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UNUSUALLY EFFICIENT DEFORMYLATIVE SYNTHESIS OF 1,2,8,9-TETRASUBSTITUTED DIPYRRINS FROM 4,5-DISUBSTITUTED PYRROLE-2-CARBALDEHYDES

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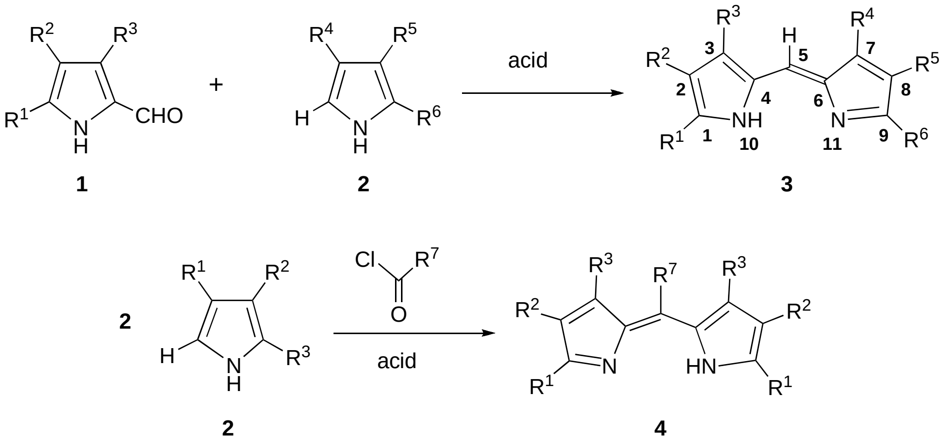
This paper is dedicated to Professor Dr. Isao Kuwajima on the occasion of his 77th birthday.

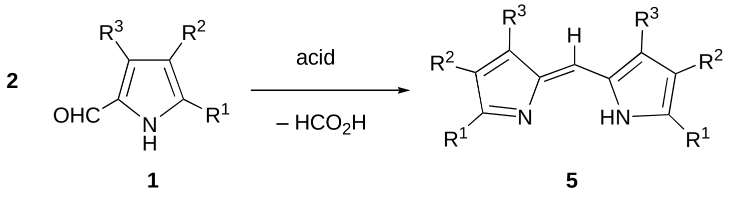
Abstract – Upon heating in a mixture of hydrobromic acid and acetic acid, 4-arylmethyl-5-(4-methoxyphenyl)pyrrole-2-carbaldehydes (**9a**–**c**) react to give 2,8-bis(arylmethyl)-1,9-bis(4-methoxyphenyl)dipyrrins (**10a**–**c**) in high yields, demonstrating the first example of an unusually efficient deformylative transformation of pyrrole-2-carbaldehyde to dipyrrin. Dipyrrins **10** show a clear color change from red to blue, when exposed to Brønsted acid. Structure of **10a·H$^+$** was determined by X-ray crystallographic analysis. The absorption change of **10a** in the presence of a metal ion was also studied.

INTRODUCTION

Dipyrrins, also called dipyrromethenes, consist of an important class of nitrogen heterocycles.[1,2] The structure of dipyrrin can be found as a core carbon skeleton in 4,4-difluoro-4-bora-3a,4a-diaza-*s*-indacene (BODIPY) dyes,[3] and some dipyrrins can be used as synthetic key intermediates for porphyrins and their analogs.[4] Therefore, a wide variety of substituted dipyrrins are already known of. Among many reported methods for preparation of dipyrrins, condensations between pyrrole and pyrrole-2-carbaldehyde under acidic conditions and between pyrroles and acid chloride have been well employed (Scheme 1). In the former condensation, besides formation of **3**, dipyrrin **5** has often been reported to form in low yields by deformylative condensation (Scheme 2).[2,3] The deformylative formation of **5** from **1** under acidic conditions is a minor process and, hence, the synthetic importance of this method has never been emphasized.

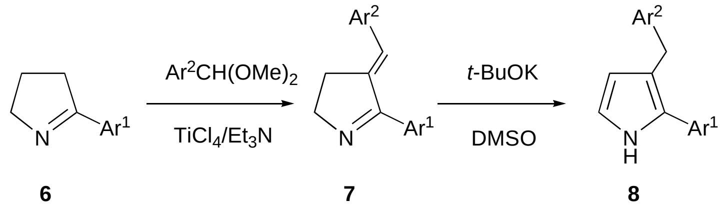


Scheme 1. Synthetic methods for dipyrrins by acid-catalyzed condensations



Scheme 2. Acid-catalyzed deformylative condensation of pyrrole-2-carbaldehyde

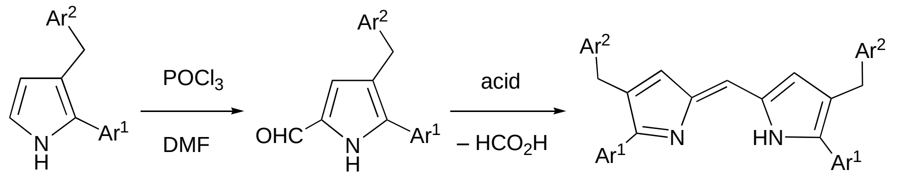
Meanwhile, we reported the facile synthesis of 2,3-disubstituted pyrroles **8** from 2-substituted-1-pyrrolines **6** via aldol condensation intermediates **7** (Scheme 3).[5] This easy access to these 2,3-disubstituted pyrroles allowed us to extend our synthetic study toward its further derivatization. During the course of this study, we have found that the α-formyl derivatives of **8** undergoes efficient condensation to produce dipyrrins. In this paper, we describe this unusual deformylative condensation, though the reaction is limited to three examples. We also describe the absorption change of the dipyrrins in the presence of Brønsted acid and a metal ion, and formation of its complexes including its BODIPY derivative.[3] Furthermore, X-ray crystallographic analysis of CF_3SO_3H salt of one of the title compounds is disclosed.



Scheme 3. Our synthetic method for 2,3-disubstituted pyrroles

RESULTS AND DISCUSSION

Aldehydes **9**, 4-arylmethyl-5-(4-methoxyphenyl)pyrrole-2-carbaldehydes, were obtained in good yields by Vilsmeier-Haack reaction[6] of 3-arylmethyl-2-(4-methoxyphenyl)pyrroles (**8**). Upon heating in an aqueous medium containing a Brønsted acid, **9a** transformed to 2,8-dibenzyl-1,9-bis(4-methoxyphenyl)dipyrrin (**10a**) (Scheme 4). Table 1 shows the results of the condensation under various acidic reaction conditions.



8 **9** **10**

a; $Ar^1 = 4\text{-}MeOC_6H_4$, $Ar^2 = Ph$
b; $Ar^1 = 4\text{-}MeOC_6H_4$, $Ar^2 = 4\text{-}BrC_6H_4$
c; $Ar^1 = 4\text{-}MeOC_6H_4$, $Ar^2 = 2\text{-thienyl}$
d; $Ar^1 = Ph$, $Ar^2 = Ph$
e; $Ar^1 = Ph$, $Ar^2 = 2\text{-thienyl}$

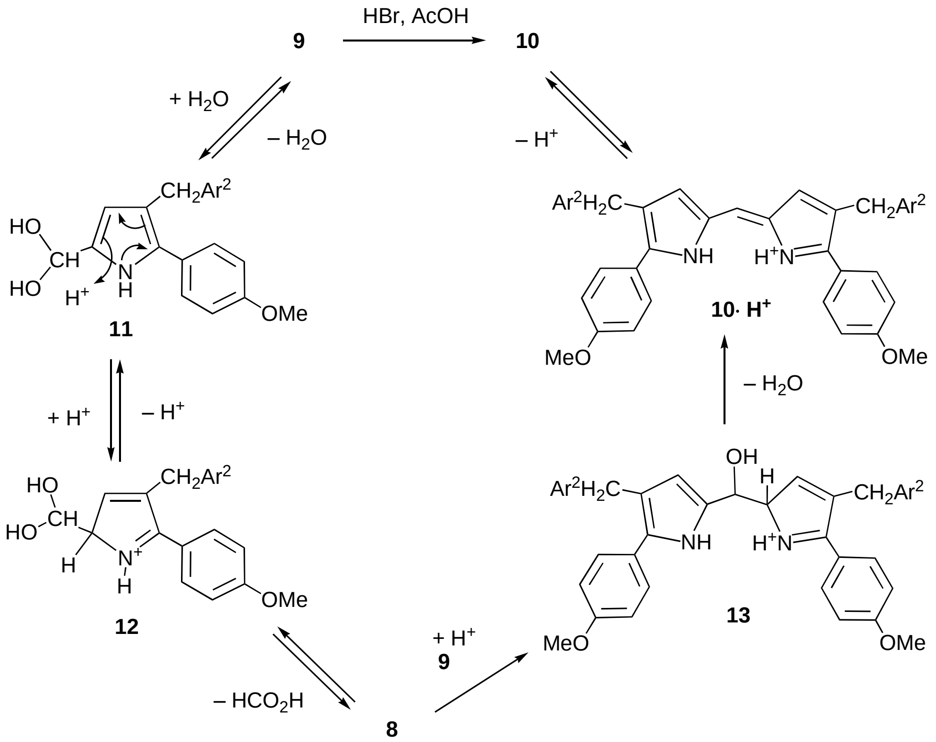
Scheme 4. Synthesis of dipyrrin **10** from **8**

Table 1. Acid-catalyzed condensation of **9** to dipyrrin **10** under various conditions

Entry	Aldehyde	Reaction conditions	Yield (%) of **10**[a]
1	**9a**	HCl / AcOH (1/1), 95 ˚C, 3 h	79
2	**9a**	HBr / AcOH (1/1), 85 ˚C, 4 h	93
3	**9a**	HBr / AcOH (1/1), 100 ˚C, 2 h	84
4	**9a**	CF_3CO_2H / H_2O (9/1), 85 ˚C, 4 h	74
5	**9a**	AcOH / H_2O (9/1), 85 ˚C, 20 h	trace (96)[b]
6	**9a**	AcOH / H_2O (9/1), 115 ˚C, 25 h	12 (74)[b]
7	**9a**	$TsOH{\cdot}H_2O$ (5 eq.) / toluene, reflux, 15 h	70
8	**9b**	HBr / AcOH (1/1), 85 ˚C, 4 h	95
9	**9c**	HBr / AcOH (1/1), 85 ˚C, 4 h	90

[a] Isolated yield after chromatography, [b] Yield of recovery in parentheses

Although acetic acid was ineffective as a key acid (entry 5–6), not as a solvent, other stronger acids worked effectively to give dipyrrin **10a** in good to high yields. The highest yield was achieved by the way of entry 2. Under the conditions of entry 2, **10b** and **10c** were obtained also in high yields (entry 8–9). A proposed reaction mechanism is shown in Scheme 5. The deformylation at the pyrrole ring[7] probably proceeds through the hydrate **11**, which undergoes protonation on the pyrrole ring to give **12**. Release of formic acid from **12** provides **8**, which adds to protonated **9** to give **13**. Finally, dehydration from **13** yields **10·H**$^+$. Indeed, it was independently confirmed that **8a** reacts with **9a** in HBr/AcOH at room temperature to give **10a** in 80% yield. It is worth noting that the yield of **10a** in the deformylative self-condensation of **9a**, requiring a high reaction temperature, is greater than that in the condensation between **8a** and **9a** at room temperature. In contrast to the results of **9a**–**c** having a 4-methoxyphenyl group, **9d**–**e** having a phenyl group behaves differently. Upon heating in refluxing HBr/AcOH, **9d** reacts slightly slower than **9a**–**c**, resulting in the formation of a complex mixture. Although the existence of **10d** in the mixture can be deduced by ^{1}H NMR analysis,[8] it could not be isolated from the mixture because of its low yield and particularly instability for SiO_2 chromatographic purification. A similar result was observed in the reaction of **9e**. Although the stability of **10d**–**e** remains uncertain, it is possible that a methoxyl group of the aryl substituents at the 1,9 positions of **10a**–**c** might contribute to their stability. The relatively higher reactivity of **9a**–**c** in comparison with **9d**–**e** in their reactions may be attributable to a more favorable protonation for **12** based on its increased π-electron density at the pyrrole ring induced by the 4-methoxyphenyl groups.



Scheme 5. A proposed reaction mechanism for the formation of **10**

Dipyrrins **10a**–**c** were obtained as red crystals. Their structures were confirmed by spectroscopic analyses. Numbers of ^{1}H- and ^{13}C-NMR signals of **10** in $CDCl_3$ are evidence for its symmetric structure around the meso carbon at the 5 position and, hence, quick tautomerism between the 1*H*-pyrrole and azacyclopentadienylidene rings under the conditions of NMR measurements. The UV-vis and emission spectra of **10a** in MeCN and 1%CF_3CO_2H(TFA)-MeCN are shown in Figure 1. The absorption maximum at the visible region is observed at 504 nm in MeCN and at 586 nm in 1%TFA-MeCN. While the color of **10a** in a MeCN solution is red, it is blue in acidic media.[9] The protonated compound, **10a·H**$^+$**X**, can be

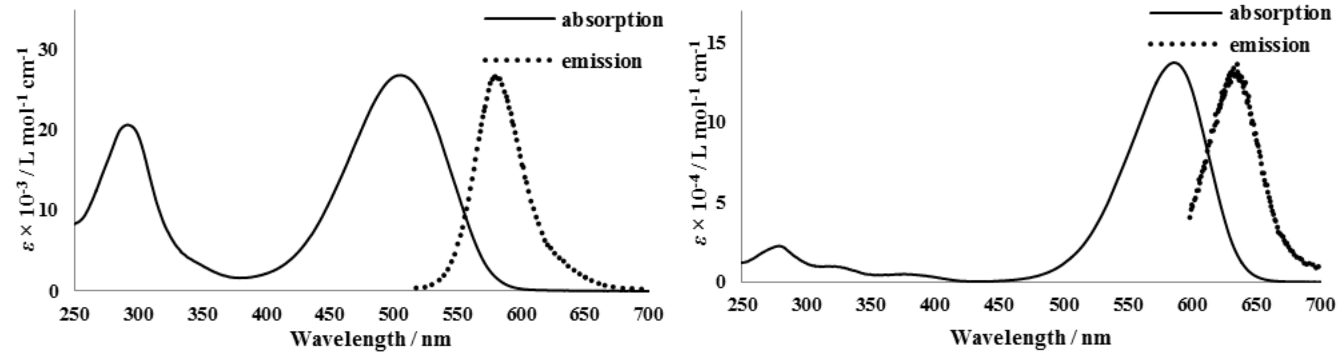


Figure 1. The UV-vis absorption and normalized emission spectra of **10a** in MeCN (left) and in 1%TFA-MeCN (right)

isolated also as stable blue crystals. This change is visibly clear even in 10^{-6} M/L of **10a** against a similar concentration of TFA. Thus, **10a** can be used as a proton sensor in organic solvents.[10] Emission upon exciting at the longest wavelength maximum of **10a** was observed both in MeCN and 1%TFA-MeCN, but quantum yields of these emissions were less than 0.01% in 2 x 10^{-5} M/L solution. The solid-state structure of **10a·H**$^{+}$ triflate was determined by X-ray analysis. ORTEP drawings are shown in Figure 2. The core dipyrrin part of the X-ray structure is almost planar. Two phenyl rings of the benzyl groups direct vertically to the core plane in different directions. One of the anisyl groups attaches to the core plane distortedly with a torsion angle of 34.3˚, and the other with a torsion angle of 18.0˚. Two C–C bonds around the meso carbon atom are 1.371 and 1.409 Å long. Although these lengths are between those of typical C–C single (1.54 Å) and double (1.34 Å) bonds, those are meaningfully different, that is,

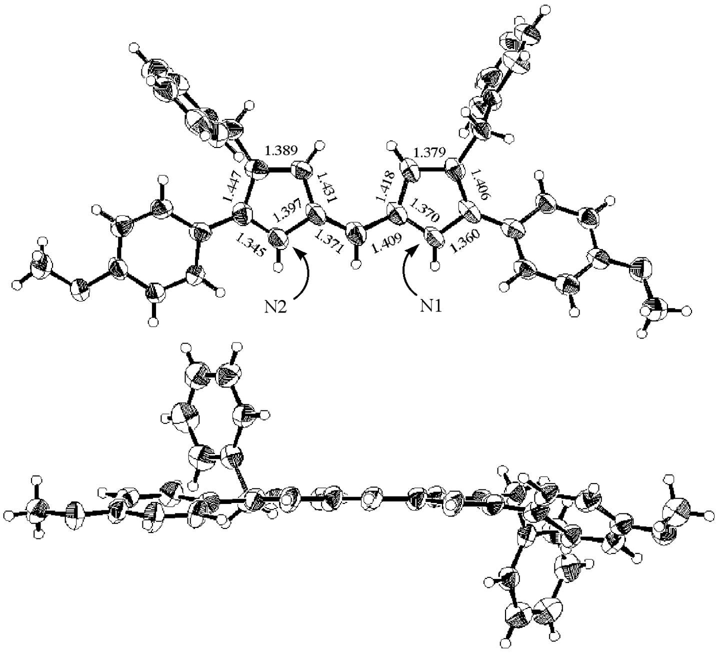


Figure 2. ORTEP drawings of **10a·HOTf**. Top view from the dipyrrin plane (top) and side view (bottom). Counter triflate anion and incorporated water were omitted for clarity. Numbers are bond lengths (in Å) of the dipyrrin part.

the dipyrrin part in the crystal structure has a bond alternation to some extent, apart from the complete resonance hybrid structure.

In addition to the proton affinity of **10a**, interaction of **10a** with a metal ion was studied in MeCN by absorption spectroscopy. While the absorption spectra of **10a** in the presence of monovalent metal ions, such as Na^+ and Ag^+, resemble that in the absence of a metal ion, the spectra in the presence of divalent and trivalent metal ions (100 eq.) show a clear change. There are two kinds of spectral changes. The spectra in the presence of Mg^{2+}, Al^{3+}, Hg^{2+}, and Pb^{2+} ions show an absorption band at 586 nm. Those spectra are very similar to that of **10a** in 1%TFA-MeCN, suggesting that these bands arise from a type of

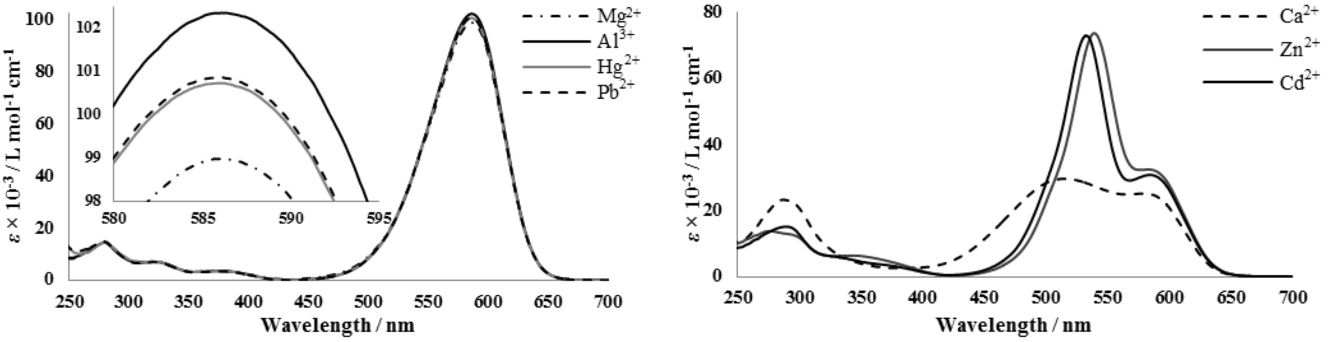


Figure 3. UV-vis spectra of **10a** in the presence of 100 eq. of Mg^{2+}, Al^{3+}, Hg^{2+}, and Pb^{2+} ions in MeCN. (left; Inset is their expanded spectra at a region between 580 and 595 nm) in the presence of 100 eq. of Ca^{2+}, Zn^{2+}, and Cd^{2+} ions in MeCN (right).

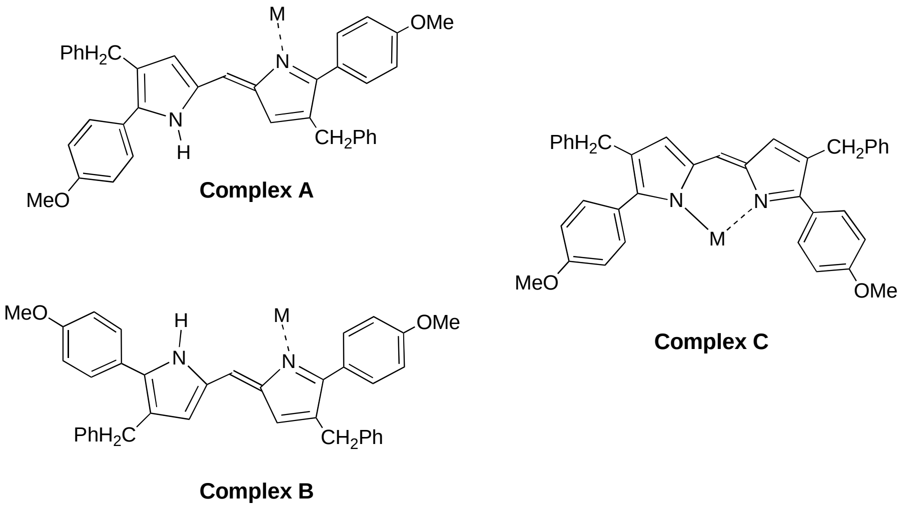
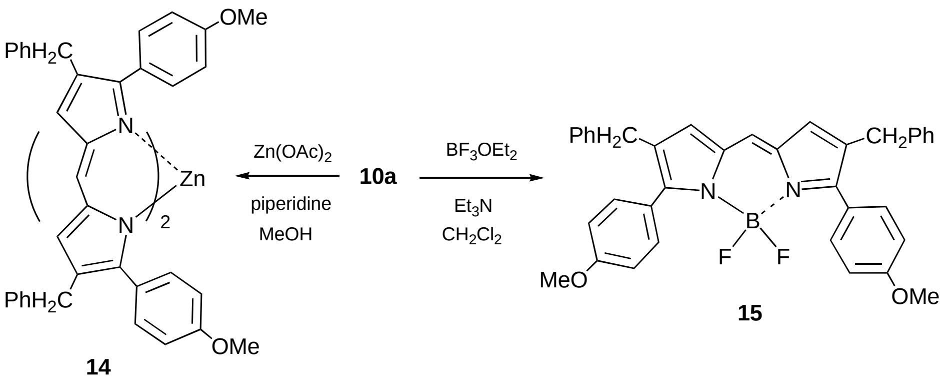


Chart 1. Possible structures of metal ion complexes of **10a** under measurements of UV-vis spectra with an excess metal ion. M is metal ion.

complex **A** and/or **B** in Chart 1. The spectra in the presence of Ca^{2+}, Zn^{2+}, and Cd^{2+} ions show two absorption bands at 530–540 nm and 585 nm (Figure 3). The absorption band observed at 540 nm can be assigned to deprotonated complex **C**, based on comparison of spectral data with that of independently isolated Zn(II) dipyrrinato complex **14** (Scheme 6). Therefore, **10a** interacts with Ca^{2+}, Zn^{2+}, and Cd^{2+} ions to form a mixture of complex **A** and/or **B** and complex **C**, though the molar ratios between **10a** and metal ions are unclear under the conditions. These results clearly indicate that the binding site around two nitrogen atoms in **10a** only fits metal ions with an relatively smaller ionic radius ranging between 0.70 and 1.00 Å, and, hence, metal ions having either larger or smaller radii are forced to bind in a mode of complex **A** and/or **B**. Besides Zn(II) dipyrrinato complex **14**, BF_2 complex **15**, a derivative of BODIPY,[3b] was also obtained. Both complexes **14** and **15** are isolated as dark red crystals, having a long-wavelength absorption maximum at 537 and 559 nm, respectively, and are stable under various purifications, such as chromatography and recrystallization. The metal to ligand ratio of the Zn(II) dipyrrinato complex was confirmed to be 1:2 by its FAB MS molecular ion peak (*m/z* 1134). The equivalency of the ^{1}H NMR signals of the dipyrrinato ligands suggests that Zn^{2+} ion is four-coordinated with a tetrahedral configuration, as previously proposed.[10,11] Upon exciting the absorption maximum, **14** emits light at 571 nm and **15** at 585 nm (Table 2). While the emission quantum yield of **14** was low, that of **15** was found to be 51%. With a substantial quantity of easily accessible **10** in hand, further complexation of **10** with other metal ions and its application to electronic materials and biochemical dyes are now in progress.



Scheme 6. Synthesis of Zn(II) and BF_2 complexes of **10a**

Table 2. Photophysical data of complexes **14** and **15** in MeCN

Complex	λ_{max}^{abs}/nm	ε_{max}[a]	λ_{max}^{emi}/nm	Stokes shift/nm	Φ[b]
14	537	113	571	34	0.01
15	558	63	585	26	51

[a] $\varepsilon \times 10^{-3}$ (L mol^{-1} cm^{-1}), [b] determined in MeCN by comparison with the value of Rhodamine 6G upon excitation at 546 nm.

EXPERIMENTAL

Melting points were measured on a Yanaco MP-3 and were not corrected. IR spectra were recorded on a JASCO FT/IR-4100 spectrometer. UV-vis spectra were measured on a Shimadzu UV-2550 spectrometer. Emission spectra were recorded on a Shimadzu RF-5300PC spectrometer. ^{1}H and ^{13}C-NMR spectra were recorded with tetramethylsilane as internal standard on JEOL λ400 and ECA500 NMR instruments. Chemical shifts of protons on nitrogen atoms are omitted because they shift depending on concentration of the substrate and also on an amount of water in $CDCl_3$. Mass spectra were measured on a JMS-700 mass spectrometer. Ionization mode was carried out by an EI method, except for **10b-c** and **14**, which were ionized by a FAB method. Column chromatography was done with Silica gel 60N from Kanto Chem., Inc. DMF and MeCN were purified by distillation over CaH_2. Phosphorus oxychloride, $BF_3 \cdot OEt_2$ and zinc acetate were purchased from Wako Chem. and used without purification. TFA and TfOH were purchased from Kotyo Chem. Ind. and used without purification. Emission quantum yields were determined by comparison of a total emission area with that of anthracene (Φ = 0.27, upon excitation at 356 nm in EtOH), if not cited. 2,3-Disubstituted pyrroles **8a**–**e** were prepared by our previously reported method.[5] Spectral data of new pyrroles, **8b**–**c**, are as follows.

8b: A dark brown oil. ^{1}H NMR ($CDCl_3$) δ = 3.80 (s, 3H, $–OCH_3$), 3.89 (s, 2H, CH_2), 6.03 (t, J = 2.7 Hz, 1H, H–4), 6.74 (t, J = 2.7 Hz, 1H, H–5), 6.90 (d, J = 8.8 Hz, 2H, 4-$MeOC_6H_4$), 7.06 (d, J = 8.1 Hz, 2H, 4-BrC_6H_4), 7.24 (d, J = 8.8 Hz, 2H, 4-$MeOC_6H_4$), 7.36 (d, J = 8.1 Hz, 2H, 4-BrC_6H_4) ppm; ^{13}C NMR ($CDCl_3$) δ = 31.9, 55.3, 111.1, 114.2, 117.2, 117.7, 119.4, 125.9, 128.2, 129.0, 130.2, 131.3, 141.4, 158.4 ppm; IR (film) ν_{max} = 3432s, 1512vs, 1250vs, 833s cm^{-1}; MS (70 eV) *m/z* (rel int) 343 (M$^+$, 98), 341 (M$^+$, 100), 340 (21), 262 (9), 187 (10), 186 (73). HRMS *m/z* Calcd for $C_{18}H_{16}{}^{79}BrNO$ (M$^+$) 341.0415, found: 341.0417.

8c: Brown solids. Mp 70–71 ˚C. ^{1}H NMR ($CDCl_3$) δ = 3.82 (s, 3H, $–OCH_3$), 4.10 (s, 2H, CH_2), 6.20 (t, J = 2.7 Hz, 1H, H–4), 6.78 (t, J = 2.7 Hz, 1H, H–5), 6.81 (m, 1H, $–C_4H_3S$), 6.91 (d, J = 3.5 Hz, 1H, $–C_4H_3S$), 6.93 (dm, J = 8.5 Hz, 2H, 4–$MeOC_6H_4$), 7.11 (dd, J = 5.2, 1.1 Hz, 1H, $–C_4H_3S$), 7.32 (dm, J = 8.5 Hz, 2H, 4–$MeOC_6H_4$) ppm; ^{13}C NMR ($CDCl_3$) δ = 27.0, 55.3, 111.0, 114.2, 117.1, 118.2, 123.2, 124.2, 125.9, 126.7, 128.3, 128.9, 146.3, 158.5 ppm; IR (KBr) ν_{max} = 3357s, 1509vs, 1253s, 851m, 828m, 816s cm^{-1}; MS (70 eV) *m/z* (rel int) 269 (M$^+$, 100), 254 (6), 204 (23). HRMS *m/z* Calcd for $C_{16}H_{15}NOS$ (M$^+$) 269.0874, found: 269.0876.

4-Benzyl-5-(4-methoxyphenyl)pyrrole-2-carbaldehyde (9a)

To a solution of 0.486 mL (6.28 mmol) of DMF in 20 mL of CH_2Cl_2 at 0 ˚C was added 0.840 mL (9.03 mmol) of $POCl_3$. After being stirred at the same temperature for 2 h, a solution of 1.58 g (6.00 mmol) of **8a** in 10 mL of CH_2Cl_2 was added dropwise to the mixture. Then, the mixture was stirred at room temperature for 3 h, and then was poured into a saturated aqueous $NaHCO_3$ solution and was extracted with CH_2Cl_2 (50 mL x 3). The combined organic layer was washed with brine and was dried over $MgSO_4$. The solvent was evaporated and the residue was purified by SiO_2 chromatography (3%AcOEt-CH_2Cl_2) to give 1.41 g of **9a** (81% yield) as colorless microcrystals. Mp 124–125 °C. ^1H NMR ($CDCl_3$) δ = 3.84 (s, 3H, –OCH_3), 3.97 (s, 2H, CH_2), 6.77 (d, J = 2.8 Hz, 1H, H–3), 6.96 (dm, J = 8.8 Hz, 2H, 4-MeOC_6H_4), 7.19–7.24 (m, 3H, *o*- and *p-H* of Ph), 7.31 (t, J = 7.2 Hz, 2H, *m-H* of Ph), 7.40 (dm, J = 8.8 Hz, 2H, 4-MeOC_6H_4), 9.40 (s, 1H, –C*H*O) ppm; ^{13}C NMR ($CDCl_3$) δ = 32.5, 55.4, 114.5, 122.2, 123.4, 123.7, 126.1, 128.46, 128.52, 128.8, 131.4, 137.4, 140.9, 159.8, 178.4 ppm; IR (KBr) ν_{max} = 3295s, 1633vs, 1243s cm^{-1}; MS (70 eV) *m/z* (rel int) 291 (M^+, 100), 290 (21), 262 (23), 215 (9), 214 (55), 186 (5), 184 (6), 115 (7). HRMS *m/z* Calcd for $C_{19}H_{17}NO_2$ (M^+) 291.1259, found: 291.1260.

4-(4-Bromophenylmethyl)-5-(4-methoxyphenyl)pyrrole-2-carbaldehyde (9b) and 5-(4-methoxyphenyl)-4-(2-thienylmethyl)pyrrole-2-carbaldehyde (9c)

By the same procedure to the synthesis of **9a**, **9b** and **9c** were synthesized from **8b** and **8c** in 87 and 64% yields, respectively. **9b**: Creamy white solids. Mp 144–145 ˚C. ^1H NMR ($CDCl_3$) δ = 3.84 (s, 3H, –OCH_3), 3.91 (s, 2H, CH_2), 6.74 (d, J = 2.6 Hz, 1H, H–3), 6.96 (dm, J = 8.8 Hz, 2H, 4-MeOC_6H_4), 7.06 (dm, J = 8.4 Hz, 2H, 4-BrC_6H_4), 7.36 (dm, J = 8.8 Hz, 2H, 4-MeOC_6H_4), 7.41 (dm, J = 8.4 Hz, 2H, 4-BrC_6H_4), 9.41 (s, 1H, –C*H*O) ppm; ^{13}C NMR ($CDCl_3$) δ= 32.0, 55.4, 114.6, 120.0, 121.5, 123.1, 123.5, 128.8, 130.2, 131.5, 131.6, 137.5, 139.9, 159.9, 178.5 ppm; IR (KBr) ν_{max} = 1640vs, 1609s, 1253s, 838s cm^{-1}; MS (70 eV) *m/z* (rel int) 371 (M^+, 100), 370 (34), 369 (M^+, 100), 368 (14), 342 (14), 340 (15), 210 (40). HRMS *m/z* Calcd for $C_{19}H_{16}{}^{79}BrNO_2$ (M^+) 369.0364, found: 369.0362. **9c**: Creamy white solids. Mp 132–134 ˚C. ^1H NMR ($CDCl_3$) δ= 3.84 (s, 3H, –OCH_3), 4.12 (s, 2H, CH_2), 6.81 (m, 1H, –C_4H_3S), 6.90 (d, J = 2.8 Hz, 1H, H–3), 6.94 (d, J = 2.8 Hz Hz, 1H, –C_4H_3S), 6.96 (dm, J = 9.5 Hz, 2H, 4–MeOC_6H_4), 7.15 (dd. J = 5.2, 1.3 Hz, 1H, –C_4H_3S), 7.41 (dm, J = 9.5 Hz, 2H, 4–MeOC_6H_4), 9.43 (s, 1H, –C*H*O) ppm; ^{13}C NMR ($CDCl_3$) δ = 27.0, 55.4, 114.5, 121.8, 123.1, 123.5, 123.8, 124.8, 126.9, 129.0, 131.5, 137.5, 144.4, 159.9, 178.6 ppm; IR (KBr) ν_{max} = 3254vs, 1642vs, 1251s, 848s, 839s, 813m cm^{-1}; MS (70 eV) *m/z* (rel int) 297 (M^+, 100), 268 (45), 214 (10). HRMS *m/z* Calcd for $C_{17}H_{15}NO_2S$ (M^+) 297.0824, found: 297.0823.

4-Benzyl-5-phenylpyrrole-2-carbaldehyde (9d) and 5-phenyl-4-(2-thienylmethyl)pyrrole-2-carbaldehyde (9e)

To a solution of 116 μL (1.50 mmol) of DMF in 10 mL of CH_2Cl_2 at 0 ˚C was added 140 μL (1.50 mmol) of $POCl_3$. After being stirred at the same temperature for 2 h, a solution of 233 mg (1.00 mmol) of **8d** in 4 mL of CH_2Cl_2 was added dropwise to the mixture. Then, the mixture was stirred at room temperature for

3 h, and then was poured into a saturated aqueous $NaHCO_3$ solution and was extracted with CH_2Cl_2 (50 mL x 3). The combined organic layer was washed with brine and was dried over $MgSO_4$. The solvent was evaporated and the residue was purified by SiO_2 chromatography (1%AcOEt-CH_2Cl_2) to give 251 mg of **9d** (96% yield) as colorless microcrystals. Mp 105–107 °C. ^{1}H NMR ($CDCl_3$) δ= 4.00 (s, 2H, C*H*$_2$), 6.77 (d, *J* = 2.5 Hz, 1H, H–3), 7.19–7.23 (m, 3H, *o*- and *p*-H of Ph), 7.30 (t, *J* = 7.5 Hz, 2H, *m*-H of Bn), 7.37 (t, *J* = 7.5 Hz, 1H, *p*-H of Bn), 7.41– 7.48 (m, 4H, *m*-H of Ph and *o*-H of Bn), 9.42 (s, 1H, –C*H*O) ppm; ^{13}C NMR ($CDCl_3$) δ= 32.4, 122.8, 123.3, 126.1, 127.5, 128.48 (2C), 128.51, 129.0, 131.2, 131.8, 137.3, 140.8, 178.8 ppm; IR (KBr) ν_{max} = 3289s, 1644vs, 692s cm^{-1}; MS (70 eV) *m/z* (rel int) 261 (M$^+$, 100), 260 (26), 233 (10), 232 (46), 185 (10), 184 (68), 154 (21), 128 (13), 127 (13), 77 (13). HRMS *m/z* Calcd for $C_{18}H_{15}NO$ (M$^+$) 261.1154, found: 261.1151.

By the same procedure to the synthesis of **9d**, **9e** was synthesized from **8e** in 72% yield. **9e**: Colorless plates. Mp 105–106 °C. ^{1}H NMR ($CDCl_3$) δ = 4.15 (s, 2H, C*H*$_2$), 6.82 (dd, *J* = 3.5, 1,1 Hz, 1H, –C_4H_3S), 6.92 (d, *J* = 2.6 Hz, 1H, H–3), 6.94 (dd, *J* = 5.0, 3.5 Hz, 1H, –C_4H_3S), 7.16 (dd, *J* = 5.0, 1,1 Hz, 1H, –C_4H_3S), 7.34 (tt, *J* = 7.1, 2.0 Hz, 1H, *p-H* of Ph), 7.45 (tt, *J* = 7.1, 2.0 Hz, 2H, *m-H* of Ph), 7.48 (dt, *J* = 7.1, 2.0 Hz, 2H, *o-H* of Ph), 9.47 (s, 1H, –C*H*O) ppm; ^{13}C NMR ($CDCl_3$) δ= 27.0, 122.4, 122.8, 123.8, 124.8, 126.9, 127.6, 128.7, 129.1, 131.1, 131.8, 137.2, 144.2, 178.8 ppm; IR (KBr) ν_{max} = 3236s, 1645vs, 922m, 850m, 807m cm^{-1}; MS (70 eV) *m/z* (rel int) 267 (M$^+$, 100), 266 (37), 239 (11), 228 (65), 154 (10). HRMS *m/z* Calcd for $C_{16}H_{13}NOS$ (M$^+$) 267.0718, found: 267.0716.

2,8-Dibenzyl-1,9-bis(4-methoxyphenyl)dipyrrin (10a) from 9a

A mixture of 209 mg (0.718 mmol) of **9a** in a mixture of AcOH (5 mL) and 48% HBr (5 mL) was heated at 85 °C on an oil bath under nitrogen atmosphere for 4 h. The resulted blue reaction mixture was carefully poured into a cold aqueous $NaHCO_3$ solution and extracted with $CHCl_3$ (20 mL x 3). The combined organic layer was washed with brine and dried over Na_2SO_4. The solvent was removed and the red residue was purified by SiO_2 chromatography (10%AcOEt-$CHCl_3$) to give 179 mg (93% yield) of **10a** as red microcrystals. Mp 161–163 °C. ^{1}H NMR ($CDCl_3$) δ= 3.85 (s, 6H, –OC*H*$_3$), 4.02 (s, 4H, C*H*$_2$), 6.55 (s, 2H, H–3,7), 6.62 (s, 1H, H–5), 6.94 (dm, *J* = 8.0 Hz, 4H, 4-MeOC_6H_4), 7.19–7.23 (m, 6H, *o*- and *p*-H of Ph), 7.29 (t, *J* = 8.0 Hz, 4H, *m*-H of Ph), 7.64 (dm, *J* = 8.0 Hz, 4H, 4-MeOC_6H_4) ppm; ^{13}C NMR ($CDCl_3$) δ= 33.7, 55.4, 114.1, 126.0, 126.7, 128.4, 128.7, 128.9, 129.0, 130.2, 139.5, 140.7, 152.6, 159.8, 169.7 ppm; IR (KBr) ν_{max} = 1604s, 1252vs, 1175m cm^{-1}; UV-vis (MeOH) λ_{max} = 291 (logε = 4.32), 504 (4.42) nm; MS (70 eV) *m/z* (rel int) 536 (M$^+$, 100), 445 (7), 276 (19), 268 (9), 264 (7), 263 (36), 262 (5), 186 (10). HRMS *m/z* Calcd for $C_{37}H_{32}N_2O_2$ (M$^+$) 536.2464, found: 536.2467. The TfOH salt of **10a**, **10a·HOTf**, was obtained quantitatively as blue microplates from **10a** and TfOH in EtOH. Mp 197–199 °C. ^{1}H NMR (DMSO-*d*$_6$) δ= 3.84 (s, 6H, –OC*H*$_3$), 4.14 (s, 4H, C*H*$_2$), 7.13 (d, *J* = 8.5 Hz, 4H, 4-MeOC$_6$H$_4$), 7.22-7.24 (m, 8H, *o*- and *p*-H of Ph and H–3,7), 7.31 (t, *J* = 7.5 Hz, 4H, *m*-H of Ph), 7.71 (d, *J* = 8.5 Hz, 4H, 4-MeOC$_6$H$_4$), 7.76 (s, 1H, H–5) ppm; ^{13}C NMR (DMSO-*d*$_6$) δ= 32.3, 55.5, 114.7, 121.2, 120.5 (q, *J* = 322.2 Hz, –*C*F$_3$), 126.3, 127.3, 127.7, 128.2, 128.5, 129.7, 131.5, 132.9, 139.2, 148.8, 161.1 ppm; IR (KBr) $\nu_{\max}$ =1598s, 1258s, 1243s, 1167s cm^{-1}. A sample for X-ray analysis was obtained by recrystallization from hexane-CH$_2$Cl$_2$. Similarly, the HBr salt, **10a·HBr**, was obtained as blue microcrystals. Mp 185–186 °C. ^{1}H NMR (DMSO-*d*$_6$) δ□= 3.84 (s, 6H, –OC*H*$_3$), 4.14 (s, 4H, C*H*$_2$), 7.12 (d, *J* = 8.5 Hz, 4H, 4-MeOC$_6$H$_4$), 7.20–7.24 (m, 8H, *o*- and *p*-H of Ph and H–3,7), 7.31 (t, *J* = 8.0 Hz, 4H, *m*-H of Ph), 7.71 (d, *J* = 8.5 Hz, 4H, 4-MeOC$_6$H$_4$), 7.76 (s, 1H, H–5) ppm; ^{13}C NMR (CDCl$_3$) δ= 32.3, 55.4, 114.7, 121.1, 126.2, 127.2, 127.7, 128.1, 128.5, 129.7, 131.5, 132.8, 139.1, 148.7, 161.1 ppm; IR (KBr) $\nu_{\max}$ =1597vs, 1256vs, 1243s, 1179s, 1169s, 1160s cm^{-1}; UV-vis (MeOH) $\lambda_{\max}$ = 279 (logε = 4.20), 317sh (3.92), 376 (3.49), 585 (4.81) nm. *Anal.* Calcd C$_{37}$H$_{33}$BrN$_2$O$_2$·H$_2$O: C 69.92, H 5.55, N, 4.41%. Found C 69.75, H 5.69, N 4.28%.

2,8-Bis(4-bromophenylmethyl)-1,9-bis(4-methoxyphenyl)dipyrrin (10b) and 1,9-bis(4-methoxyphenyl)-2,8-bis(2-thienylmethyl)dipyrrin (10c)

By the same procedure to the synthesis of **10a**, **10b** and **10c** were synthesized from **9b** and **9c** in 95 and 90% yields, respectively. **10b**: Red prisms. Mp 156–158 ˚C. ^{1}H NMR (CDCl$_3$) δ = 3.85 (s, 6H, –OC*H*$_3$), 3.97 (s, 4H, C*H*$_2$), 6.55 (s, 2H, H–3, 7), 6.64 (s, 1H, H–5), 6.95 (dm, *J* = 8.6 Hz, 4H, 4–MeOC$_6$H$_4$), 7.10 (dm, *J* = 8.6 Hz, 4–BrC$_6$H$_4$), 7.41 (dm, *J* = 8.6 Hz, 4H, 4–MeOC$_6$H$_4$), 7.61 (dm, *J* = 8.6 Hz, 4H, 4–BrC$_6$H$_4$) ppm; ^{13}C NMR (CDCl$_3$) δ = 33.3, 55.5, 114.3, 120.0, 122.4, 126.6, 129.0, 129.1, 129.6, 130.5, 131.6, 139.6, 139.8, 152.8, 160.0 ppm; IR (KBr) $\nu_{\max}$ = 1607s, 1251s, 602m cm^{-1}; UV–vis (MeCN) $\lambda_{\max}$ = 220sh (logε = 4.57), 272sh (4.33), 292 (4.44), 505 (4.55) nm; UV–vis (1%TFA–MeCN) $\lambda_{\max}$ = 278 (4.19), 321 (3.91), 381 (3.57), 586 (5.00) nm; FABMS *m/z* (rel int) 697 (M$^+$+H, 35), 695 (M$^+$+H, 56), 693 (M$^+$+H, 34), 307 (13), 289 (11), 252 (31), 154 (nitrobenzyl alcohol$^+$+H, 100).[12] HRMS *m/z* Calcd for C$_{37}$H$_{31}$^{79}Br$_2$N$_2$O$_2$ (M$^+$+H) 693.0758, found: 693.0753. **10c**: Red microcrystals. Mp 160–161 ˚C. ^{1}H NMR (CDCl$_3$) δ = 3.86 (s, 6H, –OC*H*$_3$), 4.19 (s, 4H, C*H*$_2$), 6.71 (s, 1H, H–5), 6.75 (s, 2H, H–3, 7), 6.84 (m, 2H, –C$_4$H$_3$S), 6.93 (d, *J* = 3.5 Hz, 2H, –C$_4$H$_3$S), 6.96 (dm, *J* = 9.1 Hz, 4H, 4–MeOC$_6$H$_4$), 7.16 (dd, *J* = 5.2, 0.9 Hz, 2H, –C$_4$H$_3$S), 7.65 (dm, *J* = 9.1 Hz, 4H, 4–MeOC$_6$H$_4$) ppm; ^{13}C NMR (CDCl$_3$) δ = 28.1, 55.4, 114.2, 122.7, 123.7, 124.9, 126.5, 126.9, 128.9, 129.1, 129.6, 139.5, 144.1, 152.6, 159.9 ppm; IR (KBr) $\nu_{\max}$ = 1610s, 1254s, 839m, 818m, 800m cm^{-1}; UV–vis (MeCN) $\lambda_{\max}$ = 232 (logε = 4.37), 291 (4.37), 349sh (3.64), 503 (4.46) nm; UV–vis (1%TFA–MeCN) $\lambda_{\max}$ = 237 (4.22), 279 (4.14), 322 (3.83), 386 (3.55), 585 (4.88) nm; FABMS *m/z* (rel int) 549 (M$^+$+H, 100), 307 (23), 289 (18), 154 (nitrobenzyl alcohol$^+$+H, 100).[12] HRMS *m/z* Calcd for C$_{33}$H$_{29}$N$_2$O$_2$S$_2$ (M$^+$+H) 549.1670, found: 549.1676.

2,8-Dibenzyl-1,9-bis(4-methoxyphenyl)dipyrrin (10a) from 8a and 9a

A mixture of 22 mg (0.086 mmol) of **8a** and 25 mg (0.086 mmol) of **9a** in a mixture of AcOH (1 mL) and 48% HBr (1 mL) was stirred at room temperature under nitrogen atmosphere for 15 h. The resulted blue reaction mixture was carefully poured into a cold aqueous $NaHCO_3$ solution and extracted with $CHCl_3$ (20 mL x 3). The combined organic layer was washed with brine and dried over Na_2SO_4. The solvent was removed and the red residue was purified by SiO_2 column chromatography (10%AcOEt–$CHCl_3$) to give 36 mg (80% yield) of **10a** as red solids.

Zinc(II) bis[2,8-dibenzyl-1,9-bis(4-methoxyphenyl)dipyrrinato] (14)

A mixture of 53.6 mg (0.100 mmol) of **10a**, 10.1 mg (0.0550 mmol) of zinc acetate, and 10 mL of piperidine in MeOH (3 mL) was stirred at room temperature under nitrogen atmosphere for 2 h. The solids formed were collected and washed well with water and, then recrystallized from hexane-$CHCl_3$ to give 28.0 mg (49% yield) of **14** as dark red microcrystals. Mp 188–190 °C. ^{1}H NMR ($CDCl_3$) δ= 3.70 (s, 12H –OCH_3), 3.71 (s, 8H, CH_2), 6.48 (m, 6H, H–3, 5, 7), 6.50 (dm, J = 9.0 Hz, 8H, 4-$MeOC_6H_4$), 6.99 (dm, J = 9.0 Hz, 8H, 4-$MeOC_6H_4$), 7.07 (d, J = 7.3 Hz, 8H, *o*-H of Bn), 7.21 (t, J = 7.3 Hz, 4H, *p*-H of Bn), 7.31 (t, J = 7.3 Hz, 8H, *m*-H of Bn) ppm; ^{13}C NMR ($CDCl_3$) δ□= 32.8, 55.3, 113.0, 125.7, 127.1, 128.2, 128.5, 128.9, 129.3, 131.5, 138.5, 141.8, 153.7, 158.2, 158.8 ppm; IR (KBr) ν_{max} = 1594vs, 1223s, 1168s, 1023vs, 983s cm^{-1}; UV (MeOH) λ_{max} = 290 (logε = 4.49), 347 (3.97), 537 (5.05) nm; FABMS *m/z* (rel int) 1134 (M^+, 5), 307 (10), 154 (nitrobenzyl alcohol$^+$+H, 100).[12] HRMS *m/z* Calcd for $C_{74}H_{62}N_4O_4Zn$ (M^+) 1134.4063, found: 1134.4057.

2,3-Dibenzyl-4,4-difluoro-3,5-bis(4-methoxyphenyl)-4-bora-3a,4a,-diaza-*s*-indacene (15)

A mixture of 268 mg (0.500 mmol) of **10a**, 2.76 mL (22.5 mmol) of $BF_3\cdot OEt_2$, and 1.39 mL (10.0 mmol) of Et_3N in CH_2Cl_2 (12 mL) was refluxed on an oil bath under nitrogen atmosphere for 3 h. The resulted reaction mixture was poured into a saturated aqueous $NaHCO_3$ solution and was extracted with CH_2Cl_2 (50 mL x 3). The combined organic layer was washed with brine and was dried over $MgSO_4$. The solvent was evaporated and the residue was purified by SiO_2 chromatography (toluene-CH_2Cl_2) to give 104 mg of **15** (35% yield) as dark red microcrystals. Mp 183–185 °C. ^{1}H NMR ($CDCl_3$) δ= 3.68 (s, 4H, CH_2), 3.80 (s, 6H, –OCH_3), 6.75 (s, 2H, H–3, 7), 6.89 (dm, J = 9.0 Hz, 4H, 4-$MeOC_6H_4$), 7.02 (s, 1H, H–5), 7.09 (d, J = 7.3 Hz, 4H, *o*-H of Bn), 7.19 (t, J = 7.3 Hz, 2H, *p*-H of Bn), 7.26 (t, J = 7.3 Hz, 4H, *m*-H of Bn), 7.45 (dm, J = 9.0 Hz, 4H, 4-$MeOC_6H_4$) ppm; ^{13}C NMR ($CDCl_3$) δ= 47.1, 55.2, 113.4, 123.9, 126.1, 126.5, 128.4, 128.6, 129.1, 131.2, 133.0, 134.4, 140.3, 157.4, 160.1 ppm; IR (ATR) ν_{max} = 1607vs, 1227s, 1177s, 1166s, 1065vs cm^{-1}; UV-vis (MeOH) λ_{max} = 264 (logε = 4.13), 313sh (3.79), 371 (4.00), 559 (4.80) nm; MS (70 eV) *m/z* (rel int) 584 (M^+, 100), 583 (25), 507 (7), 475 (3), 244 (3), 243 (9). HRMS *m/z* Calcd for $C_{37}H_{31}BF_2N_2O_2$ (M^+) 584.2447, found: 584.2447.

Measurement of basicity of 10a

The pK_a value of the conjugate acid, **10a·H**$^+$, was determined by measuring p*H* of a mixture of **10a** and **10a·H**$^+$. The p*H* measurement and calculations for pK_a value were carried out according to the method reported by Krumholz.[13] Since **10a** was entirely insoluble in water, measurements were done in 50%MeOH-H_2O without adding inorganic salt to adjust ionic strength. The bromide salt was used for **10a·H**$^+$. A TPX-90Si glass electrode p*H* meter, available from TOKO Chemical Laboratories Co., was used for p*H* measurements.

X-Ray crystallographic analysis of 10a·HOTf: Diffraction measurements were conducted using a Rigaku R-AXIS RAPID diffractometer at –120 ˚C. Crystal data are as follows; triclinic, space group; *P*1 (# 1), *a*; 5.5545 (1) Å, *b*; 10.8622 (2) Å, *c*; 14.3493 (3) Å, α; 79.0386 (9)°, β; 85.273 (1)°, γ; 78.4253 (9)°, *V*; 831.79 (3) Å^3, *Z*; 1, *R*; 0.1072, *wR2*; 0.2854, *R1*; 0.0908 ($I > 2.00\sigma(I)$), and *S*; 1.127. The relatively large *R* values are mainly attributed to thermal vibration of fluorine atoms of the triflate anion. Tables of fractional atomic coordinates, thermal parameters, bond lengths, and angles have been deposited at the Cambridge Crystallographic Data Centre, 12 Union Road, Cambridge CB2 1EZ, United Kingdom (CCDC 941475) [Derect line: +44 1223 762910, Fax: +44 (0) 1233 336033, e-mail: deposit@ccdc.cam.ac.uk].

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REFERENCES AND NOTES

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9. Basicity (pK_b value) of **10a** was determined to be 8.53 ± 0.06 in 50%MeOH-H_2O. For details, see Experimantal.

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