for the benzimidazoles probably would be in the range of 0.4.

This unusual decrease in the stabilities with the benzimidazoles has not been exhibited in the study with cadmium. Since cadmium forms tetrahedral complexes, the steric effects would be at a minimum.

Nozaki[7] has studied the stereochemistry of the copper(II) complexes of imidazole and 4-methylimidazole. He concluded that the 4-coördinated complexes could not have a coplanar structure because of the marked overlapping of the van der Waals radii of the hydrogen atoms on adjacent imidazole molecules. Presumably, some or all the imidazole molecules must rotate around the Cu-N bond to give a puckered complex. This same type of reasoning could be applied to the present study with copper(II) and benzimidazole. Fisher–Taylor–Hirschfelder models show that the copper(II) complex could not exist in a coplanar form by any reasonable change in dimensions. The structure which gives the least steric interference would be the one which has two adjacent benzene rings of the benzimidazole molecules orientated down with the other two benzene rings orientated upwards. Figure 1 shows the two types of orientation of the benzimidazole molecules.

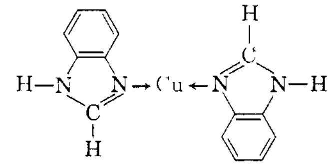

Fig. 1.—Orientation of the benzene molecule in the copper(II) complex.

The study of the stability constants of the 2-hydroxymethylbenzimidazole and 1-methyl-2-hydroxymethylbenzimidazole showed conclusively which of the two nitrogen atoms in the benzimidazole is coördinating. Basolo[17] has shown that a methyl group on the nitrogen atom of ethylenediamine decreases the stability of the complex even though the basicity of the chelating agent was increased. Results of the present study showed an increase in basicity and in chelate stability when the hydrogen atom in the 1-position of 2-hydroxymethylbenzimidazole is replaced by a methyl group. If coördination takes place through the nitrogen to which the methyl group is attached, a decrease in stability would be expected.

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[CONTRIBUTION FROM THE DEPARTMENT OF CHEMISTRY, UNIVERSITY OF NOTRE DAME]

Stability Constants of Various Metal Ions with the 2-Hydroxymethylnaphthimidazoles[1]

BY THOMAS J. LANE, C.S.C., AND KENNETH P. QUINLAN[2]

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The acid dissociation constants of 2-hydroxymethylnaphth[1,2]imidazole and 2-hydroxymethylnaphth[2,3]imidazole and the stability constants of their chelates with various metal ions have been determined in 50% aqueous dioxane by the potentiometric titration method. The preparations of the 2-hydroxymethylnaphthimidazoles by the Phillips method[3] are described. The 2-hydroxymethylnaphth[2,3]imidazole chelates of the divalent metal ions are more stable than the **1,2** isomer chelates. The difference is explained by the steric hindrance of the neighboring hydrogen atoms.

Introduction

In the preceding paper,[4] it was established that the chelation sites are the unsaturated nitrogen atom and the oxygen atom of the 2-hydroxymethylbenzimidazoles. As an extension of this work two compounds, Fig. 1, were chosen to show the steric effects of the ring system attached to the imidazole ring.

Experimental

Materials.—The dioxane was purified according to the method described by Vogel.[5] It was kept over sodium and distilled as needed.

Stock solutions of the metallic ions were prepared by dissolving the corresponding reagent grade perchlorates (G. Frederick Smith Co.) in water to approximately 0.01 *M*. In the case of lanthanum and cadmium, the nitrates (E. H. Sargent and Co.) were used. The metal ion stock solutions were standardized by the accepted methods of analysis.

Fisher reagent 0.1 *N* sodium hydroxide was standardized against Merck reagent grade potassium hydrogen phthalate. The 0.01 *N* perchloric acid was prepared from the Fisher 70% reagent grade acid. The perchloric acid was standardized against the sodium hydroxide.

2-Hydroxymethylnaphth[1,2]imidazole was originally prepared by Malmberg and Hamilton[6] by a fusion method. A modified procedure of the Phillips[3] method was used by us to prepare the compound. A mixture of 1,2-diaminonaphthalene (7.2 g., 0.043 mole), glycolic acid (3.6 g., 0.048 mole) and 185 ml. of 4 *N* hydrochloric acid was refluxed for 6 hr. A red-colored product was filtered from the cooled solution and dissolved in water. The 2-hydroxymethylnaphth[1,2]-imidazole precipitated from the aqueous solution on the addition of sodium carbonate. The imidazole was washed free of the excess 1,2-diaminonaphthalene with a small quantity of acetone. After decolorization with charcoal and three recrystallizations from dioxane, the product was dried at 132° under vacuum for 3 hr. The pure product melted at 253-255° (dec.). The yield was 40%. This

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[1] Presented before the Division of Physical Chemistry at the 134th National Meeting of the American Chemical Society, Chicago, Ill., Sept., 1958.

[2] Abstracted from a thesis presented by Kenneth P. Quinlan in partial fulfillment of the requirements for the Degree of Doctor of Philosophy.

[3] M. A. Phillips, *J. Chem. Soc.*, 2820 (1929).

[4] T. J. Lane and K. P. Quinlan, THIS JOURNAL, **82**, 2994 (1960).

[5] A. I. Vogel, "Practical Organic Chemistry," Longmans, Green and Co., New York, N. Y., 1948, p. 195.

[6] E. Malmberg and C. Hamilton, THIS JOURNAL, **70**, 2415 (1948).

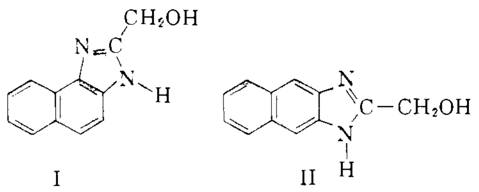

Fig. 1.—I, 2-Hydroxynaphth[1,2]imidazole; II, 2-hydroxymethylnaphth[2,3]imidazole.

material was identical (m.p., m.m.p., and infrared spectrum) with that prepared by Malmberg and Hamilton.[6]

Anal. Calcd. for $C_{12}H_{10}ON_2$: C, 72.71; H, 5.09; N, 14.14. Found: C, 72.74; H, 5.23; C, 14.31.

In preparing 2-hydroxymethylnaphth[2,3]imidazole, a solution of 2,3-diaminonaphthalene (7.2 g., 0.043 mole) in 100 ml. of 4 *N* hydrochloric acid was treated with glycolic acid (3.6 g., 0.048 mole). The mixture was refluxed for 5 hr. The solution was cooled and the solid hydrochloride salt of 2-hydroxymethylnaphth[2,3]imidazole was removed by filtration. The free amine was obtained by the addition of a 50% aqueous ethanol solution, which was about 5% in potassium hydroxide. After decolorizing with charcoal and recrystallizing twice from 50% aqueous alcohol, the free amine was dried at 132° under vacuum for 3 hr. The pure 2-hydroxymethylnaphth[2,3]imidazole decomposed at 224°. The yield was 47%.

Anal. Calcd. for $C_{12}H_{10}ON_2$: C, 72.71; H, 5.09; N, 14.14. Found: C, 72.64; H, 5.24; N, 14.30.

The copper chelate of 2-hydroxymethylnaphth[2,3]imidazole was prepared from an aqueous solution containing 1 g. of copper(II) perchlorate to which was added a 2% alcoholic solution of 2-hydroxymethylnaphth[2,3]imidazole. The solution was made basic by the dropwise addition of ammonium hydroxide. A light green solid was precipitated, filtered and washed with alcohol. The solid was dried at 132° under vacuum for 3 hr. The copper analysis of the chelate indicated a 1:1 ratio of ligand to copper ion.

Anal. Calcd. for $C_{12}H_{12}O_3N_2Cu$: Cu, 20.6. Found: Cu, 20.8.

Apparatus and Procedure.—The titration apparatus and procedure are essentially the same as that described by Walter, Ryan and Lane.[7]

All *p*H determinations were carried out using a Beckman Model G *p*H meter, provided with a glass (Beckman 1190-80)-saturated calomel electrode pair. The performance of the *p*H meter was checked with Beckman buffer solutions (*p*H 4, 7, 10).

The volume correction for 50% aqueous dioxane solution was 0.98. A value of 0.07 was added to all *p*H measurements[8] made at 25°.

Calculations of Stability Constants.—The degree of formation, $\bar{n}$, and the free ligand concentration, R^-, were calculated by the equations derived by Freiser, Charles and Johnston.[9]

$$\bar{n} = \frac{1}{T_M}\left[T_{HR} - S\left(\frac{K_{NH} + H^+}{K_{NH} + 2H^+}\right)\right]$$

$$R^- = \frac{S \times K_{NH} \times K_{OH}}{[H^+](K_{NH} + [2H^+])}$$

where $S = T_{HR} + A - [Na^+] + [OH^-] - [H^+]$
A = concn. acid added
T_{HR} = total concn. ligand
T_M = total concn. metal ion
K_{NH} and K_{OH} = acid dissociation constants of the protonated nitrogen and the hydroxyl group, respectively

Stability constants were obtained by applying the values of $\bar{n}$ and R^- to the graphical method of Rossotti and Rossotti.[10] This method is particularly useful when the data are obtained over a limited range, *e.g.*, hydrolysis of certain metals occurring at low $\bar{n}$ values. Since the formation of only one complex was evident in this study, the equation of Rossotti and Rossotti[10] was used.

$$\log \frac{\bar{n}}{1 - \bar{n}} = \log K_1 + \log [R^-]$$

Results

The acid dissociation constants for the two isomeric ligands are presented in Table I. A summary of the formation constants of the metal complexes obtained in 50% aqueous dioxane at 25° ± 0.1° appears in Table II.

TABLE I

ACID DISSOCIATION CONSTANTS OF 2-HYDROXYMETHYLNAPHTH[1,2]IMIDAZOLE AND THE 2,3 ISOMER IN 50% BY VOLUME DIOXANE AT 25° ± 1°

	pK_{NH}	pK_{OH}
2-Hydroxymethylnaphth[1,2]-imidazole	4.44 ± 0.02	12.23
2-Hydroxymethylnaphth[2,3]-imidazole	4.50 ± 0.02	12.30

TABLE II

CHELATE FORMATION CONSTANTS FOR VARIOUS METAL IONS WITH 2-HYDROXYMETHYLNAPHTH[1,2]IMIDAZOLE AND THE 2,3 ISOMER IN 50% BY VOLUME DIOXANE AT 25 ± 0.1°

Metal	2,3 Isomer log k_1	1,2 Isomer log k_1
Cu(II)	9.70	8.94
Ni(II)	6.89	[b]
Co(II)	8.98	5.63
Mn(II)	7.05	[b]
Cd(II)	[b]	[c]
Zn(II)	6.81	[b]
Pb(II)	[b]	[c]
Mg(II)	[a]	[c]
La(III)	7.21	7.70

[a] No coördination before hydrolysis. [b] No values higher than $\bar{n}$ = 0.20 were obtained. [c] Not run.

Freiser[9] has pointed out that *p*H values at which metal ions begin to hydrolyze set an approximate upper limit for the calculation of formation constants. In this study no $\bar{n}$ values were calculated beyond the point where the particular metal ion began to hydrolyze. As seen in Table II, log K_1 values are given for the 1,2 isomer with Cu(II), Co(II) and La(III). Since log K_1 values could not be obtained with Ni(II), Mn(II) and Zn(II) with the 1,2 isomer, these are less stable than those with the 2,3 isomer.

A ligand to metal ratio of 8:1 was used in the titrations. On varying the concentration of copper it was found that no polynuclear complexes were present at the concentration range under study. Duplicates were run with Cu(II) and La(III) with the ligands and the log K_1 values did not differ by more than 0.05 unit.

Formation function curves were drawn in a number of cases. The copper(II) formation curve with the 2-hydroxymethylnaphthimidazoles was symmetrical at $\bar{n}$ = 0.5 and when $\bar{n}$ was approaching a limiting value of 1, precipitation occurred. When the copper complex of 2-hydroxymethylnaphth[2,3]imidazole was prepared the expected 1:1 complex was obtained. The leveling effect at

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(7) J. L. Walter, J. A. Ryan and T. J. Lane, THIS JOURNAL, **78**, 5560 (1956).

(8) L. Van Uitert and C. G. Haas, *ibid.*, **75**, 451 (1953).

(9) H. Freiser, R. G. Charles and W. D. Johnston, *ibid.*, **74**, 1383 (1952).

(10) F. J. C. Rossotti and H. S. Rossotti, *Acta Chem. Scand.*, **9**, 1166 (1955).

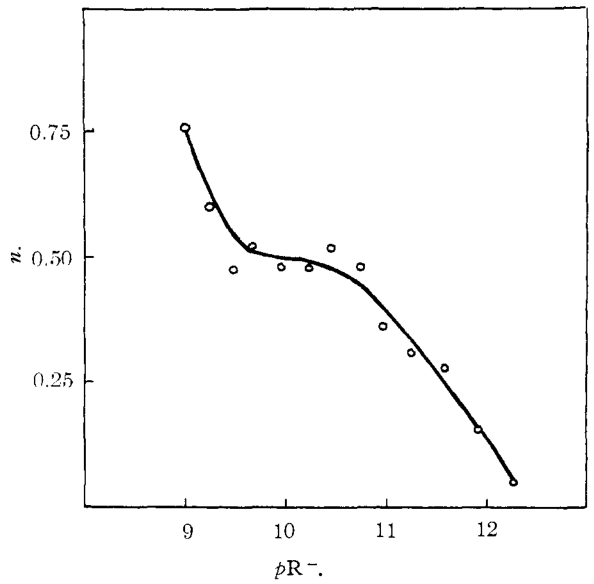

Fig. 2.—Formation curve for 2-hydroxymethylnaphth[2,3]-imidazole with copper(II) ion.

$\bar{n} = 0.5$ (Fig. 2) may be due to the formation of $\text{Cu}_2\text{R}^{+++}$ complex in solution.

Discussion

The small differences in the basicities of the two isomers may be explained by a higher inductive effect acting on the nitrogen attached to the 1-carbon atom of the naphthalene ring system. Jaffe[11] has shown by electron calculations that the carbon atoms in the 9- and 10-positions of naphthalene have an inductive effect on the other positions. This inductive effect acts more strongly on the 1- than on the 2-position. The electron density of the imidazole ring attached to the 1- and 2-positions is therefore less than if it were attached to the 2- and 3-positions. Consequently, the 1,2 isomer is a weaker base. The pK_{OH} of the isomers shows that the acid dissociation constants of the 2-hydroxymethyl groups are approximately the same. No significance can be applied to the difference in these pK values since they were obtained at a high pH range.

Since the acid dissociation constants of the two ligands are found to be about equal, one would expect that the stabilities of the chelates formed would be the same provided no steric effects took place. The data (Table II) show that the 2,3 isomer forms more stable complexes with the divalent metals than the 1,2 isomer. The 1,2 isomer can exist in two possible configurations (Fig. 3) involving either the unsaturated nitrogen attached to the 1-carbon atom of the naphthalene ring or when it is bonded to the 2-carbon atom. Molecular models of these two configurations show that the hydrogen on the 8-carbon atom sterically interferes with chelation if the unsaturated nitrogen is attached to the carbon atom in the 1-position. If this nitrogen in the 1,2 isomer were attached to the carbon atom in the 2-position, the formation constants would be the same as the 2,3 isomer. Since the formation constants of the 1,2 isomer are lower than those of the 2,3 isomer, it is concluded that the hydrogen atom in 8-position interferes sterically with chelation in this ligand.

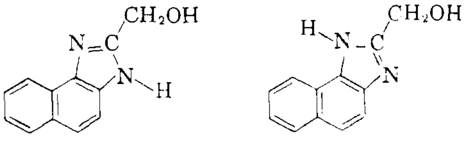

FIG. 3.—Two configurations of 2-hydroxymethylnaphth-[1,2]imidazole.

The 1,2 isomer probably exists in the form in which the unsaturated nitrogen is attached to the carbon atom in the 1-position. Jaffe[11] has shown that this atom has a greater electron density than the carbon atom in the 2-position. To satisfy its greater electrophilic character, the nitrogen with the greater electron density would be bonded to the carbon atom in the 1-position.

The 2,3-isomer could exist as a tautomeric system.

As seen in Table II, the normal metal stability sequence Cu(II) > Ni(II) > Co(II) > Zn(II) > Mn(II)[12] has been violated in that the nickel chelate is less stable than the cobalt chelate and has approximately the same stability as that of the zinc chelate in the case of the 2,3 isomer. This violation has been observed in a number of other cases[13–15] where the reagents have a substituent group on the carbon, alpha to the heterocyclic nitrogen, *e.g.*, 2-(*o*-hydroxyphenyl)-benzimidazole, 2-methyl-8-hydroxyquinoline, etc. This violation would be expected in the present study because of the similarity of structures between benzimidazoles and naphthimidazoles. However, it is difficult to understand the high stability of the Mn(II) chelate.

Greater double bond character in chelate rings enhances the stability of chelates. It is interesting to note that the greater double bond character of the metal chelate ring, formed with the 1,2 isomer, is not great enough to offset the steric effects of the hydrogen atoms.

La(III) is unusual as it shows greater stability with the 1,2 isomer. It is possible that the size of La(III) with its greater charge is better suited for the 1,2 isomer.

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[15] W. D. Johnston and H. Freiser, *ibid.*, **11**, 301 (1954).