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*[2.1.2.1]Metacyclophane ([2.1.2.1]MCP) **3** containing hydroxyl groups at the bridge is obtained by a pinacol coupling reaction using aluminum powder. The Albright-Gordman oxidation of [2.1.2.1]MCP **3** yielded tetracarbonyl derivative **4**, and the following condensation reaction of 1,2-phenylenediamine yielded quinoxaline-annulated [2.1.2.1]MCP **5**. The UV and fluorescence spectra as well as the influences of an alkali metal ion on the fluorescence spectra of quinoxaline-annulated [2.1.2.1]MCP **5** were reported*

Keywords: calixarene; fluorescence; metacyclophane; pinacol coupling; quinoxaline; UV-Vis absorption spectrum

INTRODUCTION

The pinacol coupling reaction is one of the effective reactions for preparing a 1,2-diol in which a carbon-carbon covalent bond is formed between the carbonyl groups of an aldehyde or a ketone in the presence of an electron donor in a free radical process (Scheme 1) [1].

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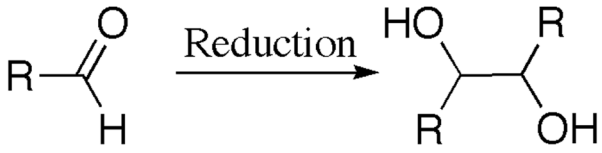


On the other hand, calixarenes, namely, [1_n] metacyclophanes (MCPs), have been investigated as a valuable host molecules for metal cations [2] and neutral molecules [3], since they are produced by a one step reaction and can be functionalized at lower and upper rims [4].

We have previously reported the novel single-step synthesis of [2.2]MCPs via the pinacol coupling of dialdehyde derivatives [5]. The synthesized MCPs had four hydroxyl groups at the exo-position of bridge moiety. Further, we have been investigating an application of the pinacol coupling reaction for preparing calixarene analogs [6]. Here, we have investigated the preparation of tetrahydroxy [2.1.2.1]MCP by the pinacol coupling method and its oxidation; further, the annulation of a quinoxaline moiety at the bridge position has also been investigated. The quinoxalin-annulated[2.1.2.1]MCP have two fluorescent heterocycles in a ring skeleton and a calixarene-like cavity that could form a complex with an alkali metal cation. Therefore, it is interesting to note the resulting properties of the complexation with the alkali metal cation and its influence on the fluorescence spectra. In this article, we describe the synthesis, structure, and photochemical properties of [2.1.2.1]MCPs and their derivatives.

EXPERIMENTAL

Materials

2,2′-Bischlorometyl-4,4′-bis(*tert*-butyl)-1,1′-dimethoxybiphenylmethane **1** was prepared as reported method [7]. Other chemicals and solvents were obtained commercially.

Synthesis

Synthesis of 4,4′-Bis(tert-butyl)-1,1′-dimethoxy-2,2′-biphenylmethanedialdehyde (2)

2,2′-Bischlorometyl-4,4′-bis(*tert*-butyl)-1,1′-dimethoxybiphenylmethane **1** (22 g, 90 mmol) was dissolved in pyridine (540 mL, 6.84 mol), and refluxed for 2 h. Then, white powder separated out and washed with

hexane gave pyridinium salt (30 g, 57%). Secondly, pyridinium salt (30 g, 50 mmol) and N,N′-Dimethyl-p-nitroso anilinium chloride (22 g, 18 mmol) was dissolved in ethanol (241 mL), and aqueous 20% sodium hydroxide solution (102 mL) was dropping to this solution slowly at rt. After stirred for 90 min, 5 N hydrochloric acid (292 mL) was added at rt. The mixture was stirred for 30 min, then water (365 mL) was added and filtrated deposit. After drying, this deposit was dissolved in heated hexane and filtrated. Then, colorless needles were obtained in filtrate and recrystallized with hexane yield **2** (14 g, 63%).

2: colorless needles; mp 118–120°C; IR (KBr) 1000, 1100, 1200, 1255, 1480, 1670, 2925 cm^{-1}; ^{1}H-NMR (400 MHz, $CDCl_3$) δ1.26 (s, 18H), 3.84 (s, 6H), 4.13 (s, 2H), 7.38 (d, $^2J_{HH} = 2.44$ Hz, 2H), 7.76 (d, $^2J_{HH} = 2.44$ Hz, 2H), 10.38 (s, 2H). Anal. Calcd for $C_{25}H_{32}O_4$: C, 75.73; H, 8.13. Found: C, 75.51; H, 8.33.

Preparation of 5,12,20-tetra-tert-butyl-1,2,16,17-tetrahydroxyl-8,15,23,30-tetramethoxyl-[2.1.2.1]metacyclophane (3) by using Aluminum Powder

To a mixture of **2** (1.0 g, 2.5 mmol), methanol (330 mL), and aluminum powder (150 mesh, 4.1 g, 15 mmol), aqueous 20% sodium hydroxide solution (150 mL) was added dropwise during a period of 2 h at rt under mechanical stirring. After 30 min, the mixture was filtered and the filtrate was extracted with chloroform (60 mL × 4). The extract was washed with water, dried over $MgSO_4$ and evaporated *in vacuo*, leaving a residue, which was subjected to column chromatographed on silica gel (Waco-gel, C-300, eluent; hexane/ethyl acetate, 3/1), to afford **3** (0.58 g, 29%).

3: white powder; mp 259–261°C ; *m/z* (FAB) 796 (M^+) for $C_{50}H_{68}O_8$; ^{1}H NMR (400 MHz, [D_6]DMSO, 100°C, TMS): $\delta = 1.01$–1.40 (brm, 36H), 2.82–3.05 (brm, 12H), 3.40–5.30 (brm, 12H), 7.00–7.34 (brm, 8H); Anal. Calcd for $C_{50}H_{68}O_8$: C, 75.34; H, 8.60. Found: C, 75.53; H, 8.47%.

Synthesis of 5,12,20-tetra-tert-butyl-1,2,16,17-tetracarbonyl-8,15,23,30-tetramethoxyl- [2.1.2.1]metacyclophane (4)

To a solution of **3** (50 mg, 0.063 mmol) in dry dimethyl sulfoxide (7.0 mL, 97 mmol) was added acetic anhydride (1.0 mL, 9.7 mmol). After the mixture was stirred for 24 h at 80°C under nitrogen, cold water (20 mL) and ammonia solution (1.0 mL) was added to it and the mixture was extracted with chloroform (60 mL × 4). The extract was washed with water, dried over $MgSO_4$ and evaporated *in vacuo*, leaving a residue, which was subjected to column chromatographed on silica gel (Waco-gel, C-300, eluent; hexane/ethyl acetate, 3/1) and recrystalized with hexane, to afford **4** (0.42 g, 18%).

4: colorless prisms; mp > 300; FT-IR 1003, 1214, 1480, 1651, 1660, 2958 $cm^{-1;}$ UV-Vis (methanol) 259 (ε1125), 313 (ε3056); ^{1}H-NMR (500 MHz, Toluene-d_8) δ1.15 (s, 36H), 3.20 (s, 12H), 3.56 (br, 4H), 7.35 (d, $^2J_{HH} = 2.44$ Hz, 4H), 8.01 (d, $^2J_{HH} = 2.44$ Hz, 4H); MS (TOF) m/z 815 ($M^+ + Al$). Found: C, 74.55; H, 7.85%. Calcd for $C_{50}H_{60}O_8 + H_2O$: C, 74.44; H, 7.69%.

Synthesis of 13,20,36,43-tetra-tert-butyl-16,23,39,46-tetramethoxy[1.1](2,3)(2,3-diphenyl)quinoxalinophane (5)

To a solution of **4** (25 mg, 0.03 mmol) in acetic acid (15 mL) was added 1,2-phenylenediamine (150 mg, 0.92 mmol). After the mixture was refluxed for 48 h under nitrogen, cold water (10 mL) was added to it and the mixture was extracted with chloroform (60 mL × 4). The extract was washed with water, dried over $MgSO_4$ and evaporated *in vacuo*, leaving a residue, which was subjected to column chromatographed on silica gel (Waco-gel, C-300, eluent; hexane/ethyl acetate, 5/1) and recrystalized with the mixture of methanol and chloroform, to afford **5** (7.0 mg, 25%).

5: colorless prisms; mp > 300; FT-IR 1010, 1217, 1363, 1479, 1743, 2959 $cm^{-1;}$ UV-Vis (methanol) 299 (ε3194), 307 (ε3333), 332 (ε2917); ^{1}H-NMR (500 MHz, Toluene-d_8) δ1.22 (s, 36H), 3.24 (d, $^2J_{HH} = 14.04$ Hz, 2H), 3.62 (s, 12H), 4.47 (d, $^2J_{HH} = 13.41$ Hz, 2H), 7.25 (d, $^2J_{HH} = 2.44$ Hz, 4H), 7.26 (d, $^2J_{HH} = 2.44$ Hz, 4H), 7.36 (m, 4H), 8.13 (m, 4H); MS (TOF) m/z 938 ($M^+ + 5H$); MS (FAB+) m/z 933 (M^+). HRMS Found: 933.52218. Calcd for $C_{62}H_{67}N_3O_5$: 933.50803.

Measurements

^{1}H-NMR and IR spectra of synthesized compounds were taken on a JEOL EX400 and Shimadzu IR-408 spectrometer, respectively. UV-visible absorption and Fluorescence spectra were obtained from Hitachi U 3210 spectrophotometer and Shimadzu RF-540 spectrofluorophotometer. X-ray crystallography was determined by Rigaku AFC 7 R radiation diffractmeter.

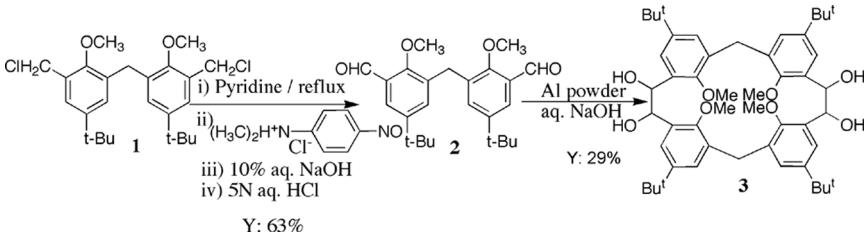
X-Ray Structure Determination

Crystal Data of 4:. colorless prism, $C_{50}H_{60}O_8$, $M = 788.98$, Monoclinic, space group $P\ 2_1/n$,a = 14.354(5) Å, b = 14.965(5) Å, c = 10.866(5) Å, b = 91.042(5°), V = 2333.7(16) $Å^3$, Z = 2, D_{calc} = 1.123 Mg/m^3, crystal dimension 0.25 × 0.20 × 0.20 mm. Data were measured on a Rigaku AFC 7 R radiation diffractmeter with

graphite-monochromated Mo-Ka radiation. Total 6442 refrections (5349 unique) were collected using w-2q scan technique with in a 2q range of 55.0°. The structure was solved by direct methods (SIR92), and refined a full-matrix least squares methods using CrystalStructure analysis software with 5349 observed refrections [$I > 2s(I)$]. The final refinement converged to $R = 0.073$ and $Rw = 0.13$. CCDC 298137 contains the supplementary crystallographic data for this article. These data can be obtained free of charge from The Cambridge Crystallographic Data Center via www.ccdc.cam.ac.uk/data_request/cif.

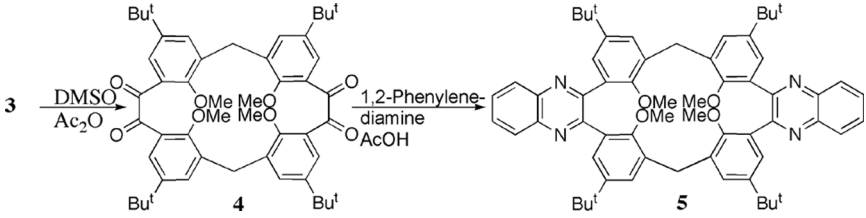
RESULTS AND DISCUSSION

The preparation of [2.1.2.1]MCP **3** is shown in Scheme 2.



Diphenylmethane dialdehyde **2** was prepared from bis(chloromethyl) diphenyl methane **1.** The pinacol coupling reaction of **2** was carried out with aluminum powder, titanium chloride, or samarium diiodide. Attempting the pinacol coupling reaction with samarium iodide yielded a complex mixture of linear chain polymers. By using titanium tetrachloride, 1:2 mixture of a 1,2-alternate and a partial-cone structure of [2.1.2.1]MCP **3** were obtained. The pinacol coupling with aluminum powder yielded a 1,2-alternate structure of [2.1.2.1]MCP **3** as a single isomer [6].

Oxidation and the subsequent condensation reaction of [2.1.2.1]MCP **3** are shown in Scheme 3.



The oxidation of [2.1.2.1]MCP **3** was performed by the Albright-Goldman oxidation [8] using dimethylsulfoxide with acetic anhydride. The X-ray crystallographic structure of [2.1.2.1]MCP-tetraone **4** is shown in Figure 1.

The conformation of tetracarbonyl[2.1.2.1]MCP **4** was determined as a 1,2-alternate type with oppositely located diphenylmethane units. The carbonyl groups of tetracarbonyl[2.1.2.1]MCP **4** were directed perpendicular to each other (94.4°). These results indicated that the π-conjugated system of [2.1.2.1]MCP did not continue at a periphery of a macrocycle. The diameter of the molecular cavity between the bridges carbon was measured as 7.4 Å. The dihedral angle of the benzene rings were determined as 177.9°. The tetracarbonyl[2.1.2.1]MCP **4** exhibit a flipping motion at rt and its dynamic NMR spectra indicated the activation energy $\Delta G^{\#}$ of the conformational mobility as 45.9 kJ/mol. This value was a little higher than that of tetramethoxy [2.1.2.1]MCP (43.6 kJ/mol) [7].

The condensation of tetracarbonyl[2.1.2.1]MCP **4** with o-phenylenediamine [9] in the presence of acetic acid yielded a [1.1]diphenylquinoxalinophane ([1.1]DPQP) **5** possessing two quinoxaline rings at the bridge moieties.

The UV-Vis absorption spectra and the fluorescence spectra of [1.1]DPQP **5** and parent quinoxaline, as the reference compound, are shown in Figure 2 and Figure 3.

UV-Vis absorption maximums ($\lambda_{max,UV}$) of [1.1]DPQP **5** were observed at 298 nm and 307 nm and those of quinoxaline were measured to be at 304 nm and 315 nm. In the case of [1.1]DPQP **5**, the decreasing intensity, blue shift, and shoulder peaks were observed at the long-wavelength region and were compared with those of the quinoxaline. The shoulder peaks appear to be influenced by the extension caused by the π-conjugated system.

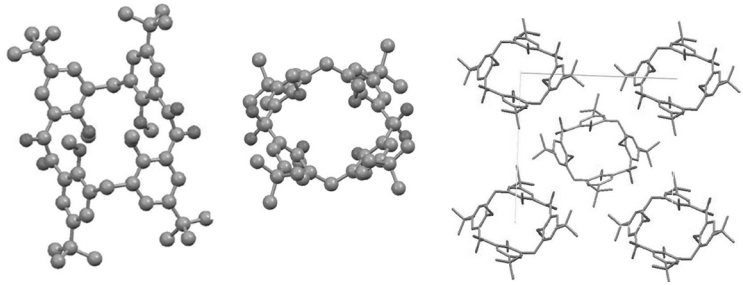


FIGURE 1 X-ray crystallographic structure of tetracarbonyl[2.1.2.1]MCP **4**

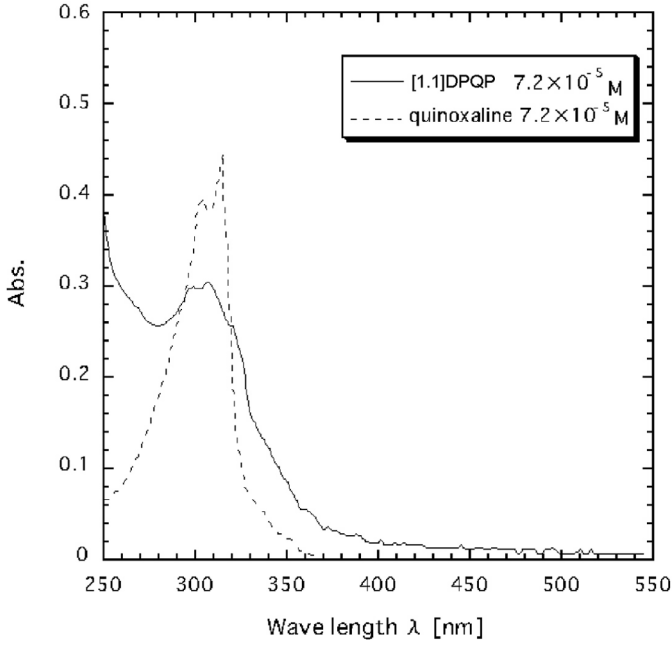


FIGURE 2 UV-Vis absorption spectra of [1.1]DPQP **5** and quinoxaline in CH_3CN at rt.

The relative emission intensity of [1.1]DPQP **5** was higher than that of the parent quinoxaline. In the case of the parent quinoxaline, the emission maxium was observed at 350 nm in 2.0×10^{-5} mol/L. However, in higher concentration ($2.0\,10^{-3}$ mol/L), its excimer emission peaks were detected at 430, 390, 360 nm. The excimer is a short-lived dimeric molecule formed from two species, at least one of which is in an electronic excited state. The excimer of the fluorescent molecules is expected to be observed at a longer wavelength than that of the monomer emission. The emission maximum of the monomeric diphenylquinoxaline and its intramolecular excimer was detected at 350 nm and 480 nm, respectively. In this case, the two quinoxaline moieties of a [1.1]DPQP **5** could form a intramolecular excimer due to its conformational flexibility.

The change in the relative emission intensity of [1.1]DPQP **5** in the presence of sodium perchlorate or litium perchlorate are shown in Figure 4.

The measurements were performed in acetonitrile at 7.5×10^{-5} M [1.1]DPQP **5** in the presence of alkali perchlorate from 10^{-6} to 10^{-1} M. Since attempting titration with potassium perchlorate caused the

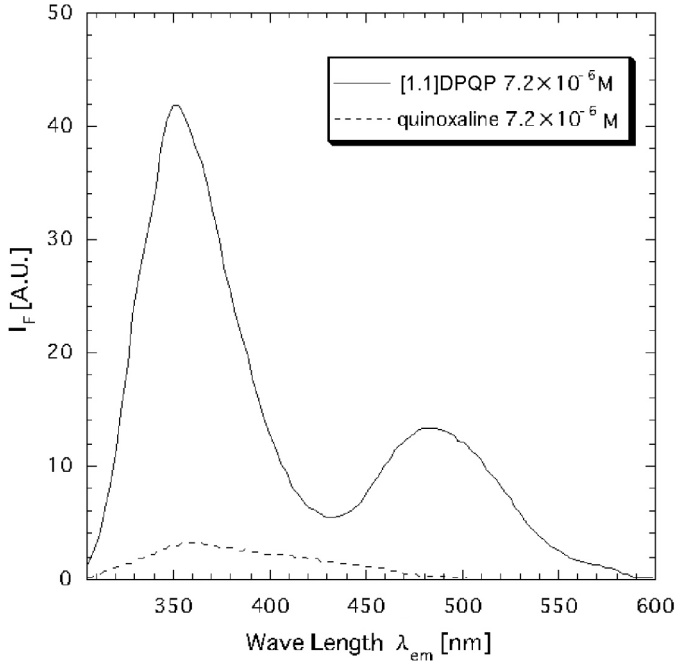


FIGURE 3 Emission fluorescence spectra of [1.1]DPQP **5** and quinoxaline in CH_3CN at 20°C.

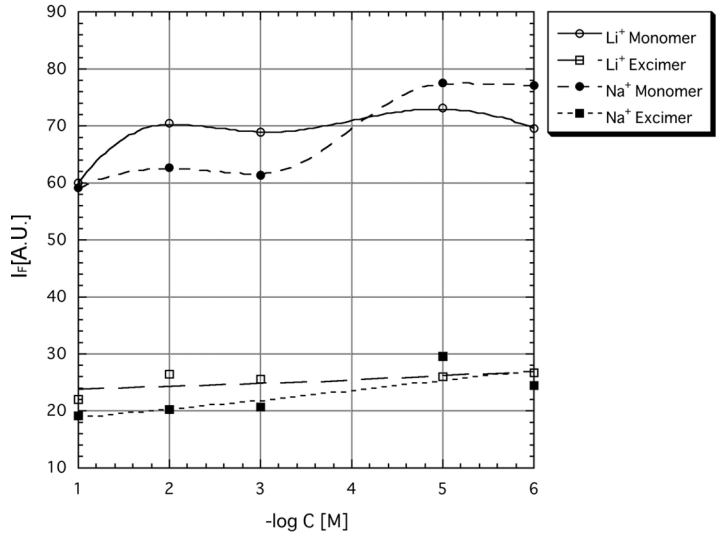


FIGURE 4 Relative intensity change in emission maximum of [1.1]DPQP **5** in the presence of $NaClO_4$ or $LiClO_4$.

acetonitrile solvent to saturate, the titration of lithium and sodium perchlorate was investigated and the intensity change is shown in Figure 4.

As compared to the case of lithium perchlorate, an increase in the amount of sodium perchlorate, decreases the relative emission intensity of the monomer (350 nm) and the excimer (480 nm). In the case of titration with sodium cations, small amount of red shifts were observed in monomeric and excimeric emissions; these shifts were identical-5nm. On the other hand, the titration with lithium perchlorate does not indicate any shift in the emission maximum although there is a small change in the relative intensity. Increasing the radiationless deactivaton and the red shift of the emission maximum by complexation of [1.1]DPQP **5** with sodium ion may be possible; however this hypothesis lacks substantial evidence with regard to complexation.

CONCLUSIONS

By the pinacol coupling reaction with aluminum powder, we have prepared the novel macrocyclic tetrahydroxy[2.1.2.1]MCP **3** as a single isomer. This compound **3** is regarded as a calixarene analog and it also comprises tetrahydroxyl groups that are functionalized at the bridge position. The oxidation and the subsequent annulation produced fluorescence macrocycle **5**. This [1.1]DPQP **5** indicated intramolecular excimer and monomer emissions, and the influenced of titration with sodium perchlorate on them. These results suggested that the pinacol coupling reaction could be a useful method to produce a novel macrocyclic calixarene analog.

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