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Quantitative Rationalization of Solution and Solid State Properties in Cobaloximes, $RCo(DH)_2L$, as a Function of the Electronic and Steric Properties of R

Lucio Randaccio,* Silvano Geremia,† Ennio Zangrando, and Cynthia Ebert

Dipartimento di Scienze Chimiche and Dipartimento di Scienze Farmaceutiche, Università di Trieste, 34127 Trieste, Italy

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A quantitative approach to the rationalization of some solution and solid state properties in a series of Co(III) organometallic derivatives is proposed, according to the following procedure. Five experimental quantities of 23 alkylcobaloximes, octahedral Co(III) complexes of type $RCo(DH)_2L$ (R = alkyl group, DH = monoanion of dimethylglyoxime, L = py) are analyzed by principal component analysis (PCA). These quantities are the Co—C and Co—N axial distances, displacements d of Co out of the coordination plane, log k's for the displacement reaction of py, and chemical shifts of the γ-C(py). A three-component PCA model, based on t_1, t_2, and t_3 scores, is significant according to cross validation criterion and accounts for 95% of the variance of the data set. The scores t_1, t_2, and t_3 are interpreted and discussed in terms of the electronic and steric properties of the R groups. With respect to the methyl derivative, t_1 values increase with an increase in both the number and the electron-donating ability of groups substituting the H methyl atoms. t_2 follows the increase in bulk of R, while t_3 is interpreted as a measure of the angular distortions at Cα. Comparison with inductive, resonance, and steric parameters, derived from organic chemistry, is discussed. The t_1 score is approximately related to a linear combination of σ_I and σ_R^-, and t_2 is approximately related to the Taft steric constants. The three component model is applied to interpret kinetic, spectroscopic, structural, and thermodynamic data of cobaloximes and of Costa models with several L ligands, by using the equation $Q_L = a_0 + a_1t_1 + a_2t_2 + a_3t_3$, where Q_L is the analyzed property in the series with a given L ligand, whereas a_i represents the contribution of the t_i parameter. The parameters t_1 and t_2 are shown to represent the two main descriptors of most of the properties. In fact, log k and Co—L distances are essentially dependent upon t_1, displacements d upon t_2, and chemical shifts upon t_1 and t_2, while Co—C distances depend upon all the scores. In particular, the latter finding represents the first attempt to rationalize quantitatively the variation observed in Co—C bond lengths as the R properties vary. Thus the bond lengthens with the increase in bulk and in σ-donor ability of R and shortens when the Co—C—Y angle increases. This may be relevant to the understanding of the mechanism of the Co—C bond homolysis occurring in the biological processes which involve the B_{12} coenzyme. Furthermore, the score comparison suggests that the ribosyl group, the sugar part of the adenosyl group of the coenzyme, is a σ-donor very similar to Me and slightly bulkier than Et. Assuming t_1 and t_2 as a measure of the electronic and steric properties of R, respectively, an interpretation of the trends observed in alkylcobaloxime properties is also proposed.

Introduction

Alkylcobaloximes, octahedral Co(III) complexes of formula $RCo(DH)_2L$, where the equatorial ligands are DH = monoanion of dimethylglyoxime and the axial ligands are an alkyl group, R, and a neutral Lewis base, L (Figure 1), are a well-known simple model of vitamin B_{12}. They and similar systems have been widely studied[1−6] and represent a unique series in organometallic chemistry where a large number of strictly related complexes have been fully characterized, both in solution and in the solid state. These studies have provided a noticeable amount of structural, spectroscopic, thermodynamic, and kinetic data[1−6] for a large variety of R and L ligands. Attempts to interpret the trend in these properties as function of the steric and electronic effects of the axial ligands have been performed.[1,2]

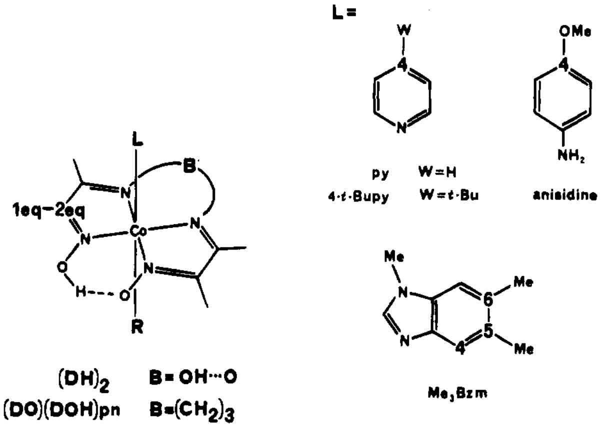

Figure 1. Schemes of $(DH)_2$ and (DO)(DOH)pn derivatives with C atom numbering scheme for the equatorial and L ligands.

The influence of the nature of R and L was qualitatively established. The weakening of the Co—C bond (steric *cis*-influence) was mainly related to the increase in bulk of R,

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* To whom correspondence should be addressed at the Dipartimento di Scienze Chimiche.

† Present address: Dipartimento di Scienze dei Materiali e della Terra, Università di Ancona, 60131 Ancona, Italy.

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whereas the weakening of the *trans* Co—L bond (electronic *trans*-influence) has been attributed to the R electron-donating ability.[2,3] However, qualitative evidence that the electronic properties of R influence the Co—C bond lengths[7] and the bulk of R,[8] through a bending of the $(DH)_2$ moiety toward L, influences the Co—L bond length (steric *trans*-influence) has been also reported. The increase in the bulk of L determines a weakening of the Co—L bond (steric *cis*-influence) and a weakening of the Co—R bond (steric *trans*-influence), especially when R is a bulky group.[8-12]

The quantitative rationalization of the above influences, when R is varied, was more intriguing. Early attempts on a limited series of data using the Taft inductive constants for the R ligands[13] were not able to explain the observed trends.

A new approach, successfully applied[14] to series of the type $LCo(DH)_2CH_2Y$, was based on the classical dual substituent parameter equation[15]

$$Q_Y - Q_H = a_I\sigma_I + a_R\sigma_R \qquad (1)$$

where Q_Y and Q_H are the kinetic or spectroscopic data of the CH_2Y and methyl derivatives, respectively. σ_I and σ_R are the substituent constants for the Y group, derived from organic chemistry, and a_I and a_R are the relative contributions of the inductive and resonance effects. This method was first applied to Y of relatively small bulk and avoids changes in the Co—C linkage itself. A more complex equation, (2),

$$Q_Y = a_I\sigma_I + a_R\sigma_R + a_s\sigma_s + C \qquad (2)$$

including steric parameters for Y, σ_S, was recently suggested by Brown[16]d and applied to correlate various kinetic, spectroscopic, and equilibrium properties of series of $LCo(DH)_2CH_2Y$ complexes, including also derivatives with bulky Y substituents. Correlations were excellent, although they showed only a slight, if significant, improvement, when the steric term was included. These methods have the advantage of transferring to organometallic chemistry substituent constants from organic chemistry, without any other assumption, although they are limited to CH_2Y alkyl groups. Therefore, the correlations are restricted to a narrow range of variability of the electronic and steric properties of organic ligands R. On the other hand, the kinetic, spectroscopic, and structural properties vary noticeably when the number of substituents at the Cα atom increases.[1,2] This was taken into account in another attempt[17] which assumed that cobaloxime properties could be described as a linear function of the electronic inductive and steric constants, again derived from organic chemistry, of the whole R group. However, this model suffered from outlying data and was limited because of the lack of constants for many R groups.

In a quite different approach,[18,19] it was assumed that in the series $RCo(DH)_2py$, the values of the difference in ^{13}C NMR chemical shift of γ-C(py), with respect to the methyl derivative, EP, was a measure of the electronic influence of the *trans* R ligand, when R varies from the less electron-donating $C(CN)Cl_2$ group to the more electron-donating adamantyl. When log *k*'s for the pseudo-first-order reaction of the py displacement and the Co—N(axial) bond lengths were plotted against EP's, fair linear relationships were obtained. However, the linear regressions improved when restricted to monosubstituted alkyl groups, CH_2Y, where Y is a substituent with small bulk. The points relative to the other R ligands, having a significant bulk, were all above the best line in both cases.[18] This finding clearly indicates that steric factors should play a role in determining the above properties. This approach has the advantage that it can be applied to any alkyl R group. However, it did not allow the quantitation of the influence of the bulk of the R ligand.

This unsatisfying situation required a new approach, able to extract and to rationalize the most important counteracting or superimposing factors, some of which are steric, the others electronic, by an *a priori* statistical treatment; as commonly known, it is impossible to separate steric and electronic effects completely. To examine this effect, we have evaluated the use of the well-known method based on the "multicomponent" analysis, namely the principal component analysis (PCA).[20] PCA allows one to investigate the relationships between a set of variables in a class of compounds and enables the identification of the descriptors relevant to the problem, without constraints, such as the object/variables ratio or independence among variables.

Furthermore, the principal component models, as recently introduced,[21] can be used to determine the principal properties, affording measures of how the experimental variables vary over a set of possible systems. Principal properties derived from PCA have the advantage of being less influenced by measurement errors and system-specific variations. They are now available for solvents,[22] aldehydes and ketones,[23] amines,[24] Lewis acids,[25] amino acids,[26] and aromatic substituents.[27] Principal properties have been successfully used for the design

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and the optimization in organic synthesis[21] and in various quantitative structure activity relationship (QSAR) investigations.[26,28] Furthermore, PCA has been used to study the Berry[29] pseudorotational interconversion of trigonal bipyramidal and square planar five-coordinate metal centers.[30] Therefore, a multivariate statistical treatment seems particularly suitable for these series of organometallic compouns, where the presence of different L and equatorial ligands adds new dimensions to the problems generally investigated in LFERs (linear free energy relationships).

This treatment could provide a quantitative interpretation of the variation with R in the properties of cobaloximes and of similar systems, such as Costa models,[31] $\{RCo[(DO)(DOH)pn]L\}^+$, where (DO)(DOH)pn is the N^2,$N^{2'}$-propanediylbis(2,3-butanedione 2-imine 3-oxime) ligand (Figure 1). The PCA approach furnishes some parameters, the so called scores, which can be related to the kind of R group, and allows one to estimate the values of the examined properties in derivatives for which experimental measurements are not available.

Multivariate Statistical Method

Statistical Procedures. PCA was performed by using the package SIMCA. Since a detailed description of the data analysis package SIMCA has been given elsewhere,[20] the presentation is only summarized.

For the PCA, the data set forms a matrix containing elements x'_{ik}, (n objects and m variables). These values were mean centered and scaled to unit variance by weights w_k, that transfer the scaled values into unscaled x_{ik} ($x_{ik} = w_k x'_{ik}$). This modification ensures the comparable importance of the variables and avoids the risk that a small but systematic variation in one variable can be masked by a large variation in another. These scaled data (n objects and m variables) form a data matrix $\mathbf{X}$ ($n \times m$), that is modeled as

$$\mathbf{X} = \mathbf{1}\cdot\mathbf{x} + \mathbf{T}\cdot\mathbf{P} + \mathbf{E}$$

where $\mathbf{x}$ is a vector whose elements are the means of the variables, $\mathbf{T}$ is the low-dimensional ($n \times A$) score matrix, $\mathbf{P}$ the corresponding ($A \times m$) loadings matrix and $\mathbf{E}$ ($n \times m$) the residuals matrix. The $\mathbf{t}_a$ and $\mathbf{p}_a$ values (the score and the loading vectors) are thus directly derived from the scaled, measured data, by minimizing the sum of the squared residuals. The number of significant product terms, A, is estimated by cross-validation. The relevance of each variable in describing the mathematical model is given by its modeling power value, MPOW_k

$$\mathrm{MPOW}_k = 1 - \frac{s_k}{s_{0k}}$$

where s_k and s_{0k} are the residual standard deviation for the kth variable after A dimensions and after dimension zero, respectively.

PCA constitutes a projection of the data points to a space of lower dimensions than that of the variables, in such a way that the first component vector describes the direction through the swarm showing the largest variation in the data. The second component vector shows the second next largest variation, *etc.* The vectors are mutually orthogonal. The components are consecutively calculated as to minimize the residual variation in each step. The score vector represents the variation of the objects along the corresponding direction, and the loading vector represents the contribution of each variable to the component.

Table 1. Correlation Results for Structural, Kinetic and Spectroscopic Data, Where D Is the Range of the Correlated Property and r Is the Correlation Factor for n Points

equation	r	n	D
$Co{-}C(py) = 0.317(5) + 0.85(3)\ Co{-}C(Me_3Bzm)$	0.99	7	0.196 Å
$Co{-}C(py) = 0.029(9) + 0.99(6)\ Co{-}C(NH_2Ph)$	0.99	6	0.086 Å
$Co{-}N(py) = 0.58(1) + 0.72(9)\ Co{-}N(Me_3Bzm)$	0.97	7	0.127 Å
$Co{-}N(py) = 1.207(6) + 0.41(7)\ Co{-}N(NH_2Ph)$	0.94	6	0.114 Å
$d(py) = -0.02(2) + 1.0(2)\ d(Me_3Bzm)$	0.92	7	0.085 Å
$d(py) = 0.02(2) + 1.1(3)\ d(NH_2Ph)$	0.90	6	0.097 Å
$\log k(4\text{-}CNpy) = 0.9(1) + 0.91(2) \log k(Me_3Bzm)$	0.99	10[a]	6.50
$^{13}C_4(py) = 12.58(4) + 0.77(2)\ ^{13}C_4(4\text{-}t\text{-}Bupy)$	0.99	13[b]	1.90 ppm

[a] log k values for R = CH_2Br (−2.58 for 4-CNpy and −3.91 for Me_3Bzm) are included. [b] Chemical shifts for R = CH_2CO_2Me (137.97 ppm for py and 162.45 ppm for 4-*t*-Bupy) and for R = CH_2Br (137.96 ppm for py and 162.37 ppm for 4-*t*-Bupy) are included.

Preparation of Data for PCA. Available ^{13}C chemical shifts, kinetic, structural, and thermodynamic data retrieved from literature for several series of $RCo(DH)_2L$ and $\{RCo[(DO)(DOH)pn]py\}^+$, with different R and L ligands, are given as in the supplementary material (Tables IS and IIS). Among these series, those with L = py and 4-CNpy were numerous enough to be analyzed by the PCA method, although data relative to some R groups were lacking. In order to fill the "holes" in these series as much as possible, a previous observation was utilized. In fact, it has been reported[18] that in series with similar N-ligands such as py, 1,5,6-trimethylbenzimidazole (Me_3Bzm), 1,2-dimethylimidazole (1,2-Me_2Im), and NH_2Ph, when R is varied, axial Co—N distances, log k and ^{13}C chemical shifts for one L ligand are linearly related to the corresponding ones for the other ligands, with good correlation factors. This trend also holds for Co—C distances and for displacements of Co out of the four N-equatorial donor plane, d (positive values of d indicate Co displacements toward L and negative values displacement toward R).

Therefore, Co—C and Co—N(axial) distances and d values in the py series were linearly correlated with the corresponding values in the series with L = Me_3Bzm and NH_2Ph. A few structural data refer to 4-Zpy derivatives instead of py, namely Z = HN=C(OMe), CN, and Me_2NH when R = Et, CH_2CF_3, and adamantyl (adam), respectively. However, there is evidence that structural data for variously 3- and 4-substituted pyridines are essentially equal within their esd's.[32,33] The log k values for 4-CNpy were linearly correlated with the corresponding values for the Me_3Bzm series. Analogously, the ^{13}C chemical shifts of γ-C(py) atom, $^{13}C_4$ (Figure 1), were linearly correlated with the corresponding data of the 4-*tert*-butylpyridine (4-*t*-Bupy) one. The equations relative to these regressions are given in Table 1. All relationships have correlation factors $r \geq 0.90$. Corresponding data for above series (Tables IS and IIS) were scaled, by using the linear equations of Table 1, to those of py for bond lengths, d, and chemical shifts and to those of 4-CNpy for log k and averaged, when possible, over each R ligand. The py and 4-CNpy series were chosen as reference, because they have the largest number of terms. Thus, it was possible to include some values (see footnote f in Table 2) not available in the reference series. These series of data will be named hereinafter as "*extended py series*".

Missing experimental data for $^{13}C_4$(py) and log k were calculated from the PCA results (see below and footnote e in Table 2).

PCA Results and Discussion

Data of the extended py series, used in PCA, consist of the five experimental quantities (variables), for each of the 23 compounds (objects) given in Table 2. The results of the statistical analysis are summarized in Table 3. Large p_{ik} values

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Table 2. Data for the Extended Pyridine Series, RCo(DH)$_2$py, Used for PCA

RCo(DH)$_2$py						
no.	R	Co—C[a]	Co—N[a]	*d*[b]	$^{13}C_4$[c]	log *k*[d]
1	CHClCN	2.014	2.020	−0.010	138.60	−4.85
2	CF_3	1.950	2.043	0.002	138.44	−4.55[e]
3	CH_2NO_2	2.002	2.027	0.028	138.48	−5.37
4	CH_2CN	2.025	2.014	0.027	138.25	−4.52
5	CF_2CHF_2	1.997	2.036	−0.031	138.45[e]	−4.37[e]
6	$CF(CF_3)_2$	2.084	2.037	−0.076	138.51	−4.51
7	$CH(CN)CH_2CN$	2.064[f]	2.040[f]	−0.003[f]	138.62	−4.47
8	$CHCl_2$	1.996	2.047	−0.013	138.18[e]	−3.14
9	CH_2CF_3	2.010	2.041	0.007	138.03	−3.56
10	$CHCNCH_3$	2.050	2.054	−0.004	138.17	−2.88
11	CH_2CH_2CN	2.013	2.061	0.021	137.78	−1.59
12	ribosyl	2.015	2.072	0.031	137.63[e]	−1.12[e]
13	CH_3	2.001	2.067	0.051	137.50	−1.33
14	CH_2Ph	2.064	2.056	0.037	137.40	−0.48
15	$CH_2CCH_3(COOCH_2CH_3)_2$	2.049	2.077	−0.013	137.53	−0.57
16	$CH(CH_3)COOCH_3$	2.088	2.062	−0.002	137.56[e]	−0.41[e]
17	CH_2CH_3	2.036	2.079	0.043	137.34	0.01
18	$CH_2Si(CH_3)_3$	2.031	2.091	0.005	137.41	−0.37
19	CH_2OCH_3	2.023[f]	2.088[f]	0.046[f]	137.24	1.38
20	$CH_2C(CH_3)_3$	2.059	2.082	0.002	137.29	1.01
21	$CH(CH_3)_2$	2.080	2.091	0.005	137.19	1.43
22	c-C_6H_{11}	2.074[f]	2.093[f]	−0.032[f]	137.15	1.60
23	adamantyl	2.163	2.109	−0.048	137.00	2.36[f]

[a] Co—C and Co—N are the axial bond lengths (Å). [b] Displacement (Å) of the Co out of the four N equatorial donors toward the alkyl group (negative value) or in the opposite direction (positive sign). [c] ^{13}C chemical shift (ppm) of the γ-carbon of 4-CNpy. [d] Rate constant for the py displacement reaction. [e] Data calculated *a posteriori* using the PCA results. [f] Value not available in the py series, it is included by regression analysis with series with other L ligand (Table 2).

indicate considerable contribution from the relative variable, whereas the MPOW$_k$ values should approach unity. The first principal component V_1 explains 50% of the total variance, with large contribution from Co—N distance, $^{13}C_4$(py), and log *k*, a minor contribution from Co—C distances and essentially no contribution from *d* displacements, as shown by the p_{1k} values. Introduction of the second component V_2 leads to an explaination of 83% of the global variance with contributions from the Co—C and *d* variables. The corresponding modeling power values increase. With the inclusion of the third component, V_3, to which essentially Co—N, Co—C, and *d* variables contribute, 95% of the variance is explained. A significant increase of the modeling power values, all above 0.80, is observed only for the Co—C and *d* variables. The cross-validation criterion indicates that only these three components are statistically significant.

The *position* of each object in the space of the three components (score space) is defined by three scores (coordinates), t_1, t_2, and t_3. These values for compounds **1**−**23** of Table 2 are given in Table 4. The t_1, t_2 score plot, which shows the distribution of the objects in the plane of the two components, is given in Figure 2.

The missing values x'_{ik} for the *i*th object are calculated by employing the following PC equation:

$$x'_{ik} = w_k^{-1} x_{ik}$$

Here

$$x_{ik} = x_k + t_{i1}p_{1k} + t_{i2}p_{2k} + t_{i3}p_{3k}$$

The scores t_{ia} are obtained from the other available variables and the loadings p_{ak} and weights w_k are derived from the whole data set.

Chemical Interpretation of the Scores. Inspection of the Table 4 shows that the trend of t_1 values appears to follow the expected increase in the donating ability of R groups. With reference to the methyl derivative, the t_1 values increase (decrease), with the increase both of the number and of the electron-donating (-withdrawing) ability of the Y groups substituting the H methyl atoms. Correlations of t_1 with the available[34] σ_I, σ_R, or σ_R^+ and σ_R^- were performed and the best result[35] was found with σ_I constants (r = 0.79; n = 14). The correlation[36] slightly improved when the contribution of σ_R^- was included, the corresponding equation being:

$$t_1 = 2(1) - 17(5)\sigma_I + 6(4)\sigma_R^- \qquad r = 0.85;\ n = 11$$

The correlation is not excellent and limited to a few t_1 data. However, this comparison does not contrast the assumption that t_1 could reflect the overall electronic properties of R, including the inductive and resonance contributions.

The trend of t_2 follows the expected increase in bulk of R from Me to $CF(CF_3)_2$ as a function of both the number and the bulk of the Y substituents at the Cα atom. Linear regression analysis of t_2 *vs* some scales of available steric constants, derived for organic compounds, such as E_s values of Taft,[37] E_s' of Dubois,[38] and those of Charton,[39] gives *r* correlation factors of 0.82 (n = 12), 0.57 (n = 9), and 0.61 (n = 12), respectively. Assuming that t_2 reflects the bulk of R, this result accords with the suggestion[40] that the steric environment of R in cobaloximes and in organic compounds may be different.

A chemical interpretation of t_3 is not straightforward. However, t_3 may be related to the opening of the Co—Cα—Y bond angle, which depends upon the nature of Y.[7,41,42] It is difficult to analyze such a relationship for alkyl groups with more than one Y substituent at Cα. However, it is apparent that, in the homogeneous PyCo(DH)$_2$CH$_2$Y series, the Co—Cα—Y angle generally increases when t_3 decreases (Table 5).

Analysis of the Extended py Series. On the basis of the chemical meaning assumed for the scores t_i, the PCA results (Table 3) allow the following interpretation of the data variation in the extended py series.

The Co—N distances and log *k* trends are essentially determined by the electron-donating ability of R, without significant contribution from t_2. The $^{13}C_4$(py) trend is determined by the electron-donating ability of R, with a small contribution, opposite in sign, from t_2. In a previous attempt to rationalize the trend of the above properties in RCo(DH)$_2$py complexes, it has been assumed that $\delta^{13}C_4$(py), more precisely

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(35) R groups included in the correlation were those of Table 2 with exclusion of CH_2NO_2, CH_2CH_2CN, ribosyl, CHClCN, $CH_2C(Me)(COOEt)_2$, $CH(CN)CH_2CN$, CH(Me)COOMe, CF_2CHF_2, and CH(Me)CN.

(36) R groups included in the correlation were CH_2CN, $CH(CF_3)_2$, CH_2CF_3, CF_3, CH_2Ph, Me, Et, CH_2SiMe_3, *i*-Pr, Chx, and adamantyl.

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Table 3. PCA Results, Where V_i Is the Total Variance Explained after Introduction of the i Component, p_{ik} Is the Contribution of the k Variable to the i Component, and MPOW$_k$ Is the Modeling Power of the k Variable

				$V_1 = 50\%$		$V_2 = 83\%$		$V_3 = 95\%$	
		w_k	x_k	p_{1k}	MPOW$_k$	p_{2k}	MPOW$_k$	p_{3k}	MPOW$_k$
1	Co—C[a]	22.842	46.566	0.390	0.26	0.507	0.56	0.734	0.94
2	Co—N[a]	38.677	79.686	0.535	0.67	−0.080	0.68	−0.431	0.80
3	d[b]	31.949	0.106	0.009	0.00	−0.822	0.69	0.513	0.94
4	$^{13}C_4$[c]	1.766	243.314	−0.512	0.68	0.217	0.83	0.039	0.83
5	log k[d]	0.395	−0.621	0.547	0.79	−0.121	0.86	−0.100	0.86

[a] Co—C and Co—N are the axial bond lengths (Å). [b] Displacement (Å) of the Co out of the four N equatorial donors toward the alkyl group (negative value) or in the opposite direction (positive sign). [c] ^{13}C chemical shift (ppm) of the γ-carbon of 4-CNpy. [d] Rate constant for the py displacement reaction.

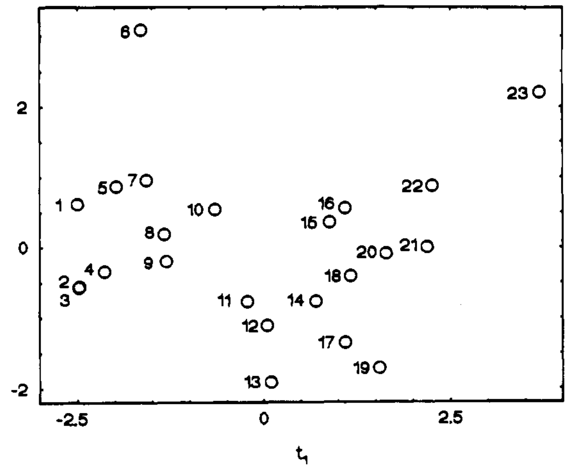

Figure 2. Score plot of the objects of Table 4. Numbers correspond to those of Table 2.

Table 4. Values of the Scores

i	R	t_{i1}	t_{i2}	t_{i3}
1	CHClCN	−2.50	0.62	0.17
2	CF_3	−2.48	−0.57	−1.11
3	CH_2NO_2	−2.47	−0.56	0.49
4	CH_2CN	−2.14	−0.35	1.03
5	CF_2CHF_2	−1.97	0.87	−0.75
6	$CF(CF_3)_2$	−1.65	3.08	−0.03
7	$CH(CN)CH_2CN$	−1.57	0.96	0.79
8	$CHCl_2$	−1.34	0.19	−0.70
9	CH_2CF_3	−1.31	−0.20	−0.03
10	$CHCNCH_3$	−0.66	0.54	0.24
11	CH_2CH_2CN	−0.22	−0.77	−0.15
12	ribosyl	0.05	−1.11	−0.16
13	CH_3	0.10	−1.91	0.07
14	CH_2Ph	0.71	−0.77	1.00
15	$CH_2CCH_3(COOCH_2CH_3)_2$	0.89	0.36	−0.41
16	$CH(CH_3)COOCH_3$	1.09	0.56	0.67
17	CH_2CH_3	1.10	−1.35	0.24
18	$CH_2Si(CH_3)_3$	1.17	−0.41	−0.66
19	CH_2OCH_3	1.55	−1.71	−0.13
20	$CH_2C(CH_3)_3$	1.64	−0.09	−0.14
21	$CH(CH_3)_2$	2.19	0.00	0.10
22	c-C_6H_{11}	2.26	0.87	−0.65
23	adamantyl	3.69	2.20	0.30

the difference, EP, between the shift of R and that of the Me derivative, was a good way to assess the electronic influence of R.[18,19] Correlation of log k and Co—N distances with EP suggested that these properties are mainly influenced by the electron-donating ability of R. However, for log k and Co—N distances, deviations above the best line were found[18] to increase with the bulk of R and were qualitatively attributed to an appreciable steric contribution. Present results support this hypothesis, even if this model suggests that chemical shifts and not log k and Co—N distances appear to be influenced by steric factors.

Table 5. Values of the Co—CH_2—Y Angles (deg) and of the t_3 Scores in the pyCo$(DH)_2CH_2Y$ Complex

Y	Co—CH_2—Y	t_3
NO_2	113.7	0.49
CN	115.7	1.03
Ph	116.7	1.00
CH_3	117.8	0.24
CF_3	122.6	−0.03
ribosyl	123.0	−0.16
CH_2CN	123.6	−0.15
$C(CH_3)(CO_2CH_2CH_3)_2$	125.4	−0.41
$Si(CH_3)_3$	127.7	−0.66
$C(CH_3)_3$	130.3	−0.14

The d trend is essentially determined by t_2, without contribution from t_1 and with a small contribution from t_3. This result agrees with the previous suggestion[1,2] that d values are determined by the difference in bulk between R and L, so that, for the same L, they are mainly dependent upon the bulk of R.

The Co—C bond length trend is determined by both the electron-donating ability and the bulk of R; i.e., the bond lengths increase with the increase of both t_1 and t_2 with a significant contribution from t_3. Up to a few years ago, it was clear that the Co—C distances elongate with the increase in bulk of R,[2,3] and only recently evidence that this distance is significantly influenced by the electronic nature of R has been reported.[7,41] *Present results strongly support the suggestion[7] that, in addition to the steric cis-influence, the increase in the donating ability of R determines a significant lengthening of the Co—C bond while an opening of the Co—C—Y angle provokes a shortening. This finding could have implications in clarifying the mechanism of the Co—C bond cleavage in B_{12} coenzyme.*

Another interesting result is that the ribosyl group, the sugar moiety of the adenosyl ligand with the nucleobase replaced by Et, has electronic properties similar to those of Me and bulk slightly larger than that of Et. This result agrees with recent NMR[43] and EXAFS[44] studies obtained for cobalamins, which suggest that the adenosyl group is slightly greater electron donor than methyl, whereas electrochemical results[45] suggest that the former group is bulkier than ethyl. On the other hand, our result for ribosyl compared to the recent estimated[46] values of 0.06, −0.20, and −1.53 for σ_I, σ_R and the Taft steric parameter E_s, respectively, for adenosyl group on cobalamins, shows that the latter group has electronic and steric properties not far from those found for ribosyl.

A more detailed, although qualitative, picture, which describes how steric and electronic influences can interact on the properties of these and similar complexes, will be presented in the Discussion.

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Table 6. Correlation Results of Chemical Shifts (ppm) for LCo(chel)R (Labeling of the C Atoms Given in Figure 1)

Q_L	a_0	a_1	a_2	range	a_1/a_2	n	R_a
chel = $(DH)_2$							
$^{13}C_4$(py)	137.79(5)	−0.29(3)	0.13(4)	137.00−138.62	−2.23	19	0.984
$^{13}C_4$(4-*t*-Bupy)	162.19(10)	−0.40(7)	0.15(8)	161.37−163.09	−2.67	10	0.984
$^{13}C_4$(anisidine)	130.4(3)	0.47(17)	−0.6(2)	129.98−132.14	−0.78	8	0.966
$^{13}C_4$(Me_3Bzm)	118.94(5)	0.18(2)	−0.09(5)	118.44−119.38	−2.00	8	0.994
$^{13}C_5$(Me_3Bzm)	132.76(4)	−0.23(2)	0.07(4)	132.29−133.40	−3.29	8	0.997
$^{13}C_6$(Me_3Bzm)	133.24(8)	−0.22(4)		132.85−133.90		8	0.981
$^{13}C(P(OMe)_3)$	52.92(7)	−0.36(4)	0.34(5)	52.16−54.62	−1.06	17	0.986
$^{31}P(P(OMe)_3)$	126(2)	3.2(9)		115.7−136.7		11	0.931
$J_{PC}(P(OMe)_3)$	7.0(3)	−0.44(17)	0.5(3)	5.4−7.9	−0.88	12	0.870
^{13}C(CN)	155(2)	4(1)		144.00−160.18		9	0.950
^{15}N(CN)	273(1)	−2.2(9)		268.56−279.83		9	0.878
$^{13}C_{1eq}$(py)	12.33(7)	−0.15(4)	0.17(7)	11.88−12.81	−0.88	12	0.941
$^{13}C_{2eq}$(py)	150.4(4)	−0.5(2)	0.5(4)	148.98−152.55	−1.00	12	0.821
$^{13}C_{1eq}$(4-*t*-Bupy)	12.3(2)	−0.13(9)	0.14(11)	11.88−12.67	−0.93	8	0.829
$^{13}C_{2eq}$(4-*t*-Bupy)	150.1(3)	−0.59(14)	0.6(3)	148.81−151.42	−0.98	8	0.975
$^{13}C_{1eq}(P(OMe)_3)$	12.19(11)	−0.14(6)	0.13(12)	11.81−12.61	−1.07	11	0.872
$^{13}C_{2eq}(P(OMe)_3)$	149.3(3)	−0.58(13)	0.6(3)	147.87−150.56	−0.87	11	0.870
chel = (DO)(DOH)pn							
$^{13}C_4$(py)	139.0(1)	−0.26(7)	0.13(11)	138.47−139.32	−2.00	7	0.970

Table 7. Correlation Results of Kinetic Data Where *k*(L) Is the Rate Constant for the L Displacement Reaction in LCo(chel)R

Q_L	a_0	a_1	a_2	a_3	range	a_1/a_2	n	R_a
chel = $(DH)_2$								
log *k*(4-CNpy)	−1.65(17)	1.43(11)	−0.23(16)		−5.37 to +1.59	−6.72	18	0.990
log *k*(Me_3Bzm)	−3.0(3)	1.6(2)	−0.4(3)	−0.9(8)	−4.89 to +1.61	−4.00	9	0.994
log *k*(1-MeIm)	−3.6(6)	1.1(3)			−4.70 to +0.64		8	0.959
log *k*(anisidine)	−0.7(3)	1.4(2)			−3.77 to +2.18		11	0.972
log *k*(DEA)	−2.6(3)	1.6(2)			−6.00 to +0.71		10	0.985
log *k*(PPh_3)	−1.2(2)	1.4(1)		−0.6(3)	−4.60 to +1.59		9	0.994
chel = (DO)(DOH)pn								
log *k*(py)	−1.6(4)	1.4(3)			−3.47 to +1.52		7	0.982

Table 8. Correlation Results of Structural[a] and Thermodynamic[b] Data in $LCo(DH)_2R$

Q_L	a_0	a_1	a_2	a_3	range	a_1/a_2	n	R_a
Co−C(py)	2.039(2)	0.017(1)	0.022(1)	0.031(3)	1.950−2.160	0.77	20	0.997
Co−C(Me_3Bzm)	2.032(3)	0.020(2)	0.026(3)	0.042(7)	1.983−2.179	0.77	9	0.998
Co−C(NH_2Ph)	2.02(3)	0.023(14)	0.021(13)		1.983−2.158	1.15	7	0.981
Co−C(PPh_3)	2.07(17)	0.017(10)	0.031(11)		2.026−2.217	0.55	9	0.949
Co−N(py)	2.061(5)	0.014(3)			2.016−2.103		20	0.930
Co−N(Me_3Bzm)	2.061(4)	0.019(2)			2.010−2.137		9	0.994
Co−N(NH_2Ph)	2.116(11)	0.027(6)			2.102−2.216		7	0.979
Co−P(PPh_3)	2.421(15)	0.017(11)			2.383−2.460		8	0.813
d(py)	0.003(3)		−0.026(3)	0.017(6)	−0.076 to +0.053		20	0.980
d(Me_3Bzm)	0.018(6)		−0.023(5)	0.018(13)	−0.028 to +0.057		9	0.972
d(NH_2Ph)	−0.013(4)		−0.023(3)		−0.064 to +0.033		7	0.993
d(PPh_3)	0.04(2)		−0.027(14)		−0.046 to +0.11		8	0.843
α(py)	−2.9(13)		−3.3(12)	4(2)	−11.0 to +5.8		20	0.839
α(Me_3Bzm)	−1(2)		−2.9(20)	6(5)	−10.1 to +4.0		9	0.832
α(NH_2Ph)	−3(3)		−3.2(19)		−10.0 to +3.8		7	0.859
α(PPh_3)	5(4)		−2.8(26)		−5.2 to +14.0		8	0.593
log K_{CN}	−7.5(3)	−0.7(2)			−8.74 to −5.94		8	0.936
log K_{eq}(2-NH_2py)	−0.86(16)		0.45(14)		−1.70 to −0.07		8	0.947

[a] Co−C(L), Co−N(L), and Co−P(L) are the axial distances (Å); *d*(L) (Å) and α(L) (deg) indicate the displacement of Co out of the four N equatorial donors and the bending angle between the two DH unit in each cobaloxime series having the ligand L specified in parentheses. [b] KCN is the equilibrium constant for the reaction $RCo(DH)_2H_2O + CN^- \rightleftharpoons [RCo(DH)_2CN]^- + H_2O$; K_{eq} is the equilibrium constant between the N-*endo* and N-*exo* coordination of 2-NH_2py to Co (Scheme 1).

Substituent Effect Analysis in Other Series

The chemical interpretation of the PCA results for the extended py series prompted us to apply the three components model to kinetic, spectroscopic, structural, and thermodynamic data for cobaloximes and Costa models. Available data are reported in Tables IS and IIS. These series have been analyzed by means of

$$Q_L = a_0 + a_1t_1 + a_2t_2 + a_3t_3 \qquad (3)$$

where Q_L is the analyzed property in a series with a given axial ligand L, a_0 is a constant, and a_1, a_2, and a_3 represent the relative contributions of t_1, t_2, and t_3, respectively.

The goodness of the fit is expressed by the corrected correlation factor R_a, given in Tables 6−8, defined as:

$$R_a^2 = 1 - (1 - r^2)(n - 1)/(n - p)$$

where p is the number of significant coefficients to be determined in the regression of n points, and r is the usual correlation factor. For large n values, $R_a \sim r$. Correlations were carried out when $(n - p)$ was greater than 4. The a_i

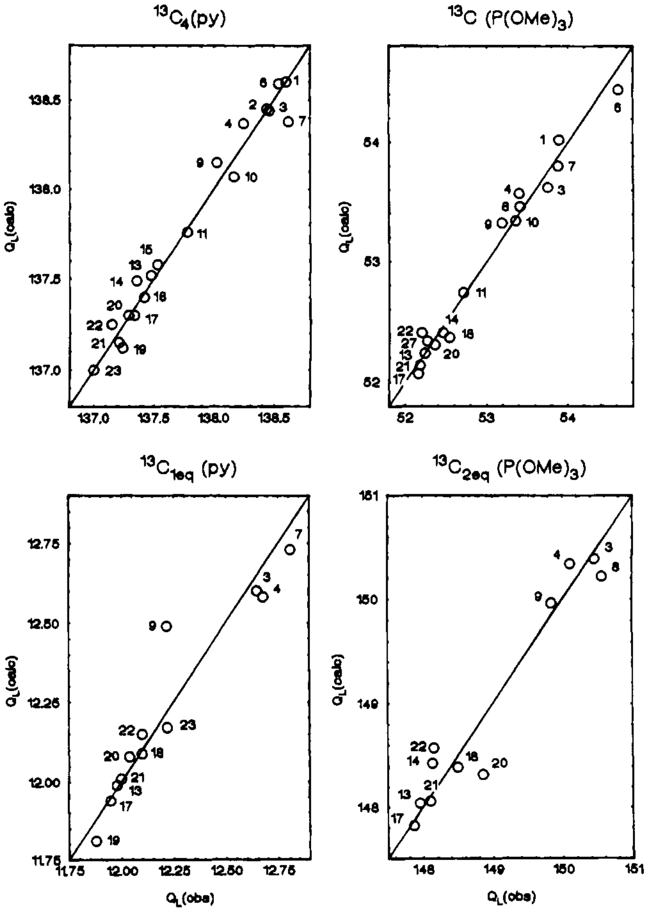


Figure 3. Correlation plots of calculated values of some ^{13}C chemical shifts vs experimental ones. Numbers correspond to those of Table 2.

coefficients were considered significant when they were larger than the estimated standard deviations of a_i. Furthermore, the *f*-test indicates that each of the coefficients reported in Tables 6–8 is significant above 95%.

For sake of clarity, the results of the regressions are reported under four separate sections concerning with NMR spectroscopic (Table 6), kinetic (Table 7), and structural and thermodynamic properties (Table 8), respectively. The range, the a_1/a_2 ratios, when calculated (a_i being the coefficients of eq 3), n, and R_a are also reported in Tables 6–8.

NMR Data Analysis. Experimental data available from literature allow the trend analysis of the ^{13}C, ^{31}P, and ^{15}N chemical shifts of atoms of L and of equatorial ligands in cobaloximes, with L = py, 4-*t*-Bupy, anisidine, Me_3Bzm, $P(OMe)_3$, PPh_3, and CN and the $^{13}C_4$(py) chemical shifts in $\{RCo[(DO)(DOH)pn]py\}^+$. For the phosphite series, the coupling constant J_{PC} has been also examined. The $\delta^{13}C$ refers to the atoms numbered, when necessary, in the formula of complexes depicted in Figure 1. No linear correlation was found only in the case of $^{31}P(PPh_3)$. Possibly, this may be due to the particular sensitivity of the chemical shift to the large bulk of the PPh_3. Statistically significant coefficients of eq 3 are given in Table 6, together with their estimated standard deviations.

Most part of the correlations exhibit R_a values larger than 0.95, although their range of variability is not particularly large (Table 4) with the exception of $^{31}P(OMe)_3$, ^{15}N(CN), and ^{13}C(CN). Some plots of the calculated chemical shifts Q_L(calc) against Q_L(obs), for the more numerous series, are reported in Figure 3.

Regressions relative to C_{1eq} and C_{2eq} of the equatorial moiety in cobaloximes, for L = py, 4-*t*-Bupy and $P(OMe)_3$, are all similar and indicate significant, but opposite, contributions from t_1 and t_2, with a_1/a_2 ratios ranging from −1.1 to −0.9.

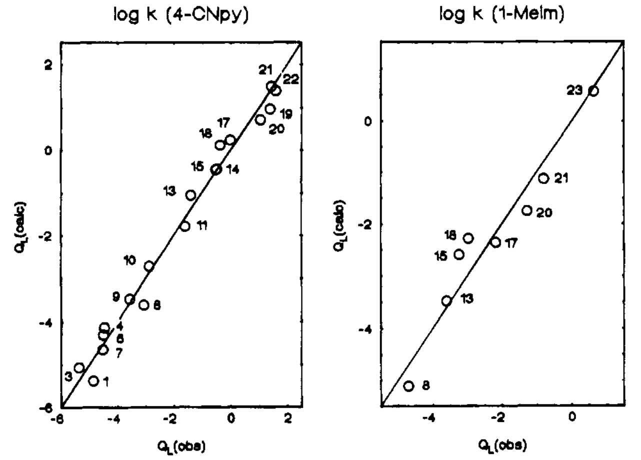


Figure 4. Correlation plots of calculated values of log *k* in 4-CNpy and 1-MeIm derivatives vs experimental data. Numbers correspond to those of Table 2.

The correlations for the L carbon atoms (Figure 1) in cobaloximes, when L = py, 4-*t*-Bupy, anisidine, Me_3Bzm, and $P(OMe)_3$, show significant contribution from t_1 and t_2, if $^{13}C_6(Me_3Bzm)$ is excluded. The a_1/a_2 ratios range from −3.3 to −0.8 (Table 6), the upper limits being for the nonplanar ligands anisidine and $P(OMe)_3$.

Regressions of $^{31}P(P(OMe)_3)$ and ^{13}C(CN), which refer to atoms directly bonded to Co, do not show significant t_2 contribution. Analogously, due to the low quality of the regression, it is difficult to assess any t_2 contribution for ^{15}N(CN) (Table 6). On the contrary, the correlation for J_{PC} (R_a = 0.87) shows a significant contribution from t_1 and t_2 of opposite sign, with an a_1/a_2 ratio of about −0.9.

The results of this analysis may be summarized as follows.

(a) The $\delta^{13}C$ trends of carbon atoms of the $Co(DH)_2$ unit are determined by the electron donating ability and by the bulk of R, with opposite contributions, as suggested by the a_1/a_2 ratios of about −1.

(b) A similar dependence upon t_1 and t_2 is also obtained for $^{13}C_4$(py), $^{13}C_4$(4-*t*-Bupy) and $^{13}C_4$ − $^{13}C_5(Me_3Bzm)$ carbon atoms of cobaloximes, but with a significant decrease (up to 0 for $^{13}C_6(Me_3Bzm)$) of the steric contribution with respect to that observed in part a. On the contrary, the steric contribution for $^{13}C(P(OMe)_3)$ is similar to that observed for equatorial atoms.

(c) Although only one series is available for comparison, it appears that change of the equatorial ligand from $(DH)_2$ to (DO)(DOH)pn does not affect significantly the trend of $^{13}C_4$(py). The a_1 and a_2 values are very close to those found in the analogous cobaloximes.

Rate Constant Analysis. Available log *k* values refer to $RCo(DH)_2L$ series where L = 4-CNpy, Me_3Bzm, 1-methylimidazole (1-MeIm), anisidine, dimethoxyethylamine (DEA), and PPh_3 and are relative to the pseudo-first-order reaction (chel = $(DH)_2$ or (DO)(DOH)pn)

$$RCo(chel)L + L' \rightarrow RCo(chel)L' + L$$

The equations relative to the linear regressions, all having R_a > 0.96, are given in Table 7. Generally, there is a negligible, if any, contribution either from t_2 and t_3. For L = Me_3Bzm and PPh_3, a small contribution from t_3 appears through. The plots of Q_L(calculated) against Q_L(observed) for log *k* in 4-CNpy and 1-MeIm are given in Figure 4.

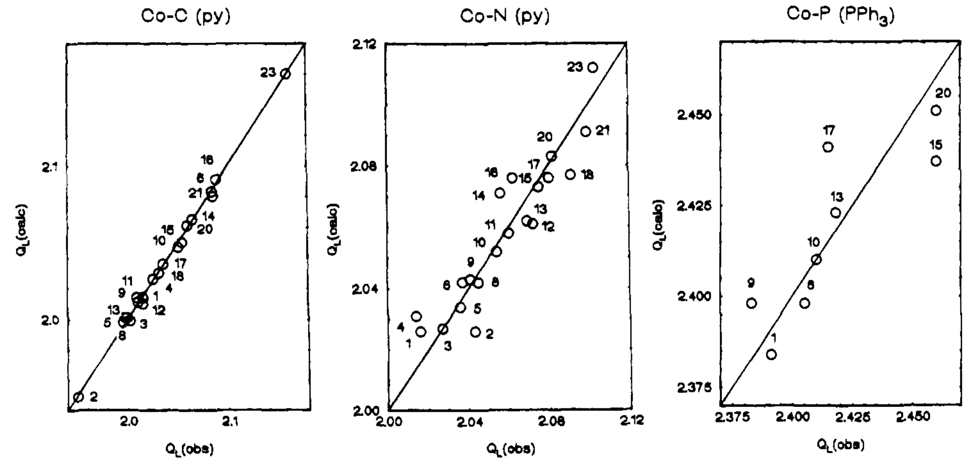


Figure 5. Correlation plots of calculated values of Co—C(py), Co—N(py), and Co—P(PPh$_3$) *vs* experimental data. Numbers correspond to those of Table 2.

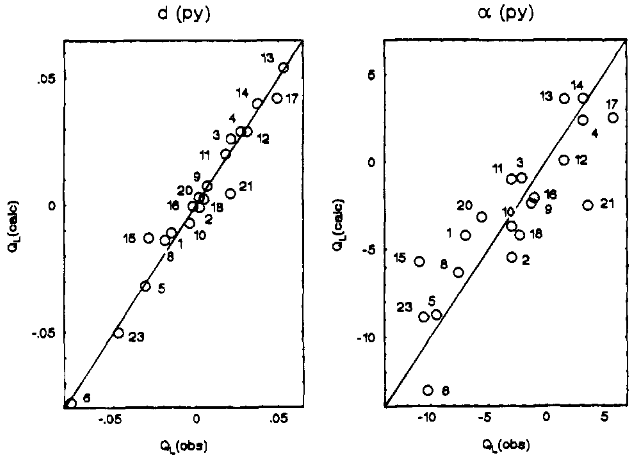


Figure 6. Correlation plots of calculated values of *d* and α in pyridines derivatives *vs* experimental data. Numbers correspond to those of Table 2.

The only available series of Costa models exhibits a trend very similar to that of the more numerous series RCo(DH)$_2$4-CNpy, with approximately the same equation (Table 7).

Analysis of Structural Properties. The correlations for Co—N and Co—C distances and *d* displacements are of quality comparable to those of chemical shifts and log *k* (Table 8).

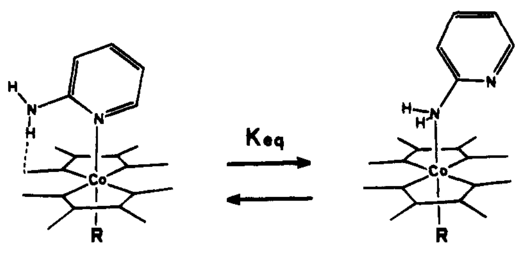
As expected, correlations relative to the most numerous RCo(DH)$_2$py series agree with the results illustrated for the extended py series. In fact, the trend of the Co—N distance depends essentially upon t_1, that of *d* upon t_2 and sometimes t_3. The Co—C distances linearly correlate with all the three variables with a_1/a_2 and a_1/a_3 ratios of 0.8 and 0.5, respectively. Correlations with other N-donor ligands give results similar to those for L = py.

The correlations, relative to the RCo(DH)$_2$PPh$_3$ series, exhibit a lower fit. The Co—P distances have no significant contribution from t_2 and t_3, whereas the Co—C ones have no contribution from t_3, and *d* depends only upon t_2.

The plots of Q_L(calculated) against Q_L(observed) for some structural properties are given in Figures 5 and 6.

The angle α (Tables IIS) is the interplanar angle between the two DH equatorial moieties. The trend of α generally follows that of $d^{1,2}$ (positive values of α indicate bending toward R and negative values toward L). Therefore, the α bending trend for several L ligand series has been also examined, and as expected, the relative correlations are of poor quality, when compared to those relative to the other crystallographic data, confirming that the bending of the equatorial ligand is influenced by additional factors,[8] such as the crystal packing, much more than the other structural observables. However, the analysis show that they are mainly influenced by t_2. The plot for α (Figure 6) should be compared with the plots reported for Co—N, Co—C, and *d* for the same py ligand.

Scheme 1



Analysis of Thermodynamic Properties. The thermodynamic properties examined are the log of the equilibrium constant, log K_{CN}, for the reaction[16]

$$RCo(DH)_2H_2O + CN^- \rightleftharpoons RCo(DH)_2CN^- + H_2O$$

and the log K_{eq} for the equilibrium between the endo- and exo-coordination of 2-NH$_2$py in the series RCo(DH)$_2$2-NH$_2$py,[47] (Scheme 1). The corresponding linear regressions are given in Table VIII and the plots of calculated values against experimental ones are reported in Figure 7.

The log K_{CN} is characterized by a trend determined only by the electronic properties of R, whereas the log K_{eq} trend is determined only by the bulk of R. The latter result confirms quantitatively the previous suggestion[47] that the Co(DH)$_2$R moiety has a greater preference for the more basic endocyclic N donor, as the electron donating ability of R decreases. Such a preference counteracts the steric effect of shorter Co—N bonds and explains the lack of dependence of K_{eq} on R electron donor properties. Therefore the only apparent influence on K_{eq} is due to the bulk of R, which distorts the equatorial moiety and increases the steric interaction between L and Co(DH)$_2$, favoring the exocoordination.

Discussion

Results illustrated in the previous sections indicate that a variety of ground state and kinetic properties of alkylcobaloximes and related systems are, to a large extent, linearly related to t_1 and t_2 parameters that may be assumed to be a

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[47] Marzilli, L. G.; Summers, M. F.; Zangrando, E.; Bresciani-Pahor, N.; Randaccio, L. *J. Am. Chem. Soc.* **1986**, *108*, 4830.

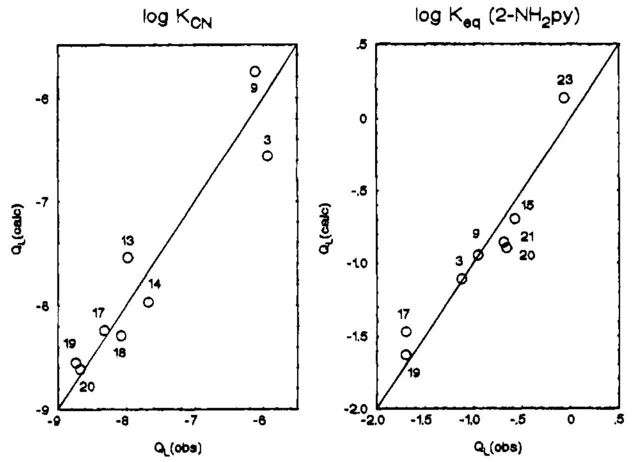

Figure 7. Correlation plots of calculated values of log K_{CN} and log K_{eq} *vs* experimental data. Numbers correspond to those of Table 2.

measure of the electronic and steric properties of R, respectively, within the limits in which their effect may be separated[48] (see below). A relevant result is the achievement of the t_2 scale, which could represent the first proposed scale of steric parameters in organometallic chemistry. A statistically significant contribution of t_3 to the Co—C distances is apparent, suggesting that these data may undergo the influence of other secondary factors represented by t_3. As discussed above, t_3 could be related to the deformation of the Co—C—Y angles (t_3 decreases when the Co—C—Y angle increases, Table 5).

An interesting result is the evidence that the Co—C distances significantly lengthen (weaken) not only with the increase in bulk,[1-3,8] but also with the increase in electron-donating ability of R. A a_1/a_2 ratio of ~0.7 is suggested for the relative contributions to the bond lengthening. Furthermore, the Co—C bond length appears also sensitive, although to a less extent, to other properties of the R group, taken into account by t_3, such as the flexibility of the Co—C—Y angles. In the regression of Table 8, the positive value of a_3 agrees with the suggestion that the opening of the Co—C—Y angles favors on one side a better approach to Co and, on the other, an increase of the s character of the Cα hybrid forming the Co—C bond. Both effects contribute to shorten the Co—C bond.[7]

The increase in bulk of R weakens the Co—C bond (steric *cis*-influence) and, hence, its donating ability which provokes a decrease of lengthening of the Co—L bond. On the other hand, the increase in bulk of R, causes a larger bending of the equatorial ligand toward L and, hence, a displacement of the latter from Co, with an extra lengthening of the *trans*-Co—L bond (steric *trans*-influence). These two counteracting factors approximately cancel the dependence of the Co—L distances upon t_2. This interpretation may be also applied to log *k* trends, since it holds also in the transition state, where the steric factors are even less important.

Similar considerations, although in a more complex way, can be applied to explain the trends of ^{13}C shifts in py and 4-*t*-Bupy cobaloximes. Although the meaning of the ^{13}C chemical shifts is not well established yet on theoretical grounds, it may be assumed that they represent an approximate measure of the electronic charge density on the carbon. As the electron donating ability of R, measured by t_1, increases, the charge donated to carbons of the equatorial ligand increases and provokes, generally, an upfield shift of their resonances. However, when the bulk of R increases, the steric *cis*-influence lengthens the Co—R bond distance and decreases the charge donated by R, provoking a downfield shift of these resonances. Since the equatorial Co—N distances are not influenced by the nature of R,[1,2] the overall trend is determined by opposite contributions from the electron donating ability and the bulk of R with a_1/a_2 ratio of about −1 (Table 6).

For ^{13}C shifts of py, 4-*t*-Bupy and Me_3Bzm ligands an additional factor has to be taken into account. In contrast to the equatorial Co—N distances, the Co—N axial bond is significantly lengthened by the increase in the donating ability of R. This lengthening is responsible for a decreased donation by L to the $Co(DH)_2$ moiety, with a consequent upfield shift of the ^{13}C resonance, which partially counterbalances the downfield shift due to steric factors. In fact, in cobaloximes the influence of the R bulk is reduced, as suggested by the correlations for $\delta^{13}C$ of L, for which the a_1/a_2 ratios are significantly more negative (from −2.0 to −3.3). The correlation for $^{13}C_4$(py) in $\{RCo[(DO)(DOH)pn]py\}^+$ derivatives shows about the same a_1/a_2 ratio as in cobaloximes (Table 6). In fact the orientation of py, different from that in cobaloximes, corresponds to longer Co—N(axial) distances and should enhance the downfield shift,[6] which compensates the electron richness of Costa models greater than that of cobaloximes.

Similar correlations are obtained for $^{13}C(P(OMe)_3)$ and $^{13}C_4$-(anisidine) although the steric contribution in these nonplanar ligands is more pronounced than in py. For the phosphite series the a_1/a_2 ratio of −1.1 is close to the values for the corresponding equatorial C atoms (−0.9 and −1.1).

The comparison of a_1/a_2 ratios in the py series with those of other series (Table 6) indicates that the change of the L ligand sometimes modifies the relative contributions of t_1 and t_2. Apparently, the steric contribution decreases in the following order:

$$P(OMe)_3 \sim \text{anisidine} < \text{planar N-ligand}$$

Obviously, the assumption that t_1 and t_2 represent the electronic and steric parameters of R, respectively, suffers for some limitations which are inherent to the nature of these parameters. In fact, the two properties interact, more or less strongly, depending upon the chemical environment of R, as stressed by Unger and Hansch.[49] Therefore, the derivation of constants related to the steric and the electronic nature of R groups always will lead to "impure" electronic and steric parameters.

That chemical environment influences the R steric parameters is apparent. In fact, when the comparison of t_1 and t_2 with the corresponding electronic and steric parameters, derived from organic molecules, is carried out, the t_1 and σ values have approximately similar trends, while t_2 has a trend approximately similar only to the steric constants proposed by Taft[37] (see the section Chemical Interpretation of the Scores). This suggests that more caution should be taken when steric constants of organic chemistry are transferred to organometallic systems. The axial R group in cobaloximes, with a rigid planar equatorial ligand, has a steric hindrance significantly different from that of the same R group attached to either a phenyl ring or a sp^3 carbon atom. This is particularly true for bulky but not symmetric R ligands, such as CH_2CMe_3, whose steric environment is more "anisotropic" in organic system than in cobaloximes. Attempts to analyse this aspect in organic molecules have been made.[50]

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(48) Geremia, S.; Dreos, R.; Randaccio, L.; Tauzher, G.; Antolini, L. *Inorg. Chim. Acta* **1994**, *216*, 125.

(49) Unger, S. H.; Hansch, C. *Prog. Phys. Org. Chem.* **1976**, *12*, 91.

(50) Dubois, J. E.; MacPhee, J. A.; Panaye, A. *Tetrahedron* **1980**, *36*, 919.

Within these limits, the present approach has the following advantages with respect to the others so far proposed: (i) no starting assumption is necessary; (ii) it can be applied to any alkyl R; (iii) it takes into account the chemical environment of the R groups.

However, the approach requires a large amount of data for series of closely related compounds. Furthermore, because of point iii, the scales, especially the steric one, may be used only for similar series of compounds, as those here examined and possibly, for other octahedral metal complexes. For example, it should work for the cobaloxime analogues, the so called rhodoximes,[51] pyRh(DH)$_2$R. Although there are only five points (R = CH$_2$CF$_3$, Me, Et, *i*-Pr, adam) for three variables, the regression suggests that Rh—C distances are linearly related to t_1 and t_2, with $R_a = 0.999$ and $a_1/a_2 = 1.4$. Comparison with the a_1/a_2 ratio of 0.9, obtained for the five cobaloximes with the same R groups, supports the previous suggestion[51] that the steric interaction between R and the equatorial moiety is reduced in rhodoximes, owing to the larger size of the metal centre. Analogously, application of these parameters to alkylcobalamins is hampered by the small number of data. Recently, Brown has reported[52] the values of the intramolecular equilibrium constants for the coordination of the pendant 5,6-dimethylbenzimidazole, K_{Co}, for a series of 10 Y—CH$_2$cobalamins, but unfortunately only for five of these (Y = H, Me, CN, CF$_3$, and Ph) are the t_1 and t_2 parameters available. However, a tentative regression ($r = 0.983$) indicates that log K_{Co}'s are linearly related to t_1 and t_2 with an a_1/a_2 ratio of 1.3. To our knowledge, no series of data relative to other complexes with different R groups, numerous enough to be examined by eq 3, is available at the present time.

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Supplementary Material Available: Tables IS and IIS containing ^{13}C, ^{31}P, and ^{15}N chemical shifts and kinetic, structural, and thermodynamic data for the RCo(DH)$_2$L and {RCo[(DO)(DOH)pn]py}$^+$ series with different R and L ligands (9 pages). Ordering information is given on any current masthead page.

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(51) Bresciani-Pahor, N.; Dreos-Garlatti, R.; Geremia, S.; Randaccio, L.; Tauzher, G.; Zangrando, E. *Inorg. Chem.* **1990**, *29*, 3437. Randaccio, L.; Geremia, S.; Dreos-Garlatti, R.; Tauzher, G.; Asaro, F.; Pellizer, G. *Inorg. Chim. Acta* **1992**, *194*, 1.

(52) Brown, K. L.; Satyanarayana, S. *Inorg. Chim. Acta* **1992**, *201*, 113.