Meisenheimer Complexes. Stopped-Flow Study of the Interaction of 3,5-Dinitro-4-methoxypyridine with Methoxide Ion in Methanol and Methanol–Dimethyl Sulfoxide Mixtures[1]

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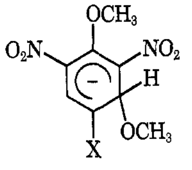
The kinetics of the reaction of methoxide ions with 3,5-dinitro-4-methoxypyridine (**3**) in methanol has been studied by the stopped-flow technique. When the methoxide ion concentration is greater than about 0.01 *M*, the appearance of the stable 1,1 complex **4** is preceded by the faster formation of the thermodynamically less stable 1,3 complex **5**. The rate and equilibrium constants for the formation of complexes **4** (k_2, K_2) and **5** (k_1, K_1), together with the rate constants for their decomposition (k_{-2}, k_{-1}) have been determined at four different temperatures, allowing a determination of the energies and entropies of activation for the reactions. A similar study has been also carried out in various methanol–dimethyl sulfoxide (DMSO) mixtures. The results are compared with previously reported data on the reactions of 2,4,6-trinitroanisole (**6**) and 4-cyano-2,6-dinitroanisole (**9**) with methoxide ions to give analogous 1,1 complexes **7** and **10** as well as 1,3 complexes **8** and **11**. The pyridinic 1,3 complex **5** appears to be the most stable transient 1,3 complex detected to date.

The reaction of methoxide ions with substituted 4-X-2,6-dinitroanisoles in DMSO often results in the fast initial formation of 1,3 complexes 1 followed by the slower appearance of the classical Meisenheimer 1,1 complexes 2 which are thermodynamically more stable.[2-5]



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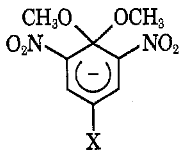

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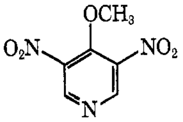
Recent kinetic studies of this interaction in CH_3OH–DMSO mixtures shed some light on its mechanism.[5,6] Whatever the composition of the solvent mixture, methoxide ions attack the unsubstituted 3 carbon faster than the substituted 1 carbon. The formation of 1,3 complexes 1 is thus initially favored and their detection, in a given medium, requires only that they be sufficiently stable and that their lifetime be sufficiently important. Since the equilibrium constants for their formation as well as their lifetime increase strongly with addition of DMSO to the methanolic solutions, 1,3 complexes are consequently more easily observed in mixtures rich in DMSO, but the minimum DMSO amount necessary to their detection is dependent on the electron-withdrawing power of the X substituent. Whereas 1,3 complexes formed from 4-fluoro- and 4-chloro-2,6-dinitroanisoles can be seen only in the mixtures with as much as 70% DMSO by weight, the 1,3 complex formed from 4-cyano-2,6-dinitroanisole can be observed in 25% DMSO.

From these results, it appeared of special interest to study a 4-X-2,6-dinitroanisole with an X substituent, such as a nitro group or an aza group, the electron-withdrawing power of which is stronger than that of a cyano group. Thus we could expect to obtain spectral evidence for a 1,3 complex as well as to follow kinetically the formation of such a transient species in the absence of DMSO cosolvent. Though a calorimetric study, recently reported by Fendler, *et al.*,[7] of the interaction of 2,4,6-trinitroanisole with methoxide ions in methanol has given some indication that a 1,3 complex is formed prior to the stable 1,1 complex, the behavior of this compound was not found very convenient for the stopped-flow method. We have thus investigated in pure methanol and various CH_3OH–DMSO mixtures the reaction of 3,5-dinitro-4-methoxypyridine (**3**) with potassium methoxide. Following a preliminary communication,[1] we wish now to report detailed results and additional data for this kinetic study.

Indeed, at the same time as our preliminary communication, a report by Bernasconi[8] appeared describing the study, by the temperature-jump method, of the transient 1,3 complex formed by the reaction of 2,4,6-trinitroanisole with methoxide ion in methanol. This study provides complementary data to our work and we have used it for the purpose of comparison in our discussion.

Results

Reaction of 3 with CH_3O^- in Methanol.—When the methoxide ion concentration *b* is kept below 0.01 *M*, the reaction of methoxide ions with 3,5-dinitro-4-methoxypyridine (**3**) in methanol gives directly, according to the scheme below, the stable 1,1 complex **4**, which shows an absorption band at 455 mμ (ϵ_{max} 1.85 × 10^4 cm^{-1} l. mol^{-1}) and whose structure has been confirmed by nmr



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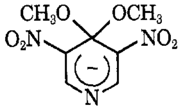

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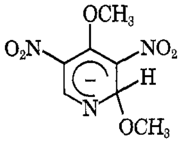

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[1] Presented, in part, at the 23rd IUPAC Meeting, Boston, Mass., July 25–30, 1971.

[2] (a) K. L. Servis, *J. Amer. Chem. Soc.*, **87**, 5495 (1965); (b) *ibid.*, **89**, 1508 (1967).

[3] M. R. Crampton and V. Gold, *J. Chem. Soc. B*, 893 (1966).

[4] (a) E. J. Fendler, J. H. Fendler, and C. E. Griffin, *Tetrahedron Lett.*, 5631 (1968); (b) J. H. Fendler, E. J. Fendler, and C. E. Griffin, *J. Org. Chem.*, **34**, 689 (1969); (c) E. J. Fendler, J. H. Fendler, C. E. Griffin, and J. W. Larsen, *ibid.*, **35**, 287 (1970).

[5] (a) F. Terrier and F. Millot, *C. R. Acad. Sci., Ser. C*, **268**, 808 (1969); (b) F. Millot and F. Terrier, *Bull. Soc. Chim. Fr.*, 2694 (1969).

[6] (a) F. Terrier and F. Millot, *ibid.*, 1743 (1970); (b) F. Terrier, C. Dearing, and R. Schaal, "Reaction Transition States," Gordon and Breach, London, 1972, in press; (c) F. Millot and F. Terrier, *Bull. Soc. Chim. Fr.*, 3897 (1971).

[7] J. W. Larsen, J. H. Fendler, and E. J. Fendler, *J. Amer. Chem. Soc.*, **91**, 5903 (1969).

[8] (a) C. F. Bernasconi, paper presented at the IUPAC meeting, Boston, Mass., July 25–30, 1971; (b) C. F. Bernasconi, *J. Amer. Chem. Soc.*, **93**, 6975 (1971).

$$3 + CH_3O^- \underset{k_{-2}}{\overset{k_2}{\rightleftharpoons}} 4$$

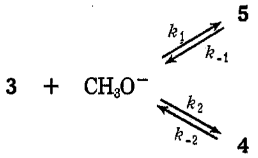
spectroscopy.[9] All the rate measurements were carried out under pseudo-first-order conditions with an excess of the methoxide reagent. The observed first-order rate constant λ_2 for the equilibrium attainment is thus given by eq 1, where k_2 is the second-order rate constant for the formation of **4** and k_{-2} is the first-order rate constant for its decomposition. Using eq 1, plots of

$$\lambda_2 = k_{-2} + k_2 b \qquad (1)$$

λ_2 against the base concentration at the four temperatures studied gave good straight lines whose slopes are k_2 and intercepts k_{-2}. Since the intercepts were susceptible to large errors, more accurate values for k_{-2} have been determined either directly, by following the decomposition of the solid complex **4** which is easily isolable,[9a] or indirectly by using the value of the equilibrium constant K_2 which could be spectrophotometrically measured. The agreement between the values of k_{-2} obtained by the two methods is reasonable.

As soon as the base concentration reaches 0.01 *M*, the form of the interaction becomes very different. As can be seen from Figure 1, the oscilloscope pictures reveal that the appearance of the 1,1 complex **4** is preceded by the fast formation of another complex which is completely formed in a solution of potassium methoxide 0.5 *M* and which shows an absorption band at 435 mμ (ϵ_{max} 2.36 × 10^4 cm^{-1} l. mol^{-1}). This thermodynamically less stable complex can reasonably be considered as being the 1,3 complex **5** due to an initial attack by CH_3O^- ions of the unsubstituted carbon of **3**. Indeed, Illuminati and Miller have observed such a complex by nmr spectroscopy in DMSO-d_6.[9]

The kinetic scheme of two competitive reactions which corresponds then to this interaction involves in fact two separated steps. The first step is the equilibrium attainment for complex **5** with an observed first-order rate constant λ_1 expressed by eq 2. Values of k_1



$$\begin{tikzcd} & 5 \\ 3 + CH_3O^- \arrow[ur, shift left, "k_1"] \arrow[dr, shift left, "k_2"] & \\ & 4 \arrow[ul, shift left, "k_{-2}"] \end{tikzcd}$$

$$\lambda_1 = k_{-1} + k_1 b \qquad (2)$$

and k_{-1} were obtained from slopes and intercepts of plots of λ_1 *vs.* *b*, which are linear. We calculated the equilibrium constant K_1 from $K_1 = k_1/k_{-1}$.

The second step is the slow equilibrium formation of the stable 1,1 complex **4**, from the molecule which is considered as being in instantaneous equilibrium with **5**. As previously shown in different papers concerning the formation of 1,1 and 1,3 complexes derived from other 4-X-2,6-dinitroanisoles,[6,8] the rate equation again gives pseudo-first-order relationships with an observed first-order rate constant λ_2' expressed by eq 3, which can be reduced to eq 3a because the equilibrium constant K_2 is much greater than K_1.

$$\lambda_2' = k_{-2}\frac{1 + K_1 b + K_2 b}{1 + K_1 b} \qquad (3)$$

$$\lambda_2' = k_{-2}\frac{1 + K_2 b}{1 + K_1 b} = \frac{\lambda_2}{1 + K_1 b} \ (K_1 \ll K_2) \qquad (3a)$$

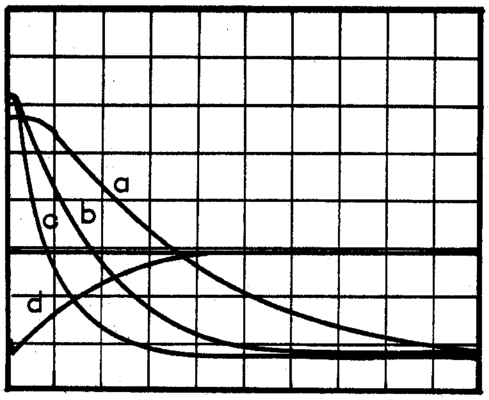


Figure 1.—Representative oscilloscope picture of the reaction of **3** with potassium methoxide in methanol at 20°; [**3**] = 3.4 × 10^{-5} *M*, *b* = 0.16 *M*. The plots (a, b, c) show the appearance of **5** (5, 10, 20 msec/horizontal division) and the plot (d) illustrates its disappearance (0.5 sec/horizontal division).

From the measured values of λ_2' and knowing K_1, we calculated the values of the first-order rate constant λ_2 which would be observed in the same experimental conditions if **4** were formed directly by reaction of CH_3O^- ions with **3**. These values allow the plots of λ_2 *vs.* *b* obtained at the very low base concentrations to be extended and confirm the value previously determined for k_2.

Reaction of 3 with CH_3O^- Ions in CH_3OH–DMSO Mixtures.—Except for the mixture containing 13.35% DMSO by weight, where again it was possible to study directly the equilibrium $3 + CH_3O^- \rightleftharpoons 4$ at the lowest methoxide ion concentrations, the formation of the less stable 1,3 complex **5** was found always to precede the appearance of **4**, whatever the amount of DMSO and the base concentration of the used solution might be.

In the mixtures where the amount of DMSO is equal to or less than 37% by weight, values of k_1 and k_{-1}, and consequently those of K_1, were obtained in all cases from the linear plots of λ_1 *vs.* *b*. Above 37% DMSO, k_{-1} became too small for a good determination from intercepts of such plots and we could only calculate k_{-1} in the mixtures containing 47.5 and 57.5% DMSO by weight, where the equilibrium constant K_1 could be thermodynamically measured.

Figure 2 illustrates the variations of the observed first-order rate constant λ_2' for the appearance of the stable complex **4**. At the highest base concentrations used in the mixtures with as much as 37% DMSO by weight, the graphs of λ_2' *vs.* *b* show a characteristic flat line of slope 0 corresponding to the maximum value given by eq 4. Thus, when the equilibrium constant

$$\lambda_2'^{\max} = k_{-2}\frac{K_2}{K_1} = \frac{k_2}{K_1} = k_{-1}\frac{k_2}{k_1} \qquad (4)$$

K_1 was known, it was possible to obtain the rate constant k_2 directly from this maximum. In mixtures with 13.35 and 25.3% DMSO, k_2 was determined, as above in methanol, through the variations of the first-order rate constant λ_2 calculated from the measured values of λ_2' by using eq 3a. In these mixtures, we were also able to follow directly the decomposition of **4** and thus to obtain k_{-2}.

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[9] (a) P. Bemporad, G. Illuminati, and F. Stegel, *ibid.*, **91**, 6742 (1969); (b) M. E. C. Biffin, J. Miller, A. G. Moritz, and D. B. Paul, *Aust. J. Chem.*, **21**, 1267 (1968).

TABLE I

RATE AND EQUILIBRIUM CONSTANTS FOR THE REACTIONS OF 3,5-DINITRO-4-METHOXYPYRIDINE WITH CH_3O^- IONS IN METHANOL AND VARIOUS METHANOL–DMSO MIXTURES AT 20°

Solvent composition, % DMSO by weight	1,3 complex **5**			1,1 complex **4**				
	k_1, M^{-1} sec^{-1}	k_{-1}, sec^{-1}	K_1, M^{-1}	k_2, M^{-1} sec^{-1}	k_{-2}, sec^{-1}	K_2, M^{-1}	λ'^{max}_2, sec^{-1}	$t^1/_2$, sec
					$5.2 \times 10^{-3\,c}$	$3,180^b$		
0	275	25	11^a	16.5	$5.75 \times 10^{-3\,d}$	$2,870^a$	1.5^f	0.46
				13.8^e	$5.00 \times 10^{-3\,e}$	$2,770^e$		
13.35	398	17.3	23^a	25.7	$3.56 \times 10^{-3\,d}$	$7,230^a$	1.12^f	0.62
25.3	630	6.95	91^a	48	$2.37 \times 10^{-3\,d}$	$20,200^a$	0.527^f	1.32
37	1,175	3.25	361^a	90			0.25	2.77
47.5	2,000	1.6^c	1250^b	180			0.144	4.8
57.5	3,710	0.7^c	5300^b	330			6.25×10^{-2}	11.1
67	6,900						2.75×10^{-2}	25.2
76	22,000						1.00×10^{-2}	69.3
84.8							1.82×10^{-3}	380
92.6							4.65×10^{-4}	1490

[a] Calculated from $K_1 = k_1/k_{-1}$ or $K_2 = k_2/k_{-2}$. [b] From equilibrium measurements. [c] Calculated from $k_{-1} = k_1/K_1$ or $k_{-2} = k_2/K_2$. [d] Decomposition of the solid complex **4**. [e] Reference 9a. [f] Calculated from $\lambda'^{max}_2 = k_2/K_1$.

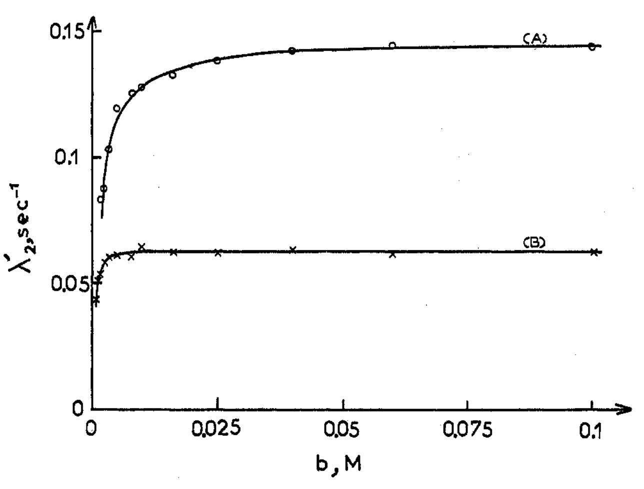


Figure 2.—Plots of λ'_2 against potassium methoxide concentration b for the appearance of **4** in 47.5 (A) and 57.5% DMSO (B).

In Table I are listed the specific rate constants and equilibrium constants associated with the formation and decomposition of the two complexes **4** (k_2, k_{-2}, K_2) and **5** (k_1, k_{-1}, K_1) and obtained at 20° in methanol and all the CH_3OH-DMSO mixtures studied. The values previously reported by Illuminati, *et al.*,[9] for k_2, k_{-2}, and K_2 in methanol are included in the table; as can be seen, the agreement with our results is fairly good.

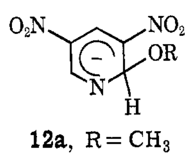
Rate coefficients and equilibrium constants determined at different temperatures in methanol and 63% CH_3OH-37% DMSO (by weight) are summarized in Table II. Table III allows a comparison of kinetic and thermodynamic data for the formation and decomposition of complexes **4** and **5** with analogous data reported on the reactions of 2,4,6-trinitroanisole[4b,7] (**6**) and 4-cyano-2,6-dinitroanisole[4b,6b] (**9**) with methoxide ions.

Discussion

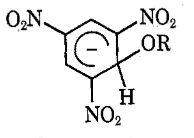
Influence of the Aza Group on Stability of Adducts 4 and 5.—Considering 3,5-dinitro-4-methoxypyridine (**3**) to be an 4-aza-2,6-dinitroanisole, a comparison of the rate and equilibrium constants for the formation as well as the rate constants for the decomposition of 1,1 and 1,3 complexes **4** and **5** to the corresponding parameters found for the benzenic analogs derived from 2,4,6-trinitroanisole (**6**) and 4-cyano-2,6-dinitroanisole (**9**) allows a quantitative analysis of the influence of the aza group on the stability of adducts.

With respect to the 1,1-complex formation, the rate of methoxide ion attack on carbon carrying the methoxy group is very similar for **3** and **6** ($k_2^3/k_2^6 = 1.4$) and somewhat slower for **9** ($k_2^3/k_2^9 = 4$; $k_2^6/k_2^9 = 2.8$). On the other hand, the trinitro adduct **7** is decomposed, respectively 8- and 21-fold more slowly than the pyridinic and cyano adducts **4** and **10**. Thus, in agreement with earlier observations of Illuminati, *et al.*,[9a] the influence of the aza group para to the geminal position on the stability of the 1,1 complex appears to be intermediate between that of the nitro and cyano groups ($K_2^4/K_2^7 = 0.158$; $K_2^4/K_2^{10} = 9.6$). This result is consistent with a more effective delocalization of the negative charge by a nitro group than by an aza group.

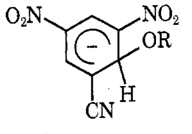
Replacing a nitro or a cyano by an aza group in the ortho position of the sp_3 carbon causes, respectively, a 4.3- and 60-fold increase in the equilibrium constant for the formation of adduct. Consequently, the pyridinic 1,3 complex **5** appears to be the most stable 1,3 transient complex which has so far been detected. Since the rate of formation of **5** is 2.5-fold slower than that of trinitro 1,3 adduct **8** and only 2.9-fold faster than that of cyano 1,3 adduct **11**, the greater thermodynamic stability of **5** relative to its benzenic analogs arises essentially from its significantly slower rate of decomposition ($k_{-1}^8/k_{-1}^5 = 10.5$; $k_{-1}^{11}/k_{-1}^5 = 20.4$). This situation is similar to one we have encountered by comparing the stabilities of complexes resulting from the reaction of methoxide or hydroxide ions with 3,5-dinitropyridine (**12a**,**12b**) on the one hand, and with 1,3,5-trinitrobenzene (**13a**,**13b**) or 3,5-dinitrobenzonitrile (**14a**,**14b**) on the other hand.[10]



12a, R = CH_3
b, R = H



13a, R = CH_3
b, R = H



14a, R = CH_3
b, R = H

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[10] (a) R. Schaal, F. Terrier, J. C. Halle, and A. P. Chatrousse, *Tetrahedron Lett.*, 1393 (1970); (b) F. Terrier, F. Millot, and M. P. Simonnin, *ibid.*, 2933 (1971); (c) F. Terrier and A. P. Chatrousse, *Bull. Soc. Chim. Fr.*, submitted for publication.

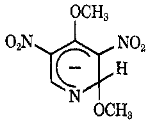
TABLE II

RATE AND EQUILIBRIUM CONSTANTS OF MEISENHEIMER COMPLEXES 4 AND 5 IN METHANOL AND IN 63% CH_3OH-37% DMSO AT DIFFERENT TEMPERATURES

	CH_3OH				63% CH_3OH-37% DMSO		
	2°	10°	20°	31°	7°	20°	32°
k_1, M^{-1} sec^{-1}	86.5	146	275	548	470	1175	2500
k_{-1}, sec^{-1}	8.5	14	25	46	1.5	3.25	6.5
$K_1 = k_1/k_{-1}$, M^{-1}	10.2	10.4	11	11.9	313	361	385
k_2, M^{-1} sec^{-1}		8	16.5	35	35	90	215
10^3 k_{-2}, sec^{-1}		2.3	5.75	13.8			
$K_2 = k_2/k_{-2}$, M^{-1}		3480	2870	2540			

TABLE III

KINETIC AND THERMODYNAMIC PARAMETERS OF MEISENHEIMER COMPLEXES AT 25°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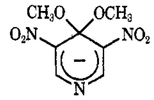
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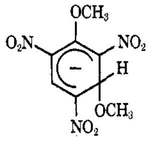
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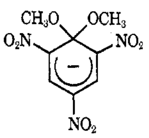
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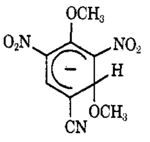
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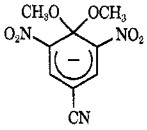
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	5		4		8	7	11	10	
	In CH_3OH[a]	In 37% DMSO[a]	In CH_3OH[a]	In 37% DMSO[a]	In CH_3OH[b]	In CH_3OH[c]	In 37% DMSO[d]	In CH_3OH[c]	In 37% DMSO[d]
$\overrightarrow{k}$, M^{-1} sec^{-1}	390	1640	23	136	950	17.3	560	6.1	22.4
$\overleftarrow{k}$, sec^{-1}	33.2	4.4	8.6×10^{-3}		350	1.04×10^{-3}	90	2.2×10^{-2}	5.02×10^{-3}
K, M^{-1}	11.7	372	2680		2.71	17,000	6.25	280	4450
$\Delta\overrightarrow{H}^{\ddagger}$, kcal mol^{-1}	10.3 ± 0.8	10.55 ± 0.6	11.4 ± 0.4	11.55 ± 0.4	10.4 ± 1	12.9 ± 1	9.7 ± 0.5	13.3 ± 0.8	12.7 ± 0.5
$\Delta\overrightarrow{S}^{\ddagger}$, eu	−12.1 ± 2.7	−8.5 ± 2.3	−14 ± 1.4	−10 ± 1.4	−10.8 ± 3.4	−9.4 ± 3.4	−13.3 ± 1.7	−10.4 ± 2.7	−9.8 ± 1.7
$\Delta\overleftarrow{H}^{\ddagger}$, kcal mol^{-1}	9.3 ± 0.8	9.45 ± 0.6	13.85 ± 0.4		8.2 ± 0.5	18.4 ± 1	10.6 ± 0.5	9.3 ± 0.8	10.1 ± 0.5
$\Delta\overleftarrow{S}^{\ddagger}$ eu	−20.4 ± 2.7	−23.8 ± 2.3	−21.5 ± 1.4		−19.3 ± 1.7	−4.8 ± 3.4	−14 ± 1.7	−32 ± 2.7	−35 ± 1.7
ΔH, kcal mol^{-1}	1 ± 1.6	1.1 ± 1.2	−2.45 ± 0.8		2.2 ± 1.5	−5.5 ± 2	−0.9 ± 1	4.3 ± 1.6	2.6 ± 1
ΔS, eu	8.3 ± 5.4	15.3 ± 4.6	7.5 ± 2.8		8.5 ± 5.1	−4.6 ± 6.8	0.6 ± 3.4	21.6 ± 5.4	25.2 ± 3.4
						−4.6 ± 4[e]			

[a] This work. [b] Reference 8. [c] Reference 4b. [d] Reference 6b. [e] Reference 7.

1,3- and 1,1-Complex Formation.—From an inspection of Table III, it is clear that the reaction of 3,5-dinitro-4-methoxypyridine (**3**) to give the 1,3 complex **5** is strongly different from the reaction to give the 1,1 complex **4**. Whereas the rate of formation of **5** is about a factor of 17 faster than that of **4**, its rate of decomposition is about a factor of 5000 greater than that observed for the latter. Consequently, the thermodynamic stability of **5** is relatively low compared to that of **4**. Changes in both the forward and reverse reactions for these complexes appear to be mainly dependent on the changes in the enthalpies of activation. The much higher value of $\Delta\overleftarrow{H}^{\ddagger}$ for **4** relatively to that for **5** is particularly significant. These results agree well with the general features reported for similar nucleophilic attacks of methoxide ions at substituted or unsubstituted 1 and 3 positions of various 4-X-2,6-dinitroanisoles.[2-6,11] Nevertheless, as can be seen from Table III, entropy changes were found to play an important role in the reactions of 2,4,6-trinitroanisole and 4-cyano-2,6-dinitroanisole.

The mechanism of the interaction has been extensively discussed in the case of 2,4,6-trinitroanisole. On the one hand, Crampton and Gold[3,11c] have attributed the slower attack of methoxide ions on the 1 carbon carrying the methoxy group, as compared to that on the unsubstituted 3 carbon, to a larger steric strain in the transition state leading to the 1,1 adduct than in the transition state leading to the 1,3 adduct. On the other hand, Bernasconi has interpreted this kinetic effect through resonance stabilization involving the methoxy group, which lowers the energy of the ground state of the 1,3 complex and of the transition state leading to its formation but not of the 1,1 complex.[8,12] The higher stability of the 1,1 complex relative to the 1,3 complex was attributed to the release of steric strain from the molecule and to the stabilizing influence of multiple alkoxy substitution at the sp^3 1 carbon.[11]

Taking into consideration the fact that all the 4-X-2,6-dinitroanisoles present the same steric strain around the carbon bearing the methoxy group, we wish to point out the major role played by the nature of the X substituent in the interaction. Since the activating as well as delocalizing influence of a nitro group is greater in the para than in the ortho position, the replacement of a nitro group at the 4 position of 2,4,6-trinitroanisole by another substituent could be expected to affect the rates of formation as well as rates of decomposition of 1,1 complexes to a greater extent than those of 1,3 complexes. Indeed, in Table IV, we observe that the ratio k_1/k_2 of the rates of formation of the two sorts of complexes increases from 4-aza- to 4-fluoro-2,6-dinitroanisole, *i.e.*, as the electron-withdrawing effect of the X substituent on the 1 carbon decreases; the value of this ratio for the trinitro derivative appears, however, abnormally high with respect to the series. On the other hand, the ratio k_{-1}/k_{-2} is found to decrease going from 2,4,6-trinitroanisole to 4-fluoro-2,6-

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[11] For recent reviews see (a) R. Foster and C. A. Fyfe, *Rev. Pure Appl. Chem.*, **16**, 61 (1966); (b) E. Buncel, A. R. Norris, and K. E. Russell, *Quart. Rev., Chem. Soc.*, **22**, 123 (1968); (c) M. R. Crampton, *Advan. Phys. Org. Chem.*, **7**, 211 (1969); (d) M. J. Strauss, *Chem. Rev.*, **70**, 667 (1970).

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TABLE IV

INFLUENCE OF THE 4-X SUBSTITUENT ON THE EQUILIBRIUM AND RATE CONSTANTS FOR THE FORMATION AND DECOMPOSITION OF 1,3 AND 1,1 COMPLEXES DERIVED FROM 4-X-2,6-DINITROANISOLES

	X					
	NO_2[a]	Aza[b]	CN[c]	CF_3[c]	Cl[c]	F[c]
k_1/k_2	55	16.6	26	36	130	360
k_{-1}/k_{-2}	3.5×10^5	4.35×10^3	1.5×10^4	200	430	225
K_1/K_2	1.6×10^{-4}	3.80×10^{-3}	1.75×10^{-3}	0.18	0.3	1.6

[a] Reference 8. [b] This work at 20° in methanol. [c] Reference 6.

dinitroanisole. The greater thermodynamic stability of the fluoro 1,3 complex compared to that of the 1,1 complex emphasizes clearly the important influence of both these variations on the interaction. As to the abnormal value of the ratio k_1/k_2 for 2,4,6-trinitroanisole, an explanation might be that resonance stabilization involving the methoxy group, as described by Bernasconi,[8,12] would be much more important in this compound and its 1,3 complex than in the other 4-X-2,6-dinitroanisoles because of the higher capacity to resonance of a *p*-nitro group relative to the other substituents.

Effect of Solvent Composition on the Interaction.—There is a strong increase in the equilibrium constants K_1 and K_2 for the formation of complexes **4** and **5** with addition of DMSO to the methanolic solutions due to an increase in the rate constants of formation k_1 and k_2 and a decrease in the rate constants of decomposition. Furthermore, the variations of k_1 and k_{-1} are, in a first approximation, respectively analogous to those observed for k_2 and k_{-2}. Consequently, the relative thermodynamic stability of **4** and **5** probably does not change very much with increasing DMSO amount. Since these findings are similar to those found for the formation of various benzenic Meisenheimer complexes and have been already discussed in earlier papers,[4c,6,16,17] it is more interesting to appreciate their influence on the lifetime of the transient 1,3 complex **5**. Taking into account that the ratios K_1/K_2 and k_1/k_2 are approximately independent of the DMSO amount and that the maximum value $\lambda'_2{}^{max}$ of the apparent rate constant for the conversion from **5** to the stable 1,1 complex **4** can be used as reference for the lifetime of **5**, eq 4 shows that the influence of the DMSO amount on its lifetime is analogous to that observed on the rate constants k_{-1} and k_{-2} for the decomposition of complexes. Whereas the half-life of **5** is about 0.46 sec in pure methanol, it is about 1500 sec in a mixture containing 92.6% DMSO by weight, *i.e.*, 3000-fold longer than in the absence of DMSO cosolvent. This result, which can be seen from Table I where the values of $\lambda'_2{}^{max}$ are listed with the corresponding half-lives, is very important because it allows an understanding of the easier nmr observation of such transient 1,3 complexes in DMSO than in CH_3OH-DMSO mixtures.[2,3,4,11]

Experimental Section

Materials.—The solvents and reagents were prepared, purified, and standardized as previously described.[5,6,18] Solutions of potassium methoxide in methanolic DMSO were freshly prepared from the purified solvents by the appropriate dilutions.

3,5-Dinitro-4-methoxypyridine (**3**) and potassium 4-aza-1,1-dimethoxy-2,6-dinitrocyclohexadienate (**4**) were prepared by the methods described by Illuminati and Miller.[9]

Rate Measurements.—Stopped-flow determinations were performed on a Durrum stopped-flow spectrophotometer, the cell compartment of which was maintained to ±1°. The reported rate constants represent average values obtained from two or three independent determinations. The slow rates for the decomposition of the 1,1 complex **4** were carried out, using 1-cm cells, on a Beckman DU-2 spectrophotometer with a cell compartment thermostated within ±0.1°.

Registry No.—**3**, 26738-20-5; **4**, 28927-60-8; **5**, 28927-61-9; methoxide ion, 3315-60-4; methanol, 67-56-1; dimethyl sulfoxide, 67-68-5.

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