from the rate of 2-propyl tosylate in trifluoroethanol[8] and an assumed tosylate/chloride rate ratio of 3.7×10^4. See Noyce, D. S.; Virgilio, J. A. *J. Org. Chem.* **1972**, *37*, 2643 for the tosylate/chloride rate ratio.

(9) Peters, E. N. *J. Org. Chem.* **1977**, *42*, 1419.

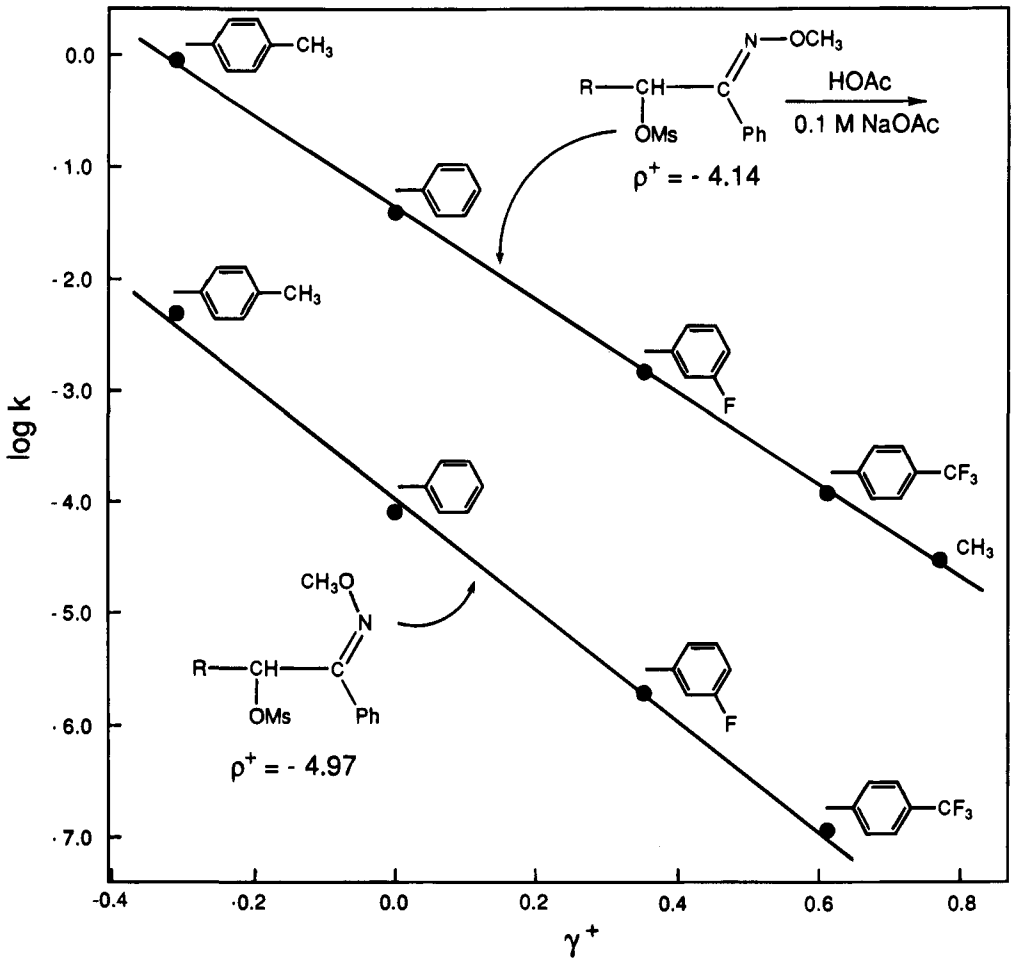
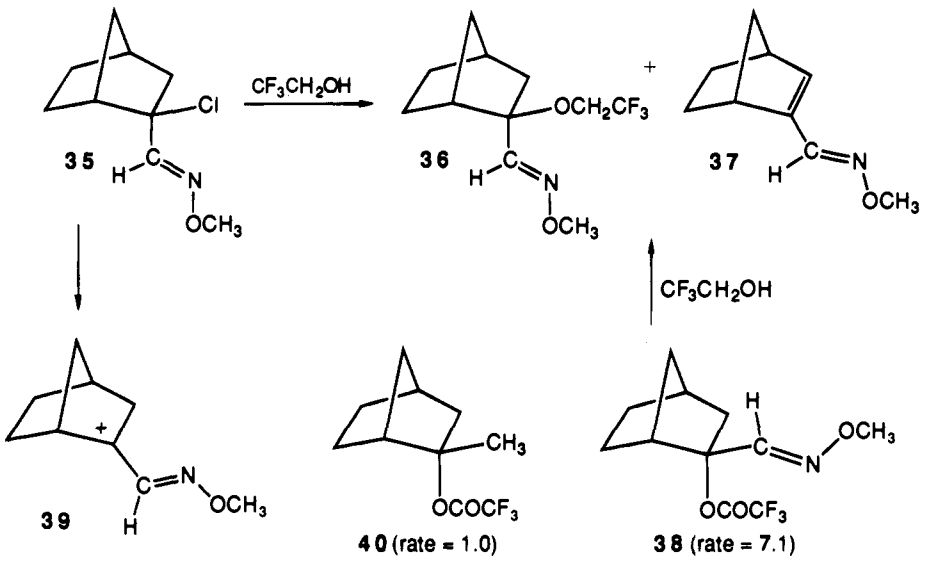


Figure 1. Plot of log k for solvolyses of **30**, **31**, and **32** *vs* γ^+ values (group σ^+ values).

Scheme 1

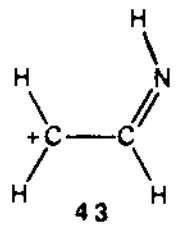


cation therefore appears to be too unstable to generate solvolytically. In more acidic solvents such as HFIP (where the rate is slower than in ethanol), solvolytic studies are complicated by facile interconversion of **41** with the *syn*-oxime.

Computational Studies. An earlier *ab initio* molecular orbital computational study has been carried out at the HF/4-31G level on the simplest α-imino cation **43**.[11] This study placed the cyclized analog **44** at a level 13.8 kcal/mol below the open cation **43**. We have now carried out a more extensive study at the MP2/6-31G** level (full geometry optimization) in order to gain further insights into the nature of α-imino cations. Table 2 lists energies of these cations and related substrates. A fundamental question concerns the open or closed nature of these cations as well as the relative stabilities of syn

(10) Bentley, T. W.; Bowen, C. T.; Morten, D. H.; Schleyer, P. v. R. *J. Am. Chem. Soc.* **1981**, *103*, 5466.

(11) Bonnet-Delpon, D.; Charpentier-Morize, M. *Chem. Phys. Lett.* **1985**, *116*, 478.



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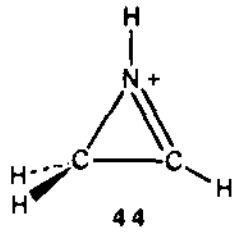
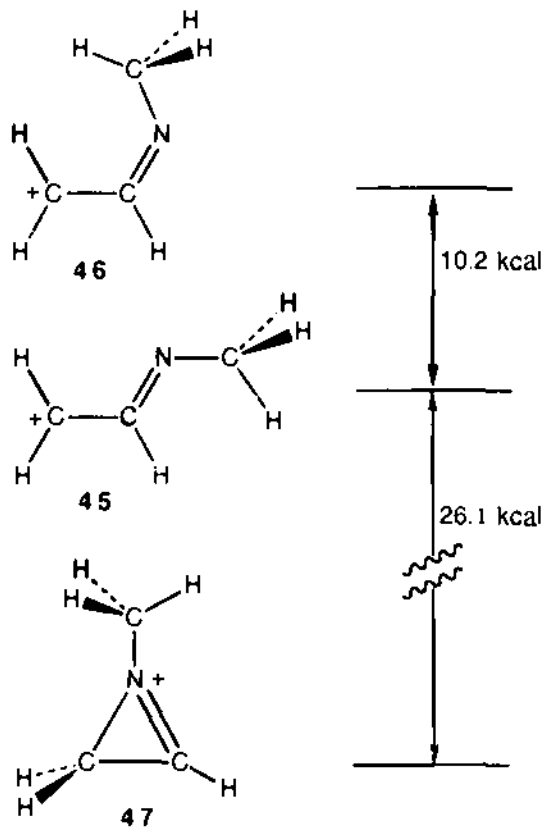


44

and anti isomers. We have examined the anti and syn cations **45** and **46**, as well as the closed analog **47**. These three cations



are all energy minima with the anti cation **45** lying 10.2 kcal/mol below the syn cation **46**.

The cyclized ion **47** is the most stable of the series. Of interest is the fact that the anti cation **45** is calculated to be more stable than the syn cation **46**. Both **45** and **46** have C−C bond lengths that are significantly shortened relative to that in acetaldehyde *N*−methylimine, **48**. The C−N bond lengths of **45** and **46** are also lengthened relative to **48**. In valence bond terms, these results are consistent with a significant contribution of form **45a** to the α-imino cation. Examination of bond angles offers a rationale for the increased stability of **45** relative to **46**. The CCN bond angle in **45** is 113°, while the analogous angle in **46** is 124°. Additionally, the carbon of the methyl group of **46** does not lie in the same plane as the remaining atoms but is displaced by 18°. This suggests that unfavorable steric interaction between the *syn*-methyl group of **46** and the cationic center destabilizes cation **46** relative to **45**.

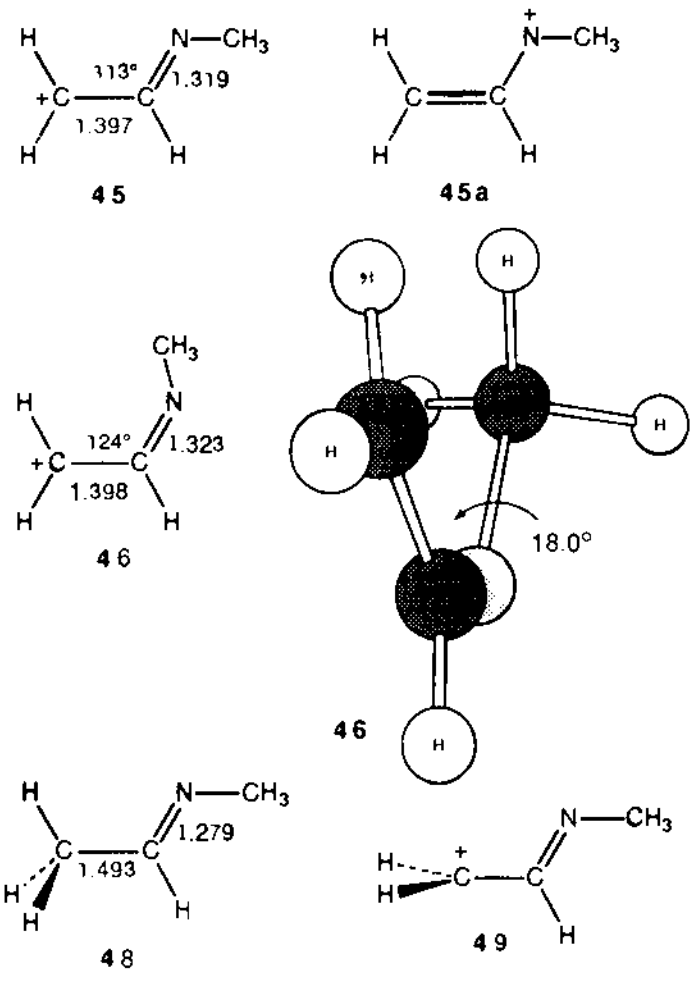
Computational methods also allow an evaluation of the importance of conjugative stabilization in cation **45**. The relative energy of the hypothetical cation **49**, where the cationic center is rotated 90° relative to the conjugating imino group, has been calculated using the same bond lengths and angles as in the planar cation **45**. The perpendicular cation **49** (not an energy minimum) lies 31.2 kcal/mol higher than the conjugated cation **45**. This again points to a significant stabilization of α-imino cations by C=N conjugation as in **45a**.

The situation is somewhat different in the case of the oxime derivatives **50**−**52**. While the anti cation **50** again lies below the syn cation **51**, both of these open cations lie *below* the closed cation **51**. This is attributed to increased stabilization of the open cations due to methoxy substitution. A comparison with acetaldehyde *O*-methyloxime, **53**, shows substantial bond length differences. In valence bond terms, these differences are quite consistent with extensive charge delocalization onto nitrogen

Table 1. Solvolysis Rates in Various Solvents at 25 °C

substrate	solvent	k (s^{-1})[a]
6	CH_3OH	1.13×10^{-3} [b]
	EtOH	1.53×10^{-4}
7	CH_3OH	1.95×10^{-4}
8	CH_3OH	4.74×10^{-4} [b]
9	CF_3CH_2OH	8.79×10^{-3}
	CH_3OH	5.42×10^{-5}
11	CF_3CH_2OH	6.55×10^{-3}
	CH_3OH	2.09×10^{-6}
12	CF_3CH_2OH	7.56×10^{-6}
14	EtOH	3.07×10^{-5}
15	EtOH	2.07×10^{-4}
16	MeOH	1.79×10^{-2}
18	MeOH	4.89×10^{-3} [c]
21	CF_3CH_2OH	1.04×10^{-4} [d]
22	CF_3CH_2OH	1.03×10^{-3}
24	HOAc	3.92×10^{-2}
26	HOAc	8.17×10^{-5}
30 (Ar = *p*-$CH_3C_6H_4$)	HOAc	9.11×10^{-1} [f]
30 (Ar = *m*-FC_6H_4)	HOAc	1.48×10^{-3}
30 (Ar = *p*-$CF_3C_6H_4$)	HOAc	1.19×10^{-4}
31 (Ar = *p*-$CH_3C_6H_4$)	HOAc	4.93×10^{-3}
31 (Ar = *m*-FC_6H_4)	HOAc	1.91×10^{-6}
31 (Ar = *p*-$CF_3C_6H_4$)	HOAc	1.16×10^{-7} [g]
32	HOAc	3.05×10^{-5}
38	CF_3CH_2OH	5.58×10^{-5} [e]
40	CF_3CH_2OH	7.91×10^{-6} [e]
41	CF_3CH_2OH at 70 °C	1.18×10^{-5}
	EtOH at 70.0 °C	1.13×10^{-4}
	MeOH at 70.0 °C	2.11×10^{-4}

[a] Maximum standard deviations in duplicate runs were ±2% for rates determined by the ^{19}F NMR (ref 5) and ^1H NMR integration methods and ±1.5% for rates determined by the ^1H NMR method of ref 19. See the Experimental Section for the kinetic method. [b] Reference 5. [c] Reference 17. [d] Reference 18. [e] Reference 19. [f] Estimated from the acetolysis rate of *p*-$CH_3C_6H_4CH(OCOCF_3)C(NOCH_3)Ph$ ($k = 9.44 \times 10^{-6}$ s^{-1} at 25.0 °C) where the mesylate/trifluoroacetate rate ratio = 9.65×10^4. [g] Extrapolated from rate data at higher temperatures. $k = 3.67 \times 10^{-5}$ s^{-1} at 70.0 °C. $k = 3.46 \times 10^{-6}$ s^{-1} at 50.0 °C.

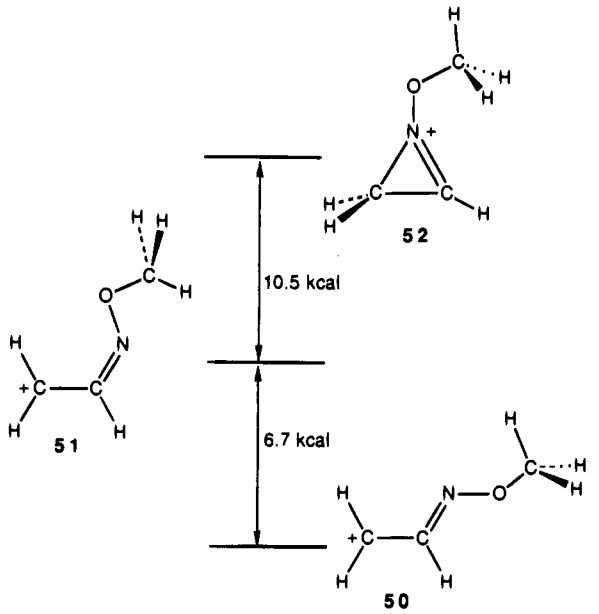


and oxygen, as in **50a** and **50b**. The C−C bond lengths of **50** and **51** are even shorter than that of the allyl cation **63**, which is also indicative of extensive resonance stabilization in the cations **50** and **51**. A calculation on the perpendicular cation

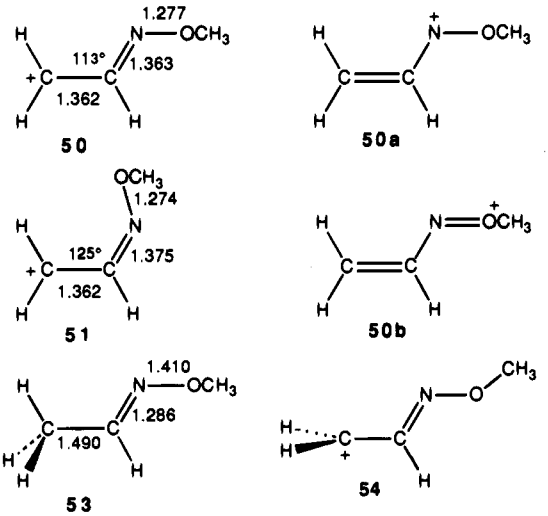
Table 2. MP2/6-31G** Energies of Cations and Corresponding Hydrocarbons (MP2 = FULL)

cation	energy (au)	hydrocarbon	energy (au)
44 (*anti*-$^+CH_2CHNCH_3$)	−171.777 745 9	**48** (CH_3CHNCH_3)	−172.729 121 3
46 (*syn*-$^+CH_2CHNCH_3$)	−171.761 562 5		
47 (cyclic)	−171.819 412 6		
49 (perpendicular)	−171.727 959 9		
50 (*anti*-$^+CH_2CHNOCH_3$)	−246.806 046 2	**53** ($CH_3CHNOCH_3$)	−247.718 513 2
51 (*syn*-$^+CH_2CHNOCH_3$)	−246.794 022 3		
52 (cyclic)	−246.777 349 4		
54 (perpendicular)	−246.711 496 8		
55 ($^+CH_2NO_2$)[a]	−243.314 693 7	**56** (CH_3NO_2)	−244.368 950 3
57 ($^+CH_2CN$)	−131.349 578 0	**58** (CH_3CN)	−132.375 162 4
59 ($^+CH_2CHO$)[a]	−152.372 799 6	**60** (CH_3CHO)	−153.391 224 3
65 (cyclic)	−152.420 445 7		
61 ($^+CH_2CHS$)[a]	−475.015 070 0	**62** (CH_3CHS)	−475.983 856 4
68 (cyclic)	−475.059 850 0		
63 ($^+CH_2CHCH_2$)	−116.595 754 8	**64** (CH_3CHCH_2)	−117.519 079 9
$^+CH_2CH_3$[b]	−78.601 182 9	CH_3CH_3	−79.553 712 7
$^+CH_3$	−39.351 194 9	CH_4	−40.369 856 0

[a] This represents a cation constrained in the open configuration. A frequency calculation shows one imaginary frequency. [b] The energy minimum for this cation is a hydrogen-bridged symmetrical cation.



54, where the cationic center is rotated out of conjugation with the oxime functionality, places this cation 66.2 kcal/mol above the conjugated cation **50**. This large stabilization when the



oxime functionality is placed in conjugation with the cationic center again points to extensive conjugative charge delocalization.

Table 3. ΔE Values (kcal/mol) for the Isodesmic Reaction (1)

substituent X	MP2/6-31G** ΔE (kcal/mol)	HF/6-31G** ΔE (kcal/mol)
NO_2	−22.3	−40.7
CF_3	*a*	−20.0
CN	−4.3	−13.0
H	0.0	0.0
CHO	0.2	−5.2
CHS	31.3	21.0
CH_3	41.5	30.2
anti-$CHNCH_3$	42.2	36.7
anti-$CHNOCH_3$	66.0	52.4
$CHCH_2$	66.1	53.9

[a] $CF_3CH_2^+$ is not an energy minimum at this level but undergoes fluorine migration.

The question arises as to the relative stabilities of α-imino cations *versus* other cations directly substituted with electron-withdrawing groups. Computationally, this question was approached using the isodesmic reaction (1), where X is an electronegative group. Table 3 lists ΔE values calculated at

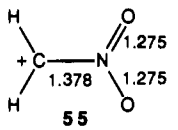
$$CH_4 + {}^+CH_2X \rightleftharpoons {}^+CH_3 + CH_3X \qquad (1)$$

the MP2/6-31G** and HF/6-31G** levels, where stabilities are relative to the methyl cation, CH_3^+. Of the cations studied computationally, the α-nitro cation **55** is the least stable, being destabilized relative to CH_3^+ by 22.3 kcal/mol at the MP2/6-31G** level. The α-cyano cation **57** is also destabilized relative to CH_3^+. The fact that destabilization amounts to only 4.3 kcal (despite the potent electron-withdrawing cyano group) implies, as previously proposed, that resonance stabilization is important for α-cyano cations.[12,13]

The α-carbonyl cation **59** has been the subject of a number of calculations over the years.[14] This cation **59** does not appear

(12) Gassman, P. G.; Tidwell, T. T. *Acc. Chem. Res.* **1983**, *16*, 279.
(13) For previous computational studies on α-cyano cations, see: (a) Dixon, D. A.; Charlier, P. A.; Gassman, P. G. *J. Am. Chem. Soc.* **1980**, *102*, 3957. (b) Paddon-Row, M. N.; Santiago, C.; Houk, K. N. *J. Am. Chem. Soc.* **1980**, *102*, 6561. (c) Dixon, D. A.; Eades, R. A.; Frey, R.; Gassman, P. G.; Hendewerk, M. L.; Paddon-Row, M. N.; Houk, K. N. *J. Am. Chem. Soc.* **1984**, *106*, 3885.
(14) For early computational studies on α-carbonyl cations, see: (a) Charpentier-Morize, M.; Lefour, J. M.; Anh, T. N. *Tetrahedron Lett.* **1974**, 1729. (b) Yarkony, D. R.; Schaefer, H. F. *J. Chem. Phys.* **1975**, *63*, 4317. (c) Nobes, R. H.; Bouma, W. J.; Radom, L. *J. Am. Chem. Soc.* **1983**, *105*, 309. See also ref 11b.

to be an energy minimum and closes without barrier to the cyclized ion **65**.[15] Our latest calculation on a fully optimized



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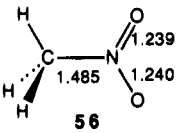

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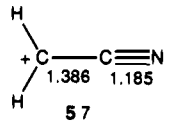

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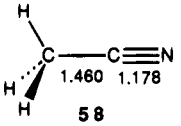

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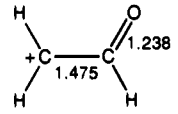

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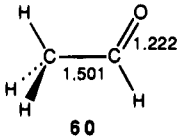

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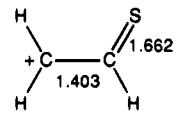

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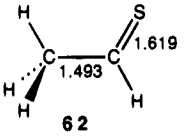

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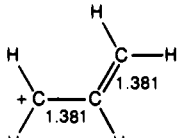

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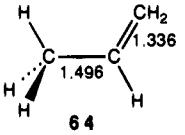
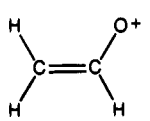


64

MP2/6-31G** geometry (where closure to the cyclized ion is prohibited) gives an energy of **59** which is comparable to that of CH_3^+ (on the basis of isodesmic reaction 1). There is a small but significant shortening of the C−C bond and a slight increase in the C=O bond length relative to acetaldehyde, **60**. These energies and bond lengths are somewhat different from previous values[15] based on HF/6-31G*-optimized geometries and single-point energies at the MP2/6-31G** level. The previous conclusion based on the 1988 computational study that "there is essentially no double bond character in the cation; i.e., valence tautomer **59a** is not a significant contributor" must be reevaluated. The fully optimized MP2/6-31G** structures indicate a small but significant stabilization of **59** by the conjugating carbonyl group. Rotation of the carbonyl group by 90° relative to the cationic center as in **66**, while maintaining the same bond lengths and angles as in the planar cation, raises the energy of **59** by only 1.7 kcal/mol. This value is far less than the destabilization that results from a 90° rotation in cations **45** and **50**. The importance of carbonyl conjugation as a cation-stabilizing feature in **59** is therefore much less than imino or oximino conjugation in **45** and **50**.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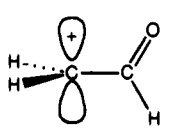
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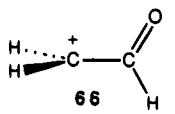
The thiocarbonyl cation **61** also displays features suggestive of substantial thiocarbonyl conjugation.[16] Comparison of bond lengths of **61** with those of the carbonyl cation **59** and also with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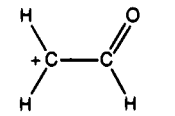
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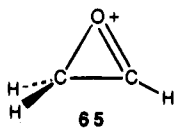
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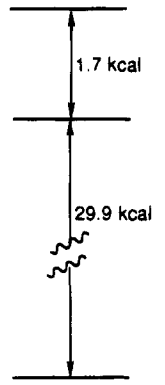
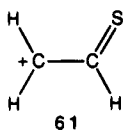


those of thioacetaldehyde, **62**, suggests that thiocarbonyl conjugative stabilization of a cationic center is more important than carbonyl conjugation. Rotation of the thiocarbonyl group out of conjugation, as in **67**, while maintaining the same C−C and C=S bond lengths and angles as in the cation **61**, raises the energy by 12.6 kcal/mol. The isodesmic reaction (1) also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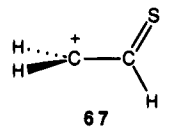
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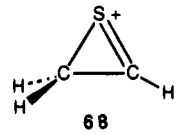

68

shows a substantial stabilization (31.3 kcal/mol) of **61** relative to CH_3^+. Despite the stabilization of **61** due to thiocarbonyl conjugation, the cyclized ion **68** still lies 28.1 kcal/mol below the open ion **61**.

The isodesmic reaction (1) places the α-imino cation **45** at a level of 42.2 kcal below that of CH_3^+, while the α-oximino cation **50** lies 66.0 kcal below CH_3^+. Computationally, the α-imino cation **45** is comparable in stability to the ethyl cation, while the α-oximino cation **50** is comparable to the allyl cation. Of the formally electron-withdrawing substituents, the α-oximino group, $CHNOCH_3$, therefore appears to be computationally the most "cation-stabilizing" by way of a conjugative interaction.

Conclusions. The imino group CHN-*t*-Bu is a weak electron-withdrawing group relative to hydrogen. However, when this group is placed directly on a developing cationic center in a solvolytic reaction, rates are slightly greater than the rate of the α-H analog. This is indicative of resonance stabilization of the intermediate α-imino cation. The oximino group $CHNOCH_3$ is also an electron-withdrawing group relative to hydrogen. When this group is placed directly on a developing cationic center in a solvolytic reaction, large rate enhancements relative to α-H analogs are observed. Solvolytic rates are even greater than for the α-CH_3 analogs, and this is indicative of extensive cation stabilization *via* a resonance interaction. Computational studies also suggest extensive charge delocalization in α-oximino cations. Computationally, these are the most stable cations of type $^+CH_2X$, where the group X is a formally electronegative group. As revealed by isodesmic reactions, stabilization of cations of general type $^+CH_2X$ decreases in the order of α-$CHNOCH_3$ > $CHNHCH_3$ > CHS

(15) Lien, M. H.; Hopkinson, A. C. *J. Am. Chem. Soc.* **1988**, *110*, 3788.

(16) For a previous computational study on thiocarbonyl cation **61**, see reference 15.

(17) Creary, X. *J. Org. Chem.* **1985**, *50*, 5080.

(18) Shiner, V. J., Jr.; Dowd, W.; Fisher, R. D.; Hartshorn, S. R.; Kessick, M. A.; Milakofsky, L.; Rapp, M. W. *J. Am. Chem. Soc.* **1969**, *91*, 4838.

> CHO ~ H > CN > NO_2. With the exception of α-thiocarbonyl cations, this stability order parallels the rates of solvolytic generation of cations of type ^+R_2CX.

Experimental Section

General. ^1H and ^{13}C NMR spectra were recorded on a General Electric GN 300 spectrometer. Mass spectra were recorded on a Finnigan MAT 8430 high-resolution spectrometer. Chromatographic purifications were carried out using EM Science 230–400 mesh silica gel 60. Elemental analyses were carried out by MHW Laboratories, Phoenix, AZ. The preparations of trifluoroacetates **8**,[5] **38**,[19] and **40**[19] have previously been described.

Preparation of Trifluoroacetate 7. The preparation of **7** from 3-(2-hydroxy-2-propyl)benzaldehyde was completely analogous to the previously described[5] preparation of trifluoroacetate **8**. ^1H NMR ($CDCl_3$): δ 8.266 (s, 1 H), 7.77–7.67 (m, 2 H), 7.48 (d, J = 5.1 Hz, 2 H), 1.920 (s, 6 H), 1.296 (s, 9 H). ^{13}C NMR ($CDCl_3$): δ 155.75 (q, J = 41.3 Hz), 154.60, 143.58, 137.69, 128.93, 127.55, 126.00, 123.93, 114.45 (q, J = 287 Hz), 87.47, 57.40, 29.71, 28.08. This substance is quite moisture sensitive and was immediately used for kinetic studies.

Preparation of α-Chloroimine 9. A mixture of 0.647 g of α-methylphenylacetaldehyde and 0.353 g of *tert*-butyl amine in 10 mL of CCl_4 was stirred at 0 °C, and 4.0 g of $MgSO_4$ was added. The mixture was then stirred at room temperature for 3 h and filtered, and the $MgSO_4$ was washed with a small amount of CCl_4. The filtrate was cooled to 15 °C, and 0.708 g of *N*-chlorosuccinamide was added in small portions. The mixture was then stirred at room temperature for 3.5 h and filtered, and the CCl_4 solvent was removed under reduced pressure. The residue was distilled, and after a small forerun, 0.537 g (50% yield) of α-chloroimine **9** was collected, bp 57–58 °C (0.12 mm). ^1H NMR ($CDCl_3$): δ 7.745 (m, 1 H), 7.56–7.42 (m, 2 H), 7.40–7.22 (m, 2 H), 2.017 (s, 3 H), 1.227 (s, 9 H). ^{13}C NMR ($CDCl_3$): δ 157.73, 142.60, 128.39, 127.76, 126.25, 72.91, 56.93, 29.53, 29.41. Exact mass: calcd for $C_{13}H_{18}ClN$ 223.1128, found 223.1136.

Preparation of Trifluoroacetates 14 and 15. A solution of 773 mg of 3-(2-hydroxy-2-propyl)benzaldehyde[5] in 6 mL of pyridine was stirred at room temperature, and 470 mg of methoxylamine hydrochloride was added. After 5 h, the mixture was taken up into ether and washed with cold water, cold dilute hydrochloric acid, and saturated NaCl solution. The ether extract was then dried over $MgSO_4$ and filtered, and the solvent was removed using a rotary evaporator, leaving 891 mg (98%) of 3-(2-hydroxy-2-propyl)benzaldehyde *O*-methyloxime. ^1H NMR ($CDCl_3$): δ 8.037 (s, 1 H), 7.695 (t, J = 2 Hz, 1 H), 7.51–7.40 (m, 2 H), 7.311 (t, J = 7.6 Hz, 1 H), 3.952 (s, 3 H), 2.280 (br, 1 H), 1.565 (s, 6 H). ^{13}C NMR ($CDCl_3$): δ 149.78, 148.75, 132.02, 128.56, 126.06, 125.44, 123.00, 72.37, 61.94, 31.68. Anal. Calcd for $C_{11}H_{15}NO_2$: C, 68.37; H, 7.82. Found: C, 68.10; H, 7.89.

A solution of 309 mg of 3-(2-hydroxy-2-propyl)benzaldehyde *O*-methyloxime and 257 mg of 2,6-lutidine in 4 mL of ether was cooled to 0 °C, and 437 mg of trifluoroacetic anhydride was added dropwise. After 10 min at 0 °C, cold water was added and a rapid aqueous workup followed. The ether extract was washed with cold dilute hydrochloric acid and saturated NaCl solution and dried over $MgSO_4$. After filtration, solvent removal left 444 mg (96%) of trifluoroactetate **14** which was used without further purification. ^1H NMR ($CDCl_3$): δ 8.071 (s, 1 H), 7.60 (m, 1 H), 7.50 (m, 1 H), 7.38 (m, 2 H), 3.984 (s, 3 H), 1.899 (s, 6 H). ^{13}C NMR ($CDCl_3$): δ 155.28 (q, J = 42 Hz), 148.49, 143.92, 132.53, 129.17, 126.93, 125.80, 122.75, 114.41 (q, J = 287 Hz), 87.23, 62.09, 27.98. Exact mass: calcd for $C_{13}H_{14}F_3NO_3$ 289.0926, found 289.0931.

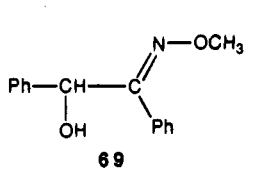
The preparation of trifluoroacetate **15**, starting with p-bromobenzaldehyde dimethyl acetal,[3b] was completely analogous to the preparation of **14**.

Preparation of α-Chlorooxime 16. A solution of 1.160 g of 2-methylphenylacetaldehyde in 6 mL of CH_2Cl_2 was added to a solution of 1.806 g of SO_2Cl_2 in 6 mL of CH_2Cl_2 at 0 °C. The mixture was stirred at room temperature for 2.5 h and then heated under reflux for 20 h with periodic monitoring by NMR. The solvent was then removed under reduced pressure, and the residue was distilled to give 0.701 g (47%) of 2-chloro-2-methylphenylacetaldehyde,[20] bp 36–37 °C (0.12 mm).

A solution of 137 mg of 2-chloro-2-methylphenylacetaldehyde in 2 mL of CH_2Cl_2 was stirred as 81 mg of methoxylamine hydrochloride was added. Pyridine (116 mg) was then added, and the mixture was stirred at room temperature for 3 h. The mixture was then diluted with ether, washed with water and cold dilute hydrochloric acid, and then dried over $MgSO_4$. After filtration, solvent removal left 146 mg (91%) of oxime **16**. This substrate **16** decomposes on prolonged standing at room temperature and was used without further purification. ^1H NMR ($CDCl_3$): δ 7.672 (s, 1 H), 7.54–7.49 (m, 2 H), 7.41–7.27 (m, 3 H), 3.905 (s, 3 H), 2.069 (s, 3 H). ^{13}C NMR ($CDCl_3$): δ 151.71, 142.31, 128.49, 128.16, 126.04, 69.30, 62.06, 29.77. Exact mass: calcd for $C_{10}H_{12}NO$ (M − Cl) 162.0919, found 169.0920.

Preparation of α-Chlorooxime 22. A solution of 582 mg of α-chloroisobutyraldehyde[21] in 5 mL of pyridine was stirred as 547 mg of methoxylamine hydrochloride was added. After 30 min at room temperature, the mixture was taken up into ether and the ether solution was washed with water, cold dilute hydrochloric acid, and saturated NaCl solution and dried over $MgSO_4$. After filtration and solvent removal using a rotary evaporator (significant losses can occur during solvent removal on the rotary evaporator), the residue was distilled to give 349 mg (47%) of **22**, bp 43 °C (28 mm). ^1H NMR ($CDCl_3$): δ 7.481 (s, 1 H), 3.853 (s, 3 H), 1.741 (s, 6 H). ^{13}C NMR ($CDCl_3$): δ 152.65, 65.25, 61.90, 30.15. Exact mass: calcd for $C_5H_{10}ClNO$ 135.0451, found 135.0446.

Preparation of Benzoin *O*-Methyloximes. A solution of 1.061 g of benzoin in 10 mL of pyridine was stirred at room temperature, and 504 mg of methoxylamine hydrochloride was added in one portion. After 18 h at room temperature, the mixture was taken up into ether and washed with water, cold dilute hydrochloric acid, and saturated NaCl solution. The ether solution was then dried over $MgSO_4$ and filtered, and the solvent was removed using a rotary evaporator. The crude residue (1.183 g, 98%) consisted of *anti*- and *syn*-*O*-methyloximes **69** and **70** in a 4:1 ratio. The entire crude product was chromatographed



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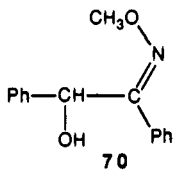

70

on silica gel and eluted with 12.5% ether in hexanes. The *syn*-oxime **70** (214 mg), mp 77–77.5 °C, eluted first, followed by 150 mg of a mixture of *syn*- and *anti*-oximes. The *anti*-oxime **69** (727 mg), mp 66–67 °C, eluted last. ^1H NMR of **69** ($CDCl_3$): δ 7.32–7.02 (m, 10 H), 5.558 (d, J = 5.3 Hz, 1 H), 3.984 (d, J = 5.3 Hz, 1 H), 3.945 (s, 3 H). ^{13}C NMR of **69** ($CDCl_3$): δ 157.01, 139.86, 131.21, 128.98, 128.32, 128.06, 127.98, 127.93, 126.97, 75.28, 62.48. Anal. Calcd for $C_{15}H_{15}NO_2$: C, 74.67; H, 6.27. Found: C, 74.77; H, 6.39.

^1H NMR of **70** ($CDCl_3$): δ 7.59–7.25 (m, 10 H), 6.139 (d, J = 9.5 Hz, 1 H), 3.996 (s, 3 H), 3.697 (d, J = 9 Hz, 1 H). ^{13}C NMR of **70** ($CDCl_3$): δ 159.34, 140.15, 133.69, 129.33, 128.45, 128.39, 127.56, 127.51, 125.91, 70.92, 62.44. Anal. Calcd for $C_{15}H_{15}NO_2$: C, 74.67; H, 6.27. Found: C, 74.56; H, 6.36.

Preparation of *syn*- and *anti*-Oximes, ArCH(OH)C(NOMe)Ph. General Procedure. A catalytic amount of anhydrous ZnI_2 was added to a stirred mixture of ArCHO (1.0 equiv) and Me_3SiCN (1.10 equiv).[22] The mixture was warmed at 60 °C for 2 h, and then the silylated cyanohydrin ArCH($OSiMe_3$)CN was purified by distillation at 0.05 mm. The silylated cyanohydrin (1 part) was then desilylated by dissolving in methanol (12 parts) containing 0.006 M CF_3CO_2H. When desilylation was complete, the methanol was removed using a rotary evaporator and the crude cyanohydrin ArCH(OH)CN was dissolved in ether. The ether solution of ArCH(OH)CN (1.0 equiv) was added

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dropwise to a solution of 1.0 M PhMgBr (2.5 equiv) in ether at room temperature. The mixture was then refluxed for 15 min and cooled to about −40 °C, and then the reaction was quenched with excess dilute hydrochloric acid. The mixture was then stirred at 0 °C until all of the solids dissolved, and the ether phase was rapidly separated. The cold aqueous phase was rapidly extracted with another small portion of ether, and the aqueous phase was then set aside to allow the substituted benzoin, ArCH(OH)COPh, to precipitate. After 6 h at room temperature, the precipitated ArCH(OH)COPh was collected on a Büchner funnel, washed with water, and air-dried.

The ArCH(OH)COPh was converted to a mixture of *syn*- and *anti*-oximes ArCH(OH)C(NOMe)Ph by reaction with methoxylamine hydrochloride in pyridine as previously described for the preparation of **69** and **70**. In all cases, the *anti*-oxime was the major isomer formed. These oximes were all separated by silica gel chromatography (elution with 12.5% ether in hexanes). In all cases, the *syn*-oxime eluted first, followed by the *anti*-oxime.

Preparation of *anti*-$CH_3CH(OH)C(NOMe)Ph$. The preparation of α-hydroxypropiophenone[23] from lactonitrile and phenylmagnesium bromide (80% yield) was carried out as described above. The α-hydroxypropiophenone was isolated by extraction into ether and purified by distillation (bp 68−69 °C at 0.1 mm). This α-hydroxy ketone was converted to a mixture of *anti*- and *syn*-*O*-methyloximes (1.6:1 ratio, 88% yield) by reaction with methoxylamine hydrochloride in pyridine as previously described for the preparation of **69** and **70**. The *anti*-oxime (major isomer) was separated by silica gel chromatography (elution with 25% ether in hexanes). ^1H NMR ($CDCl_3$): δ 7.45−7.30 (m, 5 H), 4.717 (q, J = 6.6 Hz, 1 H), 3.865 (s, 3 H), 3.319 (br, 1 H), 1.250 (d, J = 6.6 Hz, 3 H). ^{13}C NMR ($CDCl_3$): δ 158.71, 131.50, 129.11, 128.30, 127.84, 68.92, 62.21, 21.75. Anal. Calcd for $C_{10}H_{13}NO_2$: C, 67.02; H, 7.31. Found: C, 66.92; H, 7.30.

Preparation of *anti*-$CH_2(OH)C(NOMe)Ph$. α-Hydroxyacetophenone was converted to a mixture of *anti*- and *syn*-*O*-methyloximes (0.24:1 ratio, 82% yield) by reaction with methoxylamine hydrochloride in pyridine as previously described for the preparation of **69** and **70**. The *anti*-oxime (minor isomer) was separated by silica gel chromatography (elution with 40% ether in hexanes). ^1H NMR ($CDCl_3$): δ 7.66−7.57 (m, 2 H), 7.40−7.31 (m, 3 H), 4.638 (d, J = 5 Hz, 2 H), 3.993 (s, 3 H), 2.941 (br, 1 H). ^{13}C NMR ($CDCl_3$): δ 157.88, 133.90, 129.39, 128.48, 126.70, 62.34, 57.50. Exact mass: calcd for $C_9H_{11}NO_2$ 165.0790, found 165.0793.

Preparation of Mesylates 24, 26, 30, 31, 32, and 41. General Procedure. A solution of the oxime RCH(OH)C(NOMe)Ph (1.0 equiv) and CH_3SO_2Cl (1.5 equiv) in methylene chloride was cooled to −50 °C, and Et_3N (1.7 equiv) was added dropwise to the stirred solution. In the preparation of mesylates **32** and **41**, the CH_3SO_2Cl was added to a solution of alcohol and Et_3N in CH_2Cl_2. The mixture was warmed to 0 °C with stirring and taken up into ether and water, and the ether extract was washed with cold dilute hydrochloric acid. After washing with saturated NaCl solution, the solution was dried over $MgSO_4$ and filtered, and the solvents were removed using a rotary evaporator. The mesylate **24** is unstable and must be used immediately after solvent removal. The mesylate **30** (Ar = *p*-$CH_3C_6H_4$) could not be isolated. The following is representative.

Reaction of 178 mg of *syn*-oxime **70** with MsCl and Et_3N in CH_2Cl_2, as described above, gave 210 mg (93%) of mesylate **26**, mp 57−60 °C. ^1H NMR ($CDCl_3$): δ 7.56−7.49 (m, 2 H), 7.47−7.26 (m, 9 H), 4.067 (s, 3 H), 2.774 (s, 3 H). ^{13}C NMR ($CDCl_3$): δ 154.51, 134.48, 131.73, 129.59, 128.87, 128.78, 128.30, 128.12, 126.27, 74.87, 62.91, 38.46. Anal. Calcd for $C_{16}H_{17}NO_4S$: C, 60.17; H, 5.36. Found: C, 60.36; H, 5.13.

Preparation of Chloride 35. A solution of 340 mg of *exo*-2-chlorobicyclo[2.2.1]heptane-*endo*-2-carboxaldehyde[24] in 4 mL of pyridine was stirred at 0 °C, and 275 mg of methoxylamine hydrochloride was added. The mixture was then warmed to room temperature for 10 min, taken up into ether, and washed with cold water. The ether extract was then washed with cold dilute hydrochloric acid and saturated NaCl solution and then dried over $MgSO_4$. After filtration, the solvent was removed using a rotary evaporator to give 396 mg (98%) of **35** which was used without further purification. ^1H NMR ($CDCl_3$): δ 7.509 (s, 1 H), 3.859 (s, 3 H), 2.57−2.45 (m, 2 H), 2.37 (m, 1 H), 2.15−1.99 (m, 2 H), 1.60−1.05 (m, 5 H). ^{13}C NMR ($CDCl_3$): δ 150.63, 75.17, 61.87, 49.90, 43.06, 37.27, 37.25, 27.55, 24.37. Exact mass: calcd for $C_9H_{11}NO_2$ 187.0764, found 187.0768.

Solvolysis of α-Chloroimine 9 in Trifluoroethanol. A solution of 112 mg of 2,6-lutidine in 4.20 mL of trifluoroethanol was added to 194 mg of α-chloroimine **9**, and the mixture was stirred for 30 min at room temperature. Most of the trifluoroethanol was removed using a rotary evaporator, and the residue was taken up into ether. The ether solution was washed with an ice cold solution of 143 mg of $KHSO_4$ in water, followed by saturated NaCl solution. The ether extract was dried over $MgSO_4$ and filtered, and the solvent was removed using a rotary evaporator to leave 197 mg (79%) of crude trifluoroethyl ether **10**. A sample of **10**, bp 71−72 °C (0.6 mm), was purified by distillation. ^1H NMR ($CDCl_3$): δ 7.599 (m, 1 H), 7.44−7.24 (m, 5 H), 3.93−3.66 (m, 2 H), 1.671 (s, 3 H), 1.185 (s, 9 H). ^{13}C NMR ($CDCl_3$): δ 158.51, 142.29, 128.48, 127.60, 125.84, 81.67, 61.57 (q, J = 34.5 Hz), 57.34, 29.49, 22.40. Exact mass (FAB): calcd for $C_{15}H_{21}F_3NO$ 288.1575, found 288.1538.

Solvolysis of α-Chlorooxime 16 in Methanol. A solution of 59 mg of 2,6-lutidine in 22 mL of methanol was added to 99 mg of α-chlorooxime **16**, and the mixture was stirred for 30 min at room temperature. The methanol was removed by rotary evaporator, and the residue was taken up into ether. The ether solution was washed with dilute hydrochloric acid, followed by saturated NaCl solution. The ether extract was dried over $MgSO_4$ and filtered, and the solvent was removed using a rotary evaporator to leave 81 mg (84%) of **17**. ^1H NMR ($CDCl_3$): δ 7.46−7.23 (m, 6 H), 3.895 (s, 3 H), 3.282 (s, 3 H), 1.661 (s, 3 H). ^{13}C NMR ($CDCl_3$): δ 152.65, 142.96, 128.40, 127.51, 125.86, 78.40, 61.83, 51.12, 22.51. Exact mass (FAB): calcd for $C_{11}H_{16}NO_2$ 194.1181, found 194.1185.

Solvolyses of Mesylates in Acetic Acid. General Procedure. A solution of the appropriate mesylate in acetic acid containing 0.1 M NaOAc (1.2 equiv) and 1% acetic anhydride was kept at an appropriate temperature for 10 half-lives. The mixture was then taken up into ether, and water was added. The acetic acid was then neutralized with solid Na_2CO_3, and the ether extract was dried over $MgSO_4$. After filtration, the solvent was removed using a rotary evaporator to leave the acetate product. The following procedures are representative.

Mesylate **24** was prepared from 474 mg of alcohol **69**, CH_3SO_2Cl, and Et_3N in methylene chloride as previously described. After rapid solvent removal using a rotary evaporator, the crude mesylate (unstable for prolonged periods at room temperature) was immediately dissolved in 30 mL of 0.1 M NaOAc in acetic acid containing 1% acetic anhydride. After 12 h at room temperature, the acetic acid was neutralized with Na_2CO_3, and an aqueous workup followed, as described above. Removal of the ether solvent using a rotary evaporator left 540 mg (97%) of acetate **25**, mp 64−65 °C, which was identical to an authentic sample prepared by acetylation of **69** with acetic anhydride in pyridine. ^1H NMR of **25** ($CDCl_3$): δ 7.34−7.24 (m, 8 H), 7.13−7.05 (m, 2 H), 6.556 (s, 1 H), 3.888 (s, 3 H), 2.140 (s, 1 H). ^{13}C NMR ($CDCl_3$): δ 169.76, 155.24, 136.21, 131.43, 128.83, 128.43, 128.39, 128.20, 127.95, 127.19, 76.45, 62.42, 21.08. Exact mass (FAB): calcd for $C_{17}H_{17}NO_3$ 284.1287, found 284.1269.

Mesylate **26** (81 mg) was dissolved in 3.8 mL of 0.1 M NaOAc in acetic acid, and the solution was kept at room temperature for 48 h. After a standard workup as described above, solvent removal gave 66 mg (92%) of acetate **27**, mp 89−90 °C, which was identical to an authentic sample prepared by acetylation of **70** with acetic anhydride in pyridine. ^1H NMR of **27** ($CDCl_3$): δ 7.50−7.24 (m, 11 H), 4.037 (s, 3 H), 1.955 (s, 3 H). ^{13}C NMR ($CDCl_3$): δ 169.79, 156.17, 135.93, 132.49, 129.07, 128.62, 128.11, 127.96, 126.37, 69.97, 62.57, 20.76. Exact mass (FAB): calcd for $C_{17}H_{17}NO_3$ 284.1287, found 284.1270.

Solvolysis of Chloride 35 in Trifluoroethanol. A solution of 110 mg of 2,6-lutidine in 5 mL of trifluoroethanol was added to 136 mg of chloride **35**, and the mixture was stirred for 1 h at room temperature. Examination of a sample by ^1H NMR 3 min after mixing shows that the reaction of **35** is complete. Most of the trifluoroethanol was

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removed using a rotary evaporator, and the residue was taken up into ether. The ether solution was washed with dilute hydrochloric acid, followed by saturated NaCl solution. Solvent removal using a rotary evaporator left 170 mg (82%) of a mixture of **36** and **37** in a 92:8 ratio as determined by NMR. A pure sample of **36** was isolated by chromatography on silica gel. A pure sample of **37** was isolated by preparative gas chromatography. ^{1}H NMR of **36** ($CDCl_3$): δ 7.330 (s, 1 H), 3.867 (s, 3 H), 3.76−3.56 (m, 2 H), 2.39 (m, 1 H), 2.33 (m, 1 H), 1.92−1.80 (m, 2 H), 1.63−1.06 (m, 6 H). ^{13}C NMR of **36** ($CDCl_3$): δ 149.83, 124.07 (q, J = 277 Hz), 86.40, 61.94, 61.14 (q, J = 34 Hz), 45.77, 37.64, 36.51 (d), 36.48 (t), 27.93, 22.70. Exact mass: calcd for $C_{11}H_{16}F_3NO_2$ 251.1133, found 251.1139.

^{1}H NMR of **37** ($CDCl_3$): δ 7.687 (s, 1 H), 6.241 (d, J = 3 Hz, 1 H), 3.887 (s, 3 H), 3.30 (m, 1 H), 2.95 (m, 1 H), 1.74 (m, 2 H), 1.46 (m, 1 H), 1.22 (m, 1 H), 1.09 (m, 2 H). ^{13}C NMR of **37** ($CDCl_3$): δ 145.57, 142.79, 140.86, 61.72, 47.81, 42.94, 41.12, 26.49, 24.73.

Solvolysis of Trifluoroacetate 38 in Trifluoroethanol. A solution of 160 mg of 2,6-lutidine in 6 mL of trifluoroethanol was added to 268 mg of trifluoroacetate **38**,[19] and the mixture was kept at 25 °C for 40 h. The trifluoroethanol was removed using a rotary evaporator, and the residue was taken up into ether. The ether solution was washed with dilute hydrochloric acid, followed by saturated NaCl solution. The ether extract was then dried over $MgSO_4$ and filtered, and the solvent was removed using a rotary evaporator to give 207 mg (85%) of a mixture of **36** and **37** in a 91:9 ratio as determined by NMR.

Kinetics Procedures. Rates of reaction of the substrates described in this paper were determined by either UV, ^{19}F NMR, or ^{1}H NMR spectroscopy. Rates of solvolyses of **6** (in ethanol, 245 nm), **9** (in CF_3CH_2OH, 266 nm), **11** (in CF_3CH_2OH, 226 nm), **12** (225 nm), **15** (284 nm), **16** (240 nm), **22** (247 nm), **24** (267 nm), **26** (267 nm), **30** (Ar = m-F-C_6H_4, 268 nm), **30** (Ar = p-$CF_3C_6H_4$, 268 nm), **31** (Ar = p-$CH_3C_6H_4$, 268 nm), and **32** (268 nm) were monitored by UV spectroscopy at the wavelengths given using previously described methods.[3c] Rates of solvolyses of **9** (in methanol), **14**, **31** (Ar = m-FC_6H_4), and **31** (Ar = p-$CF_3C_6H_4$) were monitored by ^{1}H NMR spectroscopy by integration of appropriate signals due to starting material and solvolysis product. Rates of solvolyses of **11** (in methanol), **38**, **40**, and **41** were monitored by ^{1}H NMR spectroscopy using the recently described method based on measurement of the chemical shift of the methyl groups of the buffering base 2,6-lutidine.[19] Rates of solvolysis of **7**, **8**, and p-$CH_3C_6H_4CH(OCOCF_3)C(NOCH_3)$-Ph were determined by ^{19}F NMR spectroscopy.[5]

Computational Studies. *Ab initio* molecular orbital calculations were performed using either the Gaussian 90 or the Gaussian 92 series of programs.[25] The frozen core approximation was not used in MP2 calculations.

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