Supplementary Material (ESI) for Dalton Transactions

Supporting Information

For

Dinickel Complexes of Disubstituted Benzoate Polydentate Ligands: Mimics for the Active Site of Urease

Way-Zen Lee,*[a] Huan-Sheng Tseng,[a] Meng-Yu Ku,[a] and Ting-Shen Kuo[b]

Department of Chemistry, National Taiwan Normal University, Taipei 11650, Taiwan,
and Instrumentation Center, Department of Chemistry, National Taiwan Normal
University, Taipei 11650, Taiwan

Experimental Section

General Methods

All manipulations were performed under nitrogen using standard Schlenk and glovebox techniques. Methanol was dried over magnesium iodide prior to use. Acetonitrile was distilled once from P_2O_5, and freshly distilled from CaH_2 before use. Dichloromethane was distilled from CaH_2 before use. Diethyl ether and THF were dried by distillation from sodium benzophenone prior to use. All reagents were obtained from commercial sources and used as received without further purification. UV-vis spectra were recorded on Hitachi U-3501 spectrophotometers. IR spectra were recorded using KBr pellets on a Perkin-Elmer Paragon 500 spectrometer. NMR spectra were recorded on Bruker Avance-400 MHz and Bruker Avance-500 MHz FT NMR spectrometers. ESI-Ms spectra were recorded on a Thermo Finnigan LCQ Advantage spectrometer. Elemental analyses for C, H, and N were performed on a Perkin-Elmer 2400 analyzer at the NSC Regional Instrumental Center at National Taiwan University, Taipei, Taiwan.

Synthesis

Methyl 2,6-bis[di(pyridinyl-2-methyl)aminomethyl]benzoate (MeL). Di-(2-picolyl)amine (6.24 g, 31.3 mmol), triethylamine (3.16 g, 31.3mmol), and methyl 2,6-bis(bromomethyl)benzoate (4.80 g, 14.9 mmol) were mixed and dissolved in 200 mL of THF. The reaction mixture was then refluxed for 3 days under nitrogen. Some insoluble white solid was formed and filtered out, and the solvent of the filtrate was removed under vacuum. The resulting residue was dissolved in dichloromethane and washed with water, and the volatiles were evaporated under reduced pressure and purified by chromatography (R_f = 0.4, EA/MeOH 9:1) on silica gel to give a light yellow solid of Me**L** in a yield of 87% (7.28 g). ^{1}H NMR (400 MHz, $CDCl_3$, ppm): 8.50 (d, 4H, Ar, J = 4.4 Hz), 7.61 (t, 4H, Ar, J = 7.6 Hz), 7.47-7.42 (m, 6H, Ar), 7.28 (t, 1H, Ar, J = 7.6 Hz), 7.11 (t, 4H, Ar, J = 6.0 Hz), 3.82 (s, 3H, CH_3), 3.78 (s, 4H, CH_2), 3.76 (s, 8H, CH_2). ^{13}C NMR (100 MHz, $CDCl_3$, ppm): 169.48, 158.92, 148.73, 137.12, 136.23, 133.71, 129.17, 128.64, 123.23, 121.88, 59.81, 56.87, 51.78.

2,6-bis[di(pyridinyl-2-methyl)aminomethyl]benzoate acid (HL). MeL (0.558 g, 1 mmol) was dissolved in a 0.2 M ethanol solution of KOH (25 mL) and refluxed for 2 days. The solvent of the resulting mixture was evaporated under reduced pressure, and the residue was dissolved in 5 mL of water, acidified with concentrated hydrochloric acid to pH 6.6 and extracted with ethyl acetate. The ethyl acetate solution was then dried over $MgSO_4$ and the solvent was removed under vacuum to give a light yellow oil of H**L** (0.523 g, 96%). Anal. Calcd for $C_{33}H_{32}N_6O_2$: C, 72.77; H, 5.92; N, 15.43. Found: C, 72.78; H, 6.16; N, 14.93. ^{1}H NMR (400 MHz, $CDCl_3$, ppm): 8.48 (d, 4H, Ar, *J* = 3.4 Hz), 7.6 (t, 4H, Ar, *J* = 6.1 Hz), 7.48-7.46 (m, 6H, Ar), 7.27 (t, 1H, Ar, *J* = 6.5 Hz), 7.10 (t, 4H, Ar, *J* = 4.8 Hz), 3.79 (s, 12H, CH_2). ^{13}C NMR (100 MHz, $CDCl_3$, ppm): 169.08, 158.76, 148.64, 136.65, 136.48, 134.08, 129.24, 128.70, 123.34, 122.02, 59.77, 56.70. IR (KBr), ν/cm^{-1}: 3228 (ν_{OH}), 1720 (ν_{COOH}), 1594 , 1571, 1476, 1435, 1366, 1278, 1249, 1150, 1123, 1068, 770, 625 cm^{-1}. ESI-MS (*m*/*z*, amu): 545 [M + 1]$^+$.

Methyl 2,6-bis[di(1-methylbenzimidazolyl-2-methyl)aminomethyl]benzoate (MeL'). Bis[(1-methylbenzimidazolyl-2-methyl)amine[1] (3.38 g, 11.06 mmol), sodium carbonate (1.67 g, 15.8mmol), and methyl 2,6-bis(bromomethyl)benzoate (1.69 g, 5.26 mmol) were mixed and dissolved in 140 mL of DMF. The reaction mixture was heated to 80 °C for 3 days under nitrogen. Some insolubile white solid was formed and filtered out, and the solvent of the filtrate was removed under vacuum. The resulting residue was dissolved in chloroform and washed with water, and the volatiles were evaporated under reduced pressure and purified by chromatography (R_f = 0.7, MeOH/CH_2Cl_2 1:1) on silica gel to give a light yellow solid of Me**L'** in a yield of 99% (4.04 g). ^{1}H NMR (400 MHz, $CDCl_3$, ppm) : 7.69-7.67 (m, 4H, Ar), 7.31-7.28 (m, 3H, Ar), 7.24 - 7.17 (m, 12H, Ar), 3.93 (s, 8H, CH_2), 3.85 (s, 4H, CH_2), 3.29 (s, 12H, CH_3), 2.87 (s, 3H, CH_3). ^{13}C NMR (100 MHz, $CDCl_3$, ppm): 168.70, 151.03, 141.80, 135.94, 135.87, 135.63, 130.74, 129.24, 123.07, 122.40, 119.52, 109.42, 57.28, 51.50, 50.36, 29.66.

2,6-bis[di(1-methylbenzimidazolyl-2-methyl)aminomethyl]benzoate acid (H L'). Potassium hydroxide (9.77 g, 174 mmol) was dissolved in 18 mL of water and transferred into a DMF solution (60 mL) of Me**L** (1.35 g, 1.75 mmol) to form a light pink solution. The reaction mixture was refluxed for 3 days. The solvent of the resulting mixture was evaporated under reduced pressure, and the residue was dissolved in 5 mL of water, acidified with concentrated hydrochloric acid to pH 7.0 and extracted with chloroform. The chloroform solution was then dried over $MgSO_4$ and the solvent was removed under vacuum to give a light yellow solid of H**L'** (1.17 g, 89%). Anal. Calcd for $C_{45}H_{44}N_{10}O_2$: C, 71.41; H, 5.86; N, 18.51. Found: C, 71.02; H, 5.88; N, 18.10. ^{1}H NMR (400 MHz, $CDCl_3$, ppm) : 7.52-7.50 (m, 4H, Ar), 7.10-6.98 (m, 15H, Ar), 4.02 (s, 8H, CH_2), 3.97 (s, 4H, CH_2), 3.47 (s, 12H, CH_3). ^{13}C NMR (100 MHz, $CDCl_3$, ppm): 173.28, 151.33, 140.95, 140.01, 135.33, 134.17, 129.96, 127.40, 123.23, 122.72, 118.51, 109.49, 58.89, 50.76, 30.16. mp: 251~253 °C. IR (KBr), ν/cm^{-1}: 3354 (ν_{OH}), 1661 (ν_{COOH}), 1615 , 1570, 1481, 1444, 1404, 1334, 1289, 1237, 1105, 996, 862, 770, 746 cm^{-1}. ESI-MS (*m*/*z*, amu): 757 [M + 1]$^+$.

[LNi$_2$(DMF)$_4$](ClO$_4$)$_3$ (1). Sodium methoxide (0.045 g, 0.83 mmol) was dissolved in 20 mL of methanol and transferred into a methanol solution (40 mL) of H**L** (0.453 g, 0.83 mmol) to form a pale yellow solution, subsequently added to an acetonitrile solution (15 mL) of [Ni(H$_2$O)$_6$](ClO$_4$)$_2$ (0.608 g, 1.66 mmol) to yield a light blue solution. The reaction mixture was stirred at room temperature for one hour. Removal of the solvent from the resulting solution by vacuum gave a blue residue, which was then washed with THF (3 × 80 mL) and dissolved in 80 mL of acetonitrile. The acetonitrile solution was filtered through celite, and the solvent of the filtrate was removed under vacuum to give a light blue solid of **1**. The light blue solid was dissolved in DMF and recrystallized by slow diffusion of diethyl ether into the DMF solution of **1** at room temperature. Light blue crystals of **1** was obtained in a week with a yield of 83% (0.884 g). Anal. Calcd for [LNi$_2$(DMF)$_4$](ClO$_4$)$_3$·MeOH (Ni$_2$C$_{46}$H$_{63}$N$_{10}$- Cl$_3$O$_{19}$): C, 43.04; H, 4.95; N, 10.91. Found: C, 42.43; H, 5.25; N, 11.42. UV-vis (DMF): 351 (sh, 70 M^{-1}cm^{-1}), 589 (23 M^{-1}cm^{-1}), 959 nm (40 M^{-1}cm^{-1}). IR (KBr, cm^{-1}): 3384 (ν_{OH}), 1662 (ν_{COO^-}), 1652 (ν_{COO^-}) , 1608 (ν_{py}), 1593 (ν_{bz}), 1558 (ν_{bz}), 1445, 1296, 1147 ($\nu_{ClO_4^-}$), 1116 ($\nu_{ClO_4^-}$), 1088 ($\nu_{ClO_4^-}$), 766, 668, 636 ($\nu_{ClO_4^-}$), 626 ($\nu_{ClO_4^-}$). ESI-MS (*m/z*, amu): 318 [LNi$_2$(DMF)$_4$]$^{3+}$, 293 [LNi$_2$(DMF)$_3$]$^{3+}$, 269 [LNi$_2$(DMF)$_2$]$^{3+}$.

[LNi$_2$(NO$_3$)$_2$](NO$_3$) (2). Sodium methoxide (0.052 g, 0.96 mmol) was dissolved in 20 mL of methanol and transferred into a methanol solution (40 mL) of H**L** (0.522 g, 0.96 mmol) to form a pale yellow solution, subsequently added to an acetonitrile solution (15 mL) of [Ni(H$_2$O)$_6$](NO$_3$)$_2$ (0.557 g, 1.92 mmol) to yield a light blue solution. The reaction mixture was stirred at room temperature for one hour. Removal of the solvent from the resulting solution by vacuum gave a blue residue, which was redissolved in 100 mL of acetonitrile and filtered through celite. The solvent of the filtrate was removed under vacuum to give a light blue solid of **2**. The light blue solid was dissolved in methanol and recrystallized by slow diffusion of diethyl ether into the methanol solution of **2** at room temperature. Light blue crystals of **2** was obtained in a week with a yield of 91% (0.782 g). Anal. Calcd for [LNi$_2$(NO$_3$)$_2$]-(NO$_3$)·CH$_3$CN·H$_2$O (Ni$_2$C$_{35}$H$_{36}$N$_{10}$O$_{12}$): C, 46.39; H, 4.00; N, 15.46. Found: C, 46.08; H, 4.04; N, 15.38. UV-vis (MeOH): 372 (sh, 32 M^{-1}cm^{-1}), 606 (19 M^{-1}cm^{-1}), 927 nm (31 M^{-1}cm^{-1}). IR (KBr, cm^{-1}): 3314 (ν_{OH}), 1658 (ν_{COO^-}), 1650 (ν_{COO^-}), 1608 (ν_{py}), 1592 (ν_{bz}), 1555 (ν_{bz}), 1482, 1445, 1384 ($\nu_{NO_3^-}$), 1155, 1100, 1052, 1026, 971, 866, 825, 800, 765, 719, 650. ESI-MS (*m/z*, amu): 785 $[LNi_2(NO_3)_2]^+$, 362 $[LNi_2(NO_3)]^{2+}$.

$[L'Ni_2(CH_3CN)_4](ClO_4)_3$ (3). Sodium methoxide (0.095 g, 1.75 mmol) was dissolved in 20 mL of methanol and transferred into a dichloromethane solution (60 mL) of H**L'** (1.324 g, 1.75 mmol) to form a pale yellow solution, subsequently added to an acetonitrile solution (15 mL) of $[Ni(H_2O)_6](ClO_4)_2$ (1.281 g, 3.50 mmol) to yield a light blue solution. The reaction mixture was stirred at room temperature for one hour. Removal of the solvent from the resulting solution by vacuum gave a blue residue, which was then washed with THF (3 × 80 mL) and dissolved in 80 mL of acetonitrile. The acetonitrile solution was filtered through celite, and the filtrate was concentrated for recrystallization by slow diffusion of diethyl ether into the concentrated acetonitrile solution at room temperature. Complex **3** was obtained as light blue crystals in a week (yield: 1.155 g, 47%). Anal. Calcd for $[L'Ni_2(CH_3CN)_4]$-$(ClO_4)_3\cdot 2CH_3CN\cdot 0.5H_2O$ ($Ni_2C_{57}H_{62}N_{16}Cl_3O_{14.5}$): C, 47.98; H, 4.38; N, 15.71. Found: C, 47.76; H, 4.47; N, 15.75. UV-vis (CH_3CN): 370 (48 $M^{-1}cm^{-1}$), 598 (29 $M^{-1}cm^{-1}$), 962 nm (25 $M^{-1}cm^{-1}$). IR (KBr, cm^{-1}): 3369 (ν_{OH}), 2024 (ν_{CN}), 1622 (ν_{COO^-}),1616 (ν_{COO^-}), 1592 (ν_{bzim}), 1565 (ν_{bz}), 1504 (ν_{bzim}), 1483, 1456, 1418, 1326, 1296, 1145 ($\nu_{ClO_4^-}$), 1112 ($\nu_{ClO_4^-}$), 1088 ($\nu_{ClO_4^-}$), 1008, 931, 859, 800, 750, 636 ($\nu_{ClO_4^-}$), 626 ($\nu_{ClO_4^-}$), 537, 432. ESI-MS (*m/z*, amu): 486 $[L'Ni_2(ClO_4)]^{2+}$, 318 $[L'Ni_2(CH_3CN)_2]^{3+}$, 304 $[L'Ni_2(CH_3CN)]^{3+}$.

$[LNi_2(urea)_4](ClO_4)_3$ (4). Excess urea (0.120 g, 2 mmol) was dissolved in 15 mL of methanol and added to an acetonitrile solution (20 mL) of **1** (0.286 g, 0.2 mmol). The reaction mixture was stirred at room temperature for one hour. Removal of the solvent from the resulting solution by vacuum gave a blue residue, which was redissolved in 50 mL of acetonitrile and filtered through celite. The filtrate was concentrated for recrystallization by slow diffusion of diethyl ether into the concentrated methanol solution at room temperature. Complex **4** was obtained as light blue crystals in a week (yield: 0.205 g, 78%). Anal. Calcd for $[LNi_2(urea)_4]$-$(ClO_4)_3\cdot 2MeOH\cdot urea$ ($Ni_2C_{40}H_{59}N_{16}Cl_3O_{21}$): C, 36.29; H, 4.49; N, 16.93. Found: C, 36.32; H, 4.40; N, 16.96. UV-vis (MeOH): 367 (sh, 39 $M^{-1}cm^{-1}$), 606 (18 $M^{-1}cm^{-1}$), 920 nm (31 $M^{-1}cm^{-1}$). IR (KBr, cm^{-1}): 3352 (ν_{OH}) , 3187 (ν_{NH}) , 1664 (ν_{CO}), 1652 (ν_{COO^-}),1644 (ν_{COO^-}), 1609 (ν_{py}), 1591 (ν_{bz}), 1553 (ν_{bz}), 1479, 1444, 1422, 1294, 1144 ($\nu_{ClO_4^-}$), 1116 ($\nu_{ClO_4^-}$), 1088 ($\nu_{ClO_4^-}$), 1027, 866, 782, 761, 636 ($\nu_{ClO_4^-}$), 627 ($\nu_{ClO_4^-}$). ESI-MS (*m/z*, amu): 410 $[LNi_2(urea)(ClO_4)]^{2+}$, 380 $[LNi_2(ClO_4)]^{2+}$, 260 $[LNi_2(urea)_2]^{3+}$, 240 $[LNi_2(urea)]^{3+}$.

$[L'Ni_2(urea)_4](ClO_4)_3$ (5). Excess urea (0.030 g, 0.5 mmol) was dissolved in 15 mL of methanol and added to an acetonitrile solution (20 mL) of **3** (0.071 g, 0.05 mmol). The reaction mixture was stirred at room temperature for one hour. Removal of the solvent from the resulting solution by vacuum gave a blue residue, which was redissolved in 50 mL of acetonitrile and filtered through celite. The filtrate was concentrated for recrystallization by slow diffusion of diethyl ether into the concentrated acetonitrile solution at room temperature. Complex **5** was obtained as light blue crystals in a week (yield: 0.061 g, 82%). Anal. Calcd for $[\mathrm{L'Ni_2(urea)_4}]$-$(\mathrm{ClO_4})_3$ ($\mathrm{Ni_2C_{49}H_{59}N_{18}Cl_3O_{18}}$): C, 41.69; H, 4.21; N, 17.86. Found: C, 41.89; H, 4.53; N, 17.65. UV-vis ($\mathrm{CH_3CN}$): 373 (42 $\mathrm{M^{-1}cm^{-1}}$), 604 (27 $\mathrm{M^{-1}cm^{-1}}$), 977 nm (25 $\mathrm{M^{-1}cm^{-1}}$). IR (KBr, $\mathrm{cm^{-1}}$): 3193 (ν_{NH}), 2021 (ν_{CN}), 1668 (ν_{CO}), 1622 ($\nu_{\mathrm{COO-}}$), 1616 ($\nu_{\mathrm{COO-}}$) , 1592 (ν_{bzim}), 1560(ν_{bz}), 1500 (ν_{bzim}), 1482, 1418, 1327, 1296, 1149, 1145 ($\nu_{\mathrm{ClO_4^-}}$), 1114 ($\nu_{\mathrm{ClO_4^-}}$), 1088 ($\nu_{\mathrm{ClO_4^-}}$), 1008, 931, 798, 746, 636($\nu_{\mathrm{ClO_4^-}}$), 627($\nu_{\mathrm{ClO_4^-}}$), 537. ESI-MS (*m/z*, amu): 1071 $[\mathrm{L'Ni_2(ClO_4)_2}]^{+}$, 516 $[\mathrm{L'Ni_2(urea)(ClO_4)}]^{2+}$, 486 $[\mathrm{L'Ni_2(ClO_4)}]^{2+}$, 318 $[\mathrm{L'Ni_2(CH_3CN)_2}]^{3+}$, 311 $[\mathrm{L'Ni_2(urea)_2}]^{3+}$.

X-ray Structure Determination.

Crystals with a suitable size for CCD X-ray diffractometer were selected under a microscope and mounted on the tip of a glass fiber fashioned on a copper pin. X-ray data for complexes **1-5** were collected on a Brucker-Nonius Kappa CCD diffractometer employing graphite monochromated Mo Kα radiation ($\lambda = 0.7107$ Å) at 200 K and a θ - 2θ scan mode. The space groups for all complexes were determined on the basis of systematic absences and intensity statistics, and the structures of **1-5** were solved by direct methods using SIR92 or SIR97, and refined using SHELXL-97. An empirical absorption correction by multiscans was applied to all structures. All non-hydrogen atoms were refined with anisotropic displacement factors. Hydrogen atoms were placed in ideal positions and fixed with relative isotropic displacement parameters. Detail crystallographic data of all complexes are provided in CIFs. CCDC reference numbers are 667937 - 667941.

References

1. W.-Z. Lee, H.-S. Tseng and T.-S. Kuo, *Dalton Trans.* 2007, 2563-2570.

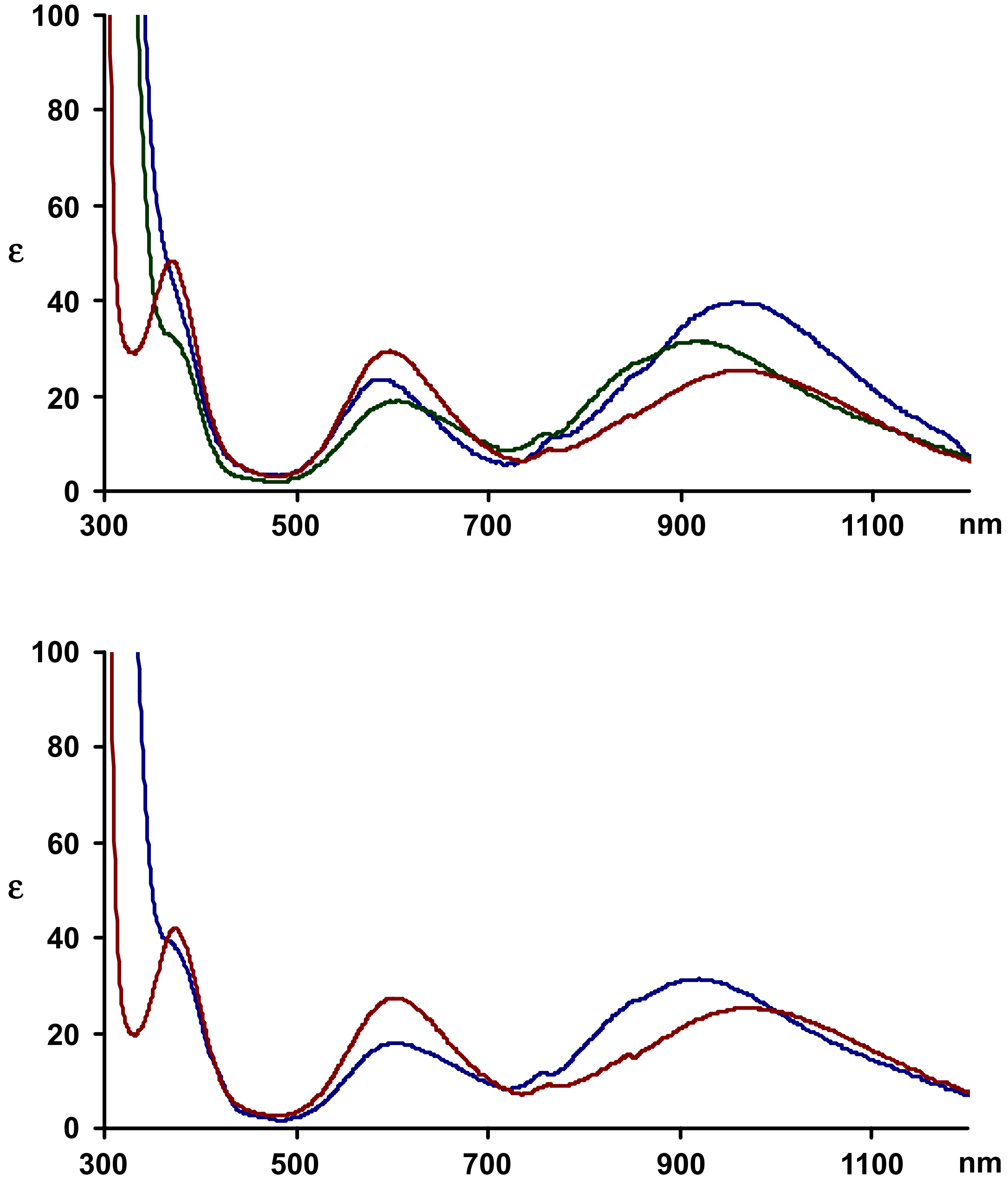
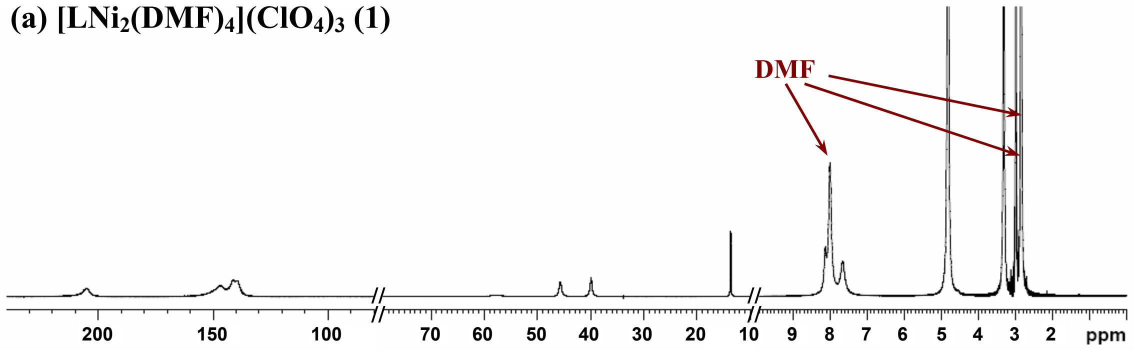
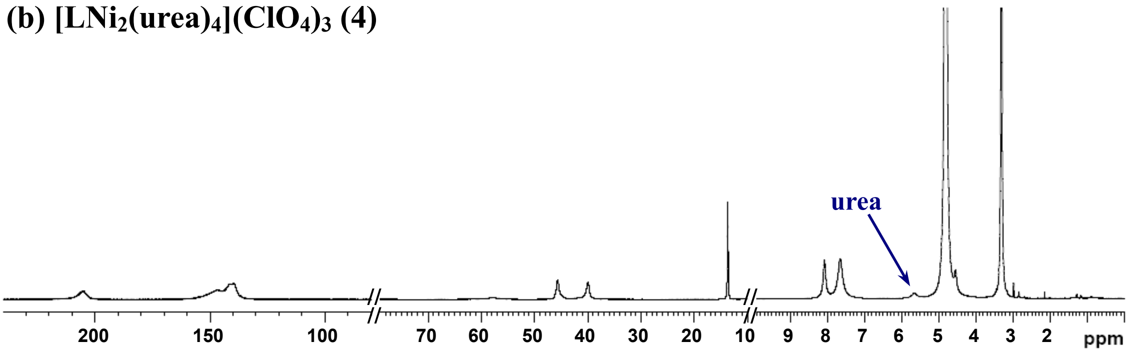


Fig. S1 UV-vis spectra of (a) complexes **1-3** (blue for **1**, green for **2**, red for **3**), and (b) complexes **4** and **5** (blue for **4**, red for **5**). Detail UV-vis data of all complexes are listed in experimental section.

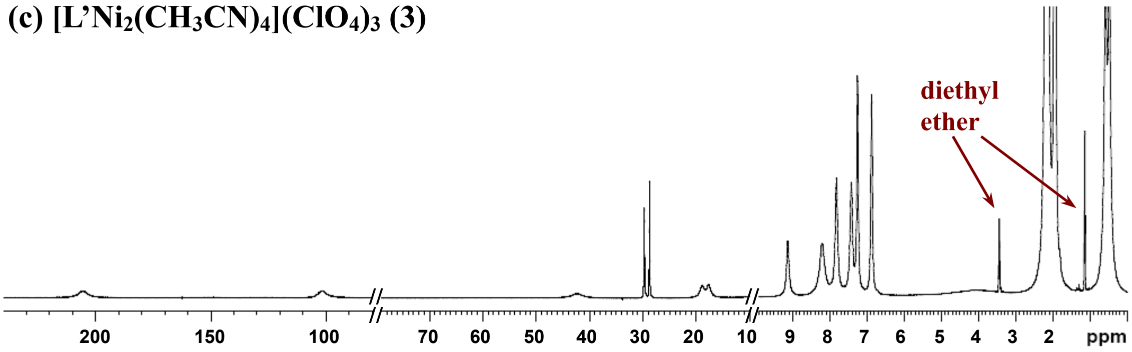
(a) [LNi$_2$(DMF)$_4$](ClO$_4$)$_3$ (1)



(b) [LNi$_2$(urea)$_4$](ClO$_4$)$_3$ (4)



(c) [L'Ni$_2$(CH$_3$CN)$_4$](ClO$_4$)$_3$ (3)



(d) [L'Ni$_2$(urea)$_4$](ClO$_4$)$_3$ (5)

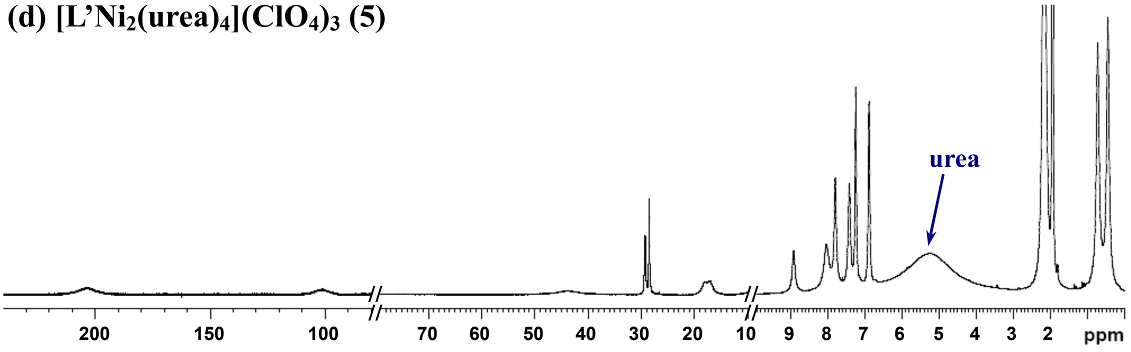


Fig. S2 ^{1}H-NMR spectra of (a) [LNi$_2$(DMF)$_4$](ClO$_4$)$_3$ (**1**), (b) [LNi$_2$(urea)$_4$](ClO$_4$)$_3$ (**4**), (c) [L'Ni$_2$(CH$_3$CN)$_4$](ClO$_4$)$_3$ (**3**). and (d) [L'Ni$_2$(urea)$_4$](ClO$_4$)$_3$ (**5**).