

EFFECTS OF *ortho*-SUBSTITUENTS IN PROTONOLYSIS OF ARYLMERCURIC CHLORIDES WITH HYDROCHLORIC ACIDYulan WANG^{a,*} and Yangjie WU^b^a Institute of Chemical Metallurgy, Chinese Academy of Sciences, Beijing, 100080, China;
e-mail: ylwang@ns.icm.ac.cn^b Zhengzhou University, Zhengzhou, 450052, China

Received April 7, 1999

Accepted September 30, 1999

The kinetics of reaction of *ortho*-substituted phenylmercuric chlorides, 2-R-C₆H₄HgCl (R = H, CH₃, CH₃O, C₂H₅O, CF₃, COOC₂H₅, Cl, Br, F, NO₂), with hydrochloric acid in absolute ethanol in the presence of sodium iodide has been studied. The reaction is of the overall second order, first order with respect to each reactant. The rate constant determined at a fixed temperature decreases in the order of R: C₂H₅O > CH₃O > CH₃ > H > COOC₂H₅ > F > Cl > Br > CF₃ > NO₂. The role of inductive, resonance and field effects of the *ortho*-substituents, and the relation between steric demands of the *ortho*-substituents and volume of attacking species are discussed. The underlying mechanism is proposed on the basis of experimental results.

Key words: Reaction kinetics; Arylmercuric halides; Substituent effects; Protonolysis; Mercury.

The reactivity of a large number of benzylmercuric halides and their derivatives has been investigated¹. In contrast to this, studies of phenylmercuric halides and their derivatives, in particular *ortho*-substituted phenylmercuric halides, are scarce. Yadav *et al.* examined the reaction between iodine and 2-R-C₆H₄HgCl (R = H, OH, CH₃, NO₂) in ethanol, and found that the overall order of reaction is two, the rate constant for the derivatives of phenylmercuric chloride decreasing in the order OH > H > CH₃ > NO₂. They proposed that the proximity of the methyl to the HgCl group (in *ortho*-position) is responsible for the reverse effect². However, Fujita and Nishioka³ reported that the steric effect of a single *ortho*-substituent in a benzene derivative is not straightforward. In general, the influence of *ortho*-substituents on the reaction rate, including electronic inductive, steric and field effects, more complex than that of *para*- and *meta*-substituents. Besides these effects, other factors have to be considered, such as the attacking species in the case of second order reactions. In order to get revealing information about the effects of *ortho*-substituents, we have studied the kinetics of the

reaction of *ortho*-substituted phenylmercuric chlorides, 2-R-C₆H₄HgCl (R = H, CH₃, CH₃O, C₂H₅O, CF₃, COOC₂H₅, Cl, Br, F, NO₂), with hydrochloric acid in absolute ethanol in the presence of sodium iodide.

EXPERIMENTAL

Materials

2-Trifluoromethylphenylmercuric chloride (m.p. 132.5–132.7 °C) was prepared from 2-trifluoromethylnitrobenzene and 2-fluorophenylmercuric chloride (m.p. 151.5–152 °C) from 2-chloronitrobenzene⁴. Phenylmercuric chloride (m.p. 258 °C), 2-methylphenylmercuric chloride (m.p. 143 °C), 2-chlorophenylmercuric chloride (m.p. 149 °C), 2-bromophenylmercuric chloride (m.p. 157–159 °C), 2-(ethoxycarbonyl)phenylmercuric chloride (m.p. 150–151 °C), 2-nitrophenylmercuric chloride (m.p. 186–187 °C), 2-ethoxyphenylmercuric chloride (m.p. 114–114.5 °C), and 2-methoxyphenylmercuric chloride (m.p. 178 °C) were prepared and purified using the literature procedures⁵. Sodium iodide was purified by recrystallization from distilled water and dried at 160 °C for 24 h. Hydrochloric acid, special purity grade, was used as purchased. Absolute ethanol was prepared by treating anhydrous ethanol with iodine-activated magnesium.

Kinetic Measurements

All the reactions were conducted in absolute ethanol at temperature ranging from 35 to 50 ± 0.02 °C. Concentration range of reactants: [ArHgCl] = [HCl] = 2.17–4.90 · 10⁻³ mol l⁻¹. The molar ratio of reactants to catalyst was [ArHgCl] : [NaI] = 1 : 7, which is the same as that for NaI-catalyzed reactions of phenylmercuric bromide with HCl in aqueous dioxane mixtures⁶. All reactions were conducted in a glass reactor (Fig. 1), with the upper and lower chambers connected by a ground glass passage, and with a ground hollow glass stopper with a long hollow glass handle fitted to the passage. The reactor has a ground glass cover on the top. When the cover is removed and the stopper is pulled out, a reaction solution can be put into the lower chamber of the reactor with a pipet. The stopper is then put back to block the passage and another reaction solution is put into the upper chamber of the reactor. Finally, the cover is put on to prevent evaporation of the reaction solution. Thus, ArHgCl and NaI were dissolved in absolute ethanol (10 ml) in the lower chamber of the glass reactor. HCl was dissolved in absolute ethanol (10 ml) in the upper chamber. Ethanol was pre-

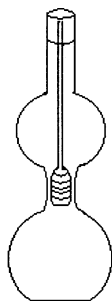
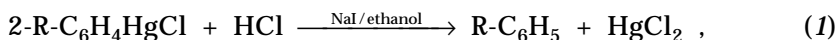


FIG. 1
The sketch of the reactor employed in this study

heated to the reaction temperature before use. The reactor containing the reactants was placed in a thermostat for 15 min to reach the reaction temperature. Immediately after the glass stopper in the centre passage had been pulled out, the reaction mixture was shaken to achieve thorough mixing. The reaction time was taken from this moment on. Samples (2.00 ml) withdrawn at certain time intervals were quickly transferred to conical flasks containing distilled water (4 ml). The unreacted HCl was titrated with standard NaOH using Methyl Red/Methylene Blue as indicator. The reaction rates were calculated from the decrease in HCl.

RESULTS AND DISCUSSION

The observed reaction of *ortho*-substituted phenylmercuric chlorides with HCl in absolute ethanol catalyzed by NaI is described by Eq. (1):



where R = H, CH₃, CH₃O, C₂H₅O, CF₃, COOC₂H₅, Cl, Br, F and NO₂.

The overall order of the reaction equal to two was found by linear regression of $X/(C_0 - X)$ vs time. The results at 40 °C are depicted in Fig. 2. The first order with respect to each reactant was evidenced by monitoring the

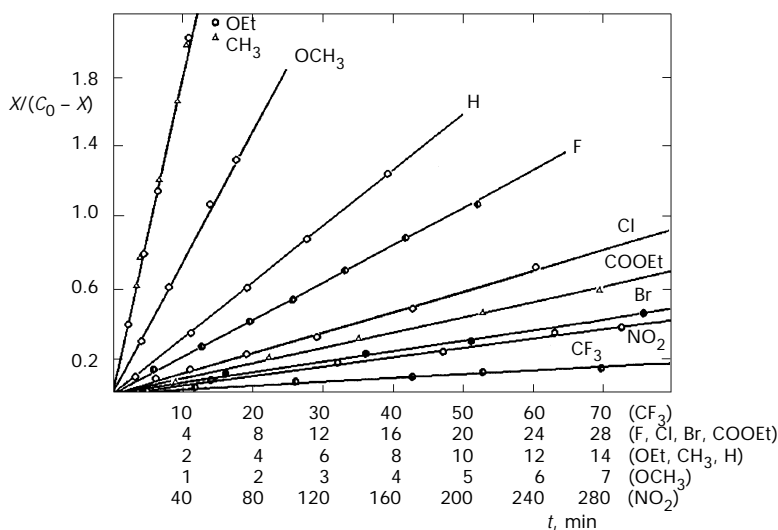


FIG. 2

The reaction of 2-R-C₆H₄HgCl (R = OC₂H₅, CH₃, OCH₃, H, F, Cl, COOC₂H₅, Br, NO₂, CF₃) with HCl in absolute ethanol at 40 °C

decrease in the HCl concentration, keeping the concentration of arylmercuric chlorides constant.

The rate law that represents the experimental kinetic data is given as Eq. (2)

$$\frac{-d[2-R-C_6H_4HgCl]}{dt} = k_2[2-R-C_6H_4HgCl][HCl] \quad (2)$$

Integrating Eq. (2) from $t = 0$ to $t = T$ gives Eq. (3)

$$k_2 = \frac{1}{C_0} \frac{1}{T} \frac{X}{C_0 - X}, \quad (3)$$

where C_0 and X represent the initial and decreased concentration of the reactants at the reaction time, t , respectively. The rate constants k_2 at various temperatures were obtained from the slopes of the $X/(C_0 - X)$ vs time plots, multiplying by $1/C_0$. The experiments were repeated several times so that the relative precision, σ_{rel} , falls in all cases below 4.4%. The values of the rate constant k_2 are summarized in Table I.

According to the Arrhenius equation (4)

$$k = Ae^{-E/RT} \quad (4)$$

the energy of activation, E , for the protonolysis of each *ortho*-substituted phenylmercuric chloride was obtained from the linear regression of $\log k$ vs $1/T$. The frequency factor, $\ln A$, was also calculated. The entropy of activation, ΔS^\ddagger , was obtained from Eq. (5):

$$\ln k = \ln \left(\frac{RT}{Nh} \right) + \frac{\Delta S^\ddagger}{R} - \frac{\Delta H^\ddagger}{RT}, \quad (5)$$

where $\Delta H^\ddagger = E - RT$, and the other symbols have their usual meaning. The values of E , $\ln A$, ΔS^\ddagger and ΔH^\ddagger are given in Table II.

Inductive and Resonance Effects of ortho-Substituents on the Reaction Rate

The *ortho*-substituents impose electronic, inductive, steric and field effects. The overall picture is more complex than in the case of *para*- or *meta*-substituents. In general, the main approach to understanding the effects of

ortho-substituents includes attempts to specify quantitatively the polar effect and then to draw inferences about the contribution of the other factors. In recent years a more complete analysis through multiple regression on appropriate parameters has become possible in some cases. In Table III, we have summarized the reaction rate constants at 40 °C in absolute ethanol together with the corresponding substituent constants, σ_I , σ_R^0 , $\sigma_R(\text{BA})$ and σ_R^+ (ref.⁷), to facilitate ready comparison. The regression of $\log(k/k_H)$ with σ_I and σ_R shows the dual-parameter equation (6)

$$\log \frac{k}{k_H} = \rho_I \sigma_I + \rho_R \sigma_R \quad (6)$$

fit the reaction series.

In the case of $\sigma_R = \sigma_R^0$, the fit is expressed as Eq. (7)

TABLE I
Rate constants for the reaction of 2-R-C₆H₄HgCl with HCl in absolute ethanol

R	ArHgCl 10 ³ . mol l ⁻¹	Temp. °C	k ₂ M ⁻¹ s ⁻¹	σ _{rel} %	R	ArHgCl 10 ³ . mol l ⁻¹	Temp. °C	k ₂ M ⁻¹ s ⁻¹	σ _{rel} %
C ₂ H ₅ O	3.15	35.0	4.03	2.3	CO ₂ C ₂ H ₅	4.90	40.0	1.59 · 10 ⁻¹	2.1
	2.47	40.0	5.57	1.1		3.906	45.0	2.50 · 10 ⁻¹	2.5
	2.55	45.0	7.83	2.3		3.87	50.0	3.45 · 10 ⁻¹	3.5
	3.30	50.0	10.13	2.7		F	4.54	40.0	1.52 · 10 ⁻¹
CH ₃ O	3.48	35.0	3.27	3.1	Cl	3.23	35.0	6.60 · 10 ⁻¹	4.0
	3.29	40.0	4.65	2.2		2.25	40.0	9.25 · 10 ⁻²	2.0
	3.88	45.0	7.08	2.0		2.98	45.0	1.52 · 10 ⁻¹	2.3
	2.99	50.0	9.50	2.3		3.03	50.0	2.18 · 10 ⁻¹	3.1
CH ₃	2.79	35.0	2.05	3.0	Br	4.02	35.0	4.80 · 10 ⁻²	3.0
	2.77	40.0	4.12	2.0		3.95	40.0	6.58 · 10 ⁻²	1.9
	3.65	45.0	8.40	2.3		4.12	45.0	1.11 · 10 ⁻¹	2.1
	3.97	50.0	12.73	3.0		3.57	50.0	1.51 · 10 ⁻¹	3.5
H	3.56	35.0	1.21	2.6	CF ₃	4.53	35.0	9.25 · 10 ⁻³	2.8
	2.17	40.0	1.73	1.9		3.78	40.0	1.16 · 10 ⁻²	2.2
	2.77	45.0	3.02	2.0		3.99	45.0	1.50 · 10 ⁻²	1.9
	2.38	50.0	4.30	2.5		4.23	50.0	1.89 · 10 ⁻²	3.3
CO ₂ C ₂ H ₅	4.23	35.0	1.18 · 10 ⁻¹	3.0	NO ₂	4.21	40.0	4.78 · 10 ⁻³	4.3

TABLE II
Thermodynamic parameters for the NaI-catalyzed reaction of 2-R-C₆H₄HgCl with HCl in absolute ethanol and Swain-Lupton field parameters, ρ

R	E_a	$\ln A$	$\Delta S_{40^\circ}^\ddagger$ J K mol ⁻¹	$\Delta H_{40^\circ}^\ddagger$ kJ mol ⁻¹	ρ
C ₂ H ₅ O	50.71	21.19	-77.43	48.11	0.61
CH ₃ O	58.21	23.89	-54.98	55.61	0.54
CH ₃	101.86	40.53	83.39	99.26	-0.10
H	70.92	27.78	-22.62	68.32	0.00
CO ₂ C ₂ H ₅	76.44	27.52	-24.95	73.84	0.47
Cl	66.33	23.09	-61.63	63.73	0.72
Br	63.57	21.69	-73.27	60.97	0.72
CF ₃	38.75	10.42	-166.95	36.15	0.64

TABLE III
Rate constants for the NaI-catalyzed reaction of 2-R-C₆H₄HgCl with HCl at 40 °C in absolute ethanol and the corresponding substituent constants

R	$k, M^{-1} s^{-1}$	$\log k/k_H$	σ_I	σ_R^0	$\sigma_R(BA)$	σ_R^+	σ_m^+	σ_p^+
CH ₃ O	4.65	$4.29 \cdot 10^{-1}$	0.26	-0.41	-0.61	-1.02	0.047	-0.778
CH ₃	4.12	$3.76 \cdot 10^{-1}$	-0.05	-0.10	-0.11	-1.25	-0.066	-0.311
H	1.73	0	0.00	0.00	0.00	0.00	0.000	0.000
CO ₂ C ₂ H ₅	$1.59 \cdot 10^{-1}$	-1.04	0.31	0.15	0.14	0.14	0.366	0.482
F	$1.52 \cdot 10^{-1}$	-1.06	0.15	-0.34	-0.45	-0.57	0.352	-0.073
Cl	$9.25 \cdot 10^{-2}$	-1.27	0.47	-0.21	-0.23	-0.23	0.399	0.114
Br	$6.58 \cdot 10^{-2}$	-1.42	0.45	-0.16	-0.19	-0.19	0.405	0.150
CF ₃	$1.16 \cdot 10^{-2}$	-2.17	0.41	0.13	0.08	0.08	0.520	0.612
NO ₂	$4.78 \cdot 10^{-3}$	-2.56	0.64	0.19	0.15	0.15	0.674	0.790

$$\log \frac{k}{k_H} = -3618\sigma_I - 1.486\sigma_R^0 . \quad (7)$$

The equation is significant at $\alpha = 0.025$ ($F = 10.62 > F_c \langle 4, 4; 0.025 \rangle = 9.600$). The coefficient of determination, R^2 , and the adjusted coefficient of determination, R_{adj}^2 , are 0.7798 and 0.7431, respectively.

In the case of $\sigma_R = \sigma_R(\text{BA})$, the fit is expressed as Eq. (8)

$$\log \frac{k}{k_H} = -3.576\sigma_I - 0.5297\sigma_R(\text{BA}) . \quad (8)$$

The equation is significant at $\alpha = 0.05$ ($F = 8.267 > F_c \langle 4, 4; 0.05 \rangle = 6.390$). The coefficient of determination, R^2 , and the adjusted coefficient of determination, R_{adj}^2 , are 0.7337 and 0.6894, respectively.

In the case of $\sigma_R = \sigma_R^+$, the fit is expressed as Eq. (9)

$$\log \frac{k}{k_H} = -3.6232\sigma_I - 0.5110\sigma_R^+ . \quad (9)$$

The equation is significant at $\alpha = 0.05$ ($F = 9.539 > F_c \langle 4, 4; 0.05 \rangle = 6.390$). The coefficient of determination, R^2 , and the adjusted coefficient of determination, R_{adj}^2 , are 0.7607 and 0.7209, respectively.

For the Eqs (7)–(9) the ratios of the two regression coefficients (ρ_R/ρ_I) are 0.411, 0.148 and 0.141, respectively. This indicates that for the studied reaction series the inductive effects of the *ortho*-substituents are more significant than the resonance effects. The same conclusion can also be drawn from the comparison of the relationships between $\log(k/k_H)$ and *meta*-Hammett–Brown substituent constants, σ_m^+ , and *para*-Hammett–Brown substituent constants, σ_p^+ , for the studied reaction series, using σ_m^+ and σ_p^+ to substitute for σ_o^+ , respectively.

The corresponding Hammett–Brown substituent constants⁸ for the *meta*- and *para*-substituents are collected in Table III. Considering the large range of reactivity covered by the protonolysis, the linear relationship between σ_m^+ and $\log(k/k_H)$ is good (Fig. 3, correlation coefficient 0.982). Least squares treatment of these points leads to a value for the reaction constant, $\rho = -4.35$. It is known that the *ortho*- and *para*-substituents always possess similar electronic effects on aromatic substitution, for the resonance effects of substituents exist in both cases, but the resonance effects are not obvious in the case of *meta*-substituents. Nevertheless, it was observed for the reaction

series that the linear relationship between σ_p^+ and $\log(k/k_H)$ (Fig. 4, correlation coefficient 0.915) is not as apparent as that between σ_m^+ and $\log(k/k_H)$, which suggested that the resonance effects of *ortho*-substituents are weaker.

One explanation for the small resonance effects of *ortho*-substituents is in their intramolecular coordination at the mercury atom, which was confirmed by our previous study of the crystal structure of 2-(ethoxycarbonyl)phenylmercuric chloride⁹. This intramolecular coordination transfers the p- or π -electron pairs from the heteroatoms of *ortho*-substituents to d-orbitals of mercury to form coordination bonds between the atoms. Hence, the *ortho*-substituents have no p- or π -electrons capable of mesomeric interaction with the reaction centre in the benzene ring.

Mechanism

While analogies to other electrophilic substitution reactions of organometallic, in particular arylmercuric compounds¹⁰ can be cited, we have presently got some direct evidence for a S_E2i mechanism (Scheme 1).

It is believed that the protonolysis of *ortho*-substituted phenylmercuric chlorides involves: (i) coordination of I^- at the mercury atom; (ii) slow electrophilic attack of the electrophilic H atom of the HCl reagent at the mercury-bonded C atom, and coordination of the Cl nucleophile at the

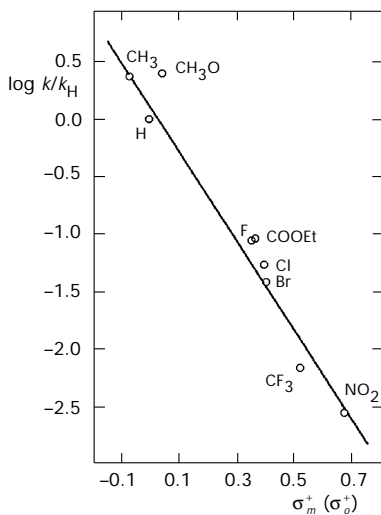


FIG. 3
Relationship between σ_m^+ and $\log(k/k_H)$

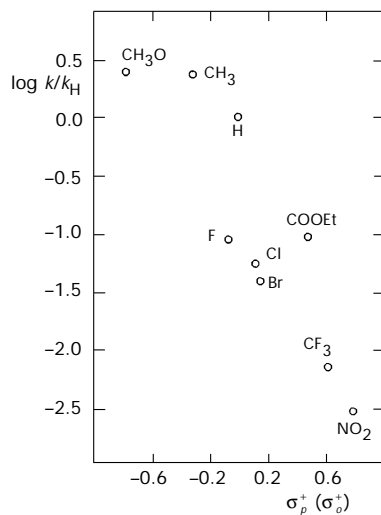
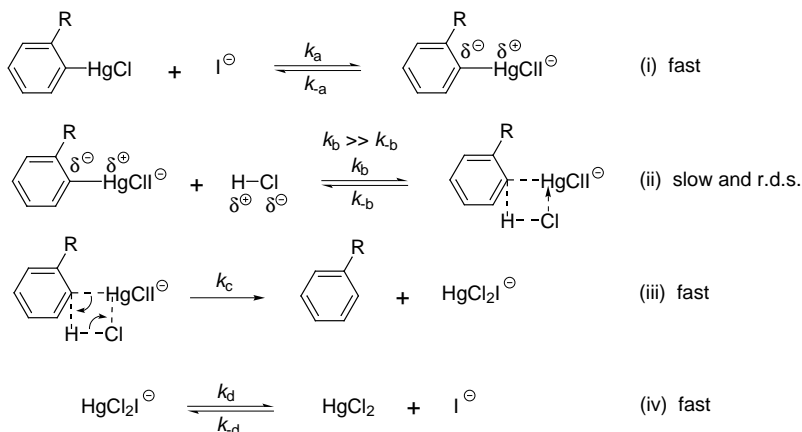


FIG. 4
Relationship between σ_p^+ and $\log(k/k_H)$

mercury atom to produce a four-centre transition state (the rate-determining step); (iii) fast decomposition of the transition state and (iv) regeneration of the catalyst I^- .



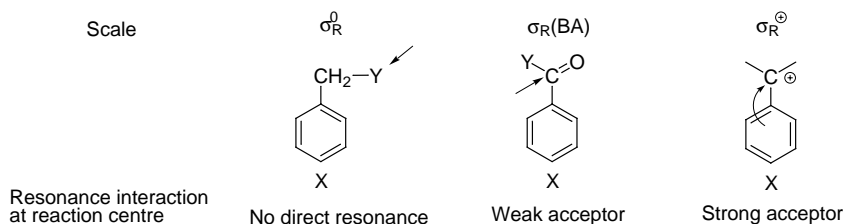
SCHEME 1

The coordinated complex, $2\text{-R-C}_6\text{H}_4\text{HgClI}^-$, produced in the first reaction step, was identified by its absorption band at about 303 nm in the UV spectrum¹¹. In fact, this equilibrium precedes other steps, since before the protonolysis begins, arylmercuric chlorides and sodium iodide have been mixed and preheated. The nucleophilic catalytic action of I^- on increasing the reactivity of the C–Hg bond in arylmercurials and the relationship between the concentrations of I^- and reactants were reported in a previous paper⁶. The nucleophilic catalytic action of I^- was also confirmed by our observation that no protonolysis occurred during one day at 40 °C if the system contained no NaI. The rate-determining coordination of the nucleophilic part (N) of the electrophilic agent (E–N) at the metal atom appears to be quite significant for occurrence of such reactions¹⁰. The influence of the coordination of the nucleophilic part (Cl) of HCl at the mercury atom on occurrence of the protonolysis was revealed by the fact observed in our study that the S_{E2i} protonolysis did not occur when HCl completely ionized in the aqueous ethanol solvent.

For the dual-parameter equation (6), the applicability of three resonance substituent constants, σ_R^0 , $\sigma_R(\text{BA})$ and σ_R^+ is obvious from Scheme 2.

Among the three dual-parameter equations (7)–(9), Eq. (7) is the most significant one at $\alpha = 0.025$, and its coefficient of determination, R^2 , and adjusted coefficient of determination, R_{adj}^2 , are the largest. This suggests that

the reaction centre for the reaction series under investigation is not only concentrated on the mercury-bonded C atom, but also partly located on the mercury atom, resulting in a four-centre transition state.



SCHEME 2

Based on the slow step in Scheme 1.

$$\text{rate} = k_b [2\text{-R-C}_6\text{H}_4\text{HgClI}^-] [\text{HCl}] \quad (k_b \gg k_{-b}) \quad (10)$$

Solving for $[2\text{-R-C}_6\text{H}_4\text{HgClI}^-]$ from the first equilibrium gives after proper substitution

$$[2\text{-R-C}_6\text{H}_4\text{HgClI}^-] = \frac{k_a}{k_{-a}} [\text{I}^-] [2\text{-R-C}_6\text{H}_4\text{HgCl}] \quad (k_a \gg k_b) \quad (11)$$

Equation (10) transforms on substitution for $[2\text{-R-C}_6\text{H}_4\text{HgClI}^-]$ in Eq. (11) to Eq. (12)

$$\text{rate} = \frac{-d[2\text{-R-C}_6\text{H}_4\text{HgCl}]}{dt} = k_b \frac{k_a}{k_{-a}} [\text{I}^-] [2\text{-R-C}_6\text{H}_4\text{HgCl}] [\text{HCl}] \quad (12)$$

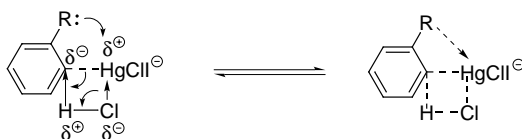
Finally, considering $k_b k_a [\text{I}^-] / k_{-a} = k_2$, as the concentration of the catalyst I^- remains constant, we obtain

$$\text{rate} = \frac{-d[2\text{-R-C}_6\text{H}_4\text{HgCl}]}{dt} = k_2 [2\text{-R-C}_6\text{H}_4\text{HgCl}] [\text{HCl}] \quad (13)$$

Equation (13) is identical with the experimentally found Eq. (2).

Field Effects of ortho-Substituent

It is well known that the entropy of activation ΔS^\ddagger is a measure of the change in regularity for a process from the ground state to the transition state. If other factors in a reaction system were ignored, the more ordered the transition state, the smaller the entropy of activation ΔS^\ddagger . In the process of the formation of a four-centre transition state, the electron pair of the C-Hg bond partly expands to the space between the C and H(Cl) atoms, which reduces the electron density at the Hg atom. At the same time *ortho*-substituents with the p- or π -electron pair coordinate at the mercury atom, that is, the field effects of *ortho*-substituent arise (Scheme 3).



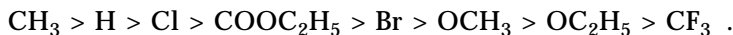
SCHEME 3

Such coordination leads to a more orderly cyclic structure of the transition state.

In Table II we have summarized the entropy of activation ΔS^\ddagger of the reactions together with the corresponding Swain-Lupton field effect parameters⁷, \mathfrak{F} , to facilitate ready comparison. From Table II it is obvious that the values of Swain-Lupton field effect parameters increase for the 2-R-substituents in the order



and the values of the entropy of activation for the studied reaction series decrease in the order



Except for the two halogens, Cl and Br, the latter series correlates with the former series on the whole, which supports the existence of field effects of the *ortho*-substituent in the studied reaction series.

For the reaction series, field effects and resonance effects caused by the p- or π -electron pairs of the *ortho*-substituents are strongly competitive: the strong one would suppress the weaker. The position of Cl and Br, in the second series can be explained by such reasoning.

Relationship Between Steric Effects of ortho-Substituents and Volume of Attacking Species

It was reported that the rate constant for the reaction between 2-CH₃-C₆H₄HgCl and I₂ in ethanol, catalyzed by I⁻, is smaller than that for C₆H₄HgCl. This was explained by considering the proximity of the methyl and HgCl groups (in *ortho*-position) to be responsible for the reverse effect². However, from Table I it is obvious that in the case of HCl as attacking species, the order of rate constants for different 2-R-substituents of phenylmercuric chloride is 2-C₂H₅O > 2-CH₃O > 2-CH₃ > H > 2-COOC₂H₅ > 2-F > 2-Cl > 2-Br > 2-CF₃ > 2-NO₂. That is, the reverse effect of the *ortho*-methyl group is not observed. The difference in the size of attacking species may explain these experimental facts. In particular, the I-I bond length in molecular I₂ is 2.666 Å, which is much larger than that of H-Cl (1.274 Å) in the HCl molecule. In the rate-determining step, the reaction of 2-CH₃-C₆H₄HgClI⁻ with I₂ produces a four-centre transition state, and the methyl group would hinder the attack of I₂ at the mercury-bonded C atom. In the case of the much smaller attacking HCl molecule, the steric hindrance by the methyl group is likely less significant.

The authors wish to thank Dr X. Gao, Dr C. Liu (both Institute of Botany, Chinese Academy of Sciences, Beijing), Prof. Z. Mao (Institute of Chemical Metallurgy, Chinese Academy of Sciences, Beijing) and Dr M. Tang (Zhengzhou University) for their support of this work.

REFERENCES

1. Jenson F. R., RicxBorn B.: *Electrophilic Substitution of Organomercurials*, p. 75. McGraw-Hill, New York 1968.
2. Yadav P. L., Ramakrishna V., Jha N. K.: *Indian J. Chem., Sect. A: Inorg., Phys., Theor. Anal.* **1978**, 16, 623.
3. Fujita T., Nishioka T.: *Prog. Phys. Org. Chem.* **1976**, 12, 49.
4. Wang Y., Wu Y.: *Synth. React. Inorg. Met.-Org. Chem.* **1998**, 28, 1535.
5. Hy H., Ni J., Kao T.: *Hua Hsueh Hsueh Pao* **1979**, 37, 9; *Chem. Abstr.* **1979**, 91, 20645.
6. Beletskaya I. P., Meicki L. E., Reutov O. A.: *Izv. Akad. Nauk SSSR, Ser. Khim.* **1965**, 2, 240.
7. Isaacs N. S.: *Physical Organic Chemistry*, p. 157. Wiley, New York 1987.
8. Brown H. C., Okamoto Y.: *J. Am. Chem. Soc.* **1958**, 80, 4979.
9. Pan Z., Wei X., Shao M., Wu Y., Chen Z., Wang Y., Hu H.: *Huaxue Xuedao* **1985**, 43, 801; *Chem. Abstr.* **1986**, 104, 43559.
10. Reutov O. A.: *Tetrahedron* **1978**, 34, 2827.
11. Chen Z., Wu Y., Zhang X., Chen R., Hu H.: *Acta Chim. Sinica* **1983**, 41, 57; *Chem. Abstr.* **1983**, 98, 160863.