NEW INSIGHT INTO THE MECHANISMS OF REACTIONS BETWEEN SOME ANIONIC NUCLEOPHILES
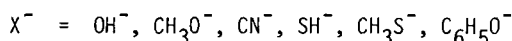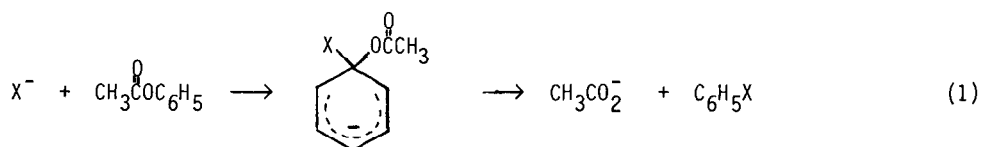
AND PHENYL ACETATE IN THE GAS PHASE

Jan C. Kleingeld and Nico M.M. Nibbering*
Laboratory of Organic Chemistry, University of Amsterdam
Nieuwe Achtergracht 129, 1018 WS Amsterdam, The Netherlands

Joseph J. Grabowski and Charles H. DePuy*
Department of Chemistry, University of Colorado
Boulder, Colorado 80309

Elaine K. Fukuda and Robert T. McIver, Jr.*
Department of Chemistry, University of California
Irvine, California 92717

Abstract: Experiments carried out in an ion cyclotron resonance (ICR) drift cell, an ICR trapped ion cell and a flowing afterglow (FA) system show that in the gas phase phenyl acetate reacts with a variety of clustered and unclustered nucleophiles to yield mainly the product ion $C_6H_5O^-$.
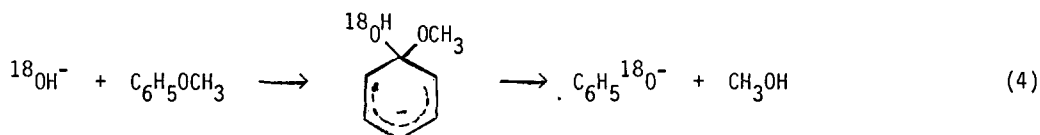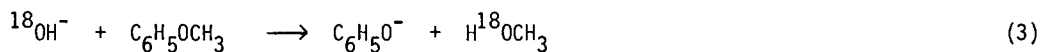
Recently the gas-phase reactions of phenyl acetate with various nucleophiles were reported

to produce acetate ions by nucleophilic aromatic substitution (reaction 1):[1]

$$X^- + CH_3\overset{O}{\overset{\|}{C}}OC_6H_5 \longrightarrow \left[\text{X}\overset{\overset{\text{O}}{\|}}{\underset{\text{OCCH}_3}{\bigcirc}}\right] \longrightarrow CH_3CO_2^- + C_6H_5X \tag{1}$$

$$X^- = OH^-, CH_3O^-, CN^-, SH^-, CH_3S^-, C_6H_5O^-$$

In spite of the fact that these reactions are exothermic in the gas phase, the results were

surprising because of earlier reports [2-6] that gas-phase nucleophilic aromatic substitution

reactions on unactivated benzene rings are slow, as they are in solution. Reference 1 also

reported that solvated nucleophiles such as $CH_3O^-\cdot\cdot H_2O$, $CH_3O^-\cdot\cdot CH_3OH$ and $SH^-\cdot\cdot CH_3OH$ produced

phenoxide ions instead of acetate ions upon reaction with phenyl acetate by what was presumed

to be a $B_{AC}2$ mechanism (reaction 2):

$$CH_3O^-\cdot\cdot H_2O + CH_3\overset{O}{\overset{\|}{C}}OC_6H_5 \longrightarrow C_6H_5O^- + CH_3\overset{O}{\overset{\|}{C}}OCH_3 + H_2O \tag{2}$$
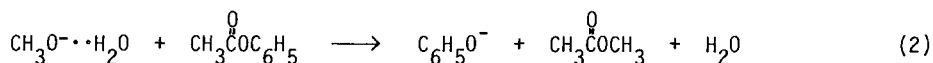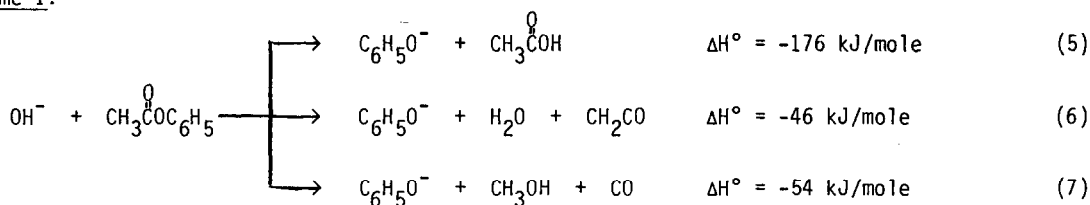
These unusual observations prompted further studies of phenyl acetate at the University of Colorado with a flowing afterglow (FA) system and at the University of Amsterdam with an ion cyclotron resonance (ICR) spectrometer employing a drift cell. Of particular interest were reactions of phenyl acetate with $^{18}OH^-$ since recent work in Amsterdam with ^{18}O labelling has shown that S_N2 displacement (reaction 3) is the dominant channel for formation of phenoxide ions from anisole in the gas phase, while nucleophilic aromatic substitution (reaction 4) accounts for

$$^{18}OH^- + C_6H_5OCH_3 \longrightarrow C_6H_5O^- + H^{18}OCH_3 \qquad (3)$$

$$^{18}OH^- + C_6H_5OCH_3 \longrightarrow \qquad \longrightarrow C_6H_5{}^{18}O^- + CH_3OH \qquad (4)$$

at most 15% of the reaction.[2] When $^{18}OH^-$ was allowed to react with phenyl acetate in the Amsterdam ICR instrument $C_6H_5O^-$ (m/z 93) was the major product ion observed. Smaller signals due to $^-CH_2COOC_6H_5$ (m/z 135) and $C_6H_5O^-\cdots H_2O$ (m/z 113) were detected, but neither CH_3COO^- (m/z 59) nor $CH_3CO^{18}O^-$ (m/z 61) were significant. Similar observations were made when the unsolvated nucleophiles OH^- or CH_3O^- were used. For the experiments carried out in the FA at the University of Colorado, unclustered OH^- ions were produced in a helium stream (0.4 torr) by electron impact on a mixture of N_2O and CH_4, and unclustered CH_3O^- ions were formed by reaction of NH_2^- with 1,2-dimethoxyethane. When phenyl acetate was introduced downstream, no acetate ions were produced. Instead, three ionic products were formed corresponding to those observed in the Amsterdam ICR experiment. New experiments with the pulsed ICR instrument at Irvine with purified samples of phenyl acetate also confirm these results. It appears that the original samples used in the ICR were contaminated with acetic acid. Our conclusion, therefore, is that acetate ions are not a major product of these reactions and that phenyl acetate does not react by ipso attack on the benzene ring.

The question remains as to the pathways by which phenyl acetate reacts with anionic nucleophiles. Scheme I shows three possible mechanisms for producing phenoxide from OH^-. Reaction 5, the most exothermic channel, is a $B_{AC}2$ reaction involving attack by the nucleophile at the carbonyl carbon. This is probably not a major channel for OH^- since one would expect acetate ion (the weaker base) and not phenoxide ion to be formed as the ion-molecule complex breaks apart. Furthermore, Riveros has shown[7] that $B_{AC}2$ hydrolysis of aliphatic esters by OH^- does not

Scheme I:

$$OH^- + CH_3\overset{O}{\overset{\|}{C}}OC_6H_5 \longrightarrow \begin{cases} \longrightarrow & C_6H_5O^- + CH_3\overset{O}{\overset{\|}{C}}OH & \Delta H^\circ = -176 \text{ kJ/mole} & (5) \\ \longrightarrow & C_6H_5O^- + H_2O + CH_2CO & \Delta H^\circ = -46 \text{ kJ/mole} & (6) \\ \longrightarrow & C_6H_5O^- + CH_3OH + CO & \Delta H^\circ = -54 \text{ kJ/mole} & (7) \end{cases}$$

occur if the ester has α-hydrogens since these protons are acidic and only the M-1 ion is formed. Formation of the M-1 ion of phenyl acetate is a very minor reaction channel in spite of the fact that with OH^- the reaction is exothermic by 75 kJ/mole. An alternative pathway is reaction 6, an exothermic E_2 reaction which proceeds with α-proton abstraction from phenyl acetate. Reaction 7 is a S_N2 displacement reaction. At this time no distinction can be made between the S_N2 and E_2 channels for OH^-.

Phenoxide ion is also the major ionic product in reactions of phenyl acetate with weaker anionic bases such as CH_3O^-, $CH_3COCH_2^-$ and solvated anions such as $CH_3O^-\cdot\cdot CH_3OH$. In some of these cases recent Fourier transform ICR experiments at the University of Amsterdam have indicated that the S_N2 channel rather than the $B_{AC}2$ mechanism is responsible for the formation of phenoxide ion, whereas the E_2 channel is less likely because of its endothermicity.[8] Using the pulsed ICR spectrometer at UC Irvine, the rate constant for reaction of CH_3O^- with phenyl acetate was measured as 8×10^{-11} cm^3/molecule sec. This could not be confirmed by FA because the vapor pressure of phenyl acetate is too low to be measured accurately in the FA apparatus.

The most definitive way of elucidating the mechanisms of these reactions is to isolate and analyze the neutral products, but this is very difficult because the number of neutral product molecules generated by the reaction is the same as the number of reactant ions, typically only a few million per second.[9-11] At the ICR Laboratory in Irvine a new ICR spectrometer that has been specially designed for detection of the neutral products of ion-molecule reactions has just been brought into operation. We hope it will provide a new means for investigating gas-phase rearrangement reactions and complex reactions with several possible channels.

References and Notes

1. E.K. Fukuda and R.T. McIver, Jr., J. Am. Chem. Soc., 101, 2498 (1979).
2. J.C. Kleingeld and N.M.M. Nibbering, Tetrahedron Lett., 21, 1687 (1980).
3. S.M.J. Briscese and J.M. Riveros, J. Am. Chem. Soc., 97, 230, (1975).
4. S.A. Sullivan and J.L. Beauchamp, J. Am. Chem. Soc., 99, 5017 (1977).
5. I. Dzidic, D.I. Carroll, R.N. Stilwell and E.C. Horning, Anal. Chem., 47., 1308 (1975).
6. J.K. Bowie and B.J. Stapleton, Aust. J. Chem., 30, 795 (1977).
7. K. Takashima and J. M. Riveros, J. Am. Chem. Soc., 100, 6128 (1978).
8. J. C. Kleingeld and N.M.M. Nibbering, to be published in the proceedings of the 2nd International Symposium on Ion Cyclotron Resonance Spectrometry, Mainz, West Germany, 23-27 March 1981. These proceedings will appear as a volume in the series "Lecture Notes in Chemistry" ed. by H. Hartmann and K.-P. Wanczek, Springer Verlag, Berlin.
9. C. A. Lieder and J. I. Brauman, Int. J. Mass Spectrom. Ion Phys., 16, 307 (1975).
10. W. J. Martinelli and T. H. Morton, J. Am. Chem. Soc., 100, 3536 (1978).
11. M. A. Smith, R. M. Barkley and G. B. Ellison, J. Am. Chem. Soc., 102, 6851 (1980).

(Received in USA 7 July 1982)