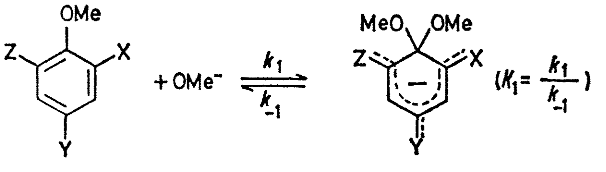
The Stabilities of Meisenheimer Complexes. Part I. Adducts from Sodium Methoxide and Highly Activated Anisoles in Methanol

By **M. R. Crampton** * and **H. A. Khan**, Chemistry Department, The University, Durham

The thermodynamic equilibrium constants (K_1) for the formation of Meisenheimer complexes by methoxide addition to several substituted anisoles have been determined spectrophotometrically in methanol. The values are for 2-methoxycarbonyl-4,6-dinitroanisole, $K_1 = 10$ l mol^{-1} and for 4-methoxycarbonyl-2,6-dinitroanisole $K_1 = 6$ l mol^{-1}. Complex formation for these compounds and for 2-chloro-4,6-dinitroanisole is sufficiently slow to allow individual rate coefficients, k_1 and k_{-1}, for the equilibrium process to be determined. The values of the equilibrium constants increase markedly with sodium methoxide concentration owing mainly to apparent decreases in k_{-1} values. It is suggested that this may be due to stabilisation of the adducts by ion association.

MUCH interest has centred recently on the highly coloured Meisenheimer complexes [1] formed by the covalent addition of nucleophiles to activated aromatic molecules. One aspect of this interest is in the relative stabilities of these adducts. Although some measurements have been made with other nucleophiles (*e.g.*, sulphite,[2] cyanide [3]) most data relate to reaction with sodium methoxide in methanol and equilibrium constants for the formation of *ca.* 20 compounds have been reported. In the present work which extends these measurements we are concerned with equilibria of the type (I) $\rightleftharpoons$ (II)



(I) (II)

where methoxide addition occurs at the methoxy-substituted position. There is considerable evidence,[1,4] particularly for reaction in dimethyl sulphoxide, that the formation of stable adducts of structure (II) is preceded by addition at unsubstituted ring positions. We are not primarily concerned with these intermediates here.

The best known example of a reaction of the type shown is that of 2,4,6-trinitroanisole and the equilibrium constant for methoxide addition has been determined in several laboratories.[5-7] In addition the Fendlers [6-9] and their co-workers have made careful studies of a number of compounds in which the nitro-groups have been variously replaced by cyano-groups. Terrier [10] has made measurements on a number of dinitro-compounds containing chloro-, fluoro-, or trifluoromethyl substituents. In favourable cases the approach to equilibrium is sufficiently slow to enable its rate to be measured which leads to values for the individual rate constants k_1 and k_{-1}. Surprisingly some reports [7,10] have indicated variations in values of the equilibrium constant with sodium methoxide concentration even in dilute solutions where ideal behaviour would be expected.

We report here values of the equilibrium constants, K_1, and in three cases rate constants, k_1 and k_{-1}, for four relatively reactive compounds where complex formation

---

[1] For recent reviews see: M. R. Crampton, *Adv. Phys. Org. Chem.*, 1969, **7**, 211; M. J. Strauss, *Chem. Rev.*, 1970, **70**, 667.

[2] M. R. Crampton, *J. Chem. Soc.* (*B*), 1967, 1341.

[3] E. Buncel, A. R. Norris, W. Proudlock, and K. E. Russell, *Canad. J. Chem.*, 1969, **47**, 4129.

[4] K. L. Servis, *J. Amer. Chem. Soc.*, 1967, **89**, 1508.

[5] V. Gold and C. H. Rochester, *J. Chem. Soc.*, 1964, 1687.

[6] J. H. Fendler, E. J. Fendler, and C. E. Griffin, *J. Org. Chem.*, 1969, **34**, 689.

[7] P. Bemporad, G. Illuminati, and F. Stegel, *J. Amer. Chem. Soc.*, 1969, **91**, 6742.

[8] E. J. Fendler, J. H. Fendler, C. E. Griffin, and J. W. Larsen, *J. Org. Chem.*, 1970, **35**, 287.

[9] E. J. Fendler, W. Emsberger, and J. H. Fendler, *J. Org. Chem.*, 1971, **36**, 2333.

[10] F. Terrier, *Ann. Chim.* (*France*), 1969, **4**, 153.

occurs in dilute sodium methoxide solutions: 2-methoxycarbonyl-4,6-dinitroanisole, 4-methoxycarbonyl-2,6-dinitroanisole, 2-chloro-4,6-dinitroanisole, and 4-trifluoromethyl-2,6-dinitroanisole. In addition we confirm the occurrence of, and seek an explanation for, the variation in value of these parameters with sodium methoxide concentration.

In the following paper we examine the behaviour of several less reactive substrates where complex formation occurs only in more basic media.

EXPERIMENTAL

2-Methoxycarbonyl-4,6-dinitroanisole, m.p. 68 °C (lit.,[11] 69 °C) was prepared from 2-chlorobenzoic acid in three stages; nitration of the acid, followed by esterification to give the methyl ester and nucleophilic replacement of chlorine by methanolic sodium methoxide. 4-Methoxycarbonyl-2,6-dinitroanisole, m.p. 45 °C (lit.,[12] 54 °C) was prepared by esterification of 4-chloro-3,5-dinitrobenzoic acid followed by nucleophilic substitution of chlorine by methoxide (Found: C, 42·0; H, 2·9; N, 10·7. Calc. for $C_9H_8O_7N_2$: C, 42·1; H, 3·1; N, 10·9%). 1,2-Dichloro-3,5-dinitrobenzene was prepared from 2-chloro-4,6-dinitrophenol by the method of Ullman and Sané.[13] Reaction with methanolic sodium methoxide gave the required 2-chloro-4,6-dinitroanisole, m.p. 37 °C (lit.,[14] 37 °C). 4-Trifluoromethyl-2,6-dinitroanisole, m.p. 60 °C (lit.,[10] 60 °C) was prepared from 4-trifluoromethyl-2,6-dinitrochlorobenzene by reaction with methanolic sodium methoxide. ^{1}H N.m.r. spectra of the products and intermediates in dimethyl sulphoxide showed bands consistent with the required compounds and indicated the absence of impurities.

AnalaR methanol was used without purification. Sodium methoxide solutions were prepared by the reaction of clean sodium with methanol under nitrogen. Concentrations were determined by titration with standard acid. Dimethyl sulphoxide was dried (CaH_2) and fractionally distilled under vacuum, the middle fraction being collected.

^{1}H N.m.r. measurements were made on 0·2M solutions with a Varian A56/60 instrument with tetramethylsilane as internal reference. Visible spectral measurements were made at 25 °C on a Unicam SP 500 instrument fitted with a thermostatted cell compartment. Solutions containing the required concentrations of reagents were prepared immediately before measurement by suitable dilution of stock solutions. It was found convenient to make kinetic measurements by the addition from a syringe of a small quantity of a concentrated solution of parent anisole to a solution of methanolic sodium methoxide which had previously been brought to 25 °C in the measuring cell. Measurement of optical densities was begun 10 s after mixing and continued until completion of reaction. Typical data with calculated first-order rate constants for the reaction of 2-methoxycarbonyl-4,6-dinitroanisole ($3·84 \times 10^{-5}$M) with sodium methoxide (0·04M) are in Table 1. Rate constants were in all cases reproducible within 5%.

TABLE 1

t/s	O.D. (472 nm)	10^2k_{obs}/s^{-1}
19	0·140	1·95
25	0·177	1·94
32	0·211	1·95
46	0·270	1·95
63	0·320	1·96
76	0·350	1·96
91	0·376	1·97
100	0·387	1·95
127	0·413	1·96
∞	0·450	

RESULTS

Spectral and Structural Studies.—Solutions in methanol of each of the four compounds under investigation are colourless. In dilute methanolic sodium methoxide colours are produced. In each case, increasing the concentration of sodium methoxide caused an increase in visible absorption without changing the shape of the spectrum or positions of the absorption maxima. Eventually at sodium methoxide concentrations near 1M (the exact value depending upon the compound) complete conversion into complex was achieved so that further increase in base concentration caused no further spectral change. We did not examine spectra at much higher base concentrations where higher complexes may be formed. Spectral details are in Table 2 and are in good agreement with previous reports.[10,15]

TABLE 2

Visible spectra in methanol

Structure (II)	$\lambda_{max.}$/nm	$10^{-4}\varepsilon$ l mol^{-1} cm^{-1}	$\lambda_{max.}$/nm	$10^{-4}\varepsilon$ l mol^{-1} cm^{-1}
X = CO_2Me, Y = Z = NO_2	384	2·1	472	1·9
X = Cl, Y = Z = NO_2	352, 364	1·6	492	2·3
Y = CO_2Me, X = Z = NO_2	361	1·3	525	2·1
Y = CF_3, X = Z = NO_2			540	2·5

We have measured ^{1}H n.m.r. spectra to confirm that the ionisations we are studying involve methoxide addition at the 1-position to give adducts of structure (II). These spectra were recorded in dimethyl sulphoxide where the visible spectra are similar but shifted slightly to longer wavelength than those recorded in methanol. Data for the parent molecules and stable adducts produced in the presence of one equivalent of sodium methoxide are in Table 3.

TABLE 3

Chemical shifts (downfield from internal tetramethylsilane) for parent molecules and adducts in dimethyl sulphoxide

Structure (I)			Ring protons		OMe	CO_2Me
X	Y	Z				
CO_2Me	NO_2	NO_2	8·76	9·96 [a]	4·02	3·98
Cl	NO_2	NO_2	8·74	8·80 [a]	4·08	
NO_2	CO_2Me	NO_2	8·72		4·03	3·95
NO_2	CF_3	NO_2	8·75		4·05	
Structure (II)						
X	Y	Z				
CO_2Me	NO_2	NO_2	8·32	8·71 [a]	2·93	3·70
Cl	NO_2	NO_2	7·50	8·73 [a]	2·95	
NO_2	CO_2Me	NO_2	8·43		2·98	3·68
NO_2	CF_3	NO_2	8·07		3·02	

[a] Ring protons give an AB quartet, J = 3 Hz.

---

[11] A. Salkowski, *Annalen*, 1874, **173**, 47.

[12] W. D. Chandler, W. MacFarlane Smith, and R. Y. Moir, *Canad. J. Chem.*, 1964, **42**, 2549.

[13] F. Ullman and S. M. Sané, *Ber.*, 1911, 3734.

[14] A. F. Holleman and M. A. J. den Hollander, *Rec. Trav. chim.*, 1920, **39**, 435.

[15] R. J. Pollitt and B. C. Saunders, *J. Chem. Soc.*, 1964, 1132.

It is well known that in media rich in dimethyl sulphoxide addition of methoxide at C(1) to give thermodynamically stable adducts is often preceded by base addition at a ring-carbon atom carrying hydrogen. Spectral evidence for the intermediacy of such adducts in dimethyl sulphoxide has been given in the case of 4-methoxycarbonyl-2,6-dinitroanisole,[16] 4-trifluoromethyl-2,6-dinitroanisole,[17] and 2-chloro-4,6-dinitroanisole.[18] Our n.m.r. and visible spectral measurements again showed evidence for these intermediates in dimethyl sulphoxide. However the stable adducts in each case resulted from base addition at C(1).

Kinetics and Equilibria.—The rate of formation of colour in solutions of 2-methoxycarbonyl-4,6-dinitroanisole in dilute methanolic sodium methoxide was sufficiently slow to allow measurement by conventional techniques. Measurements of optical density at the absorption maximum in solutions where the sodium methoxide concentration was in considerable excess (>100) of that of the anisole yielded first-order rate constants, k_{obs} [equation (1)]. The equilibrium optical densities were used in conjunction with the

$$k_{obs} = k_1[\text{NaOMe}] + k_{-1} \qquad (1)$$

known extinction coefficient of the complex to obtain values of the stoicheiometric equilibrium constant K_c ($= k_1/k_{-1}$). Individual values for the rate coefficients k_1 and k_{-1} were then calculated. Measurements were made in solutions containing various concentrations of sodium methoxide

TABLE 4

Kinetic and equilibrium measurements at 25 °C for 2-methoxycarbonyl-4,6-dinitroanisole and sodium methoxide in methanol

[NaOMe]/ M	Optical density at equilibrium [a] (472 nm)	K_c/ l mol^{-1}	10^2k_{obs}/ s^{-1}	10^3k_1/ l mol^{-1} s^{-1}	10^3k_{-1}/ s^{-1}
0·0039	0·036 [b]	13·2	1·85 ± 0·10	2·3	17·5
0·0069	0·074 [b]	16·0	1·70	2·4	15·3
0·0098	0·118 [b]	19·5	1·55	2·5	13·0
0·0096	0·116	19·5	1·60	2·6	13·5
0·0192	0·254	27·2	1·54	2·8	10·1
0·0288	0·365	33·8	1·82	3·1	9·3
0·0384	0·450	40·5	1·97	3·1	7·4
0·0625	0·575	56	3·05	3·8	6·8
0·077	0·61	61	3·60	3·8	6·3
0·3	0·73				
0·7	0·74				
1·0	0·74				
0·0048 [c]	0·120	40·5	0·93	3·1	7·8
0·0096 [c]	0·215	43	1·12	3·4	7·9
0·0192 [c]	0·330	42	1·45	3·4	8·0
0·0288 [c]	0·412	44	1·70	3·3	7·5
0·0384 [c]	0·476	44·5	2·00	3·3	7·4
0·0480 [c]	0·500	43·5	2·37	3·3	7·7
0·0096 [d]	0·220	44	1·12	3·4	7·9
0·0096 [e]	0·090	14·5	2·14	2·7	18·5

[a] Concentration of 2-methoxycarbonyl-4,6-dinitroanisole is 3·84 × 10^{-5}M except where otherwise stated. [b] For greater accuracy measurements were made with 1·94 × 10^{-4}M-2-methoxycarbonyl-4,6-dinitroanisole. The values quoted are the actual values divided by 5. [c] Solutions made up to constant ionic strength (0·05M) with sodium perchlorate. [d] Containing 0·04M-sodium chloride. [e] Containing 0·04M-lithium chloride 0·04M.

TABLE 5

Kinetic and equilibrium measurements at 25 °C for 4-methoxycarbonyl-2,6-dinitroanisole (5 × 10^{-5}M) and sodium methoxide in methanol

[NaOMe]/ M	Optical density (525 nm)	K_c/ l mol^{-1}	10^2k_{obs}/s^{-1}	k_1/ l mol^{-1} s^{-1}	10_2k_{-1}/ s^{-1}
0·0040	0·028 [a]	7·0			
0·0080	0·065 [a]	8·4	4·9 ± 0·5	0·38	4·6
0·0120	0·108 [a]	9·8	4·4 ± 0·3	0·39	3·9
0·020	0·203	12·2	4·15 ± 0·3	0·41	3·3
0·030	0·315	14·7	4·15 ± 0·3	0·42	2·9
0·040	0·410	16·5	4·3 ± 0·3	0·43	2·6
0·050	0·496	18·7	4·65 ± 0·3	0·45	2·4
0·060	0·584	21·8	5·25 ± 0·4	0·49	2·3
0·080	0·706	27·0	6·6 ± 0·5	0·56	2·1
0·10	0·77	29			
0·15	0·86	32			
0·20	0·93	42			
0·25	0·96	45			
0·60	1·01				
1·0	1·03				
1·5	1·04				

[a] For greater accuracy measurements were made with 2·0 × 10^{-4}M-4-methoxycarbonyl-2,6-dinitroanisole. Values quoted are these values divided by 4.

TABLE 6

Kinetic and equilibrium measurements for 2-chloro-4,6-dinitroanisole and sodium methoxide in methanol at 25 °C

[NaOMe]/ M	Optical density [a] (492 nm)	K_c/ l mol^{-1}	10^2k_{obs}/s^{-1}	k_1/ l mol^{-1} s^{-1}	10^2k_{-1}/ s^{-1}
0·0048	0·015 [b]	3·5	5·3 ± 0·3	0·18	5·2
0·0096	0·034 [b]	4·0	5·1 ± 0·3	0·19	4·9
0·0144	0·055 [b]	4·3	4·7 ± 0·3	0·19	4·4
0·0192	0·076 [b]	4·6	4·6 ± 0·2	0·19	4·2
0·029	0·119	5·1			
0·0385	0·166	5·6	4·25 ± 0·2	0·20	3·5
0·048	0·216	6·3	4·25 ± 0·3	0·21	3·3
0·0625	0·276	6·8	4·3 ± 0·3	0·21	3·0
0·077	0·340	7·5	4·4 ± 0·3	0·21	2·8
0·096	0·400	8·0	4·8 ± 0·4	0·22	2·7
0·15	0·565	10·4			
0·20	0·67	12·9			
0·25	0·735	15·4			
0·30	0·79	18·8			
0·40	0·85	26·5			
0·50	0·875	35			
1·0	0·92				
1·7	0·93				

[a] For 4 × 10^{-5}M-2-chloro-4,6-dinitroanisole. [b] Measured with indicator concentration of 4 × 10^{-4}M.

TABLE 7

Equilibrium measurements with 4-trifluoromethyl-2,6-dinitroanisole (4 × 10^{-5}M) in methanolic sodium methoxide at 25 °C

[NaOMe]/M	Optical density (540 nm)	K_c/l mol^{-1}
0·010	0·024	2·5
0·020	0·056	3·0
0·030	0·095	3·5
0·040	0·14	4·1
0·060	0·232	5·0
0·080	0·325	6·0
0·10	0·40	6·7
0·15	0·57	8·9
0·20	0·69	11·1
0·25	0·775	13·7
0·30	0·83	16·3
0·40	0·90	22·5
0·6	0·96	
1·0	1·00	

---

[16] M. R. Crampton, M. A. El Ghariani, and H. A. Khan, *Chem. Comm.*, 1971, 834.

[17] F. Terrier and F. Millot, *Bull. Soc. chim. France*, 1970, 1743.

[18] F. Millot and F. Terrier, *Bull. Soc. chim. France*, 1969, 2694.

some of which contained added electrolyte (sodium perchlorate, sodium chloride, or lithium chloride). Results are in Table 4.

Similar measurements for the other anisoles are reported in Tables 5—7. Due to the higher rates observed with these compounds the measured rate constants are slightly less accurate than those for 2-methoxy-4,6-dinitroanisole.

DISCUSSION

Spectral measurements show that for each of the four compounds studied base addition occurs at C(1) to give an adduct of structure (II). Higher complexes were not formed in the sodium methoxide concentration range used here. In each case the results show that the values of the stoicheiometric equilibrium constant K_c (= [Complex]/[Parent][NaOMe]) increase with increasing sodium methoxide concentration. We first consider the values of the thermodynamic equilibrium constants and rate constants found by extrapolation to zero base concentration. These are collected in Table 8 together with some data from the literature.

As expected the substitution of a methoxycarbonyl group for the more strongly electron-withdrawing nitro-group causes a considerable decrease in complex stability.

TABLE 8

Thermodynamic constants for reaction in methanol at 25 °C

Substituent					
X	Y	Z	K_1/l mol^{-1}	k_1/ l mol^{-1} s^{-1}	k_{-1}/s^{-1}
CO_2Me	NO_2	NO_2	10	0·22	2·2 × 10^{-2}
NO_2	CO_2Me	NO_2	6	0·36	6·0 × 10^{-2}
Cl	NO_2	NO_2	3(2·5) [a]	0·18	6·0 × 10^{-2}
NO_2	CF_3	NO_2	2(2·0) [a]		
CF_3	NO_2	NO_2	(14) [a]		
NO_2	NO_2	NO_2	17,000 [b]	17·3	1·0 × 10^{-3}
CN	NO_2	NO_2	2600 [b]	18·8	7·2 × 10^{-3}
NO_2	CN	NO_2	280 [b]	6·1	2·2 × 10^{-2}
CN	CN	NO_2	10 [c]	2·0	2·0 × 10^{-1}
CN	NO_2	CN	34 [c]	12	3·7 × 10^{-1}
NO_2	NO_2	H	5 × 10^{-5} [d]	2·1 × 10^{-3}	42

[a] Ref. 10. [b] Ref. 6. [c] Ref. 8. [d] Ref. 19.

In general it has been found that substitution of a nitro-group by a less strongly electron withdrawing group *para* to the position of addition reduces complex stability considerably more than equivalent substitution in the *ortho*-position. However the effects of methoxycarbonyl substitution are fairly similar at these two positions. It may well be that the stability of the complex from 2-methoxycarbonyl-4,6-dinitroanisole is reduced by steric interactions in the complex. Table 8 shows that overall changes in complex stability result from changes both in the values of k_1 and k_{-1}.

The large variations of K_c with sodium methoxide concentration even in very dilute solutions (<10^{-2}M) are surprising. This effect has been noted by Terrier [10] and also, though in more concentrated sodium methoxide solutions, by Bernasconi [19] using 2,4-dinitroanisole. Calculation of the individual rate coefficients (Tables 4—6) indicates that the overall variations in K_c are due mainly to large decreases in the apparent values of k_{-1} and much smaller increases in the corresponding k_1 values. It is noteworthy that the variations of the equilibrium constants with sodium methoxide concentration are not identical for the four compounds studied. Thus for 2-methoxycarbonyl-4,6-dinitroanisole the value of the equilibrium constant at 0·05M-sodium methoxide is 4·5 times greater than the thermodynamic value while the corresponding ratios for 4-methoxycarbonyl-2,6-dinitroanisole, 2-chloro-4,6-dinitroanisole, and 4-trifluoromethyl-2,6-dinitroanisole are 3·1, 2·1, and 2·3 respectively. Clearly no single J_M acidity function can adequately represent the behaviour of these four compounds.

The increase in K_c values with sodium methoxide concentration was attributed by Terrier [10] to a decrease in the activity coefficient ratio $f_{complex^-}/f_{parent} \cdot f_{OMe^-}$. However H_M indicators which ionise by proton loss and also 1,3,5-trinitrobenzene [20] where base addition occurs at a ring carbon carrying hydrogen behave ideally up to at least 0·1M-sodium methoxide concentration so that no variation in the value of K_c is observed. In all these reactions a large polarisable anion is produced from methoxide ion and a neutral substrate so it is hard to see why the adducts (II) from the anisoles should behave anomalously. It seems possible that the variation of equilibrium constants with concentration observed in the present case may be in part due to the effects of ion association and we suggest the Scheme.

$$\begin{tikzcd}
P + OMe^- + M^+ \arrow[r, shift left, "k_1"] \arrow[d, shift left, "K_3"] & POMe^- + M^+ \arrow[l, shift left, "k_{-1}"] \arrow[r, shift left, "K_2"] & POMe^-, M^+ \arrow[l, shift left] \\
M^+, OMe^- \arrow[u, shift left] & &
\end{tikzcd}$$

SCHEME

Qualitatively the value of the measured equilibrium constant would be expected to increase with sodium methoxide concentration (as observed) if ion-pair formation stabilised the addition complex to a greater extent than the methoxide ion. We suggest that this is the case when sodium is used as the cation. It would be expected that ion-pairing with lithium would be more pronounced than with sodium. The result (Table 4) where added lithium chloride causes a decrease in K_c indicates that relative to sodium, lithium has a greater stabilising effect on methoxide than on the adduct. It is known that the equilibrium constant for adduct formation of 4-cyano-2,6-dinitroanisole with lithium methoxide [21] is considerably smaller than the value with sodium methoxide.[6]

In an attempt to carry out a more quantitative analysis we make the assumption that the free adduct and its ion-pair have identical visible spectra. This seems justified as there is no variation in spectral shape with sodium methoxide concentration when the fraction of

---

[19] C. F. Bernasconi, *J. Amer. Chem. Soc.*, 1968, **90**, 4982.

[20] V. Gold and C. H. Rochester, *J. Chem. Soc.*, 1964, 1692.

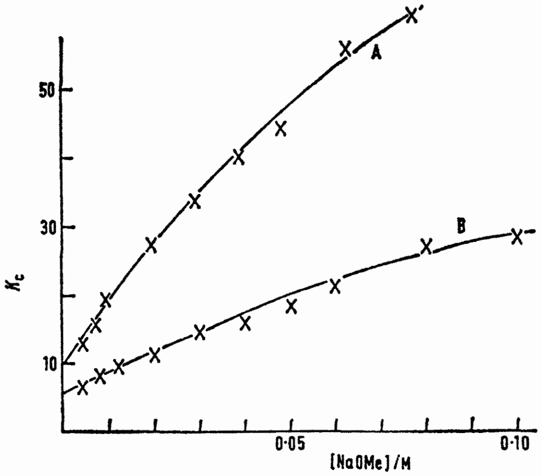
[21] J. E. Dickeson, L. K. Dyall, and V. A. Pickles, *Austral. J. Chem.*, 1968, **21**, 1267.

ion-pairs would be varying. Then the measured equilibrium constant is given by equations (2) and (3)

$$K_c = [\mathrm{P.OMe^-}] + [\mathrm{P.OMe^-, M^+}]/\{[\mathrm{P}]([\mathrm{OMe^-}] + [\mathrm{M^+, OMe^-}])\} \quad (2)$$

$$= K_1(1 + K_2[\mathrm{M^+}])/(1 + K_3[\mathrm{M^+}]) \quad (3)$$

where K_1 is the thermodynamic equilibrium constant in terms of free ions. The precise value of the ion-pair association constant of sodium methoxide is not known but a value close to 10 l mol^{-1} seems likely.[10] In addition ion-pair association with sodium may not substantially reduce the activity of methoxide ions. If then we make the further assumption that at low sodium methoxide concentrations most of the sodium methoxide is present as free ions and that $K_2 > K_3$ then we obtain $K_c = K_1 + K_1K_2[\mathrm{NaOMe}]_{\mathrm{stoich}}$. Accordingly plots of K_c against [NaOMe] approach linearity at sufficiently low concentration (Figure). From the limiting slopes we obtain the following very approximate values for the ion-pair association constants of the sodium salts of the complexes: 2-methoxycarbonyl-4,6-dinitroanisole, 90; 4-methoxycarbonyl-2,6-dinitroanisole, 50; 2-chloro-4,6-dinitroanisole, 25; and 4-trifluoromethyl-2,6-dinitroanisole, 25 l mol^{-1}. The apparent decrease in k_{-1} with increasing sodium methoxide concentration is predicted by this Scheme since, association of the sodium methoxide being neglected, the observed value is given by $k_{-1}/(1 + K_2[\mathrm{M^+}])$. The observed value of k_1 would be expected to remain constant, or decrease if ion-pair formation significantly reduces the reactivity of methoxide ions. The observed increases in k_1 values with concentration may be due to a genuine salt effect.[19]



Variation of K_c with sodium methoxide concentration for A, 2-methoxycarbonyl-4,6-dinitroanisole and B, 4-methoxycarbonyl-2,6-dinitroanisole

Our results suggest then, but do not prove, that a major factor affecting the variation of K_c values with sodium methoxide concentration is ion-association in the complex. We hope to carry out a more detailed examination of these effects later when more data are available. There appears to be some correlation between the ion-pair association constants (K_2) and equilibrium constants for adduct formation (K_1). This may be connected with the localisation of charge on specific nitro-groups on complex formation which should favour ion-pair formation. It would then be expected that the ion-pair association constants for more reactive compounds, such as 2,4,6-trinitroanisole, would be large. Additionally the invariance of experimental K_c values for H_M indicators and for 1,3,5-trinitrobenzene would indicate the unimportance of ion-association in these cases.

It is noteworthy that the Fendlers in their careful studies have not noticed variations in K_c values with sodium methoxide concentration. Their work has been mainly with dilute solutions ($<10^{-2}$M) where variations will be minimised. However, close examination of their results for 1-methoxy-2,4-dinitronaphthalene[22] and 1-(2-hydroxyethoxy)-2,4-dinitronaphthalene[23] indicates significant increases in the values of equilibrium constants with sodium methoxide concentration. Illuminati and his co-workers[7] similarly found a marked increase in the value of the equilibrium constant for complex formation from 2,4,6-trinitroanisole and sodium methoxide. Their measurements were made in solutions containing less than 10^{-3}M-sodium methoxide where carbon dioxide may interfere; however if the increase is genuine then again ion-pair association in the complex is indicated. The Fendlers[6] measured k_{-1} in the latter reaction by direct decomposition of the complex in methanol and combined this value with the constant value of k_1 determined in solutions containing up to 5×10^{-3}M-sodium methoxide. They thus found values of the equilibrium constant which were independent of base concentration. Their results no doubt give the thermodynamic value of the equilibrium constant, but since the results do not allow for possible variation of k_{-1} with sodium methoxide concentration they could not be expected to show up variations in the equilibrium constant. Similarly their determinations[6] with 2-cyano-4,6-dinitroanisole and 4-cyano-2,6-dinitroanisole involve the combination of k_{-1} values determined at zero base concentration with k_1 values determined in dilute sodium methoxide solutions. Again the values of the equilibrium constants so determined will be the thermodynamic ones but if, as we suggest, the main variation is in k_{-1} then their results would not be expected to show up possible variations in equilibrium constant with sodium methoxide concentration.

[1/2357 *Received, 9th December*, 1971]

---

[22] J. H. Fendler, E. J. Fendler, W. E. Byrne, and C. E. Griffin, *J. Org. Chem.*, 1968, **33**, 979 (Table 1).

[23] J. H. Fendler, E. J. Fendler, W. E. Byrne, and C. E Griffin, *J. Org. Chem.*, 1968, **33**, 4142 (Table 1).