(±)-**Fukinone** (**17**).—A stirred solution of 82.8 mg of Ca in 5 ml of liquid ammonia was treated with a solution of 48 mg of keto acetate **23** in 0.8 ml of ether. After 10 min, excess ammonium chloride was added and the ammonia was allowed to evaporate through a Mercury bubbler. The product was isolated with ether and distilled affording 33 mg of an oil, bp 75° (bath temperature) (0.01 mm). Elution from 10 g of Merck alumina with 50% benzene–hexane afforded 15 mg (39%) of (±)-fukinone: λ_{max}^{film} 5.93, 6.12, 6.93, 7.33, 7.88, 8.21, 8.61, and 9.39 μm; $\delta_{TMS}^{CDCl_3}$ 0.85 (CH_3 doublet, J = 7 Hz), 0.97 (CH_3), 1.79 and 1.94 ppm [$(CH_3)_2C{=}$].[34] The infrared and nmr spectra matched those of natural fukinone and the gas chromatographic behavior of the two substances was identical on three columns (peak enhancement).[1,26]

Registry No.—**2**, 27693-90-9; **8**, 27755-32-4; **9**, 27693-91-0; **10**, 27693-92-1; **11**, 27755-33-5; **12**, 27693-93-2; (*E*)-**13**, 27693-94-3; (*Z*)-**13**, 27693-95-4; **14**, 27693-96-5; **16**, 27693-97-6; **17**, 25828-19-7; **18**, 27693-99-8; **20**, 27694-00-4; **22**, 27694-01-5; **23**, 27694-02-6.

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[34] This spectrum was secured using a Brucker 90-MHz spectrometer.

The Nature of the Ortho Effect. VIII. Composition of the Ortho Effect as a Function of Side-Chain Structure

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Twenty-two sets of ionization constants, in water, for ortho-substituted compounds of the type XGZY (where X is a substituent; Z, a side chain; Y, the reaction site; and G, a skeletal group to which X and Z are attached) were correlated with the equation $Q_X = \alpha\sigma_{I,X} + \beta\sigma_{R,X} + \psi_{V,X} + h$, and 27 sets were correlated with the equation $Q_X = \alpha\sigma_{I,X} + \beta\sigma_{R,X} + h$. Significant correlations were obtained in most cases. Steric effects were absent in most of those sets which were of diagnostic value. Examination of the ε values obtained shows that the composition of the ortho electrical effect is indeed a function of the side chain. It is shown that this implies the existence of electrical proximity effects. The delocalized electrical proximity effect is found to be a function of the side chain. No conclusion can be reached as to whether or not the localized electrical proximity effect is a function of the side chain. In the majority of the sets studied, the value for the unsubstituted compound does lie on the correlation line.

In a further extension of our work on the nature of the ortho effect,[1-7] we consider here the variation of the composition of the ortho electrical effect as a function of side-chain structure in sets of the type $2XC_6H_4ZY$, in which X is the substituent, Y is the reaction site, and Z is the side chain. For this purpose, it is advisable to consider the composition of the overall effect of an ortho substituent on some reaction site. This overall effect is composed of the normal electrical effect of the substituent at the ortho position and of a proximity effect which results from the nearness of the substituent to the reaction site. This proximity effect can be separated into three possible contributions.

I. Proximity Electrical Effects.—These electrical effects are a property of the proximity effect and are exerted in addition to the normal electrical effects of the substituent. They may be resolved into (1) localized effects, which are a function of the σ_I constants, and (2) delocalized effects, which are a function of the σ_R constants.

II. Steric Effects.—These effects are a function of the size of the substituent. They may consist of (1) steric hindrance to solvation of the substituent and/or the reaction site, (2) steric hindrance of the reaction site to attack by a reagent, (3) steric inhibition of resonance in the substituent and/or the reaction site, and (4) steric control of the reacting conformation.

III. Intramolecular Secondary Bonding Forces.—(1) Hydrogen bonding, (2) Keesom (dipole–dipole), Debye (dipole–induced dipole), and London (induced dipole–induced dipole), and (3) charge transfer interactions comprise this group.

It is readily seen that not all ortho-substituted sets will show a proximity effect. The existence of the proximity effect depends on the closeness in space of the substituent to the reaction site. In sets of the type $2XC_6H_4ZY$, the closeness of X to Y is a function of the size and geometry of the side chain Z. For a sufficiently large Z, X and Y must be far enough apart to exclude the possibility of proximity effects. Furthermore, the magnitude of the proximity effect must be a function of the distance between the reaction site and the substituent. We would predict then a dependence of the overall substituent effect upon the size of Z. We may quantitatively represent the overall substituent effect of an ortho substituent by the expression

$$Q_X = \alpha_{norm}\sigma_{I,X} + \beta_{norm}\sigma_{R,X} + \alpha_{prox}\sigma_{I,X} + \beta_{prox}\sigma_{R,X} + \psi r_{V,X} + \nu\omega_X + d \quad (1)$$

where $\alpha_{norm}\,\sigma_{I,X} + \beta_{norm}\,\sigma_{R,X}$ represents the proximity electrical effect, $\psi r_{V,X}$ signifies the steric effect, and $\nu\omega_X$ denotes the contribution due to secondary bonding. Equation 1 simplifies to

$$Q_X = \alpha\sigma_{I,X} + \beta\sigma_{R,X} + \psi r_{V,X} + \nu\omega_X + h \quad (2)$$

Of the types of secondary bonding considered above, hydrogen bonding and charge transfer occur only in

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TABLE I

DATA USED IN CORRELATIONS[a]

1. pK_a, 2-substituted pyridinium ions, 25°[b]
   OMe, 3.06; $PhCH_2$, 5.13; C_2H_3, 4.98; *H*, 5.17; F, −0.44; Cl, 0.72; Br, 0.90; I, 1.82; Me, 5.97; Et, 5.97; Pr, 5.97; *i*-Pr, 5.83; *tert*-Bu, 5.76; NH_2, 6.71
2. pK_a, 2-substituted pyridinium ions, 20°[b]
   CN, −0.26; $CONH_2$, 2.10; CO_2Me, 2.21; Me, 5.97; Et, 5.99; OMe; 3.40; MeS, 3.59; NH_2, 6.82; NHAc, 4.09; NHBz, 3.33; *H*, 5.28
3. pK_a, 2-substituted quinolinium ions, 25°[b]
   MeS, 3.71; OMe, 3.17; OEt, 3.04; *H*, 4.959; Me, 5.832; CO_2Me, 1.755; NH_2, 7.25
4. pK_a, 2-substituted imidazolinium ions, 25°[c]
   H, 6.95; Me, 7.86; Et, 8.00; Ph, 6.39; NO_2, −0.81; NH_2, 8.46
5. pK_a, 2-substituted benzimidazolinium ions, 25°[c]
   H, 5.58; Me, 6.29; Et, 6.27; CH_2OH, 5.40; OEt, 4.18; Ph, 4.23; NH_2, 7.54
6. pK_b, 2-substituted benzimidazoles, 25°[c]
   H, 8.6; Me, 8.3; Ph, 9.2; $PhCH_2$, 8.9; Cl, 11.4; Me_2N, 6.6; CH_2OH, 8.4; $AcOCH_2$, 9.4; $PhCH_2CH_2$, 7.9; PhC_2H_3, 8.8
7. pK_a, 2-substituted 5,6,7,8-tetrahydronaphth[2,3]imidazolinium ions, 20°[c]
   H, 5.98; Et, 6.64; Cl, 2.68; NH_2, 7.69; Me_2N, 7.65; MeS, 5
8. pK_a, 2-substituted phenols, 25°[d]
   H, 10.00; F, 8.705; Cl, 8.53; Br, 8.44; I, 8.51; Me, 10.29; OMe, 9.98
9. pK_a, 2-substituted phenols, 0.1 *M* KCl, 20°[e]
   NMe_2, 10.62; *i*-Pr, 10.31; Et, 10.27; OMe, 9.90; I, 8.44; Br, 8.33; Cl, 8.46; $\mathit{NO_2}$, 7.21; *H*, 9.89
10. pK_a, 2-substituted anilinium ions, 25°[d]
    H, 4.60; F, 3.20; Cl, 2.65; Br, 2.53; I, 2.60; OMe, 4.52; Me, 4.45
11. pK_a, 2-substituted 1-hydroxypyridinium ions, 25°[f]
    H, 0.79; $PhCH_2S$, −0.23; NHAc, −0.42; NHBz, −0.44; NH_2, 2.67; OMe, 1.23; OEt, 1.18; NO_2, −2.71; CN, −2.08; Ac, −0.45; Cl, −0.77
12. pK_a, 2-substituted benzoic acids, 25°[g]
    F, 3.267; Cl, 2.9215; Br, 2.854; I, 2.863; Me, 3.9083; Et, 3.793; OMe, 4.094; Ph, 3.460; *H*, 4.203; $\mathit{NO_2}$, 2.173
13. pK_b, 2-substituted phenylhydrazines, 25°[h,i]
    OMe, 8.47; OEt, 8.64; Me, 8.68; *H*, 8.73; Cl, 9.35; Br, 9.46; CO_2Et, 9.34; NO_2, 10.50
14. pK_b, 2-substituted *N*-methylphenylhydrazines, 25°[i,j]
    OMe, 8.58; OEt, 8.75; *H*, 9.02; Cl, 9.22; Br, 9.32; $\mathit{CO_2Et}$, 9.09; NO_2, 9.68; Me, 8.71
15. pK_{bH^+}, 2-substituted benzoic acids[k]
    H, 7.18; Me, 7.13; Et, 7.15; *i*-Pr, 7.23; *tert-Bu*, 7.56; F, 7.60; Cl, 7.68; Br, 7.75; I, 7.78; OH, 6.78; OMe, 6.10; OEt, 6.10; $\mathit{NO_2}$, 7.03; $\mathit{CO_2H}$, 5.95
16. pK_a, 2-substituted benzene phosphonic acids, 25°[l]
    H, 1.83; Me, 2.10; F, 1.64; Cl, 1.63; Br, 1.64; I, 1.74; OMe, 2.16
17. pK_{a_2}, 2-substituted benzene phosphonate ions, 25°[l]
    H, 7.07; Me, 7.68; *Ph*, 8.13; F, 6.80; Cl, 6.98; Br, 7.00; I, 7.06; OMe, 7.77
19. pK_a, 2-substituted mandelic acids, 25°[m]
    F, 3.30; Cl, 3.31; Br, 3.32; OMe, 3.64
20. pK_a, 3-(2′-substituted phenyl)propanic acids, 25°[n]
    H, 4.66; Me, 4.66; F, 4.60; Cl, 4.58; Br, 4.58; NO_2, 4.50; OMe, 4.80; *OH*, 4.75
21. pK_a, 2-substituted cinnamic acids, 25°[n]
    H, 4.44; Me, 4.50; F, 4.28; Cl, 4.23; Br, 4.23; NO_2, 4.15; OMe, 4.46; *OH*, 4.61
22. 10^4 K_a, 2-substituted phenoxyacetic acids, 25°[o]
    H, 6.75; Me, 5.93; OMe, 5.88; NO_2, 12.7; CN, 10.6; F, 8.22; Cl, 8.90; Br, 7.53; I, 6.72
23. 10^4 K_a, 2-substituted phenoxyacetic acids, 25°[p]
    OMe, 5.8; Me, 6.8; Cl, 10.2; NO_2, 15.8
24. 10^4 K_a, 2-substituted phenylthioacetic acids, 25°[p]
    OMe, 1.8; Me, 2.8; Cl, 3.0; NO_2, 5.5
25. pK_a, 2-substituted phenylthioacetic acids, 20°[q]
    H, 3.38; Me, 3.38; Cl, 3.23; OMe, 3.59; NO_2, 3.10; SMe, 3.57
26. 10^4 K_a, 2-substituted phenylselenoacetic acids, 25°[q]
    OMe, 1.4; Me, 1.5; Cl, 2.3; NO_2, 3.2
27. pK_a, 2-substituted phenylselenoacetic acids, 20°[q]
    H, 3.75; Me, 3.76; Cl, 3.57; OMe, 3.87; OEt, 3.90; NO_2, 3.42; Br, 3.58; SMe, 3.80

[a] Substituents in italics were excluded from the correlations. [b] M. Charton, *J. Amer. Chem. Soc.*, **86**, 2033 (1964). [c] M. Charton, *J. Org. Chem.*, **30**, 3346 (1965). [d] A. I. Biggs and R. A. Robinson, *J. Chem. Soc.*, 388 (1961). [e] C. van Hooidonk and L. Ginjaar, *Recl. Trav. Chim. Pays-Bas*, **86**, 449 (1967). [f] D. D. Perrin, "Dissociation Constants of Organic Bases in Aqueous Solution," Butterworths, London, 1965. [g] Reference 8. [h] H. H. Stroh and G. Westphal, *Chem. Ber.*, **96**, 184 (1963). [i] G. Westphal and H. H. Stroh, *Z. Chem.* **7**, 192 (1967). [j] H. H. Stroh and G. Westphal, *Chem. Ber.*, **97**, 83 (1964). [k] R. Stewart and M. R. Granger, *Can. J. Chem.*, **39**, 2508 (1961). [l] G. Kortum, W. Vogel, and K. Andrussow, *Pure Appl. Chem.*, **1**, 190 (1961). [m] J. J. Klingenberg, J. P. Thole, and R. D. Lingg, *J. Chem. Eng. Data*, **11**, 94 (1966). [n] K. Bowden and D. C. Parkin, *Can. J. Chem.*, **46**, 3909 (1968). [o] N. V. Hayes and G. E. K. Branch, *J. Amer. Chem. Soc.*, **65**, 1555 (1943). [p] O. Behagel and M. Rollman, *Chem. Ber.*, **62**, 2693 (1929). [q] L. D. Petit, A. Royston, C. Sherrington, and R. J. Whewell, *J. Chem. Soc. B*, 588 (1968).

TABLE II

SUBSTITUENT CONSTANTS

X	σ_I	σ_R	Ref	X	σ_I	σ_R	Ref
C_2H_3		−0.11	*a, b*	CH_2OH		−0.06	*a, f*
$CONH_2$		0.09	*a, c*	CH_2OAc	0.14	−0.05	*a, f*
CO_2Me		0.10	*a, d*	$PhCH_2CH_2$		−0.15	*a, f*
$PhCH_2S$		−0.16	*a, e*	PhC_2H_2	0.06	−0.06	*a, f*

[a] Calculated from the equation $\sigma_R = \sigma_p - \sigma_I$. [b] σ_p from M. Charton, *J. Org. Chem.*, **30**, 552 (1965). [c] σ_p from M. Charton, *ibid.*, **28**, 3121 (1963). [d] σ_p from M. Charton and H. Meislich, *J. Amer. Chem. Soc.*, **80**, 5940 (1958). [e] σ_p from M. Charton, *J. Org. Chem.*, **34**, 1871 (1969). [f] M. Charton, *ibid.*, **30**, 3346 (1965).

certain cases; they are not observed for all substituents. Keesom, Debye, and London forces may be proportional to the σ_I constants if they do in fact make a significant contribution to the proximity effect. Then, excluding from consideration any substituent for which hydrogen bonding or charge transfer interaction may be important, eq 2 either reduces to

$$Q_X = \alpha\sigma_{I,X} + \beta\sigma_{R,X} + \psi r_{V,X} + h \tag{3}$$

or its equivalent.

If the steric effect is zero or negligible, eq 3 reduces to the extended Hammett equation

$$Q_X = \alpha\sigma_{I,X} + \beta\sigma_{R,X} + h \tag{4}$$

Let us now consider the composition of the ortho electrical effect which may be represented as

$$\epsilon = \beta/\alpha \tag{5}$$

Now

$$\beta = \beta_{norm} + \beta_{prox} \tag{6}$$

where

$$\beta_{prox} = f_1(Z) \tag{7}$$

and

$$\alpha = \alpha_{norm} + \alpha_{prox} \tag{8}$$

where

$$\alpha_{prox} = f_2(Z) \tag{9}$$

It is highly probable that

$$f_1(Z) \neq cf_2(Z) \tag{10}$$

TABLE III
RESULTS OF CORRELATIONS

Set	$-\alpha$	$-\beta$	ψ	h	R^{a}	F^{b}	r_{12}^{c}	r_{13}^{c}	r_{23}^{c}
1A	11.3	2.31	−0.00254	5.28	0.979	70.57^{g}	0.339	0.243	0.526
1B	11.3	2.31		5.28	0.979	117.6^{g}	0.339		
2A	9.50	2.38	−1.27	7.47	0.997	41.35^{g}	0.317	0.286	0.451
2B	9.18	2.64		5.25	0.976	69.18^{g}	0.317		
3A	10.7	3.62	3.22	−0.372	0.950	6.115^{h}	0.120	0.107	0.654
3B	11.2	2.77		5.30	0.939	11.22^{m}	0.120		
4A	10.7	3.57	1.12	5.08	0.9998	893.1^{k}	0.370	0.653	0.361
4B	11.0	3.32		7.05	0.9997	1957.0^{g}	0.370		
5A	13.0	3.88	−2.41	9.51	0.982	17.83^{m}	0.583	0.702	0.910
5B	12.4	4.54		5.27	0.979	35.31^{i}	0.583		
6A	−6.71	−1.96	4.37	10.12	0.982	45.21^{g}	0.123	0.115	0.909
6B	−7.15	−2.95		8.68	0.979	69.10^{g}	0.123		
7A	8.37	2.87	−0.337	6.59	0.995	36.67^{n}	0.179	0.437	0.864
7B	8.43	2.96		5.99	0.995	109.3^{i}	0.179		
8A	4.05	2.19	−0.0187	9.87	0.999	236.7^{h}	0.295	0.020	0.866
8B	4.06	2.21		9.83	0.999	531.9^{g}	0.295		
9A	4.01	1.09	−0.644	11.13	0.997	200.7^{g}	0.348	0.086	0.406
9B	3.98	1.23		9.99	0.994	198.4^{g}	0.348		
10A	4.24	3.21	−0.218	4.24	0.998	193.3^{i}	0.295	0.020	0.866
10B	4.30	3.45		3.82	0.998	395.2^{g}	0.295		
11A	5.04	2.52	−0.244	1.35	0.968	29.56^{g}	0.676	0.033	0.401
11B	4.98	2.57		0.923	0.968	51.57^{g}	0.676		
12A	2.47	2.51	0.193	3.11	0.998	297.7^{g}	0.503	0.023	0.790
12B	2.40	2.31		3.47	0.997	475.4^{g}	0.503		
13A	−2.05	−1.42	−0.0537	8.87	0.971	16.68^{k}	0.327	0.033	0.327
13B	−2.05	−1.41		8.78	0.971	33.30^{h}	0.327		
14A	−1.30	−0.562	0.568	7.77	0.972	17.04^{k}	0.327	0.053	0.327
14B	−1.24	−0.671		8.76	0.956	21.25^{i}	0.327		
15A	3.22	6.49	−3.01	13.21	0.986	58.30^{g}	0.466	0.010	0.807
15B	2.22	3.61		7.59	0.932	19.87^{h}	0.466		
16A	1.38	1.58	0.848	0.387	0.995	62.56^{k}	0.295	0.020	0.866
16B	1.14	0.660		2.02	0.956	16.09^{k}	0.295		
17A	2.32	2.72	1.69	4.34	0.986	23.45^{l}	0.295	0.020	0.866
17B	1.85	0.889		7.59	0.929	9.505^{m}	0.295		
18B	−0.704	−0.658		0.767	0.99994	385.6^{l}	0.680		
19B	1.20	0.252		3.81	0.9998	1003.0^{k}	0.505		
20A	0.240	0.241	0.129	4.87	0.907	3.079^{h}	0.199	0.235	0.317
20B	0.216	0.274		4.64	0.890	5.724^{m}	0.199		
21A	0.529	0.0978	−0.241	4.88	0.994	53.64^{k}	0.199	0.235	0.317
21B	0.484	0.159		4.46	0.966	21.00^{k}	0.199		
22A	−0.337	−0.262	−0.198	1.15	0.974	25.11^{h}	0.309	0.214	0.236
22B	−0.386	−0.210		0.786	0.936	17.64^{i}	0.309		
23B	0.391	0.427		0.902	0.996	57.09^{m}	0.390		
24B	0.208	0.638		0.534	0.99998	13123.0^{i}	0.390		
25A	0.282	0.661	−0.0559	3.41	0.932	2.215^{h}	0.411	0.353	0.059
25B	0.272	0.664		3.31	0.932	6.592^{n}	0.411		
26B	0.377	0.314		0.231	0.992	32.83^{n}	0.390		
27A	0.408	0.499	−0.224	4.08	0.984	30.06^{i}	0.408	0.091	0.203
27B	0.379	0.540		3.68	0.969	31.01^{h}	0.408		

Set	s_{est}^{d}	s_{α}^{d}	s_{β}^{d}	s_{φ}^{d}	s_{h}^{d}	n^{e}	t_{α}^{f}	t_{β}^{f}	t_{ψ}^{f}	t_{h}^{f}
1A	0.577	0.789	0.973	0.806	1.57	13	14.32^{g}	2.375^{l}	0.033^{r}	3.373^{i}
1B	0.547	0.746	0.807		0.244	13	15.15^{g}	2.866^{j}	21.64^{g}	
2A	0.561	1.22	0.873	2.49	4.35	10	7.787^{g}	2.724^{l}	0.512^{q}	1.719^{o}
2B	0.531	0.995	0.663		0.342	10	9.230^{g}	3.988^{i}		15.35^{g}
3A	1.01	3.28	1.99	5.10	9.03	6	3.271^{m}	1.820^{p}	0.632^{q}	0.041^{r}
3B	0.899	2.84	1.31		0.849	6	3.955^{l}	3.114^{o}		6.244^{i}
4A	0.150	0.637	0.478	1.84	3.23	5	16.78^{l}	7.461^{m}	0.608^{q}	1.537^{p}
4B	0.124	0.220	0.204		0.0831	5	50.09^{g}	16.28^{i}		84.81^{g}
5A	0.394	2.11	1.49	4.72	8.31	6	6.142^{l}	2.603^{o}	0.511^{q}	1.144^{p}
5B	0.342	1.58	0.651		0.202	6	7.870^{j}	6.981^{j}		26.04^{i}
6A	0.308	0.872	1.14	4.74	8.31	9	7.703^{g}	1.731^{o}	0.923^{p}	0.122^{r}
6B	0.304	0.721	0.394		0.145	9	9.924^{g}	7.469^{g}		59.87^{g}
7A	0.403	1.27	1.26	4.17	7.39	5	6.606^{m}	2.279^{p}	0.081^{r}	0.891^{q}
7B	0.286	0.738	0.411		0.283	5	11.41^{i}	7.20^{j}		21.18^{i}
8A	0.0696	0.188	0.466	0.394	0.761	6	21.49^{i}	4.687^{l}	0.047^{r}	12.97^{i}
8B	0.0569	0.126	0.156		0.0562	6	32.25^{g}	14.18^{g}		175.0^{g}
9A	0.133	0.206	0.184	0.342	0.615	8	19.44^{g}	5.921^{i}	1.882^{o}	18.09^{g}
9B	0.163	0.253	0.206		0.119	8	15.76^{g}	5.940^{i}		83.62^{g}

TABLE III
(Continued)

Set	s_{est}^{d}	s_{α}^{d}	s_{β}^{d}	s_{φ}^{d}	s_{h}^{d}	n^{e}	t_{α}^{f}	t_{β}^{f}	t_{ψ}^{f}	t_{h}^{f}
10A	0.0862	0.233	0.577	0.487	0.942	6	18.19^{i}	5.563^{l}	0.448^{q}	4.498^{l}
10B	0.0738	0.163	0.202		0.0729	6	26.37^{g}	17.08^{g}		52.35^{g}
11A	0.488	1.33	0.836	1.85	3.29	10	3.785^{i}	3.009^{l}	0.132^{r}	0.411^{q}
11B	0.452	1.16	0.665		0.533	10	4.308^{i}	3.866^{i}		1.732^{o}
12A	0.0439	0.116	0.267	0.232	0.436	8	21.29^{g}	9.396^{g}	0.832^{p}	7.130^{i}
12B	0.0426	0.0796	0.112		0.0284	8	30.20^{g}	20.58^{g}		122.4^{g}
13A	0.235	0.451	0.424	0.792	1.38	7	4.549^{j}	3.347^{l}	0.068^{r}	6.409^{i}
13B	0.203	0.386	0.343		0.185	7	5.326^{i}	4.105^{j}		47.42^{g}
14A	0.131	0.252	0.236	0.442	0.772	7	5.145^{j}	2.377^{m}	1.286^{p}	10.07^{i}
14B	0.141	0.268	0.238		0.129	7	4.639^{i}	2.815^{l}		68.09^{g}
15A	0.138	0.331	0.735	0.698	1.31	9	9.722^{g}	8.830^{g}	4.312^{i}	10.11^{g}
15B	0.275	0.468	0.614		0.176	9	4.736^{i}	5.890^{i}		43.10^{g}
16A	0.0399	0.108	0.267	0.225	0.435	6	12.76^{i}	5.908^{i}	3.765^{l}	0.890^{p}
16B	0.0925	0.205	0.253		0.0914	6	5.583^{j}	2.607^{m}		22.11^{g}
17A	0.107	0.289	0.714	0.603	1.16	6	8.043^{j}	3.805^{m}	2.804^{o}	3.728^{m}
17B	0.193	0.427	0.529		0.191	6	4.339^{l}	1.683^{o}		39.80^{g}
18B	0.00920	0.0295	0.113		0.0158	4	23.86^{l}	5.823^{o}		58.54^{j}
19B	0.00639	0.0360	0.0281		0.0223	4	33.33^{j}	8.967^{m}		170.9^{i}
20A	0.0680	0.129	0.148	0.224	0.404	6	1.864^{p}	1.627^{p}	0.577^{q}	12.04^{i}
20B	0.0600	0.108	0.121		0.0607	6	2.010^{o}	2.267^{o}		76.45^{g}
21A	0.0245	0.0464	0.0534	0.0808	0.146	6	11.40^{i}	1.833^{p}	2.977^{m}	33.53^{g}
21B	0.0466	0.0836	0.0939		0.0472	6	5.794^{j}	1.689^{o}		94.52^{g}
22A	0.0353	0.0653	0.0661	0.0817	0.153	8	5.162^{i}	3.963^{j}	2.418^{m}	7.483^{i}
22B	0.0495	0.0871	0.0877		0.0472	8	4.431^{i}	2.394^{m}		16.65^{g}
23B	0.0314	0.0631	0.0763		0.0342	4	6.196^{o}	5.596^{o}		26.37^{l}
24B	0.00213	0.00428	0.00518		0.00232	4	48.59^{j}	127.6^{i}		230.2^{i}
25A	0.154	0.331	0.362	0.660	1.16	5	0.853^{q}	1.826^{p}	0.085^{r}	2.940^{p}
25B	0.109	0.219	0.256		0.118	5	1.243^{p}	2.599^{o}		28.02^{i}
26B	0.0357	0.0716	0.0866		0.0388	4	5.265^{o}	3.626^{o}		59.53^{j}
27A	0.0454	0.0900	0.0959	0.138	0.248	7	4.530^{l}	5.201^{j}	1.627^{p}	16.44^{g}
27B	0.0540	0.105	0.110		0.0575	7	3.615^{l}	4.915^{i}		64.06^{g}

[a] Multiple correlation coefficient. [b] F test for significance of correlation. [c] Partial correlation coefficients for σ_I on σ_R, σ_I on r_V, and σ_R on r_V, respectively. [d] Standard errors of the estimate, α, β, ψ, and h. [e] Number of points in set. [f] "Student's t" tests for signifiance of α, β, ψ, and h. [g] 99.9% confidence level (CL). [h] 99.5% CL. [i] 99.0% CL. [j] 98.0% CL. [k] 97.5% CL. [l] 95.0% CL. [m] 90.0% CL. [n] <90.0% CL. [o] 80.0% CL. [p] 50.0% CL. [q] 20.0% CL. [r] <20.0% CL.

Then we would predict that if there are proximity electrical effects

$$\epsilon = \frac{\beta_{norm} + f_1(Z)}{\alpha_{norm} + f_2(Z)} \qquad (11)$$

A dependence of ϵ on Z may therefore be taken as evidence that proximity electrical effects do in fact exist. Furthermore, such a dependence of ϵ on Z would once and for all preclude the definition of σ_0 constants for use with ortho substituents, as no single set of σ_0 constants could be expected to represent data for various $2XC_6H_4ZY$.

To test the validity of eq 11, we have correlated data for 27 sets of proton transfer reactions with eq 3 and 4. The data used are set forth in Table I. Only data obtained in water as solvent have been considered, as we have previously established a dependence of ϵ on solvent composition in the case of the ionization constants of 2-substituted benozic acids.[8] The sources of the substituent constants and van der Waals radii used in the correlations are set forth in previous papers of this series.[1-7] Substituent constants from other sources are reported in Table II. The data have been correlated with eq 3 and 4 by means of multiple linear regression analysis.[9]

The value for X = H was excluded from all the sets studied as this value often does not lie on the correlation line for ortho-substituted compounds.

Results

Results of the correlations are presented in Table III. Sets labeled A were correlated with eq 3. Sets labeled B were correlated with eq 4. Of the 22 sets correlated with eq 3, nine sets gave excellent, two gave very good, five gave good, one gave fair, and one gave poor correlation. Four sets did not give significant results. Of the 27 sets correlated with eq 4, 12 sets gave excellent, five gave very good, three gave good, one gave fair, and four gave poor results. Two sets did not give significant correlations.

Discussion

Steric Effects.—Of the 22 sets correlated with eq 5, 13 gave significant correlation and did not have a significant value of r_{13} or r_{23} (that is, neither σ_I and r_V nor σ_R and r_V are related to each other). Only these sets are of diagnostic value. Of these 13 sets, ten did not give significant values of t_{ψ}, whereas three did give significant values. We conclude, therefore, that in most cases proton transfer reactions of ortho-substituted compounds are free of steric effects. This result is in accord with our previous findings.[1-7] Lend-

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[8] M. Charton and B. I. Charton, *J. Org. Chem.*, **33**, 3872 (1968).

[9] K. A. Brownlee, "Statistical Theory and Methodology in Science and Engineering," 2nd ed, Wiley, New York, N. Y., 1965; E. L. Crow, F. A. Davis, and M. W. Maxfield, "Statistical Manual," Dover Publications, New York, N. Y., 1960.

ing credence to this conclusion is the generally better correlation obtained with eq 4 as compared with eq 3.

Variation of the Composition of the Electrical Effect with the Side Chain.—Values of ϵ are reported in Table IV. It is convenient for the purpose of discussing the variation of ϵ with Z to classify Z according to the number of atoms n intervening between the aromatic ring and the ionizable proton. Examination of the results in Table IV certainly show considerable variation with Z. There seems to be a possible dependence on n, with low values of ϵ at $n = 0$, and higher values of ϵ at $n > 0$. The results are not yet conclusive however. For para-substituted benzene derivatives of the type $4XC_6H_4ZY$, the value of ϵ_p is dependent on the electronic demands of Y and the degree to which Z can transmit resonance effects. Thus, ϵ_p for para-substituted benzene derivatives may range from a value of 0.74 for $4XPnCH_2CO_2H$ to 1.47 for $4XC_6H_4OH$. It is necessary, therefore, to correct for the electronic demands of Y and the variable resonance effect transmission of Z. For this purpose only those sets will be considered for which $\epsilon_p = 1.0 \pm 0.1$. Thus, the sets considered are those for which the para-substituted analogs are best correlated by the σ_p constants. Sets which meet this requirement are given in italics in Table IV. Their ϵ values show a dependence on Z, with $\bar{\epsilon} = 0.2$ for $n = 0$, $\bar{\epsilon} = 0.8$ for $n = 2$, and $\bar{\epsilon} = 1.0$ for $n = 4$, where n is the number of atoms between the ring and the ionizable proton.

TABLE IV

VALUES OF ϵ

Set	ϵ	n[a]	Set	ϵ	n	Set	c	n
1	*0.20*	0	10	0.80	1	19	0.21	3
2	*0.29*	0	11	...[c]	1	20	...[d]	4
3	...[b]	0	12	*0.96*	2	21	...[b]	4
4	0.30	0	13	0.69	2	22	*0.54*	4
5	0.37	0	14	0.54	2	23	...[d]	4
6	0.41	0	15	1.6	2	24	3.1	4
7	0.35	0	16	*0 .58*	2	25	...[e]	4
8	0.54	1	17	...[b]	2	26	...[e]	4
9	0.32	1	18	...[b]	3	27	*1.4*	4

[a] n is the number of atoms separating the ring and the ionizable proton. Values of ϵ are calculated from correlations with eq 8. Values in italics are for sets for which $\epsilon_p \cong 1.0$. [b] Value of β is not significant. [c] r_{12} shows $\sigma_I = f(\sigma_R)$. [d] Values of α and β are not significant. [e] Correlation with eq 4 was not significant.

The Existence of Proximity Electrical Effects.—The variation of ϵ with Z shows the existence of proximity electrical effects. Further evidence of their existence may be inferred as follows. Consider β as a function of ZY in the species XGZY where G is the skeletal group to which the substituent X and the side chain Z are attached. We may write for β

$$\beta = (\beta_N + \beta_P)\gamma_R\eta_R \qquad (12)$$

where β_N is the normal delocalized electric effect through the group G, β_P is the delocalized proximity electrical effect, η_R represents the factor which accounts for the electronic demands of Y, and γ_R represents the factor which accounts for the transmission of the resonance effect by the group Z. The quantities γ_R and η_R are assumed to be characteristic of Z and Y, respectively, and independent of G. They are defined by the equations

$$\gamma_R = \frac{\beta GZY}{\beta GZ^0Y} \qquad (13)$$

and

$$\eta_R = \frac{\beta GZY}{\beta GZY^0} \qquad (14)$$

where Z^0 is a reference side chain and Y^0 is a reference reaction site. Then for the 2-substituted benzene derivatives we may write

$$\beta_2 = (\beta^2{}_N + \beta_P)\gamma_R\eta_R \qquad (15)$$

and for the 4-substituted benzene derivatives we may write

$$\beta_4 = \beta^4{}_N\gamma_R\eta_R \qquad (16)$$

Then

$$\frac{\beta_2}{\beta_4} = \frac{\beta^2{}_N + \beta_P}{\beta^4{}_N} \qquad (17)$$

where $\beta_{^2N}$ is a constant characteristic of the *o*-phenylene group and $\beta_{^4N}$ is a constant characteristic of the *p*-phenylene group. β in general may conceivably be a function of Z, Y, reagent, medium, temperature, and pressure. As in the sets studied, the only reaction is proton transfer in water at 20–25° and 1 atm. β can in these sets vary only as a function of Y and Z. The quantity β_2/β_4 is independent of the electronic demands of Y and the extent of transmission of the resonance effect by Z. If this quantity varies with Z, then this can only be due to β_P being a function of Z. Thus examination of the quantity β_2/β_4 for various side chains Z will show whether or not β_P is dependent on Z. Values of β_2/β_4 are given in Table V. There is obviously variation of β_2/β_4 with Z. Excluding the values for pK_a and pK_{bH^+} of benzoic acids, which seem anomalously large, there seems to be a trend toward an increasing value of β_2/β_4 with increasing n.

TABLE V

VALUES OF β_2/β_4

Set	$-\beta_2$	$-\beta_4$	β_2/β_4	n
1	2.64	5.11[a]	0.52	0
2	2.31	5.63[b]	0.41	0
8	2.21	2.99[b]	0.74	1
9	1.23	1.61[b]	0.76	1
10	3.45	4.38[b]	0.79	1
12	2.31	1.00[c]	2.3	2
13	−1.41	−1.78[c]	0.79	2
14	−0.671	−2.74[c]	0.25	2
15	3.62	1.41[b]	2.6	2
16	0.660	0.755[c]	0.87	2
22	−0.210	−0.297[b]	0.71	4
24	0.638	0.528[b]	1.2	4
27	0.540	0.430[b]	1.3	4

[a] M. Charton, Abstracts, 154th National Meeting of the American Chemical Socieity, Chicago, Ill., 1967, S-137. [b] M. Charton, unpublished results. [c] Calculated from $\beta = \rho\delta$.

These results may be taken as evidence for the existence of a delocalized proximity electrical effect which is a function of the side chain Z. The exact nature of this delocalized proximity electrical effect remains to be established.

Deviation of the Unsubstituted Compound.—We have excluded the value for X = H from the correlations as this value often deviates from the correlation line obtained for ortho-substituted compounds. It was shown, however, that, in the case of polarographic half-wave potentials of ortho-substituted compounds, h_{calcd} was not significantly different from h_{obsd} (the value for the unsubstituted compound). In the case of nmr data of ortho-substituted compounds, 16 of 18 sets studied showed no significant difference between h_{calcd} and h_{obsd}.[7] It seemed of interest to determine whether h_{calcd} and h_{obsd} are significantly different in the case of the proton transfer equilibria studied here. A Student's t test was carried out for the significance of h_{calcd} for all sets for which significant correlation with eq 4 was obtained and h_{obsd} values were available. The results are given in Table VI. Of the 23 sets studied, 17 did not give significant differences between h_{obsd} and h_{calcd}. It would seem that the unsubstituted compound more often than not does lie on the correlation line for ortho-substituted compounds. It seems to deviate in some examples, however.

TABLE VI

SIGNIFICANCE OF h_{calcd}

Set	h_{obsd}	h_{calcd}	$\lvert\Delta\rvert h^a$	$s_h{}^b$	t^c	n^d	CL^e
1	5.17	5.28	0.11	0.244	0.451	13	20.0
2	5.28	5.25	0.03	0.342	0.088	10	<20.0
3	4.959	5.30	0.34	0.849	0.400	6	20.0
4	6.95	7.05	0.10	0.0831	1.203	5	50.0
5	5.58	5.27	0.31	0.202	1.535	6	50.0
6	8.6	8.68	0.08	0.145	0.552	9	20.0
7	5.98	5.99	0.01	0.283	0.035	5	<20.0
8	10.00	9.83	0.17	0.0562	3.024	6	90.0
9	9.89	9.99	0.10	0.119	0.840	8	50.0
10	4.60	3.82	0.78	0.0729	10.70	6	99.0
11	0.79	0.923	0.13	0.533	0.244	10	<20.0
12	4.203	3.47	0.73	0.0284	25.70	8	99.9
13	8.73	8.78	0.05	0.185	0.280	7	20.0
14	9.02	8.76	0.26	0.129	2.016	7	80.0
15	7.18	7.59	0.41	0.176	2.330	9	90.0
16	1.83	2.02	0.19	0.0914	2.079	6	80.0
17	7.07	7.59	0.52	0.191	2.723	6	90.0
18	0.340	0.767	0.43	0.0158	27.22	4	95.0
20	4.66	4.64	0.02	0.0607	0.329	6	20.0
21	4.44	4.46	0.02	0.0472	0.424	6	20.0
22	0.829	0.786	0.04	0.0472	0.847	8	50.0
27	3.75	3.68	0.07	0.0575	1.217	7	50.0

[a] Absolute value of the difference between h_{obsd} and h_{calcd}. [b] Standard error of h_{calcd}. [c] Student's t test for the significance of h_{calcd}. [d] Number of points in the set. [e] Confidence levels for the significance of h_{calcd}.

Specific Salt Effects upon the Rates of SN1 Solvolyses[1]

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Specific kinetic salt effects upon the solvolyses of *tert*-butyl bromide, 1- and 2-methyl-*exo*-2-chloronorbornane, isobornyl chloride, and camphene hydrochloride have been examined in methanol, aqueous methanol, acetone, 1,2-dimethoxyethane, and methanol–1,2-dimethoxyethane. Anion effects are important but cation effects are small (for Li^+, Na^+, and Et_4N^+). The anion order is $ClO_4^- > OTos^- \approx NO_3^- \approx Br^- > Cl^- \approx$ no salt $> F^- > OH^-$. Isotopic and azide trapping experiments show that carbonium ions or ion pairs can return in solvolyses of camphene hydrochloride and *tert*-butyl chloride, but return is not large enough to explain the salt effects. This conclusion is supported by the observation of specific salt effects upon solvolyses of isobornyl chloride and 1-methyl-*exo*-2-chloronorbornane. Retention of configuration in the methanolysis of isobornyl chloride and camphene hydrochloride shows that methyl or hydride shifts do not occur during the lifetime of the carbonium ions. Experiments on isobornyl chloride in aqueous methanol and acetone show that chloride and perchlorate ions have little effect upon the activity coefficient of the substrate. The transition state effects appear to be related, at least in part, to solvent structure induced interactions between the carbonium-like transition state, especially with a large anion such as perchlorate.

Salt effects upon the SN1 solvolyses of alkyl halides and sulfonic esters in polar hydroxylic solvents have been widely studied. It was postulated that increase of ionic strength should assist any reaction in which a neutral molecule dissociates into ions,[3,4] and Ingold and his coworkers observed such an effect in SN1 solvolyses of secondary and tertiary alkyl halides in aqueous organic solvents. They used a simple electrostatic model to explain stabilization of the dipolar transition state, and for a limited number of salts obtained a reasonable fit between experiment and theory by assuming that the transition state could be represented as a dipole in which the carbon–halogen bond was stretched by *ca.* 0.4 Å.[4]

They also observed a rate retardation for some SN1 solvolyses when the common halide ion competed with the solvent for the carbonium ion.[3-5] This common ion retardation becomes very important with relatively stable carbonium ions and in solvents of low nucleophilicity.[4,6]

The simple electrostatic theory of the ionic strength effect assumed that ions acted nonspecifically, as point

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