

Molecular Engineering. Part 14. Self-Assembled Oligovelcralexes by π - π Stacking Interaction and Metal Coordination

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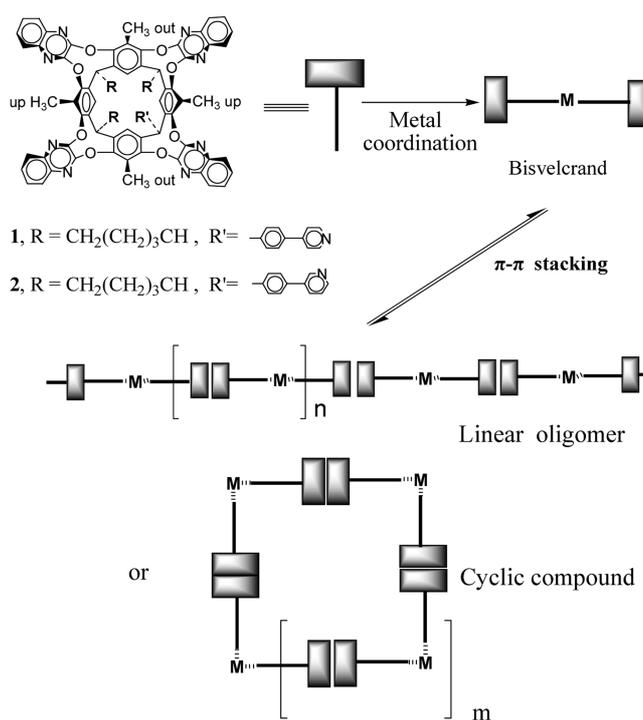
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Various interesting supramolecular systems which self-assemble by noncovalent interactions have been developed rapidly. Cram *et al.* reported velcralex which dimerize to velcralex by solvophobic π - π stacking interactions.¹ Based on this concept bisvelcralex composed of two velcralex units bridged in back-to-back fashion by covalent bond was reported to self-assemble oligovelcralex only by solvophobic π - π stacking interactions.² Dalcanele *et al.* reported a dynamic velcralex operating in multimodal fashions, solvophobic π - π stacking interaction of velcralex unit and metal coordination of pyridyl feet, which is quite insoluble in normal organic solvents due to the freeze of all 4 feet by metal coordination.³

New velcralexes **1** and **2** composed of a 2-methylresorcin-[4]arene-based quinoxaline kite velcralex unit and a *p*-pyridylphenyl foot (Scheme 1), which are quite soluble in many organic solvents, were reported to form a dimer (bisvelcralex) by metal coordination.⁴ The characteristics of their self-assembled oligomeric nanostructures by solvophobic π - π stacking interaction and metal coordination were studied.

Scheme 1 shows the structural possibilities of self-assembled nanostructures based on velcralex **1** or **2** which dimerize to bisvelcralex upon metal-coordination and then oligomerize to a linear or cyclic structure depending on the pyridyl unit and metal geometry. For example, velcralex **1** and *trans*-Pd(DMSO)₂Cl₂ will form Pd(II)-coordinated bisvelcralex **3**, but velcralex **1** and *cis*-Pt(dppp)(CF₃SO₃)₂ will form Pt(II)-coordinated bisvelcralex **4** as shown in Scheme 2. It is probable that bisvelcralexes **3** and **4** may form a linear and a cyclic oligovelcralexes, respectively.

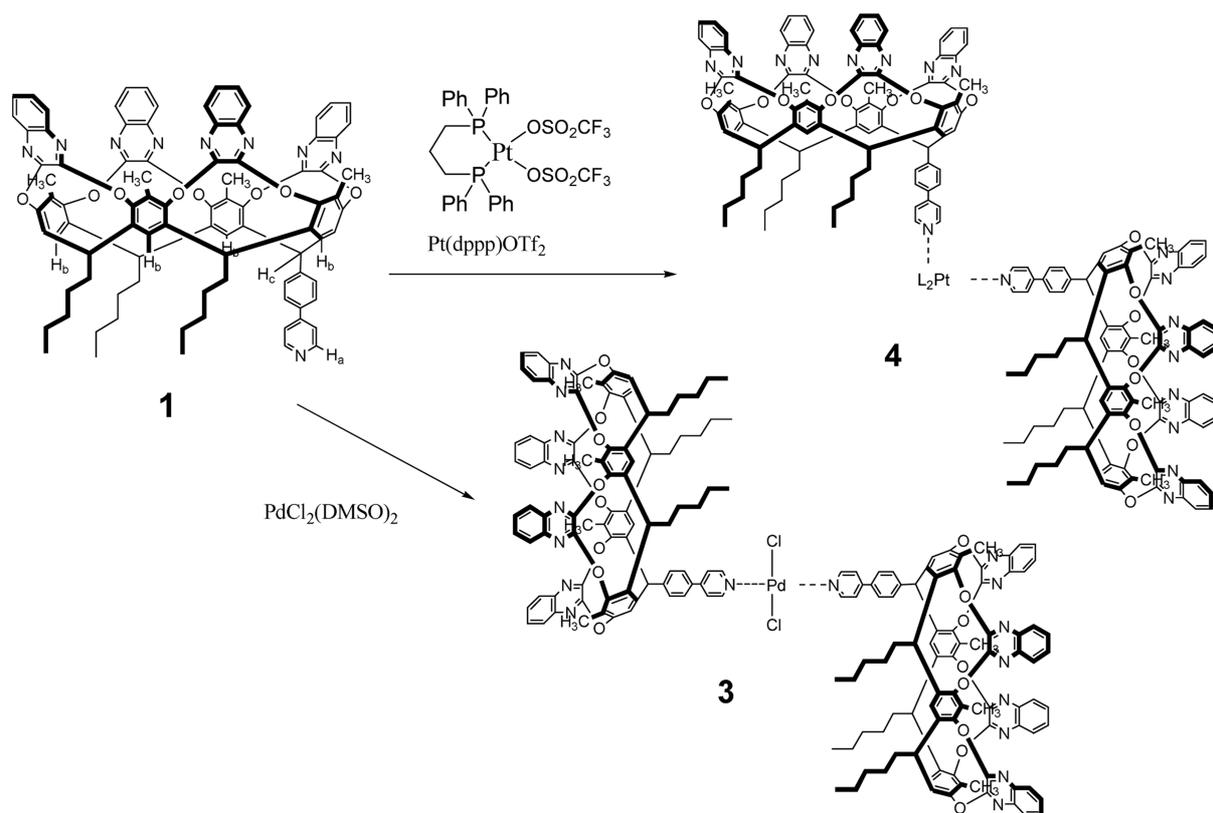
MALDI-TOF mass spectra of **1** and **2** in CH₂Cl₂ show molecular ion peaks at *m/z* 2825 attributable to velcralexes [**1**·**1**]⁺ or [**2**·**2**]⁺. Velcralex **1**·**1** and oligobisvelcralex **3**_n were observed by ¹H NMR spectroscopy. The ¹H NMR spectrum of velcralex **1**·**1** in CDCl₃ (4.80 mM) at 298 K showed two kinds of methyl peaks (δ 3.20 for out, δ 2.31 for up as designated in Scheme 1) and three kinds of methine peaks (δ 5.26, 3.61, 3.49 ppm). As this solution is diluted from 4.80 mM to 0.30, and then to 0.15 mM, methyl peaks for monomeric velcralex **1** appeared at 2.70 ppm (for out methyl) and 2.50 ppm (for up methyl). These chemical shifts at high concentration (0.50 ppm down-field shift for out methyl, 0.19 ppm up-field shift for up methyls) prove the formation of velcralex **1**·**1** in solution.⁵ In case of oligobis-



Scheme 1

velcralex **3**_n in CDCl₃ (4.80 mM) at 298 K appeared two kinds of methyl peaks (δ 3.15 for out, δ 2.26 for up) and three kinds of methine peaks (δ 5.30, 3.56, 3.45 ppm). As this solution is diluted from 4.80 mM to 0.15 mM, methyl peaks for bisvelcralex **5** appeared at 2.60 (for out methyl) and 2.51 (for up methyl) ppm, which resulted in 0.55 ppm down-field shift for out methyl and 0.25 ppm up-field shift for up methyls upon oligovelcralex formation in solution. The larger chemical shifts of oligobisvelcralex **3**_n compared to those of velcralex **1**·**1** (0.55 vs. 0.50 and 0.25 vs. 0.19) imply the stronger association of **3** than **1**.

Square planar *trans* Pd(DMSO)₂Cl₂ was prepared by the reaction of the PdCl₂ with DMSO. Square planar *cis* bis(triflate) Pt(II) complex was prepared by the reaction of dppp (dppp = 1,3-bis diphenylphosphinopropane) and PtCl₂, followed by exchange of the anionic ligands with AgOTf (OTf = triflate).⁶ Metal-coordinated **3** or **4** was formed by simply mixing velcralex **1** with Pd(DMSO)₂Cl₂ or Pt(dppp)(OTf)₂ in a 2:1 molar ratio at room temperature in a nonpolar solvent such as CHCl₃, CH₂Cl₂.



Scheme 2

The formation of oligobisvelcraplex **4**, which is likely to be a cyclic tetramer ($m = 1$) as shown in Scheme 1 was observed by the electrospray ionization mass spectrometry (ESI-MS), wherein the specific molecular ion peaks of tetrameric oligobisvelcraplex **4** were observed at m/z 1716.1 [$(\mathbf{1}\text{-Pd(dppp)OTf}_2\text{-1})_4\text{-8OTf}]^{8+}$ (100%, calc 1716.4), 2338.1 [$(\mathbf{1}\text{-Pd(dppp)OTf}_2\text{-1})_4\text{-6OTf}]^{6+}$ (20%, calc 2338.2), and 2835.8 [$(\mathbf{1}\text{-Pd(dppp)OTf}_2\text{-1})_4\text{-5OTf}]^{5+}$ (10%, calc 2835.8) as shown in Figure 1.

The energy barriers for pseudorotation between the so-called two kite conformers of velcraplexes **1**, **2**, **3**, and **4** in high concentration were observed by VT ^1H NMR experiment⁵ in tetrachloroethane- d_2 (Figure 2) and the results were

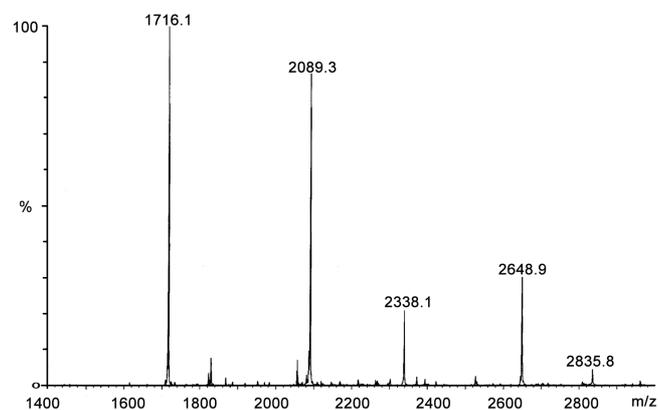


Figure 1. Partial ESI-MS spectrum of Pt(II)-coordinated bisvelcraplex **4**.

summarized on Table 1. The chemical shifts of methyls of oligobisvelcraplex **3**_n and **4**_n in $\text{C}_2\text{D}_2\text{Cl}_4$ were broadened and coalesced at about 130 °C and 120 °C to provide ΔG^\ddagger of 18.5 kcal mol⁻¹ and 18.0 kcal mol⁻¹, respectively. But the corresponding coalescence temperatures for velcraplexes **1**·**1** and **2**·**2** were observed at 110 °C to give ΔG^\ddagger of 17.5 kcal mol⁻¹. The higher energy barrier for oligobisvelcraplexes **3**_n and **4**_n compared to those of velcraplexes **1**·**1** and **2**·**2** implies the higher steric hindrance imposed on **3** and **4** by extended association.

The pulsed-field gradient spin-echo (PGSE) NMR technique⁷ was used to measure the diffusion coefficients of CDCl_3 solution of oligovelcraplex of **1**·**1** (oligobisvelcraplex **4**_n) and oligovelcraplex of **2**·**2** coordinated by Pt(II)(dppp) at

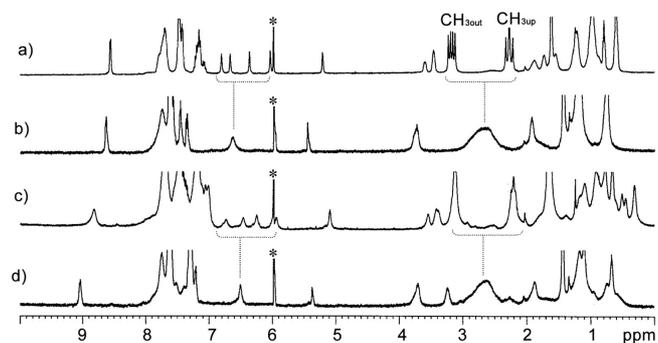


Figure 2. Variable temperature ^1H NMR spectra (400 MHz, $\text{CDCl}_2\text{CDCl}_2$) of a) **1** at 298 K, b) **1** at 383 K, c) **4** at 298 K, and d) **4** at 393 K. *: residual $\text{CHCl}_2\text{CHCl}_2$

Table 1. The coalescence temperatures and the activation energy barriers for pseudorotation between the two kite conformers of velcrands (400 MHz NMR in $C_2D_2Cl_4$, The estimated error: ± 0.5 kcal mol $^{-1}$)

Velcraplex or Oligovelcraplex	M(II)(L ₂)	T _{coalescence} , K	ΔG^\ddagger , kcal mol $^{-1}$
1-1	–	383	17.5
2-2	–	383	17.5
3_n	Pd(DMSO) ₂ Cl ₂	403	18.5
4_n	Pt(dppp)OTf ₂	393	18.0

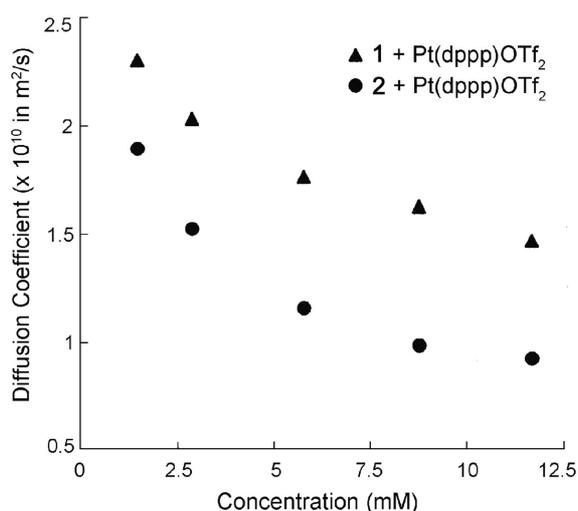


Figure 3. Concentration dependences of diffusion coefficients of oligovelcraplexes of **1-1** and **2-2** coordinated by Pt(II)(dppp) in $CDCl_3$ at 298 K.

298 K.

The measured diffusion coefficients show a noticeable change depending on the concentrations from 1.5 mM to 11.7 mM as shown in Figure 3. The concentration dependent decreases of diffusion coefficients indicate that metal-coordinated velcraplexes form larger self-assembly as its concentration increases. Overall the volume of oligovelcraplex of **2-2** increases faster than that of oligovelcraplex of **1-1**. As proposed from the ESI mass spectral data, the relatively small volume change of oligovelcraplex of **1-1** (oligobisvelcraplex **4_n**) as concentration increases may be also due to the formation of tetrameric cyclic structure shown in Scheme 1.

In conclusion, the formations of their metal-coordinated oligobisvelcraplex were studied by 1H NMR peak shifts comparison, the comparison of energy barrier for pseudorotation of kite conformers, and ESI MS. The pulsed-field gradient spin-echo (PGSE) NMR technique showed the

volume change of oligovelcraplexes coordinated by Pt(II)-(dppp) depends on the position of nitrogen at pyridyl foot.

Experimental Section

Solvents and all commercially available reagents were used without any purification. All reactions were performed under argon. MALDI-TOF mass spectra were run on a Voyager-DE STR Biospectrometry. Electrospray ionization (ESI)-MS experiments were performed on a Micromass QTOF2-MS spectrometer (Korea Basic Science Institute). 1H NMR spectra were recorded on a Bruker Avance (400 MHz).

Pulsed field gradient spin-echo (PGSE) NMR experiments. The diffusion coefficient measurements were carried out using a 5 mm Bruker QNP probe with an actively shielded z gradient coil. Diffusion coefficients were extracted from a series of 1H NMR spectra measured by the bipolar pulse longitudinal encode-decode (BPPLED) pulse sequence as a function of gradient amplitude. In each experiment, the gradient duration time was 2.0 or 2.5 ms and the amplitudes of gradient pulses ranged from 1 to 40 G/cm. The diffusion time was 50 to 100 ms. Diffusion coefficients were calculated from the data obtained by 2D diffusion-ordered spectroscopy (DOSY).

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