960 J. Org. Chem. 1982, 47, 960-962

Positional Selectivity and Heteroatom Effect in the Reaction of 2,4,6-Triphenylpyrylium and 2,4,6-Triphenylthiopyrylium Ions with Methoxide Ion

Giancarlo Doddi,* Gabriello Illuminati,* Normanno Insam, and Franco Stegel*

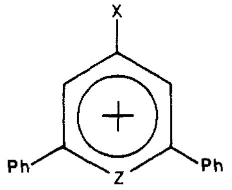
Centro di Studio sui Meccanismi di Reazione del Consiglio Nazionale delle Ricerche, c/o Istituto di Chimica Organica, Università di Roma, 00185 Roma, Italy

Received November 2, 1981

The rate constants for 2*H* and 4*H* adduct formation were determined for the reaction of the 2,6-diphenyl-4-X-pyrylium ion (1, X = Ph) and of 2,4,6-triphenylthiopyrylium ion 2 with methoxide ion in methanol solution. The equilibrium constants were evaluated for the formation of the 4*H* adducts. The ipso attack at the 4-position is found to be in the order H > MeO > Ph for the 4-X substituents and mainly caused by ground-state stabilization for X = Ph. The substrate and positional reactivities of 1 and 2 differ appreciably from each other and suggest that the reactions of 1 and, possibly, 2 are charge rather than orbital controlled.

In recent work[1] we have studied the reactivity of 2,6-diphenyl-4-X-pyrylium ions (X = H, OCH_3) toward methoxide ion and the equilibria involved in 2*H* and 4*H* adduct formation in connection with the reaction of aromatic and heteroaromatic substrates with nucleophiles to give σ adducts as identifiable products as well as reactive intermediates in more complex reactions.

In the examples above, positional selectivities are influenced by the fact that the reactive α- and γ-positions are occupied by unlike substituents and do not reflect intrinsic properties of the pyrylium system alone. Although the unsubstituted pyrylium ion would be the most obvious choice for a positional reactivity study, 2,4,6-triphenylpyrylium ion (1) has proved to be experimentally more tractable in methanol. Furthermore, substrate 1 belongs in the same series as above (X = Ph) and yields further information about structural effects on reactivity.



1 Z=O

2 Z=S

Use of the 2,4,6-triphenyl-substituted ring is particularly significant for the study of the heteroatom effect including both substrate and positional selectivity.

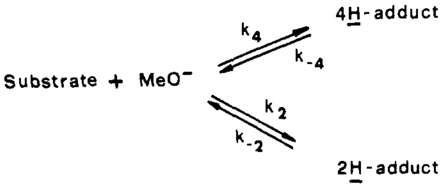
In the present paper we report on a rate and equilibrium study for the reaction of 1 and its sulfur analogue 2 with methoxide ion in methanol solution.

Results

The kinetics of the reaction of cations 1 and 2 with CH_3O^- were studied in methanol at 25 °C by the stopped-flow technique in the presence of a triethylamine/triethylammonium buffer system. Under such conditions the CH_3O^- concentration could be kept as low as 10^{-7}–10^{-6} M, and the fast reaction rates could be measured.

2,4,6-Triphenylpyrylium Ion (1). ^1H NMR spectral measurements for the reaction of 2,6-diphenyl-4-X-pyrylium ions with CH_3O^- show the formation of the 4*H* adduct in dipolar aprotic solvents and of both 4*H* and 2*H* isomers in methanol solution for X = H and OCH_3.[2,3] In the latter solvent the formation of the 2*H* adduct for X = H is inferred by the formation of the related diphenylpentadienone as a ring-opening product. Starting from 1 (X = Ph), one finds that the 4*H* adduct accompanies the formation of the 2*H* adduct to only a slight extent in dipolar aprotic solvents and is not detected at all in methanol solution. In neither solvent type does ring opening occur from the 2*H* adduct deriving from 1.

Scheme I



When the stopped-flow technique was applied, the observed UV–vis spectral changes were consistent with the formation of both adducts at the very start even in methanol solution, followed by the fast equilibration phenomena. The contribution of each adduct to the dynamics of the whole process was assessed by a kinetic analysis. The reaction was followed at two wavelengths, 405 and 311 nm. The former was in a region where only 1 displays a strong absorption, and the latter was in a region where the absorption of the 2*H* adduct overlaps with that of 1 but is more intense. Furthermore, whereas the 2*H* adduct does not interfere with the absorption of 1 at 405 nm, the absorption of the 4*H* adduct is known to be negligible at any wavelength greater than 300 nm.[1,4] At 405 nm, the disappearance of 1 takes place according to a first-order course. In contrast, the spectral change with time at 311 nm shows the occurrence of two processes since the increase in the absorption is initially fast and proceeds more slowly later on. The former process corresponds to the complete conversion of the substrate into a kinetically controlled mixture of 2*H*- and 4*H*-pyran, where 2*H*-pyran is prevailing, and the latter corresponds to the equilibration of this mixture and the eventual complete conversion of 4*H*-pyran into the thermodynamically more stable 2*H*-pyran, according to Scheme I.[5] The absorbance data

---

[1] Doddi, G.; Fornarini, S.; Illuminati, G.; Stegel, F. *J. Org. Chem.* **1979**, *44*, 4496.

[2] Aveta, R.; Doddi, G.; Insam, N.; Stegel, F. *J. Org. Chem.* **1980**, *45*, 5160.

[3] Bersani, S.; Doddi, G.; Fornarini, S.; Stegel, F. *J. Org. Chem.* **1978**, *43*, 4112.

[4] Dimroth, K.; Wolf, K.; Kroke, H. *Justus Liebigs Ann. Chem.* **1964**, *678*, 183.

0022-3263/82/1947-0960$01.25/0 © 1982 American Chemical Society

Table I. Rate and Equilibrium Constants for the Reaction of 2,4,6-Triphenylpyrylium (1) and 2,4,6-Triphenylthiopyrylium (2) Ions with CH_3O^- in Methanol at 25 °C

compd	k_4, M^{-1} s^{-1}	k_{-4}, s^{-1}	K_4, M^{-1}	k_2,[a] M^{-1} s^{-1}
1	6.3×10^5	0.67	6.9×10^5	5.9×10^6
2	1.8×10^5	0.07	2.6×10^6	1.3×10^5

[a] Uncorrected for the statistical factor.

Table II. Rate Constants for the Adduct Formation from 4-Substituted 2,6-Diphenylpyrylium Ions

4-R	$10^{-5}k_4$, M^{-1} s^{-1}	K_4, M^{-1}	$10^{-5}k_2$, M^{-1} s^{-1}	ref
H	1100	$>10^7$		1
OCH_3	31.5	$\sim 3 \times 10^6$	5.05[a]	1
C_6H_5	6.3	$\sim 7 \times 10^5$	59[a]	this work

[a] Uncorrected for the statistical factor.

allowed the evaluation of the concentrations of the substrate, [1], and 2*H* adduct, [2*H*], at any given time *t* and of the 4*H* adduct by difference: $[4H]_t = [1]_0 - ([1]_t + [2H]_t)$. The kinetic analysis was based on Scheme I and was simplified by the fact that in the presence of the buffer system the CH_3O^- concentration was constant under fixed reaction conditions so that pseudo-first-order rate constants $k_2' = k_2\,[MeO^-]$ and $k_4' = k_4\,[MeO^-]$ were obtained. Furthermore, the reverse rate constant, k_{-2}, could be neglected because the overall reaction eventually led to complete conversion to the 2*H* adduct. Plots (not shown) of k_2' and k_4' vs. MeO^- ion concentration, linear for both substrates, intersect the axes at the origin. Therefore, any attack of the solvent under these conditions can be ruled out. The rate constants are reported in Table I.

2,4,6-Triphenylthiopyrylium Ion (2). The UV–vis spectral behavior of 2 in the reaction with methoxide ion in methanol shows some analogies to that of the pyrylium analogue 1. The reaction yields a 2*H* adduct only as a final product, whose structure was established by ^1H NMR spectra.[2] However, the detailed course of the absorbance changes with time as recorded at 400 and 315 nm differs from that of 1. On the assumption of the same reaction pattern as that of Scheme I, the kinetic analysis was carried out by the same procedure used for 1. The *k* values (Table I) show that the observed differences from the reaction of 1 are due to the fact that the formation of the 4*H* adduct from 2 is slightly faster than that of the 2*H* adduct.

We also inspected the behavior of 2 at 510 nm, since thiabenzene derivatives absorb at 510–530 nm,[6,7] and a pale purple color developed in the methanol solution of 2 in the presence of 0.1 M methoxide. At the shortest scanning times of the stopped-flow technique only very slight absorbance increases, if any, were observed. Since thiabenzenes have high ϵ values, the formation of such compounds was assumed not to interfere with our rate measurements.

Discussion

Effect of the Ipso Substituents. The rate and equilibrium constants for the 4*H* adduct formation from 2,4,6-triphenylpyrylium ion (1) are compared with the corresponding data for X = H and MeO in Table II. These data show that the ipso substituent effect follows the order H > MeO > Ph for both the reaction rates and equilibrium constants. The deactivating effect of the ipso MeO group has been shown to be evidence for the ability of this group to stabilize the initial state by C_{Ar}–O conjugation.[1] Conjugation undoubtedly also occurs between the phenyl substituent and the pyrylium ring since significant downfield shifts at the para position of such substituents have been observed in the ^{13}C NMR spectrum of ion 1.[8] However, the conjugative ability of the phenyl group is expected to be appreciably less than that of the methoxy group as it is inferred by their σ_R values.[9] Also, a strong conjugative electron release of the 4-substituent toward the pyrylium ring would tend to reduce the electron deficiency at the positions α with respect to the heteroatom, as observed in other heteroaromatic systems.[10] This effect is expectedly greater for the MeO group than for phenyl and is presumably responsible for the 4-Ph > 4-MeO order that is observed for the reactivity at the 2-position. Therefore, the MeO > Ph order for the ipso substituents at the 4-position does not seem to reflect the conjugative order of these groups and should arise from the concomitance of some other factor.

One such factor is the marked electron-withdrawing inductive effect of the methoxy group which would tend to reduce the total charge density at the ipso position relative to that for phenyl and to facilitate the 4*H* adduct formation. According to recent ab initio and CNDO calculations[11] the π charge density for the α-carbon of unsaturated oxonium ions, $(CH_3O\cdots CH\cdots Y)^+$, is greater with Y = OMe than with Y = Ph, whereas the opposite order is obtained for the total charges ($\pi + \sigma$), which would be consistent with the present reactivity sequence.

A second factor is the stabilizing effect arising from geminally substituted O substituents at a tetrahedral carbon.[12,13] This factor becomes important when the transition state has progressed far enough along the reaction coordinate and should lead to a reactivity vs. equilibrium correlation. Although this is qualitatively shown by the values in Table II, a fair assessment of the role of this effect is not possible with the data at hand.

Apart from the Ph vs. MeO order, the low reactivity of the phenyl-substituted substrate relative to hydrogen (H/Ph rate ratio of 239) deserves a comment in its own right. We have wondered whether it is contributed by an F-strain effect. A steric effect of this kind is in contrast with the observation that the reactivities grossly parallel the equilibrium constants, as shown by the data in Table II, since much of the strain should be relieved in the 4*H* adduct where the tetrahedral 4-carbon accommodates the reagent group and the phenyl group with a reduced hindrance, if any. A lack of reactivity vs. equilibrium correlation has indeed been observed and interpreted in terms of steric effects in Meisenheimer adduct formation from polynitro benzene and thiophene derivatives.[14,15] The same data lead to an estimate of a return constant, k_{-4}, for X = Ph that is comparable with or even higher than that for X = H. This confirms that the transition state for the

---

(5) Traces of OH^- ion are not likely to interfere with the kinetic pattern, because they would not be able to compete with the similarly reactive MeO^- ions. Furthermore, we did not observe any absorbance in the visible region where the expected ring-opening decomposition product would absorb in a basic medium (Dilthey, W. *J. Prakt. Chem.* **1916**, *94*, 53).

(6) Price, C. C.; Follweiler, J.; Pirelahi, H.; Siskin, M. *J. Org. Chem.* **1971**, *36*, 791.

(7) Suld, G.; Price, C. C. *J. Am. Chem. Soc.* **1962**, *84*, 2094.

(8) Balaban, A. T.; Wray, V. *Org. Magn. Reson.* **1977**, *9*, 16.

(9) Taft, R. W., Jr.; Deno, N. C.; Skell, P. S. *Annu. Rev. Phys. Chem.* **1958**, *9*, 287.

(10) Belli, M. L.; Illuminati, G.; Marino, G. *Tetrahedron* **1963**, *19*, 345.

(11) Bégué, J. P.; Bonnet-Delpon, D. *Org. Magn. Reson.* **1980**, *14*, 349.

(12) Hine, J. *J. Am. Chem. Soc.* **1963**, *85*, 3239.

(13) Bernasconi, C. F. *J. Am. Chem. Soc.* **1970**, *92*, 4682.

(14) Baldini, G.; Doddi, G.; Illuminati, G.; Stegel, F. *J. Org. Chem.* **1976**, *41*, 2153.

(15) Gold, V.; Rochester, C. H. *J. Chem. Soc.* **1964**, 1692.

phenyl derivative is not particularly affected by steric factors relative to hydrogen. The low reactivity of the phenyl derivative is then more likely caused by electronic effects. Conjugation with the pyrylium ring is believed to be made unusually strong in the initial state by the positive charge of the pyrylium ion.

Little sensitivity of the ipso attack to bulky groups has also been noted in an admittedly different case, i.e., the brominative electrophilic attack on the para position of phenols. Ipso reactivity was found to change slightly in going from hydrogen to methyl and to *tert*-butyl.[16]

Substrate and Positional Selectivity. Reactivity changes at positions 2 (α) and 4 (γ) of 2,4,6-triphenylpyrylium and -thiopyrylium ions should essentially reflect electronic structural effects provided that changes in the steric environment are unimportant. Since we have noted that F-strain effects of the phenyl group do not seem to be very relevant, we assume that their changes can be even more convincingly neglected. This is supported by the fact that in solution the cationic charge is delocalized in a similar way from the pyrylium ring to the phenyl substituents in the 2-, 4-, and 6-positions, and presumably the phenyl rings are nearly coplanar with the pyrylium ring.[8] In the crystal the phenyl groups are tilted from the plane of the pyrylium ring at angles of 2.3–18.0°.[17] The thiopyrylium analogue is assumed to behave similarly.

The data in Table I show that the α- and γ-positions differ in reactivity by small factors but in opposite orders, the α position being more reactive by a factor of 4.6 in the pyrylium ion and less reactive by a factor of 2.8 in the thiopyrylium ion. The pyrylium ion is consistently more reactive than the thiopyrylium ion at both positions, the reactivity ratios being 45 and 3.5 at the positions α and γ, respectively.

Palmer et al.[18] have carried out nonempirical calculations for the electronic charge distribution of unsubstituted pyrylium and thiopyrylium ions, and their results compare well with those obtained for pyrylium ion by other methods.[19,20] Although charge densities are known to predict reactivities to a crude approximation, it is remarkable that in this case they vary in the same orders as those observed for positional and substrate selectivities.

From cyclic voltammetry measurements, Saeva and Olin[21] have obtained information on the LUMO energy for compounds **1** and **2** and have found that the LUMO level is higher for the former by some 2 kcal/mol. In terms of generalized perturbation theory[22] this would affect the covalent term in the direction of a greater reactivity of **2** relative to **1**. The fact that a reverse reactivity order is in fact observed suggests that the reaction is charge rather than orbital controlled, a conclusion which implies a large difference between the HOMO level of the donor and the LUMO level of the acceptor. This is indeed the case when a hard nucleophile such as CH_3O^- is used.

A charge-controlled reaction is consistent with the above-noted charge density–reactivity correlation and with the notion that the transition states for the reactions of highly reactive cations are reactant-like. The higher reactivity of the pyrylium ion relative to that of the thiopyrylium ion and a positional selectivity favoring attack at position 2 of the former substrate make it quite likely that charge control is important at least in the pyrylium ion reaction.[23]

We point out that these features should be confronted with certain puzzling aspects of cation–anion combination reactions, especially with reference to the apparently unimportant role of coulombic effects in such reactions.[24] These problems have been discussed in some detail in recent years.[24-26] We plan to look for an appraisal of such a confrontation on further development of the present studies.

Experimental Section

Materials. Perchlorates of **1** and **2** were available from our previous work.[2] The purification of methanol and triethylamine and the preparation of the methanol solution of perchloric acid were carried out as previously described.[1]

Rate Measurements with Et_3N/Et_3NH^+ Buffers. The measurements were made spectrophotometrically by the stopped-flow technique with a procedure similar to the one followed for the addition of methoxide ion to other pyrylium systems. For the present substrates the absorbance values were recorded at two different wavelengths (405 and 311 nm for **1** and 400 and 315 nm for **2**). Since at these wavelengths the contribution to the absorbance from the 4*H* adducts may be neglected,[4,27] the absorbance A_i at each wavelength i was assumed to take the form of eq 1, where S is the substrate. The $\epsilon_{S,i}$ values were obtained

$$A_i = \epsilon_{S,i}[S] + \epsilon_{2H,i}[2H] \qquad (1)$$

in the presence of perchloric acid wherein the substrates do not undergo any addition (**1**, log ϵ_{405} 4.39, log ϵ_{311} 3.91; **2**, log ϵ_{400} 4.34, log ϵ_{315} 3.78). The $\epsilon_{2H,i}$ values were determined in the presence of an excess of methoxide ion, in order to keep the equilibria completely shifted to the 2*H* adducts (2,4,6-triphenyl-2*H*-pyran, log ϵ_{311} 4.02; 2,4,6-triphenyl-2*H*-thiopyran, log ϵ_{315} 3.87).

Rate Constant Determination for the Formation of the Adducts. The kinetic analysis was performed with a procedure similar to that already described[1] for analogous reactions, leading to both 2*H*- and 4*H*-pyrans at equilibrium. Since in the present systems only 2*H* adducts are observed at equilibrium, the kinetic expressions previously[1] reported reduce to eq 2–6. The pseudo-first order k_i' values were obtained by putting $[2H]_0 = [4H]_0 = 0$ and by fitting the experimental values for 2*H* and 4*H* adduct concentrations to those calculated from eq 2–6 with the aid of a computerized program of multiparameter optimization (MINUIT).[28] At each time the experimental concentration of 4*H* adduct was obtained by subtracting the concentration values for substrate and 2*H* adduct from the initial concentration of the substrate.

$$[4H] = [S]_0 \frac{k_4'(e^{-\lambda_2 t} - e^{-\lambda_3 t})}{\lambda_3 - \lambda_2} \qquad (2)$$

$$[S] = [S]_0 \left(\frac{k_{-4} - \lambda_2}{\lambda_3 - \lambda_2} e^{-\lambda_2 t} - \frac{k_{-4} - \lambda_3}{\lambda_3 - \lambda_2} e^{-\lambda_3 t} \right) \qquad (3)$$

$$[2H] = [S]_0 \left(\frac{k_2' k_{-4}}{\lambda_2 \lambda_3} - \frac{k_2'(k_{-4} - \lambda_2)}{\lambda_2(\lambda_3 - \lambda_2)} e^{-\lambda_2 t} + \frac{k_2'(k_{-4} - \lambda_3)}{\lambda_3(\lambda_3 - \lambda_2)} e^{-\lambda_3 t} \right) \qquad (4)$$

$$\lambda_2 = (p + q)/2; \ \lambda_3 = (p - q)/2 \qquad (5)$$

$$p = k_4' + k_2' + k_{-4}; \ q = (p^2 - 4k_{-4}k_2')^{1/2} \qquad (6)$$

Registry No. **1** (X = Ph), 15959-35-0; **2** (X = Ph), 18342-83-1; CH_3O^-, 3315-60-4.

---

[16] Baciocchi, E.; Illuminati, G. *J. Am. Chem. Soc.* **1967**, *89*, 4017.

[17] Tamamura, T.; Yamane, T.; Yasuoka, N.; Kasai, N. *Bull. Chem. Soc. Jpn.* **1974**, *47*, 832.

[18] Palmer, M. H.; Findlay, R. H.; Moyes, W.; Gaskell, A. J. *J. Chem. Soc., Perkin Trans. 2* **1975**, 841.

[19] Bigelow, R. W. *J. Chem. Phys.* **1977**, *67*, 4498.

[20] Martensson, O.; Warren, C. H. *Acta Chem. Scand.* **1970**, *24*, 2745.

[21] Saeva, F. D.; Olin, G. R. *J. Am. Chem. Soc.* **1980**, *102*, 299.

[22] Klopman, G. In "Chemical Reactivity and Reaction Rates"; Klopman, G., Ed.; Wiley: New York, 1974; p 55.

[23] Hudson, R. F. *Angew. Chem., Int. Ed. Eng.* **1973**, *12*, 36.

[24] Ritchie, C. D. *Pure Appl. Chem.* **1978**, *50*, 1281.

[25] Ritchie, C. D. *Pure Appl. Chem.* **1979**, *51*, 153.

[26] Pross, A. *Tetrahedron Lett.* **1975**, *1289*.

[27] Suld, G.; Price, C. C. *J. Am. Chem. Soc.* **1962**, *84*, 2090.

[28] James, F.; Roos, M. CERN Computer 6000 Series Program Library, CERN: Geneva, Switzerland, 1971.