International Journal of Applied Research 2016; 2(11): 317-321

ISSN Print: 2394-7500
ISSN Online: 2394-5869
Impact Factor: 5.2
IJAR 2016; 2(11): 317-321
www.allresearchjournal.com
Received: 17-09-2016
Accepted: 18-10-2016

R Kavitha
PG & Research Department of Chemistry, Urumu Dhanalakshmi College, Tiruchirappalli, Tamil Nadu, India

S Ananthalakshmi
PG & Research Department of Chemistry, Urumu Dhanalakshmi College, Tiruchirappalli, Tamil Nadu, India

Correspondence
R Kavitha
PG & Research Department of Chemistry, Urumu Dhanalakshmi College, Tiruchirappalli, Tamil Nadu, India

Kinetic studies on the reaction of *p*-Toluenesulfonyl chloride with α-Hydroxy acids in the presence of pyridine in acetonitrile

R Kavitha and S Ananthalakshmi

Abstract
The kinetic studies on the reaction of *p*-Toluenesulfonyl Chloride (TsCl) with α-Hydroxy acids in the presence of Pyridine under equimolar and *pseudo* first order conditions in Acetonitrile at 20, 30 and 40 ˚C have been studied by conductometric method. The rate constants were obtained by the least square method. Kinetic data shows that the reaction follows second order kinetics and first order with respect to each of the reactants. The attacking nucleophile is found to be a hydrogen bonded ion pair. Thermodynamic parameters have been evaluated by using kinetic data. The entropy of activation is negative as expected for bimolecular reactions. Kinetic data and product analysis indicate that the reaction proceeds through direct nucleophilic attack on the sulfur center.

Keywords: Substitution kinetics, sulfonyl ester, hydrogen bonded ion-pair, activation parameters, isokinetic temperature

1. Introduction
Chemical kinetics is the study of rate of chemical processes which includes investigations of a reaction in different experimental conditions and their influences on the speed of chemical reaction. The various factors such as concentration, pressure, temperature, medium, effect of catalyst etc., decides the rate of reaction [1]. Kinetic studies provide information about the transition state and reaction mechanism. The mechanism tells about the changes in arrangement of electrons in the starting materials that led to products and help us to generate hypotheses about the rate and stereo chemical aspects of the reaction. The interpretation of the reaction mechanism is based on the rate of the reaction and product analysis [2].
A lot of kinetic studies were done on the nucleophilic substitution reactions between triethyl ammonium carboxylates and active organic halides containing saturated carbon atom[3-10]. Aryl sulfonyl halides are acted as a good substrate for nucleophilic substitution processes at sulfonyl sulfur [11-15], and especially Benzenesulfonyl halides attracted much interest. Nucleophilic substitution of sodium benzoate(s) with Benzenesulfonyl chloride in methanol follows S_N2 mechanism and the nucleophilic substitution takes place at sulfonyl sulphur [16]. S. Ozturk and H. Kutuk have reported the kinetics of nucleophilic substitution reaction of *p*-substituted arylsulfonylphthalimides with several amines in acetonitrile [17]. Kinetic studies on the reactions of TsCl with *p*-substituted Benzoic acids in the presence of triethylamine in aprotic solvents has been extensively studied by Ananthalakshmi and Nallu [18]. They concluded that the reaction follows second order kinetics with respect to the whole and first order with respect to each of the reactants. Similar investigation on the reaction of TsCl with *p*-substituted phenols and triethylamine in acetone and acetonitrile were reported in the literature [19]. The electron withdrawing chlorine on sulfur atom in TsCl induces an electron deficient centre at the tetra coordinated sulfur atom and thereby facilitates the approach of a nucleophile towards the sulfur atom.
The literature reviewed indicates that few kinetic studies have made on nucleophilic substitution at sulfonyl sulfur centre by acids/phenols in the presence of tertiary base, and the kinetic studies of TsCl with α-Hydroxy acids (such as Glycolic acid, Lactic acid, Mandelic acid etc) in the presence of base have not been reported yet. Thus, we planned to investigate the nucleophilic substitution reaction of Tscl with α-Hydroxy acids in the presence of Pyridine in Acetonitrile.

2. Materials and methods

2.1 Materials

p-Toluenesulfonyl chloride (TsCl), Glycolic acid, Lactic acid, Mandelic acid, Malic acid, Tartaric acid, Pyridine and Acetonitrile (Analytical grade) were purified before use by recrystallization or distillation until their physical constants (melting point/boiling point) agreed with the literature values [20, 21].

2.2 Kinetic measurements

The themostated solutions (±0.1 ˚C) of *p*-Toluenesulfonyl chloride (10 ml, 0.05 mol dm^{-3}) and the mixture of Glycolic acid - Pyridine (10ml, 0.05 mol dm^{-3}) in acetonitrile were mixed. The progress of the reaction was followed by measuring the conductance of the reaction mixture at different time intervals. The conductivity is due to pyridinium cation formed by the interaction between glycolic acid and pyridine and chloride anion liberated from TsCl by the attack of pyridinium glycolate. The conductance was measured at convenient time intervals (minutes) till the reaction has completed. Same experimental procedure was adopted for all other α-Hydroxy acids studied. Second order rate constant (k_2) was obtained from the following special integrated equation which was derived from Guggenheim's method [22].

$x_2-x_1 = k_2 C_0 [t_1x_1-t_2x_2] – k_2C_\infty x_\infty [t_1-t_2]$

x_1 = Conductance at time t_1

x_2 = Conductance at time t_2

x_∞ = Conductance at time t_∞

k_2 = Second order rate constant

C_0 = Initial concentration of the reactant

Plot of (x_2-x_1) against $– (t_1x_1-t_2x_2)$ should be a straight line. From the slope, the second order rate constant k_2 was calculated by the method of least-Square analysis. Also the rate constants of the reaction of TsCl with mixture of α-Hydroxy acid – Pyridine in acetonitrile under pseudo first order conditions were determined. From control experiments it was observed that the conductance of TsCl with α-Hydroxy acid or TsCl with Pyridine did not increase with time in acetonitrile. It indicates that the ions responsible for conductance were not liberated from the above mentioned mixtures. The activation parameters were calculated from the rate constants at 20, 30 and 40 ˚C by the usual methods [3-19, 23, 24].

2.3 Product analysis

Equal volumes of equimolar solutions of *p*-Toluenesulfonyl chloride and mixture of Glycolic acid – Pyridine (25ml, 0.05 mol dm^{-3}) in acetonitrile were mixed under kinetic conditions and were kept at about 30 ˚C for overnight. The needle shaped crystalline solid formed was filtered. The solid product was washed well with acetone [Yeild 0.256g (60%), melting point 143 ˚C]. Thin layer chromatography tests on this solid using methanol as an eluent showed a single spot. The solid product was identified as Pyridinium chloride on the basis of IR(KBr), ^{1}H NMR (200MHz, $CDCl_3$) and ^{13}C- NMR (DMSO-d_6) spectral data. IR: Two bands at 3101 and 2927 υ_{N^+-H}, 1522 $\upsilon_{-C=C-}$ and 1338 cm^{-1} $\upsilon_{=C-N-}$ and ^{1}H NMR: δ= 4.08(s, 1H, N-H) and 7.32 – 8.01(m, 5H, C_6H_5 –) ppm. ^{13}C NMR: 146,139 and 122ppm.

The filtrate was completely evaporated in vacuum to get residue, which was dissolved in Diethylether and dried over anhydrous Na_2SO_4. The solid product obtained was recryslallized from Toluene [Yield 0.387g (74%), melting point 106˚C]. The product was identified as *p*-Toluenesulfonyl glycolate (Fig. 1) from IR (KBr) and ^{1}H NMR (200MHz, $CDCl_3$) data. IR: 3417 $\upsilon_{-OH\ (H\text{-}bonded)}$, 3063 $\upsilon_{C\text{-}H\ (aromatic)}$, 2924 $\upsilon_{C\text{-}H\ (aliphatic)}$, 1730 $\upsilon_{C=O}$, 1375 $\upsilon_{S\text{-}O\ (asy.)}$, 1182 $\upsilon_{S\text{-}O\ (sym.)}$, 693 $\upsilon_{S\text{-}O\text{-}C}$ $cm^{-1}$and ^{1}H NMR: 2.31(s, 3H, CH_3-C_6H_5), 3.18 (s, 2H, CH_2), 7.22-7.20 (d, 2H, C_3- and C_5-H, -$SO_2C_6H_4CH_3$), 7.68-7.66 (d, 2H, C_2- and C_6-H, -$SO_2C_6H_4CH_3$), 3.69 (s, 1H, -OH) ppm ^{13}C NMR: 175, 171,132,129,126 and 22ppm.

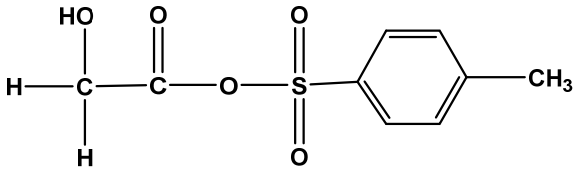


Fig 1: *p*-Toluenesulfonyl glycolate

The similar method was adopted for Lactic acid, Mandelic acid, Malic acid and Tartaric acid. The products were identified (by IR (KBr), ^{1}H NMR (200MHz, $CDCl_3$) and ^{13}C- NMR (DMSO-d_6) data) as *p*-Toluenesulfonyl lactate, *p*-toluenesulfonyl mandelate, *p*-toluenesulfonyl malate, and *p*-toluenesulfonyl tartarate respectively.

3. Results and Discussion

Second order rate constants (k_2) for different equimolar concentrations of the substrate (TsCl) and the nucleophile [mixture of α-Hydroxy acid (X-CHOHCOOH) and Pyridine] at 30 ˚C in acetonitrile have been determined by conductometric method (Table 1). It was observed that the rate constants were almost constant for different equimolar concentrations.

Table 1: Second order rate constants (k_2) for the reaction of TsCl with equimolar mixture of X-CHOHCOOH-Pyridine in Acetonitrile at 30 ˚C [TsCl] = [X-CHOHCOOH + Pyridine]

Concentration mol dm^{-3}	Rate constant (k_2) dm^3 mol^{-1} min^{-1}				
	Glycolic acid (X = H)	Lactic acid (X = CH_3)	Mandelic acid (X = C_6H_5)	Malic acid (X = CH_2COOH)	Tartaric acid (X = CHOHCOOH)
0.05	4.791	2.797	7.735	5.376	2.823
0.04	4.721	2.749	7.590	5.324	2.737
0.03	4.815	2.698	7.615	5.300	2.827
0.02	4.701	2.767	7.713	5.319	2.749
0.01	4.771	2.742	7.598	5.460	2.810

The reaction was also carried out under *pseudo* first order conditions, [substrate]>>[nucleophile], in acetonitrile at 30 ˚C (Table 2). The *pseudo* first order rate constant (k_1) increases with increase in [substrate] or [nucleophile] and the second order rate constant (k_2) is invariant which indicate that the reaction is second order with respect to the whole and first order with respect to each of the reactant.

Table 2: Rate constants for the reaction of TsCl with mixture of XCHOHCOOH – Pyridine under *pseudo*-first order condition in Acetonitrile at 30°C

Hydroxy acid (Xchohcooh)	[TsCl]x10^{-2} mol dm^{-3}	[Nu]x10^{-3} mol dm^{-3}	k_1x10^{-2} min^{-1}	$k_2 = k_1/[Nu]$ dm^3 mol^{-1} min^{-1}
Glycolic acid (X = H)	5.0	5.0	2.443	4.886
	5.0	6.0	2.922	4.869
	5.0	7.0	3.351	4.787
	5.0	8.0	3.912	4.889
	5.0	9.0	4.243	4.714
	4.0	5.0	2.422	4.845
	3.0	5.0	2.407	4.813
	2.0	5.0	2.397	4.796
	1.0	5.0	2.375	4.749
Lactic acid ($X = CH_3$) Lactic acid ($X = CH_3$)	5.0	5.0	1.416	2.833
	5.0	6.0	1.595	2.658
	5.0	7.0	1.762	2.518
	5.0	8.0	2.002	2.503
	5.0	9.0	2.459	2.732
	4.0	5.0	1.339	2.678
	3.0	5.0	1.326	2.652
	2.0	5.0	1.275	2.550
	1.0	5.0	1.225	2.450
Mandelic acid ($X = C_6H_5$)	5.0	5.0	3.938	7.876
	5.0	6.0	4.572	7.621
	5.0	7.0	5.349	7.642
	5.0	8.0	6.229	7.787
	5.0	9.0	6.853	7.614
	4.0	5.0	3.919	7.839
	3.0	5.0	3.905	7.810
	2.0	5.0	3.852	7.704
	1.0	5.0	3.762	7.525
Malic acid ($X = CH_2COOH$)	5.0	5.0	2.706	5.413
	5.0	6.0	3.251	5.418
	5.0	7.0	3.749	5.356
	5.0	8.0	4.234	5.293
	5.0	9.0	4.782	5.313
	4.0	5.0	2.695	5.390
	3.0	5.0	2.654	5.307
	2.0	5.0	2.638	5.276
	1.0	5.0	2.610	5.220
Tartaric acid (X = CHOHCOOH)	5.0	5.0	1.427	2.854
	5.0	6.0	1.631	2.719
	5.0	7.0	1.895	2.707
	5.0	8.0	2.220	2.774
	5.0	9.0	2.539	2.821
	4.0	5.0	1.418	2.865
	3.0	5.0	1.377	2.753
	2.0	5.0	1.339	2.679
	1.0	5.0	1.326	2.652

TsCl = *p*-Toluenesulfonyl Chloride, Nu = XCHOHCOOH - Pyridine mixture Second order rate constants (k_2) for the reaction of *p*-Toluenesulfonyl chloride with equimolar mixture of α-Hydroxy acid - Pyridine in Acetonitrile at different temperatures (20, 30 and 40 ˚C) have been determined (Table 3). From the rate data, as temperature increases second order rate constant also increases.

Table 3: Second order rate constants (k_2) for the reaction of TsCl with mixture of α-Hydroxy acid-Pyridine (0.05 mol dm^{-3}) in Acetonitrile at different temperatures [TsCl] = [XCHOHCOOH-Pyridine] = 0.05 mol dm^{-3}

Temperature K	Rate constant (k_2) dm^3 mol^{-1} min^{-1}				
	Glycolic acid X = H	Lactic acid X = CH_3	Mandelic acid X = C_6H_5	Malic acid (X = CH_2COOH)	Tartaric acid (X = CHOHCOOH)
293	2.346	1.318	3.255	2.691	1.496
303	4.791	2.797	7.735	5.376	2.823
313	9.813	6.752	15.571	10.721	6.628

The activation parameters have been evaluated by usual methods and presented in Table 4. Experiments were conducted at different temperatures and corresponding rate data were obtained and the activation parameters (Ea, $\Delta H^{\ddagger}$, $\Delta S^{\ddagger}$ and $\Delta G^{\ddagger}$) were calculated based on Eyring's equation [3-10, 17-19, 23, 24].

Table 4: Activation parameter for the reaction of TsCl with mixture of α-Hydroxy acid - Pyridine in Acetonitrile [TsCl] = [X-CHOHCOOH - Pyridine] = 0.05 mol dm^{-3}

α-Hydroxy acid	Ea kJ mol^{-1}	$\Delta H^{\ddagger}$ kJ mol^{-1}	$\Delta S^{\ddagger}$ J K^{-1} mol^{-1}	$\Delta G^{\ddagger}$ kJ mol^{-1}
Glycolic acid (X = H)	52.703	50.184	-66.392	70.300
Lactic acid (X = CH_3)	55.538	53.019	-61.511	71.656
Mandelic acid (X = C_6H_5)	63.888	61.369	-25.495	69.094
Malic acid (X = CH_2COOH)	51.080	48.560	-70.792	70.010
Tartaric acid (X = CHOHCOOH)	46.870	44.351	-90.039	71.633

Entropy of activation is negative as expected for nucleophilic bimolecular reactions [17-19, 23, 24]. The high negative $\Delta S^{\ddagger}$ values observed in these reactions support the operation of "electrostriction" in these compounds pointing towards more polar transition state. In the transition state, it is shown that the sulfonyl sulphur of TsCl is subjected to S_N2 reaction by the oxygen of the hydrogen bonded glycolate anion (where X=H) and chlorine atom being pulled out as Pyridinium chloride.

Isokinetic relationship

A linear relationship between activation enthalpies and activation entropies in a series of related reaction is called isokinetic relationship. Leffler deduced the following Isokinetic equation which holds good for a series of related reactions [25].

$\Delta H^{\ddagger} = \Delta H^{0} + \beta \Delta S^{\ddagger}$

Where, β is the isokinetic temperature.

The slope of the plot, $\Delta H^{\ddagger}$ versus $\Delta S^{\ddagger}$ gives the value of 'β' and it has an important physical meaning. It represents the temperature at which all the compounds of the reaction series react equally fast. Also, at the isokinetic temperature, the variation of substituent has no influence on the free energy of activation. The linear plot between $\Delta H^{\ddagger}$ and $-\Delta S^{\ddagger}$ (β = 268 K) signifies that the same mechanism operates in all the series (Fig. 2).

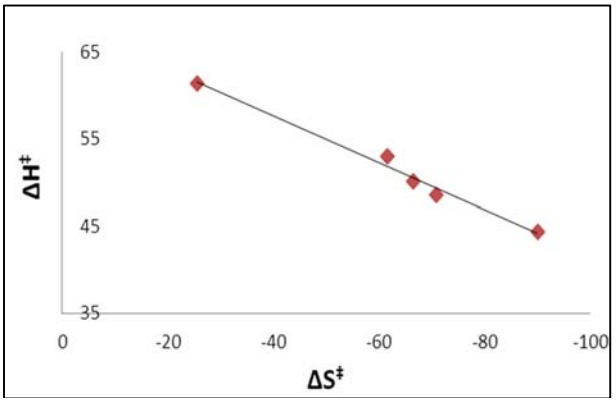


Fig 2: Plot of $\Delta H^{\ddagger}$ verses $\Delta S^{\ddagger}$ for the reaction of TsCl with α-Hydroxy acids-Pyridine in acetonitrile at 303 K

Further the plots of $\Delta H^{\ddagger}$ versus Ea (Fig. 3) were also made as per Leffler's modified equation. The value of β was determined from the slope (β = 268 K) and it was found that this β value was in agreement with the β value obtained from the isokinetic plot ($\Delta H^{\ddagger}$ versus $\Delta S^{\ddagger}$).

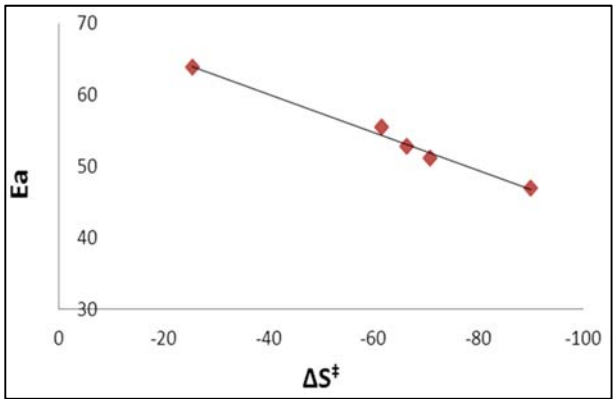


Fig 3: Plot of Ea verses $\Delta S^{\ddagger}$ for the reaction of TsCl with α-Hydroxy acids-Pyridine in acetonitrile at 303 K

The validity of isokinetic plot is questionable, because the quantities $\Delta H^{\ddagger}$ and $\Delta S^{\ddagger}$ are mutually dependent, both being derived from the experimental rate constants.

Exner suggested an alternative graphical method for testing the validity of isokinetic relationship [26-31]. The isokinetic relationship is tested by plotting the logarithms of rate constants at two different temperatures (T2 > T1) against each other according to following equation.

$\beta = [T_1T_2 (b-1)] / bT_2 - T_1$

Isokinetic temperature for this series has been determined by plotting log k_2 at 313 K *vs.* log k_2 at 303 K. The plot gave a linearity with slope b = 0.807 (r = 0.9949) and the isokinetic temperature is found to be equal to 363 K (Fig. 4).

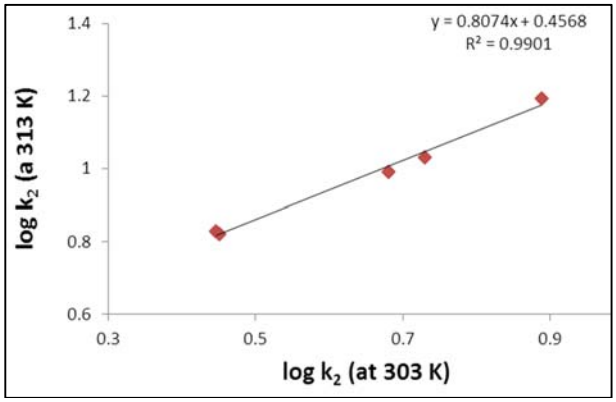
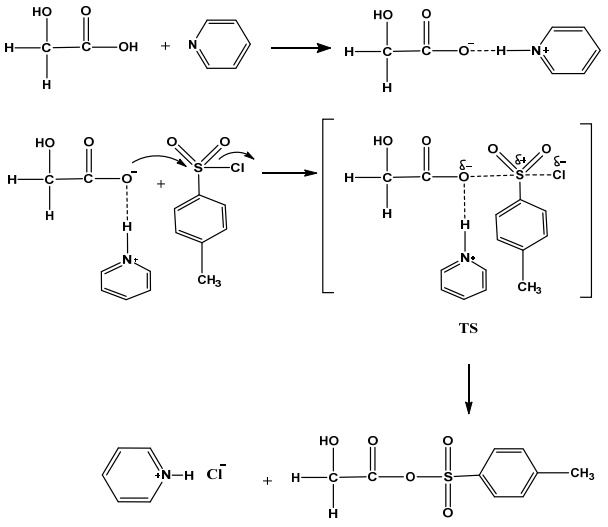


Fig 4: Exner's plot of log k_2 (313 K) verses log k_2 (303 K) for the reaction of TsCl with α-Hydroxy acids-Pyridine in acetonitrile

The linear relationship is observed in the present study implies the validity of the isokinetic relationship. The linear correlation implies that all α-hydroxy acids studied are esterified by the same mechanism and the changes in the rate are governed by the changes in both enthalpy and entropy of activation. The slope value 'b' for this reaction is less than unity. This indicates that the reaction is neither isenthalpic nor isenthalpic but complies with the compensation law also known as the isokinetic relationship. The isokinetic temperature of this series is found to be greater than the experimental temperatures, indicating enthalpy as controlling factor.

Based on the kinetic and spectral data, the synchronous direct nucleophilic displacement mechanism of glycolate ion (for X = H) at the sulfur atom of TsCl has been proposed for the reaction studied (Scheme 1).

Mechanism



Scheme 1: Proposed mechanism for the reaction of *p*-Toluenesulfonyl chloride with α-Hydroxy acid (Glycolic acid) and Pyridine

4. Conclusion

Rate constants for the reactions of *p*-Toluenesulfonyl chloride with α-Hydroxy acid and Pyridine have been determined in acetonitrile at different concentration and temperatures by the conductometric method. Conductivity data are used to determine the rate constants and activation parameters. The reaction was also conducted under *pseudo*-first order condition in Acetonitrile. The reaction is found to be second order in total and first order with respect to each of the reactant. The negative $\Delta S^{\ddagger}$ indicate the formation of rigid transition state. The plot of log k_2 (40 ˚C) with log k_2 (30 ˚C) gives a straight line, indicate similar mechanism is operated in all the reaction series studied. Products are isolated under kinetic condition and TLC tests were made on the products. The isolated products are identified as corresponding *p*-Toluenesulfonyl ester from IR (KBr), ^{1}H-NMR (200MHz, $CDCl_3$) and ^{13}C- NMR (DMSO-d_6) spectral data. From the kinetic and product analysis data the reaction mechanism proposed for this series is a synchronous bimolecular S_N2 mechanism.

5. References

1. (a) Miller. J Rev Pure Appl Chem. 1951; 1:171.
   (b) Ross SD. Progr. Phys. Org. Chem. 1963; 1:31.
   (c) Ross SD. Comprehensive Chemical Kinetics. 1972; 13:407-431.
   (d) Miller. J Aromatic Nucleophilic Substitution Elsevier New York. 1968.
2. (a) Lailder KJ. Chemical Kinetics, Tata-McGraw Hill, New Delhi, 1965
   (b) Rogne O. J Chem Soc. 1971; (B):1855.
   (c) Ryan JJ, Humffray AA. J Chem Soc. 1967; B:1300.
3. Krishnapillay M, Kannan K, Rama Subramanian P. Tetrahedron. 1983; 39:3899.
4. DeLos F, DeTar, Ronald W Novak. J Am Chem Soc. 1970; 92(5):1361-1365.
5. Kim JW, Uhm T, Lee I, Koo IS. J Korean Chem Soc. 1985; 29:15.
6. Nallu M, Subramanian M, Vembu N, Akbar Hussain A. Int J Chem Kinet. 2004; 36:401.
7. Raghavan R, Kalavathy S. Proc. Indian Acad, Sci. (Chem. Sci.), 1985; 94:481-485.
8. Nallu M, Kanagadurgadevi G. Asian J Chem. 2002; 14(3-4):1320-1324.
9. Ranga Reddy, Maniyamba S. J Chem Sci. 2006; 118(3):257-260.
10. Ranga Reddy, Maniyamba S. Indian J Chem. 2004; 43A:1092-1094.
11. Sung DD, Kang DH, Chang JA, Park SB, Ryu ZH. Bull. Korean Chem. Soc, 1998; 19(5):561.
12. Choi JH, Lee BC, Lee I. J Org Chem. 2002; 67:1277.
13. Pierre Monjoint, Marie-Francoise Ruasse. Tetrahedron Lett. 1984; 25(30):3183-3186.
14. Percec V, Bera Tk, De BD, Sanai Y, Smith J, Holerca MN *et al*. J Org Chem. 2001; 66:2104.
15. Lee I, Koo IS. Tetrahedran, 1983; 39:1803.
16. Banjoko O, Okwuiwe R. J Org Chem. 1980; 45:4966-4968.
17. Seyhan Ozturk. Halil Kutuk. International Journal of Organic Chemistry. 2011; 1:202-206.
18. Ananthalakshmi S, Nallu M. Int J Chem Kinet. 2008. DOI 10. 1002/ Kin.
19. Vembu N, Arunmozhithevan V. Der Chemica Sinica. 2013; 4(1):84-95.
20. Vogel AI. A Text Book of Practical Organic Chemistry, 4th ed, ELBS, London, 1978.
21. The Merck Index, 10th ed, Merck, Rahway, NJ, 1983.
22. Guggenheim EA, Pure JE. Physiochemical Calculations, Interscience Publishers, Inc., London, 1955.
23. Good W, Ingham DB, Stone J Tetrahedran. 1975; 3:257.
24. Nayak PL, Mohanty TR. J Chem. Soc Perkin Trans. 1975; 2:242.
25. Leffler JE. J Org Chem. 1955; 20:1202.
26. Exner O. Coll. Czech. Commun, 1964, 1094.
27. Chokalingam Karunakaran, Vaithiyalingam Chidambaranathan, Croatica Chemica Acta. 2001; 74(1):51-59
28. Liu L, Guo QX. Chem. Rev. 2001; 101:673-695.
29. Linert W, Yelon A. Monatsh Chem, 2013; 144:1-2.
30. Bunnet JF. Investigation of rates and mechanism of Reactions- Techniques of Chemistry, E. S. Lewis Ed., John Wiley & Sons, New York, 1961; 6:417.
31. Carneiro P, Pereira E, Garcia P, Breia S, Burgess J, Castro B. Eur J Inorg Chem. 2001, 2343.