1967

A Polarographic Study Of Selected Metal Complex Ions Of Several P-Tosyl Amino Acids

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A POLAROGRAPHIC STUDY OF SELECTED METAL COMPLEX IONS OF SEVERAL p-TOSYL AMINO ACIDS

A Dissertation

Submitted to

The Department of Chemistry

University of the Pacific

In Partial Fulfillment

of the Requirements for the Degree

Doctor of Philosophy

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by

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A POLAROGRAPHIC STUDY OF SELECTED METAL COMPLEX IONS OF SEVERAL p-TOSYL AMINO ACIDS

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ABSTRACT OF DISSERTATION

A polarographic study of the complexes of selected metal ions and the p-Tosyl derivatives of the amino acids; glycine, glutamic acid and lysine has been made to determine their coordination number, formula, dissociation constant and free energy of formation.

All polarographic measurements in this study were made using the Leeds and Northrup Electro-Chemograph Type E polarograph. Polarographic determinations were made in the conventional "H-Cell" immersed in a constant temperature held at 25°C.

Metal ion solutions of Cu(II), Cd^{++}, Zn^{++}, Hg(II), Pb(II) and Mn(II) to be analyzed at the dropping mercury electrode were made up to 5.0×10^{-4} M metal ion.

Two different salts (KCl, KNO_3) were used as supporting electrolytes. When needed, a 0.002% solution of Triton X-100 was used as a maximum suppressor.

Polarograms were run at current ranges of 5 and 10 microamperes. Each polaragram consisted of a forward and reverse run. Corrections were made for residual current.

The reversibility of the electrode reaction was tested for each analysis by determining the slope of plots of log $\frac{i}{i_d - i}$ against $E_{d.e.}$. The analysis was discarded unless a straight line was obtained, with slope equal to the theoretical value $\pm$ 5 mv.

Correction for iR drop was made using the following equation:

$$(E_{1/2})_{d.e.} = (E_{1/2})_{obs.} + (i_d / 2 + i_{r_{1/2}})R$$

when $(E_{1/2})$ is the half-wave potential observed from the recorded polarogram, i_d is the average diffusion current and $i_{r_{1/2}}$ is the average residual current at the observed half-wave potential.

Data obtained in this investigation reveals the existence of fourteen previously unreported complexes. They are: Copper (II) p-tosyl glycinate, Copper (II) p-tosyl-L-glutamate, Cadmium p-tosyl glycinate, Cadmium p-tosyl-L-glutamate, Cadmium p-tosyl-L-lysinate, Zinc p-tosyl glycinate, Zinc p-tosyl-L-glutamate, Mercury (II) p-tosyl glycinate, Mercury (II) p-tosyl-L-glutamate, Lead p-tosyl glycinate, Lead(II) p-tosyl-L-glutamate, Lead (II) p-tosyl-L-lysinate, Manganese (II) p-tosyl glycinate and Manganese (II) p-tosyl-L-lysinate.

The pK values of Mn (II) and Pb (II) of the p-tosyl glycine complexes are somewhat higher than those of the unsubstituted glycine, indicating a lesser degree of stability. Of the remaining metal complexes of the substituted and the unsubstituted glycine there is practically no difference in pK values. Apparently the substitution of a p-tosyl group for a hydrogen on the amino group of glycine does not drastically effect the stability of metal complexes examined in this study.

Group II B metal complexes of the glycinates and the glutamates show an increase in stability with an increase in atomic weight.

Both cadmium and zinc glutamates have the rarely reported coordination number of three.

ACKNOWLEDGEMENT

The writer wishes to express his appreciation to Dr. Herschel G. Frye and other members of his committee who were instrumental in providing the impetus that brought this work to a successful conclusion.

Thanks also for the encouragement given by Dr. Emerson Cobb, which gave the writer the will to persevere.

And finally, thanks to my wife Carol, my daughter Risa, and my sons Joey and Rex for putting up with me during those trying and sometimes dark days.

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CHAPTER I

THE PROBLEM

Many investigators have studied the complex ions formed between metal ions and amino acids. Most of the experimental data reported in these studies were obtained by means other than polarographic.

A search of the literature failed to reveal any data on complex ions between metal ions and p-toluenesulfonyl (p-tosyl) amino acids. These compounds are employed in peptide synthesis. The p-tosyl group masks the chemical activity of the amino group and because of bulk may produce steric hindrance. Brown (2,3) in several papers discusses the phenomenon of F-strain, where the clashing of groups on two co-ordinated ligands will result in a distortion of bond angles and a decrease in stability.

A comparison of the dissociation constants of complex ion between metal ions of the unsubstituted amino acids and those of its p-tosyl derivatives might indicate whether or not steric hindrance was involved in the complex formation.

The purpose of this study was to determine the co-ordination number, formula, dissociation constant, and free energy of formation of complexes of p-tosyl derivatives of glycine, glutamic acid, lysine and selected metal ions. Additionally the stability of these complexes would

be compared with those of the unsubstituted amino acids.

A study of these complexes is important in biological chemistry, in that the accumulation of sufficient data on the complexes of amino acids and its derivatives with metal ions may contribute to a better understanding of the type of linkage involved in metal-protein interactions.

CHAPTER II

INTRODUCTION

I. THEORY

Jaroslav Heyrovsky was the originator of polarographic analysis. The theoretical principles of polarography can be found in a number of current publications; "Polarography" by Kolthoff and Lingane (17), in particular is an excellent reference.

The application of polarography to the study of complex ion, is made possible by the fact that the half-wave potentials of metal ions are usually shifted to a more negative potential by complex formation. By measuring this shift as a function of concentration of the complex ion substance both the formula and the dissociation constant (25) of complex can be determined. The essential requirement is that reduction or oxidation of the metal ion complex takes place reversibly at the dropping electrode.

The reduction to the metallic state (amalgam) of a complex ion of a metal may be represented by:

$$MX_p^{(n-pb)} + ne + Hg \longrightarrow M(Hg) + pX^{-b} \qquad (1)$$

Where M(Hg) represents the amalgam formed at the surface of the dropping electrode and X^{-b} is the complex forming substance. It is customary to regard reaction 1 as the sum of

two partial reactions,

$$MX_p^{(n-pb)+} \rightleftharpoons M^{n+} + pX^{-b} \qquad (2)$$

and

$$M^{n+} + ne + Hg \rightleftharpoons M(Hg) \qquad (3)$$

where M^{n+} is the simple or aquo ion of the metal.

If the assumed foregoing reactions are <u>rapid</u> and <u>reversible</u> at the dropping electrode, then the potential of the latter at any point on the wave should be given by

$$E_{d.e.} = - \frac{RT}{nF_y} \ln \frac{C_a^o \quad f_a}{C_M^o \quad f_M} \qquad (4)$$

Where the constant is equal to $E_a^o + (RT/nF_y) \ln a_{Hg}$, C_a^o is the concentration of amalgam formed on the surface of the dropping electrode, C_M^o is the concentration of the simple ions at the electrode surface, f_a and f_m are the corresponding activity coefficients and a_{Hg} is the activity of the surface of the dropping electrode. When the dissociation of the complex ion is sufficiently rapid so that equilibrium with respect to reaction 2 is practically maintained at the electrode surface, then C_M^o can be replaced by

$$C_M^o = K_d \frac{C_{MX}^o f_{MX}}{(C_X^o)^p f_X f_m} \qquad (5)$$

Where K_d is the dissociation constant of the metal ion

complex, C^{o}_{MX} and C^{o}_{x} are, respectively, the concentration at the electrode surface of the complex metal ion and the complexing metal ion and the complexing agent X^{-b}, and the f's are activity coefficients. Equation 4 then becomes

$$E_{d.e.} = -\frac{RT}{nF_y} \ln \frac{K_d f_{MX}}{f_a f_x^p} - \frac{RT}{nF_y} \frac{\ln C^{o}_{a}(C^{o}_{x})^p}{C^{o}_{MX}} \qquad (6)$$

When the equations for the current (i), the diffusion current (i_d), C^{o}_{mx}, C^{o}_{a}, and C^{o}_{x} are substituted into equation 6 the equation of the wave at 25° is obtained. With an excess of the complex forming substance present in solution

$$E_{d.e.} = E_{\frac{1}{2}} - \frac{0.0591}{n} \log \frac{i}{i_d - i}$$

Where

$E_{d.e.}$ = potential at dropping mercury electrode in volts

$E_{\frac{1}{2}}$ = the half-wave potential in volts. $E_{\frac{1}{2}}$ is constant and independent of concentration

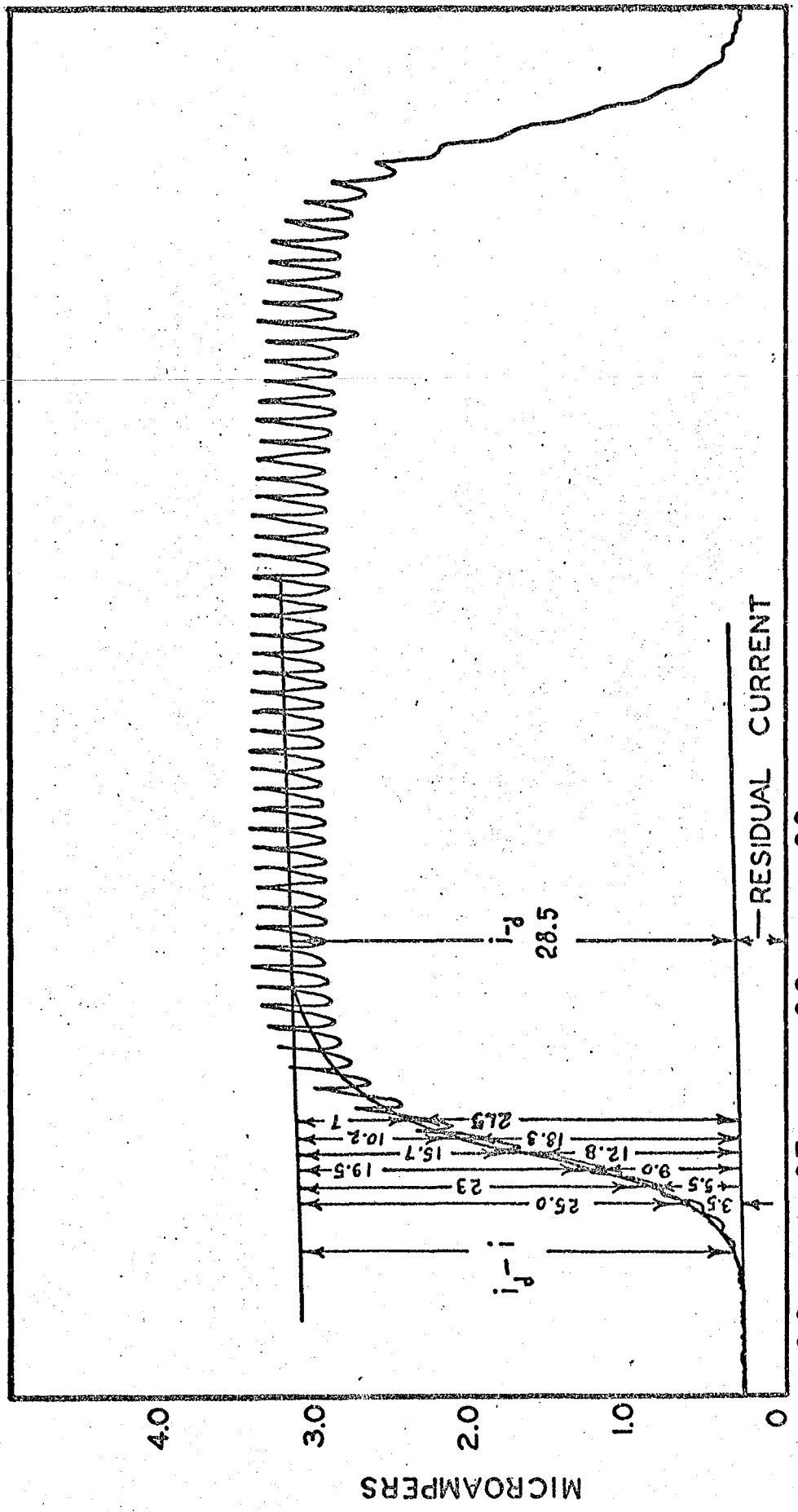
n = number of electrons involved with the reducible ion

i = the current at any point on the wave, in microamperes

i_d = limiting diffusion current in microamperes

Values of i and $(i_d - i)$ are taken from a polarogram (Figure 1) and converted into workable data.

FIGURE 1



A TYPICAL POLAROGRAM

A plot of $\log \frac{i}{i_d - i}$ vs $E_{d.e.}$ will produce a straight line having a slope equal to $\frac{n}{0.0591}$. If i equals $i_d - i$, then $E_{d.e.}$ will equal $E_{\frac{1}{2}}$. The straight line is used as a criterion of the reversibility of the dropping mercury electrode reaction.

The half-wave potential $E_{\frac{1}{2}}$ is given by

$$E_{\frac{1}{2}} = - \frac{0.0591}{n} \log \frac{K_d \, f_{MX} k_a}{f_a k_c} - p \frac{0.0591}{n} \log C_x f_x \quad (8)$$

Where k_a and k_c are proportional to the square roots of the diffusion coefficients of the complex metal ions and the metal in the amalgams, respectively.

The concentration of the metal ion complex is not used in equation 8, thus $E_{\frac{1}{2}}$ is constant and independent of the concentration of the complex metal ion.

Equation 8 predicts that the half-wave of a complex metal ion should shift with changing activity of the complex forming substance according to

$$\frac{E_{\frac{1}{2}}}{\log C_x f_x} = -p \frac{0.0591}{n} \quad (9)$$

from this relationship, the co-ordination number p of the metal ion can be determined, and thus the formula of the complex.

From equation 8 it is apparent that the half-wave potential depends on the logarithm of the dissociation

constant of the complex metal ion, and it is more negative the smaller the value of K_d, that is, the more stable the complex ion.

The dissociation constant is determined from the difference between the $E_{\frac{1}{2}}$ of the simple ion and that of the complex metal ion.

$$(E_{\frac{1}{2}})_c - (E_{\frac{1}{2}})_s = \frac{0.0591}{n} \log \frac{K_d f_c k_s}{f_c k_c} - p \frac{0.0591}{n} \log C_x f_x \qquad (10)$$

The ratio $\frac{k_s}{k_c}$ is determined experimentally from the ratio of the observed diffusion currents of the simple and complex metal ions at the same concentration holding all other variables constant.

Equation 10 may be more specifically applied (21, 22) to the case of α amino acids complexes where the concentration of the complexing agent is dependent on pH. From the expression for the dissociation constant of the α amino acid

$$k_a = \frac{C_{A^-} \cdot C_{H^+}}{C_{AH}} \qquad (11)$$

it follows that

$$C_a = pH + \log C_{AH} \qquad (12)$$

keeping the ionic strength (μ) constant, would keep the activity coefficient of the amino acid nearly constant, and as a first approximation this may be considered to be unity.

Equation 12 is then substituted into equation 10 for log $C_x f_x$, from which equation 13 is obtained.

$$(E_{\frac{1}{2}})_c - (E_{\frac{1}{2}})_s = \frac{0.0591}{n} \log K_d \frac{k_s}{k_c} - p\frac{0.0591}{n}(pH-pK_a) - p\frac{0.0591}{n} \log C_{AH} \qquad (13)$$

In many instances the ratio k_s/k_c is unity or nearly so, and may be omitted.

Related Work

From a search of the literature it was found that most studies (14) involving the determination of dissociation constants of complexes of amino acids, utilized the potentiometric method.

The complex ions formed from copper (II) with glycinate and alinate ions were determined polarographically by Keefer (15). He reports that the complexes formed are mainly $[Cu(gly)_2]$ or $Cu[Cu(alan)_2]$ with ligand concentration of 0.08M to 0.1 molar, at higher concentrations $[Cu(gly)_3]$. Two electron reductions are reported indicating the instability of the complexes. The determinations were made in a pH range of 9.80 - 11.75.

Kierson and Barsily (16) have found that Copper (II) forms two types of complexes with aspartic acid [CuA] and $[CuA_2]$. The formation of these complexes was studied by spectrophotometric and potentiometric measurements, and it was observed that the composition does not depend on the

ratio Cu(II): ligand but solely on pH. At pH less than 4 [CuA] was formed, at pH 6 [CuA_2] was the main product.

By measuring (43) the free Cu^{++} concentration, the pH, and using titration curves of various solutions, evidence of two complexes Cu^{++} and L-leucine was obtained. The Cu^{++} concentration is measured potentiometrically with a copper-amalgam electrode. The two complexes are formed from negative amino ions and are postulated to be CuR^+ and CuR_2 (R = leucine). The complex CuR can be precipitated as the hydroxide CuROH. The equilibrium constants for the complexes are pK(CuR^+) = 8.11 and pK(CuR_2) - 15.84. Spectrophotometric evidence for the formation of CuR^+ and CuR^{++} is presented. Stability constants are in good agreement with those reported above.

Malik and Khan (27) report that copper-asparagine complexes were reducible reversibly at the dropping mercury electrode. Studies were conducted at pH 7.2-12.04. Two asparagine molecules were found to combine with one copper at a pH of approximately 11, while for higher pH ranges only one asparagine was found to combine with one copper.

Kostromin and associates (12) polarographically studied the reaction of α aminobutylene and α amino propionic acids with Copper (II), data obtained show that these reactions are pH dependent.

Li, Doddy, and White (23) in a study of Copper (II),

nickel and uranyl complexes report the formation constants of Copper (II) and nickel complexes of hydroxyproline, asparagine and N, N-dimethylglycine. The pK_2 of asparagine and the formation constants of its complexes are independent of optical configuration. The formation constant of the Cu(II) and hydroxyproline, which was determined by the polarographic method, is 15.4. The nickel complexes of serine methyl ester and glycine methyl ester are equally stable, indicating that the serine ester co-ordinates to the metal ion through the amino group only.

Pleticha (36) writes that in solutions of 0.1M KCl and 0.001 N $NiCl_2$, L-histidine and methionine produce two polarographic waves and D-argine three, with $E_{\frac{1}{2}}$ at -0.96, -1.11, -0.86, -1.03, -0.87, -0.94, and -1.09 V (vs S.C.E.), respectively. The more positive waves are caused by the amino acid complexes and the more negative by the aquo complexes. All the Ni-amino acid complexes are polarographically irreversible.

In a dropping mercury electrode investigation (15) of cadmium-thiocynate complexes in absolute ethanol, the dissociation constants of the complexes were found to be appreciably lower than in water.

The formation constants of Cd(II) complexes (24) of glycine dipeptides have been determined. In each case n = 2 and p = 2.

The cadmium complexes of glycine (32) DL- -alanine, DL- alanine, DL Valine, L-asparagine, DL aspartic acid L-glutamic acid were examined polarographically in solutions pH 11.3. The analysis of the results indicate that in all cases three moles of the acid enter into the complex. pK for glycine complex was 9.90. $E_{\frac{1}{2}}$ did not shift when pH was changed from 11.3 to 12.3.

The complex formation of uranyl ion (26) with glycine was studied polarographically at pH 1.5 - 5.0. The reduction of UO_2^{++}-glycine complex was a one electron reversible process.

The preceding periodical citations represent a part of the library research undertaken prior to entering the laboratory.

CHAPTER III

EXPERIMENTAL

I. INSTRUMENTATION AND ACCESSORIES

The Polarograph

All polarographic measurements in this study were made using the Leeds and Northrup Electro-Chemograph Type E polarograph. This visual recording instrument (9) employs the null balance principle for precise measurements. For damping control, four positions are available, 0, 1, 2, and 3. The number one position should yield half-wave potential values in agreement with accepted literature values. All polarograms in this work were made at the one position, which is the galvanometer equivalent.

The instrument is provided with an internal standard for proper adjustment of the voltage supplied to measuring circuit and polarizing circuit.

The reverse polarization feature of the Electro-Chemogram, enables one to reverse polarization at completion of a forward run, and continue the curve in reverse then obtaining the $E_{\frac{1}{2}}$ of both forward and reverse sections of the curve and recording the mean of the sum of these two values as the half-wave potential.

Polarograph "H-Cell". The polarograph "H-Cell"

with a saturated calomel electrode (the type that is generally used with an external reference electrode) was made according to directions in Meites' "Polarographic Techniques" (29).

Internal resistance. The internal resistance of the "H-Cell" was measured by comparing the half-wave potentials of different concentrations of $Cd(NO_3)_2$ in the same electrolyte, first in 0.1M KNO_3 and then in 0.1M KCl, calculating the resistance (R) from the relationship

$$R = E_{\frac{1}{2}}/0.5 \Delta i_d \qquad (14)$$

to be 2100 ohms.

The capillary. The capillary used as the dropping electrode was broken from a 6-12 second drop time E. H. Sargent Capillary so as to deliver a drop every 3 to 5 seconds. The drop t was determined by measuring the time for 20 drops to fall and obtaining the mean value. This was done prior to each run. The 3-second drop time was held constant by keeping the pressure at 59 cm. This was done by adding mercury to the reservoir as needed to keep it at the same level.

Temperature. The temperature was held at 25° C by a 5-10 ampere rating Fenwal Thermoswitch hooked up to the heating element, immersed in large pyrex glass jar. A light

duty electric stirrer provided the necessary circulation of water around the H-Cell.

pH meter. The Beckman model 76 expanded scale pH meter was used in determining the pK_a values of p-tosylamino acids and in measuring the pH of each solution which was polarographically analyzed.

II. CHEMICALS

The p-tosylamino acids were purchased from K & K Laboratories, Plainview, New York. Their melting points were used as a criterion of purity. Reagent quality inorganic salts were used without further purification.

Stock solutions of 0.1M potassium salts of the p-tosylamino acids were prepared using boiled distilled water and less than the equivalent amount of potassium hydroxide. Less than equivalent amount of KOH was used because other workers (8) had reported that at low concentrations of amino acids, the electrode reactions were irreversible if the solutions were prepared using the equivalent amount of p-tosylamino acids and potassium hydroxide.

The salts of the metal ions that were to be complexed were made up to 5.0×10^{-4}M. The stock solutions were prepared ahead of time, with the exception of the Mn(II) salt, which was prepared before Mn(II) runs to prevent change in concentration by formation of the oxide.

Supporting Electrolyte

The two different salts (KCl, KNO_3) were used as supporting electrolytes because other investigators in working with cadmium (20), cupric (13), lead(II) (12), manganese(II) (91), mercury(II) (17), and zinc (11) salts had reported well-defined reversible waves of the simple ion. Molar stock solutions of the salts were prepared.

Maximum Suppressor

The maximum suppressor, Triton X-100, was obtained from Rohm and Haas Company, Philadelphia. A 0.2% stock solution was prepared by shaking 0.2 grams of the substance thoroughly with 100 ml of distilled water.

III. PROCEDURE

Solutions

All solutions to be analyzed at the dropping mercury electrode were made up to 5.0×10^{-4} M metal ion. The concentrations of supporting electrolyte was 0.1 M, and that of the maximum suppressor 0.002% (when used).

Usually seven solutions were made up in 50 ml volumetric flasks. Solution one was the simple metal ion, solution two a p-tosylamino acid at the same concentration as the simple metal ion, used to determine k_s/k_c ratio. The five solutions ranged from 5.0×10^{-4} to 4.0×10^{-2} M, their concentration being dependent on the particular metal ion and

p-tosylamino acid reacting.

Sufficient potassium nitrate was added to solutions to keep the ionic strength constant at μ = 0.1.

Removal of oxygen. To remove the last traces of oxygen, the oil pumped nitrogen (Air Reduction Company) was bubbled through a train consisting of (1) an ammoniacal solution of cuprous salt containing copper turnings, (2) a sulfuric acid wash bottle to absorb ammonia gas which may be liberated by the initial absorber, and (3) a flask containing dilute sodium hydroxide, to neutralize any acid vapor. The [osygen] free nitrogen was then bubbled through the solution to be analyzed (in H-Cell) for ten minutes. A two-way stopcock permitted change of direction of nitrogen flow from bottom of H-Cell to the area immediately above the solution, during the recording of a polarogram.

Polarograms

Polarograms were run at current ranges of 5 and 10 microamperes. Each polarogram consisted of a forward and reverse run. Corrections were made for residual current.

Criterion of reversibility. The reversibility of the electrode reaction was tested for each analysis by determining the slope of plots of $\log \frac{i}{i_d - i}$ against $E_{d.e.}$ The analysis was discarded unless a straight line was obtained, with slope equal to the theoretical value $\pm$ 5 mv.

This range was based on experimental work by Meites (30) who found that it was possible for experimental errors to combine in such a way that the observed slope of a plot for a reversible wave will differ from theoretical value by as much as 3-5 mv. $E_{\frac{1}{2}}$ is the point on the plot where log i/i_d - i is equal to zero.

Correction for iR drop. Correction for ohmic potential drop was a major concern. Meites (29) suggests that the iR drop through the cell may be corrected by subtracting the value $i_dR/2$ (where i_d is the diffusion current in microamperes and R is the measured cell resistance), from the apparent half-wave value. In a recent publication (36) Schapp and McKinney state that the ohmic potential correction depends on the total current given by

$$(E_{\frac{1}{2}})_{d.e.} = (E_{\frac{1}{2}})_{obs.} + (i_d/2 + i_{r\frac{1}{2}})R \qquad (15)$$

when $(E_{\frac{1}{2}})_{d.e.}$ is the true half-wave potential, $(E_{\frac{1}{2}})_{obs.}$ is the half-wave potential observed from the recorded polarogram, i_d is the average diffusion current and $i_{r\frac{1}{2}}$ is the average residual current at the observed half-wave potential.

The latter method was used to correct for iR drop.

The value n was determined from the slope of $\log \frac{i}{i_d - i}$ vs $E_{d.e.}$ plot using the equation

$$\text{slope} = \frac{n}{0.0591}$$

CHAPTER IV

RESULTS AND DISCUSSIONS

Data obtained in this investigation are given in Tables I through XIV. The electrode reactions of thirteen of the complexes undoubtedly involve two electrons as shown by the values of the plot of log i/i_d-i against the potential. Straight lines were obtained in all cases, indicating the reversibility of the electrode reaction. Slope of log plot values up to 0.040 were considered two electron reactions, although the usual value is $\pm$ 5 mv of the theoretical value. Support for this assumption is provided by Bailar (21) and associates, who used this slope value (0.040) as a criterion for a two electron reaction. Only single waves were observed on all polarograms made in this study, a further indication that at least thirteen of these complex ions are probably reduced directly to the almalgam.

I. COMPLEX ION CO-ORDINATION NUMBER AND FORMULA

Copper(II)

p-tosyl glycinate. The supporting electrolyte used was 0.01 M KNO_3. Initially a methyl red-bromo cresol green mixture was considered as a maximum suppressor, but experience proved Triton X-100 to be more dependable. A 0.002% solution was used in the copper ion complex

determinations. The cupric nitrate stock solution (0.005 M) was practically colorless, but when made up to 0.005 M with the glycinate ion, gave a pale blue color that deepened, with increased concentration of the glycinate ion.

Well-defined waves were obtained in all seven runs. The half-wave potential of the simple (aquo) cupric ion as determined from a plot of log i/i_d-i vs $E_{d.e.}$ was 0.011 V in fair agreement with literature (8) values. The ratio of the diffusion current (3.1 μ amps) of the simple cupric ion to that of the glycinate ion at the same concentration (0.005 M), was for all practical purposes, equal to one.

As evident from Table I, there is a very definite shift of the half-wave potential of the complex to more negative values as the p-tosyl glycinate ion concentration is increased, with the diffusion current remaining nearly constant.

Knowing the value of n, and using equation 9, the number of groups p, co-ordinated to each cupric ion is determined from the plot of the slope (Figure 2, page 23), which in this case is 0.085, indicating that three groups are co-ordinated. This is precisely the value reported previously (15), for the unsubstituted glycine. Thus the formula for this complex would be $[Cu(p\text{-tosyl-gly})_3]$.

<u>p-tosyl-L-glutamate</u>. The conditions of analysis for the glutamate ion are about the same as those for glycinate

TABLE I

HALF-WAVE POTENTIAL OF THE COPPER p-TOSYL GLYCINATE COMPLEX AS A FUNCTION OF THE p-TOSYL GLYCINATE ION CONCENTRATION

Total p-Tosyl Glycinate Moles/liter	pH	$-E_{\frac{1}{2}}$ vs S.C.E.	i_d u amp.	Slope of log plot
0.005	10.4	0.228	2.80	0.037
0.010	11.00	0.253	2.70	0.032
0.020	11.30	0.276	2.75	0.037
0.030	11.40	0.291	2.75	.0037
0.040	11.50	0.304	2.67	0.034

pK_a of p-tosyl glycine = 2.86.

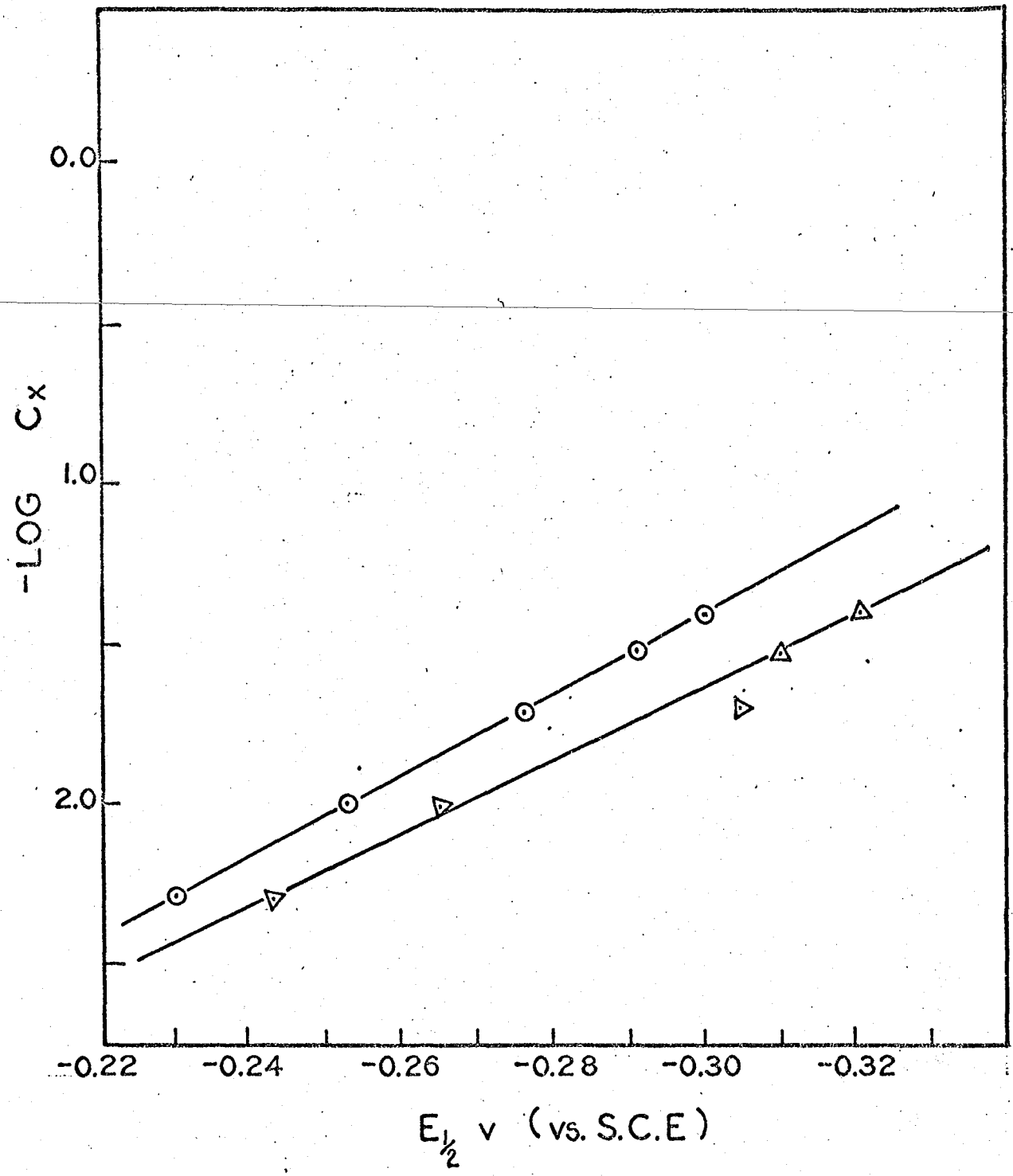
TABLE II

HALF-WAVE POTENTIAL OF THE COPPER p-TOSYL-L-GLUTAMATE COMPLEX AS A FUNCTION OF THE p-TOSYL-L-GLUTAMATE ION CONCENTRATION

Total p-Tosyl-Glutamate Moles/liter	pH	$-E_{\frac{1}{2}}$ vs S.C.E.	i_d u amp.	Slope of log plot
0.005	11.30	0.244	2.60	0.032
0.010	11.60	0.265	2.60	0.033
0.020	11.90	0.305	2.50	0.032
0.030	12.00	0.310	2.40	0.028
0.04	12.20	0.320	2.30	0.034

pK_a of p-tosyl-L-glutamate acid = 3.67.

FIGURE 2



VARIATION OF HALF-WAVE POTENTIAL OF THE CUPRIC COMPLEX ION WITH CONCENTRATION OF THE P-TOSYLAMINO ACIDS: O, P-TOSYL GLYCINATE: Δ, P-TOSYL- L-GLUTAMATE

ion. However, there is a greater depression of the diffusion current. The co-ordination number again is found to be three, giving a complex $[Cu(p\text{-tosyl-glu})_3]$.

p-tosyl-L-lysine. At 5.0×10^{-4} M lysinate ion, a complex was formed with a half-wave potential of -0.151 and a diffusion current of 0.92 microamperes. When the concentration was increased to 5.5×10^{-4} M, the copper wave was completely obliterated. This was at a current range of five. At a current range of three, the diffusion current of the simple ion was too great to be measured; therefore, the ratio k_s/k_c could not be directly obtained at this current range. Since it was not possible to obtain an additional run at current range five, p, for this complex cannot be calculated, consequently, neither can the instability constant of p-tosyl-lysinate cupric complex.

Cadmium

p-tosyl glycinate. As in the case of the cupric ion 0.1 M KNO_3 was the supporting electrolyte. The half-wave potential of the simple ion was -0.563 with a diffusion current of 3.5 microamperes. The seven solutions analyzed were perfectly clear. A maximum suppressor was not needed in any of the cadmium determinations. The plot of $E_{\frac{1}{2}}$/ log C_x gave a slope 0.060, which is the value for p = 2. The formula of this complex is then $[Cd(p\text{-tosyl-gly})_2]$.

p-tosyl-L-glutamate. It was not polarographically possible to analyze the glutamate solutions at the same concentration as the glycinate ions, because a precipitate formed at 0.002 M glutamate ion. For this reason it was necessary to analyze the solutions at a very low concentration. These solutions exhibited a very slight turbidity, but no solid material was observed to fall from solutions on standing. A k_s/k_c ratio of 1.46 was indicative of the extent of depression of the cadmium wave. The co-ordination number (p) for this complex was three. This same value has been reported (17) for the unsubstituted glutamic acid. The cadmium p-tosyl-L-glutamate would have the formula $[Cd(p\text{-tosyl-L-glu})_3]$.

p-tosyl-L-lysinate. As in the case of the glutamate, it was necessary to work with the more dilute solutions of the lysinate ion. The co-ordination number of cadmium in this complex is ten. Four is usually the highest co-ordination number reported (8, 38, 39) for organic addends. The plot of log i/i_d-i versus $E_{d.e.}$ ranges from 0.039 to 0.040, an apparent two electron reaction, from which p must equal to 10. The dilemma can be more happily resolved if n is assumed to be one, then p becomes five and the formula of the complex is $[Cd(p\text{-tosyl-L-Lysine})_5]$ which is in the realm of reason, since both zinc and cadmium (7) are known to exhibit a co-ordination number of five.

TABLE III

HALF-WAVE POTENTIAL OF THE CADMIUM p-TOSYL GLYCINATE COMPLEX AS A FUNCTION OF THE p-TOSYL GLYCINATE ION CONCENTRATIONS

Total p-Tosyl Glycinate Moles/liter	pH	$-E_{\frac{1}{2}}$ vs S.C.E.	i_d u amp.	Slope of Log Plot
0.005	10.40	0.640	2.85	0.032
0.01	10.90	0.690	2.80	0.032
0.02	11.10	0.739	2.80	0.035
0.03	11.20	0.756	2.75	0.031
0.04	11.30	0.765	2.70	0.031

pK_a of p-tosyl glycine = 2.86

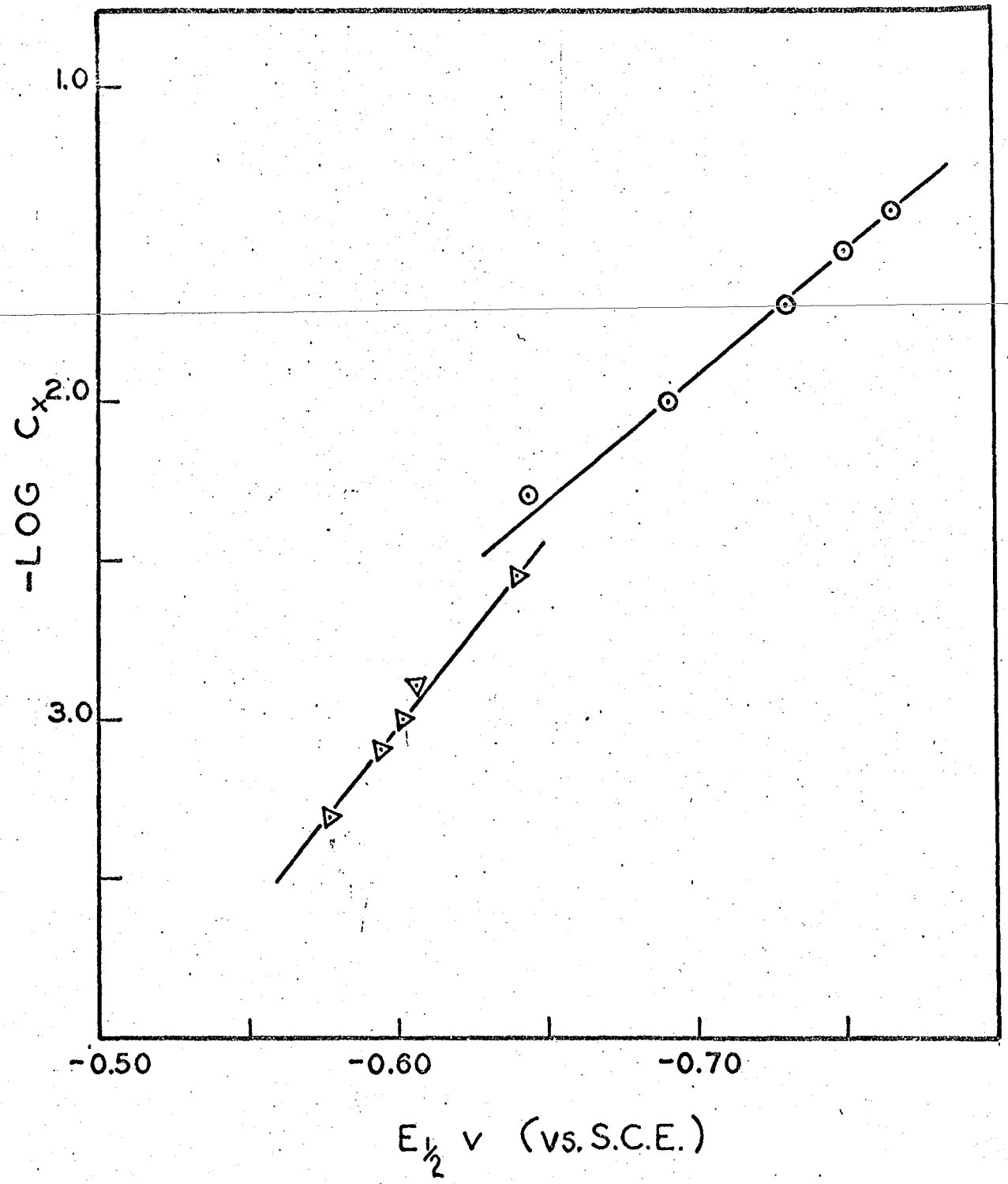
TABLE IV

HALF-WAVE POTENTIAL OF THE CADMIUM p-TOSYL-GLUTAMATE-L-COMPLEX AS A FUNCTION OF THE p-TOSYL-L-GLUTAMATE ION CONCENTRATION

Total p-Tosyl-L-Glutamate Moles/liter	pH	$-E_{\frac{1}{2}}$ vs S.C.E.	i_d u amp.	Slope of Log Plot
0.0005	8.90	-0.5780	2.38	0.031
0.0008	9.20	0.5940	1.68	0.033
0.001	9.60	0.6080	1.12	0.031
0.0012	9.70	0.6085	0.9	0.036
0.0016	10.30	0.6412	0.5	0.0296

pK_a of p-tosyl-L-Glutamic acid = 3.67

FIGURE 3



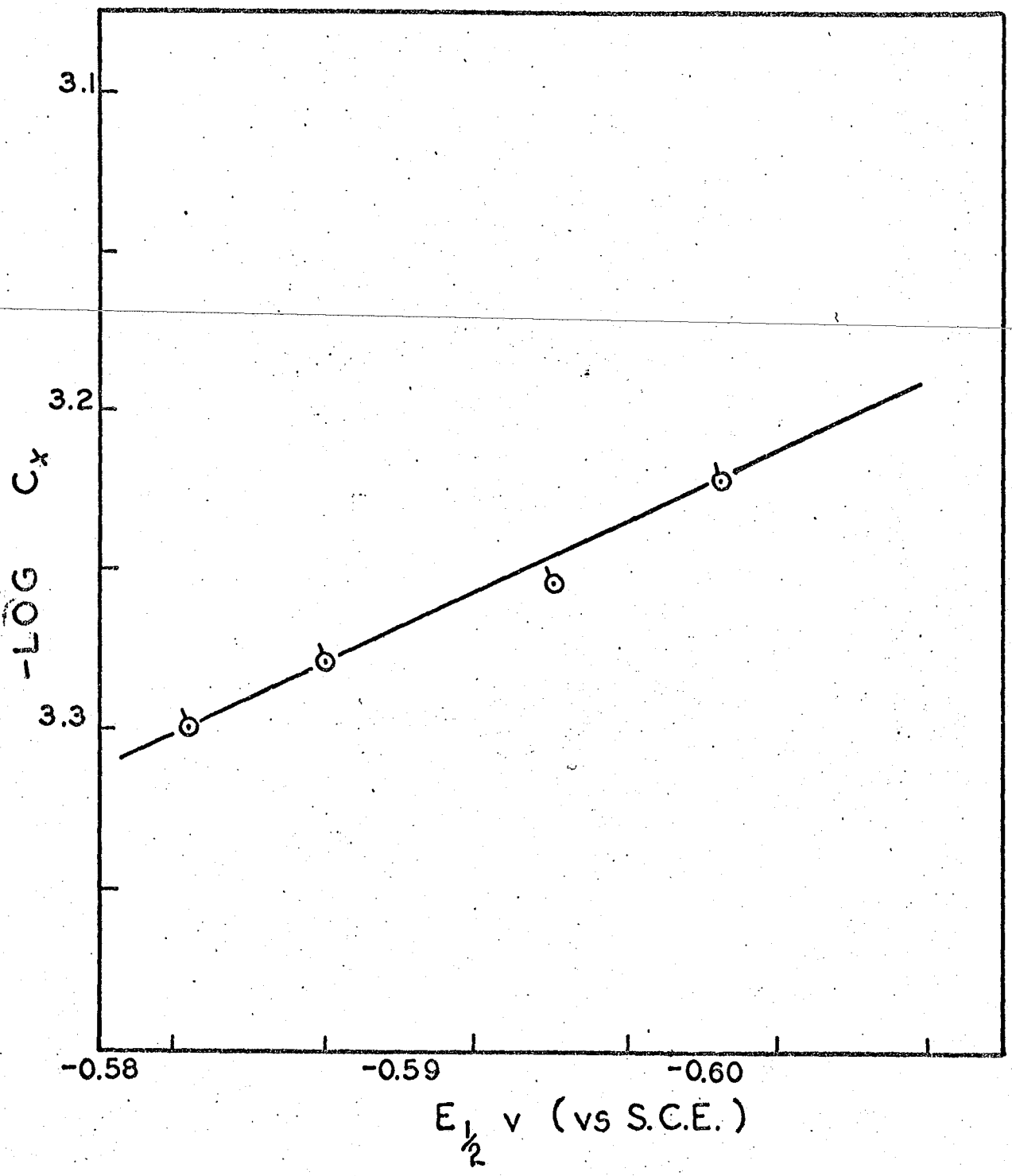
VARIATION OF HALF-WAVE POTENTIAL OF THE CADMIUM COMPLEX ION WITH CONCENTRATION OF THE P-TOSYLAMINO ACID: ⊙, P-TOSYL GLYCINATE; △, P-TOSYL-L- GLUTAMATE

TABLE V

HALF-WAVE POTENTIAL OF CADMIUM p-TOSYL-L-LYSINATE COMPLEX AS A FUNCTION OF THE p-TOSYL-L-LYSINATE ION CONCENTRATION

Total p-Tosyl-Lysinate Moles/liter	pH	$-E_{\frac{1}{2}}$ vs S.C.E.	i_d u amp.	Slope of Log Plot
0.0005	9.30	-0.583	1.09	0.04
0.00525	9.33	0.585	0.85	0.039
0.0055	9.40	0.595	0.56	0.04
0.0006	9.49	0.605	0.35	0.04

FIGURE 4



VARIATION OF HALF-WAVE POTENTIAL OF THE CADMIUM COMPLEX ION WITH CONCENTRATION OF P-TOSYL-L-LYSINATE

Zinc

p-tosyl glycinate. In the zinc series, the supporting electrolyte was 0.1M KCl. The half-wave potential of the simple ion was -0.991 V with a diffusion current of 3.25 microamperes. The k_s/k_c is equal to unity. The slight shift in the half-wave potential could not be detected from a visual inspection of the polarograms. Only when corrections for iR drop were made, did the shift become apparent

If n is two, then p is also two and the formula of the complex is $[Zn(p\text{-tosyl-gly})_2]$. This formula is within reason. Monk (31) has reported data for $[Zn(gly)_2]$.

p-tosyl-L-glutamate. These solutions were more dilute than those of the preceding determination, the pH is lower, but the zinc wave was depressed to about the same extent; this depression is probably due (20) to the large size of the complex ions. From the test for reversibility, n = 2, thus the co-ordination number must be three. This is rather surprising because zinc (6) complexes with two moles of aspartic acid. Co-ordination number two is encountered in the work with diamines (4) such as ethylenediamine. With p equal three the formula of this complex is $[Zn(p\text{-tosyl-glu})_3]^{++}$.

p-tosyl-L-lysinate. The half-wave potential of the complex ion -1.093 was apparently different from that of

TABLE VI

HALF-WAVE POTENTIAL OF ZINC p-TOSYL GLYCINATE COMPLEX AS A FUNCTION OF THE p-TOSYL GLYCINATE ION CONCENTRATION

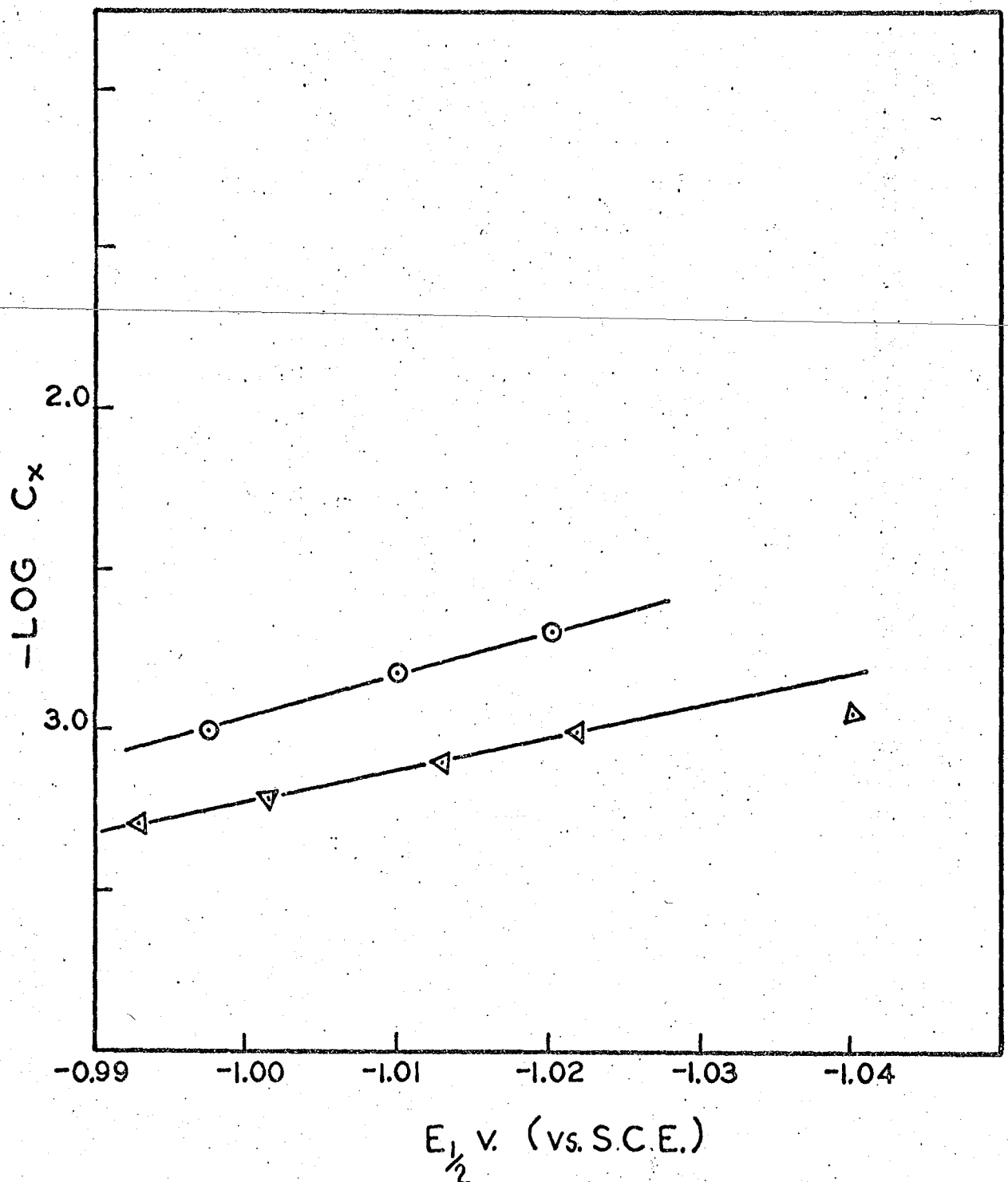
Total p-Tosyl Glycinate Moles/liter	pH	$-E_{\frac{1}{2}}$ vs S.C.E.	i_d u amp.	Slope of Log Plot
0.001	8.00	0.97	2.80	0.037
0.0015	8.10	1.010	2.20	0.040
0.002	8.25	1.020	1.50	0.040
0.003	8.50	1.045	0.7	0.040

TABLE VII

HALF-WAVE POTENTIAL OF ZINC p-TOSYL-L-GLUTAMATE COMPLEX AS A FUNCTION OF THE p-TOSYL-L-GLUTAMATE ION CONCENTRATION

Total p-Tosyl-L-Glutamate Moles/liter	pH	$-E_{\frac{1}{2}}$ vs S.C.E.	i_d u amp.	Slope of Log Plot
0.0005	7.90	0.993	2.25	0.036
0.0006	7.95	1.002	2.10	0.034
0.0008	8.00	1.013	1.40	0.032
0.001	8.05	1.002	1.00	0.04
0.0012	8.20	1.293	0.45	0.04

FIGURE 5



VARIATION OF HALF-WAVE POTENTIAL OF THE ZINC COMPLEX ION WITH CONCENTRATION OF THE P-TOSYLAMINO ACIDS: O, P-TOSYL GLYCINATE; Δ, P-TOSYL-L-GLUTAMATE

the simple ion with k_s/k_c equal to 3.56 microamperes. The zinc wave was almost completely obliterated at higher concentrations of the lysinate, making further analysis under these conditions impossible.

Mercury (II)

p-tosyl glycinate. The half-wave potential of the simple ion in 0.1 M KCl as supporting electrolyte and 0.002% Triton X-100 as maximum suppressor was -0.113 V, with diffusion current of 4.1 microamperes. The k_s/k_c ratio was 1.1, or for purposes of calculations, unity. The $E_{\frac{1}{2}}$/ Log C_x slope is 0.12, for a two electron reaction, the co-ordination number of mercury (II) is four. The formula for this complex is then $[Hg(p\text{-tosyl gly})_4]^{++}$. For organic addends the co-ordination number of mercury (II) is usually two. No complexes of organic addends with p equal four are cited in Iatsmiskii's (14) comprehensive volume.

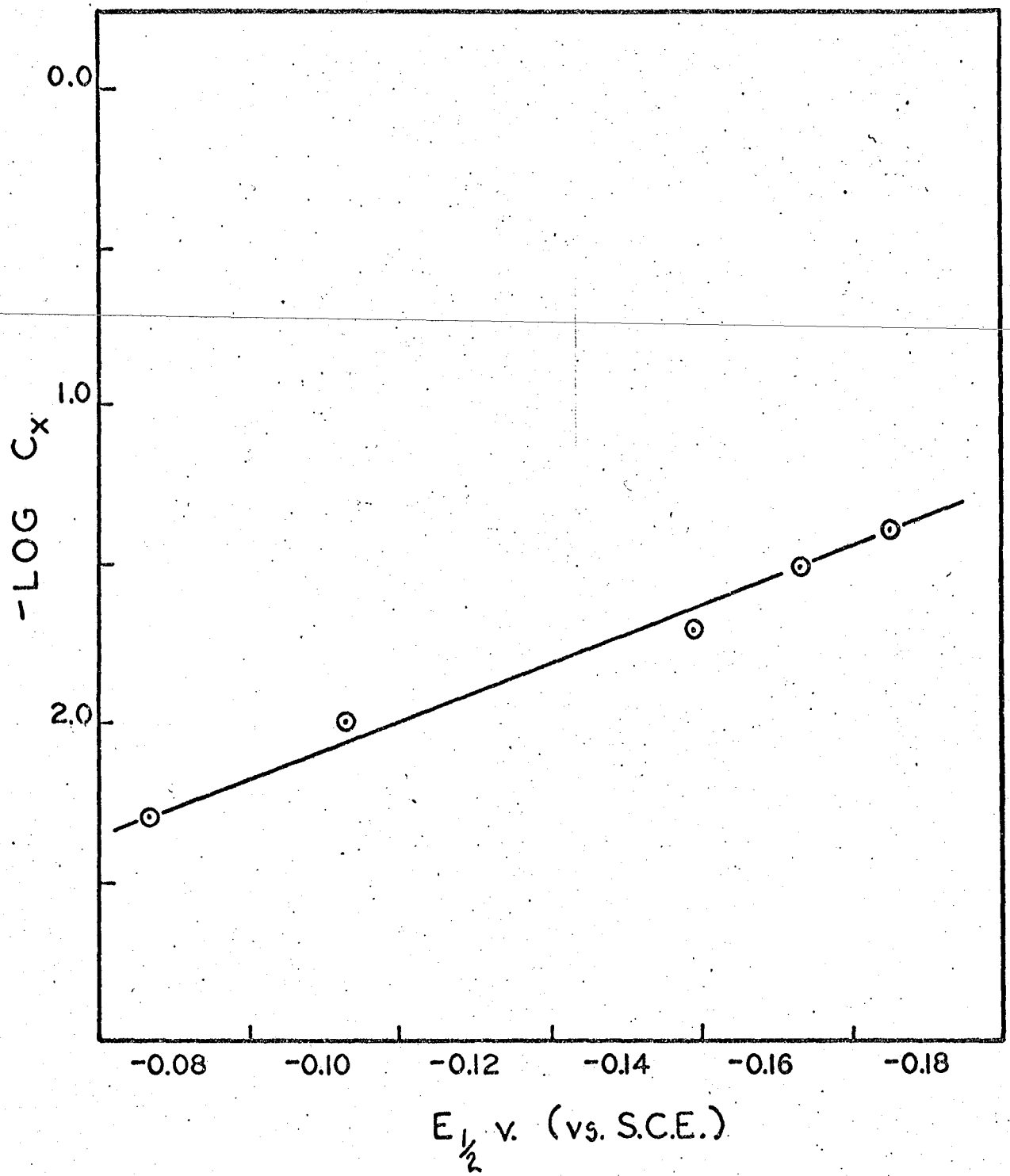
p-tosyl-L-glutamate. The supporting electrolyte and maximum suppressor are the same as in the glycinate analysis. Again the solutions are colorless. k_s/k_c (1.1) for all practical purposes is unity. The slope of the log plot ranges from 0.029 to 0.040 V. Kolthoff and Miller (18) in working with simple mercuric ion obtained a slope 0.039, and consider it a two electron reduction. They attribute the upward divergence of slope to the presence of gelatin,

TABLE VIII

HALF-WAVE POTENTIAL OF THE MERCURY (II) p-TOSYL GLYCINATE COMPLEX AS A FUNCTION OF THE p-TOSYL GLYCINATE ION CONCENTRATION

Total p-Tosyl-L-Glutamate Moles/liter	pH	$-E_{\frac{1}{2}}$ vs S.C.E.	i_d u amp.	Slope of Log Plot
0.005	10.35	0.0765	2.95	0.029
0.01	10.85	0.1130	2.70	0.034
0.02	11.10	0.1490	2.65	0.033
0.03	11.20	0.1630	2.70	0.029
0.04	11.25	0.1751	2.60	0.033

FIGURE 6



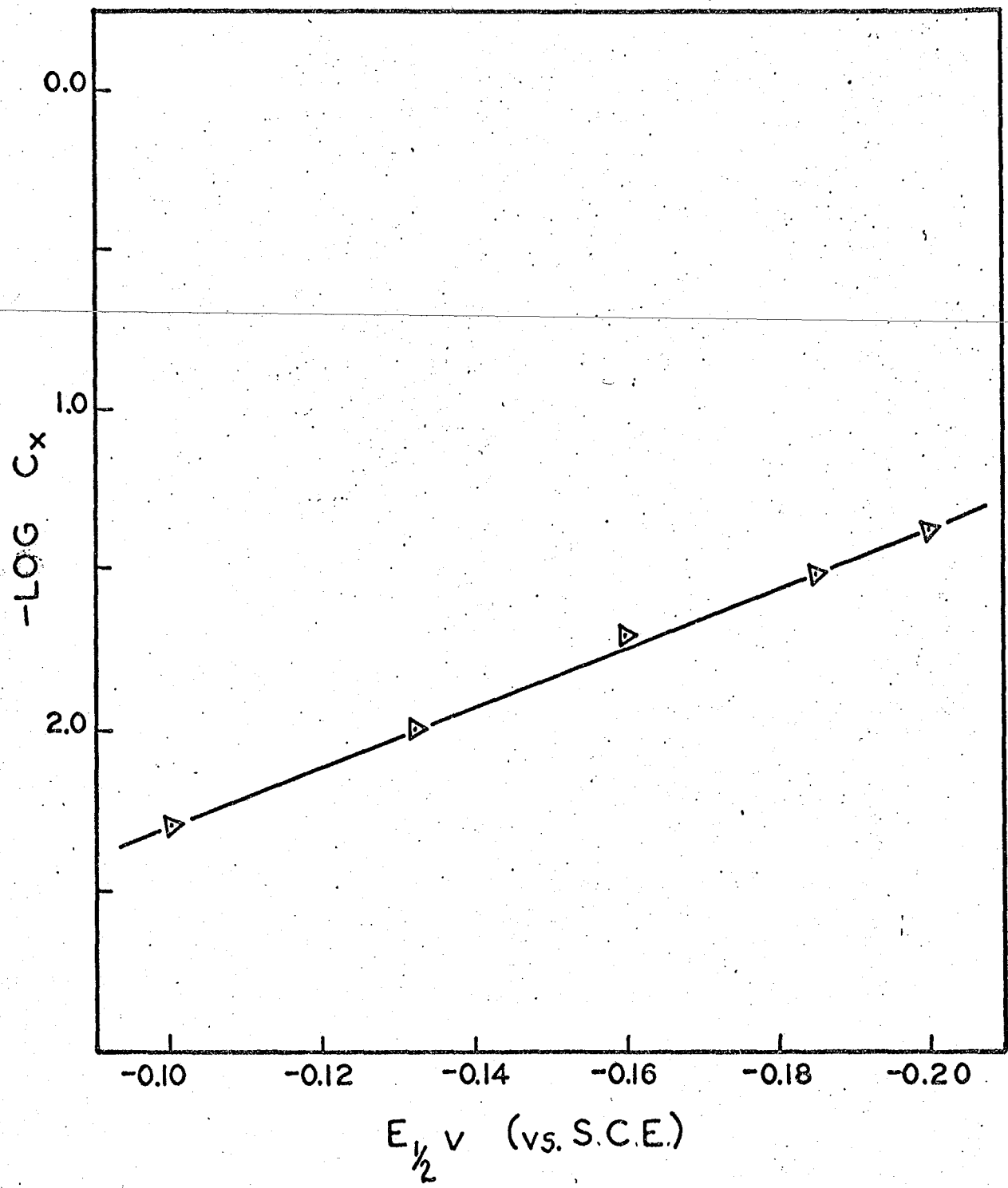
VARIATION OF HALF-WAVE POTENTIAL OF THE MERCURY (II) COMPLEX ION WITH CONCENTRATION OF P-TOSYL GLYCINATE

TABLE IX

HALF-WAVE POTENTIAL OF THE MERCURY (II) p-TOSYL-L-GLUTAMATE COMPLEX AS A FUNCTION OF THE p-TOSYL-L-GLUTAMAGE ION CONCENTRATION

Total p-Tosyl-L-Glutamate Moles/liter	pH	$-E_{\frac{1}{2}}$ vs S.C.E.	i_d u amp.	Slope of Log Plot
0.005	11.05	0.1005	2.7	0.036
0.01	11.35	0.1318	2.5	0.04
0.02	11.65	0.1588	2.6	0.04
0.03	11.80	0.1850	2.6	0.036
0.04	11.90	0.2021	2.2	0.029

FIGURE 7



VARIATION OF HALF-WAVE POTENTIAL OF THE MERCURY(II) COMPLEX ION WITH CONCENTRATION OF P-TOSYL - L - GLUTAMATE

which had been added to suppress the maximum. In this analysis the high slope value might be due to bulkiness of the molecule being studied. The plot of $E_{\frac{1}{2}}$/ Log C_x give a slope of 0.125, for n equals 2, the co-ordination number is 4, thus for the complex the formula is $[Hg(p\text{-tosyl-L-glu})_4]^{++}$.

p-tosyl-L-lysinate. These solutions were cloudy and a precipitate formed on bubbling nitrogen through them. The height of the zinc wave was depressed to 0.65 micro-amperes, although the concentrations were to the order of 10^{-4} M. No attempt was made to evaluate these polaro-grams.

Lead (II)

p-tosyl glycine. Lead complexes were studied in a 0.1 M KNO_3 supporting electrolyte with 0.002% Triton X-100 as the maximum suppressor. The height of the simple wave was 3.45 amperes with half-wave potential of -0.370 V and $k_s/k_c = 1$. These solutions became turbid on standing and had to be made up immediately prior to oxygen removal. On use of appropriate data p is found to be equal to three, with the formula of the complex as $[Pb(p\text{-tosyl glu})_3]$. Although $Pb(Gl)_2$ (30) is listed as being determined potentiometrically, no mention is made of a higher complex of lead and glycine. A Russian worker (42) reports a

tartrate complex of lead as $[Pb(H\ Tart)_3]$. There is no reason to believe that this is a lead hydroxo complex. Lingane (25) has shown that the half-wave potential of the lead hydroxo complexes increase linearly with concentration of sodium hydroxide only in the range 0.01 M to 0.5 The strongest concentration of glycinate ion used was 0.006 M, yet a linear increase in $E_{\frac{1}{2}}$ was observed at these low concentrations. From Lingane's observations, this would not have been true were the complex being formed that of the hydroxo.

p-tosyl-L-glutamate. Analytical conditions were generally the same as those in the preceding glycinate runs. These solutions were perfectly clear. From slope of plot it is evident that there is a genuine one electron reduction, with slope values ranging from 0.050 to 0.073. The co-ordination number is calculated to be one. The formula of this complex is postulated to be Pb(OH)p-tosyl-L-glu. There is ample evidence (32, 5) for the existence of $Pb(OH)^+$. Pederson (34) of the Royal Veterinary Agriculture College of Copenhagen explains the formation of $Pb(OH)^+$ on the basis of three equilibriums:

$$Pb^{++} + H_2O = PbOH^+ + H^+ + H_2O = Pb_2OH^{+++} + H^+$$

and

$$4Pb^{++} + 4H_2O = Pb_4(OH)_4{}^{++++} + 4H^+.$$

TABLE X

HALF-WAVE POTENTIAL OF THE LEAD (II) p-TOSYL GLYCINATE COMPLEX AS A FUNCTION OF THE p-TOSYL GLYCINATE ION CONCENTRATION

Total p-Tosyl Glycinate Moles/liter	pH	$-E_{\frac{1}{2}}$ vs S.C.E.	i_d u amp.	Slope of Log Plot
0.003	8.70	0.475	1.90	0.035
0.002	8.80	0.486	1.90	0.036
0.004	10.20	0.534	1.40	0.032
0.005	10.48	0.542	1.60	0.030
0.006	10.55	0.554	1.40	0.029

TABLE XI

HALF-WAVE POTENTIAL OF THE LEAD (II) p-TOSYL-L-GLUTAMATE COMPLEX AS A FUNCTION OF THE p-TOSYL-L-GLUTAMATE ION CONCENTRATION

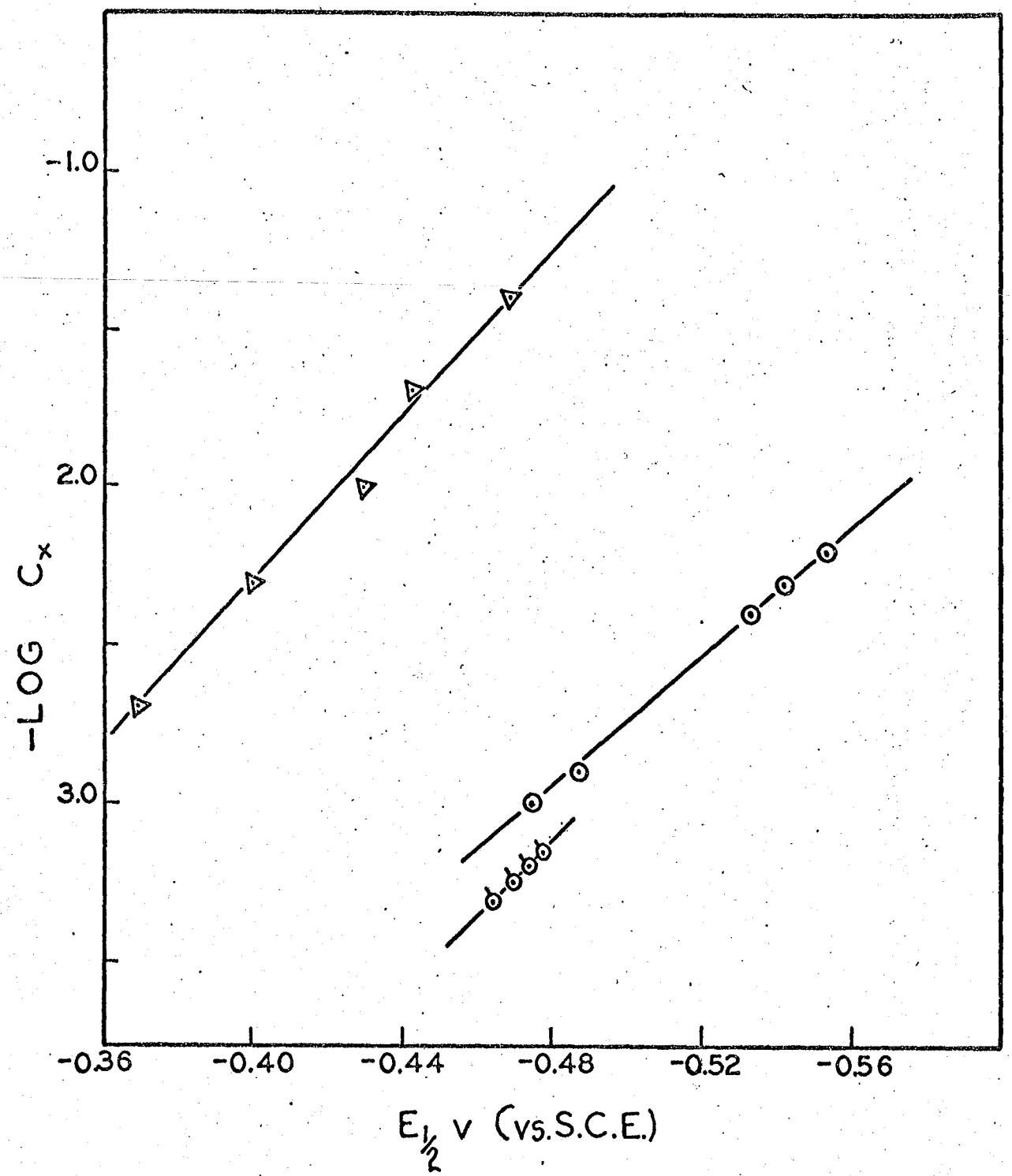
Total p-Tosyl-L-Glutamate Moles/liter	pH	$-E_{\frac{1}{2}}$ vs S.C.E.	i_d u amp.	Slope of Log Plot
0.002	6.55	0.371	3.35	0.050
0.005	6.75	0.402	3.20	0.073
0.01	6.90	0.428	3.10	0.070
0.02	7.1	0.443	2.90	0.060
0.04	7.5	0.469	2.88	0.050

TABLE XII

HALF-WAVE POTENTIAL OF THE LEAD (II) p-TOSYL-L-LYSINATE COMPLEX AS A FUNCTION OF THE p-TOSYL-L-LYSINE ION CONCENTRATION

Total p-Tosyl-L-Lysinate Moles/liter	pH	$-E_{\frac{1}{2}}$ vs S.C.E.	i_d u amp.	Slope of Log Plot
0.0005	8.70	0.4665	1.82	0.039
0.00055	9.20	0.4700	1.45	0.04
0.0006	9.30	0.4722	1.25	0.04
0.0007	9.60	0.4773	1.1	0.04

FIGURE 8



VARIATION OF HALF-WAVE POTENTIAL OF THE LEAD (II) COMPLEX ION WITH CONCENTRATION OF THE P-TOSYLAMINO ACIDS: O, P-TOSYL GLYCINATE; Δ, P-TOSYL-L-GLUTAMATE; ȯ, P-TOSYL-L-LYSINATE

The presence of oxonium ions in solution is supported by the low pH values of the solutions. Usually the pH of a 0.04 M solution of the glutamate was approximately 11.9; in this solution it is 7.5.

The presence of hydrogen ions in solution may hydrolize some of the glutamate and make possible the formation of Pb(OH)Glu., much in the same manner as Zn(OH) $Tart^-$ (31) is formed.

p-tosyl-L-lysine. Supporting electrolyte and maximum suppressor, are the same as for the glycinate ion. The shift of the half-wave potential is very slight, between that of glycinate and glutamate; the lead wave, however, is depressed more than that of glycinate or glutamate. p is calculated to be two. The formula of the complex would be [Pb(p-tosyl-L-lysinate)$_2$].

Manganese (II)

p-tosyl-glycinate. All solutions in the manganese (II) series were de-aerated completely before preparing the solution to be analyzed. This additional precaution was necessary to prevent basic manganese (II) from oxodizing to the dioxide. Although the solution gave a very light tan color on addition of the glycinate, no precipitate was observed to form. p is found to be one. The formula then is $[Mn(p\text{-tosyl-gly})]^+$. Monk (31) reports the same type

TABLE XIII

HALF-WAVE POTENTIAL OF THE MANGANESE (II) p-TOSYL GLYCINATE COMPLEX AS A FUNCTION OF THE p-TOSYL GLYCINATE ION CONCENTRATION

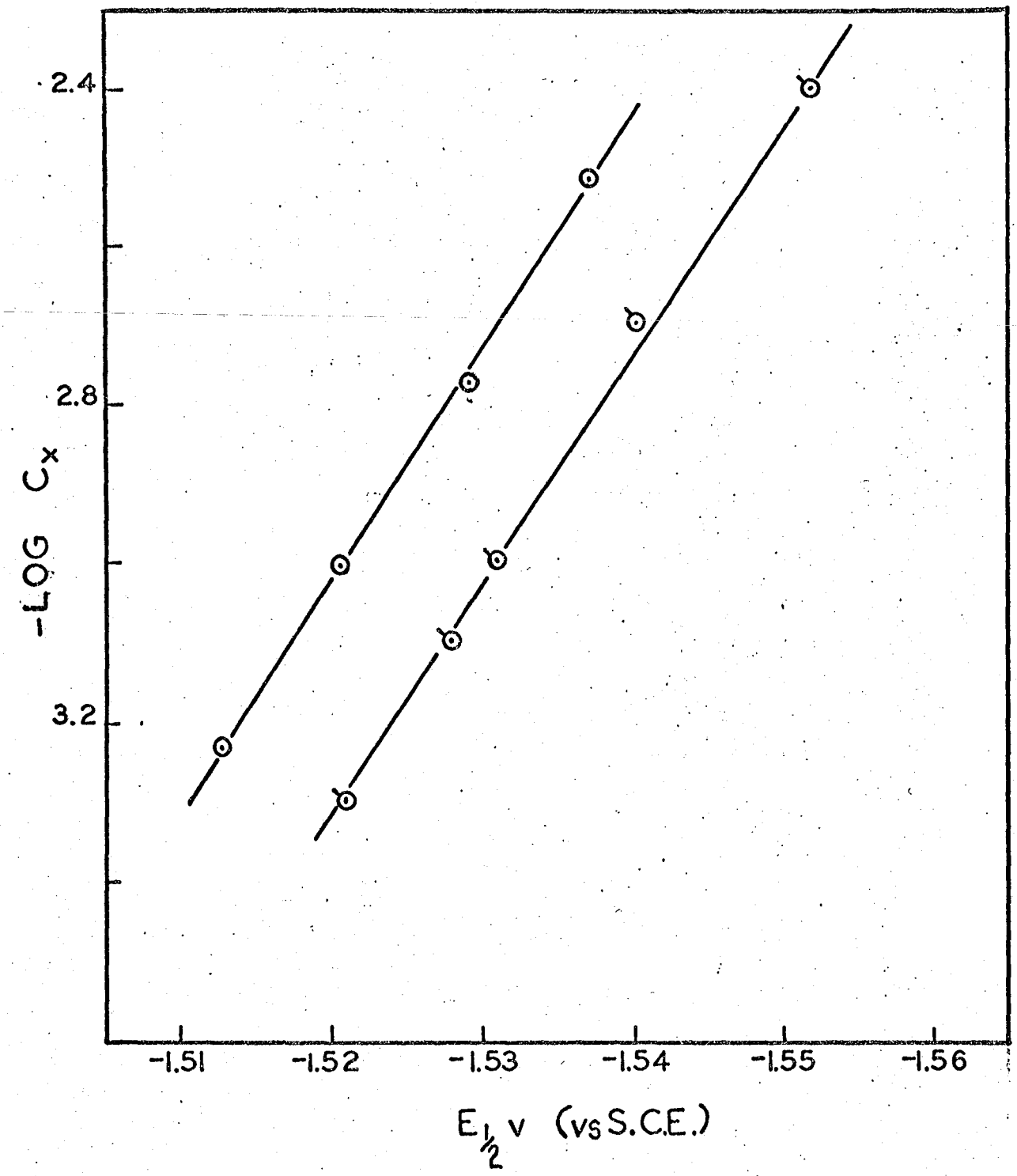
Total p-Tosyl Glycinate Moles/liter	pH	$-E_{\frac{1}{2}}$ vs S.C.E.	i_d u amp.	Slope of Log Plot
0.0005	9.65	1.513	2.85	0.04
0.001	9.85	1.521	2.84	0.04
0.002	10.05	1.529	1.72	0.036
0.003	10.10	1.537	1.00	0.036
0.004	10.25	1.554	0.55	0.030

TABLE XIV

HALF-WAVE POTENTIAL OF THE MANGANEZE (II) p-TOSYL-L-LYSINATE COMPLEX AS A FUNCTION OF THE p-TOSYL-L-LYSINATE ION CONCENTRATION

Total p-Tosyl-L-Lysinate Moles/liter	pH	$-E_{\frac{1}{2}}$ vs S.C.E.	i_d u amp.	Slope of Log Plot
0.0005	9.85	1.5217	2.38	0.038
0.0007	10.00	1.528	1.90	0.038
0.0009	10.15	1.5310	1.45	0.038
0.002	10.20	1.540	1.10	0.040

FIGURE 9



VARIATION IN HALF-WAVE POTENTIAL OF MANGANESE (II) COMPLEX ION WITH CONCENTRATION OF THE P-TOSYLAMINO ACIDS: O, P-TOSYL GLYCINATE; Ó, P-TOSYL-L-LYSINATE

formula for Mn(II) with glycine and alanine.

p-tosyl-L-glutamate. No apparent shift of the half-wave potential was observed.

p-tosyl-L-lysinate. While the shift of the half-wave potential for lysinate complex is greater than the glycinate's the n and p values are the same, making the formula $[Mn(p\text{-tosyl-L-lysine})]^{+}$.

II. DISSOCIATION CONSTANTS AND FREE ENERGY OF FORMATION OF COMPLEXES

Dissociation Constants

Dissociation constants for the complexes studied are listed in Tables XV, XVI, and XVII (see pages 52, 53, and 54). The order of stability of the p-tosyl glycinate complexes as found in this study is:

$$Hg > Cu > Pb > Cd > Mn > Zn$$

This order of stability of complex formation among metals is different from that reported by Albert (1) for the unsubstituted acid,

$$Cu > Zn > Cd > Mn$$

but is in substantial agreement with that found by Blood and Loras (10) for the unsubstituted glycine,

Hg > Cu > Zn > Cd

Maley and Mellor (28) working with glycine alanine and valine list the following order of stability of complexes:

Cu > Zn > Mn

In this study of the p-tosyl-L-glutamate complexes, the order of stability is about the same as that of the p-tosyl-glycinates:

Hg > Cu > Cd > Zn > Pb

In group IIB, there is an increase of stability of p-tosyl glycinates and glutamates metal complexes with an increase in atomic weight (Figure 10, page 56). Perkins (34) in working with glycine reports the following order for group IIB:

Hg > Zn > Cd

In this instance there is no apparent relationship between stability and atomic weight, as found in this study.

Throughout this investigation it was apparent that the metal was the dominating factor in the stability of the complexes studied.

A comparison of pK values of metal complex ions of glycine with those of p-tosyl glycine (Table XVIII, page 55)

TABLE XV

CONCENTRATION DISSOCIATION CONSTANTS AND pK'S FOR THE p-TOSYL GLYCINATE-METAL COMPLEX IONS

Metal Ion	-Log C_x	K_d	Mean K_d*	pK
Cu^{++}	2.3010	2.0×10^{-15}	1.22×10^{-15}	14.92
	1.3979	1.5×10^{-15}		
Cd^{++}	2.3010	7.0×10^{-10}	3.2×10^{-10}	9.50
	1.3979	2.4×10^{-10}		
Zn^{++}	3.0000	6.3×10^{-7}	4.3×10^{-7}	6.36
	2.5229	2.7×10^{-7}		
Hg^{++}	2.0000	2.5×10^{-16}	3.5×10^{-16}	15.46
	1.3979	4.0×10^{-16}		
Pb^{++}	3.0000	1.3×10^{-13}	1.3×10^{-13}	12.88
	2.2218	1.3×10^{-13}		
Mn^{++}	3.0000	5.0×10^{-10}	1.43×10^{-9}	8.85
	2.3979	15×10^{-10}		

*Mean of five values.

TABLE XVI

CONCENTRATION DISSOCIATION CONSTANTS AND pK FOR THE p-TOSYL-L-GLUTAMATE-METAL COMPLEX IONS

Metal Ion	-Log C_x	K_d	Mean K_d*	pK
Cu^{++}	2.3010	3.1×10^{-16}	3.4×10^{-16}	15.47
	1.5229	3.9×10^{-16}		
Cd^{++}	3.3010	3.5×10^{-16}	3.6×10^{-6}	5.46
	2.9208	4.0×10^{-16}		
Zn^{++}	3.3010	1.0×10^{-14}	9.5×10^{-15}	14.02
	3.0000	0.9×10^{-14}		
Hg^{++}	2.3010	4.4×10^{-17}	8.0×10^{-17}	16.10
Pb^{++}	2.6990	3.63×10^{-6}	1.68×10^{-6}	5.77
	1.3979	0.15×10^{-6}		
Mn^{++}	-	-	-	-
	-	-		

*Mean of five values.

TABLE XVII

CONCENTRATION DISSOCIATION CONSTANTS AND pK FOR THE p-TOSYL-L-LYSINATE-METAL COMPLEX IONS

Metal Ion	-Log C_x	K_d	Mean K_d*	pK
Cu^{++}	-	-	-	-
	-	-		
Cd^{++}	3.3010	1.8×10^{-101}	2.1×10^{-101}	100.68
	3.2218	2.4×10^{-101}		
Zn^{++}	-	-	-	-
	-	-		
Hg^{++}	-	-	-	-
	-	-		
Pb^{++}	3.2596	1.32×10^{-10}	1.78×10^{-10}	9.74
	3.1871	1.29×10^{-10}		
Mn^{++}	3.1549	1.29×10^{-4}	1.76×10^{-4}	3.74
	2.6990	1.45×10^{-4}		

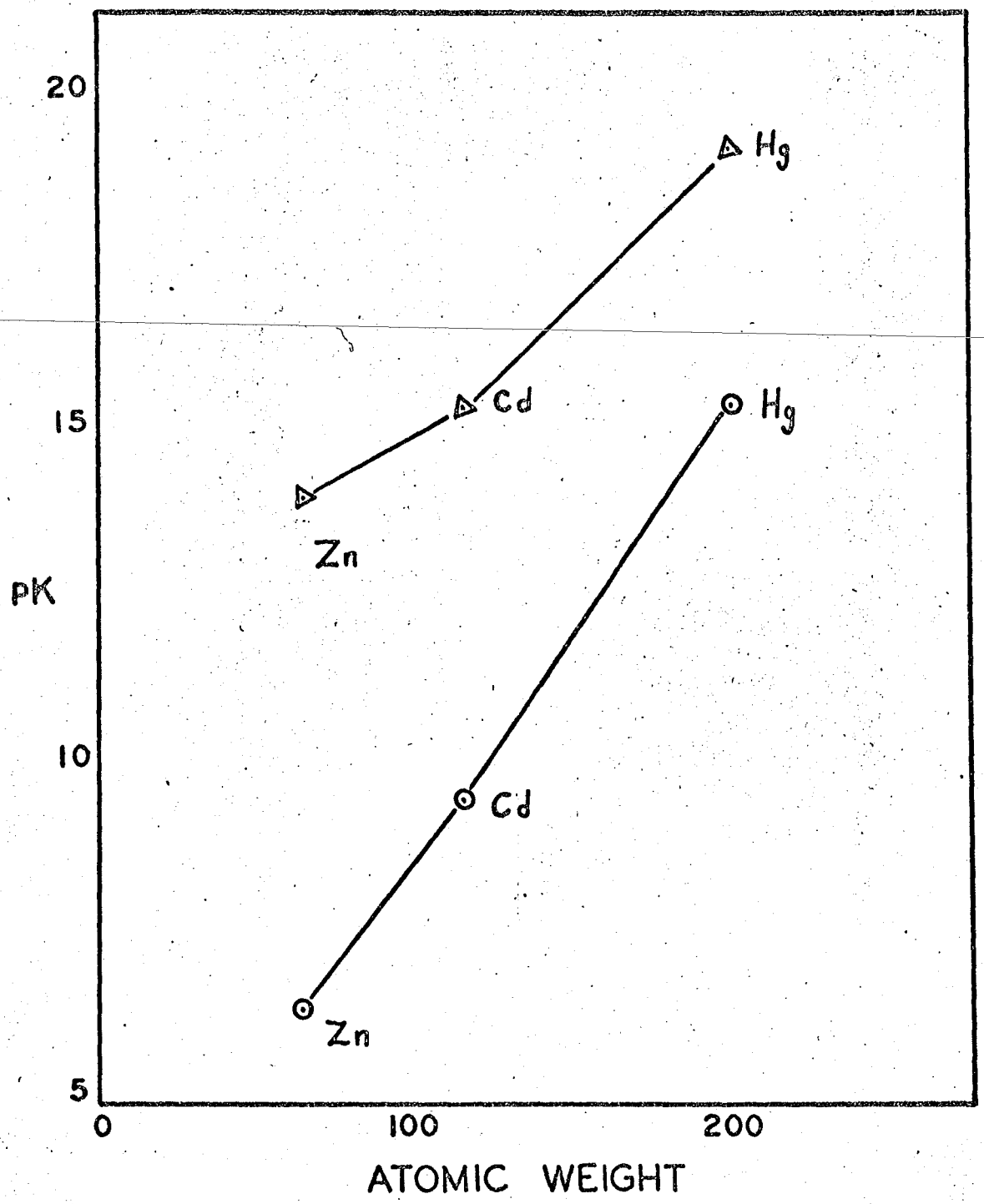
*Mean of five values.

TABLE XVIII

pK VALUES OF METAL COMPLEX IONS OF GLYCINE
COMPARED WITH THOSE p-TOSYL GLYCINE

Compound	pK					
	Mn	Cu	Zn	Cd	Hg	Pb
Glycine	3.44 (41)	16.27 (8)	9.6 (33)	8.1 (48)	18.2 (44)	9.3 (31)
p-Tosyl Glycinate	8.55	14.93	6.37	9.49	15.46	12.93

FIGURE 10



DISTRIBUTION OF pK VALUES OF GROUP II METALS WITH P-TOSYL AMINO ACIDS: O, P-TOSYL GLYCINATE; Δ P-TOSYL-L-GLUTAMATE

indicates that in some instances there is an appreciable effect on the stability of a complex when the hydrogen atom of the glycine amino acid group was substituted by the p-tosyl group. The differences are small however (except in the case of MnII) when compared with the metal effects.

Free Energy of Formation of Complexes

Towards the end of the last century it was found that an energy quantity called its free energy (F) can be assigned to each substance in a reaction, such that a reaction in a system held at constant temperature tends to proceed if it is accompanied by a decrease in free energy--that is, if the free energy of the reactants is greater than that of the products. At equilibrium the driving force of the heat content (ΔH) accompanying a reaction is exactly balanced by the driving force of the probability change (ΔS).

The discovery of the relation between equilibrium constants and free energy has simplified the task systematizing chemical reactions.

The magnitude of the equilibrium constant of a reaction is an approximate indication of the completeness of the reaction under specified conditions. A large K_e indicates that the reaction goes from left to right, a long way toward completion, a small value indicates that the reaction proceeds right to left.

The relationship between the equilibrium constant and free energy is expressed in the equation.

$$F = - RT \ln K \qquad (16)$$

Li and Doody (6) have reported the free energy of formation of cupric complexes of aspartic acid and alanine from polarographically determined dissociation constants.

The free energy of formation of the metal complexes of p-tosyl glycinate and p-tosyl-L-glutamate are shown in Table XIX. For the lead (II) lysinate complex F = 13.3 kcal and for the Manganese (II) lysinate F = 4.99 kcal.

TABLE XIX

FREE ENERGY OF FORMATION OF p-TOSYL GLYCINATE AND GLUTAMATES COMPLEXES

Compound	F (kCal)					
	Mn	Cu	Zn	Cd	Hg	Pb
p-Tosyl Glycinate	12.2	-20.00	-8.68	-12.90	-22.10	-17.50
p-Tosyl-L-Glutamate	-	-21.10	-19.1	-21.1	-27.80	-5.77

CHAPTER V

SUMMARY

This study has been fruitful in that the complexes synthesized are new, consequently there is no data available in the literature concerning these compounds, thus it represents a contribution to knowledge.

1. The names and formulas of the fourteen new and previously unreported complexes are:

   a. Copper (II) p-tosyl glycinate, $[Cu(p\text{-tosyl-gly})_3]^-$.

   b. Copper (II) p-tosyl-L-glutamate, $[Cu(p\text{-tosyl-glu})_3]^-$.

   c. Cadmium p-tosyl glycinate, $[Cd(p\text{-tosyl-gly})_2]^{++}$.

   d. Cadmium p-tosyl-L-glutamate, $[Cd(p\text{-tosyl-L-glu})_3]^-$.

   e. Cadmium p-tosyl-L-lysinate, $[Cd(p\text{-tosyl-lysinate})_5]^{3-}$.

   f. Zinc p-tosyl glycinate, $[Zn(p\text{-tosyl-gly})_2 2$.

   g. Zinc p-tosyl-L-glutamate $[Zn(p\text{-tosyl-glu})_3]^-$.

   h. Mercury (II) p-tosyl glycinate, $[Hg(p\text{-tosyl-gly})_4]^{2+}$.

i. Mercury (II) p-tosyl-L-glutamate, $[Hg(p\text{-tosyl-L-glu})_4]^{2-}$

j. Lead (II) p-tosyl glycinate, $[Pb(p\text{-tosyl-gly})_3]^-$.

k. Lead (II) p-tosyl-L-glutamate $Pb(OH)^+$ p-tosyl-L-glu.

l. Lead (II) p-tosyl-L-lysinate, $[Pb(p\text{-tosyl-L-lysinate})_2]$.

m. Mangenese (II) p-tosyl glycinate, $[Mn(p\text{-tosyl-gly})]^+$

n. Manganese (II) p-tosyl-L-lysinate, $[Mnp\text{-tosyl-L-lysinate})]^+$

2. Of the amino acids studied, only the dissociation constants of the metal (Cu II, Cd, Zn, Hg II, Pb II, and Mn II) complexes of the unsubstituted glycine were to be found in the literature, hence only the stability of these complexes can be compared with the p-tosyl glycine complexes prepared in this study.

The pK values of Mn (II) and Pb (II) of the substituted glycine (p-tosyl) are a little higher than those of the metal complexes of the unsubstituted glycine, denoting a lesser degree of stability. Of the remaining metal complexes of the substituted and unsubstituted glycine there is practically no difference in pK values.

A careful appraisal of these data would seem to

indicate that the substitution of the bulky p-tosyl group for a hydrogen on the amino group of glycine does not drastically effect the stability of the metal complexes examined in this study.

3. The order of stability of complex formation among metals with the substituted glycine is in general agreement with those listed in the literature for glycine. The notable exception is the zinc complex, which is the most stable instead of being among the least stable of the complexes. The data for the order of stability were obtained by a variety of techniques, generally not polarographic. This method might account for the difference in pK values, along with the nature of the co-ordinating agent.

With the glutamate complexes the order of stability is in fair agreement with the expected order of stability.

4. The Copper II complex of p-tosyl glycine pK values were essentially the same as those reported previously for the unsubstituted glycine, further evidence that steric hindrance of the p-tosyl group does not appreciably effect the stability of the simple amino acid complex.

5. Group II B metal complexes of the glycinates and glutamates show an increase in stability with atomic weight.

6. Polarographic evidence indicates the existence of the mercury complexes $[Hg(\text{p-tosyl-gly})_4]^{++}$ and

$[Hg(p\text{-tosyl-gly})_4]^{++}$. A search of the available literature showed that mercury complexes of organic addends with p equal to four, have not been previously reported.

7. In their complexes, zinc and cadmium have co-ordination numbers 2, 4, 5, and 6. In this study both the cadmium and zinc glutamates have the rarely reported co-ordination number of three.

8. Only single wave polarograms were observed in this study, indicating a constancy of oxidation state of the metal ion during experimentation.

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APPENDIX A

POLAROGRAM . . 5.0 x 10^{-4} M $Cd(NO_3)_2$

SOLVENT . . H_2O

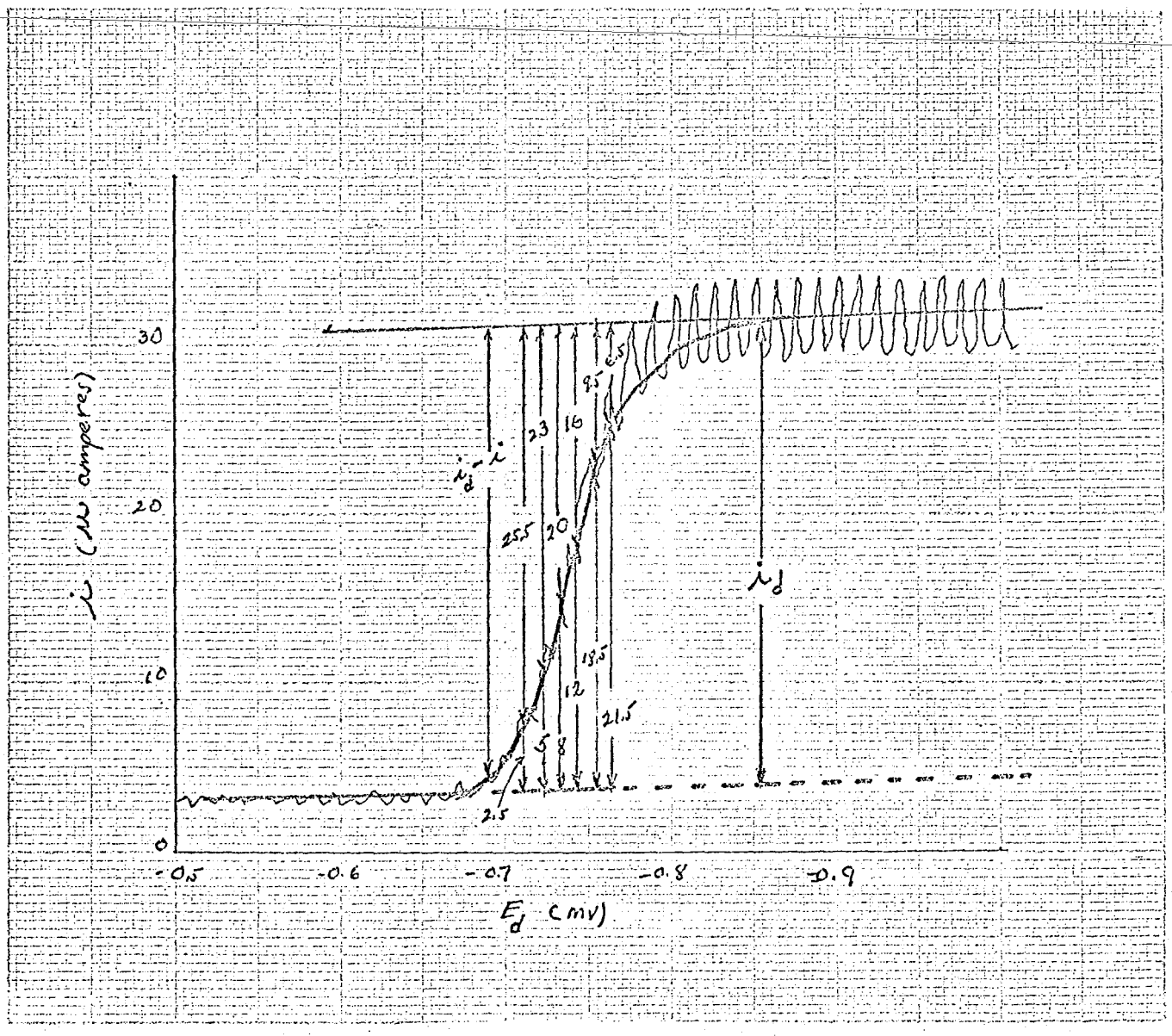
ELECTROLYTE . . 0.1 M KNO_3

SAMPLE . . 0.1 M p-Tosylglycine

CURRENT RANGE . . 10

DROP TIME . . 3 seconds

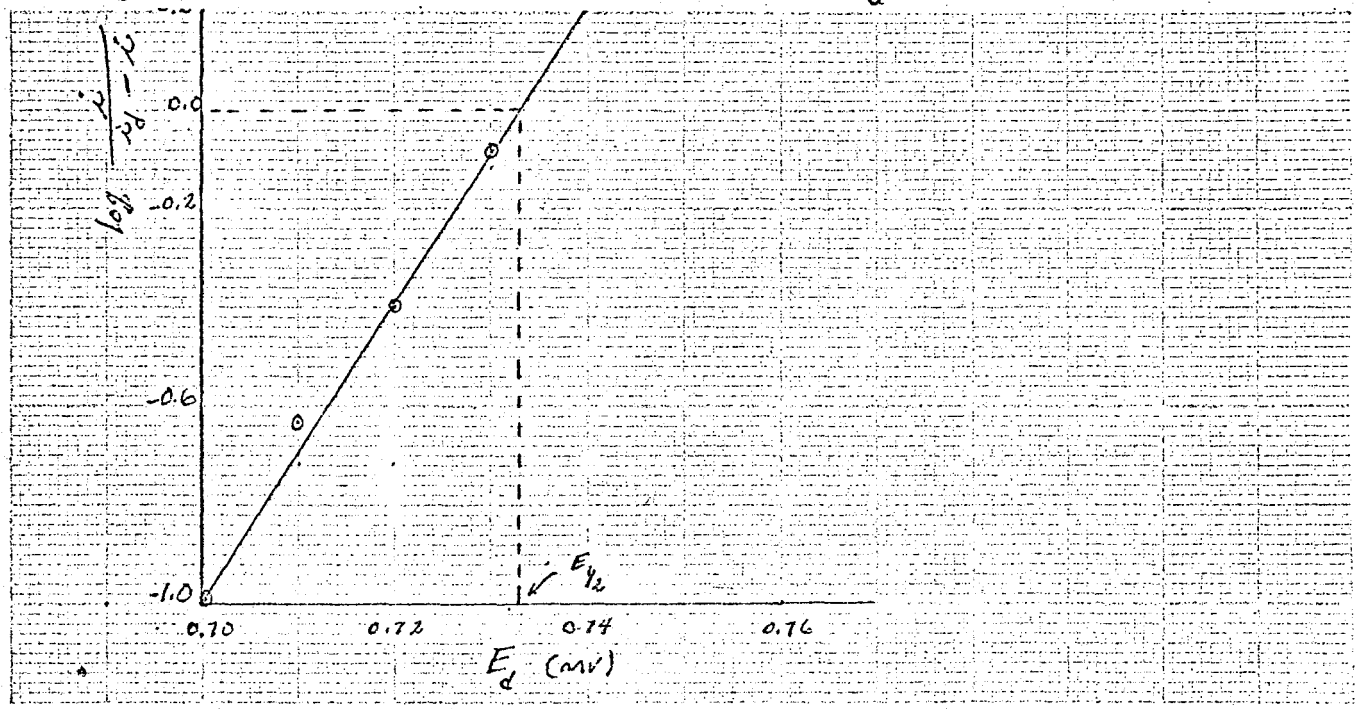
MAXIMUM SUPPRESSOR . . None



Values of i and i_d are taken from the polarogram on the preceding page and converted into workable data as show in the following table.

E_d	$\frac{i}{i_d - i}$	$\log \frac{i}{i_d - i}$
-0.70	2.5/25.5	-1.0086
-0.71	5/23	-0.6627
-0.72	8/20	-0.3979
-0.73	12/16	-0.1249
-0.74	18.5/9.5	0.2895
-0.75	21.5/6.5	0.5195

When a plot of log $i/i_d - i$ vs $E_{d.e.}$ gives a straight line, the reaction is reversible at the dropping electrode, and thus the data from the polarogram can be used. A plot of the data from this polarogram is shown below. $E_{1/2}$ is the potential where the value of i equals $i_d - i$ or at log 1.



$$\text{The slope} = \frac{\Delta \log \frac{i}{i_d - i}}{\Delta E_{d.e}} = \frac{1.5281}{0.05} = 30.5$$

$$\text{then } 30.5 = \frac{n}{0.059}$$

$$n = (30.5)\ (0.059) = 1.8 \text{ or } 2$$

The data used to caculate p, is obtained from figure 3, page 28, the plot of $E_{1/2}$ vs Log C_x (of the amino acid) and plugged into equation (9), page 7

$$\frac{\Delta E_{1/2}}{\Delta \log C_x} = - p \frac{0.0591}{2}$$

$$\frac{0.765 - 0.756}{1.52 - 1.39} = - p\ (0.0296)$$

$$p = 2$$