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Synthesis of *N*,*N*′-bis and *N*,*N*,*N*′,*N*′-tetra-[(3,5-di-substituted-1-pyrazolyl)methyl]-*para*-phenylenediamines: new candidate ligands for metal complex wires

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Abstract—A series of tridentate ligands *N*,*N*-bis-[(di-substituted-1-pyrazolyl)methyl]arylamines **2**–**3a**,**b** and benzylamine **4a**,**b**, tetradentate *N*,*N*′-bis-[(di-substituted-1-pyrazolyl)methyl]*para*-phenylenediamines **7a**,**b** and hexadentate *N*,*N*,*N*′,*N*′-tetra-[(di-substituted-1-pyrazolyl)-methyl]*para*-phenylenediamines **8a**,**b** has been prepared in good yield by condensation of arylamines, benzylamine or *para*-phenylenediamine with *N*-hydroxymethyl disubstituted pyrazoles **1a**,**b**. The synthesis and characterisation of these various polydentate ligands are described.

1. Introduction

Polymetallic complexes with suitable polydentate bridging ligands can be useful models of molecular wires.[1] By reference to macroscopic electrical devices, the concept of a wire is fundamentally based on intramolecular electron transfer that occurs in its simplest form in mixed-valence complexes. Bimetallic metal complexes with suitable bridging ligands can be useful models to study electronic interaction or electron transfer rates with distance including in biological electron transfer.[1] Another interesting use of long distance coordinating ligands is the electronic communication between remote metallic atoms and the development of molecular switches, that is, molecules able to promote or block intramolecular electron transfer.[1] This development clearly requires the mastering of long distance electron transfer (over 15–20 Å).

In search of new terminal coordinating groups to study intramolecular electron transfers, we have considered the case of polydendate pyrazole ligands. Such compounds are particularly interesting as ligands for the building of polynuclear complexes as models for bioinorganic systems[2] as well as for the discovery of new catalyst precursors.[3]

The flexibility of the pyrazolic *N*-coordinating groups of the tridentate ligands could allow them to act as meridional[4,5] or as facial ligands[6,7] when coordinating to transition metal complexes (Scheme 1).

In the case of polydentate ligands, they could coordinate in facial and meridional fashion as proposed in Scheme 1, such as by combination of bis-tridentate ligands with Ru^{2+} metal sites. In contrast, with bis-bidentate ligand, the four nitrogen atoms cannot coordinate to the same metal atom and are expected to lead to polymeric metal complex.[8–11]

To gain insight into the coordination behaviour of larger ligand systems containing at the same time pyrazolyl nitrogen groups and electron releasing amine *N*-donor

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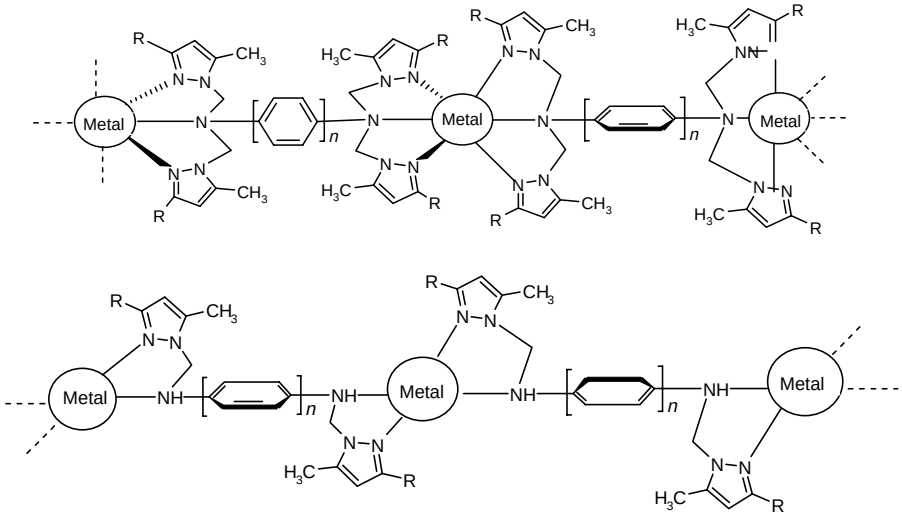


Scheme 1. Examples of possible polymetallic wires.

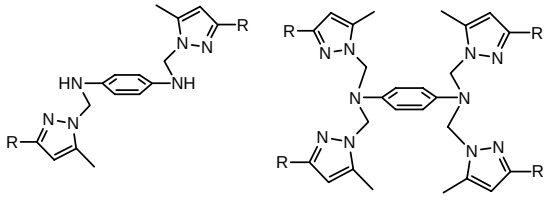
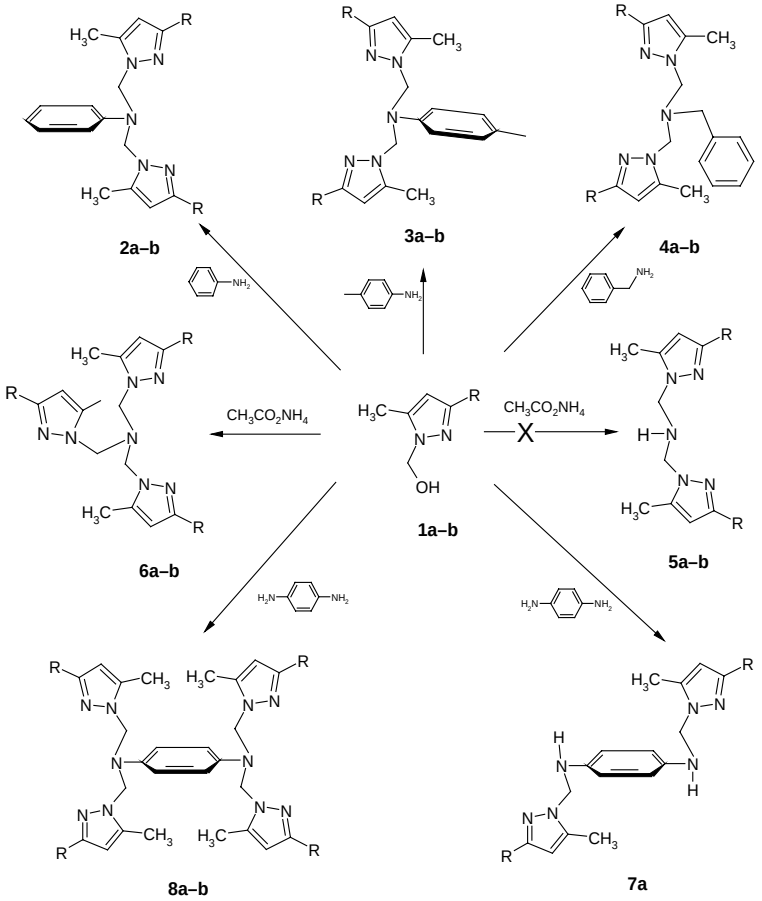


Figure 1.

atoms we have developed initial work on tridentate *N*,*N*-bis-[(3,5-dimethyl-1-pyrazolyl)methyl] alkylamines.[12]

In the present paper, we report the synthesis of a family of tridentate, tetradentate, bis-bidentate and bis-tridentate ligands containing pyrazol groups bridged by aminomethyl groups, with the general topology shown in Figure 1, on reaction of (pyrazol-1-yl)methanol and primary amines.



Scheme 2. Synthesis of tridentate (**2**–**4**), tetradentate (**6a**–**b**), bis-bidentate (**7a**) and bis-tridentate (**8a**–**b**) *N*-ligands with [R = –CH_3 (**a**), –CO_2CH_3 (**b**)].

2. Results and discussion

On the basis of our initial work for the synthesis of compounds **2a**[12] the new tridentate ligands **2b**, **3a**,**b**, **4a**,**b** were prepared on reaction of (3,5-dimethyl-1*H*-pyrazol-1-yl)methanol **1a** and methyl 1-(hydroxymethyl)-5-methyl-1*H*-pyrazole-3-carboxylate **1b**, respectively, with aniline, *p*-methylaniline or benzylamine. The tridentate compounds **2**–**4** were easily prepared from the condensation of 2 equiv of 1-(hydroxymethyl)-3,5-dimethyl-pyrazole **1a** or 1-(hydroxymethyl)-3-methoxycarbonyl-5-methyl-pyrazole **1b** with 1 equiv of arylamine under mild conditions (room temperature), using anhydrous acetonitrile as solvent. The reaction is very slow but selective at room temperature. Thus after 4–5 days of stirring at room temperature the derivatives **2b** (94%), **3a** (74%), **3b** (64%), **4a** (77%) and **4c** (53%) were isolated (Scheme 2).

Tetradentate molecules **6a**,**b** have been prepared using ammonium acetate as the source of ammonia as outlined in Scheme 2. In this way, the reaction of **1a**–**b** with ammonium acetate in acetonitrile could not be stopped to afford the expected tridentate ligands **5a**,**b** with central N–H group, and the tetradentate compounds **6a**,**b** were directly obtained.

The reaction of precursors **1a**,**b** with the *p*-phenylenediamine in CH_3CN at room temperature produces bis-bidentate ligand **7a** and bis-tridentate ligands **8a**,**b**. This reaction selectivity is simply controlled by the use of 2 and 4 equiv of **1a**–**b**, respectively, with respect to *p*-phenylenediamine, and **7a** (61%), **8a** (67%) and **8b** (73%) were isolated after 5 days of stirring at room temperature (Scheme 2). The crystal structure of hexadentate compound **8a** was recently reported and confirmed the molecular structure.[13]

By comparison with various bis-bidentate and bis-tridentate ligands for the synthesis of known bimetallic or polymetallic complexes in the literature,[14,15] we describe here bis-bidentate and bis-tridentate compounds, for which the synthesis is relatively easy. Their synthesis from *p*-phenylenediamine could certainly be generalised to a large variety of other aromatic diamines.

3. Experimental

3.1. General methods

Infrared spectra were recorded on a PYE Unicam SP3-300 spectrometer as KBr pellets. The ^1H and ^{13}C NMR spectra were recorded on Varian EM 360 (operating at 60 MHz for ^1H) or/and Bruker spectrometer (250 and 400 MHz) using TMS as internal standard. Chemical shifts are reported downfield from the standard in ppm. The FAB mass spectra were obtained on a NERMANG R10-LOC instrument. For the chemical ionisation ($DCI/NH_3/CH_3$), the compounds were dissolved in DMSO or MeOH and dispersed in a matrix solution, currently the 3-nitrobenzyl (MNBA) or Glycerol (GLY). Elemental analyses were performed by the Service Central d'Analyse du CNRS LCC (Toulouse).

3.2. Synthesis of compounds 2–8.

General procedure for the synthesis of **2**–**4** *and* **6**. The products were prepared by the addition of arylamine (p-R-$C_6H_4NH_2$), and ($C_6H_5CH_2NH_2$) or ammonium acetate to **1a** or **1b**. To a solution of the substituted hydroxymethylpyrazole **1a** (1.26 g, 10 mmol) or **1b** (1.70 g, 10 mmol) in acetonitrile (25 ml) was added the desired amine (5 mmol) and the mixture was continued at room temperature for 4–5 days. The formed compound was precipitated by addition of cold water to acetonitrile solution, washed with hexane and dried under vacuum. Compounds **2**–**4** and **6** were obtained as white solids (60–94% yield).

General procedure for the synthesis of **7**–**8**. The products **7**–**8** were prepared by the addition of *p*-phenylenediamine (NH_2–C_6H_4–NH_2) to **1a** or **1b**. To a solution of the substituted hydroxymethylpyrazole **1a** (1.26 g, 10 mmol) or **1b** (1.70 g, 10 mmol) in acetonitrile (25 ml) was added *p*-phenylenediamine (2.5 mmol) for **8** or (5 mmol) for **7** and the mixture and the stirring was continued at room temperature for 4–5 days. The product was precipitated by simple addition of cold water, washed with hexane and dried under vacuum. The compounds **7**–**8** were obtained as white solids (60–67%).

3.2.1. *N*,*N*-Bis[(3,5-dimethyl-1*H*-pyrazol-1-yl)methyl] aniline (2a). Yield 65%. Mp 85 °C (mp lit.[16] = 83 °C). IR (KBr, υ cm^{-1}): 3260 (=C–H Ar), 3080 (C–H Me), 1600 (C=C), 1500, 1470 (C=N); 1500, 1350, 1290, 1230, 1170, 1110, 1050. ^1H NMR (60 MHz, $CDCl_3$) δ ppm: 7.00 (m, 5H, Ph), 5.75 (s, 2H, pyrazol–$H^{4,4'}$), 5.40 (s, 4H, NCH_2N), 2.30 (s, 6H, CH_3), 2.10 (s, 6H, CH_3). MS (DCI/NH_3, CH_2Cl_2): Calcd for $[M]^+$ $C_{18}H_{23}N_5$: 310. Found $[M+H]^+$ (m/z) = 311 (45%).

3.2.2. Methyl-1-[({[3-(methoxycarbonyl)-5-methyl-1*H*-pyrazol-1-yl]methyl}anilino)methyl]-5-methyl-1*H* pyrazole-3-carboxylate (2b). Yield 94%. Mp 124–126 °C. IR (KBr, υ cm^{-1}): 3200 (CH, Ar), 2920 (CH), 1730 (C=O), 1600 (C=C), 1490 (C=N), 1460, 1420, 1230. ^1H NMR (250 MHz, $CDCl_3$) δ ppm: 6.70–7.45 (m, 5H, C_6H_5), 6.5 (s, 2H, pyrazol–$H^{4,4'}$), 5.65 (s, 4H, NCH_2N), 3.90 (s, 6H, OCH_3), 2.05 (s, 6H, pyrazol–CH_3). MS (MeOH/GLY): Calcd for $[M]^+$ $C_{20}H_{23}N_5O_4$: 397. Found $[M+H]^+$ (m/z) = 398 (19%). Elemental analysis for $C_{20}H_{23}N_5O_4$ Calcd (Found): C 60.45 (60.48), H 5.79 (5.81), N 17.63 (17.56).

3.2.3. (3,5-Dimethyl-1*H*-pyrazol-1-yl)-*N*-[(3,5-dimethyl-1*H*-pyrazol-1-yl)methyl]methanamine (3a). Yield 74%. Mp 108–109 °C. IR (KBr, υ cm^{-1}): 3025 (=C–H Ar), 2950 (CH), 1720/1600 1500/1472 (C=N). ^1H NMR (60 MHz, $CDCl_3$) δ ppm: 6.8, 7.3 (m, 4H, Ph), 5.90 (s, 2H, pyrazol–$H^{4,4'}$), 5.60 (s, 4H, $2NCH_2N$), 2.25 (s, 15H, CH_3-Ph + CH_3-pz). MS (DCI/NH_3, CH_2Cl_2): Calcd for $[M]^+$ $C_{19}H_{25}N_5$: 323. Found $[M+H]^+$ (m/z) = 324 (23%).

3.2.4. (3-(Methoxycarbonyl)-5-methyl-1*H*-pyrazol-1-yl)methyl]methanamine (3b). Yield 64%. ^1H NMR (400 MHz, $CDCl_3$) δ ppm: 7.10 (d, 2H, C_6H_5), 6.90 (d, 2H, C_6H_5), 6.50 (s, 2H, pyrazol–$H^{4,4'}$), 5.70 (s, 4H,

2NCH$_2$N), 3.95 (s, 6H, 2OCH$_3$), 2.30 (s, 3H, CH$_3$-ph), 2.10 (s, 6H, pyrazol–CH$_3$). MS (CI/CH$_3$): Calcd for [M]$^{\cdot+}$ $C_{21}H_{25}N_5O_4$: 411. Found [M+H]$^{\cdot+}$ (m/z)=412 (4.92%).

3.2.5. (3,5-Dimethyl-1*H*-pyrazol-1-yl)-*N*-[(3,5-dimethyl-1*H*-pyrazol-1-yl)methyl]benzylamine (4a). Yield 65%. Mp 73 °C. IR (KBr, υ cm^{-1}): 3085 (=C–H aromat), 2930 (CH), 1550 (C=C), 1450 (C=N), 1380, 1310, 1100, 1000, 960, 800, 750. ^{1}H (60 MHz, CDCl$_3$) δ ppm: 7.4 (s, 5H, C$_6$H$_5$), 5.9 (s, 2H, pz, C$^{4,4'}$), 5 (s, 2N–CH$_2$–N), 3.9 (s, 2H, ph-CH$_2$–N), 2.3 (s, 6H, 2CH$_3$, C$^{3,3'}$), 2.1 (s, 6H, 2CH$_3$, C $^{5,5'}$). MS (DCI/NH$_3$): Calcd for [M]$^{\cdot+}$ $C_{19}H_{25}N_5$: 323. Found [M+H]$^{\cdot+}$ (m/z)=324 (92.5%), 228 (100%), 137 (21.7%), 120 (37.5%), 114 (42.5%).

3.2.6. (-3-(Methoxycarbonyl)-5-methyl-1*H*-pyrazol-1-yl)methyl]]benzylamine (4b). Yield 65%. Mp 85 °C. IR (KBr, υ cm^{-1}): 3025 (=CH aromat), 2950 (CH), 1750 (C=O), 1600, 1450 (C=C), 1310, 1220 (C–O), 940, 820, 780. ^{1}H (400 MHz, CDCl$_3$) δ ppm: 7.4. (s, 5H, C$_6$H$_5$), 5.2 (s, 4H, 2NCH$_2$N), 3.9 (s, 6H, 2O–CH$_3$), 3.8 (s, 2H, ph-*CH*$_2$–N), 2.1 (s, 6H, 2CH$_3$, C$^{5,5'}$). C^{13} (400 MHz, CDCl$_3$) δ ppm: 163.04 (CO$_2$Me), 142.62–140.69 (ph), 130.1 (C$^{3,3'}$), 122.85 (C$^{5,5'}$), 108.83 (C$^{4,4'}$), 66.73 (N–*CH*$_2$–N), 52.04 (O–CH$_3$), 20.84 (ph-*CH*$_2$–N), 11.08 (CH$_3$–CH3$^{5,5'}$). Elemental analysis for $C_{21}H_{25}N_5O_4$ Calcd (Found): C 61.31 (61.48), H 6.08 (6.20), N 17.03 (17.40). MS (CI/CH$_3$): Calcd for [M]$^{\cdot+}$ $C_{21}H_{25}N_5O_6$: 411. Found [M+C_2H_5]$^{\cdot+}$ (m/z)=440 (5%).

3.2.7. (3,5-Dimethyl-1*H*-pyrazol-1-yl)-*N*-[(3,5-dimethyl-1*H*-pyrazol-1-yl)methyl] amine (6a). Yield 77%. Mp 94–96 °C. IR (KBr, υ cm^{-1}): 3000 (=C–H aromat), 290 (CH), 1560, 1440 (C=N), 1400, 1350, 1290, 1230, 1160, 1050, 830, 690. ^{1}H (60 MHz, CDCl$_3$) δ ppm: 5.70 (s, 3H, pz, H^4), 5.00 (s, NCH$_2$N), 2.10 (s, 9H, 3CH$_3$), 1.90 (s, 9H, 3CH$_3$). MS (DCI/NH$_3$): Calcd for [M]$^{\cdot+}$ $C_{18}H_{27}N_7$: 341. Found [M+H]$^{\cdot+}$ (m/z)=342 (100%).

3.2.8. (-3-(Methoxycarbonyl)-5-methyl-1*H*-pyrazol-1-yl)methyl]] amine (6b). Yield 53%. IR (KBr, υ cm^{-1}): 3080 (=C–H aromat), 2940 (CH), 1730 (C=O), 1450 (C=N), 1380, 1330, 1240, 1180, 1120, 1040, 830, 800. ^{1}H (400 MHz, CDCl$_3$) δ ppm: 6.50 (s, 3H, pz, H^4), 5.20 (s, 6H, 3NCH$_2$N), 3.90 (s, 9H, 3O–CH$_3$), 1.90 (s, 9H, 3CH$_3$). C^{13} (400 MHz, CDCl$_3$) δ ppm: 162.67 (CO$_2$Me), 142.85 (C$^{3,3',3''}$), 141.13 (C$^{5,5',5''}$), 109.15 (C$^{4,4',4''}$), 63.55 (N–CH$_2$–N), 52.04 (O–CH$_3$); 10.09 (CH$_3$–C$^{5,5',5''}$). MS (CI/CH$_3$): Calcd for [M]$^{\cdot+}$ $C_{21}H_{27}N_7O_6$: 473. Found [MH]$^{\cdot+}$ (m/z)=474 (3%).

3.2.9. *N*,*N*′ Bis[(3,5-dimethyl-1*H*-pyrazol-1-yl)methyl]-1,4-benzenediamine (7a). Yield 61.5%. Mp 158–160 °C. IR (KBr, υ cm^{-1}): 3300 (–NH), 2920 (=CH), 1520 (C=C), 1450 (C=N), 1380, 1180. NMR ^{1}H (60 MHz, CDCl$_3$) δ ppm: 6.65 (s, 4H, Ph), 5.7 (s, 2H, pyrazol–C^4), 5.4 (s, 4H, N*CH*$_2$N), 4.4 (s, 2H, Ph-N–H), 2.2 (s, 6H, CH$_3$, C$^{3,3'}$), 2.1 (s, 6H, CH$_3$, C$^{5,5'}$). MS (DCI/NH$_3$, CH$_2$Cl$_2$): Calcd for [M]$^+$ $C_{18}H_{24}N_6$: 324.219. Found [M+H]$^{\cdot+}$ (m/z)=325 (2.52%).

3.2.10. *N*,*N*,*N*′,*N*′-Tetrakis[(3,5-dimethyl-1*H*-pyrazol-1-yl)methyl]-1,4-benzenediamine (8a). Yield 67%. Mp 174–176 °C. IR (KBr, υ cm^{-1}): 2980 (C–H), 1590 (C=C), 1220, 1170, 1490. ^{1}H NMR (250 MHz, CDCl$_3$) δ ppm: 7 (s, 4H, Ph), 5.8 (s, 4H, pyrazol), 5.5 (s, 8H, NCH$_2$N), 2.3 (s, 12H, CH$_3$), 2.0 (s, 12H, CH$_3$). MS Calcd for [M]$^+$ $C_{34}H_{40}N_{10}O_8$: 716; [M+Na$^+$]$^{\cdot}$ (m/z)= 739, 613, 585, 460. MS (FAB<0, MeOH/GLY): Calcd for [M]$^{\cdot+}$ $C_{30}H_{40}N_{10}$: 540. Found [M+H]$^{\cdot+}$ (m/z)=541 (11.5%). Elemental analysis for $C_{30}H_{40}N_{10}$ Calcd (Found): C 65.66 (65.82), H 7.40 (6.98), N 25.90 (25.24).

3.2.11. Methyl-1-[(4-(bis{[3-(methoxycarbonyl)-5-methyl-1*H*-pyrazol-1-yl]methyl}amino){[3-(methoxycarbonyl)-5-methyl-1*H*-pyrazol-1-yl]methyl}anilino)methyl]-5-methyl-1*H*-pyrazole-3-carboxylate (8b). Yield 73.5%. Mp 196–198 °C. IR (KBr, υ cm^{-1}): 3140 (=CH), 2990 (CH), 1730 (C=O), 1540 (C=C), 1480 (C=N), 1450, 1410. ^{1}H NMR (250 MHz, CDCl$_3$) δ ppm: 7.3 (s, 4H, Ph), 6.6 (s, 4H, pyrazol), 5.6 (s, 8H, 4N–CH$_2$–N), 4.0 (s, 12H, 4O–CH$_3$), 2.2 (s, 12H, 4CH$_3$). MS (FAB<0, DMSO/MNBA): Calcd for [M]$^+$ $C_{34}H_{40}N_{10}O_8$: 716; [M+Na]$^{\cdot+}$ (m/z)=739 (100%). Elemental analysis for $C_{30}H_{40}N_{10}O_8$ Calcd (Found): C 56.97 (56.62), H 5.63 (5.51), N 19.54 (19.47).

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