ester intermediate which probably decomposes uni-molecularly to products.[2k,17-19]

$$\rightarrow \quad R_2C{=}O \ + \ H_3CrO_3{}^+$$
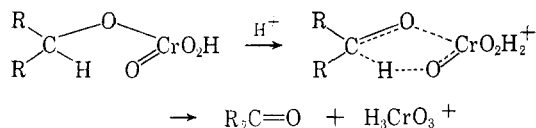
Protonation of the chromate part of the ester increases the electron-attracting properties of the chromium, but the exact mode of electron transfer would depend on the amount of orbital overlap between the developing H–O and the separating O–Cr bonds in the transition state and could well vary with changes in

(17) J. Rocek, F. H. Westheimer, A. Eschenmoser, L. Moldovanyi, and J. Schreiber, *Helv. Chim. Acta*, **45**, 2554 (1962).
(18) R. Stewart, "Oxidation Mechanisms: Applications to Organic Chemistry," W. A. Benjamin, Inc., New York, N. Y., 1963.
(19) R. Stewart and D. G. Lee, *Can. J. Chem.*, **42**, 439 (1964).

the nature of the reactants and the conditions employed.

In light of the results presented in the present paper this mechanism would have to be modified in moderately concentrated acid regions to allow for participation by the conjugate base of the proton source used in the reaction.

$$\rightarrow \quad R_2C{=}O \ + \ H_2CrO_2A^+$$
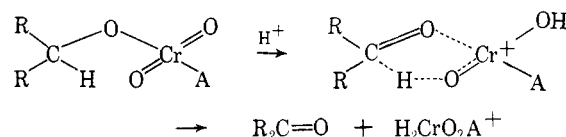
The present results show that the identity of the conjugate base has a profound effect on the rate of reaction.

[Contribution from the Department of Chemistry, University of Arizona, Tucson, Arizona]

Metal Ion Induced Rearrangements of Bisbenzthiazolines to Schiff-Base Chelates

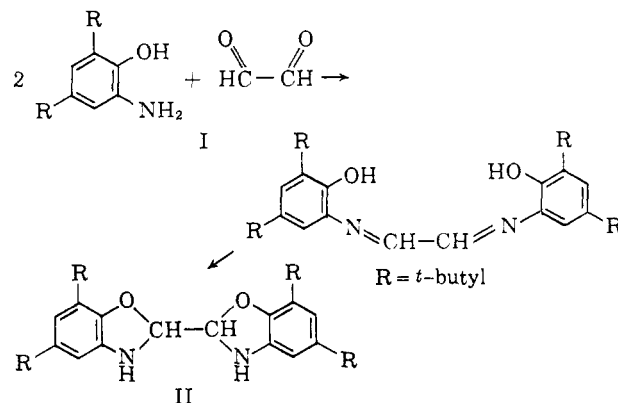By Hans Jadamus, Quintus Fernando, and Henry Freiser

The condensation products of o-aminobenzenethiol with glyoxal, diacetyl, and benzil were prepared and their reactions with zinc(II), cadmium(II), and mercury(II) have been studied. 2,2'-Bisbenzthiazoline and its 2,2'-dimethyl homolog were found to rearrange under the influence of these metal ions to give the corresponding Schiff-base chelates. A kinetic study was carried out to help explain the nature of the reactions.

Schiff bases constitute an important class of polydentate ligands. The direct approach in synthesizing a Schiff base from the condensation of an o-hydroxy-, o-amino-, or o-mercaptoamine with a carbonyl compound often results in the undesirable side reaction involving ring closure with the formation of a heterocyclic compound. The solution to this problem, first used by Schiff in 1869,[2] is to prepare the Schiff base in the form of its metal chelate by reacting the metal complex of one of the starting materials with the other. For example, bissalicylaldehyde–copper(II) reacts with 4-methyl-1,2-phenylenediamine to give the Schiff base chelate. This technique of avoiding the formation of the heterocyclic compound has been widely used by P. Pfeiffer[3] and others.[4]

In some restricted cases, it is possible to isolate the intermediate Schiff base before it is isomerized to the heterocycle, e.g., if a substituent on one of the reactants provides steric hindrance to ring closure. An example is the reaction of 4,6-di-t-butyl-2-aminophenol and glyoxal which gives the intermediate yellow glyoxal bis(2-hydroxy-3,5-di-t-butylanil) (I)[5] as well as the colorless 5,7,5',7'-tetra-t-butyl-2,2'-bisbenzoxazoline (II). As might be expected, this Schiff base forms chelates with a number of metal ions.

Another route to these chelates is to start from a reduced form of the ligand such as N,N'-bis(2-hydroxy-3,5-di-t-butylphenyl)ethylenediamine (III),[6] which is

(1) A preliminary account of this work was received on Sept. 3, 1963.
(2) H. Schiff, *Ann. Chem. Pharm.*, **150**, 193 (1869).
(3) P. Pfeiffer, W. Offermann, and A. Werner, *J. prakt. Chem.*, **159**, 313, (1942).
(4) (a) H. S. Verter and A. E. Frost, *J. Am. Chem. Soc.*, **82**, 85, (1960); (b) M. S. Thompson and D. H. Busch, *ibid.*, **84**, 1962, (1962).
(5) H. Haeussler and H. Jadamus, *Ber.*, in press.

itself a chelating agent, and to oxidize it in the presence of a suitable metal ion to the Schiff base chelate.

III, R = t-butyl
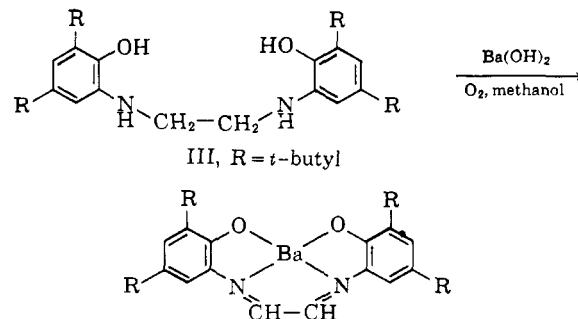
Although most workers have attempted to avoid the formation of the heterocyclic compound, Bayer and Schenk have recently shown that in the presence of

(6) F. Lober and K. Ley. German Patent 1,104,552; *Chem. Abstr.*, **56**, 5887a, (1962).

certain metal ions 2,2'-bisbenzoxazoline rearranges to give the Schiff base chelate quantitatively.[7] The authors, who give experimental evidence for an equilibrium between the oxazoline and the corresponding Schiff base, assume the reaction to take place with the Schiff base present.
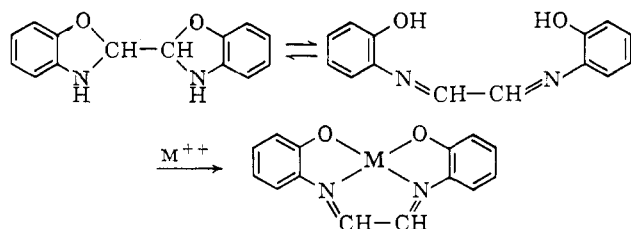
The 2,2'-bisbenzoxazolines are not expected to be the only substances able to undergo a metal ion induced rearrangement. This rearrangement should be possible in any case involving an equilibrium in which a molecule that is not a ligand itself can be reversibly transformed to one which can act as a ligand. Bayer reported the rearrangement of 2,2'-bisbenzthiazoline by mercury(II) salts to the corresponding Schiff base chelate.[8] One would expect the C–S bond rupture to be more difficult than that of a C–O bond. For example, o-aminobenzenethiol reacts with salicylaldehyde to form the benzthiazoline, not the Schiff base as does o-aminophenol. Furthermore, the base-catalyzed ring opening of the 2,2'-bisbenzthiazoline was found to be slower and to occur at a higher pH than that of the corresponding oxazoline.

It was, therefore, surprising to find that mercury(II) salts react practically instantaneously with 2,2'-bisbenzthiazoline, whereas the reaction with 2,2'-bisbenzoxazoline requires prolonged heating. For these reasons, it was decided to carry out a kinetic study of the rearrangement of 2,2'-bisbenzthiazoline by metal ions.

Experimental

2-Hydroxy-2,3-diphenyl-1,4-benzothiazine.—A solution containing 2.1 g. (0.01 mole) of benzil in 20 ml. of methanol was mixed at 50° with 2.5 g. (0.02 mole) of o-aminobenzenethiol when yellow crystals were formed. The resulting mixture was allowed to stand for 1 hr. at room temperature and the crystals were separated by suction, washed with methanol, and dried in air, yielding 3.0 g., m.p. 119–121°. The structure of this hemimercaptal was established by analysis and by its infrared spectrum (O—H stretching frequency at 3200 cm.$^{-1}$, C=N stretching frequency at 1640 cm.$^{-1}$, and no S—H stretching frequency).
Anal. Calcd.: C, 75.69; H, 4.76; N, 4.42; S, 10.10. Found: C, 75.69; H, 4.90; N, 4.25; S, 10.05.

2,2'-Diphenyl-2,2'-bisbenzthiazoline.—A solution containing 2 g. of benzil 2-mercaptoanil in 20 ml. of glacial acetic acid was refluxed for 1 hr. After cooling to room temperature, 10 ml. of water was added in small portions. After the addition of each portion of water, the precipitate that was formed was allowed to separate before addition of the next portion. The colorless crystalline needles that separated were recrystallized from ligroin and dried *in vacuo*, yielding 1.1 g., m.p. 115–116° (lit. m.p. 116–117°).[9]
Anal. Calcd.: C, 73.55; H, 4.75; N, 6.60; S, 15.10. Found: C, 74.00; H, 4.48; N, 6.37; S, 15.27.

2,2' Bisbenzthiazoline.—A 30% aqueous solution weighing 9.7 g. (0.05 mole) of glyoxal was added dropwise to a boiling solution of 18.8 g. (0.15 mole) of o-aminobenzenethiol in 50 ml. of acetonitrile. The mixture was refluxed for 15 min. and allowed

(7) E. Bayer and G. Schenk, *Ber.*, **93**, 1184 (1960).

(8) E. Bayer, *Angew. Chem.*, **73**, 659 (1961).

(9) R. C. Elderfield and E. C. McClenachan, *J. Am. Chem. Soc.*, **82**, 1982 (1960).

to stand overnight at room temperature. The colorless crystalline material that was formed was separated by filtration, washed with methanol, and dried *in vacuo*. The compound was purified by precipitation with methanol from a dioxane solution, yielding 13 g. (decomposes above 160°).
Anal. Calcd.: C, 61.71; H, 4.43; N, 10.29; S, 23.65. Found: C, 62.0; H, 4.0; N, 10.0; S, 27.7.

2,2'-Dimethyl-2,2'-bisbenzthiazoline.—Diacetyl (8.6 g., 0.1 mole) was added dropwise to a boiling solution of 37.5 g. (0.3 mole) of o-aminobenzenethiol in 100 ml. of methanol. The solution was refluxed for 15 min. and allowed to stand overnight. The white crystalline product was filtered by suction, washed with methanol, and dried in air, yielding 28 g. (93%), m.p. after crystallization from dioxane–water 149–150°. The compound cannot be stored for a long period unless it is pure and dry.
Anal. Calcd.: C, 63.96; H, 5.37; N, 9.33; S, 21.35. Found: C, 64.15; H, 5.37; N, 9.37; S, 21.39.

2,2'-Bisbenzthiazole.—An acetone solution containing KMnO₄ (210 mg. in 60 ml.) was added dropwise into a solution containing 272 mg. (0.001 mole) of 2,2'-bisbenzthiazoline in 30 ml. of acetone. A precipitate of MnO₂ was formed immediately. The solvent was allowed to evaporate overnight and the residue treated with 8 M HCl. The insoluble crystals were separated by suction, washed with water and methanol, and dried *in vacuo*, yielding 105 mg., m.p. 298–306°. The infrared and ultraviolet spectra of a sublimed sample were identical with an authentic sample prepared according to a previously described method.[10]

Cadmium(II) Complex of Benzil 2-Mercaptoanil.—To a hot solution containing 951 mg. (0.003 mole) of 2-hydroxy-2,3-diphenyl-1,4-benzothiazine and 267 mg. (0.001 mole) of cadmium acetate dihydrate in 30 ml. of methanol, 10 ml. of a 0.2 M NaOH solution in methanol was added dropwise with stirring. A red crystalline material precipitated. The solution was cooled, the crystals were separated by suction and dried in a drying pistol at 61°, yielding 715 mg. *Anal.* Found: C, 64.45; H, 3.95; N, 3.85.

When the same procedure was used with zinc acetate, no colored metal complex precipitated.

Glyoxal Bis(2-mercaptoanil)cadmium(II).—Ten ml. of a methanol solution containing 267 mg. (0.001 mole) of cadmium acetate dihydrate was added dropwise into 100 ml. of a boiling solution of methanol containing 272 mg. (0.001 mole) of 2,2'-bisbenzthiazoline. Boiling was continued for 15 min., after the addition of the cadmium acetate solution, and the solution was allowed to cool to room temperature. The blue crystalline material that was obtained was separated by suction, washed with methanol, and dried in a drying pistol at 80°, yielding 339 g. The compound decomposes above 290°.
Anal. Calcd.: C, 43.93; H, 2.63; Cd, 29.37; N, 7.32; S, 16.75. Found: C, 43.98; H, 3.03; Cd, 28.47; N, 7.15; S, 16.72.

Glyoxal Bis(2-mercaptoanil)zinc(II).—The above procedure used in the preparation of the cadmium(II) complex was used to prepare the zinc(II) complex. A blue-black compound (205 mg.) was obtained from 220 mg. (0.01 mole) of zinc acetate dihydrate and 272 mg. (0.001 mole) of 2,2'-bisbenzthiazoline.
Anal. Calcd.: C, 50.08; H, 3.00; N, 8.34. Found: C, 50.07; H, 3.28; N, 8.08.

Diacetyl Bis(2-mercaptoanil)cadmium(II).—The above procedure was used to prepare a red cadmium(II) complex (364 mg.) from 267 mg. (0.001 mole) of cadmium acetate dihydrate and 300 mg. (0.001 mole) of 2,2'-dimethyl-2,2'-bisbenzthiazoline.
Anal. Calcd.: C, 46.78; H, 3.44; N, 6.82. Found: C, 46.88; H, 3.80; N, 6.53.

Diacetyl Bis(2-mercaptoanil)zinc(II).—The above procedure was used to prepare a red zinc(II) complex (265 mg.) from 220 mg. (0.001 mole) of zinc acetate dihydrate and 300 mg. (0.001 mole) of 2,2'-dimethyl-2,2'-bisbenzthiazoline.
Anal. Calcd.: C, 52.82; H, 3.88; N, 7.70; S, 17.6. Found: C, 53.00; H, 4.35; N, 7.65; S, 17.44. A summary of the electronic absorption spectra of the reagents and their metal chelates is given in Table I.

Preparation of o-Aminobenzenethiol Chelates of Zn^{II}, Cd^{II}, and Hg^{II}.—Hydrated cadmium acetate (2.67 g., 0.01 mole), 2.20 g. (0.01 mole) of hydrated zinc acetate, and 3.19 g. (0.01 mole) of mercury(II) acetate were each dissolved in 10 ml. of water and 150 ml. of glacial acetic acid at 100°. Into each of these solutions, 3.75 g. (0.03 mole) of o-

(10) A. W. Hoffmann, *Ber.*, **13**, 1223 (1880).

Table I

Absorption Spectra of Reagents
and Their Metal Chelates

Compound	Solvent	λ_{max}, (mμ)	log ϵ_{max}
2,2'-Bisbenzthi- azoline (Va)	Methanol	255 (shoulder)	3.81
		315	3.93
2,2'-Dimethyl-2,2'- bisbenzthiazo- line(Vb)	Methanol	255 (shoulder)	3.89
		317	3.98
Va, Zn^{II} chelate	Pyridine	380	4.12
		590	3.56
Va, Cd^{II} chelate	Pyridine	376	4.10
		575	3.64
Vb, Zn^{II} chelate	Pyridine	350	3.88
		510	3.33
Vb, Cd^{II} chelate	Pyridine	335	3.69
		463	3.31

aminobenzenethiol dissolved in 50 ml. of glacial acetic acid was added with stirring. The chelates crystallized from the hot solutions. Before complete addition of the o-aminobenzenethiol, the mercury(II) solution acquired a transient deep violet color. After cooling to room temperature, the crystals were filtered by suction, washed with methanol, and dried over P_2O_5 in a drying pistol at 60°.

Anal. Calcd. for bis(o-aminobenzenethiol)zinc(II) (colorless crystals, yield 3.08 g.): C, 45.94; H, 3.86; N, 8.98; S, 20.44; Zn, 20.837. Found: C, 46.38; H, 4.11; N, 8.62; S, 18.85; Zn, 22.21.

Anal. Calcd. for bis(o-aminobenzenethiol)cadmium(II) (colorless crystals, yield 3.52 g.): C, 39.95; H, 3.35; Cd, 31.16; N, 7.77; S, 17.78. Found: C, 40.68; H, 3.90; Cd, 30.09; N, 7.86; S, 17.22.

Anal. Calcd. for bis(o-aminobenzenethiol)mercury(II) (yellow crystals, yield 4.10 g.): C, 32.10; H, 2.69; Hg, 44.68; N, 6.24; S, 14.28. Found: C, 32.65; H, 3.03; Hg, 44.03; N, 6.28; S, 13.81. All the above chelates are slightly soluble in dimethylformamide, dimethyl sulfoxide, and pyridine, but insoluble in most other solvents.

Kinetic Experiments. A. Determination of the Order of Reactions of 2,2'-Bisbenzthiazoline.—A freshly prepared 5×10^{-4} M solution of 2,2'-bisbenzthiazolinyl in dimethylformamide (Fisher A.R.) was mixed with an equal volume of a solution of either hydrated zinc acetate (1×10^{-2}, 4×10^{-3}, 1×10^{-3}, 2×10^{-4} M) or hydrated cadmium acetate (1×10^{-3}, 5×10^{-2}, 2×10^{-4}, 1×10^{-4} M). An aliquot was immediately transferred to a 10 cm. cell and its absorbance at 550 mμ was recorded with a Cary Model 14 spectrophotometer against a dimethylformamide blank as a function of time at 23–24°. A similar set of experiments was carried out keeping the metal ion concentration constant but with varying reagent concentration. The initial slopes were used as a measure of the rate of reaction.

B. Determination of the Order of Reactions of 2,2'-Dimethyl-2,2'-bisbenzthiazoline.—A freshly prepared 1×10^{-2} M solution of 2,2'-dimethyl-2,2'-bisbenzthiazoline in dimethylformamide was mixed with an equal volume of a solution of either hydrated zinc acetate (2×10^{-2}, 1×10^{-2}, 4×10^{-3}, 2×10^{-3}, 1×10^{-3}, 4×10^{-4}, 2×10^{-4} M) or hydrated cadmium acetate (2×10^{-3}, 1×10^{-3}, 7.5×10^{-4}, 5×10^{-4} M). An aliquot was immediately transferred to a 1 cm. cell and its absorbance, at 470 mμ for the zinc solution, and at 440 mμ for the cadmium solution, was recorded with a Cary Model 14 spectrophotometer against a dimethylformamide blank as a function of time at 23–24°. A similar set of experiments were carried out keeping the metal ion concentration constant but with varying reagent concentration. As before, the initial slope was used as a measure of the rate of reaction

Results and Discussion

The condensation of glyoxal, diacetyl, or benzil with o-aminobenzenethiol does not give the expected Schiff bases (IV). With glyoxal and diacetyl, the condensation reaction involves two moles of the o-aminobenzenethiol and one mole of the dicarbonyl compound as shown by the analysis of the products. Of the possible structures V and VI, the former has been

shown to be correct, where R = H, by the oxidation of the product, 2,2'-bisbenzthiazoline (Va), to the known compound 2,2'-bisbenzthiazole. Hence, in the reaction with diacetyl, the structure of the product can be represented by Vb. The anionic forms of IV can be produced, however, in solutions of high pH, from Va or Vb. The condensation of o-aminobenzenethiol with benzil under the same reaction conditions involves only one mole of each of the reactants with the formation of the compound, 2-hydroxy-2,3-diphenyl-1,4-benzothiazine (VII), containing an azomethine group, rather than Vc. This compound, too, gives a colored anion in solutions of high pH. The compound rearranges when heated in glacial acetic acid to give the known 2,2'-diphenyl-2,2'-bisbenzthiazoline, (Vc),[9] which unlike Va and Vb does not dissolve in methanolic alkali to give the Schiff base anion.

IV

Va, R = H
b, R = CH$_3$
c, R = C$_6$H$_5$

VIa, R = H
b, R = CH$_3$
c, R = C$_6$H$_5$

VII
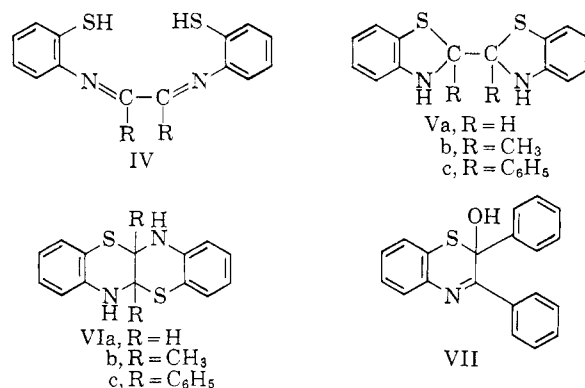
The bisbenzthiazolines Va and Vb reacted similarly with a variety of metal ions in neutral methanolic solutions giving rise to highly colored crystalline metal complexes. It is of interest that the oxazoline analog of Vb does not react with metal ions.[7] The 2,2'-diphenyl compound (Vc) failed to react with any of the metal ions that were tested. Compound VII reacted with cadmium(II) to give a red neutral chelate having a metal ligand ratio of 1:2. Surprisingly, zinc(II) did not react with compound VII.

All of these metal complexation reactions are accompanied by proton loss from the reagents. Undoubtedly the metal complexes are of the Schiff base type, whose formation involved a rearrangement of the heterocyclic reagents. Not only do the analytical data for these complexes correspond to the Schiff base chelates, but they can also be prepared by the stepwise synthesis of the chelate rings as described above.[3] For example, by the reaction of the bis-o-aminobenzenethiol–zinc(II) or –cadmium(II) complex with glyoxal in dimethylformamide solution, one obtains the same metal complex as that with Va.

The utilization of the heterocyclic compound for the synthesis of the metal chelates is superior to the stepwise synthesis for the following reasons. (a) In general, it is more convenient to use a single stable crystalline solid. (b) The intermediate chelates are in some cases so insoluble that only a few solvents can be used in the synthesis of the Schiff base chelates. For example, the bis-o-aminobenzenethiol–zinc(II) or –cadmium(II) chelates react with glyoxal only in dimethylformamide, of the common solvents tested. (c) The final step in the synthesis of the Schiff base chelate does not always occur readily. For instance,

diacetyl does not react to any appreciable extent in dimethylformamide with bis-*o*-aminobenzenethiol-zinc-(II) or -cadmium(II) to give the Schiff base chelate.

The manner in which the Schiff base metal chelate is formed from the heterocyclic reagent can be explained in one of three ways. (a) If an equilibrium exists between the heterocycle and the Schiff base, the formation of a stable metal complex could occur with the latter. (b) If an equilibrium exists between the heterocycle and the two starting materials, these could react with the metal ion in a stepwise manner to give the Schiff base chelate. (c) The metal ion can react directly with the heterocycle inducing a rearrangement which can result in the final product.
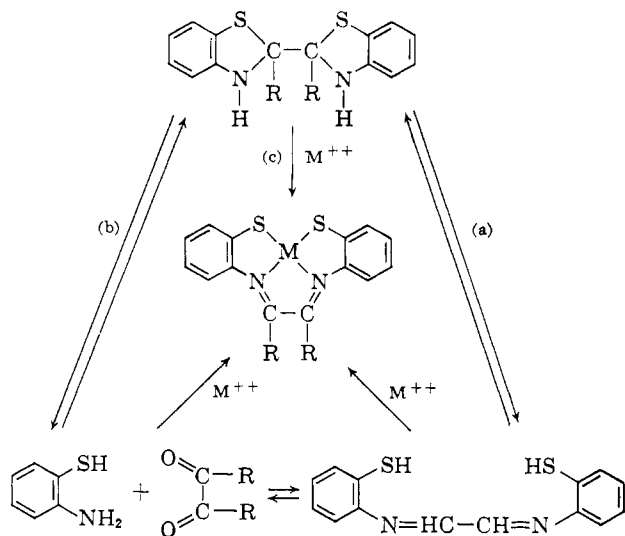
Since these chelates form instantaneously from the Schiff base anion and the metal ion, it follows that the rate-determining step in a is the rearrangement of the heterocycle to the Schiff base and therefore the rate of formation of the chelate would be first order with respect to the reagent and zero order with respect to the metal ion concentration. With mechanism b only small amounts of the uncombined starting materials would be present at any time, so that effectively there will be a high metal:*o*-aminobenzenethiol ratio.

This would result in the formation of a 1:1 metal:*o*-aminobenzenethiol intermediate chelate rather than a 1:2 chelate which is a prerequisite for the formation of the Schiff base chelate. The rate of formation of the Schiff base chelate would therefore be expected to decrease with increasing metal ion concentration. With mechanism c, the rate of chelate formation would be expected to be first order with respect to both metal ion and reagent concentrations.

The order of the chelate formation reaction of Va and Vb with zinc(II) and cadmium(II) was determined spectrophotometrically in dimethylformamide solution by observing the initial rate of reaction at different metal ion and reagent concentrations.

The reaction of cadmium(II) with reagents Va and Vb is first order with respect to both metal and reagent indicating that cadmium reacts according to mechanism c. The reaction of zinc(II) with Va on the other hand is zero order in metal ion, but first order with respect to reagent, conforming to the requirements of mechanism a. The reaction of zinc(II) with Vb resembles the previously described reactions in that it is first order with respect to the reagent, but differs in having a fractional order (0.35) with respect to the metal ion. It seems reasonable to explain the difference between the behavior of cadmium(II) and zinc(II) by assuming that the reaction of cadmium(II) with the heterocycle proceeds at a rate that is faster than the tautomeric reaction, whereas that with zinc(II) is slower. From a qualitative observation of the rate of reaction of these reagents with mercury(II), one notes the following trend of decreasing reactivity: Hg^{II}, Cd^{II}, Zn^{II}. This parallels the stability of the complexes of these metal ions with sulfur-containing ligands. Possibly the reaction of zinc(II) with Vb involves simultaneous contribution from pathways a and c. In none of these examples then was the stepwise formation mechanism b consistent with experimental results. In this connection it was observed that although the reactions of the bis-*o*-aminobenzenethiol–cadmium(II) and –zinc(II) complexes with glyoxal did give the Schiff base chelates, the intermediate chelates failed to react with diacetyl.