

Kinetics and mechanism of oxidation of L-leucine by alkaline diperiodatocuprate(III) — A free radical intervention, deamination and decarboxylation

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Abstract. The kinetics of oxidation of L-leucine by diperiodatocuprate (III) (DPC) in aqueous alkaline medium at a constant ionic strength of 0.10 mol dm^{-3} was studied spectrophotometrically. The reaction between L-leucine and DPC in alkaline medium exhibits 1:4 stoichiometry (L-leucine: DPC). The reaction is of first order in [DPC] and has less than unit order in both [L-leucine] and [alkali]. However, the order in [L-leucine] and [alkali] changes from first order to zero order as their concentration increase. Intervention of free radicals was observed in the reaction. Increase in periodate concentration decreased the rate. The oxidation reaction in alkaline medium has been shown to proceed via a monoperiodatocuprate (III) – L-leucine complex, which decomposed slowly in a rate-determining step followed by other fast steps to give the products. The main oxidative products were identified by spot test and GC-MS. The reaction constants involved in the different steps of the mechanism were calculated.

Keywords. L-leucine; diperiodatocuprate (III); oxidation; kinetics; mechanism.

1. Introduction

Amino acids not only act as the building blocks in protein synthesis, but they also play a significant role in metabolism. Amino acids can undergo many types of reaction depending on whether a particular amino acid contains nonpolar groups or polar substituents. The oxidation of amino acids is of interest as the oxidation products differ for different oxidants.¹ Thus, the study of amino acids becomes important because of their biological significance and selectivity toward the oxidant. L-leucine is an essential amino acid. It forms active sites of enzymes and helps in maintaining their proper conformation by keeping them in proper ionic states. So, oxidation of L-leucine may help in understanding some aspects of enzyme kinetics. Recent research has discovered that L-leucine acts in a unique way: it can help burn fat without burning muscle.

In recent years, the study of the highest oxidation state of transition metals has intrigued many researchers. Transition metals in a higher oxidation state can be stabilized by chelation with suitable

polydentate ligands. Metal chelates such as diperiodatocuprate(III),² diperiodatoargentate(III),³ and diperiodatonickelate(IV)⁴ are good oxidants in a medium with an appropriate pH value. Copper (III) is shown to be an intermediate in the copper(II)-catalysed oxidation of amino acids by peroxydisulfate.⁵ The oxidation reaction usually involves the copper(II) – copper(I) couple, and such aspects are detailed in different reviews.⁶ The use of diperiodatocuprate(III) (DPC) as an oxidant in alkaline medium is new and restricted to a few cases because of its limited solubility and stability in aqueous medium. Copper complexes have occupied a major place in oxidation chemistry because of their abundance and relevance in biological chemistry.⁷ Copper (III) is involved in many biological electron transfer reactions.⁸ When the copper (III) periodate complex is oxidant and multiple equilibria between different copper (III) species⁹ are involved, it would be interesting to know which of the species is the active oxidant.

The kinetics of oxidation of L-leucine by DPC has not been reported in the literature. In view of the medicinal value and potential pharmaceutical importance of L-leucine and lack of literature on the oxidation mechanism of this drug by DPC, there was a need for understanding the oxidation mechanism of this bioactive

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compound. Hence the title reaction was investigated in detail.

2. Experimental

2.1 Materials and methods

All chemicals used were of reagent grade, and doubly distilled water was used throughout the work. A solution of L-leucine was prepared by dissolving an appropriate amount of L-leucine (S. D. Fine Chemicals) in doubly distilled water. The required concentration of L-leucine was prepared from its stock solution. The copper (III) periodate complex was prepared by standard procedure.¹⁰ Existence of copper (III) complex was verified by its UV-vis spectrum, which showed an absorption band with maximum absorption at 415 nm. The aqueous solution of copper (III) was standardized by iodometric titration and gravimetrically by the thiocyanate¹¹ method. The copper (II) solution was prepared by dissolving the known amount of copper sulfate (BDH) in distilled water. Periodate solution was prepared by weighing the required amount of sample in hot water and used after keeping it for 24 h. Its concentration was ascertained iodometrically¹² at neutral pH by phosphate buffer. KOH and KNO₃ (BDH, AR) were employed to maintain the required alkalinity and ionic strength, respectively, in reaction solutions.

2.2 Instruments used

(i) For kinetic measurements, a Peltier Accessory (temperature control) attached Varian CARY 50 Bio UV-vis Spectrophotometer (Varian, Victoria-3170, Australia) was used. (ii) For product analysis, a QP-2010S Shimadzu gas chromatograph mass spectrometer, Nicolet 5700-FT-IR spectrometer (Thermo, U.S.A.) and for pH measurements, an Elico pH meter model LI120 were used.

2.3 Kinetic measurements

The kinetic measurements were performed on a Peltier Accessory (temperature control) attached Varian CARY 50 Bio UV-vis Spectrophotometer (Varian, Victoria-3170, Australia). The kinetics was followed under pseudo first-order condition, where $[L\text{-leucine}] \gg [DPC]$ at $25 \pm 0.1^\circ\text{C}$, unless specified. The reaction was initiated by mixing the DPC with L-leucine solution, which also contained the required concentration of KNO₃,

KOH, and KIO₄. The progress of the reaction was followed spectrophotometrically at 415 nm by monitoring the decrease in absorbance due to DPC with the molar absorptivity index, ϵ to be $6230 \pm 100 \text{ dm}^3 \text{ mol}^{-1} \text{ cm}^{-1}$. It was verified that there is a negligible interference from other species present in the reaction mixture at this wavelength.

The pseudo first-order rate constants, k_{obs} , were determined from the log (absorbance) versus time plots and were the average of duplicate runs (table 1). The plots were linear up to 80% completion of reaction under the range of $[\text{OH}^-]$ used and the rate constants were reproducible to within $\pm 5\%$. The orders for various species were determined from the slopes of plots of $\log k_{\text{obs}}$ versus \log respective concentration of species except for [DPC] in which no variation of k_{obs} was observed as expected to the reaction condition. During the kinetics, a constant concentration viz. $1.0 \times 10^{-5} \text{ mol dm}^{-3}$ of KIO₄ was used throughout the study unless otherwise stated. Since periodate is present in excess in DPC, the possibility of oxidation of L-leucine by periodate in alkaline medium at 25°C was tested. The progress of the reaction was followed iodometrically. However, it was found that there was no significant reaction under the experimental conditions employed compared to the DPC oxidation of L-leucine. The total concentrations of periodate and OH^- was calculated by considering the amount present in the DPC solution and that additionally added. Kinetic runs were also carried out in N₂ atmosphere in order to understand the effect of dissolved oxygen on the rate of reaction. No significant difference in the results was obtained under a N₂ atmosphere and in the presence of air. In view of the ubiquitous contamination of carbonate in the basic medium, the effect of carbonate was also studied. Added carbonate had no effect on the reaction rates. The spectral changes during the reaction are shown in figure 1. It is evident from the figure that the concentration of DPC decreases by observing the absorbance at 415 nm.

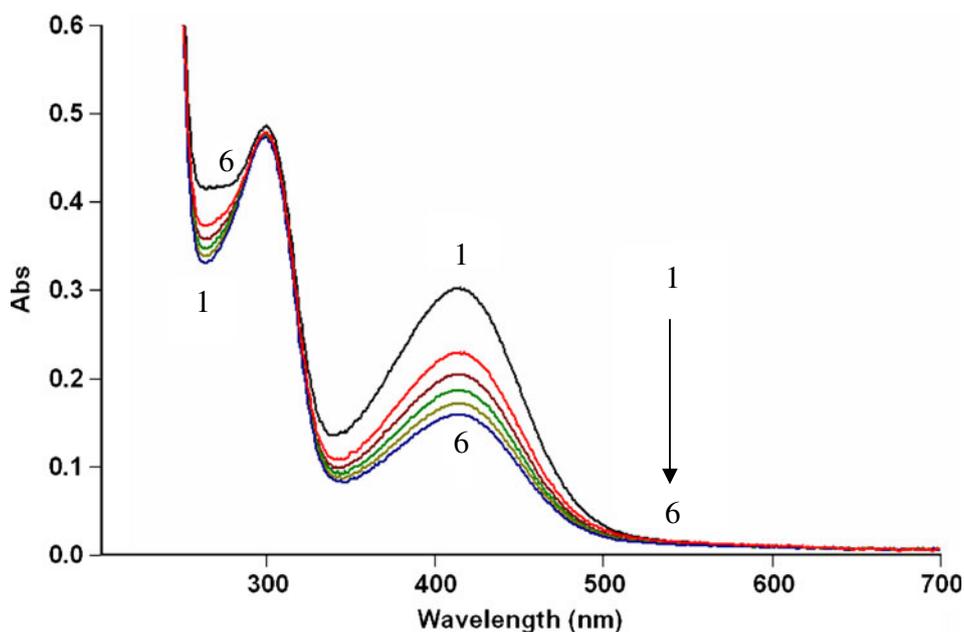
Regression analysis of experimental data to obtain the regression coefficient r and standard deviation S of points from the regression line was performed using Microsoft 2003 Excel program.

2.4 Stoichiometry and product analysis

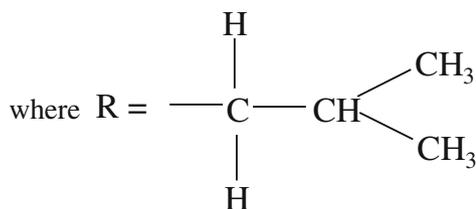
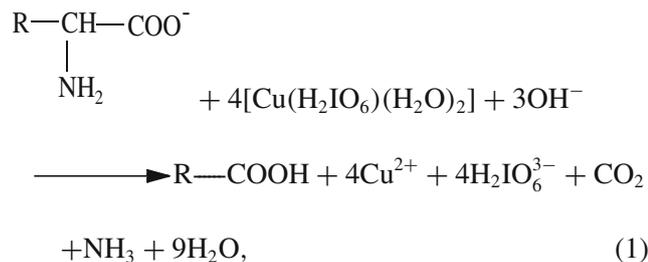
Different sets of reaction mixtures containing various ratios of DPC to L-leucine in the presence of constant amounts of OH^- and KNO₃ were kept for 6 h in a closed vessel under nitrogen atmosphere. The remaining concentration of DPC was estimated by spectrophotomet-

Table 1. Effect of [DPC], [L-leucine], $[\text{IO}_4^-]$ and $[\text{OH}^-]$ on the oxidation of L-leucine by diperiodatocuprate(III) in alkaline medium at 25°C, $I = 0.1 \text{ mol dm}^{-3}$.

| [DPC] $\times 10^5$ (mol dm^{-3}) | [L-leucine] $\times 10^3$ (mol dm^{-3}) | $[\text{IO}_4^-] \times 10^5$ (mol dm^{-3}) | $[\text{OH}^-]$ (mol dm^{-3}) | $k_{\text{obs}} \times 10^3$ (s^{-1}) | $k_{\text{cal}} \times 10^3$ (s^{-1}) |
|-------------------------------------------------|-------------------------------------------------------|-----------------------------------------------------------|---------------------------------------------|-----------------------------------------------------|-----------------------------------------------------|
| 1.0 | 3.0 | 1.0 | 0.05 | 3.01 | 2.89 |
| 3.0 | 3.0 | 1.0 | 0.05 | 2.77 | 2.89 |
| 5.0 | 3.0 | 1.0 | 0.05 | 2.79 | 2.89 |
| 8.0 | 3.0 | 1.0 | 0.05 | 2.98 | 2.89 |
| 10.0 | 3.0 | 1.0 | 0.05 | 2.85 | 2.89 |
| 5.0 | 1.0 | 1.0 | 0.05 | 2.00 | 2.00 |
| 5.0 | 3.0 | 1.0 | 0.05 | 2.79 | 2.89 |
| 5.0 | 5.0 | 1.0 | 0.05 | 3.14 | 3.16 |
| 5.0 | 8.0 | 1.0 | 0.05 | 3.34 | 3.34 |
| 5.0 | 10.0 | 1.0 | 0.05 | 3.51 | 3.41 |
| 5.0 | 3.0 | 1.0 | 0.05 | 2.79 | 2.89 |
| 5.0 | 3.0 | 3.0 | 0.05 | 2.11 | 2.13 |
| 5.0 | 3.0 | 5.0 | 0.05 | 1.68 | 1.69 |
| 5.0 | 3.0 | 8.0 | 0.05 | 1.28 | 1.29 |
| 5.0 | 3.0 | 10.0 | 0.05 | 1.07 | 1.11 |
| 5.0 | 3.0 | 1.0 | 0.01 | 1.76 | 1.73 |
| 5.0 | 3.0 | 1.0 | 0.02 | 2.20 | 2.13 |
| 5.0 | 3.0 | 1.0 | 0.05 | 2.79 | 2.89 |
| 5.0 | 3.0 | 1.0 | 0.08 | 3.13 | 3.08 |
| 5.0 | 3.0 | 1.0 | 0.1 | 3.34 | 3.15 |

**Figure 1.** UV-vis spectra changes during the oxidation of L-leucine by alkaline diperiodatocuprate(III) at 298 K, $[\text{DPC}] = 5.0 \times 10^{-5}$, $[\text{L-leucine}] = 3.0 \times 10^{-3}$, $[\text{OH}^-] = 0.05$ and $I = 0.1 \text{ mol dm}^{-3}$ with scanning time of (1) 0.5 min, (2) 1.0 min, (3) 1.5 min, (4) 2.0 min, (5) 2.5 min and (6) 3.0 min.

rically. The results indicated 1:4 stoichiometry as given in Eq. (1).



The reaction product was extracted with ether and recrystallised from aqueous alcohol. Only one product was obtained as evidenced by a single spot on thin layer chromatography, which was identified as 3-methyl butanoic acid by spot test¹³ and was characterized by GC-MS spectral studies.

GC-MS data was obtained on a QP-2010S Shimadzu gas chromatograph mass spectrometer. The mass spectral data showed a molecular ion peak at 102 m/z confirming the presence of 3-methyl butanoic acid (figure 2). The by-product, ammonia was detected by Nessler's reagent, and the product CO₂ was qualitatively detected by bubbling N₂ gas through the acidified reaction mixture and passing the liberated gas through tube containing limewater. Another product, Cu (II) was identified by UV-vis spectra. The reaction products do not undergo further oxidation under the present kinetic conditions.

3. Results

3.1 Reaction orders

The reaction orders were determined from the slope of log k_{obs} versus log (concentration) plots by varying the concentrations of L-leucine, alkali, and periodate in turn, while keeping all other concentrations and conditions constant, except for DPC concentration.

3.2 Effect of DPC

The oxidant, DPC concentration was varied in the range 1.0×10^{-5} to 1.0×10^{-4} mol dm⁻³, and the fairly constant k_{obs} values indicate that order with respect to [DPC] was unity (table 1). This was also confirmed by linearity of the plots of log [absorbance] versus time ($r \geq 0.9711$, $S \leq 0.013$) up to 80% completion of the reaction.

3.3 Effect of L-leucine

The effect of [L-leucine] on the rate of reaction was studied at constant concentrations of alkali, DPC, and periodate at a constant ionic strength of 0.1 mol dm⁻³. The substrate L-leucine was varied in the range 1.0×10^{-3} to 1.0×10^{-2} mol dm⁻³. The k_{obs} values increased with increase in concentration of L-leucine. The order with respect to [L-leucine] was found to be less than unity (table 1) ($r \geq 0.9933$, $S \leq 0.005$) under the experimental concentrations. The order in [L-leucine] changes from first order to zero order as [L-leucine] increases (figure 3).

3.4 Effect of alkali

The effect of increase in concentration of alkali on the reaction was studied at constant concentrations of

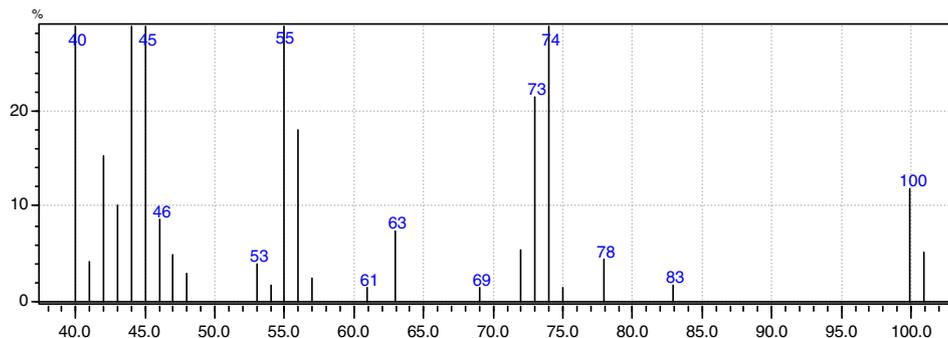


Figure 2. Mass spectrum of reaction product, 3-methyl butanoic acid with its molecular ion peak at 102 m/z.

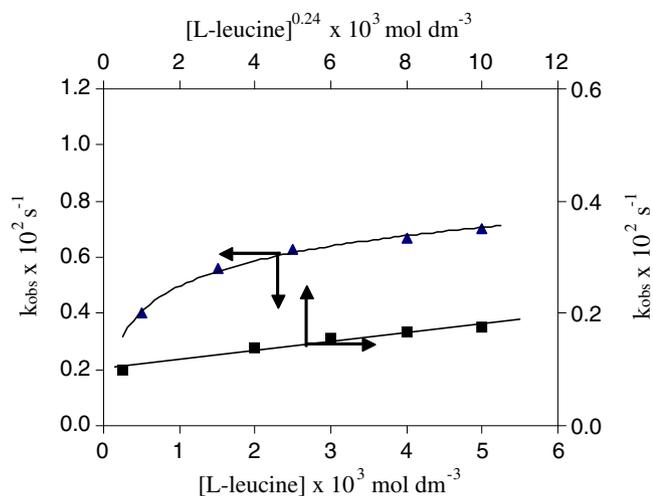


Figure 3. Plots of k_{obs} vs. $[\text{L-leucine}]^{0.24}$ and k_{obs} vs. $[\text{L-leucine}]$ (from table 1).

L-leucine, DPC, and periodate at a constant ionic strength of 0.1 mol dm^{-3} at 25°C . The rate constants increased with increase in alkali concentration (table 1), indicating apparent less than unit order dependence of rate on alkali concentration ($r \geq 0.9780$, $S \leq 0.006$). Similar to the case of L-leucine, the order in alkali changes from first order to zero order as $[\text{OH}^-]$ increases.

3.5 Effect of Periodate

The effect of increasing concentration of periodate was studied by varying the periodate concentration from 1.0×10^{-5} to $1.0 \times 10^{-4} \text{ mol dm}^{-3}$ keeping all other reactants concentrations constant. It was found that the added periodate had a retarding effect on the rate of reaction, the order with respect to periodate concentration being negative less than unity (table 1).

3.6 Effect of ionic strength (I) and dielectric constant of the medium (D)

Ionic strength was varied by the addition of KNO_3 at constant $[\text{DPC}]$, $[\text{L-leucine}]$, $[\text{OH}^-]$, and $[\text{IO}_4^-]$. It was found that increasing ionic strength had no significant effect on the rate of the reaction thereby indicating that the reaction is insensitive to ionic strength.

Dielectric constant of the medium, D , was varied by varying t -butyl alcohol and water percentage (1–5%). The D values were calculated from the equation $D = D_w V_w + D_B V_B$, where D_w and D_B are dielectric constants of pure water and t -butyl alcohol, respectively, and V_w and V_B are the volume fractions of

components water and t -butyl alcohol, respectively, in the total mixture. The t -BuOH was not oxidized under the experimental conditions. There was no effect of dielectric constant on the rate of reaction.

Thus from the observed experimental results, the rate law for reaction is given as follows:

$$\text{Rate} = k_{\text{obs}} [\text{L-leucine}]^{0.24} [\text{DPC}]^{1.0} [\text{OH}^-]^{0.27} [\text{IO}_4^-]^{-0.40}.$$

3.7 Effect of added products

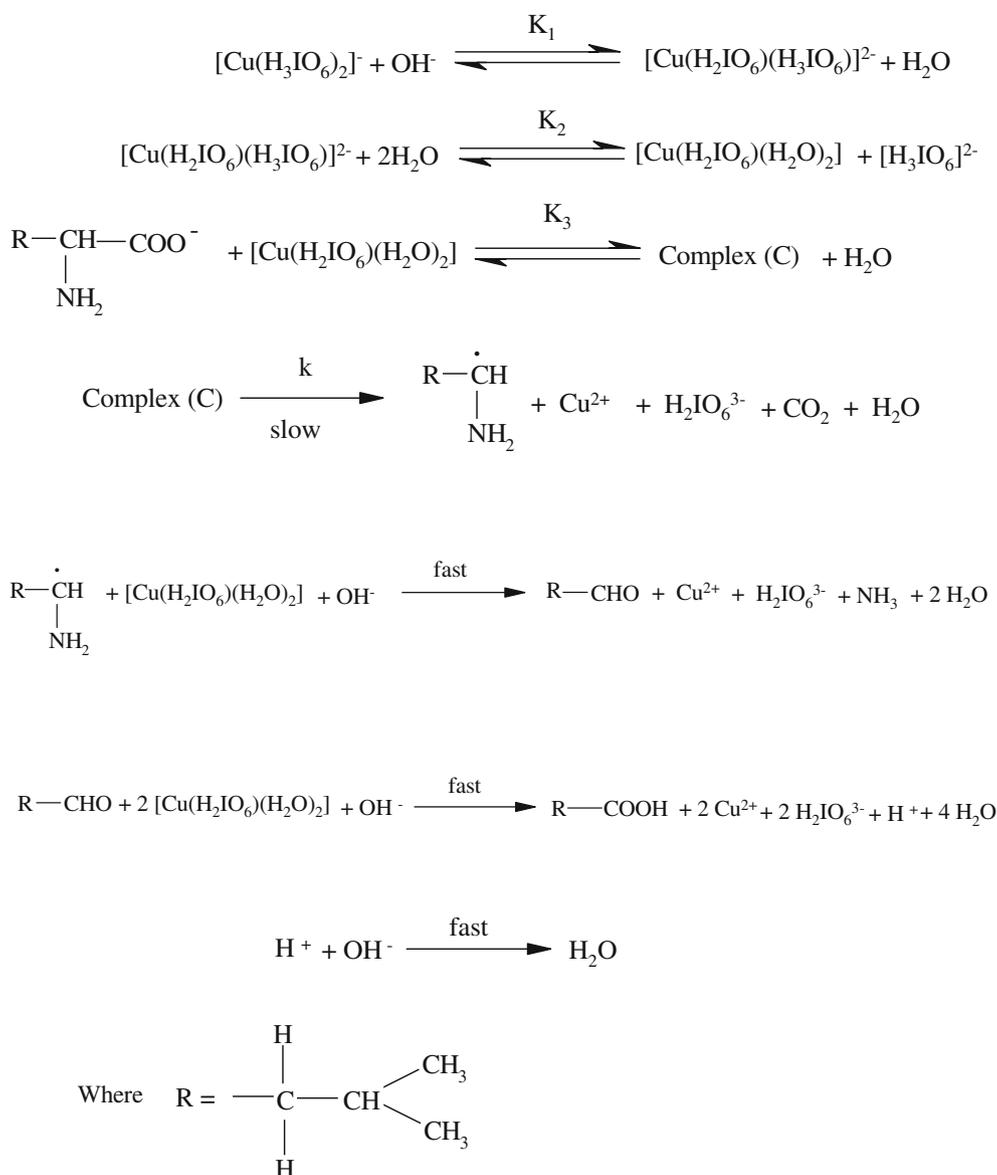
The externally added products, 3-methyl butanoic acid and copper (II) (CuSO_4) in the range 1.0×10^{-4} to $1.0 \times 10^{-3} \text{ mol dm}^{-3}$ did not have any significant effect on the rate of the reaction.

3.8 Polymerization study (test for free radicals)

DPC is a one equivalent oxidant. Hence, intervention of a free radical, generated from the organic compound, was expected. The possibility of intervention of free radicals was detected as follows. The reaction mixture, to which a known quantity of acrylonitrile (scavenger) had been added initially, was kept in an inert atmosphere for two hours. On diluting the reaction mixture with methanol, a white precipitate was formed, indicating the intervention of free radicals in the reaction. The blank experiments of either DPC or L-leucine alone with acrylonitrile did not induce any polymerization under the same condition as those induced for reaction mixture. Initially, added acrylonitrile decreases the rate of reaction indicating free radical intervention, which is the case in earlier work.¹⁴ The rate constant obtained in the absence of acrylonitrile was found to be $2.79 \times 10^{-3} \text{ s}^{-1}$, whereas this value decreased to $1.67 \times 10^{-3} \text{ s}^{-1}$ in the presence of acrylonitrile ($1 \times 10^{-4} \text{ M}$).

3.9 Effect of temperature

The rate of reaction was measured at four different temperatures under standard condition. The rate constant of the slow step (k) of scheme 1 were obtained from the slopes and intercepts of $1/k_{\text{obs}}$ versus $1/[\text{L-leucine}]$, $1/k_{\text{obs}}$ versus $[\text{H}_3\text{IO}_6^{2-}]$, and $1/k_{\text{obs}}$ versus $1/[\text{OH}^-]$ plots at four different temperatures. The data are subjected into least square analysis which is given in tables 2a and 2b. From the plot of $\log k$ vs $1/T$, E_a was obtained and other activation parameters have also been calculated and tabulated in tables 2a and 2b.



Scheme 1. Detailed mechanistic pathways for the oxidation of L-leucine by alkaline diperiodatocuprate (III).

4. Discussion

The water-soluble copper (III) periodate complex is reported¹⁵ to be $[\text{Cu}(\text{HIO}_6)_2]^{5-}$. However, in an

aqueous alkaline medium and at a high pH range as employed in the study, periodate is unlikely to exist as HIO_6^{4-} (as present in the complex) as is evident from its involvement in the multiple

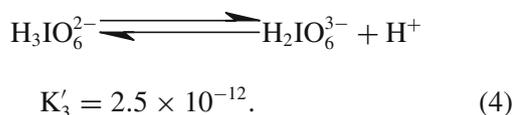
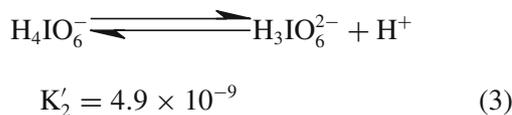
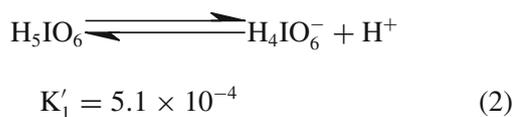
Table 2a. Effect of temperature on *k* for the oxidation of L-leucine by diperiodatocuprate(III) in aqueous alkaline medium.

| Temperature (K) | <i>k</i> × 10 ³ s ⁻¹ |
|-----------------|--------------------------------------------|
| 288 | 1.42 |
| 298 | 3.70 |
| 303 | 7.29 |
| 308 | 10.29 |

Table 2b. Activation parameters for the oxidation of L-leucine by diperiodatocuprate (III) in aqueous alkaline medium.

| Parameters | Values |
|---------------------------------------------------------|------------|
| E _a (kJ mol ⁻¹) | 75 ± 3 |
| ΔH [#] (kJ mol ⁻¹) | 72 ± 4 |
| ΔS [#] (J K ⁻¹ mol ⁻¹) | -49 ± 3 |
| ΔG _{298K} [#] (kJ mol ⁻¹) | 87 ± 1 |
| log A | 10.6 ± 1.0 |

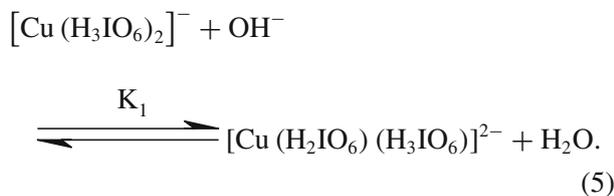
equilibria¹⁶ ((2)–(4)) depending on the pH of the solution.



Periodic acid exists in acid medium as H_5IO_6 and as H_4IO_6^- around pH 7. Thus, under the conditions employed in alkaline medium, the main species are expected to be $\text{H}_3\text{IO}_6^{2-}$ and $\text{H}_2\text{IO}_6^{3-}$. At higher concentrations, periodate also tends to dimerize.¹⁷ However, formation of this species is negligible under conditions employed for kinetic study. Hence, at the pH employed in this study, the soluble copper(III) periodate complex exists as diperiodatocuprate (III), $[\text{Cu}(\text{H}_3\text{IO}_6)(\text{H}_2\text{IO}_6)]^{2-}$, also supported by earlier work.²

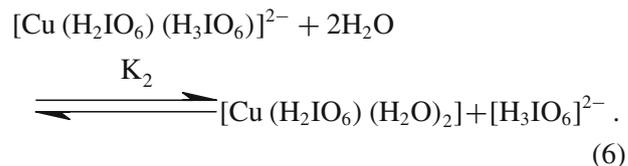
4.1 Mechanism

Based on the experimental results, a mechanism is proposed for which all the observed orders in each constituent such as [oxidant], [reductant], $[\text{OH}^-]$, and $[\text{IO}_4^-]$ may be well-accommodated. Lister¹⁸ proposed three forms of copper (III) periodate in alkaline medium as diperiodatocuprate(III)(DPC), monoperiodatocuprate(III)(MPC) and tetrahydroxocuprate(III). The tetrahydroxocuprate(III) is ruled out, as its equilibrium constant is 8.0×10^{-11} at 40°C. Hence, in the present study, DPC and MPC are considered to be as active forms of copper (III) periodate complex. The result of increase in rate of reaction with increase in alkalinity (table 1) can be explained in terms of prevailing equilibrium of formation of $[\text{Cu}(\text{H}_3\text{IO}_6)(\text{H}_2\text{IO}_6)]^{2-}$ from $[\text{Cu}(\text{H}_3\text{IO}_6)_2]^-$ as given below



Also the decrease in the rate with increase in periodate concentration suggests that the displacement of a

ligand periodate takes place to give a free periodate and monoperiodatocuprate(III) (MPC) species from $[\text{Cu}(\text{H}_2\text{IO}_6)(\text{H}_3\text{IO}_6)]^{2-}$ as given in equation (6)



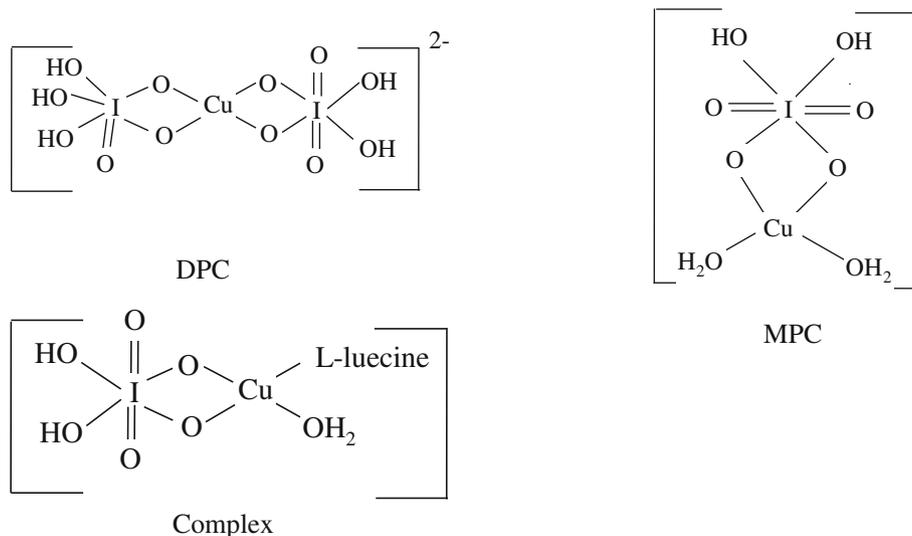
Such type of equilibria have been well-noticed in literature.¹⁹ It may be expected that a lower periodate complex such as monoperiodatocuprate(III) (MPC) is more important in the reaction than the DPC in view of the observed inverse fractional order in periodate. With the known equilibrium constants,¹⁹ the individual concentrations of $[\text{DPC}]_f$, DPC and MPC were calculated. It was found that MPC was in higher concentration and nearly paralleled the rate variation with different $[\text{OH}^-]$. Furthermore, the spectra of Cu(III) periodate complex was dependent on $[\text{OH}^-]$ and the absorption becomes almost constant, indicating the predominance of one species, presumably $[\text{Cu}(\text{H}_2\text{IO}_6)(\text{H}_2\text{O})_2]$. Because of this and the fact that rate is a function of $[\text{OH}^-]$ (less than unit order), the main oxidation species is likely to be $[\text{Cu}(\text{H}_2\text{IO}_6)(\text{H}_2\text{O})_2]$ and its formation equilibrium (6) is important in the reaction.

The less than unit order in [L-leucine] presumably results from formation of a complex (C) between the MPC species and L-leucine prior to the formation of the products. K_3 is the composite equilibrium constant comprising the equilibrium to bind active species, MPC to L-leucine species to form a complex (C). This complex(C) undergoes decomposition in a slow step to give the free radical species of L-leucine, periodate, CO_2 and Cu(II). This free radical species of L-leucine reacts with one mole of MPC species in a fast step to form corresponding aldehyde, Cu(II), NH_3 and periodate. This aldehyde further reacts with two more mole of MPC in a fast step to form the final products i.e., 3-methyl butanoic acid, Cu(II) and periodate. So, the detailed mechanistic pathway for the oxidation of L-leucine by diperiodatocuprate (III) is presented in scheme 1.

Since scheme 1 is in accordance with the generally well-accepted principle of non-complementary oxidations taking place in sequence of one-electron steps, the reaction between the substrate and oxidant would afford a radical intermediate. A free-radical scavenging experiment revealed such a possibility. This type of radical intermediate has also been observed in earlier work.²⁰ Spectroscopic evidence for the complex formation between oxidant and substrate was obtained from UV-Vis spectra of L-leucine

(3.0×10^{-4} mol dm $^{-3}$), DPC (5.0×10^{-5} mol dm $^{-3}$), [OH $^{-}$] (0.05 mol dm $^{-3}$) and mixture of both. A hypsochromic shift of about 5 nm from 306 to 301 nm in the spectra of DPC was observed. The Michaelis–Menten plot also proved the complex formation between DPC and L-leucine, which explains the less than unit

order dependence on [L-leucine]. Such a complex between a substrate and an oxidant has been observed in other studies.²¹ The diamagnetic (dsp 2) square planar structure of Cu(III) periodate in the form of DPC, MPC and the paramagnetic (sp 3) complex of Cu(III) and L-leucine can be formulated as shown below.



Scheme 1 leads to the rate law (7) (see appendix A)

$$\text{Rate} = \frac{-d[\text{DPC}]}{dt} = \frac{k K_1 K_2 K_3 [\text{DPC}] [\text{L-leucine}] [\text{OH}^-]}{[\text{H}_3\text{IO}_6^{2-}] + K_1 [\text{H}_3\text{IO}_6^{2-}] [\text{OH}^-] + K_1 K_2 [\text{OH}^-] + K_1 K_2 K_3 [\text{OH}^-] [\text{L-leucine}]} \quad (7)$$

this explains all the observed kinetic orders of different species.

$$k_{\text{obs}} = \frac{\text{Rate}}{[\text{DPC}]} = \frac{k K_1 K_2 K_3 [\text{L-leucine}] [\text{OH}^-]}{[\text{H}_3\text{IO}_6^{2-}] + K_1 [\text{H}_3\text{IO}_6^{2-}] [\text{OH}^-] + K_1 K_2 [\text{OH}^-] + K_1 K_2 K_3 [\text{OH}^-] [\text{L-leucine}]} \quad (8)$$

The rate law (8) can be rearranged into the following form, which is suitable for verification.

$$\frac{1}{k_{\text{obs}}} = \frac{1}{k K_1 K_2 K_3 [\text{L-leucine}] [\text{OH}^-]} + \frac{[\text{H}_3\text{IO}_6^{2-}]}{k K_2 K_3 [\text{L-leucine}]} + \frac{1}{k K_3 [\text{L-leucine}]} + \frac{1}{k} \quad (9)$$

According to Eq. (9), other conditions being constant, plots of $1/k_{\text{obs}}$ versus $1/[\text{OH}^-]$ ($r \geq 0.9780$, $S \leq 0.029$), $1/k_{\text{obs}}$ versus $1/[\text{L-leucine}]$ ($r \geq 0.9933$, $S \leq 0.016$), and $1/k_{\text{obs}}$ versus $[\text{H}_3\text{IO}_6^{2-}]$ ($r \geq 0.991$, $S \leq 0.011$) should be linear and are found to be so (figure 4). The slopes and intercepts of such plots lead to the values of K_1 , K_2 , K_3 , and k as (1.19 ± 0.03) dm 3 mol $^{-1}$, (4.25 ± 0.30) $\times 10^{-5}$ mol dm $^{-3}$, (6.14 ± 0.10) $\times 10^3$ dm 3 mol $^{-1}$, and (3.70 ± 0.40) \times

10^{-3} s $^{-1}$, respectively at 298 K. The value of K_1 is in good agreement with earlier work.¹⁹ Using these K_1 , K_2 , K_3 , and k values, the rate constants under different experimental conditions were calculated by Eq. (8) and compared with experimental data. The results show a good agreement (table 1), which fortifies the scheme 1. Similarly K_1 , K_2 , K_3 , and k values were calculated at four different temperatures and are given in tables 3a and 3b. A vant Hoff's plot was made for variation

of K_1 with temperature ($\log K_1$ vs. $1/T$ ($r \geq 0.9811$, $S \leq 0.006$)) and the values of enthalpy of reaction ΔH , entropy of reaction ΔS , and free energy of reaction ΔG

Table 3a. Effect of temperature on equilibrium constants of scheme 1 for the oxidation of L-leucine by diperiodatocuprate (III) in aqueous alkaline medium.

| Temperature (K) | K_1 (mol dm ⁻³) | $K_2 \times 10^5$ (mol dm ⁻³) | $K_3 \times 10^{-3}$ (dm ³ mol ⁻¹) |
|-----------------|-------------------------------|-------------------------------------------|-----------------------------------------------------------|
| 288 | 0.68 | 6.21 | 4.68 |
| 298 | 1.19 | 4.25 | 6.14 |
| 303 | 2.43 | 3.01 | 8.44 |
| 308 | 4.53 | 1.94 | 9.59 |

Table 3b. Thermodynamic quantities with respect to K_1 , K_2 and K_3 .

| Thermodynamic quantities | Values from K_1 | Values from K_2 | Values from K_3 |
|---------------------------------------------------|-------------------|-------------------|-------------------|
| ΔH (kJ mol ⁻¹) | 69 ± 3 | -42 ± 4 | 27 ± 3 |
| ΔS (J K ⁻¹ mol ⁻¹) | 236 ± 15 | -224 ± 10 | 165 ± 10 |
| ΔG (kJ mol ⁻¹) | -1.4 ± 0.1 | 25.5 ± 2.0 | -22.1 ± 1.1 |

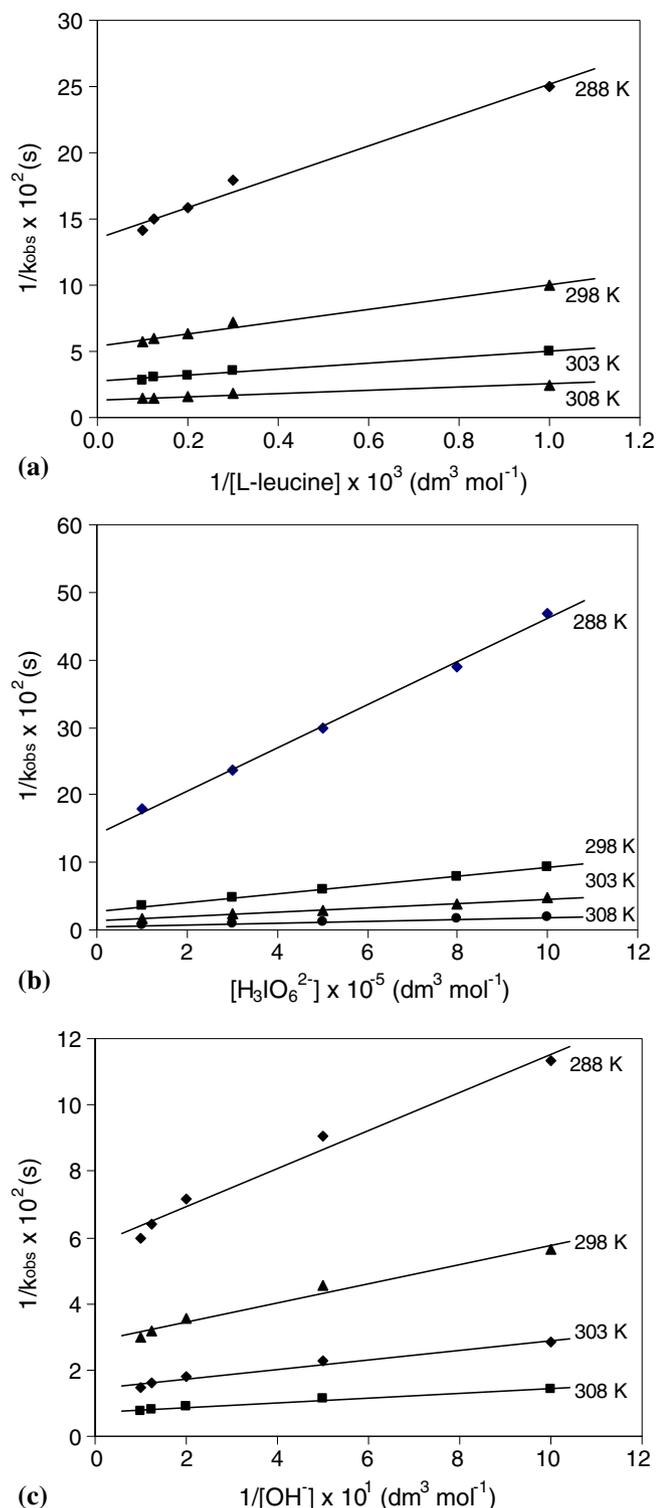


Figure 4. Verification of rate law (eqn. (8)) for the oxidation of L-leucine by diperiodatocuprate(III). (a) Plot of $1/k_{\text{obs}}$ vs $1/[L\text{-leucine}]$, (b) Plot of $1/k_{\text{obs}}$ vs $1/[H_3IO_6^{2-}]$ and (c) Plot of $1/k_{\text{obs}}$ vs $1/[OH^-]$ at four different temperatures.

were calculated for the first equilibrium step (tables 3a and 3b). A comparison of ΔH value (69 kJ mol^{-1}) from K_1 with that of ΔH^\ddagger (72 kJ mol^{-1}) of rate limiting step supports that the first step of scheme 1 is fairly fast since it involves low activation energy with those obtained for the slow step of the reaction.²² In the same manner, K_2 and K_3 values were calculated at different temperatures and their corresponding values of the thermodynamic quantities are given in tables 3a and 3b.

The negligible effect of ionic strength and dielectric constant of the medium on the rate qualitatively explains the reaction between neutral charged species, as seen in scheme 1. The values of ΔH^\ddagger and ΔS^\ddagger were both favourable for electron transfer processes. The negative value of ΔS^\ddagger indicates that the complex (C) is more ordered than the reactants.²³ The value of ΔS^\ddagger within the range for radical reaction has been described²⁴ to the nature of electron pairing and unpairing processes and to the loss of degrees of freedom formerly available to the reactants upon the formation of rigid transition state. The observed modest enthalpy of activation and a relatively low value of the entropy of activation as well as a higher rate constant of the slow step indicate that the oxidation presumably occurs via inner-sphere mechanism. This conclusion is supported by earlier observation.²⁵

5. Conclusions

Among the various species of DPC in aqueous alkaline medium, $[Cu(H_2IO_6)(H_2O)_2]$ is considered as

active species for the title reaction. The results indicated that in carrying out this reaction, the role of pH in the reaction medium is crucial. Rate constant of slow step and other equilibrium constants involved in the mechanism are evaluated. The overall mechanistic sequence described here is consistent with all the experimental evidences including the product, spectral, mechanistic and kinetic studies.

Appendix A

Derivation of rate law for the reaction

According to scheme 1

$$\text{Rate} = \frac{-d[\text{DPC}]}{dt} = k[\text{C}]$$

$$\text{Rate} = \frac{k K_1 K_2 K_3 [\text{L-leucine}] [\text{DPC}] [\text{OH}^-]}{[\text{H}_3\text{IO}_6^{2-}]} \quad (\text{I})$$

$$[\text{DPC}]_f = \frac{[\text{DPC}]_T [\text{H}_3\text{IO}_6^{2-}]}{[\text{H}_3\text{IO}_6^{2-}] + K_1 [\text{OH}^-] [\text{H}_3\text{IO}_6^{2-}] + K_1 K_2 [\text{OH}^-] + K_1 K_2 K_3 [\text{OH}^-] [\text{L-leucine}]} \quad (\text{II})$$

Similarly,

$$[\text{L-leucine}]_T = [\text{L-leucine}]_f + [\text{Complex}]$$

$$[\text{L-leucine}]_f = \frac{[\text{L-leucine}]_T [\text{H}_3\text{IO}_6^{2-}]}{[\text{H}_3\text{IO}_6^{2-}] + K_1 K_2 K_3 [\text{OH}^-] [\text{Cu}(\text{H}_3\text{IO}_6)_2]^-}$$

Total concentration of DPC is given by

$$[\text{DPC}]_T = [\text{DPC}]_f + [\text{Cu}(\text{H}_2\text{IO}_6)(\text{H}_3\text{IO}_6)]^{2-} + [\text{Cu}(\text{H}_2\text{IO}_6)(\text{H}_2\text{O})_2] + \text{Complex}$$

$$[\text{DPC}]_T = [\text{DPC}]_f \left\{ 1 + K_1 [\text{OH}^-] + \frac{K_1 K_2 [\text{OH}^-]}{[\text{H}_3\text{IO}_6^{2-}]} + \frac{K_1 K_2 K_3 [\text{OH}^-] [\text{L-leucine}]}{[\text{H}_3\text{IO}_6^{2-}]} \right\},$$

where T and f refer to total and free concentrations. Therefore,

In view of low concentration of DPC used, the term $K_1 K_2 K_3 [\text{OH}^-] [\text{Cu}(\text{H}_3\text{IO}_6)_2]^-$ compared to $[\text{H}_3\text{IO}_6^{2-}]$ can be neglected. Hence,

$$[\text{L-leucine}]_f = [\text{L-leucine}]_T \quad (\text{III})$$

$$\text{Similarly, } [\text{OH}^-]_f = [\text{OH}^-]_T \quad (\text{IV})$$

Substituting (II), (III), and (IV) in (I) and omitting the subscripts T and f,

We get,

$$\text{Rate} = \frac{-d[\text{DPC}]}{dt} = \frac{k K_1 K_2 K_3 [\text{DPC}] [\text{L-leucine}] [\text{OH}^-]}{[\text{H}_3\text{IO}_6^{2-}] + K_3 [\text{H}_3\text{IO}_6^{2-}] [\text{OH}^-] + K_1 K_2 [\text{OH}^-] + K_1 K_2 K_3 [\text{OH}^-] [\text{L-leucine}]} \quad (\text{V})$$

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