

Studies on the Complexation of Succinic Hydrazide with Copper Chloride Salt

Shereen. E. Salem, Esam A. Gomaa, Mohamed M. El-Defraway, Noha. M. Mohamed

ABSTRACT

The electrochemical behavior of the complexation between copper chloride salt and succinic hydrazide can be explained using cyclic voltammetric measurements. The complex is formed through the interaction with nitrogen and hydroxyl group or carbonyl group of succinic hydrazides. This interaction can be observed by decreasing in the height peak of current and measuring the (anodic/cathodic) shift of the potentials. All the solvation and thermodynamic parameters for the interaction of copper ions with succinic hydrazide as stability constant, Gibbs free energies, enthalpies and entropies of interaction were calculated. Finally, the activity of the formed complex was compared with the succinic hydrazide by comparing their effects on different types of gram-negative bacteria and fungi indicating high activity of the formed complex and its ability to be used in different medical applications.

Keywords: Succinic hydrazide, Complexation, Cyclic voltammetry, Solvation and Kinetic parameters, Stability constant, Antimicrobial activity.

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S. E. Salem*

Chemistry Department, Faculty of Science, Mansoura University, Mansoura, Egypt.

(e-mail: sara_salem669@yahoo.com)

Esam A. Gomaa

Chemistry Department, Faculty of Science, Mansoura University, Mansoura, Egypt.

(e-mail: eahgomaa65@yahoo.com)

Mohamed M. El-Defraway

Chemistry Department, Faculty of Science, Mansoura University, Mansoura, Egypt.

(e-mail: mmedefraway@yahoo.com)

Noha. M. Mohamed

Chemistry Department, Faculty of Science, Mansoura University, Mansoura, Egypt.

(e-mail: said158456@gmail.com)

*Corresponding Author

I. INTRODUCTION

Electroanalytical techniques have been found a wide application in the characterization of the formed complex in a solution. Cyclic voltammetry is the first experiment performed in an electrochemical study of a compound, biological material or an electrode surface due to its capability for rapidly observing the redox behavior over a wide potential range [1-3].

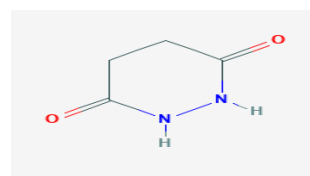
Organic chemists used this technique to study the electrochemically generated free radicals while inorganic chemists used it to evaluate the effects of ligands on the oxidation and reduction potential of the central metal ion in complexes. This information can be useful for nonanalytical purposes as the studies of the oxidation and reduction process, adsorption process in various media and electron transfer processes at chemically modified electron surfaces [4-7].

In our work, we use the cyclic voltammetry to study the interaction between copper ions and succinic hydrazide in 0.1 M HCl using solid glassy carbon electrode and scan rate 0.1 V/Sec. The complex formation was observed by the change in peak heights and shift in the anodic and cathodic couples of peaks of multivalent copper ions.

II. EXPERIMENTAL

A. Materials and Solvents

Copper chloride salt ($\text{CuCl}_2 \cdot 2\text{H}_2\text{O}$) with Mol.Wt equal 170.48 g/mol, Succinic hydrazide as a ligand and ethanol (EtOH) as analytical reagent grade material were used in this study and all from Merck Company. Hydrochloric acid pure (HCl) from Adwic Co. and bidistilled water was prepared in our laboratory with conductivity of $3 \mu\text{S cm}^{-1}$.



Succinic hydrazide	
Formula	$\text{C}_4\text{H}_6\text{N}_2\text{O}_2$
Mol. Wt.	114.104 g/mol

B. Preparation of Copper Complex

A traditional method was used to prepare the copper complex by refluxing 1 mmol of $\text{CuCl}_2 \cdot 2\text{H}_2\text{O}$ salt under investigation with 1 mmol of Succinic hydrazide using an ethanolic solution for 2-3 h close to the boiling point of the solvent. Then, the precipitate was filtered off, washed

several times with absolute ethanol and dried in vacuum desiccators over anhydrous calcium chloride. Finally, the complex was characterized by using different techniques.

C. Cyclic Voltammetry

The cyclic voltametric studies were done by using DY2000 multichannel potentiometer, delivered from USA. It was connected to a cell of three electrodes; silver/silver chloride put in saturated KCl solution used as reference electrode, solid glassy Carbon electrode (SGC) was used as working electrode and platinum wire as auxiliary electrode. The solid glassy Carbon electrode (SGR) surface was polished to mirror state using (1-0.03) μ alumina powder. The SGR was washed with absolute alcohol and doubly distilled water till removing any adhering alumina particles. Area of electrode is (7.068x10⁻²) cm². The system was applied from (1 to -1) V potential window and (0.1, 0.02, 0.01) V.s⁻¹ scan rates. Passing purified N₂ was done before each experiment to insure inert atmosphere and diffusion experiment. Finally, the data was analyzed using origin software.

D. Biological Activity (Antibacterial and Antifungal) Activity

The antimicrobial activities of Succinic hydrazide and its complex were studied on LB agar by the disc diffusion technique against clinical isolates of gram-negative bacteria (*Enterobacter*, *Staphylococcus aureus*) and Fungi (*Candida albicans*).

Sterile filter paper discs (6mm) were individually immersed in Dimethylsulfoxide (DMSO) extract of Succinic hydrazide, copper complex and DMSO was taken as control. All the discs were dried, placed on the surface of the test bacterial and fungal and incubated for 18 to 24 h at 37 °C. The standard antibiotic used is Ceftriaxone (30 mg) and finally the size of inhibition zones was measured.

III. RESULTS AND DISCUSSION

A. Infrared Analysis (IR)

Infrared spectra (IR) are an important and popular tool for structural elucidation and compound identification. IR of Succinic hydrazide and its complex with copper chloride salt were obtained by detecting changes in transmittance (or absorption) intensity as a function of frequency (Fig. 1, 2).

From IR spectra of Succinic hydrazide two symm (-NH) group appear at wavenumber (3312 and 3287) cm⁻¹, respectively. Also, two amidic (C=O) appear at wavenumber (1627 and 1608) cm⁻¹, respectively and (N-H) bend appear at 1532 cm⁻¹ (Fig. 1).

In IR spectra of copper complex indicates presence of a broad band at 3481 cm⁻¹ due to water molecules, the two symm (-NH) group shifted to lower wavenumber (3234 and 3137) cm⁻¹, respectively. One amidic (C=O) shifted to higher wavenumber 1635 cm⁻¹ while the other amidic (C=O) shifted to lower wavenumber 1579 cm⁻¹ and the (N-H) bend appear at 1542 cm⁻¹ (Fig. 2). This indicates the formation of complex between CuCl₂ salt and Succinic hydrazide.

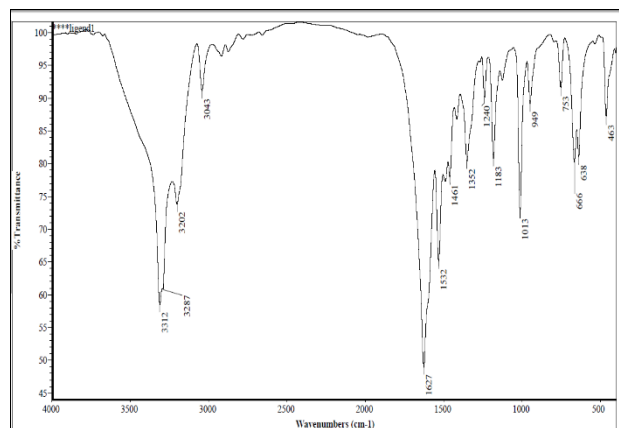


Fig. 1. IR Spectra of Succinic hydrazide.

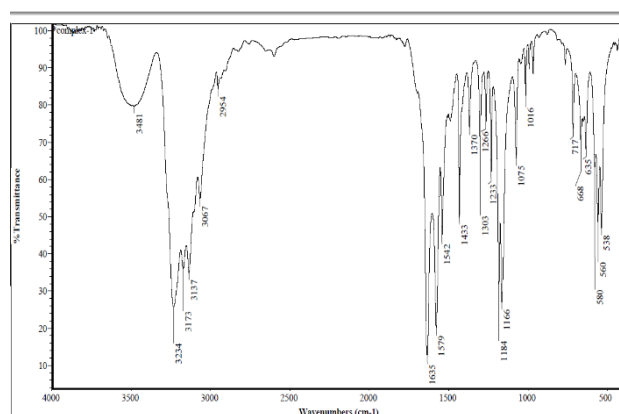


Fig. 2. IR Spectra of copper complex.

B. Cyclic Voltammetry (CV)

1. Solvation and kinetic parameters in absence of Succinic hydrazide

1.1. Effect of different copper ions concentrations alone

The redox behavior of Cu²⁺ ions was examined in 30 ml HCl (0.1) M as a supporting electrolyte from (1 to -1) V of potential window and the measured current unit is Ampere, whereas the scan is 0.1 V/S (volt per second) at 290.65 K (Fig. 3). The copper chloride solution is added step wisely from 0.5 ml (1.64 x 10⁻³) M to reach 1.6 ml (5.06 x 10⁻³) M (Fig. 4).

The electrochemical redox behavior of Cu²⁺ ions at the solid glassy carbon electrode was studied at the steady state current, cyclic waves were obtained and explained using the following equations [8-18]:

$$i_p = 0.4463 n F A C (n F D v / R T)^{1/2} \quad (1)$$

$$\Delta E_p = E_{pa} - E_{pc} \quad (2)$$

$$k_s = 2.18 * [D_C \alpha n_a F v / RT]^{1/2} * \exp [\alpha^2 n F \Delta E_p / RT] \quad (3)$$

$$\alpha n_a = 1.857 RT / (E_{pc} - E_{pc}/2) F \quad (4)$$

$$\Gamma = i_p 4RT / n^2 F^2 A v \quad (5)$$

$$Q = n F A \Gamma \quad (6)$$

where, i_p is the current in Ampere, A is the surface area of working electrode in cm², D is the diffusion coefficient in cm²/Sec, v is the scan rate in volts/Sec, C is the

concentration of the Cu^{2+} ions, ΔE_p is the peak potential difference, n is the number of electrons in redox reactions, k_s is the standard heterogeneous electron transfer rate constant in cm/sec, α is charge transfer coefficient, n_a is the numbers of electron transfer in the rate determining step, $E_{pc/2}$ is the half wave potential for cathodic peak, Γ is the surface coverage in $\text{mol}\cdot\text{cm}^{-2}$ and Q is the quantity of charge consumed during the reduction or adsorption of the adsorbed layer.

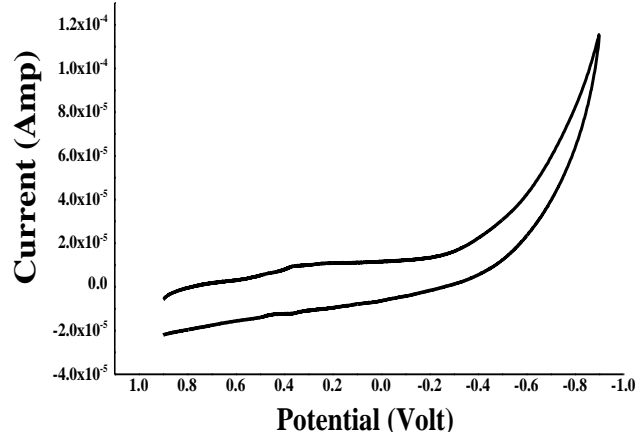


Fig. 3. Cyclic voltammogram of 30 ml HCl (0.1) M and scan rate 0.1 V/S at 290.65K.

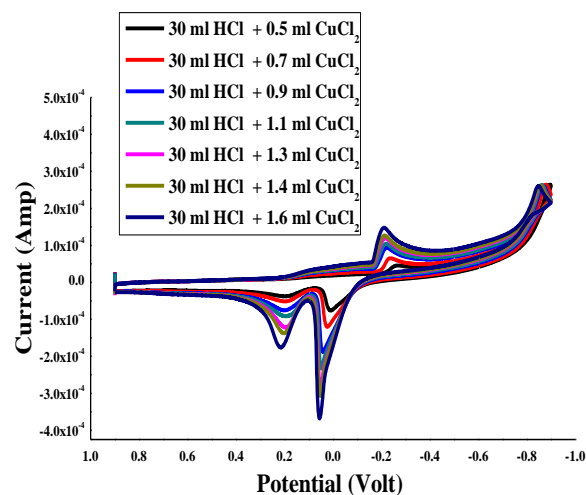


Fig. 4. Cyclic voltammogram of different Cu^{2+} ions concentrations in 30 ml HCl (0.1) M and scan rate 0.1 V/S at 290.65K.

The different cyclic voltametric data [E_{pa} (anodic peak potential), E_{pc} (cathodic peak potential), I_{pa} (anodic peak current), I_{pc} (cathodic peak current), ΔE_p (peak potential difference), $E_{pc/2}$ (half wave potential), D_a (anodic diffusion coefficient), D_c (cathodic diffusion coefficient), k_s (electron transfer rate constant), Γ_a (anodic surface coverage), Γ_c (cathodic surface coverage), Q_a (anodic quantity of electricity) and Q_c (cathodic quantity of electricity)] were calculated in Table I (A,B).

TABLE I (A): THE SOLVATION AND KINETIC PARAMETERS [E_{pa} , E_{pc} , I_{pa} , I_{pc} , ΔE_p , $E_{pc/2}$] OF DIFFERENT Cu^{2+} IONS CONCENTRATIONS AT SCAN RATE 0.1 V/S AND 290.65 K

ml Of M	[M] $\times 10^{-3}$ (mol. L $^{-1}$)	E_{pa} (V)	E_{pc} (V)	$(-I_{pa}) \times 10^{-4}$ (A)	$I_{pc} \times 10^{-5}$ (A)	ΔE_p (V)	$E_{pc/2}$ (V)
0.5	1.64	0.0044	0.26332	0.687	2.16	0.259	0.2398
0.7	2.28	0.022	0.235616	1.10	3.49	0.2136	0.2166
0.9	2.91	0.0411	0.227596	1.75	5.34	0.1865	0.2012
1.1	3.54	0.0487	0.218511	2.26	6.17	0.1698	0.197
1.3	4.15	0.0518	0.217647	2.78	7.36	0.1658	0.1885
1.4	4.46	0.0512	0.211839	3.09	7.61	0.1606	0.1868
1.6	5.06	0.0553	0.208432	3.57	9.47	0.1532	0.1841

TABLE I (B): THE SOLVATION AND KINETIC PARAMETERS [D_a , D_c , k_s , Γ_a , Γ_c , Q_a , Q_c] OF DIFFERENT Cu^{2+} IONS CONCENTRATIONS AT SCAN RATE 0.1 V/S AND 290.65 K

ml Of M	[M] $\times 10^{-3}$ (mol. L $^{-1}$)	$D_a \times 10^{-7}$ (cm 2 .s $^{-1}$)	$D_c \times 10^{-9}$ (cm 2 .s $^{-1}$)	k_s C (cm.s $^{-1}$)	$\Gamma_a \times 10^{-7}$ (mol/cm 2)	$\Gamma_c \times 10^{-7}$ (mol/cm 2)	$(-) Q_a \times 10^{-4}$ (C)	$(+) Q_c \times 10^{-5}$ (C)
0.5	1.6393	0.5938	5.8450	0.0823	2.5237	0.7917	0.34425	1.0800
0.7	2.2801	0.7840	7.9372	0.0432	4.0332	1.2832	0.55014	1.7504
0.9	2.9126	1.2195	11.364	0.0255	6.4253	1.9614	0.87644	2.6755
1.1	3.5370	1.3807	10.270	0.0193	8.3026	2.2643	1.1325	3.0886
1.3	4.1534	1.5113	10.610	0.0155	10.2003	2.7026	1.3914	3.6865
1.4	4.4586	1.6268	9.8367	0.0145	11.3604	2.7935	1.5496	3.8105
1.6	5.0633	1.6801	11.812	0.0139	13.111	3.4764	1.7884	4.7419

Fig. 5 gives straight lines from the relation between cathodic and anodic peak current I_p against different concentrations of Cu^{2+} ions in 0.1M HCl. indicating diffusion process.

Two couples of copper ion peaks were obtained the first two cathodic peaks on the scan towards negative potentials and the second at reversal of scan shows two well defined anodic peaks (see Fig. 4). The cathodic couple of peaks are attributed to the reduction of Cu^{2+} to Cu^+ and then to Cu as cathodic mechanism. Then Cu transfers to Cu^+ and Cu^{+2} as anodic mechanism. Fig. 4 gave the effect of scan rate on the peak potential and peak current.

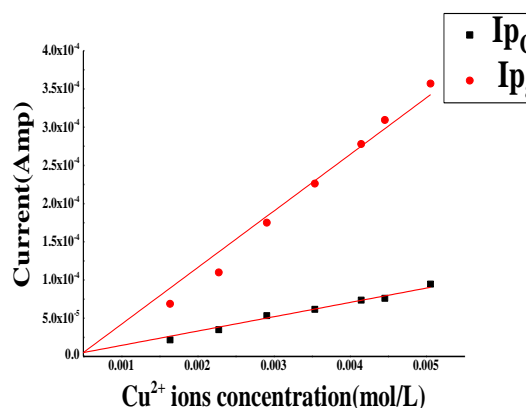


Fig.5: The relation between peak current I_p (I_{pa} - I_{pc}) against different Cu^{2+} ions concentration at 290.65 K and scan rate 0.1 V/S.

1.2. Effect of different scan rates

Effect of different scan rates for the redox behavior of Cu^{2+} ions in 0.1 M HCl was studied at (0.1, 0.02, 0.01) ($\text{V}\cdot\text{s}^{-1}$) and 290.65 K (Fig. 6). The solvation and kinetic parameters (E_p , I_p , ΔE_p , $E_{p_c/2}$, D , k_s , Γ and Q) of different scan rates of Cu^{2+} ions were presented in Table II (A, B).

The cathodic mechanism showed nearly constant peak current from the relation with square root of scan rate indicating it is diffusion controlled process while the anodic mechanism of dissolution of the deposited copper at the cathodic potential is a stripping process.

TABLE II (A): THE SOLVATION AND KINETIC PARAMETERS (E_{p_a} , E_{p_c} , I_{p_a} , I_{p_c} , ΔE_p , $E_{p_c/2}$) OF DIFFERENT SCAN RATES OF (0.1) M Cu^{2+} IONS AT 290.65 K

v	E_{p_a} (V)	E_{p_c} (V)	$(-I_{p_a}) \times 10^{-4}$ (A)	$I_{p_c} \times 10^{-5}$ (A)	ΔE_p (V)	$E_{p_c/2}$ (V)
0.1	0.0553	0.2084	3.570	9.467	0.1532	0.1841
0.02	0.0393	0.1785	2.219	3.760	0.1391	0.1563
0.01	0.0352	0.160	1.795	2.858	0.1247	0.147

TABLE II (B): THE SOLVATION AND KINETIC PARAMETERS (D_a , D_c , k_s , Γ_a , Γ_c , Q_a , Q_c) OF DIFFERENT SCAN RATES OF (0.1) M Cu^{2+} IONS AT 290.65K

v	$D_a \times 10^{-7}$ ($\text{cm}^2\cdot\text{s}^{-1}$)	$D_c \times 10^{-8}$ ($\text{cm}^2\cdot\text{s}^{-1}$)	$k_s \times 10^{-3}$ ($\text{cm}\cdot\text{s}^{-1}$)	$\Gamma_a \times 10^{-6}$ (mol/cm^2)	$\Gamma_c \times 10^{-7}$ (mol/cm^2)	$(-Q_a) \times 10^{-4}$ (C)	$(+Q_c) \times 10^{-5}$ (C)
0.1	1.680	1.181	0.1393	1.311	3.476	1.788	4.742
0.02	3.244	0.9319	4.379	4.074	6.905	5.557	9.418
0.01	4.245	1.077	3.267	6.590	10.49	8.989	14.32

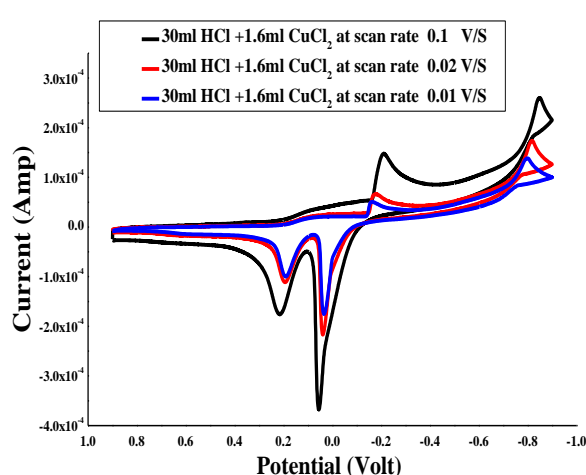


Fig. 6. Cyclic voltammogram of different scan rates of (5.06×10^{-3}) M Cu^{2+} ions in 0.1M HCL at 290.65K.

2. Solvation and kinetic parameters in presence of Succinic hydrazide

2.1. Effect of different copper ions concentrations in presence of Succinic hydrazide

The electrochemical redox behavior of Cu^{2+} ions in the presence of Succinic hydrazide at the solid glassy carbon electrode was studied at the steady state current and cyclic waves were explained using equations (1-6) (Fig. 8). The solvation and kinetic parameters (E_p , I_p , ΔE_p , $E_{p_c/2}$, D , k_s , Γ and Q) of interaction of (5.06×10^{-3}) M Cu^{2+} ions and different concentrations of Cu^{2+} ions at 290.65 K and scan rate 0.1 V/S were presented in Table III (A, B).

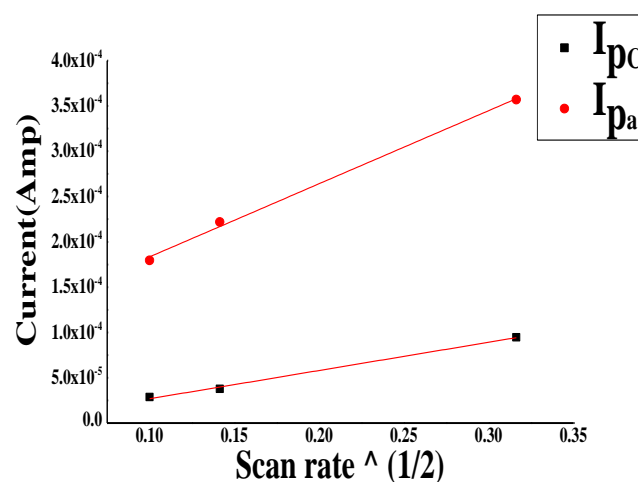


Fig. 7. The relation between peak current I_p (I_{p_a} - I_{p_c}) against the square root of different scan rates for (0.1) M Cu^{2+} ions at 290.65 K.

Randles Sevcik equation was used to apply the relation between cathodic and anodic peak current I_p against different concentrations of Cu^{2+} ions in the presence of Succinic hydrazide (Fig. 9).

2.2. Effect of different scan rates

Effect of scan rate on the interaction between Cu^{2+} ions and Succinic hydrazide was studied in (0.1, 0.02 and 0.01) $\text{V}\cdot\text{s}^{-1}$ (Fig. 10). The solvation and kinetic parameters (E_p , I_p , ΔE_p , $E_{p_c/2}$, D , k_s , Γ and Q) of different scan rates of Cu^{2+} ions in the presence of Succinic hydrazide were presented in Table VI (A, B).

TABLE III (A): THE SOLVATION AND KINETIC PARAMETERS (E_{p_a} , E_{p_c} , I_{p_a} , I_{p_c} , ΔE_p , $E_{p_c/2}$) OF INTERACTION OF (5.06×10^{-3}) M Cu^{2+} IONS AND DIFFERENT CONCENTRATIONS OF SUCCINIC HYDRAZIDE AT 290.65 K AND SCAN RATE 0.1 V/S

ml of M	[M] $\times 10^{-3}$ ($\text{mol}\cdot\text{L}^{-1}$)	ml of L	[L] $\times 10^{-5}$ ($\text{mol}\cdot\text{L}^{-1}$)	E_{p_a} (V)	E_{p_c} (V)	$(-I_{p_a}) \times 10^{-4}$ (A)	$I_{p_c} \times 10^{-5}$ (A)	ΔE_p (V)	$E_{p_c/2}$ (V)
1.6	4.984	0.5	0.6307	0.0623	0.2061	3.419	10.99	0.1438	0.1798
1.6	4.954	0.7	0.8775	0.0625	0.2063	3.175	10.39	0.1438	0.1806
1.6	4.923	0.9	1.121	0.064	0.2029	2.950	9.958	0.139	0.1799
1.6	4.893	1.1	1.362	0.0665	0.2058	2.786	9.403	0.1392	0.1818
1.6	4.863	1.3	1.600	0.0665	0.2057	2.644	7.176	0.1392	0.1852
1.6	4.848	1.4	1.718	0.0639	0.2093	2.606	7.554	0.1454	0.1872
1.6	4.819	1.6	1.951	0.0614	0.2061	2.347	7.452	0.1448	0.1901
1.6	4.420	4.6	5.145	0.0611	0.2186	2.156	4.449	0.1575	0.1987
1.6	4.082	7.6	7.850	0.0528	0.2281	1.818	4.173	0.1753	0.2129

TABLE III (B): THE SOLVATION AND KINETIC PARAMETERS (D_a , D_c , k_s , Γ_a , Γ_c , Q_a , Q_c) OF INTERACTION OF (5.06×10^{-3}) M Cu^{2+} IONS AND DIFFERENT CONCENTRATIONS OF SUCCINIC HYDRAZIDE AT 290.65 K AND SCAN RATE 0.1 V/S

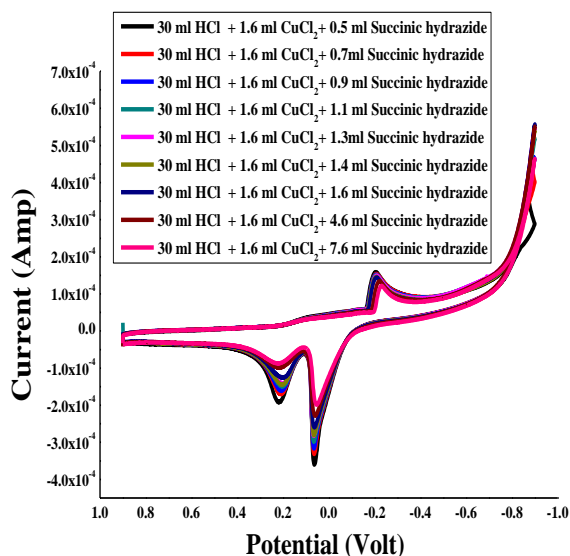
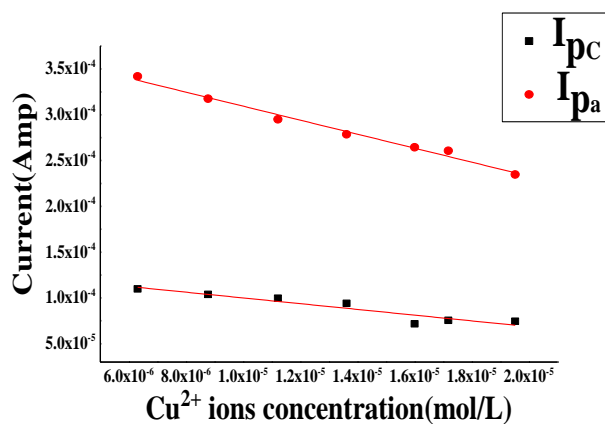
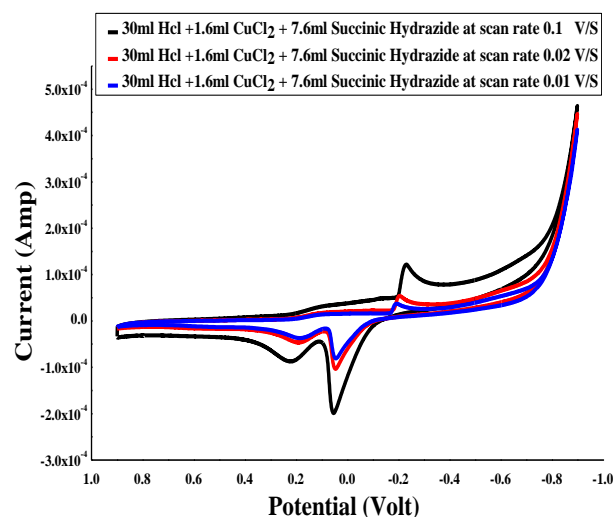
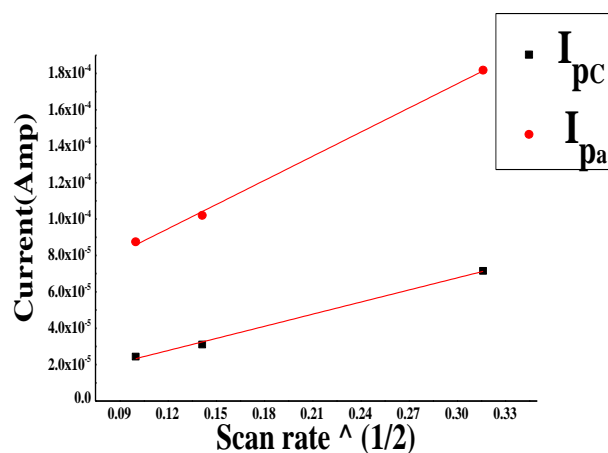
[M] $\times 10^{-3}$ (mol. L $^{-1}$)	[L] $\times 10^{-5}$ (mol. L $^{-1}$)	$D_a \times 10^{-8}$ (cm 2 .s $^{-1}$)	$D_c \times 10^{-9}$ (cm 2 .s $^{-1}$)	k_s C (cm.s $^{-1}$)	$\Gamma_a \times 10^{-7}$ (mol/cm 2)	$\Gamma_c \times 10^{-7}$ (mol/cm 2)	(-) Q_a $\times 10^{-4}$ (C)	(+) Q_c $\times 10^{-5}$ (C)
4.984	0.6307	15.90	16.42	0.0131	12.55	4.035	1.712	5.504
4.954	0.8775	13.88	14.85	0.0126	11.66	3.814	1.590	5.202
4.923	1.121	12.14	13.82	0.0117	10.83	3.657	1.478	4.988
4.893	1.362	10.95	12.48	0.0109	10.23	3.453	1.395	4.710
4.863	1.600	9.987	7.358	0.0091	9.709	2.635	1.324	3.595
4.848	1.718	9.763	8.202	0.0104	9.570	2.774	1.305	3.784
4.819	1.951	8.016	8.079	0.012	8.620	2.736	1.176	3.733
4.420	5.145	8.039	3.423	0.009	7.917	1.634	1.080	2.228
4.082	7.850	6.706	3.532	0.015	6.677	1.532	0.9108	2.090

TABLE IV (A): THE SOLVATION AND KINETIC PARAMETERS (E_{pa} , E_{pc} , I_{pa} , I_{pc} , ΔE_p , $E_{pc/2}$) OF DIFFERENT SCAN RATES OF COPPER COMPLEX AT 290.65K

ν	[M] $\times 10^{-3}$ (mol. L $^{-1}$)	[L] $\times 10^{-5}$ (mol. L $^{-1}$)	E_{pa} (v)	E_{pc} (v)	(-) I_{pa} (A) $\times 10^{-4}$	I_{pc} (A) $\times 10^{-5}$	ΔE_p (v)	$E_{pc/2}$ (v)
0.1	4.082	7.850	0.0528	0.2281	1.8183	7.154	0.1404	0.2129
0.02	4.082	7.850	0.048	0.2042	1.0199	3.104	0.1261	0.1924
0.01	4.082	7.850	0.0455	0.1942	0.8749	2.442	0.1198	0.1775

TABLE IV (B): THE SOLVATION AND KINETIC PARAMETERS (D_a , D_c , k_s , Γ_a , Γ_c , Q_a , Q_c) OF DIFFERENT SCAN RATES OF COPPER COMPLEX AT 290.65 K

ν	[M] $\times 10^{-3}$ (mol. L $^{-1}$)	[L] $\times 10^{-5}$ (mol. L $^{-1}$)	$D_a \times 10^{-7}$ (cm 2 .s $^{-1}$)	$D_c \times 10^{-8}$ (cm 2 .s $^{-1}$)	k_s C $\times 10^{-3}$ (cm.s $^{-1}$)	$\Gamma_a \times 10^{-6}$ (mol/cm 2)	$\Gamma_c \times 10^{-7}$ (mol/cm 2)	(-) Q_a $\times 10^{-4}$ (C)	(+) Q_c $\times 10^{-5}$ (C)
0.1	4.082	7.850	0.6706	1.038	0.2574	0.677	2.627	0.9108	3.583
0.02	4.082	7.850	1.055	0.9772	8.651	1.873	5.700	2.554	7.774
0.01	4.082	7.850	1.553	1.209	4.916	3.213	8.966	4.382	12.23

Fig. 8. Cyclic voltammograms for the interaction of (5.06×10^{-3}) M Cu^{2+} ions with different concentrations of Succinic hydrazide at 290.65K and scan rate 0.1 V/S.Fig. 9. The relation between peak current I_p (I_{pa} - I_{pc}) against different Cu^{2+} ions concentration in the presence of Succinic hydrazide at 290.65 K and scan rate 0.1 V/S.Fig. 10. Cyclic voltammogram of different scan rate of (4.08×10^{-3}) M Cu^{2+} ions with (7.85×10^{-5}) M Succinic hydrazide at 290.65K.Fig. 11. The relation between peak current I_p (I_{pa} - I_{pc}) against different scan rates of copper complex at 290.65 K.

3. Electrochemical behavior of the complexation between Cu²⁺ ions and Succinic hydrazide

A stability constant is a measure of the strength of the interaction between the reagents that come together to form the complex.

The stability constants (β_j) for copper complex for each addition are calculated by applying the following equations [19-28].

$$\Delta E^\circ = E^\circ_C - E^\circ_M = 2.303 (RT/nF) * (\log \beta_j + j \log C_x) \quad (7)$$

$$E^\circ = (E_{pa} + E_{pc})/2 \quad (8)$$

$$\Delta G = -2.303 RT \log \beta_{MX} \quad (9)$$

where, E°_M is the formal peak potential of metal at finally adding in the absence of Succinic hydrazide, E°_C is the formal peak potential of metal complex after each addition

of Succinic hydrazide, R is a gas constant (8.314 J.mol⁻¹. degree⁻¹), T is the absolute temperature, j is the coordination number of the Stoichiometric complex, C_x is the concentration of Succinic hydrazide in the solution, E° is the formal potential, E_{pa} is the anodic peak potential, E_{pc} is the cathodic peak potential, β_j is the stability constant and ΔG is the Gibbs free energy of interaction between Cu²⁺ ions and Succinic hydrazide.

The calculated values of E° , β_j and ΔG for copper complex are estimated and collected in Table V.

The values of the stability constant and Gibbs free energy of complexation indicating that the interaction between copper ions and Succinic hydrazide is in the range of electrostatic interaction under the studying of concentration conditions.

TABLE V: THE VALUES OF (FORMAL POTENTIAL E° , STABILITY CONSTANT β_j AND GIBBS FREE ENERGY ΔG) FOR COPPER COMPLEX AT 290.65 K AND SCAN RATE 0.1 V/S

[M] x10 ⁻³ (mol.L ⁻¹)	[L] x10 ⁻⁵ (mol.L ⁻¹)	E _{pa} (V)	E _{pc} (V)	j	Log[L]	Log β_j	β_j	ΔG (KJ/mol)
4.984	0.6307	0.0623	0.2061	0.0013	-5.2002	0.0193	1.045	-0.1072
4.954	0.8775	0.0625	0.2063	0.0018	-5.0567	0.1668	1.468	-0.9282
4.923	1.121	0.064	0.2029	0.0023	-4.9503	0.2464	1.763	-1.3711
4.893	1.362	0.0665	0.2058	0.0028	-4.8658	0.2374	1.728	-1.3213
4.863	1.600	0.0665	0.2057	0.0033	-4.7959	0.3807	2.403	-2.1188
4.848	1.718	0.0639	0.2093	0.0035	-4.765	0.2057	1.606	-1.1447
4.819	1.951	0.0614	0.2061	0.004	-4.7097	0.3236	2.107	-1.8011
4.420	5.145	0.0611	0.2186	0.0116	-4.2886	-0.08	0.832	0.4456
4.082	7.850	0.0528	0.2281	0.0192	-4.1051	-0.331	0.467	1.8417

4. Biological activity (Antimicrobial and Antifungal) activity

The antimicrobial activity was estimated based on inhibition zone size formed around discs of Succinic hydrazide and its complex on a petri dish with Luria Bertani agar (LB-agar) plates to measure the efficacy of the used compounds [29-34].

4.1. Antibacterial activity

The antibacterial activity of copper complex was compared with the activity of Succinic hydrazide using *Enterobacter* and *Staphylococcus aureus* (gram-negative bacteria) (Table VI). Presence of higher inhibition zone was observed around disc of copper complex with (9, 11) mm, respectively while absence of it around disc of Succinic hydrazide. So, it can act as bacteriostatic agent towards these bacteria (Fig. 13).

Table VI: Inhibition zone disc (mm) of Succinic hydrazide and copper complex with gram-negative bacteria and Fungi.

Solid	Inhibition zone disc (mm)		
	Types of gram-negative bacteria		Type of Fungi
	<i>Enterobacter</i>	<i>Staphylococcus aureus</i>	<i>Candida albicans</i>
Succinic hydrazide	Absence	Absence	Absence
Copper complex	9	11	7

4.2. Antifungal activity

Also, the experimental antifungal activity of copper complex was compared with the activity of Succinic hydrazide using *Candida albicans* (Table VI) indicating

formation of higher inhibition zone (7 mm) around disc of copper complex only so, it can be used as antifungal drug (Fig. 14).

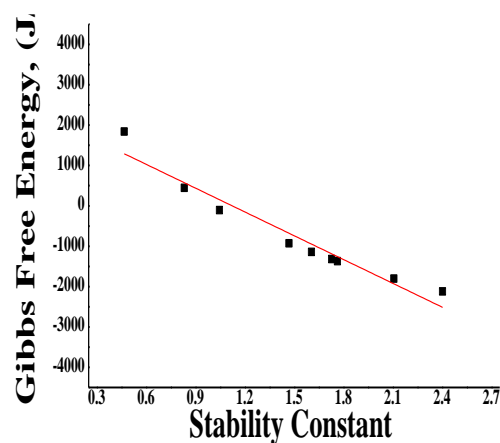


Fig. 12. The relation between Gibbs free energy (ΔG) against stability constant (β_{MX}) at 290.65 K and scan rate 0.1 V/S.



Fig. 13. Inhibition zone discs (6mm) of [(1) Succinic hydrazide (2) copper complex] on the surface of an LB-agar plate with (a) *Enterobacter* (b) *Staphylococcus aureus*.



Fig. 14. Inhibition zone discs (6mm) of [(1) Succinic hydrazide (2) copper complex] on the surface of an LB-agar plate with *Candida albicans*.

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