Scientific paper

Estimation of Stability Constants of Mixed Copper(II) Chelates Using Valence Connectivity Index of the 3rd Order Derived from Two Molecular Graph Representations

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Abstract

Valence connectivity index ${}^3\chi^v$ was correlated to the log K_1(L) of copper(II) complexes with diethylenetriamines (CuL, $N = 8$), and to logarithm of the second, log K_2(L) and log K_2(A), and overall stability constant, log β_2, of copper(II) mixed complexes (CuLA, $N = 18$) with diethylenetriamines and amino acids. Regression on log K_1(L) strongly indicates that influence of alkylation at middle nitrogen atom differs from the influence of alkylation at terminal nitrogens. Thereby, in models for estimation of all stability constants we introduced an indicator variable, *In*; *In* = 1 for a complex with triamine alkylated at the middle nitrogen, otherwise *In* = 0. Also, we developed second set of models assuming there is no bonding between Cu(II) and middle N atom. Both approaches gave nearly the same standard error of estimate, *i.e.* 0.3 for log K_1(L) and log K_2(A), and 0.5 for log K_2(L) and log β_2.

Keywords: Diethylenetriamines, amino acids, mixed complexes, indicator variable

1. Introduction

The application of topological indices, particularly valence connectivity index ${}^3\chi^v$, for estimation of the stability constants is a new approach despite the fact that topological indices are omnipresent in modeling of various physicochemical properties (QSPR), like boiling point, density, viscosity, molar heat capacity, solubility and chromatography-related properties.[1–6] Also, they are used for modeling of biological activities and drug design (QSAR),[7–11] and for description of conjugated systems.[12,13]

In our previous papers we applied topological indices for calculation of stability constants of *mono*-, *bis*-, and mixed complexes of copper(II) and nickel(II) with aliphatic diamines, triamines, amino acids along with their derivatives, dipeptides and oligopeptides.[14–23] Among the variety of topological indices,[24] interpreted in various ways,[25–30] the valence connectivity index of the 3rd order (${}^3\chi^v$)[31,32] proved best.[15,17] Despite the conceptual as well as computational simplicity of our method, the results obtained were in no way of lesser quality than these yielded by more demanding OS method.[17,18] Moreover, the method based on ${}^3\chi^v$ index proved to be capable of estimating stability constants of one class of compounds from the constants of other classes, like estimation of the constants of diamine chelates from the constants of triamine complexes and vice versa,[18] and stability constants of the fructose–amino acid chelates from the constants of complexes with amino acids.[19]

An important methodological difference between QSPR of organic and inorganic compounds (*i.e.* chelates) is that organic compounds were usually treated by varying the type of topological index, in contrast to varying the graph (*i.e.* constitutional formula) of chelates, which is not so well defined. Thus, regressions could be done on the formula of the ligand, aquated and non-aquated complex, and also on the formula of a complex with additional bond ("secondary valence") between side chain and the central atom.[17]

Previously,[18] we estimate stability constants K_1(L) and β_2 of copper(II) mixed complexes with diethylenetria-

mines (Table 1) and amino acids. Stability constant K_1(L) is equilibrium constant of reaction:[33]

$$Cu^{2+} + L \overset{K_1(L)}{\rightleftarrows} CuL^{2+} \quad (1)$$

and K_2(A) is equilibrium constant of reaction:[34]

$$CuL^{2+} + A^- \overset{K_2(A)}{\rightleftarrows} CuLA^+ \quad (2)$$

while the overall stability constant, β_2, of the complex $CuLA^+$ is product of those two constants:

$$\beta_2 = K_1(L)K_2(A) \quad (3)$$

In this report we present improved models for estimation of log K_1(L) and log β_2, along with models for estimation of log K_2(L) and log K_2(A), which are estimated here for the first time. K_2(L) is the equilibrium constant of reaction:

$$CuA^+ + L \overset{K_2(L)}{\rightleftarrows} CuLA^+ \quad (4)$$

2. Methods

2. 1. Calculation of Topological Indices

Topological indices were calculated with a program system DRAGON 2.1, written by Todeschini and coworkers,[35] which is capable of yielding 262 topological indices in a single run, along with many other molecular descriptors. The connectivity matrix[36] was constructed with the aid of *Online SMILES Translator and Structure File Generator*.[37]

All calculations were carried out with the connectivity index ${}^3\chi^v$ (the valence molecular connectivity index of the 3rd order):[31,32,38–41]

$${}^3\chi^v = \sum_{\text{path}} [\delta(i)\delta(j)\delta(k)\delta(l)]^{-0.5} \quad (5)$$

where $\delta(i)$, $\delta(j)$, $\delta(k)$, and $\delta(l)$ are weights (valence values) of vertices (atoms) i, j, k, and l making up the path of length 3 (three consecutive chemical bonds) in a vertex-weighted molecular graph. Valence value, $\delta(i)$, of a vertex i is defined by:

$$\delta(i) = [Z^v(i) - H(i)]/[Z(i) - Z^v(i) - 1] \quad (6)$$

Table 1. Experimental values of stability constants (log K_1, log K_2 and log β_2) of copper(II) mixed complexes with diethylenetriamines (N = 8) and amino acids (N = 3).

Amino acid (A)	Triamine (L)	log K_1(A)[a]	log K_1(L)[a]	log K_2(A)[a]	log K_2(L)[b]	log $\hat{a}_2$[b]
Glycine	dien (**1**)	8.22	15.91	4.42	12.11	20.33
	1-(Me)dien (**2**)	8.22	15.32	4.65	11.75	19.97
	1,4-$(Me)_2$dien (**3**)	8.22	15.11	4.68	11.57	19.79
	1,1-$(Me)_2$dien (**4**)	8.22	14.33	4.38	10.49	18.71
	1,1,4,7,7-$(Me)_5$dien (**5**)	8.22	12.16	5.04*	8.98*	17.20*
	1,1-$(Et)_2$dien (**6**)	8.22	13.17	4.16	9.11	17.33
	1,4,7-$(Et)_3$dien (**7**)	8.22	13.17	4.25	9.20	17.42
	1,1,7,7-$(Et)_4$dien (**8**)	8.22	10.43			
Valine	dien (**1**)	8.05		3.79	11.65	19.70
	1-(Me)dien (**2**)	8.05		3.99	11.26	19.31
	1,4-$(Me)_2$dien (**3**)	8.05		4.22	11.28	19.33
	1,1-$(Me)_2$dien (**4**)	8.05		3.96	10.24	18.29
	1,1,4,7,7-$(Me)_5$dien (**5**)	8.05		4.79*	8.90*	16.95*
	1,1-$(Et)_2$dien (**6**)	8.05		3.46	8.58	16.63
	1,4,7-$(Et)_3$dien (**7**)	8.05		3.84	8.96	17.01
	1,1,7,7-$(Et)_4$dien (**8**)	8.05				
Sarcosine	dien (**1**)	7.85		3.98	12.04	19.89
	1-(Me)dien (**2**)	7.85		3.98	11.45	19.30
	1,4-$(Me)_2$dien (**3**)	7.85		3.79	11.05	18.90
	1,1-$(Me)_2$dien (**4**)	7.85		3.10	9.58	17.43
	1,1,4,7,7-$(Me)_5$dien (**5**)	7.85		3.23	7.54	15.39
	1,1-$(Et)_2$dien (**6**)	7.85		3.05	8.37	16.22
	1,4,7-$(Et)_3$dien (**7**)	7.85				
	1,1,7,7-$(Et)_4$dien (**8**)	7.85				

[a] Measured: log K_1(L)[33], log K_1(A)[43,44,45] and log K_2(A).[34]

[b] Calculated: log K_2(L) = log β_2 – log K_1(A); log β_2 = log K_1(L) + log K_2(A).

* Values of doubtful quality, not included in regressions.

where $Z^v(i)$ is the number of valence electrons belonging to the atom corresponding to vertex i, $Z(i)$ is its atomic number, and $H(i)$ is the number of hydrogen atoms attached to it. For instance, δ values for primary, secondary, tertiary, and quaternary carbon atoms are 1, 2, 3, and 4, respectively; for oxygen in OH group it is 5, and for NH_2 group $\delta(N) = 3$. It has to be pointed out that $^3\chi^v$ is only a member of the family of valence connectivity indices, $^n\chi^v$, which differ in the path length, *i.e.* in the number of δs in the summation term, Eq. 5.

2. 2. Graph Representations

Valence connectivity index $^3\chi^v$ used in all models was calculated from the graph representations of *diaqua*, CuL and CuA, complexes (Table 2). *Diaqua* representations are from the point od chemical intuition most realistic, and also enable the best estimates of stability constants.[17]

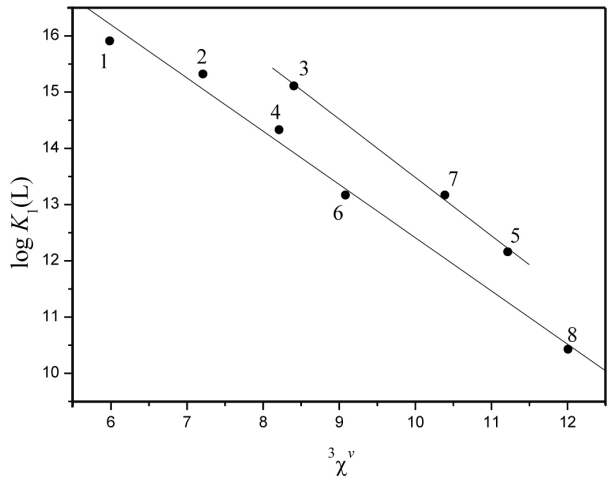

Figure 1. Plot of log K_1 *vs.* $^3\chi^v$ for copper(II) complexes with diethylenetriamines (**1–8**, Table 1), Representation I, which indicates two subsets of complexes. Regression lines on those two subsets are nearly paralel and call for using the indicator variable, *In*.

Table 2. Values of valence connectivity indices, $^3\chi^v$, and indicator variable, *In*, for copper(II) chelates with diethylenetriamines (CuL) and amino acids (CuA).

Ligand	$^3\chi^v$ (CuL) Representation I	$^3\chi^v$ (CuL) Representation II	$^3\chi^v$ (CuA)	*In*
Gly			1.818	
Val			2.671	
Ser			2.699	
dien (**1**)	5.984	2.961		0
1-(Me)dien (**2**)	7.21	3.978		0
1,4-$(Me)_2$dien (**3**)	8.405	4.359		1
1,1-$(Me)_2$dien (**4**)	8.21	4.802		0
1,1,4,7,7-$(Me)_5$dien (**5**)	11.215	6.77		1
1,1-$(Et)_2$dien (**6**)	9.083	5.838		0
1,4,7-$(Et)_3$dien (**7**)	10.389	6.295		1
1,1,7,7-$(Et)_4$dien (**8**)	12.007	8.541		0

2. 3. Regression Calculations

Regression calculations, including the leave-one-out (LOO) procedure of cross validation, *cv*, were done using the CROMRsel program.[42] The standard error of cross validation estimate is defined as:

$$S.E._{cv} = \sqrt{\sum_i \frac{\Delta X_i^{\,2}}{N}} \qquad (7)$$

where ΔX and N denotes *cv* residuals and number of reference points, respectively.

3. Results

3. 1. Models with Indicator Variable

Plot of log K_1 *vs.* $^3\chi^v$ (Figure 1) indicates two subsets of the diethylenetriamine complexes. The subsets differ with respect to alkylation at the middle nitrogen (Figure 2). This is in accordance with the finding of Allison and Angelici[33] who concluded that the alkylation at the middle nitrogen does not affect the magnitude of K_1. Furthermore, the protonation constant of the middle nitrogen is several orders of magnitude lower than the protonation constants of terminal nitrogens.[33]

To differentiate two subsets we introduced an indicator variable (*In* = 1, for triamine complexes alkylated at middle nitrogen, *In* = 0 for complexes not substituted at middle nitrogen) into the regression (Model 2, Table 3). Despite the small number of points in this regression (8 points, 2 descriptors) this resulted in much better $S.E._{cv}$, 0.30, in contrast to the model without indicator variable (Model 1), $S.E._{cv} = 0.74$. In favour of good statistics also speaks the fact that regression parameters of Model 2 are within the limits of reliability of Model 1, and that $S.E._{cv}/S.E.$ for Model 2 (1.58) is not substantially higher than the same ratio for other regressions in Table 3 (1.22–1.42).

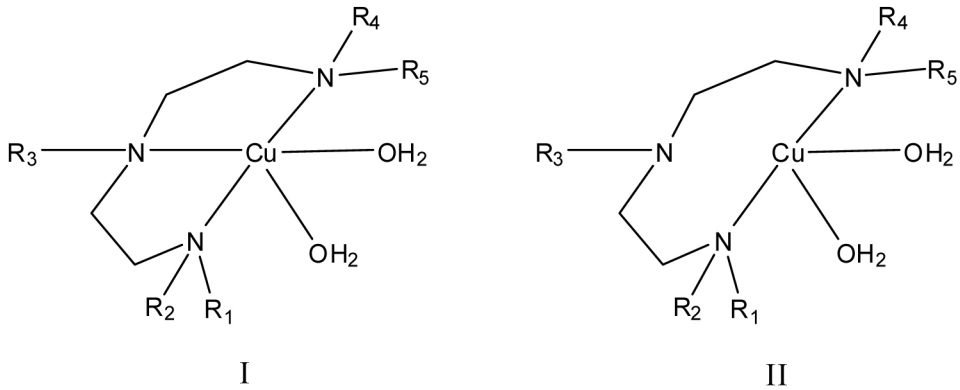

Figure 2. Two molecular graph representations of copper(II) complexes with diethylenetriamines (**1–8**, Table 1)

Table 3. Linear regression models for the estimation of log K_1, log K_2 and log β_2 of copper(II) mixed complexes with diethylenetriamines (1-8) and three amino acids (Table 1) using Representation I (Figure 2) for calculation of $^3\chi^v$ index.

Model	*N*	Dependent variable	Intercept (*S.E.*)	$^3\chi^v$ (CuL) Slope(*S.E.*)	$^3\chi^v$ (CuA) Slope(*S.E.*)	*In* Slope(*S.E.*)	*r*	*S.E.*	$S.E._{cv}$
1	8	log K_1(L)	21.5(10)	–0.86(11)			0.952	0.52	0.74
2	8	log K_1(L)	22.00(41)	–0.962(47)		1.09(18)	0.994	0.19	0.30
3	18	log K_2(L)	20.36(82)	–1.115(81)	–0.55(23)	1.51(25)	0.968	0.35	0.44
4	18	log K_2(A)	7.36(53)	–0.192(52)	–0.83(15)	0.46(16)	0.877	0.23	0.28
5	18	log β_2	29.16(87)	–1.118(85)	–0.85(24)	1.52(27)	0.966	0.37	0.47

For estimation of the second, log K_2(L) and log K_2(A), and overall stability constant, log β_2, we also used models with indicator variable. These models yielded much better statistics than the previous models without indicator variable.[18] For instance, the model for estimation of log K_2(L) without indicator variable has r = 0.880, $S.E._{cv}$ = 0.76 and maximal cross-validated error 1.33. Analogous model with the indicator variable (Model 3, Table 3) has substantially better statistical parameters, and maximal *cv* error of 0.83.

The regressions 3–5 (Table 3) were carried out on data for 18 mixed complexes. Namely, complexes Cu(1,1,4,7,7–(Me)$_5$dien)(Gly)$^+$ and Cu(1,1,4,7,7–(Me)$_5$dien)(Val)$^+$ were found to undergo unusual color change during the titration,[34] indicating the formation of another kind of complexes. Thus, their log K_2 and log β_2 values were not included in the regressions.

3. 2 Models with a Modified Constitutional Formula

For the system discussed, we developed another suit of models based on Representation II (Fig. 2). Rationale for their development we found in mentioned lower basicity of the middle nitrogen of diethylenetriamines. Namely, measured protonation constants of the middle nitrogen are several orders of magnitude lower than the protonation constants of terminal nitrogens.[33] Because of its much lower basicity, and thus weaker interaction of Cu(II) with this bite atom, we assumed there is no bonding between these two atoms. Starting from this assumption we obtained a new series of models (Table 4, Figure 3).

Despite less regression parameters, model with a modified constitutional formula (Representation II, Fig. 2) gave the results only slightly worse than the regressions with the indicator variable, both in respect to r and $S.E._{cv}$. The maximal errors of estimate are also very similar in both kinds of models, namely, for two models for estimation of log β_2, Model 5 (Table 3) and for Model 9 (Table 4), maximal *cv* error is 0.84.

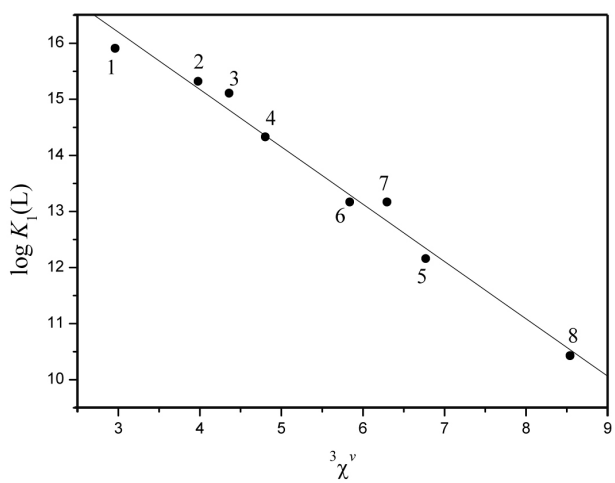

Figure 3. Regression model based on Representation II (Figure 2) for the estimation of log K_1 of copper(II) complexes with diethylenetriamines (Model 6, Table 4).

Table 4. Linear regression models for the estimation of log K_1, log K_2 and log β_2 of copper(II) mixed complexes with diethylenetriamines and three amino acids (Table 1) based on $^3\chi^v$ index calculated from Representation II (Figure 2).

Model	*N*	Dependent variable	Intercept (*S.E.*)	$^3\chi^v$ (CuL) Slope(*S.E.*)	$^3\chi^v$ (CuA) Slope(*S.E.*)	*r*	*S.E.*	$S.E._{cv}$
6	8	log K_1(L)	19.26(31)	–1.022(54)		0.992	0.22	0.31
7	18	log K_2(L)	17.06(77)	–1.123(93)	–0.59(26)	0.954	0.42	0.50
8	18	log K_2(A)	6.70(48)	–0.160(58)	–0.84(16)	0.833	0.26	0.30
9	18	log β_2	25.85(81)	–1.124(97)	–0.89(28)	0.952	0.44	0.53

4. Discussion

Rationale for succesfull implementation of our Representation II can hardly be found straightforwardly, namely assuming there is no bond between Cu and middle nitrogen. From calorimetric measurement Ciampolini *et al.* stated "it is doubful how many copper-nitrogen bonds exist in the complex $[Cu(den_2)]^{2+}$»,[46] but latter potentiometric and spectrophotometric investigation on copper(II) chelates with diethyltrimamines did not find any indication that only two nitrogens are bound to the copper.[47,48] The two crystal structures of bis(diethylenetriamine)copper(II),[49,50] as well as related structures of dichloro-1,7,7,7-tetraethyldiethylenetriaminecobalt(II)[51] and dichlorobis(2-dimethylaminoethyl) methylaminecobalt(II)[52] undoubtly showed that all three nitrogens are bound to the central atom.

It is hard to find an easy explanation for the established lack of influence of substitution at middle nitrogen on stability of copper(II) chelates with diethylenetriamines. There is an explanation that the bond between Cu and middle nitrogen is weaker than Cu(II) bonds with terminal nitrogens. Such hypothesis is in accordance with the protonation constants of the ligands, which we mentioned previously, and also with the measured heat of formation of complexes with diethylenetriamines[46] and other alkylamines.[53,54]

Alternatively, the effect can be tentatively attriburted to higher distortion of coordination polyhedron of these complexes, which reduces the sterical strain generated by substitution at middle nitrogen. Molecular-mechanics calculations on copper(II) chelates with naturally occuring amino acids and their derivatives,[55–59] show that distortion of coordination polyhedron lowers the sterical strain, leading to lower, more realistic values of calculated enantioselectivity. The structures of bis(diethylenetriamine)copper(II)[49,50] were described as distorted octahedron, and closer inspection shows that the sum of their *trans*-angles differ for 41.6 and 44.3° for nitrate[49] and bromide monohydrate,[50] respectively, from the values for ideal octahedron (540°). Structures of cobalt complexes[51,52] were also distorted, and were described as intermediate between square pyramid and trigonal bipyramid.

Following the presented arguments we can state that our Representation II is justified by assuming weakening the bond between Cu(II) and middle nitrogen and/or by higher distortion of coordination polyhedron. Unfortunately, neither of the effects can be modelled directly by graph-theoretical method, but one must bear in mind that our models are empirical, so they provide mere a tool for distinguishing stronger or weaker interactions – or, generally, influences – in the molecule.

Due to our efforts in improving the models for estimation of the stability constants, we succeeded to halve *S.E., S.E.*$_{cv}$, and maximal difference between experimental and cross validated values for Cu(II) mixed complexes with diethylenetriamines and amino acids. As far as the two approaches developed in this paper appear to be different, they describe the same phenomenon, namely the weak interaction with the middle nitrogen, so they could be regarded as complementary.

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6. References

1. B. Lučić, A. Miličević, S. Nikolić, N. Trinajstić, *Croat. Chem. Acta* **2002**, *75*, 847–868.
2. E. V. Konstantinova, M. V. Diudea, *Croat. Chem. Acta* **2000**, *73*, 383–403.
3. B. Lučić, S. Nikolić, N. Trinajstić, *Croat. Chem. Acta* **1995**, *68*, 417–434.
4. A. T. Balaban, D. Mills, O. Ivanciuc, S. C. Basak, *Croat. Chem. Acta* **2000**, *73*, 923–941.
5. D.H. Rouvray, W. Tatong, Z. Naturforsch. **1986**, *41a*, 1238.
6. N. Bošnjak, N. Adler, M. Perić, N. Trinajstić, On the structural origin of chromatographic retention data: alkanes and cycloalkanes, in: Z. B. Maksić (Ed.), Modelling of Structure and Properties of Molecules, Wiley, New York, 1987, p. 103.
7. L. B. Kier, L. H. Hall, Molecular Connectivity in Chemistry and Drug Research, Academic Press, New York, 1976.
8. L. H. Hall, L. B. Kier, *Eur. J. Med. Chem.* **1981**, *16*, 399–407.
9. A. Miličević, S. Nikolić, N. Trinajstić, *Mol. Diversity* **2006**, *10*, 95–99.
10. M. Medić-Šarić, Ž. Maleš, S. Šarić, A. Brantner, *Croat. Chem. Acta* **1996**, *69*, 1603–1616.
11. S. Bajaj, S. S. Sambi, A. K. Madan, *Croat. Chem. Acta* **2005**, *78*, 165–174.

12. A. Graovac, I. Gutman, and N. Trinajstić, *Topological Approach to the Chemistry of Conjugated Molecules,* Lecture Notes in Chemistry, Vol 4, Springer-Verlag, Berlin, 1977.
13. A. Miličević, S. Nikolić, N. Trinajstić, *J. Chem. Inf. Comput. Sci.* **2004**, *44*, 415–421.
14. B. Grgas, S. Nikolić, N. Paulić, N. Raos, *Croat. Chem. Acta* **1999**, *72*, 885–895.
15. S. Nikolić, N. Raos, *Croat. Chem. Acta* **2001**, *74*, 621–631.
16. N. Raos, *Croat. Chem. Acta* **2002** *75* 117–120.
17. A. Miličević, N. Raos, *Polyhedron* **2006**, *25*, 2800–2808.
18. A. Miličević, N. Raos, *Polyhedron* **2007**, *26*, 3350–3356.
19. A. Miličević, N. Raos, *Croat. Chem. Acta* **2007**, *80*, 557–563.
20. A. Miličević, N. Raos, *Polyhedron* **2008**, *27*, 887–892.
21. A. Miličević, N. Raos, *J. Phys. Chem. A*, in **2008,** *112,* 7745–7749.
22. N. Raos, G. Branica, A. Miličević, *Croat. Chem. Acta*, **2008,** *81,* 511–517.
23. A. Miličević, N. Raos, *Croat. Chem. Acta*, in press.
24. N. Trinajstić, *Chemical Graph Theory*, 2nd ed., CRC Press, Boca Raton, FL, 1992.
25. I. V. Stankevich, M. I. Skvortsova, N. S. Zefirov, *J. Mol. Struct.* (*Theochem*) **1995**, *342*, 173–179.
26. J. Galvez, *J. Mol. Struct.* (*Theochem*) **1998**, *429*, 255–264.
27. J. Galvez, *J. Chem. Inf. Comput. Sci.* **2003**, *43*, 1231–1239.
28. E. Estrada, *J. Phys. Chem.* A. **2002**, *106*, 9085–9091.
29. E. Estrada, *J. Phys. Chem.* A. **2003**, *107*, 7482–7489.
30. E. Estrada, *J. Phys. Chem.* A. **2004**, *108*, 5468–5473.
31. L. B. Kier, L. H. Hall, *J. Pharm. Sci.* **1976**, *65*, 1806–1809.
32. L. B. Kier, L. H. Hall, *Molecular Connectivity in Structure-Activity Analysis,* Wiley, New York, 1986.
33. J. W. Allison, R. J. Angelici, *Inorg. Chem.* **1971**, *10*, 2233–2238.
34. R. J. Angelici, J. W. Allison, *Inorg. Chem.* **1971**, *10*, 2238–2243.
35. http://www.disat.unimib.it/chm/
36. D. Janežič, A. Miličević, S. Nikolić, N. Trinajstić, *Graph-Theoretical Matrices in Chemistry,* Mathematical chemistry Monographs, No.3, University of Kragujevac and Faculty of Science Kragujevac, 2007.
37. http://cactus.nci.nih.gov/services/translate/
38. M. Randić, *J. Am. Chem. Soc.* **1975**, *97*, 6609–6615.
39. K. Altenburg, *Z. Phys. Chem.* **1980**, *261*, 389.
40. M. Randić, *J. Mol. Graph. Modell.* **2001**, *20*, 19–35.
41. X. Li, I. Gutman, *Mathematical Aspects of Randić-Type Molecular Structure Descriptors,* Mathematical Chemistry Series, Kragujevac, 2006.
42. B. Lučić, N. Trinajstić, *J. Chem. Inf. Comput. Sci.* **1999**, *39*, 121–132.
43. A. Gergely, I. Sovago, I. Nagypal, R. Kiraly, *Inorg. Chim. Acta* **1972**, *6*, 435–439.
44. G. Brookes, L. D. Pettit, *J. Chem. Soc., Dalton Trans.* **1977**, 1918–1924.
45. S. P. Datta, R. Leberman, B. R. Rabin, *Trans Faraday Soc.* **1959**, *55*, 2141–2151.
46. M. Ciampolini, P. Paoletti, L. Sacconi, *J. Chem. Soc.* **1961**, 2994–2999.
47. D. W. Margerum, B.L. Powell, J. A. Luthy, *Inorganic Chemistry* **1968**, *7*, 800.
48. M. Ciampolini, G.P.Speroni, *Inorganic Chemistry* **1966**, *5*, 45–49.
49. F. S. Stephens, *J. Chem. Soc* (*A*) **1969**, 883–890.
50. F. S. Stephens, *J. Chem. Soc* (*A*) **1969**, 2233–2240.
51. Z. Dori, R. Eisenberg, H. B. Gray, *Inorg. Chem.* **1967**, *6*, 483–486.
52. M. Di Vaira, P. L. Orioli, *Inorg. Chem.* **1969**, *8*, 2729–2734.
53. L. Sacconi, G. Lombardo, R. Ciofalo, J. Amer. Chem. Soc. **1960**, *82*, 4182–4184.
54. D. H. Everett, W. F. K. Wynne-Jones, Trans. Faraday Soc. **1939**, *35*, 1380–1401.
55. N. Raos, Vl. Simeon, *Croat. Chem. Acta* **1983**, *56*, 79–85.
56. N. Raos, Vl. Simeon, *Croat. Chem. Acta* **1983**, *56*, 127–132.
57. B. Kaitner, B. Kamenar, N. Paulić, N. Raos, Vl. Simeon, *J. Coord. Chem.* **1987**, *15*, 373–381.
58. J. Sabolović, N. Raos, *Polyhedron* **1990**, *9*, 2419–2427.
59. N. Raos, *Croat. Chem. Acta* **1996**, *69*, 1189–1200.

Povzetek

Indeks valenčnega vezanja $^3\chi^v$ smo korelirali z logaritmom konstante tvorbe kompleksa Cu(II) z dietilenetriamini (CuL, $N = 8$), K_1(L), z logaritmom druge konstante, K_2(L) ter K_2(A) ter z logaritmom celokupne konstante stabilnosti log β_2, mešanih bakrovih kompleksov (CuLA, $N = 18$) z dietilenetriamini in amino kislinami. Regresija log K_1(L) jasno kaže, da je vpliv alkilacije na srednji dušikov atom različen od vpliv aalikalcije n aterminalne dušikove atome. V model za oceno vseh konstant stabilnosti smo zato uvedli idikatorsko spremenjlivko *In*; *In* = 1 za komplekse s triamini alkiliranimi na srednjem dušikovem atomu, sicer je *In* = 0. Predlagamo tudi model s predpostavko, da med Cu(II) in srednjim dušikovim atomom ne pride do vezanja. Obas modela dajeta podobne rezultate, ocenjene z standardnimi odmiki.