Volume : 2 | Issue : 4 | Apr 2013 • ISSN No 2277 - 8179

Oxidation of L-Tyrosine by Tetrachloroaurate(III) – a Kinetic Study.

Chemistry

KEYWORDS : L-tyrosine, tetrachloroaurate(III), oxidation, kinetics, mechanism

N. Baby Nirmala Department of Inorganic and Analytical Chemistry, Andhra University, Visakhapatnam, Andhra Pradesh, India - 530 003.

P. Vani Department of Inorganic and Analytical Chemistry, Andhra University, Visakhapatnam, Andhra Pradesh, India - 530 003.

ABSTRACT

The kinetics of oxidation of L-tyrosine by tetrachloroaurate(III) was studied spectrophotometrically in perchloric acid medium at 313 nm at 30 oC. The orders with respect to the oxidant and substrate were found to be one and fractional respectively and the reaction exhibits Michaelis-Menten behaviour. Increase in [H+] and [Cl-] retard the rate of reaction. One of the products, AuI, and ionic strength did not show any significant effect on the reaction rate. The energy of activation, Ea and entropy of activation, ΔS≠ were calculated using linear least squares method and were found to be 42.90 ± 2.99 kJmol-1 and -88.96 ± 9.86 JKmol-1 respectively. A plausible mechanism consistent with the observed kinetics was proposed.

Introduction

Gold(III) compounds are biologically active substances and were reported to be potential anticancer agents. Not only gold(III) compounds but also gold nano particles have biomedical applications. These nano particles were synthesized by the reduction of tetrabromoaurate(III) (Bhargava, Booth, Agarwal, Coloe and Gopa Kar, 2005) or tetrachloroaurate(III) (Toroz and Corni, 2011) with peptides. Many kinetic investigations were performed on the reduction of tetrachloroaurate(III) and in most of these studies, AuI is the reduction product while in the oxidation of oxalic acid, AuIII was reduced to metallic gold as has been proven (Soni, Sandal andMehrotra, 2007) .

Toroz and Corni (2011) studied the reduction of tetrachloroaurate(III) with tyrosine in peptides. But their study is concentrated on the formation of gold nano particals rather than the kinetics of the reaction and thermodynamic parameters. Hence, in continuation of our kinetic investigations on the oxidation of L-tyrosine (Nirmala and Vani, 2011), we have carried out the title reaction in perchloric acid medium to deduce the mechanism of oxidation.

Experimental

Stock solutions of tetrachloroaurate(III) were prepared from HAuCl4.3H2O in 0.1 mol dm-3 perchloric acid. The absorption spectrum of gold(III) was recorded in the ultra violet region and two strong bands were observed at 226 nm (ε = 34750 mol-1 dm3 cm-1) and 313 nm (ε = 4830 mol-1 dm3 cm-1). All the other reagents used were of analytical reagent grade.

The kinetic studies were carried out under pseudo-first order conditions by keeping the concentration of tyrosine in large excess compared to that of the oxidant. The progress of the reaction was followed spectrophotometrically using Milton Roy Spectronic 1201 UV- Visible spectrophotometer by measuring the absorbance of tetrachloroaurate(III) at 313 nm, where other reactants of the reaction had negligible absorption. A Siskin Julabo-V constant temperature liquid circulatory bath was used as the constant temperature bath. The rate constants of duplicate runs were found to be reproducible within ±3%.

Results

Product analysis

The reaction mixture containing 1.0 x 10-2 mol dm-3 tyrosine, 1.0 x 10-4 mol dm-3 gold(III) in 0.1 mol dm-3 perchloric acid was allowed to react completely and it was extracted with ether after completion of the reaction. The product obtained from the ethereal layer was identified as dityrosine by IR spectral data (Fig.1) and the same product, dityrosine was reported in the reduction of tetrachloroaurate(III) with tyrosine in peptides as Toroz and Corni (2011) proved.

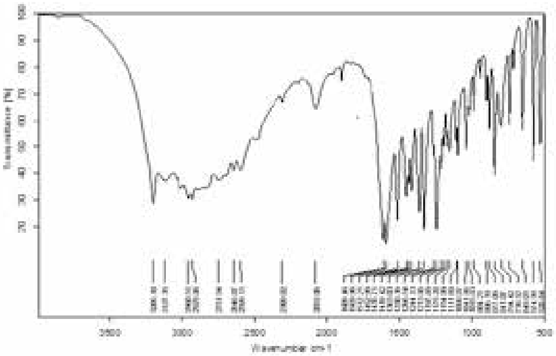


Fig.1: FT-IR spectrum of dityrosine

In the IR spectrum of the product, the peaks at 3205.10 cm-1, 3127.35 cm-1, 2960.51 cm-1, 2751.94 cm-1, 1609.46 cm-1 and 1589.96 cm-1 are corresponding to N-H(str), O-H(str), C=C-H(str), C-H(str), C=O(str) and C-H(str) frequencies respectively. Several peaks between 1600-1450 cm-1 are due to C=C(str) and the peaks between 1400-1050 cm-1 are the stretching frequencies of C-O and C-N.

Test for free radicals

The test for free radicals was carried out by adding the monomer, acrylonitrile, to the reaction mixture. The negative response indicating the absence of intervention of free radicals during the course of the reaction.

Effect of [tetrachloroaurate(III)]

In order to view the effect of [gold(III)] on the rate of oxidation of tyrosine, the reaction was studied at various initial concentrations of gold(III) by varying its concentration from 0.5 – 3.0 x 10-4 mol dm-3, keeping [tyr], [H+] and temperature constant. The plots of log(absorbance) versus time were found to be linear upto 75% completion of the reaction, suggesting the order with respect to [AuIII] was unity and the pseudo-first order rate constants, k/, were evaluated from the slopes of the plots of log(absorbance) versus time. The pseudo-first order rate constants were calculated from the plots of log(absorbance) versus time and were found to decrease with increase in [AuIII] (Table.1).

Table.1: Effect of [Au^{III}] on the pseudo-first order rate constant, k$^{/}$

[tyr] = 1.0 x 10-2 mol dm-3 ; [H+] = 0.1 mol dm-3 ; temp. = 30 ± 0.1 oC

[AuIII] x 104 (mol dm-3)	0.5	1.0	1.5	2.0	2.5	3.0
k/ x 104 (sec-1)	13.02	7.90	6.14	4.90	3.45	2.13

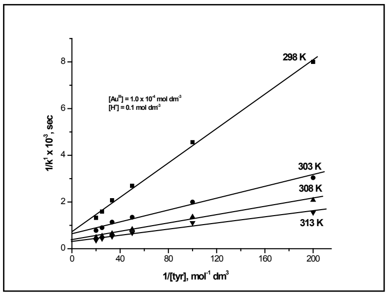
Effect of [tyrosine]

To find out the dependence of [tyrosine] on the reduction rate of tetrachloroaurate(III), kinetic runs were carried out at four different temperatures, 298, 303, 308 and 313 K by ranging tyrosine concentrations from 0.5 - 5.0 x 10-2 mol dm-3, keeping the concentrations of [H+], [AuIII] constant. It was found that the rate was increased with increase in the concentration of tyrosine (Table.2) and the order with respect to tyrosine was found to be fractional. Further, the plots of 1/k/ versus 1/[tyr], at four temperatures, were found to be straight lines with positive intercepts on ordinate, indicating fractional order dependence on [tyr] (Fig.2).

Table.2: Effect of [tyr] on the pseudo-first order rate constant, k/

$[Au^{III}]$ = 1.0 x 10^{-4} mol dm^{-3} ; $[H^+]$ = 0.2 mol dm^{-3}				
[tyr] x 10^2 (mol dm^{-3})	k/ x 10^4 (sec^{-1})			
	298 K	303 K	308 K	313 K
0.5	1.24	3.26	4.72	6.40
1.0	2.19	4.98	7.33	8.88
2.0	3.69	7.39	11.99	14.71
3.0	4.80	8.76	15.51	19.19
4.0	6.43	11.03	18.23	23.02
5.0	7.48	12.79	20.23	27.87

Fig.2: Plot of 1/k1 versus 1/[tyr] at different temperatures



Effect of [H+]

The effect of [H+] on the rate of reaction was studied at four various temperatures, 298, 303, 308 and 313 K by changing the perchloric acid concentration in the range 0.05 – 0.30 mol dm-3, keeping the concentrations of reductant and oxidant constant. From the pseudo-first order rate constants, it was found that the rate was decreased with increase in the concentration of H+ (Table.3).

Table.3: Effect of [H+] on the pseudo-first order rate constant, k/

[tyr] = 1.0 x 10-2 mol dm-3 ; [AuIII] = 1.0 x 10-4 mol dm-3				
[H+] (mol dm-3)	k/ x 104 (sec-1)			
	298 K	303 K	308 K	313 K
0.05	7.39	9.82	16.99	23.58
0.10	5.18	7.96	10.67	15.83
0.15	2.96	5.80	8.16	10.14
0.20	2.25	4.78	6.81	9.26
0.25	1.65	3.34	5.48	7.89
0.30	1.29	2.78	4.06	6.60

Effect of [Cl-]

In presence of added [Cl-], there is a small increase in the optical density of gold(III) and the same was also noticed earlier (Soni and Mehrotra, 2003) . Further, the effect of [Cl-] on the reaction rate was studied in the range 0.2 – 10.0 x 10-4 mol dm-3, keeping [tyr], [AuIII], [H+] constant at 30 oC. It was observed that the reaction rate decreased with increase in the [Cl-] (Table.4).

Table.4: Effect of [Cl-] on the pseudo-first order rate constant, k/

[tyr] = 1.0 x 10-2 mol dm-3 ; [H+] = 0.1 mol dm-3 ;						
[AuIII] = 1.0 x 10-4 mol dm-3 ; temp. = 30 ± 0.1 oC						
[Cl-] x 104 (mol dm-3)	0.2	0.5	1.0	2.0	5.0	10.0
k/ x 104 (sec-1)	6.83	6.14	5.69	4.60	3.07	1.89

Effect of ionic strength

The effect of ionic strength was studied by changing the ionic strength from 0.2 – 0.7 mol dm-3 using sodium perchlorate and it was observed that the rate of the reaction was unaffected with increase in ionic strength.

Discussion

Tyrosine has three pKa values, 2.2, 9.01 and 10.1 corresponding to –COOH, -H3N+ and phenolic –OH groups respectively as given in (Robert, Daryl, Peter and Victor , 2000, p.29).

Under the present experimental conditions (0.1 mol dm-3 perchloric acid), tyrosine exists as 6% in the form of zwitter ionic species, tyrz (HO-C6H4-CH2-CH(+NH3)-COO-) and the remaining 94% in its protonated form, Htyr (HO-C6H4-CH2-CH(+NH3)-COOH). In view of the decrease in rate with increase in hydrogen ion concentration, tyrz is presumed to be the reactive species of the substrate.

Chloroauric acid, HAuCl4 is a strong acid undergoes ionisation even in dilute mineral acids to AuCl3(H2O) and AuCl3(OH)- as shown in equilibria (2) and (3). Since the rate decreases with increase in [H+] and [Cl-], the retardation effect of [Cl-] may be attributed to the fact that with increasing [Cl-], equilibrium(2) is shifted towards right and similarly the retardation of rate by an increase in [H+], may be ascribed to shifting of the equilibrium(3) to right. Basing on these observations, AuCl3(OH)- is presumed to be the reactive species of tetrachloroaurate(III) and the following mechanism is proposed.

$$\text{tyr}_z + H^+ \overset{K}{\rightleftharpoons} \text{Htyr} \qquad \text{------------ (1)}$$

$$AuCl_4^- + H_2O \overset{K_1}{\rightleftharpoons} AuCl_3(H_2O) + Cl^- \qquad \text{------------ (2)}$$

$$AuCl_3(H_2O) \overset{K_2}{\rightleftharpoons} AuCl_3(OH)^- + H^+ \qquad \text{------------ (3)}$$

$$AuCl_3(OH)^- + \text{tyr}_z \overset{K_3}{\rightleftharpoons} \text{Complex (C)} \qquad \text{------------ (4)}$$

$$C \xrightarrow[\text{slow}]{k} \text{tyr}\dot{O} + Au^{II} \qquad \text{------------ (5)}$$

$$2\ \text{tyr}\dot{O} \xrightarrow{\text{fast}} \text{dityrosine} \qquad \text{------------ (6)}$$

$$2\ Au^{II} \xrightarrow{\text{fast}} Au^{III} + Au^{I} \qquad \text{------------ (7)}$$

Where tyrz = HO-C6H4-CH2-CH(+NH3)-COO-
and Htyr = HO-C6H4-CH2-CH(+NH3)-COOH.

From the above equations, the rate law can be written as

$$\text{rate} = \frac{-d[Au^{III}]}{dt} = k\,[C] \qquad \text{------------ (8)}$$

$$= k\,K_3\,[AuCl_3(OH)^-]_e\,[\text{tyr}_z]_e \qquad \text{------------ (9)}$$

where

$$[\text{tyr}_z]_e = \frac{[\text{tyr}]_t}{1 + K\,[H^+]} \qquad \text{and}$$

$$[AuCl_3(OH)^-]_e = \frac{K_1 K_2 [Au^{III}]_t}{[H^+][Cl^-] + K_1[H^+] + K_1K_2 + K_1K_2K_3[\text{tyr}_z]} \qquad \text{---------- (10)}$$

Substituting the values of [tyrz]e and [AuCl3(OH)-]e from equation(10) in equation (9) gives,

$$\text{rate} = \frac{k\,K_1 K_2 K_3 [\text{tyr}]_t [Au^{III}]_t}{\{1 + K[H^+]\}\{[H^+][Cl^-] + K_1[H^+] + K_1K_2\} + K_1K_2K_3[\text{tyr}]_t} \qquad \text{---------- (11)}$$

This rate equation explains the experimental kinetics like unit order on [AuIII], fractional order on [tyr] and retarding effect of [H+] and [Cl-]. Equation (11) can be written as

$$\frac{\text{rate}}{[\text{Au}^{\text{III}}]_t} = k^{/} = \frac{k\,K_1\,K_2\,K_3\,[\text{tyr}]_t}{\{1 + K[\text{H}^+]\}\{[\text{H}^+][\text{Cl}^-] + K_1[\text{H}^+] + K_1K_2\} + K_1K_2K_3[\text{tyr}]_t} \qquad \text{------------ (12)}$$

The above equation can be transformed to

$$\frac{1}{k^{/}} = \frac{\{1 + K[\text{H}^+]\}\{[\text{H}^+][\text{Cl}^-] + K_1[\text{H}^+] + K_1K_2\}}{k\,K_1\,K_2\,K_3\,[\text{tyr}]_t} + \frac{1}{k} \qquad \text{------------ (13)}$$

In the absence of added [Cl-], equation(13) reduces to

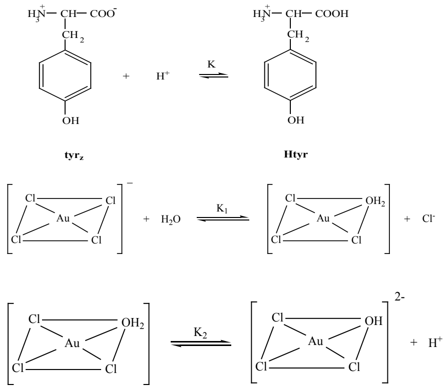
$$\frac{1}{k^{/}} = \frac{\{1 + K[\text{H}^+]\}\{[\text{H}^+] + K_2\}}{k\,K_2\,K_3\,[\text{tyr}]_t} + \frac{1}{k} \qquad \text{------------ (14)}$$

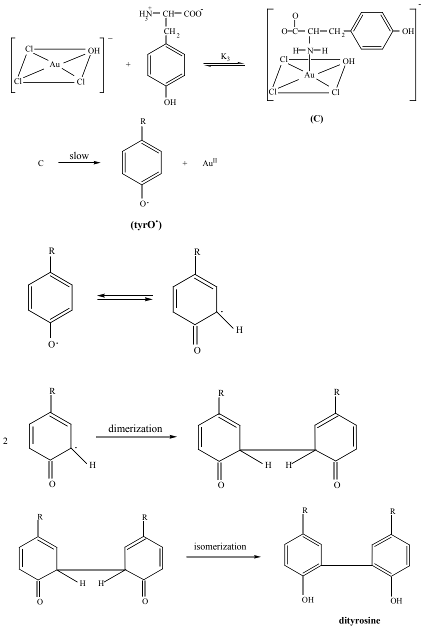
Equation(14) predicts the plot of 1/k/ versus 1/[tyr] should be a straight line with a positive intercept on y- axis and the same was obtained experimentally thus supporting the proposed mechanism. Further, the values of 'k' and 'K3' were calculated at four different temperatures (Table.5) from the slopes and intercepts of the plots of 1/k/ versus 1/[tyr] (fig.2) after substituting the literature values for K1 = 9.5 x 10-6 and K2 = 0.25 ((i).Van, Bekker and Robb, 1972 (ii) Moodley and Niol, 1977 (iii) Hans, Bjorn and Lars-G, 1960). From the values of k, the energy of activation, Ea and entropy of activation, ΔS≠ were calculated using linear least squares method and were found to be 42.90 ± 2.99 kJmol-1 and -88.96 ± 9.86 JKmol-1 respectively.

Table.5: Calculated values of k and K_3 at four different temperatures

[AuIII] = 1.0 x 10-4 mol dm-3 ; [H+] = 0.2 mol dm-3		
Temp.	k x 103	K3 x 103
(K)	(sec-1)	mol-1 dm3
298	1.33	` 1.20
303	1.56	6.60
308	2.56	5.81
313	3.22	6.45

Intimate mechanism





where R = - CH_2 - CH ($^+NH_3$) - COO $^-$

The following arguments are in support of the proposed intimate mechanism:

1. Gold(III) complexes are square planar in nature and undergo ligand substitution by associative mechanism. In general, amino acids are coordinated through carboxylate oxygen to metal ions because of the low pKa value of –COOH group. But, the transition metal ions with d8 electron configuration like platinum(II) and gold(III) are frequently coordinated only through amino nitrogen atom which brings a considerable increase in the crystal field stabilization energy in square planar d8 metal complexes (Eichhorn, 1973).
2. This complex undergoes redox decomposition with a transfer of one electron in the slow step to form tyrosyl radical and AuII.
3. Furthur, tyrosyl radical undergoes dimerization to form dityrosine.
4. Finally AuII undergoes disproportionation and gives AuIII and AuI.

Acknowledgements

One of the authors, N.Baby Nirmala, thanks the management of V.S.M.College, Ramachandrapuram, for the encouragement and University Grants Commission for the award of teacher fellowship under Faculty Development Programme.

REFERENCE

1. Bhargava, S. K., Booth, J.M., Agarwal, S., Coloe, P. & Gopa Kar. (2005). Gold nanoparticle formation during bromoaurate reduction by amino acids. Langmuir 21, 5949 - 5956. doi: 10.1021/a050283e. 2. Toroz, D. & Corni, S. (2011). Peptide synyhesis of gold nano partcles: The early steps of gold reduction investigated by density functional theory. Nano Lett. 11, 1313 – 1318. doi: 10.1021/nl1043924. 3. Soni, V., Sandal, R. S. & Mehrotra, R. N. (2007). Kinetics and mechanism of the oxidation of oxalic acid by tetrachloroaurate(III) ion. Inorg. Chim. Acta. 360, 3141 – 3148. doi: 10.1016/j.jca.2007.03.006. 4. Nirmala, N. B. & Vani, P. (2011). Kinetics and mechanism of oxidation of L- tyrosine by hexachloroiridate(IV) in perchloric acid medium. Proc. Ind. Natl. Sci. Acad. 7(4), 929 - 936. 5. Soni, V. & Mehrotra, R. N. (2003). Kinetics and mechanism of oxidation of hydroxylamine by tetrachloroaurate(III) ion. Trans. Met. Chem. 28, 893 - 898. 6. Robert, K.M., Daryl, K.G., Peter, A.M. & Victor, W.R. (2000). 'Harper's Biochemistry' 25th ed. p.29. 7. Van, P., Bekker, Z. & Robb, W. (1972). Kinetics of hydrolysis of the tetrachloroaurate(III) anion in aqueous perchloric acid. Inorg. Nucl. Chem. Lett. 8(10), 849 – 854. doi: org/10.1016/0020–1650(72)80234-4. 8. Moodley, K.G. & Niol, M.J. (1977). Kinetics of reduction of gold(III) by platinum(II) and iron(III) in aqueous chloride solutions. J. Chem. Soc. Dalton Trans 993 – 996. doi: 10.1013/Dt9770000993. 9. Hans, G.F., Bjorn, W. & Lars-G.W. (1960). Distribution coefficients and ionization constant for HAuCl4: A radioactive tracer method. J. Chem. Educ. 37(1), 44 – 46. doi: 10.1021/ed037p44. 10. Eichhorn, G.L.(1973). Inorganic Chemistry. p.129.