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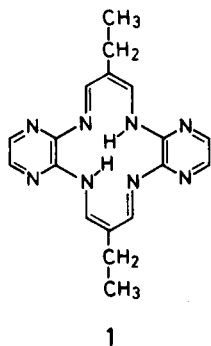
A novel macrocycle, 5,14-dihydro-7,16-diethyldipyrazo[*b,i*][1,4,8,11]tetraazacyclotetradecine, has been synthesized from 1,2-diaminopyrazine and 2-ethyl-3-ethoxyacrolein. The absorption bands appearing in the energy range greater than 20000 cm^{-1} were attributable to the $\pi \rightarrow \pi^*$ transitions. The bands in the range of the 20100-23300 cm^{-1} show more bathochromic shift and greater intensity than those observed for corresponding 5,14-dihydro-7,16-diethyldibenzo[*b,i*][1,4,8,11]tetraazacyclotetradecine and/or 5,14-dihydro-7,16-diethyl-(*Z*)-dipyrido[*b,i*][1,4,8,11]tetraazacyclotetradecine. The nickel(II), copper(II) and palladium(II) complexes of 5,14-dihydro-7,16-diethyldipyrazo[*b,i*][1,4,8,11]tetraazacyclotetradecine have been synthesized using a metal template reaction. In ^1H and ^{13}C nmr spectra, the signals of annulene skeleton for metal-free ligand and its complexes were found to observe in the lower field than those of the dibenzo-analogue.

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Introduction.

Considerable effort has been expended on the study of tetraaza[14]annulene complexes containing benzene rings [1]. Though tetraaza[14]annulene complexes containing pyridine [2], 1,2,5-thiadiazole [3] and thiophene [4] rings and carbonitriles [5] instead of benzene rings have been synthesized because of the structural interest, the spectral research for a series of tetraaza[14]annulene has not been advanced satisfactorily. Examples of tetraaza[14]annulene complexes containing pyrazine rings in place of benzene and pyridine rings are nothing.

In the present work, we synthesized novel tetraaza[14]annulene having pyrazine rings, 5,14-dihydro-7,16-diethyldipyrazo[*b,i*][1,4,8,11]tetraazacyclotetradecine (**1**). Subsequently, we prepared the nickel(II), copper(II) and palladium(II) complexes of **1**. We characterized the spectral



properties of the present tetraaza[14]annulene and its nickel(II), copper(II) and palladium(II) complexes by means of electronic and nmr spectroscopy.

The Cyclization Reaction.

General cyclization reactions with 2-alkyl-3-ethoxyacro-

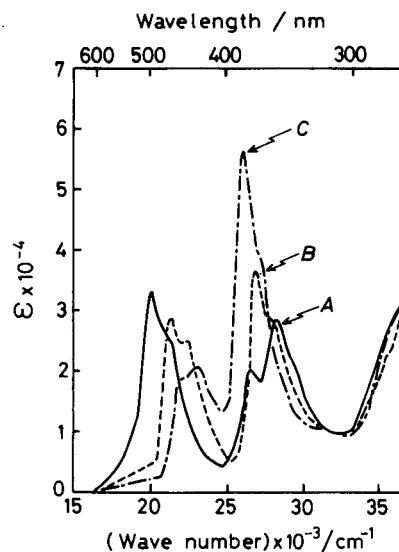


Figure 1. Electronic absorption spectra of macrocyclic ligands in chloroform at room temperature. A, 5,14-Dihydro-7,16-diethyldipyrazo[*b,i*][1,4,8,11]tetraazacyclotetradecine (**1**); B, 5,14-dihydro-7,16-diethyl-(*Z*)-dipyrido[*b,i*][1,4,8,11]tetraazacyclotetradecine (**2**); C, 5,14-dihydro-7,16-diethyldibenzo[*b,i*][1,4,8,11]tetraazacyclotetradecine (**3**).

lein and 1,2-diamine occurred in ethanol and/or *N,N*-dimethylformamide in 10-40% yield [1a], [2a], [3], [4], [5a]. In this work the cyclization reaction with 2-ethyl-3-ethoxyacrolein and 2,3-diaminopyrazine did not occur in ethanol and/or *N,N*-dimethylformamide but in mixed solvent of *N,N*-dimethylformamide and cyclohexanol (1:1 v/v). However, this yield is very poor (3%). A nickel(II) complex has been synthesized in *N,N*-dimethylformamide from 2-alkyl-3-ethoxyacrolein, 1,2-diamine and nickel(II) ion using a metal template reaction, which is produced in significant yields (up to ~50%). Nevertheless, the present yield

Table I

Proton NMR Data for the Macrocycles and their Metal Complexes [a]

Compound [b]	-NH	-CH=	Aromatic	-CH ₂ -	-CH ₃	Reference
1	14.19 (t) (J = 5.1 Hz)	8.34 (d) (J = 5.1 Hz)	7.76 (s)	2.33 (q) (J = 7.8 Hz)	1.18 (t) (J = 7.8 Hz)	this work
1-Ni	--	8.42 (s)	7.76 (s)	2.49 (q) (J = 7.2 Hz)	1.25 (t) (J = 7.2 Hz)	this work
1-Pd	--	8.25 (s)	7.74 (s)	2.50 (q) (J = 7.9 Hz)	1.25 (t) (J = 7.9 Hz)	this work
2	13.61 (t) (J = 6.1 Hz)	7.57 (d) J = 6.1 Hz)	6.78 (dd) (J = 8.1 Hz) (J = 4.6 Hz)	2.18 (q) (J = 7.0 Hz)	1.13 (t) J = 7.0 Hz)	[2a]
	14.39 (t) (J = 5.6 Hz)	8.38 (d) (J = 5.6 Hz)	7.25 (dd) (J = 8.1 Hz) (J = 1.7 Hz)	2.26 (q) (J = 7.0 Hz)	1.16 (t) (J = 7.0 Hz)	
			7.87 (dd) (J = 4.6 Hz) (J = 1.7 Hz)			
3	13.57 (t) (J = 5.9 Hz)	7.61 (d) (J = 5.9 Hz)	6.7-7.2 (m)	2.25 (q) (J = 7.3 Hz)	1.13 (t) (J = 7.3 Hz)	[1b]
3-Ni	--	7.62 (s)	6.7-7.4 (m)	2.42 (q) (J = 7.4 Hz)	1.19 (t) (J = 7.4 Hz)	[1b]
3-Pd	--	7.38 (s)	6.6-7.5 (m)	2.33 (q) (J = 6.9 Hz)	1.17 (t) (J = 6.9 Hz)	[c]

[a] Chemical shifts in ppm from internal TMS. Measured in chloroform-d. Multiplicity of a proton signal is given in parentheses after δ -value: s = singlet, d = doublet, t = triplet, q = quartet, dd = doublet of doublets, m = multiplet. [b] See Figure 1 for numbering the ligands. [c] Unpublished result.

Table II

¹³C NMR Data for the Macrocycles [a]

Macrocycle	C(1), C(4)	C(2), C(3)	C(5), C(6)	C(7), C(8)	C(9), C(10)	-CH ₂ -	-CH ₃	Reference
1 [b]		137.38	144.67	149.61	114.16	26.21	16.43	this work
2 [c]		144.67	132.99	149.12	112.16	26.21	16.77	[2b]
	121.50	120.28	147.95	142.57	111.13	25.47	17.26	
3 [c]	113.85	123.74	137.63	147.35	110.20	25.66	17.38	[d]

[a] Chemical shifts in ppm from internal TMS. See Figure 1 for numbering the ligands. [b] Measured in chloroform-d. [c] Measure in hexamethylphosphoric triamide-d₆. [d] Unpublished result.

of (7,16-diethyldipyrazo[*b*,*i*][1,4,8,11]tetraazacyclotetradecinato) nickel(II) was 20%. The copper(II) and palladium(II) complexes were also obtained in very lower yield. The electron-withdrawing effect of pyrazinic nitrogens may cause the low yield of **1** and its metal complexes.

Electronic Spectra.

The electronic absorption spectra covering the 15000-37000 cm⁻¹ region are shown in Figure 1 for **1** together with those 5,14-dihydro-7,16-diethyl-(*Z*)-dipyrido[*b*,*i*][1,4,8,11]tetraazacyclotetradecine (**2**) and 5,14-dihydro-7,16-diethyldibenzo[*b*,*i*][1,4,8,11]tetraazacyclotetradecine (**3**). The absorption bands appearing in the energy region greater than 20000 cm⁻¹ are reasonably attributed to $\pi \rightarrow \pi^*$

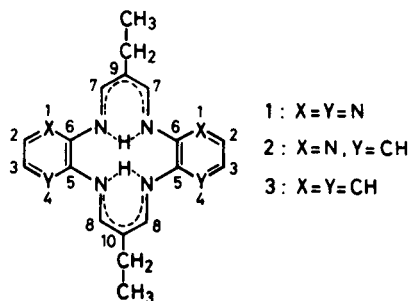
transitions within a ligand molecule. The intense absorption bands for **1**, **2** and **3** in the 26200-28200 cm⁻¹ region are observed in nearly similar energy region, but their molar extinction coefficients decrease in the following order: **1** < **2** < **3**. On the contrary, intense absorption bands observed in the 20100-23300 cm⁻¹ region have a increasing tendency on their red shift and ϵ -value in the following order: **1** > **2** > **3**. The spectral change is associated with the number of nitrogen atoms in aromatic rings of the tetraaza[14]annulene. This may be attributable to the electron-withdrawing effect of nitrogen atoms in aromatic rings.

The electronic absorption spectra covering the 15000-37000 cm⁻¹ region are shown in Figure 2 for the metal

chelates of 5,14-dihydro-7,16-diethyldipyrazo[*b,t*][1,4,8,11]-tetraazacyclotetradecine. The nickel(II), copper(II) and palladium(II) complexes do not show any significant absorption below *ca.* 16000 cm^{-1} . The spectral behavior is consistent with the square-planer coordination and is analogous to that observed for tetraaza[14]annulene metal(II) complexes containing benzene rings and pyridine rings which are described previously [1b, 2a,b]. The absorption bands for the copper(II) complex appearing in the 19200-25600 cm^{-1} region are attributed to $\pi \rightarrow \pi^*$ or CT transitions from metal to ligand. The behavior for copper(II) complexes of **1**, **2** and **3** in the 19200-25600 cm^{-1} region is considerably similar to that of metal-free ligand. A spectral feature in the 16600-25000 cm^{-1} region for the nickel(II) and palladium(II) complexes is different from that of the metal-free ligand and its copper(II) complex, but the spectral feature of the nickel(II) and palladium(II) complexes is similar, respectively.

NMR Spectra.

Proton nmr data and their assignments for **1** and its nickel(II) and palladium(II) chelates are summarized in Table I. The amine proton of the metal-free macrocycle couples with both methine protons and the amine proton signal is split into a triplet. On the other hand, the methine proton signal is split into a doublet. The amine proton signal was found to be extinguished on metal coordination, and the methine proton signal turned to be a singlet owing to no coupling with the amine proton. The amine and the methine proton peaks are observed in a lower field by 0.62-0.80 ppm than that for corresponding **3** and its metal chelate. This is attributable to electron-withdrawing effect of nitrogen atoms in pyrazine rings. The ^{13}C nmr data and their assignments for macrocyclic ligands **1**, **2**, and **3** are compiled in Table II. The carbon signals of 5-, 6-, 7-, 8-, 9- and 10-positions in the annulene



skeleton for **1** are observed in a lower field relative to those of **3** due to the electron-withdrawing effect of pyrazinic nitrogens. This result is consistent with the corresponding proton nmr spectral behavior.

EXPERIMENTAL

Unless otherwise noted all materials were reagent grade and were used

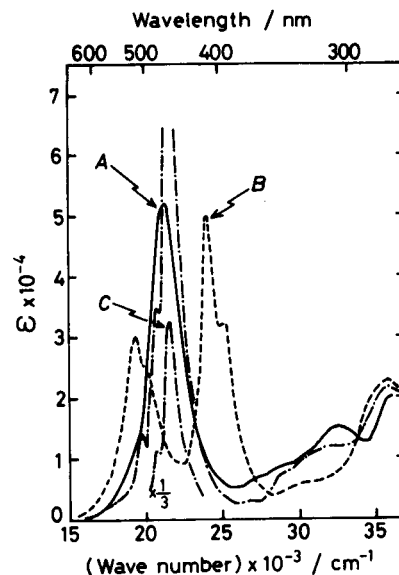


Figure 2. Electronic absorption spectra of (7,16-diethyldipyrazo[*b,t*][1,4,8,11]tetraazacyclotetradecinato)metal chelates in chloroform at room temperature. A, Nickel(II); B, copper(II); C, palladium(II).

without further purification.

Ultraviolet and visible spectra covering the 12500-50000 cm^{-1} region were recorded on a Shimadzu UV 200S double beam spectrophotometer at room temperature. Mass spectral measurements were carried out with a JEOL JMS-DX 300 gas chromatograph-mass spectrometer at 20 eV. Infrared spectra in the range of the 400-4000 cm^{-1} were measured with a Hitachi 260-10 spectrophotometer at room temperature by the potassium bromide disk technique. Proton and ^{13}C nmr measurements were taken on a JEOL JNM-FX 60 spectrometer. The nmr spectra were run in chloroform-*d* and dimethyl sulfoxide-*d*₆ and chemical shifts are reported in ppm relative to tetramethylsilane as an internal reference standard.

Pyrazine 1-Oxide.

This was prepared according to the procedure of Klein *et al.* [6]. This compound was prepared in 60% yield as colorless needles (benzene) (lit [7] mp 113-114°, mp 114.0-115.0°; ir: ν NO 1305 cm^{-1} ; ^1H -nmr (chloroform-*d*): δ 8.0-8.5 (m, 4H); λ max (methanol): 267, 219 nm; ms: *m/e* (relative intensity) 96 (100).

2-Chloropyrazine.

Phosphoryl chloride (120 ml) was warmed with stirring about 70° and pyrazine 1-oxide (12.0 g) was added in small portion to it. The reaction mixture was heated at 70° for another 2 hours with stirring. The dark mixture was chilled and poured cautiously into ice water (700 g) and kept below 15° with stirring. After the decomposition was complete (2 days), the solution was neutralized with 50% sodium hydroxide and extracted with ten 100 ml portions of chloroform. The combined extracts were washed with water and dried over anhydrous potassium carbonate. The solvent was removed *in vacuo* and the residue distilled, collecting 5.25 g (37%) product, bp 67.5° (40 mm) (lit [8] bp 60.5° (26 mm)); ^1H -nmr (chloroform-*d*): δ 8.37 (dd, 1H, *J* = 2.6, 1.3 Hz), 8.50 (d, 1H, *J* = 2.6 Hz), 8.61 (d, 1H, *J* = 1.3 Hz); λ max (ethanol): 274, 268 nm; ms: *m/e* (relative intensity) 114 (100).

3-Chloropyrazine 1-Oxide.

This was prepared according to the procedure of Klein *et al.* [8]. This compound was obtained in 35% yield as colorless needles (ethanol) (lit [8] 95-96°, mp 95.0-96.0°; ir: ν NO 1275 cm^{-1} ; ^1H -nmr (chloroform-*d*): δ 8.02 (dd, 1H, *J* = 4.1, 1.5 Hz), 8.16 (dd, 1H, *J* = 1.5, 0.7 Hz), 8.26 (dd, 1H, *J* = 4.1, 0.7 Hz); λ max (water): 267, 223 nm; ms: *m/e* (relative intensity) 130 (100).

2,3-Diaminopyrazine.

This was prepared according to the procedure of Klein *et al.* [9]. This compound was obtained in 10% yield as colorless needles (water) (lit [9] mp 205-206°), mp 205-206°; ir: ν NH 3300, 3120 cm^{-1} ; $^1\text{H-nmr}$ (dimethyl sulfoxide- d_6): δ 5.86 (s, 4H), 7.13 (s, 2H); λ max (methanol): 325, 243 nm; ms: m/e (relative intensity) 110 (100).

5,14-Dihydro-7,16-diethyldipyrzazo[*b,i*][1,4,8,11]tetraazacyclotetradecine (I).

A mixture of 2-ethyl-3-ethoxyacrolein [1b] (0.24 ml), 2,3-diaminopyrazine (0.20 g), *N,N*-dimethylformamide (2 ml) and cyclohexanol (2 ml) was heated under reflux for 4 hours while nitrogen gas was continuously bubbled through it. After the solvent was evaporated off *in vacuo*, the residue was applied to the top of a chromatographic column of silica gel (60-80 mesh, Kanto Chemical Co., Inc.) and eluted with chloroform. The solid residue, which was recovered by evaporating the initial effluent to dryness *in vacuo*, was recrystallized from chloroform to obtain 0.010 g of dark-red needles (3%), mp > 300°; ir: ν C=N 1635, ν C=C 1580, 1545 cm^{-1} ; ms: m/e (relative intensity) 349 (22.3), 348 (100).

Anal. Calcd. for $\text{C}_{18}\text{H}_{20}\text{N}_8$: C, 60.28; H, 5.67; N, 31.87. Found: C, 60.05; H, 5.79; N, 32.16.

(7,16-Diethyldipyrzazo[*b,i*][1,4,8,11]tetraazacyclotetradecinato)nickel(II).

2-Ethyl-3-ethoxyacrolein (0.12 ml) was added to a mixture of 2,3-diaminopyrazine (0.10 g), nickel(II) acetate tetrahydrate (0.12 g) and *N,N*-dimethylformamide (2 ml) at 80°. The reaction mixture was heated at 120° for another 4 hours with stirring. After the mixture was cooled down with ice-water, the precipitated crystalline solid was recrystallized from chloroform as dark-violet needles. The yield was 0.040 g (20%), mp > 300°; ir: ν C=C 1598, 1427 cm^{-1} ; ms: m/e (relative intensity) 407 (11.8), 406 (41.3), 405 (26.0), 404 (100.0), 392 (6.8), 391 (26.3), 390 (15.2), 389 (63.6).

Anal. Calcd. for $\text{C}_{18}\text{H}_{18}\text{N}_8\text{Ni}$: C, 53.37; H, 4.48; N, 27.66. Found: C, 52.92; H, 4.82; N, 27.31.

(7,16-Diethyldipyrzazo[*b,i*][1,4,8,11]tetraazacyclotetradecinato)copper(II).

N,N-Dimethylformamide (2 ml), 2-ethyl-3-ethoxyacrolein (0.12 ml), 2,3-diaminopyrazine (0.10 g) and copper(II) acetate monohydrate (0.10 g) were reacted as described above for 4 hours to yield 0.028 g of dark-brown needles (15%), mp > 300°; ir: ν C=C 1590, 1434 cm^{-1} ; ms: m/e (relative intensity) 412 (11.5), 411 (47.7), 410 (26.2), 409 (100.0), 397 (5.9),

396 (25.1), 395 (12.7), 394 (52.8).

Anal. Calcd. for $\text{C}_{18}\text{H}_{18}\text{N}_8\text{Cu}$: C, 52.74; H, 4.43; N, 27.33. Found: C, 52.72; H, 4.32; N, 27.30.

(7,16-Diethyldipyrzazo[*b,i*][1,4,8,11]tetraazacyclotetradecinato)palladium(II).

2-Ethyl-3-ethoxyacrolein (0.12 ml) was added to a mixture of 2,3-diaminopyrazine (0.10 g), sodium tetrachloropalladate(II) trihydrate (0.16 g) and *N,N*-dimethylformamide (4 ml) at 80°. The reaction mixture was heated at 120° for another 2 hours with stirring. After the mixture was cooled down, the precipitated crystalline was recovered on addition of water (100 ml) and chromatographed with chloroform as an eluent to give 0.008 g of dark-red needles (4%); mp > 300°; ir: ν C=C 1588, 1482 cm^{-1} ; ms: m/e (relative intensity) 456 (37.7), 455 (22.3), 454 (82.0), 453 (25.7), 452 (100.0), 451 (76.4), 450 (35.8), 441 (29.8), 440 (16.1), 439 (65.5), 438 (18.5), 437 (79.5), 436 (59.8), 435 (27.7).

Anal. Calcd. for $\text{C}_{18}\text{H}_{18}\text{N}_8\text{Pd}$: C, 47.75; H, 4.01; N, 24.75. Found: C, 47.72; H, 4.05; N, 24.98.

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