1029. *Kinetic Studies of the Fluorene Series. Part V.*[1] *The Reaction of 4-Substituted Fluorenones with Sodium Borohydride*

By Keith D. Warren and J. R. Yandle

The rates of sodium borohydride reduction of some 4-substituted fluorenones in anhydrous isopropyl alcohol have been determined. The reaction is hindered by electron-releasing substituents and accelerated by electron-withdrawing groups, but the familiar compensating relationship between energies and entropies of activation is again observed.

In contrast to the 9-diazofluorene system, correlation of the data by Hammett type equations indicates that transmission of T effects to the 9-position is here substantially more effective than for 2-substituents. The relatively small resonance effects of 4-substituents in the 9-diazo-fluorene series cannot thus be due solely to interaction of the substituent with the 5-hydrogen atom.

The results agree satisfactorily with the predictions of simple molecular orbital calculations.

Although substituents in the 2-position of 9-diazofluorene have been shown[2] to exert unusually large resonance effects on the rate of acid-catalysed solvolysis, 4-substituents behave virtually as normal *meta*-groupings.[1] For 2-substituents in the fluorenone system, however, the rates of sodium borohydride reduction[3] indicate that resonance contributions are much nearer the standard quantities. For further comparison, therefore, of formally *meta*-substituents, the rates for eleven 4-substituted fluorenones are now reported (Table 1).

TABLE 1

Reaction of 4-substituted fluorenones with sodium borohydride in isopropyl alcohol

Substituent	Me	C_6H_5	SMe	Cl	I	NH_2
$10^4 k$ (sec.$^{-1}$ mole^{-1} l.) (25·00°)	47·9	101	82·5	554	357	22·9
$10^4 k$ (sec.$^{-1}$ mole^{-1} l.) (40·00°)	122	214	258	1207	936	46·9
E_A (kcal.)	11·5	9·3	14·1	9·6	11·9	8·9
$-\Delta S^{\ddagger}$ (e.u.)	32·5	38·6	22·9	34·1	27·3	42·9

Substituent	H	OMe	Br	F	CO_2Me	CN
$10^4 k$ (sec.$^{-1}$ mole^{-1} l.) (25·00°)	83·5	65·3	448	451	255	5316
$10^4 k$ (sec.$^{-1}$ mole^{-1} l.) (10·10°)	31·1	25·8	170	175	106	1208 (at 0·00°)
E_A (kcal.)	11·1	10·5	10·9	10·6	9·6	9·5
$-\Delta S^{\ddagger}$ (e.u.)	32·8	35·5	30·0	31·0	35·7	29·9

TABLE 2

Spectrophotometric data

Subst.	Me	C_6H_5	SMe	Cl	I	NH_2	H	OMe	Br	F	CO_2Me	CN
$\lambda_{max.}$ (mμ) ...	383	385	421	380	384	405	383	418	384	395	365 *	368
ε	354·9	380·0	389·3	419·7	417·2	725·0	250·6	1010·3	396·1	525·0	274·3	268·4

* Not maximum.

Energy–Entropy Relationships.—Except for the expected rate-retarding and rate-enhancing effects of electron-releasing and electron-withdrawing groups, respectively, the present results show some marked similarities to those for the 4-substituted 9-diazo-fluorenes. (i) In neither series does a regular relationship exist between E_A and $\log_{10} k_{rel}$. (ii) In both cases, although the usual compensating variation[4] of E_A with $\Delta S^{\ddagger}$ is observed, the scatter about the regression line is markedly greater than for the 2-substituted analogues. (iii) The isokinetic temperatures are both considerably lower than for the corresponding 2-substituted series; the present data yield a value of 14° as compared with 210° for 2-substituted fluorenones.[3]

[1] Part IV, K. D. Warren and J. R. Yandle, *J.*, 1965, 4221.
[2] K. D. Warren, *J.*, 1963, 598.
[3] J. A. Parry and K. D. Warren, *J.*, 1965, 4049.
[4] J. E. Leffler, *J. Org. Chem.*, 1955, **20**, 1202.

It thus seems likely that such steric repulsions between the 4-substituent and the 5-hydrogen atom as were earlier considered [1] may be appreciable in both systems. This view is supported by the complex pattern of the E_A and $\Delta S^{\ddagger}$ values (similar to that in the 4-substituted 9-diazofluorene series), but further comment on this point has been deferred until values for 3-substituents are also available.

Application of the Hammett Equation.—The data were correlated as before,[1,3] using the equation $\log_{10} k_{rel} = \rho(\sigma_I + a\sigma_{Rm})$, the results at $25\cdot00°$ giving $\rho = +2\cdot445$ and $a = +1\cdot404$. (Excluding the 4-CO$_2$Me derivative, for which substantial hindrance to coplanarity of substituent with the ring is probable, the values become $\rho = +2\cdot558$ and $a = +1\cdot489$). Clearly, then, in the fluorenone system, resonance effects of substituents operate appreciably more effectively from the 4- than from the 2-position. Thus, with the exception of the 4-NH$_2$ group, all the $+T$ substituents, and especially the 4-OMe and 4-SMe groups, react substantially more slowly than the corresponding 2-substituted compounds.

As regards the influence of substituent position on tautomeric effects, the fluorenones show, therefore, exactly opposite behaviour to the 9-diazofluorenes; in the latter, resonance contributions are large for 2-substituents and almost normal for groups in the 4-position.

Relationship between substituent constants and relative rates of reaction of 4-substituted fluorenones

4-Substituents: 1, CN; 2, Cl; 3, F; 4, Br; 5, I; 6, CO$_2$Me; 7, C$_6$H$_5$; 8, H; 9, SMe; 10, OMe; 11, Me; 12, NH$_2$.
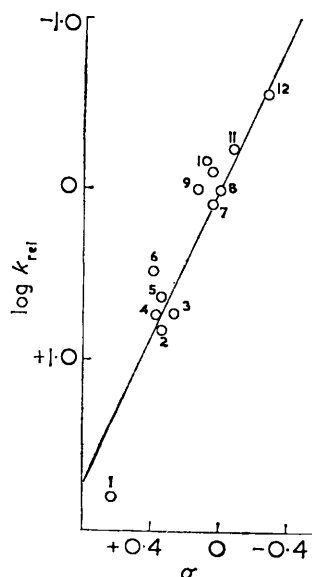
In Part IV of this series, there was considered the hypothesis that distortion of substituents from the plane of the benzenoid ring, owing to steric repulsion by the 5-hydrogen atom, might be responsible for the relatively small T effects found for 4-substituents in 9-diazofluorene. If it were assumed that such effects are responsible for the small resonance contributions of 4-substituents in the 9-diazofluorene system, it would be expected that T effects in 4-substituted fluorenones would be at least similarly restricted. Furthermore, the calculated bond orders [5] for the 8a,9- and 9,9a-bonds indicate that these will be longer in the fluorenones than in the 9-diazofluorenes, and therefore that steric crowding of the 4-substituent will probably be greater in the ketone series. Finally, the absolute magnitude of the ρ values for the two 4-substituted series suggests that the transition state for the borohydride reduction is probably further advanced along the reaction co-ordinate than that for the diazofluorene solvolysis. Since attack at the 9-carbon atom should, in both cases, involve lengthening of the 8a,9- and 9,9a-bonds, steric effects should again be more significant for the fluorenones. Thus, since the resonance effects, which should be

[5] K. D. Warren and J. R. Yandle, unpublished calculations.

reduced by such steric interactions, are actually greater for the ketone series, it is apparent that steric factors are not predominant in determining the effects of 4-substituents in either fluorenones or 9-diazofluorenes.

Molecular Orbital Calculations.—Whereas, in the 9-diazofluorene series, substituents exert greater resonance effects in the 2- than in the 4-position, in the fluorenone system the opposite is true. Furthermore, T effects in the present series are considerably greater than in the 4-substituted 9-diazofluorenes [1] ($\rho = -1 \cdot 836$, $a = +1 \cdot 083$). Since steric causes are not responsible for this difference, it is evident that the transmission of resonance effects to the 9-position cannot depend only on the aromaticity of the central ring, as was earlier [3] thought possible.

However, the results for 2- and 4-substituted fluorenones show good agreement with the predictions of simple molecular orbital calculations, as did those for the corresponding 9-diazofluorenes. In Table 3 are shown the values of L_r^- (localisation energy [6] for nucleo-

TABLE 3

Localisation energies (L_r^-) for substituted fluorenones

Substituent	2-CH$_2^+$	2-CH$_2^-$	4-CH$_2^+$	4-CH$_2^-$
$L_r^-(\beta)$	2·054	2·139	2·034	2·131
$\Delta L_r^-(\beta)$		0·085		0·097

Calculated by simple Hückel MO method: $\alpha_0 = \alpha + \beta$, $\beta_{C=O} = \beta$

philic attack at the 9-position) for the substituents CH_2^- and CH_2^+ in the 2- or 4-positions. (As before [1] electron-supplying and electron-withdrawing substituents are modelled by CH_2^- and CH_2^+, respectively, and the differences, ΔL_r^-, taken as representing the susceptibility of the system to substituent effects.) The calculations [5] also indicate that, both in this system and in the 9-diazofluorene series, somewhat better correlation may be obtained with Δq_r, the corresponding charge density change at the 9-position, but elaboration of this point awaits the completion of work on the 3-substituted derivatives.

EXPERIMENTBL

Reagents.—Anhydrous isopropyl alcohol and pure sodium borohydride were obtained as before [3] and standard solutions made up as previously described.

Kinetic Runs.—The reaction was followed by the spectrophotometric procedure used previously,[3] measurements being made at $25 \cdot 00° \pm 0 \cdot 01°$ or $40 \cdot 00 \pm 0 \cdot 01°$, and in one case at $0 \cdot 00°$ (the values of λ_{max} and ε are shown in Table 2); the values of k, the second-order rate constant, were calculated as before.[7]

For each fluorenone the reaction gave good second-order kinetics for at least the first 60% of its course, and five consistent values of k were obtained for widely different ($4b - a$) terms. The standard deviation from the mean was less than $\pm 3\%$ and the probable errors in E_A and $\Delta S^{\ddagger}$, not more than $\pm 0 \cdot 6$ kcal. and $\pm 2 \cdot 0$ e.u.

Attempted kinetic runs on 4-nitrofluorenone did not follow the usual course but gave a deep yellow solution which gradually deposited a pale orange-brown solid, m. p. 304° (Found: C, 67·1; H, 3·2; N, 5·9%); the infrared spectrum indicated that destruction of the nitro-group had occurred.

Ketones.—The preparation of 4-iodo- and 4-thiomethyl-fluorenone has been previously described.[1] The remaining ketones were prepared from 4-aminofluorenone by recorded methods; all were purified by chromatography on neutral alumina and recrystallisation to constant melting points (in agreement with literature values).

UNIVERSITY COLLEGE OF SOUTH WALES AND MONMOUTHSHIRE,
CATHAYS PARK, CARDIFF.

[6] A. Streitwieser, jun., "Molecular Orbital Theory for Organic Chemists," Wiley, New York, 1961, p. 335.
[7] H. C. Brown, O. H. Wheeler, and K. Ichikawa, *Tetrahedron*, 1957, **1**, 214.