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Kinetics and mechanism of oxidation of semicarbazide by Keggin type 12-tungstocobaltate(III) in acidic medium

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ABSTRACT

The kinetics of oxidation of semicarbazide by 12-tungstocobaltate (III) in aquous acidic medium at 300K and a constant ionic strength of 0.3 mol dm^{-3} *was studied spectrophotometrically at* λ_{max} *624nm under pseudo first-order conditions. The reaction between semicarbazide and 12-tungstocobaltate (III) in acidic medium exhibits 1:2 stiochiometry [Semicarbazide:12-tungstocobaltate (III)]. The main oxidative products were indentified by Spot test and spectral studies. The effect of* $[H^+]$ *ion and ionic strength of the reaction medium have been investigated. The reaction constants involved in the different steps of the mechanism are calculated. From the log k versus 1/T values of activation parameters have been evaluated. The activation parameters with respect to the slow steps of the mechanism are computed and discussed.*

Key words: Kinetics, mechanism, semicarbazide, oxidation, 12-tungstocobaltate (III).

INTRODUCTION

Polyoxometalates (POMs) are polynuclear metal–oxygen complexes of early transition metals and often have heteroatoms incorporated within the structure [1]. Many Polyoxometalates have been shown to biologically active [2]. The antiviral activity of polyoxomelates was reported as early as 1971 [3]. Further studies of various groups showed the effectiveness of these polyoxometalates against several viruses such as vesicular, stomatitis, polio, Rubella, rabies etc [3]. Heteropolytungstates and heteropolymolybdates are of special interest because of their acidic stability and extensive reversible redox chemistry. Importantly, from the perspective of this study, extensive investigations with polyoxotungstates and polyoxomolybdates [4]. The redox potentials of $[Co^{III}W_{12}O_{40}]^{5-}$/ $[Co^{II}W_{12}O_{40}]^{6-}$ ions is 1.0V [5]. Among various heteropolyacids structural classes the keggin type heteropolyacids have been widely used as homogeneous and heterogeneous catalysts for acid-base and oxidation reactions[6].

Semicarbazide is used in preparing pharmaceuticals including nitrofuran antibacterials (furazolidone, nitrofurazone, nitrofurantoin) and related compounds. It is used as a detection reagent in thin layer chromatography (TLC). Semicarbazide stains α-keto acids on the TLC plate, which must then be viewed under ultraviolet light to see the results. Semicarbazide-cadmium therapy was an experimental cancer therapy that was tested in several clinical trials in the Soviet Union during the 1960s. It is an irreversible inhibitor of semicarbazide-sensitive amine oxidase (SSAO), an enzyme possibly involved in exacerbation of inflammation. Cadmium is a heavy metal and can also induce apoptosis. This method was successfully used for treatment of patients in later stages of lung, intestinal, and brest cancer, melanoma, and some other cancer types. The experiments were accompanied by organizational problems (conflict of interest) [7]. Clinical use of semicarbazide(aSSAO-inhibitor) gives the evidence that an inflammatory reaction can be reduced by blocking the enzymatic activity of the enzyme semicarbazide-sensitive amine oxidase (SSAO). SSAO activity was found significantly increased in blood and tissues in some pathological conditions. The enzyme activity has been reported to be elevated in diabetes and cancer. The mean specific activity of SSAO was significantly elevated in the group of patients having prostate cancer with skeletal metastases[8]. Semicarbazide is a known inhibitor of glutamic acid decarboxylase (GAD), the enzyme responsible for GABA synthesis. GABA has emerged as a tumor signaling molecule in the periphery that controls the proliferation of tumor cells and perhaps tumor stem cells[9]. The present study is an attempt to explore the kinetics and mechanism of oxidation of semicarbazide by 12- tungstocobaltate (III) in acidic medium on the basis of kinetic parameters.

MATERIALS AND METHODS

All chemicals used were of analytical reagent grade and double distilled water was used throughout the work. A solution of semicarbazide was prepared by dissolving a known amount of recrystalised sample in double distilled water. The purity of semicarbazide sample was checked by comparing its IR spectrum with literature data and with its Melting Point 96°C. The cobalt complex $[Co^{III}W_{12}O_{40}]^{5-}$ and $[Co^{II}W_{12}O_{40}]^{6-}$ were prepared by the reported method[10-11] The cobalt complexes $K_6[CO^{II}W_{12}O_{40}]$ were prepared by the reported method as, 198 gm of $Na_2WO_4.2H_2O$ (SD Fine) was dissolved in 400 ml water and the pH of the solution was adjusted to a value between 6.5 to 7.5 by the addition of 40 ml glacial acetic acid (BDH). A separate solution was prepared by dissolving 24.9 gms of cobaltous acetate tetrahydrate in 125 ml of warm water to which few drops of glacial acetic acid had been added. The sodium tungstate solution was brought to boil and cobaltus acetate solution was added to it slowly with constant stirring. Small amount of transitory pink precipitate appeared and re-dissolved very rapidly forming a deep green solution. After all the cobaltous acetate solution was added and the resultant solution was boiled for ten minutes and then filtered to remove traces of insoluble matter. To this extremely soluble sodium salt of $[CO^{II}_2(H_2O)W_{11}O_{39}]^{8-}$ a hot saturated solution containing 130gms of potassium chloride was added. The green crystals of potassium salt were separated on cooling. The product was recrystalised with water containing 2 ml of acetic acid. The product obtained was potassium salt of $[CO^{II}_2(H_2O)W_{11}O_{39}]^{8-}$ (salt I). The recrystalised product (20 gms) was dissolved in 100 ml of 0.1 mol dm^{-3} HCl and evaporated on steam bath until green needle like crystals of $K_6[Co^{II}W_{12}O_{40}]$ were begun to form and cooled in ice box. The resulting crystals (salt II) were recrystalised from water.

In order to obtain salt $K_5[Co^{III}W_{12}O_{40}]$ 75 gms salt II was dissolved in 80 ml of sulphuric acid and solid potassium persulphate was added to the boiling solution of salt II in small amounts. The green color becomes progressively lighter changing through light emerald green to light brownish yellow. The resulting solution was cooled to obtain yellow needle like crystals of salt $K_5[Co^{III}W_{12}O_{40}]$. The product was washed with 95% ethanol, air dried and standardrised spectrophotometrically [12]. The ionic strength was maintained using $NaClO_4$ (BDH) and HCl (BDH) were used to vary the hydrogen ion concentrations.

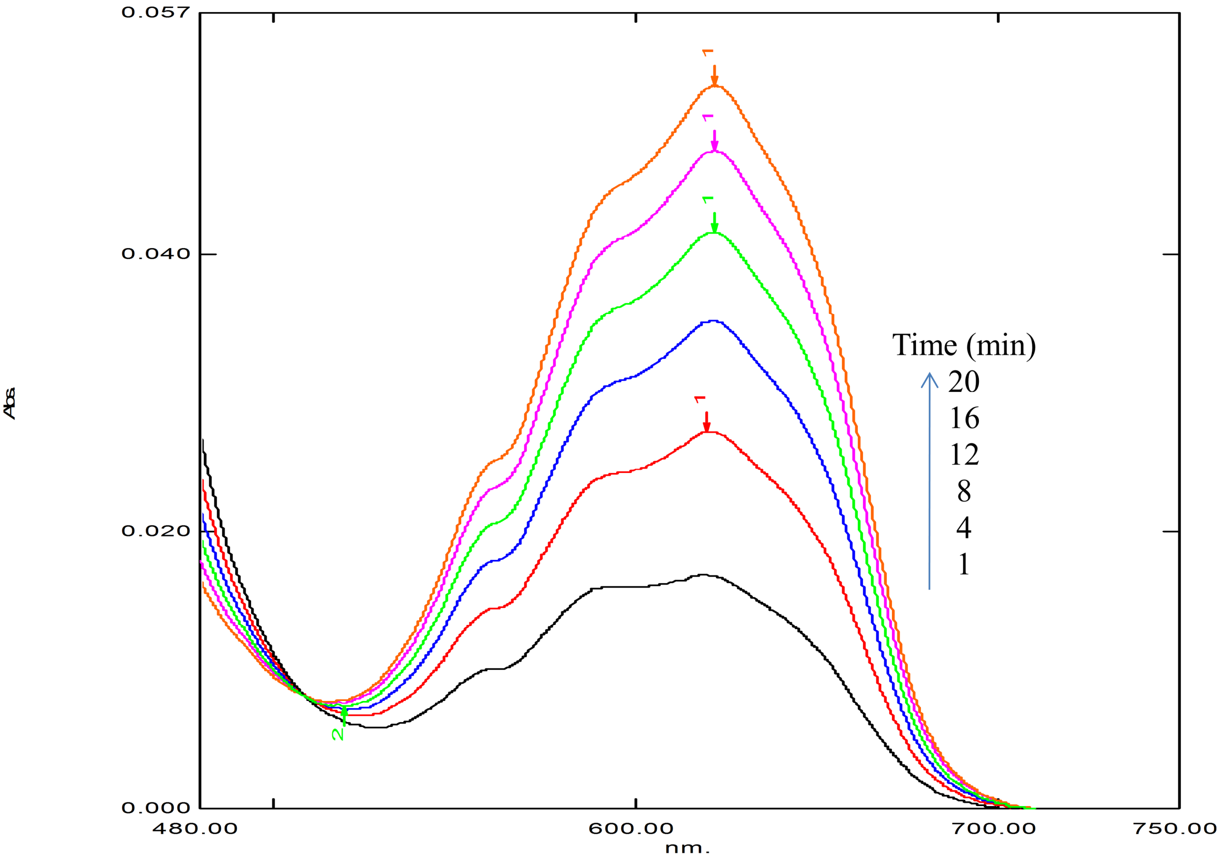
2.2 Kinetic studies

The kinetic measurements were performed on a ShimadzuUV-1800-UV-Visible spectrophotometer. The kinetics was followed under pseudo first-order conditions where semicarbazide was always in excess over $[Co^{III}W_{12}O_{40}]^{5-}$ at a constant ionic strength of 0.3mol dm^{-3} in acidic medium at constant temperature 27 ±0.2°C. The reaction was initiated by mixing the $[Co^{III}W_{12}O_{40}]^{5-}$ and semicarbazide solutions , which also contains required concentration of HCl and $NaClO_4$. The reaction was followed by measuring the absorbance of $[Co^{III}W_{12}O_{40}]^{5-}$ at 624 nm as a function of time. Beer's law was tested for $[Co^{II}W_{12}O_{40}]^{6-}$ between the concentration of 1.0×10^{-3} and 5.0×10^{-3} mol dm^{-3} ($\varepsilon_{624} = 180 \pm 2$ mol dm^{-3} cm^{-1})[13] under the experimental conditions. The pseudo first-order rate constants, were obtained from the plot of log $[Co^{II}W_{12}O_{40}]^{6-}$ versus time. The plots were linear for more than 70% completion of the reaction and the rate constants were reproducible within ±10%.

2.3 Spectrophotometric measurement

The UV-Visible spectra of $[Co^{III}W_{12}O_{40}]^{5-}$ complex and the reaction mixture were recorded by using ShimadzuUV-1800-UV-Visible spectrophotometer between the wavelength range 480-750 nm. The spectrum of the reaction mixture at various time intervals is shown in (Figure 1).

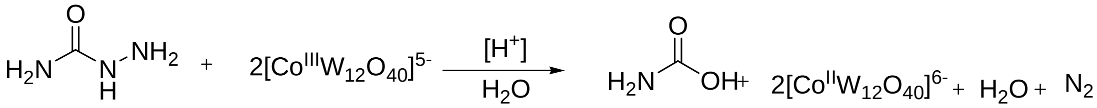
Figure 1. spectra of the reaction mixture at different time intervals at 27±0.2°C $[Co^{III}W_{12}O_{40}]^{5-}$ 2 $\times10^{-3}$mol dm^{-3}, semicarbazide 3 $\times10^{-2}$mol dm^{-3}, HCl 1.5 mol dm^{-3} and $NaClO_4$ 0.3 mol dm^{-3}



RESULTS AND DISCUSSION

3.1 Stoichiometry and product Analysis

Five different sets of reaction mixtures containing different concentrations of semicarbazide and $[Co^{III}W_{12}O_{40}]^{5-}$ in presence of 1.5 mol dm^{-3}HCl were equilibrated at 27 ± 0.2°C for 24 hours in a nitrogen atmosphere. The progress of the reaction was followed by measuring the absorbance at 624 nm for the formation of $[Co^{II}W_{12}O_{40}]^{6-}$. The results indicated that the two moles of $[Co^{III}W_{12}O_{40}]^{5-}$ consumed one mole of semicarbazide.



After completion of the reaction, the reaction product was extracted and recrystallised from double distil water. The product was identified as carbamic acid by the spot test [14]. Further the carbamic acid was identified by its FT-IR Spectrum (KBr), which showed a band at 1681cm^{-1} due to >C=O stretching of acid and a broad band at 3387cm^{-1} due to -OH stretching.

3.2 Reaction order

The reaction orders have been determined from the slopes of logk_{obs} versus log (concentration) plots by varying the concentration of semicarbazide, $[Co^{III}W_{12}O_{40}]^{5-}$ and HCl in turn while keeping other constant. The concentration of $[Co^{III}W_{12}O_{40}]^{5-}$ was varied in the range 0.1×10^{-3} to 3.0×10^{-3} mol dm^{-3} at fixed [semicarbazide], $[H^+]$ and ionic strength. The non-variation in the pseudo first order rate constant at various concentrations of $[Co^{III}W_{12}O_{40}]^{5-}$ indicates the order in $[Co^{III}W_{12}O_{40}]^{5-}$ as unity (Table1). The semicarbazide concertation was varied in the range 2.0×10^{-2} to 3.0×10^{-2} mol dm^{-3} at 27 ± 0.2°C keeping all other reactants concentration and conditions constant. The apparent order in semicarbazide was found to be less than unity under the experimental condition. The effect of increasing concentration of acid on the reaction rate at constant concentration of semicarbazide and $[Co^{III}W_{12}O_{40}]^{5-}$ at constant ionic strength was studied. The rate constants were found to be decreased with the increase in acid concentration and the order in acid was less than unity (Table1).

Table 1. Effect of $[Co^{III}W_{12}O_{40}]^{5-}$, [semicarbazide], [HCl]] for the oxidation of semicarbazide by $[Co^{III}W_{12}O_{40}]^{5-}$ in acidic medium at 27±0.2°C, I= 0.3 mol dm^{-3}

$[Co^{III}W_{12}O_{40}]^{5-}10^3$	[semicarbazide] 10^2	[HCl]	$k_{obs}\,10^3$ Found
0.1	3.0	1.5	4.6
1.5	3.0	1.5	4.6
2.0	3.0	1.5	4.6
2.5	3.0	1.5	4.6
3.0	3.0	1.5	4.7
2.0	2.0	1.5	2.3
2.0	2.5	1.5	3.4
2.0	3.0	1.5	4.6
2.0	3.5	1.5	5.7
2.0	4.0	1.5	6.9
2.0	3.0	1.0	6.8
2.0	3.0	1.25	5.7
2.0	3.0	1.5	4.6
2.0	3.0	1.75	3.4
2.0	3.0	2.0	2.3

3.3 Effect of hydrogen ion concentration

The Effect of hydrogen ion concentration on the reaction were studied in order to understanding the nature of reactant species present in the solution. The concentration of $[H^+]$ ion was varied from 1.0 to 2.0 mol dm^{-3} keeping all other reactant concentrations constant. It was found that the reaction rate decreases with the increasing concentration of $[H^+]$ ion [15]. The order in $[H^+]$ ion concentration was found to be 0.81 as found from the plot of log k_{obs} against log $[H^+]$plot.

3.4 Effect of ionic strength

The effect of ionic strength was studied by varying the sodium perchlorate concentration in the reaction mixture. The ionic strength of the reaction medium was varied from 0.5 to 2.0 mol dm^{-3}, with all other reactants concentrations are other conditions being constant. It was found that as ionic streangth increased, the rate of reaction increases [16]. The plot of log K_{obs} versus $\sqrt{\mu}$ was linear with positive slope.

3.5 Effect of solvent polarity

The relative permittivity effect was studied by varying the percentage of acetonitrile from 10 to 40 % v/v in the reaction mixture with all other conditions being constant. The relative permittivities of the reactions mixtures were computed from the values of the pure solvents. It was found that the decrease in dielectric constant of the reaction mixture to increases the rate of the reactions [17]. The plot of log k_{obs} versus (1/D) was linear with negative slope.

3.6 Test for free radicals

The reaction was studied in presence of added acrylonitrile to understand the intervention of free radicals in the reaction [18-20]. The reaction mixture was mixed with acrylonitrile scavenger and kept for 24 hours under nitrogen atmosphere. On diluting the reaction mixture with methanol it form white precipitate of polymer, indicating the involvement of free radicals in the reaction. The initially added acrylonitrile decreases the rate of reaction indicating the free radical intervention.

3.7 Effect of temperature

The kinetics was studied at four different temperatures on the rate was studied by performing the kinetics at various temperatures (293k-313k) as shown in (Table 2). keeping other experimental conditions constant. The rate constants were found to increase with increase in temperature. The energy of activation corresponding to these constants was evaluated from the Arrhenius and Eyring plots of logk_{obs} vs. (1/T) (Figure 2) and log (k/T) vs. 1/T and other activation parameters obtained are tabulated in (Table 2)

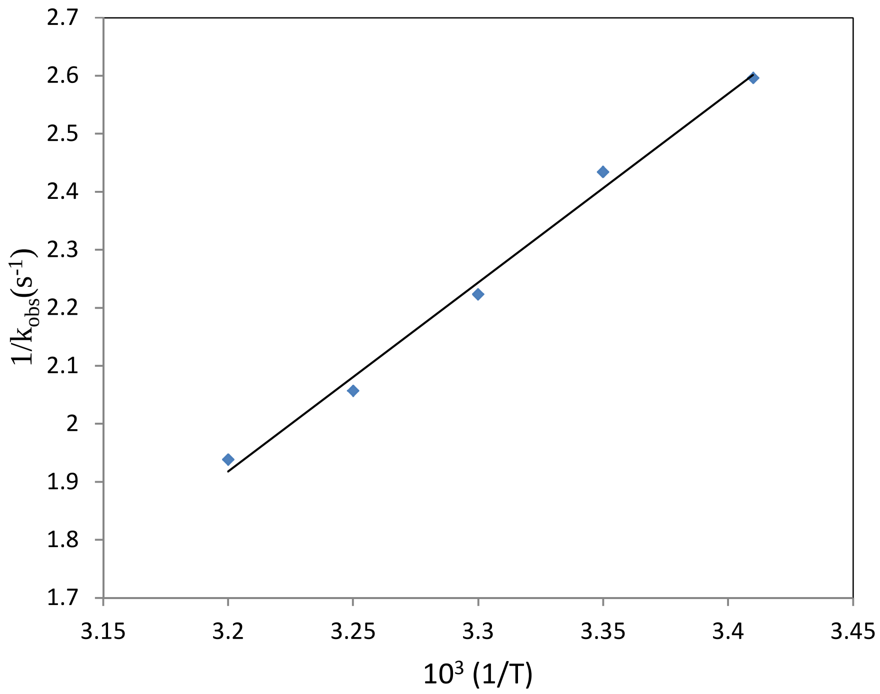
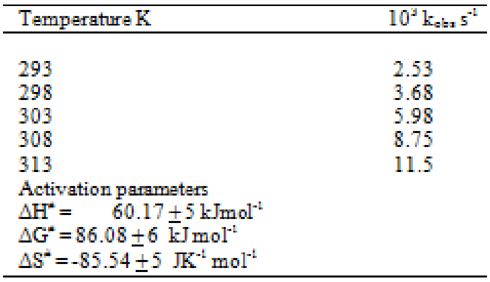


Figure 2. Effect of temperature on reaction rate by Arrhenius and Eyring plots of logkobs vs. (1/T)

Table 2. Effect of temperature on rate for the oxidation of semicarbazide by $[Co^{III}W_{12}O_{40}]^{5-}$ in aqueous acidic medium



Temperature K	10^3 k_{obs} s^{-1}
293	2.53
298	3.68
303	5.98
308	8.75
313	11.5
Activation parameters	
$\Delta H^{\#}$ = 60.17 ± 5 kJmol^{-1}	
$\Delta G^{\#}$ = 86.08 ± 6 kJ mol^{-1}	
$\Delta S^{\#}$ = -85.54 ± 5 JK^{-1} mol^{-1}	

In the present study oxidation by the Co(III) complex $[Co^{III}W_{12}O_{40}]^{5-}$ a well known outer-sphere oxidants [21-22]. The kinetics of electron exchange between Co(II) and Co(III) using ^{60}Co tracer techniques from the structure and stability of these anions it appers that the tungustate groups are subistitutionally inert and species of this type represent ideal complexes for the study of outer-sphere electron transfer in solution [23]. The $[Co^{III}W_{12}O_{40}]^{5-}$ ion is powerful oxidant in aqueous acidic medium under the present experimental conditions. The colour changes of $[Co^{III}W_{12}O_{40}]^{5-}$ solutions from yellow $[Co^{III}W_{12}O_{40}]^{5-}$ ion to blue $[Co^{II}W_{12}O_{40}]^{6-}$ ion has been observed. In acidic medium, semicarbazide exists in the protonated form. The reaction between semicarbazide and $[Co^{III}W_{12}O_{40}]^{5-}$ in acidic medium has a stoichiometry of 1:2. As the hydrochloric acid concentration was increased, the rate of reaction also decreases (Table 1). The order with respective to hydrochloric acid was found to be 0.81. The results indicates that the $[H^+]$ ion combines first with semicarbazide to give a protonated semicarbazide species [semicarbazide H^+] in prior equilibrium step, such protonated species have been observed in other studies, which is also supported by the observed less than unit order in $[H^+]$ ion.

$$\text{Semicarbazide} + H^{+} \underset{}{\overset{K_1}{\rightleftharpoons}} \text{Semicarbazide } H^{+} \qquad (1)$$

Protonated semicarbazide and $[Co^{III}W_{12}O_{40}]^{5-}$ combines to give complex

$$\text{Semicarbazide } H^{+} + [Co^{III}W_{12}O_{40}]^{5-} \overset{K_2}{\rightleftharpoons} \text{Complex} \qquad (2)$$

$$\text{Complex} + [Co^{III}W_{12}O_{40}]^{5-} \xrightarrow{\text{fast}} \text{product} \qquad (3)$$

scheme 1

The protonated semicarbazide species and unprotonated $[Co^{III}W_{12}O_{40}]^{5-}$ as active species to give a complex (C) in further fast to yield the product. The result can be accommodated in the from of scheme 1. The rate law for the scheme 1 can be derived as follows

$$\text{Rate} = \frac{K_1 k_1\,[\text{Semicarbazide}]_T\,[Co^{III}W_{12}O_{40}]^{5-}}{(K_1 + [H^{+}]\,)} \qquad (4)$$

$$k_{obs} = \frac{K_1 k_1\,[\text{Semicarbazide}]_T}{(K_1 + [H^{+}]\,)} \qquad (5)$$

12-tungstocobaltate (III) $[Co^{III}W_{12}O_{40}]^{5-}$ catalysed kinetics of oxidation of semicarbazide was investigated at several initial concentrations of reactants in acid medium. The oxidant $[Co^{III}W_{12}O_{40}]^{5-}$ concentration was varied from 0.1×10^{-3} to 3.0×10^{-3} mol dm^{-3} keeping constant values of [semicarbazide], [HCl], $[NaClO_4]$ at 27±0.2°C and the observed constant values of k_{obs} indicate that the order with respect to $[Co^{III}W_{12}O_{40}]^{5-}$ was one. It was further supported by linear plot of log $[Co^{III}W_{12}O_{40}]^{5-}$ versus time. The values of rate constants (k_{obs}) are listed in (Table 1). Similarly, varying the concentration of substrate [semicarbazide] keeping all other parameters constant, showed that the order with respect to semicarbazide was found from log k_{obs} against log [semicarbazide] concentration and the order was less than unity. The effect of increasing concentration of $[H^{+}]$ was studied on the reaction rate at constant concentrations of $[Co^{III}W_{12}O_{40}]^{5-}$ and semicarbazide at constant ionic strength at 27±0.2°C. The rate constant decreases with increase in concentration and order in $[H^{+}]$ was less than unity.

The reaction rates were determined at different temperature (20, 25, 30,35, 40 °C) and from the Arrhenius and Erying plots of log k_{obs} versus 1/T and log k_{obs}/T versus 1/T respectively. The values of activation parameters for the overall reaction were calculated and presented in (Table 2). The values of enthalpy of reaction ($\Delta H^{\#}$), entropy of reaction ($\Delta S^{\#}$) and free energy of activation($\Delta G^{\#}$) were calculated as 60.17 ± 5 kJmol^{-1} -85.54 ± 5 JK^{-1} mol^{-1} and 86.08 ± 6 kJ mol^{-1} respectively. The larger negative values of ΔS indicates that the activated complex in the transition state has a more rigid structure than the reactants. The negative values of $\Delta S^{\#}$ for radical reaction have been artibuted to the nature of electron pairing and unpairing reactions and to the loss of degrees of freedom by the formation of a rigid transition state[24].

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