KINETICS AND MECHANISM OF IODINATION OF SUBSTITUTED HYDROXYACETOPHENONES BY IODINE MONOCHLORIDE IN ACETIC ACID : WATER MEDIUM

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ABSTRACT

Kinetics of iodination of substitued hydroxyacetophenones using iodine monochloride in acetic acid : water medium has been investigated, in the temperature range of $25^0C – 45^0C$. The substrates used were, 5'- chloro, 5'-methyl- 5'-bromo, 3' -chloro 5'-chloro - 4' methyl ; derivatives of 2'- hydroxy-acetophenones and res, 2,5-dihydroxyacetophenones.

The overall order is found to be two and individual orders were found to be one in substrate and in ICl as well. The effects of solvent, temperature, concentration of sodium perchlorate and perchloric acid on iodinaton is also investigated. Probable mechanism is proposed on the basis of kinetic results and thermodynamic parameters.

Key words: Kinetics, Iodination, Iodine monochloride, Acetophenone.

INTRODUCTION

Hydroxy halogeno-acetophenones are well known for their antifungal and antibacterial activities[1,2]. Electrophilic aromatic substitution (Iodinations) have been extensively investigated[3-9]. The kinetics of iodination of phenols in dil. aq. perchloric acid is also studied[10]. It is also studied by using by ICl in aq. AcOH medium[10-12]. Very few attempts have been made to elucidate structure and reactivity in the iodination of hydroxyacetophenones.

Hence, some hydroxyacetophenones were considered for iodination by ICl in aq. AcOH medium, keeping in view to identify the nature of substrate species and also to study

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the effect of acidity and the dielectric constant of the medium on rate of iodination of hydroxylacetophenones.

EXPERIMENTAL

Purification of materials used

Acetic acid

The preparation of pure anhydrous acid ($\pm$ fp. 16.3^{0}C) was carried out by the method of Orton and Brandfiend. Aqueous acetic acid solution was prepared by adding the purified acetic acid into calculated amount of distilled water, taken in volumetric flask. The comosition being expressed as the number of volume of water contained in 1000 volume of the aqueous acid.

Iodine monochloride

Iodine monochloride from ampoules (Merck, AR) were used after dilution. The kinetics of the reaction was followed by estimation the unreacted iodine monochloride iodometrically to a strach end point in presence of iodide ion and H$^+$. The rate constants calculated were reproducible within $\pm$ 3% error.

Sodium perchlorate

Highly pure AR-grade sodium perchlorate (BDH) was used after making it's required concentration in distilled water.

Prechloric acid

The BDH-AR grade perchloric acid was used after making solution of required concentration in distilled water.

Sodium thioulphate

Sodium thiosulphate (BDH AR) was used. Its stock solution was prepared and standardized against potassium dichromate. Approximately 3 mL of chlorofrom (BDH AR) was added to one litre of solution (0.2 M) of sodium thiosulphate as a preservative. Other solutions were prepared from the stock solution by suitable dilutions.

Substrates

(i)   5'-Chloro-2'-hydroxyacetophenone

(ii)   5'-Methyl-2'-hydroxyacetophenone

    (iii)   3'-Choloro-2'-hydroxyacetophenone

    (iv)   5'-Bromo-2'-hydroxyacetophenone

    (v)   3'-Bromo-2'-hydroxyacetophenone

    (vi)   2', 4' -Dihydroxyacetophenone

    (vii) 2', 5', -Dihydroxyacetophenone

The compounds, (i) to (vii) were prepared and recrystallised and used for iodination.

Temperature control

Thermostatic bath, with fitted automatic temperture control device, was used to maintain the temperature with accuracy of $\pm\, 0.05^{\circ}$C.

Kinetic measurements

The kinetic mesurements have been carried out by plotting concetration of ICl iodometrically as function of time using 'batch mathod' recommended by Gananapragasam and Yaddanapalli.

RESULTS AND DISCUSSION

Iodination of 5'-chloro, 5'-methyl, 3'-chloro-4-methyl, 3'-chloro, 4'-hydroxy and 5'-hydroxy substituted 2'-hydroxyacetophenes in AcOH : H_2O (80 : 20v/v) medium by iodine monochloride has been Investigated. It was found that the oerall order dertemined by fractional life method is two (Table 1) in case of all the hydroxyacephenones.

The individual orders were determined by fractional life method.

The concertration of hydroxyacetophenone was kept constant and that of ICl was varied to find the order in ICl. The results show that the order w.v.t. ICl is unity (Table 2).

The concentration ICl is kept constant and that of hydroxyacetophenone was varied to find the order w.v.t. hydroxyacetophenone. The results show that the order w.v.t. hydroxyacetophenone is unity (Table 3).

The orders for hydroxyacetophenone and for ICl were also determined by initial rate method and found to be unity (Table 4).

Table 1: Determination of overall order in iodionation of 2'-hydroxyacetophenones by fractional life method

[HClO$_4$] = 0.001M   Solvent = AcOH : H$_2$O (80 : 20 v/v)

[NaClO$_4$] = 0.002M   Δ = [Phenol]

[NaCl] = 0.002 m   * = [ICl]; Temperature = 303 K

% of ICl related	Compd.	C$_2$ Mol L^{-1}	C$_1$ Mol L^{-1}	T$_2$ (min)	T$_1$ (min)	Order
15	A	Δ 0.3	0.15	4	9	2.1
		*0.03	0.015			
	B	Δ0.02	0.15	3	4	2.0
		* 0.02	0.015			
	C	Δ 0.1	0.075	5	7	2.1
		*0.01	0.0075			
	D	Δ 0.15	0.1	5	8.5	2.3
		* 0.015	0.01			
20	A	Δ 0.3	0.15	8	19	2.2
		* 0.03	0.015			
	B	Δ 0.2	0.15	5	7	2.1
		* 0.02	0.015			
	C	Δ 0.1	0.075	8	11	2.1
		* 0.15	0.0075			
	D	Δ 0.15	0.1	8.5	14.5	2.3
		* 0.015	0.01			
15	A	Δ 0.15	0.1	9	14	2.1
		*0.015	0.015			
	B	Δ0.15	0.1	4	6.5	2.1
		* 0.015	0.01			
	C	Δ 0.15	0.05	7	11	2.1
		*0.075	0.005			

% of ICl related	Compd.	C_2 Mol L^{-1}	C_1 Mol L^{-1}	T_2 (min)	T_1 (min)	Order
	D	Δ 0.1	0.05	8.5	15.5	1.86
		* 0.01	0.005			
20	A	Δ 0.15	0.1	19	31	2.2
		* 0.015	0.01			
	B	Δ 0.15	0.1	7	1	2.1
		* 0.015	0.01			
	C	Δ 0.075	0.075	11	25	2.1
		* 0.0075	0.005			
	D	Δ 0.1	0.5	14.5	26	1.84
		* 0.01	0.005			

C_1 and C_2: Initial concentrations

t_1 and t_2: Time required for constant
        percentage of reaction

A – 5' –Chloro

B – 5' –Methyl

C – 5'–Chloro–4'–Methyl

D – 3' –Chloro

Table 2: Determination of overall order in iodination of 2'-hydroxyacetophenones by fractional life method

[HClO$_4$] = 0.001M   Solvent = AcOH : H$_2$O (80 : 20 v/v)

[NaClO$_4$] = 0.002M

[NaCl] = 0.002 m   * = [ICl]; Temperature = 303 K

% of ICl related	Compd.	C_2 Mol L^{-1}	C_1 Mol L^{-1}	T_2 (min)	T_1 (min)	Order
		Order in ICl ; [Phenol] = 0.2 M [ICl] = Varied				
15	A	0.1	2	2	4	1.0
	B	0.01	1	1	2.5	1.3
	C	0.01	1	1	2	1.0

% of ICl related	Compd.	C_2 Mol L^{-1}	C_1 Mol L^{-1}	T_2 (min)	T_1 (min)	Order
	D	0.005	1	1	2.5	1.3
20	A	0.01	5	5	10	1.0
	B	0.01	3	3	6.0	1.2
	C	0.01	0.005	2.5	5.5	1.1
	D	0.005	0.0025	3.5	6.5	0.9
15	A	0.02	0.01	4	8	1.0
	B	0.02	0.01	2.5	6.0	1.2
	C	0.02	0.01	2	4	1.0
	D	0.01	0.005	2.5	6.5	1.3
20	A	0.02	0.01	10	20	1.0
	B	0.02	0.01	6	12	1.0
	C	0.02	0.01	5.5	11	1.0
	D	0.01	0.005	6.5	17	1.3

C_1 and C_2: Initial concentrations

t_1 and t_2: Time required for constant percentage of reaction

A – 5' –Chloro
B – 5' –Methyl
C – 5'–Bromo
D – 3' –Chloro

The iodination of substituted 2'-hydroxyacetophenonoes in AcOH : H_2O = (80 : 20 v/v) medium by iodine monochloride is of overall second order. It is explained by assuming the iodination as a second order process. The general mechanism for second order iodination may be given as –

At lower $[H^+]$ (< 0.01 M).

$$ICl + S \xrightleftharpoons{K} Complex \qquad \qquad ...(1)$$

$$Complex \xrightleftharpoons[k_1]{slow} Products \qquad \qquad ...(2)$$

The rate law is given as –

$$\frac{-d\,[ICl]}{dt} = k_2\,[phenol]\,[ICl] \qquad\qquad …(3)$$

As the concentration of $HClO_4$ was increased, the rate of iodination also increases.

Hence, the reaction mecahanism may be -

$$ICl + H_3O^+ \xrightleftharpoons{K} H_2OI^+ + HCl \qquad\qquad …(4)$$

$$H_2OI^+ + S \xrightleftharpoons{K_L} Complex \qquad\qquad …(5)$$

$$Complex \xrightarrow[slow]{k_2} Products \qquad\qquad …(6)$$

The observed results are in agreement with a reaction between the phenoxide ion and the iodinating species – hypoiodous acidium ion (H_2OI^+). The rates of iodination of various hydroxyacetophenones on comparison reveals their relative activity (Table 3). The electron releasing group enhance the rate of reaction i. e. 2', 4'-dihydroxyacetophenone and 2', 5'-dihydroxyacetophenones react more faster than halogenosubstituted 2'-hydroxy acetophenones or other 2'-hydroxy acetophenones. It is observed that methyl group at 5'-position has also are rate almost the same as 5'-halogeno, 2'- hydroxyacetophenoes.

Table 3: Determination of overall order in iodination of 2'-hydroxylacetophenones by fractional life method

$[HClO_4] = 0.001$ M Solvent = AcOH : H_2O (80 : 20 v/v)
$[NaClO_4] = 0.002$ M
$[NaCl] = 0.002$ m Temperature = 303 K

% of ICl related	Compd.	C_2 Mol L^{-1}	C_1 Mol L^{-1}	T_2 (min)	T_1 (min)	Order
		Order in ICl ; [Phenol] = 0.2 M				
		[ICl] = Varied				
15	A	0.3	0.2	2.5	4.0	1.1
	B	0.2	0.15	4.5	6	1.0
	C	0.1	0.07	2	3	1.1

% of ICl related	Compd.	C_2 Mol L^{-1}	C_1 Mol L^{-1}	T_2 (min)	T_1 (min)	Order
	D	0.15	0.1	5	9	1.4
20	A	0.3	.0.2	7.5	11.5	1.0
	B	0.2	0.15	7.5	10	1.0
	C	0.1	0.07	3	5	1.3
	D	0.15	0.1	9	16	1.4
15	A	0.2	0.1	4	7	0.080
	B	0.15	0.1	6	10	1.2
	C	0.07	0.03	3	9	1.3
	D	0.1	0.05	9	16.5	0.9
20	A	0.2	0.1	11.5	23	1.0
	B	0.15	0.1	10	17	1.3
	C	0.07	0.03	3	9	1.3
	D	0.0	0.05	16	30	0.9

A – 5' –Chloro

C_1 and C_2: Initial concentrations   B – 5' –Methyl

C – 5'–Bromo

t_1 & t_2: Time required for constant   D – 3' –Chloro
        percentage of reaction

Table 4: Effect of temperature on the rate constant of iodination of 2'-hydroxyacetophenones

[HClO$_4$] = 0.001 M   Solvent = AcOH : H$_2$O (80 : 20 v/v)
[NaClO$_4$] = 0.002 M
[NaCl] = 0.002 m   Temperature = 303 K

Temp. (K)	Compound	k (lit. mol^{-1} min^{-1})
293	A	1.2×10^{-2}
	B	1.055×10^{-2}

Temp. (K)	Compound	k (lit. mol⁻¹ min⁻¹)
	C	8.63×10^{-3}
	D	$6.9.3 \times 10^{-3}$
298	A	1.38×10^{-2}
	B	1.47×10^{-2}
	C	1.03×10^{-2}
	D	8.636×10^{-3}
303	A	1.48×10^{-2}
	B	1.430×10^{-2}
	C	1.115×10^{-2}
	D	1.360×10^{-2}
308	A	2.04×10^{-2}
	B	1.727×10^{-2}
	C	1.279×10^{-2}
	D	1.465×10^{-2}
313	A	2.83×10^{-2}
	B	1.91×10^{-2}
	C	1.439×10^{-2}
	D	1.535×10^{-2}

A-5'-Chloro , B-5'-Methyl, C-5'-Chloro-4'-methyl, D-3'-Chloro

MECHANISM

The reaction for 5'-substitued hydroxyacetophenones probably occurs by the following mechanism. $\Delta H^{\neq}$ and $\Delta S^{\neq}$ values (Table 5) agree with those of other electophilic substitution reactions. Low value of ΔE^{*} of different hydroxyacetophenones (Table 5) show that iodination by ICl is fast, when a strong electron withdrawing group like ($-NO_2$) is present.
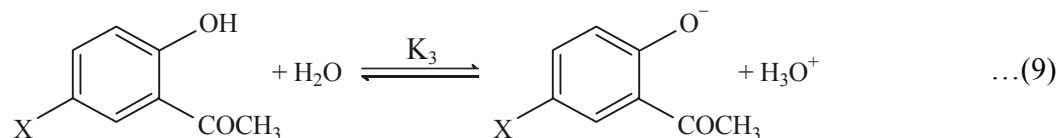
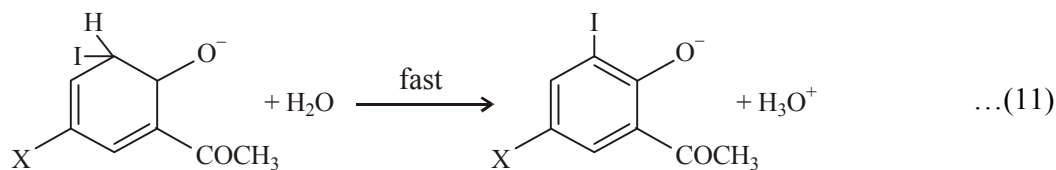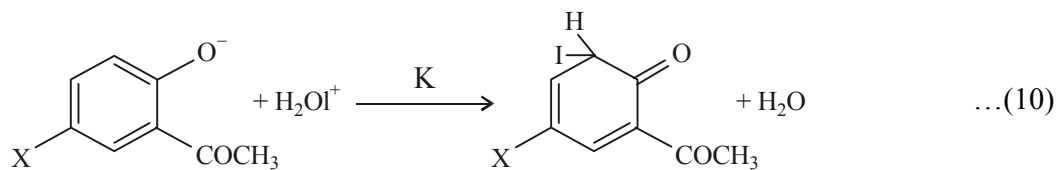**Table 5: Activation parameters for iodination of 2'-hydroxyacetophenones at 303 K**

[Phenol] = 0.05 M		[ICl] = 0.005M
[HClO$_4$] = 0.001 M		[NaClO$_4$] = 0.002M
[NaCl] = 0.002 m		Solvent = AcOH : Water (80 : 20 v/v)

Compd.	K (mol^{-1} min^{-1})	$\Delta E^{\neq}$ (KJ mol^{-1})	$\Delta H^{\neq}$ (KJ mol^{-1})	$\Delta S^{\neq}$ (JK mol^{-1})	$\Delta G^{\neq}$ (KJ mol^{-1})	log A$^{\neq}$
A	1.43×10^{-2}	33.15	30.60	179.67	-23.82	3.85
B	1.439×10^{-2}	23.79	21.24	218.10	-44.84	1.8455
C	1.100×10^{-2}	18.06	15.49	231.16	-54.51	1.16
D	0.557×10^{-2}	19.34	16.49	232.6	-54.89	1.1189
E	1.36×10^{-2}	38.69	36.14	161.95	-12.92	4.7795
F	10.03×10^{-2}	19.34	16.8	223.60	-50.94	0.57
G	15.55×10^{-2}	14.77	12.23	235.2	-59.04	0.9812

2- Hydroxyacetophenones

A = 5' – Chloro	E = 3' –Chloro
B = 5' – Methyl	F = 4' – Hydroxy
C = 5' – Bromo	G = 5' – Hydroxy
D = 5' – Chloro – 4' –methyl	($\neq$ - Calculated)

Relativly small positive value of $\Delta H^{\neq}$ and large negative values of $\Delta S^{\neq}$ show that this reaction passes through organized rate determining transition sates in which bond fromation of intermediate complex takes place. Values of $\Delta S^{\neq}$ also indicate the formation of complex in the rate determining step[12].
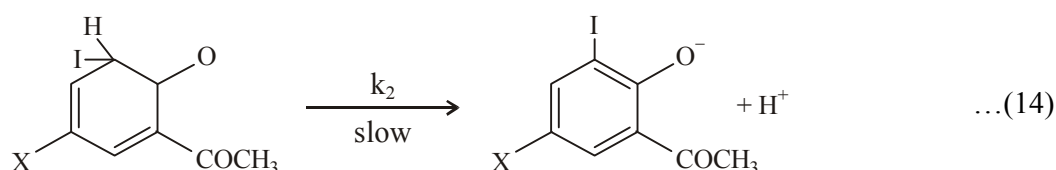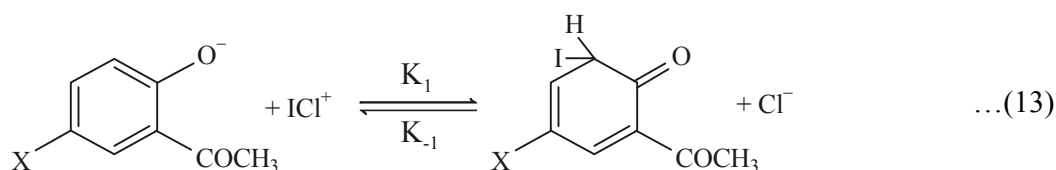
$$ICl_2^- \xrightleftharpoons{K_1} ICl + Cl^- \qquad \qquad \text{...(7)}$$

$$ICl + H_2O \xrightleftharpoons{K_2} H_2OI^+ + Cl^- \qquad \qquad \text{...(8)}$$

$$\text{...(9)}$$

$$+ H_2OI^+ \quad \xrightarrow{K} \quad + H_2O \qquad ...(10)$$

$$+ H_2O \quad \xrightarrow{fast} \quad + H_3O^+ \qquad ...(11)$$

The rate law is given as -

$$-\frac{d\,[ICl]}{dt} = \frac{K.\,K_1\,K_2\,K_3}{[H^+]^2\,[Cl^-]\,K_1 + [Cl^-]} \quad x\ [Phenol]\,[ICl] \qquad ...(12)$$

or

$$+ ICl^+ \quad \underset{K_{-1}}{\overset{K_1}{\rightleftharpoons}} \quad + Cl^- \qquad ...(13)$$

$$\xrightarrow[slow]{k_2} \quad + H^+ \qquad ...(14)$$

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