Synthesis of (*p*-Substituted phenyl)azo Calix[4]arenes

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A novel method for the preparation of chromogenic calixarenes with azo groups was reported. *p*-Substituted ($-NO_2$, $-CH_3$, $-Cl$) anilines were diazotized with *iso*amyl nitrite in EtONa/EtOH under refluxing condition. Fifteen mono-, bis-, tris- and tetrakis(*p*-substituted phenyl)azo calix[4]arenes (including *proximal* and *distal* isomers) were obtained respectively by diazo-coupling in different molar ratio to calix[4]arenes (1) under pH=7.5—9.0 in non-aqueous solution at 0—5 ℃. ^1H NMR and ^{13}C NMR spectra of (*p*-substituted phenyl)azo calix[4]-arenes indicated that they existed in cone conformation in solution.

Keywords chromogenic calix[4]arenes, diazo-coupling, *iso*amyl nitrite, *p*-substituted aniline

Introduction

Calixarenes constitute a versatile class of macrocyclic compounds which have attracted extensive interest due to their ability to form host-guest complexes and act as enzyme mimic, especially when appropriately functionalized.[1-3] For the purpose of finding a simple method for detecting them in the process of molecular recognition, azo groups have been introduced into calixarenes to give the so-called "chromogenic calixarenes".[1,4-5] Moreover, recently, double chromomeric calixarenes have also been synthesized successfully by Lamartine *et al*.[6] Similar to chromogenic crown ethers,[7] chromogenic calixarenes have absorption (or fluorescence) spectra changes when bound up with cations.[4,8] Therefore, a number of chromogenic calixarene derivatives have been applied as selective ionophores in extractive process[9-11] or as selective ligands in ion selective electrodes and optical sensors.[12-14] Chromogenic calixarenes can be obtained by introducing azo groups into calixarenes. Shinkai *et al*.[4,15] reported first synthesis of azocalixarenes by the diazo-coupling reaction of calix[4]arenes (**1**) with substituted benzene diazonium fluoroborates in an autoaccelerative manner. Other synthetic methods of azo calix[4]arenes reported by several groups[10,16-18] were usually carried out by the diazo-coupling reaction of calix[4]arenes **1** with substituted benzene diazonium chlorides prepared from the diazotization reaction of substituted anilines with sodium nitrite in concentrated HCl. However, in these preparations carried out in aqueous solvents, tetrakis(arylazo)-substituted calix[4]arenes are always obtained as a main product. Therefore, these methods are only suitable for the preparation of tetrakis(arylazo)-substituted calix[4]arenes. Here, a novel synthetic method for (*p*-substituted phenyl)azo calix[4]arenes was reported. According to this method *p*-substituted analines were diazotized with isoamyl nitrite in EtONa/EtOH, and the diazo-coupling reactions were carried out in the presence of carbon dioxide gas in non-aqueous solution at 0—5 ℃ (Scheme 1). It can be concluded that this method is suitable for the preparation of

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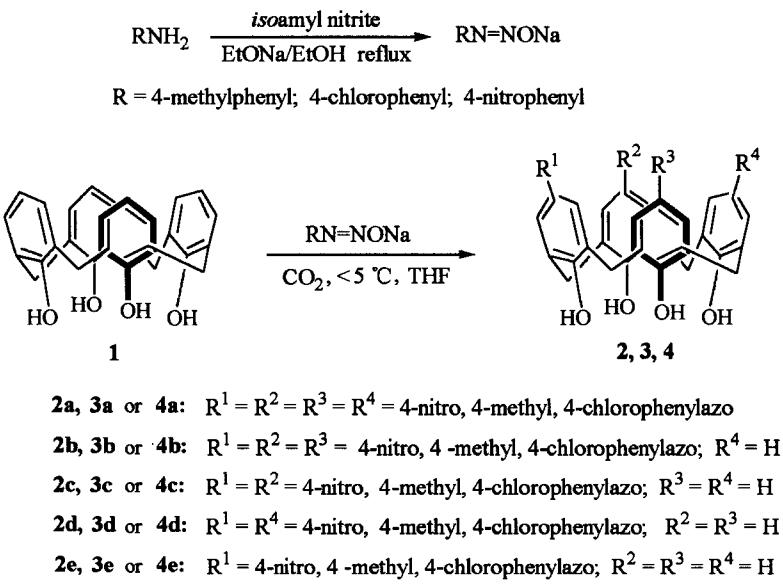
Received February 4, 2002; revised June 8, 2002; accepted June 19, 2002.

Project supported by the National Natural Science Foundation of China (No. 90101018) and the Foundation of State Key Laboratory of Bioorganic and Natural Products Chemistry in Shanghai Institute of Organic Chemistry, Chinese Academy of Sciences.

Scheme 1



2a, 3a or **4a**: $R^1 = R^2 = R^3 = R^4$ = 4-nitro, 4-methyl, 4-chlorophenylazo

2b, 3b or **4b**: $R^1 = R^2 = R^3$ = 4-nitro, 4-methyl, 4-chlorophenylazo; $R^4 = H$

2c, 3c or **4c**: $R^1 = R^2$ = 4-nitro, 4-methyl, 4-chlorophenylazo; $R^3 = R^4 = H$

2d, 3d or **4d**: $R^1 = R^4$ = 4-nitro, 4-methyl, 4-chlorophenylazo; $R^2 = R^3 = H$

2e, 3e or **4e**: R^1 = 4-nitro, 4-methyl, 4-chlorophenylazo; $R^2 = R^3 = R^4 = H$

mono-, bis-, tris- and tetrakis(*p*-substituted phenyl)azo calix[4]arenes (**2**—**4**).

Results and discussion

The synthetic pathway is shown in Scheme 1. The diazotization reactions of the *p*-substituted ($-NO_2$, $-CH_3$, $-Cl$) anilines were carried out with *iso*amyl nitrite as a source of nitrous acid in EtONa/EtOH under refluxing condition. When calix[4]arenes **1** and different molar ratio of *p*-substituted ($-NO_2$, $-CH_3$ or $-Cl$) anilines were used, and the diazo-coupling reaction solutions were adjusted to pH = 7.5—9.0 by introducing carbon dioxde gas at 0—5 ℃, corresponding mono-, bis-(including *proximal* and *distal* isomers), tris- and tetrakis(*p*-substituted phenyl)azo calix[4]arenes (**2**—**4**) were produced, respectively. The advantages of this method are that the reaction can be carried out in a non-aqueous solution and that mono-, bis-, tris- and tetrakis (*p*-substituted phenyl) azo calix[4]arenes can be prepared respectively under different conditions.

The pH value of the solution is important in the diazo-coupling reaction carried out in accondance with this method. The diazo-coupling reactions were not to occur in stronger alkaline solution because the diazoniom ions would not be formed. The pH values were adjusted to make it slightly alkaline (7.5—9.0) by introducing carbon dioxide gas so as to make phenol units of calix[4]-arenes exist as phenoxide ion which was more reactive than ordinary phenol units. The mono-, bis-, tris- and tetrakis(*p*-substituted phenyl)azo calix[4]arenes can be obtained respectively according to the radios of *p*-substituted anilines to calix[4]arenes **1**. A longer reaction time (6—8 h) was necessary for preparing multi(*p*-substituted phenyl)azo calix[4]arenes, especially tetrakis(*p*-substituted phenyl)azo calix[4]arenes with electron-donating or weak electron-withdrawing group, whereas a shorter reaction time (*ca*. 2 h) was required for preparing mono (*p*-substituted phenyl)azo calix[4]arenes.

The strong electron-withdrawing nitro group could increase the electrophilicity of ArN_2^+, so (*p*-nitrophenyl)azo calix[4]arenes were obtained in higher yields. When the radios of *p*-nitroanilines to calix[4]arenes **1** were 4:1, 3:1, 2:1 and 1:1, yields of the corresponding tetrakis-, tris-, bis-(*proximal* and *distal* isomers) and mono(*p*-nitrophenyl)azo calix[4]arenes (**2a**, **2b**, **2c**+**2d**, **2e**) were 61.9%, 17.2%, 48.5% and 52.0%, respectively, whereas $-CH_3$ and $-Cl$ were electron-donating group and weak electron-withdrawing group respectively. So (*p*-methylphenyl) azo calix[4]arenes (**3a**, 29.3%; **3b**, 12.8%; **3c**+**3d**, 14.6%; **3e**, 33.2%) or (*p*-chlorophenyl) azo calix[4]arenes (**4a**, 33.6%; **4b**, 12.1%; **4c**+**4d**, 14.1%; **4e**, 34.3%) were obtained in lower yields than the corresponding (*p*-nitrophenyl) azo calix[4]arenes. For bis(*p*-substituted phenyl)azo calix[4]arenes, the *proximal* (5,11-disubstituted) and *distal* (5,17-disubstituted) isomers were obtained though separation by means of column chro-

matography. The yields of the *proximal* isomers (**2c**, 33.5%; **3c**, 9.5%; **4c**, 9.6%) were about twice as much as those of the *distal* isomers (**2d**, 15.0%; **3d**, 5.1%; **4d**, 4.5%), and the main reason for this can be ascribed to the higher statistical probability at the *proximal* positions than to the *distal* positions in the diazo-coupling reactions.

All structures of (*p*-substituted phenyl)azo calix[4]-arenes (**2**—**4**) were characterized by ^{1}H NMR, ^{13}C NMR, MS, IR and elemental analyses. In the ^{1}H NMR spectra, the methylene protons of $ArCH_2Ar$ of azo calix[4]arenes always appeared as broad signals at room temperature. When ^{1}H NMR spectra were measured at −20 ℃, the broad signals became sharper and a splitting pattern appeared (Fig. 1). The chemical shift values and splitting pattern of the methylene protons at low-temperature are summarized in Table 1, where the tetrakis(*p*-substituted phenyl)azo calix[4]arenes (**2a**—**4a**) display one pair of doublets because they are symmetrical compounds. In Table 1 mono(*p*-substituted phenyl)azo calix[4]arenes (**2e**—**4e**) display two pairs of doublets with a ratio of 1∶1. Also in Table 1 the bis(*p*-substituted phenyl)azo calix[4]arenes (**2c**—**4c**) display three pairs of doublets with a ratio of 1:2:1, and three peaks of the methylene carbons appear in the range of δ 31.5—33.5 in the ^{13}C NMR. Therefore compounds **2c**, **3c** and **4c** are 5,11-disubstituted (*proximal*) isomers.[18-20] In Table 1 bis(*p*-substituted phenyl) azo calix[4]arenes (**2d**—**4d**) display one pair of doublets, and only one peak of the methylene carbons appears about δ 31.8 in the ^{13}C NMR. It is clear that compounds **2d**, **3d** and **4d** are 5, 17-disubstituted (*distal*) isomers.[18-20] The ^{1}H NMR chemical shift values and splitting pattern of the methylene hydrogens at low-temperature also indicate that these (*p*-substituted phenyl) azo calix[4]arenes had a cone conformation.[20,21] Moreover, in the ^{13}C NMR spectra, all signals of the methylene carbons appeared within the range of δ 31.3—33.6. This is also consistent with the cone conformation.[19,20]

The primary experimental results indicate that some novel azo calix[4]arenes have a strong ability to complex some transition and heavy metal cations. In addition, due to the existence of several D-π-A units linked by methylene bridges, azo calix[4]arenes (**2a**—**2d**) have higher second-order nonlinear effect without red shift of the charge transfer band, which made such azo calix[4]-arenes potentially suitable as organic NLO chromospheres.[22,23]

Experimental

Melting points were determined on a Yanaco micro melting point apparatus. Samples for elemental analysis were dried *in vacuo* at 60 ℃. Elemental analyses were carried out using a Perkin Elmer 240C. ^{1}H NMR and ^{13}C NMR spectra were recorded on a Inova 600. MS spectra

Table 1 ^{1}H NMR δ values and splitting pattern for methylene hydrogens of **2**—**4** (600 MHz, −20 ℃)

p-Substitution	δ	Splitting pattern[a]
tetra- (**2a**)	5.08, 3.90	one pair of doublets
tetra- (**3a**)	5.07, 3.81	one pair of doublets
tetra- (**4a**)	5.09, 3.84	one pair of doublets
tri- (**2b**)	4.55, 4.49, 3.64, 3.49	two pair of doublets (1:1)
tri- (**3b**)	4.36, 4.33, 3.82, 3.71	two pair of doublets (1:1)
tri- (**4b**)	4.37, 4.33, 3.82, 3.72	two pair of doublets (1:1)
5,11-di- (**2c**)	4.41, 4.39, 4.37, 3.84, 3.71, 3.59	three pair of doublets (1:2:1)
5,11-di- (**3c**)	4.36, 4.33, 4.30, 3.82, 3.70, 3.59	three pair of doublets (1:2:1)
5,11-di- (**4c**)	4.38, 4.34, 4.30, 3.82, 3.72, 3.60	three pair of doublets (1:2:1)
5,17-di- (**2d**)	4.35, 3.70	one pair of doublets
5,17-di- (**3d**)	4.33, 3.71	one pair of doublets
5,17-di- (**4d**)	4.34, 3.71	one pair of doublets
mono- (**2e**)	4.34, 4.29, 3.71, 3.59	two pair of doublets (1:1)
mono- (**3e**)	4.31, 4.28, 3.68, 3.57	two pair of doublets (1:1)
mono- (**4e**)	4.32, 4.29, 3.69, 3.58	two pair of doublets (1:1)

[a] All coupling constants are about 13.8 Hz.

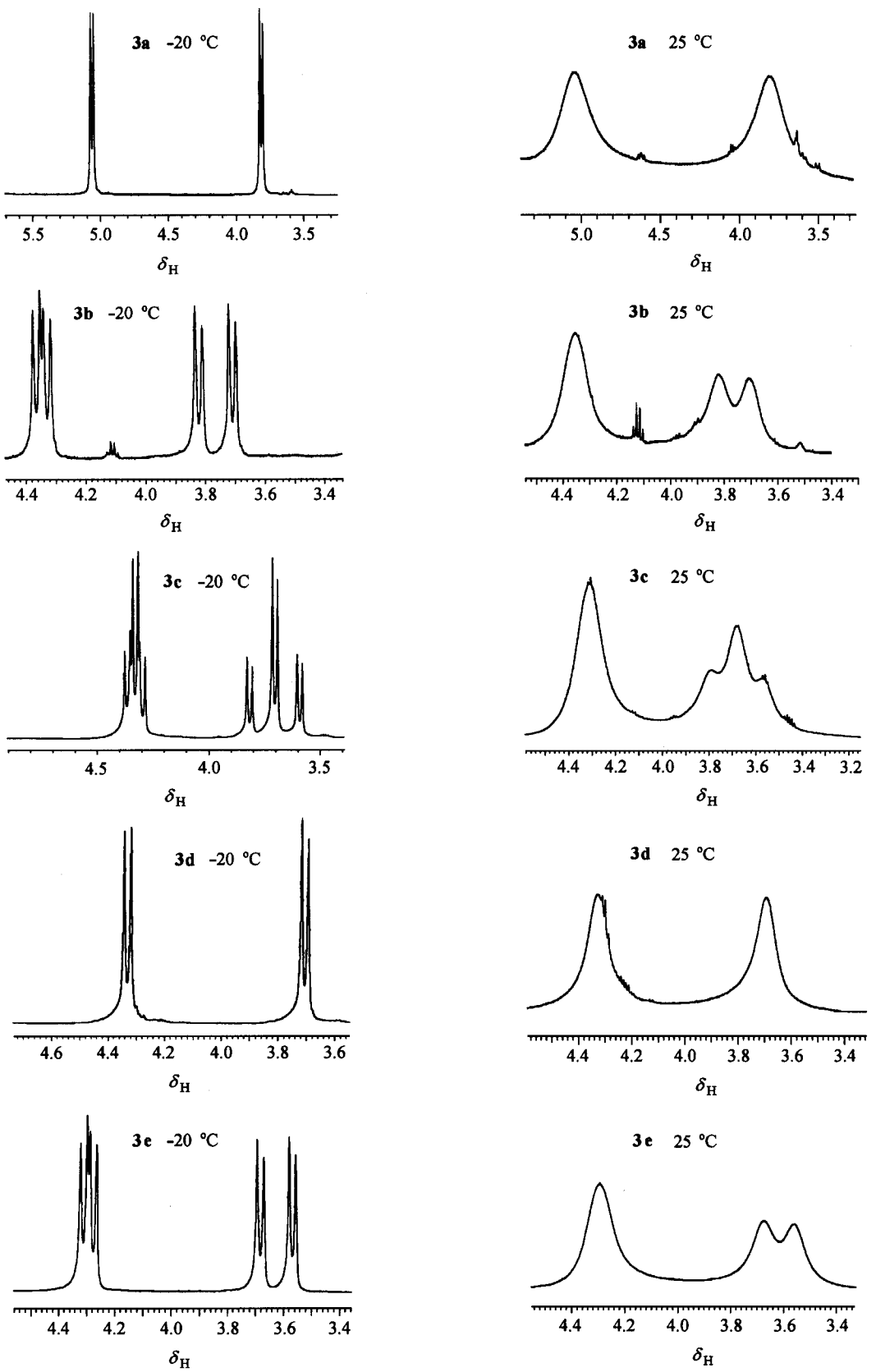


Fig. 1 ^{1}H NMR (pyridine-d_5, 600 MHz) spectral signals of methylene protons of $ArCH_2Ar$ of **3a**—**3e**.

were recorded by electrospray mass spectrometer (LCQ, Finnigan) in negative mode. IR spectra were recorded on a Bruker IFS 66v (Germany). Preparative column chromatography separations were performed on G60 silica gel, while precoated silica gel plates (GF_{254}) were used for analytical TLC. All the solvents were purified by standard procedures. All other chemicals were purchased from Sigma or Aldrich. Compound **1** was synthesized according to the reported procedure.[24]

Preparation of (p-substituted phenyl) azo calix[4]arenes derivatives (**2**—**4**)

General procedure

A solution of *p*-substituted aniline (6.0 mmol) in anhydrous ethanol (60 mL) was slowly added to a solution of NaOEt (120 mmol) in anhydrous ethanol (60 mL) under stirring, and then *iso*amyl nitrite (0.6 mL, 6.6 mmol) was added. The mixture was refluxed for 5 h. After cooling, the precipitate of diazotate salt was filtered and dissolved in 30 mL of anhydrous ethanol. A solution of a given amount of calix[4]arenes **1** in anhydrous THF (80 mL) was added to the solution of diazotate salt at 0—5 ℃, and carbon dioxide gas was passed through the mixture in order to adjuste to pH = 7.5—9.0. After continuous stirring for 2—8 h water (200 mL) was added, the red-brown precipitate was collected by filtration, which was separated by column chromatography to give (*p*-substituted phenyl)azo calix[4]arenes.

5,11,17,23-*Tetrakis*-[(4-*nitrophenyl*)*azo*]-25,26,27,28-*tetrahydroxy calix*[4]*arene* (**2a**) Yield 61.9%, m.p. > 320 ℃ (dec.), R_f 0.30 ($CH_3COOC_2H_5$: CH_3COCH_3, 10:1); ^{1}H NMR (pyridine-d_5, 600 MHz, 25 ℃) δ: 8.23 (d, J = 9.0 Hz, 8H, ArH in the 4-nitrophenyl moiety), 8.19 (s, 8H, ArH in the azo phenol moiety), 7.81 (d, J = 9.0 Hz, 8H, ArH in the 4-nitrophenyl moiety), 5.08 (brs, 4H, $ArCH_2Ar$), 3.88 (brs, 4H, $ArCH_2Ar$); ^{13}C NMR (pyridine-d_5, 600 MHz) δ: 32.4 ($ArCH_2Ar$), 118.7, 124.1, 129.1, 130.3, 141.2, 145.6, 152.3, 154.4 (aromatic C); IR (KBr) ν: 1591.2 (N = N), 1340.3 (NO_2) cm^{-1}; MS (ESIMS) *m/z*: 1019.7 ($[M-H]^-$, calcd 1019.3). Anal. calcd for $C_{52}H_{36}N_{12}O_{12}$: C 61.18, H 3.55, N 16.46; found C 60.78, H 3.79, N 16.10.

5,11,17-*Tris*-[(4-*nitrophenyl*)*azo*]-25,26,27,28-*tetrahydroxycalix*[4]*arene* (**2b**) Yield 17.2%, m.p. > 320 ℃ (dec.), R_f 0.25 ($CHCl_3$:C_5H_5N, 10:1); ^{1}H NMR (pyridine-d_5, 600 MHz, 25 ℃) δ: 8.35 (d, J = 9.0 Hz, 2H, ArH in the 4-nitrophenyl moiety), 8.29 (s, 2H, ArH in the azo phenol moiety), 8.24 (d, J = 9.0 Hz, 4H, ArH in the 4-nitrophenyl moiety), 8.07 (s, 2H, ArH in the azo phenol moiety), 8.01 (d, J = 9.0 Hz, 2H, ArH in the 4-nitrophenyl moiety), 7.97 (s, 2H, ArH in the azo phenol moiety), 7.83 (d, J = 9.0 Hz, 4H, ArH in the 4-nitrophenyl moiety), 7.22 (d, J = 7.8 Hz, 2H, ArH in the phenol moiety), 6.78 (t, J = 7.8 Hz, 1H, ArH in the phenol moiety), 4.56 (brs, 4H, $ArCH_2Ar$), 3.64 (brs, 4H, $ArCH_2Ar$); ^{13}C NMR (pyridine-d_5, 600 MHz) δ: 31.7, 32.5 ($ArCH_2Ar$), 118.9, 120.8, 122.4, 125.6, 126.4, 128.7, 130.4, 131.7, 132.5, 140.5, 141.1, 145.3, 147.8, 151.5, 152.1, 153.9, 154.7, 155.1 (aromatic C); IR (KBr) ν: 1598.2 (N = N), 1341.5 (NO_2) cm^{-1}; MS (ESIMS) *m/z*: 870.8 ($[M-H]^-$, calcd 870.4). Anal. calcd for $C_{46}H_{33}N_9O_{10}$: C 63.37, H 3.82, N 14.46; found C 63.03, H 3.94, N 14.75.

5,11-*Bis*-[(4-*nitrophenyl*)*azo*]-25,26,27,28-*tetrahydroxycalix*[4]*arene* (**2c**) Yield 33.5%, m.p. > 320 ℃, R_f 0.75 ($CHCl_3$:C_5H_5N, 10:1); ^{1}H NMR (pyridine-d_5, 600 MHz, 25 ℃) δ: 8.26 (d, J = 9.0 Hz, 4H, ArH in the 4-nitrophenyl moiety), 8.20 (s, 2H, ArH in the azo phenol moiety), 7.91 (d, J = 9.0 Hz, 4H, ArH in the 4-nitrophenyl moiety), 7.80 (s, 2H, ArH in the azo phenol moiety), 7.06 (d, J = 7.8 Hz, 2H, ArH in the phenol moiety), 6.99 (d, J = 7.8 Hz, 2H, ArH in the phenol moiety), 6.63 (t, J = 7.8 Hz, 2H, ArH in the phenol moiety), 4.30 (brs, 4H, $ArCH_2Ar$), 3.59 (brs, 4H, $ArCH_2Ar$); ^{13}C NMR (pyridine-d_5, 600 MHz) δ: 31.9, 32.5, 33.4 ($ArCH_2Ar$), 119.1, 120.3, 122.5, 125.4, 126.5, 128.9, 129.4, 130.5, 131.5, 132.6, 140.6, 141.2, 145.5, 147.6, 150.4, 152.2, 153.4, 154.9 (aromatic C); IR (KBr) ν: 1592.8 (N = N), 1341.5 (NO_2) cm^{-1}; MS (ESIMS) *m/z*: 721.4 ($[M-H]^-$, calcd 721.2). Anal. calcd for $C_{40}H_{30}N_6O_8$: C 66.48, H 4.18, N 11.63; found C 66.12, H 4.32, N 11.35.

5,17-*Bis*-[(4-*nitrophenyl*)*azo*]-25,26,27,28-*tetrahydroxycalix*[4]*arene* (**2d**) Yield 15.0%, m.p. > 320 ℃, R_f 0.87 ($CHCl_3$:C_5H_5N, 10:1); ^{1}H NMR (pyridine-d_5, 600 MHz, 25 ℃) δ: 8.20 (d, J = 9.0 Hz, 4H, ArH in the 4-nitrophenyl moiety), 7.85 (d, J = 9.0 Hz, 4H, ArH in the 4-nitrophenyl moiety), 7.78

(s, 4H, ArH in the azo phenol moiety), 7.16 (d, J = 7.8 Hz, 4H, ArH in the phenol moiety), 6.86 (t, J = 7.8 Hz, 2H, ArH in the phenol moiety), 4.34 (brs, 4H, $ArCH_2Ar$), 3.68 (brs, 4H, $ArCH_2Ar$); ^{13}C NMR (pyridine-d_5, 600 MHz) δ: 31.7 ($ArCH_2Ar$), 120.1, 122.3, 125.1, 125.5, 128.4, 129.8, 131.7, 141.2, 145.5, 150.0, 151.2, 153.4 (aromatic C); IR (KBr) ν: 1591.7 (N = N), 1341.2 (NO_2) cm^{-1}; MS (ESIMS) m/z: 721.5 ($[M-H]^-$, calcd 721.2). Anal. calcd for $C_{40}H_{30}N_6O_8$: C 66.48, H 4.18, N 11.63; found C 66.28, H 4.07, N 11.29.

5-*Mono*-[(4-*nitrophenyl*) *azo*]-25, 26, 27, 28-*tetrahydroxycalix*[4]*arene* (**2e**) Yield 52.0%, m.p. 302—304 ℃, R_f 0.30 ($CHCl_3$:petroleum ether, 3:1); ^1H NMR ($CDCl_3$, 600 MHz, 25 ℃) δ: 10.20 (brs, 4H, OH), 8.33 (d, J = 9.0 Hz, 2H, ArH in the 4-nitrophenyl moiety), 7.92 (d, J = 9.0 Hz, 2H, ArH in the 4-nitrophenyl moiety), 7.74 (s, 2H, ArH in the azo phenol moiety), 7.15 (d, J = 7.8 Hz, 2H, ArH in the phenol moiety), 7.09 (d, J = 7.8 Hz, 2H, ArH in the phenol moiety), 7.05 (d, J = 7.8 Hz, 2H, ArH in the phenol moiety), 6.77 (t, J = 7.8 Hz, 2H, ArH in the phenol moiety), 6.73 (t, J = 7.8 Hz, 1H, ArH in the phenol moiety), 4.29 (brs, 4H, $ArCH_2Ar$), 3.69 and 3.57 (brs, 4H, $ArCH_2Ar$); ^{13}C NMR ($CDCl_3$, 600 MHz) δ: 32.1, 32.7 ($ArCH_2Ar$), 118.8, 120.1, 121.8, 124.9, 126.3, 128.7, 129.3, 130.4, 131.1, 132.3, 140.9, 141.5, 150.5, 151.3, 153.8 (aromatic C); IR (KBr) ν: 1591.8 (N = N), 1341.8 (NO_2) cm^{-1}; MS (ESIMS) m/z: 572.7 ($[M-H]^-$, calcd 572.3). Anal. calcd for $C_{34}H_{27}N_3O_6$: C 71.19, H 4.74, N 7.33; found C 70.85, H 5.12, N 7.17.

5, 11, 17, 23-*Tetrakis*-[(4-*methylphenyl*) *azo*]-25, 26,27, 28-*tetrahydroxy calix*[4]*arene* (**3a**) Yield 29.3%, m.p. > 320 ℃ (dec.), R_f 0.26 ($CHCl_3$:CH_3OH:$(CH_3)_2CHOH$, 10:1:4); ^1H NMR (pyridine-d_5, 600 MHz, 25 ℃) δ: 8.12 (s, 8H, ArH in the azo phenol moiety), 7.79 (d, J = 7.8 Hz, 8H, ArH in the 4-methylphenyl moiety), 7.16 (d, J = 7.8 Hz, 8H, ArH in the 4-methylphenyl moiety), 5.05 (brs, 4H, $ArCH_2Ar$), 3.81 (brs, 4H, $ArCH_2Ar$), 2.18 (s, 12H, CH_3); ^{13}C NMR (pyridine-d_5, 600 MHz) δ: 33.6 ($ArCH_2Ar$), 21.1 (CH_3), 122.7, 124.3, 129.9, 131.8, 140.2, 145.9, 150.2, 151.5 (aromatic C); IR (KBr) ν: 1597.1 (N = N) cm^{-1}; MS (ESIMS) m/z: 895.7 ($[M-H]^-$, calcd 895.4). Anal. calcd for $C_{56}H_{48}N_8O_4$: C 74.98, H 5.39, N 12.49; found C 74.69, H 5.76, N 12.12.

5, 11, 17-*Tris*-[(4-*methylphenyl*) *azo*]-25, 26, 27, 28-*tetrahydroxycalix*[4]*arene* (**3b**) Yield 12.8%, m.p. > 320 ℃ (dec.), R_f 0.48 ($CHCl_3$:CH_3OH:$(CH_3)_2CHOH$, 10:1:4); ^1H NMR ($CDCl_3$, 600 MHz, 25 ℃) δ: 10.2 (brs, 4H, OH), 7.78 (s, 2H, ArH in the azo phenol moiety), 7.76 (s, 2H, ArH in the azo phenol moiety), 7.74 (d, J = 8.4 Hz, 2H, ArH in the 4-methylphenyl moiety), 7.71 (d, J = 8.4 Hz, 4H, ArH in the 4-methylphenyl moiety), 7.69 (s, 2H, ArH in the azo phenol moiety), 7.26 (d, J = 8.4 Hz, 2H, ArH in the 4-methylphenyl moiety), 7.25 (d, J = 8.4 Hz, 4H, ArH in the 4-methylphenyl moiety), 7.18 (d, J = 7.8 Hz, 2H, ArH in the phenol moiety), 6.79 (t, J = 7.8 Hz, 1H, ArH in the phenol moiety), 4.36 (brs, 4H, $ArCH_2Ar$), 3.82 and 3.71 (brs, 4H, $ArCH_2Ar$), 2.40 (s, 9H, CH_3); ^{13}C NMR ($CDCl_3$, 600 MHz) δ: 31.9, 31.7 ($ArCH_2Ar$), 21.4 (CH_3), 122.7, 123.3, 124.2, 124.8, 127.6, 128.1, 128.4, 129.9, 129.5, 129.6, 140.9, 141.0, 147.7, 147.8, 148.5, 150.8, 151.2 (aromatic C); IR (KBr) ν: 1594.9 (N = N) cm^{-1}; MS (ESIMS) m/z: 777.5 ($[M-H]^-$, calcd 777.3). Anal. calcd for $C_{49}H_{42}N_6O_4$: C 75.56, H 5.44, N 10.79; found C 75.78, H 5.66, N 10.52.

5, 11-*Bis*-[(4-*methylphenyl*) *azo*]-25, 26, 27, 28-*tetrahydroxycalix*[4]*arene* (**3c**) Yield 9.5%, m.p. > 320 ℃ (dec.), R_f 0.57 ($CH_3COOC_2H_5$:petroleum ether, 5:1); ^1H NMR ($CDCl_3$, 600 MHz, 25 ℃) δ: 10.21 (brs, 4H, OH), 7.76 (s, 2H, ArH in the azo phenol moiety), 7.73 (d, J = 8.4 Hz, 4H, ArH in the 4-methylphenyl moiety), 7.68 (s, 2H, ArH in the azo phenol moiety), 7.26 (d, J = 8.4 Hz, 4H, ArH in the 4-methylphenyl moiety), 7.15 (d, J = 7.8 Hz, 2H, ArH in the phenol moiety), 7.06 (d, J = 7.8 Hz, 2H, ArH in the phenol moiety), 6.75 (t, J = 7.8 Hz, 2H, ArH in the phenol moiety), 4.31 (brs, 4H, $ArCH_2Ar$), 3.63 (brs, 4H, $ArCH_2Ar$), 2.38 (s, 6H, CH_3); ^{13}C NMR ($CDCl_3$, 600 MHz) δ: 31.6, 31.8, 31.9 ($ArCH_2Ar$), 21.4 (CH_3), 122.5, 123.3, 124.6, 127.6, 128.2, 128.3, 129.0, 129.2, 129.3, 129.4, 129.6, 140.9, 147.7, 148.6, 150.8, 151.3 (aromatic C); IR (KBr) ν: 1595.3 (N = N) cm^{-1}; MS (ESIMS) m/z: 659.5 ($[M-H]^-$, calcd 659.3). Anal. calcd for $C_{42}H_{36}N_4O_4$: C 76.34, H 5.49, N 8.48; found C

76.05, H 5.67, N 8.79.

5, 17-*Bis*-[(4-*methylphenyl*)*azo*]-25, 26, 27, 28-*tetrahydroxycalix*[4]*arene* (**3d**) Yield 5.1%, m. p. > 320 ℃ (dec.), R_f 0.65 ($CH_3COOC_2H_5$: petroleum ether, 5:1); ^{1}H NMR ($CDCl_3$, 600 MHz, 25 ℃) δ: 10.21 (brs, 4H, OH), 7.71 (d, J = 7.8 Hz, 4H, ArH in the 4-methylphenyl moiety), 7.68 (s, 4H, ArH in the azo phenol moiety), 7.25 (d, J = 7.8 Hz, 4H, ArH in the 4-methylphenyl moiety), 7.18 (d, J = 7.8 Hz, 4H, ArH in the phenol moiety), 6.80 (t, J = 7.8 Hz, 2H, ArH in the phenol moiety), 4.33 (brs, 4H, $ArCH_2Ar$), 3.69 (brs, 4H, $ArCH_2Ar$), 2.39 (s, 6H, CH_3); ^{13}C NMR ($CDCl_3$, 600 MHz) δ: 31.7 ($ArCH_2Ar$), 21.4 (CH_3), 122.5, 122.6, 123.9, 127.8, 128.7, 129.4, 129.6, 140.9, 147.6, 148.6, 150.9, 151.4 (aromatic C); IR (KBr) ν: 1594.0 (N = N) cm^{-1}; MS (ESIMS) m/z: 659.5 ([M - H]$^-$, calcd 659.3). Anal. calcd for $C_{42}H_{36}N_4O_4$: C 76.34, H 5.49, N 8.48; found C 76.67, H 5.72, N 8.13.

5-*Mono*-[(4-*methylphenyl*)*azo*]-25, 26, 27, 28-*tetrahydroxycalix*[4]*arene* (**3e**) Yield 33.2%, m.p. 318—320 ℃, R_f 0.85 ($CH_3COOC_2H_5$: petroleum ether, 5:1); ^{1}H NMR ($CDCl_3$, 600 MHz, 25 ℃) δ: 10.20 (brs, 4H, OH), 7.72 (d, J = 8.4 Hz, 2H, ArH in the 4-methylphenyl moiety), 7.68 (s, 2H, ArH in the azo phenol moiety), 7.27 (d, J = 8.4 Hz, 2H, ArH in the 4-methylphenyl moiety), 7.16 (d, J = 7.8 Hz, 2H, ArH in the phenol moiety), 7.08 (d, J = 7.8 Hz, 2H, ArH in the phenol moiety), 7.05 (d, J = 7.8 Hz, 2H, ArH in the phenol moiety), 6.76 (t, J = 7.8 Hz, 2H, ArH in the phenol moiety), 6.72 (t, J = 7.8 Hz, 1H, ArH in the phenol moiety), 4.29 (brs, 4H, $ArCH_2Ar$), 3.67 and 3.56 (brs, 4H, $ArCH_2Ar$), 2.40 (s, 3H, CH_3); ^{13}C NMR ($CDCl_3$, 600 MHz) δ: 31.3, 31.6 ($ArCH_2Ar$), 21.0 (CH_3), 122.0, 122.1, 122.2, 123.5, 127.3, 127.7, 128.0, 128.5, 128.7, 128.8, 128.9, 129.3, 140.5, 147.1, 148.3, 150.5, 151.1 (aromatic C); IR (KBr) ν: 1593.6 (N = N) cm^{-1}; MS (ESIMS) m/z: 541.5 ([M - H]$^-$, calcd 541.3). Anal. calcd for $C_{35}H_{30}N_2O_4$: C 77.47, H 5.57, N 5.16; found C 77.32, H 5.52, N 4.85.

5, 11, 17, 23-*Tetrakis*-[(4-*chlorophenyl*)*azo*]-25, 26, 27, 28-*tetrahydroxy calix*[4]*arene* (**4a**) Yield 33.6%, m.p. > 320 ℃ (dec.), R_f 0.15 (CH_2Cl_2 : $CH_3COOC_2H_5$, 2:1); ^{1}H NMR (pyridine-d_5, 600 MHz, 25 ℃) δ: 8.14 (s, 8H, ArH in the azo phenol moiety), 7.75 (d, J = 8.4 Hz, 8H, ArH in the 4-chlorophenyl moiety), 7.38 (d, J = 8.4 Hz, 8H, ArH in the 4-chlorophenyl moiety), 5.07 (brs, 4H, $ArCH_2Ar$), 3.82 (brs, 4H, $ArCH_2Ar$); ^{13}C NMR (pyridine-d_5, 600 MHz) δ: 32.4 ($ArCH_2Ar$), 121.8, 124.1, 129.3, 130.8, 140.1, 145.3, 149.5, 152.3 (aromatic C); IR (KBr) ν: 1577.9 (N = N) cm^{-1}; MS (ESIMS) m/z: 977.4 ([M - H]$^-$, calcd 977.2). Anal. calcd for $C_{52}H_{36}Cl_4N_8O_4$: C 63.81, H 3.71, N 11.45; found C 64.17, H 3.96, N 11.08.

5, 11, 17-*Tris*-[(4-*chlorophenyl*)*azo*]-25, 26, 27, 28-*tetrahydroxycalix*[4]*arene* (**4b**) Yield 12.1%, m.p. > 320 ℃ (dec.), R_f 0.28 (CH_2Cl_2 : $CH_3COOC_2H_5$, 2:1); ^{1}H NMR ($CDCl_3$, 600 MHz, 25 ℃) δ: 10.2 (brs, 4H, OH), 7.78 (s, 2H, ArH in the azo phenol moiety), 7.77 (d, J = 8.4 Hz, 2H, ArH in the 4-chlorophenyl moiety), 7.76 (s, 2H, ArH in the azo phenol moiety), 7.75 (d, J = 8.4 Hz, 4H, ArH in the 4-chlorophenyl moiety), 7.70 (s, 2H, ArH in the azo phenol moiety), 7.44 (d, J = 8.4 Hz, 2H, ArH in the 4-chlorophenyl moiety), 7.42 (d, J = 8.4 Hz, 4H, ArH in the 4-chlorophenyl moiety), 7.18 (d, J = 7.8 Hz, 2H, ArH in the phenol moiety), 6.80 (t, J = 7.8 Hz, 1H, ArH in the phenol moiety), 4.36 (brs, 4H, $ArCH_2Ar$), 3.82 and 3.72 (brs, 4H, $ArCH_2Ar$); ^{13}C NMR ($CDCl_3$, 600 MHz) δ: 32.1, 32.8 ($ArCH_2Ar$), 121.8, 123.1, 124.0, 125.3, 127.8, 128.3, 129.0, 129.5, 129.9, 140.8, 141.3, 146.8, 147.9, 148.3, 150.1, 151.9 (aromatic C); IR (KBr) ν: 1577.4 (N = N) cm^{-1}; MS (ESIMS) m/z: 839.4 ([M - H]$^-$, calcd 839.2). Anal. calcd for $C_{46}H_{33}Cl_3N_6O_4$: C 65.76, H 3.96, N 10.00; found C 65.38, H 3.67, N 9.64.

5,11-*Bis*-[(4-*chlorophenyl*)*azo*]-25,26,27,28-*tetrahydroxycalix*[4]*arene* (**4c**) Yield 9.6%, m.p. > 300 ℃ (dec.), R_f 0.25 (petroleum ether: $CHCl_3$, 1:1); ^{1}H NMR ($CDCl_3$, 600 MHz, 25 ℃) δ: 10.21 (brs, 4H, OH), 7.77 (d, J = 8.4 Hz, 4H, ArH in the 4-chlorophenyl moiety), 7.76 (s, 2H, ArH in the azo phenol moiety), 7.70 (s, 2H, ArH in the azo phenol moiety), 7.44 (d, J = 8.4 Hz, 4H, ArH in the 4-chlorophenyl moiety), 7.15 (d, J = 7.8 Hz, 2H, ArH in the phenol moiety), 7.08 (d, J = 7.8 Hz, 2H, ArH in the phenol moiety), 6.76 (t, J = 7.8 Hz, 2H, ArH in the phenol moiety), 4.31 (brs, 4H, $ArCH_2Ar$), 3.69 (brs, 4H, $ArCH_2Ar$); ^{13}C NMR ($CDCl_3$, 600

MHz) δ: 31.8, 32.3, 32.7 ($ArCH_2Ar$), 121.5, 122.8, 123.7, 126.8, 128.0, 128.8, 129.3, 129.7, 130.1, 130.3, 130.5, 130.9, 140.5, 148.9, 150.5, 151.8, 152.1 (aromatic C); IR (KBr) ν: 1574.9 (N=N) cm^{-1}; MS (ESIMS) m/z: 699.4 ($[M-H]^-$, calcd 699.2). Anal. calcd for $C_{40}H_{30}Cl_2N_4O_4$: C 68.48, H 4.31, N 7.99; found C 68.13, H 4.29, N 8.16.

5,17-*Bis*-[(4-*chlorophenyl*) *azo*]-25,26,27,28-*tetrahydroxycalix*[4]*arene* (**4d**) Yield 4.5%, m.p. 296 ℃ (dec.), R_f 0.35 (petroleum ether: $CHCl_3$, 1:1); ^1H NMR ($CDCl_3$, 600 MHz, 25 ℃) δ: 10.21 (brs, 4H, OH), 7.75 (d, J = 8.4 Hz, 4H, ArH in the 4-chlorophenyl moiety), 7.68 (s, 4H, ArH in the azo phenol moiety), 7.42 (d, J = 8.4 Hz, 4H, ArH in the 4-chlorophenyl moiety), 7.18 (d, J = 7.8 Hz, 4H, ArH in the phenol moiety), 6.80 (t, J = 7.8 Hz, 2H, ArH in the phenol moiety), 4.33 (brs, 4H, $ArCH_2Ar$), 3.69 (brs, 4H, $ArCH_2Ar$); ^{13}C NMR ($CDCl_3$, 600 MHz) δ: 31.9 ($ArCH_2Ar$), 121.8, 122.3, 123.4, 127.3, 128.1, 129.0, 129.6, 140.5, 147.3, 148.0, 151.1, 151.9 (aromatic C); IR (KBr) ν: 1576.5 (N=N) cm^{-1}; MS (ESIMS) m/z: 699.4 ($[M-H]^-$, calcd 699.2). Anal. calcd for $C_{40}H_{30}Cl_2N_4O_4$: C 68.48, H 4.31, N 7.99; found C 68.19, H 4.63, N 8.16.

5-*Mono*-[(4-*chlorophenyl*) *azo*]-25,26,27,28-*tetrahydroxycalix*[4]*arene* (**4e**) Yield 34.3%, m.p. 302—304 ℃, R_f 0.62 (petroleum ether: $CHCl_3$, 2:1); ^1H NMR ($CDCl_3$, 600 MHz, 25 ℃) δ: 10.18 (brs, 4H, OH), 7.76 (d, J = 8.4 Hz, 2H, ArH in the 4-chlorophenyl moiety), 7.68 (s, 2H, ArH in the azo phenol moiety), 7.43 (d, J = 8.4 Hz, 2H, ArH in the 4-chlorophenyl moiety), 7.15 (d, J = 7.8 Hz, 2H, ArH in the phenol moiety), 7.07 (d, J = 7.8 Hz, 2H, ArH in the phenol moiety), 7.05 (d, J = 7.8 Hz, 2H, ArH in the phenol moiety), 6.76 (t, J = 7.8 Hz, 2H, ArH in the phenol moiety), 6.72 (t, J = 7.8 Hz, 1H, ArH in the phenol moiety), 4.29 (brs, 4H, $ArCH_2Ar$), 3.67 and 3.56 (brs, 4H, $ArCH_2Ar$); ^{13}C NMR ($CDCl_3$, 600 MHz) δ: 31.8, 32.0 ($ArCH_2Ar$), 121.8, 122.1, 122.5, 123.7, 127.1, 127.5, 128.3, 128.7, 128.9, 129.4, 129.6, 129.8, 140.1, 146.8, 148.0, 150.8, 151.1, 152.0 (aromatic C); IR (KBr) ν: 1576.8 (N=N) cm^{-1}; MS (ESIMS) m/z: 561.5 ($[M-H]^-$, calcd 561.2). Anal. calcd for $C_{34}H_{27}ClN_2O_4$: C 72.53, H 4.83, N 4.98; found C 72.17, H 5.16, N 5.31.

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(E0202041 SONG, J. P.; HUANG, W. Q.)