Novel synthesis of calix[*n*]arene amidoazobenzene derivatives

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A series of calix[*n*]arenas and calix[4]resorciarenes containing azo chromophores on the lower rim were synthesised with two routes. The first direct route involved alkylating calixarenes with 4-chloroacetoaminoazobenzene. The second indirect route was by acylating 4-aminoazobenzene with calix[*n*]arylacetyl chloride. Their extracting abilities for transition metal ions were tested.

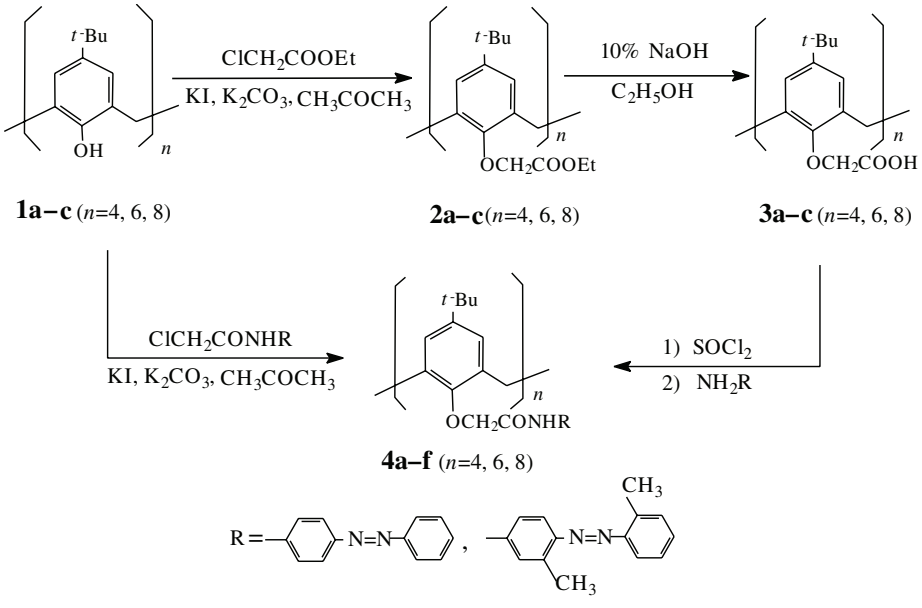
Keywords: calixarene, calix[4]resorcinarene, ionophore, azobenzene, alkylation

Calixarenes are useful building blocks in supramolecular chemistry.[1] Incorporating photo responsive azobenzene functional groups has attracted attention in the synthesis of chromogenic ionophores and photo-switchable receptors.[2] Azo groups have been mainly introduced onto the upper rim of calixarenes by azo coupling reactions,[3-7] and rarely by the transformation of the previously incorporated groups.[8,9] In this report, we have developed a direct method for introducing azobenzene groups into the lower rim of calixarenes by the alkylation of hydroxyl groups of the calixarenes or by the acylation of the upper rim of calixarenes with aminoazo-benzene.

Results and discussions

Complete *O*-alkylation of all the OH groups in calixarenes with monofunctional alkylating reagents to give the ether derivatives is the first choice for chemical modification of calixarenes.[1,11] Thus ester, amide, ketone and pyridylmethyl derivatives can be readily obtained by direct alkylation reactions with reagents such as $BrCH_2COOR$, $ClCH_2CONR_2$, $ClCH_2COR$ or $BrCH_2C_5H_4N$. Obviously if the chloroacetamide with an azo motif such as $ClCH_2CONHC_6H_4N=NC_6H_5$ was used as the alkylating reagents, the azosubstructure could be introduced onto the lower rim of the calixarene. This kind of chloroacetoamide $ClCH_2CONHC_6H_4N=NC_6H_5$ can be prepared smoothly in high yields from the acylation reactions of *p*-aminoazobenzene or 2,3'-dimethyl-4-aminoazobenzene with chloroacetyl chloride. The *p*-tert-butylcalix[*n*]arenes **1a–c** (*n* = 4, 6,8) were completed alkylated in the presence of K_2CO_3/KI/acetone in moderate yields (29–69%) after refluxing for about 5 days (Scheme 1). The work up is very simple and convenient, and the moderate yield is acceptable. A direct method for introducing the azobenzene group to lower rim of *p*-tert-butylcalix[*n*]arenes was established, and extended to the calix[4]resorcinarene system. Under similar conditions, tetraphenyl- and tetra(*p*-hydroxylphenyl)-calix[4]resorcinarene **5a–b** were alkylated with 2,3'-dimethyl-4-chloroacetoaminoazobenzene to give amide derivatives with a terminal azobenzene group **6a–b** (47%, 35% respectively). It should be noticed that the outer tetra(*p*-hydroxylphenyl) groups were also alkylated in this step to give the product **6b** with 12 *O*-acetoaminoazobenzene groups. Compounds **4a–g** and **6a–b** all have 4–12 *O*-acetoaminoazobenzene groups. Their structures were confirmed by elemental analysis, UV, IR and ^1H NMR spectroscopy. In their UV spectra, they all show two strong bands at about 330 and 440 nm, which are typical absorptions of benzene ring and azo group. In their IR spectrum, the very strong absorption band of the amide C = O appears at 1675cm^{-1}, while the peaks of N = N groups are moderate and overlapped with the peaks of benzene rings.

Another route for introducing aminoazobenzene into the lower rim of calix[*n*]arene involved the acylation of aminoazobenzene with calix[*n*]arenylacetyl chloride. Thus *p*-tert-butylcalix[*n*]arrene **1a–c** were alkylated firstly with ethyl chloroacetate to give completed O-akylated products **2a–c** according to the published method.[11] Then they were



Scheme 1

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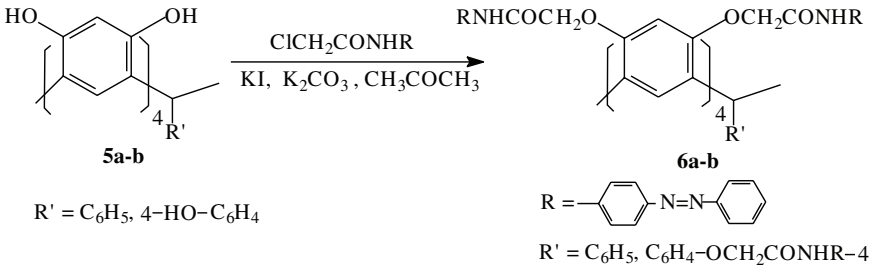

Scheme 2

hydrolysed in dilute aqueous NaOH solution to yield *p*-tert-butylcalix[*n*]arylacetic acid **3a–c**. **3a–c**. These were converted to the acetyl chlorides with thionyl chloride and reacted *in situ* with aminoazobenzene to give the expected products **4e–g**. These had similar melting point and ^{1}H NMR spectrum to the samples prepared by method A. Even through this indirect route requires four steps, it has some advantages for introducing more complicated groups.

The ability of these azobenzene to act as receptors for some transition metal ions were determined by extraction experiments from water to chloroform. The preliminary results showed that they did not have high selectivity. The extraction percentage for Cr^{3+} is 46.7 (**4a**), 21.9 (**4b**), 6.4 (**4c**); for Mn^{2+} is 2.8 (**4a**), 46.6 (**4b**), 67.9 (**4c**); for Cu^{2+} is 6.5 (**4a**), 43.0 (**4b**), 45.0 (**4c**); and for Zn^{2+} is 22.2 (**4a**), 46.9 (**4b**), 32.9 (**4c**).

Experimental

Melting points were taken on a hot-plate microscope apparatus and were not corrected. IR spectra were obtained on a Nicolet FT-IR 740 spectrometer. ^{1}H NMR spectra were recorded on a Bruker AV-600 spectrophotometer instrument with $CDCl_3$ as solvent. Elemental analysis was determined on Perkin Elmer 2400||instrument. *p*-tert-butylcalix[*n*]arenes,[10] ethyl *p*-tert-butylcalix[*n*]aryl acetate, *p*-tert-butylcalix[*n*]arylacetic acid (*n* = 4, 6, 8),[11] tetraphenyl- and tetra(*p*-hydroxylphenyl)-calix[4]resorcinarene **5a–b**,[12] 4-chlororo-acetoaminoazobenzene, 2,3'-dimethyl-4-chloroacetoaminoazoben-zene were prepared according to the published procedure. Other reagents were commercially available.

Synthesis of 4-chlororoacetoaminoazobenzene

A solution of chloroacetyl chloride (33.0 mmol, 2.50 ml) in chloroform (15 ml) was added dropwisely at zero temperature to a stirred solution of 2,3'-dimethylaminoazobenzene (30.0 mmol, 6.80 g) and triethylamine (33.0 mmol, 4.0 ml) in chloroform (50 ml). The mixture was stirred at room temperature overnight. Water (100 ml) was added, and the organic layer was separated and washed with water and dried over $MgSO_4$.The volume of solution was reduced to 10 ml, the residue was purified by column chromato-graphy on silica gel using chloroform as eluent to give 2,3'-dimethyl-4-chlororoacetoaminoazobenzene as an orange powder (89%). m.p. 170–171 °C. IR: ν_{max} = 3263(m), 3041(w), 3020(w), 1661(vs), 1534(s), 1470(w), 1414(w), 1252(m), 822(m), 759(m), 703(m) cm^{-1}. ^{1}H NMR ($CDCl_3$). δ: 2.46, 2.74(s, 6H, $2CH_3$), 4.26(s, 2H, OCH_2), 7.26–8.42 (m, 8H, ArH, NH) ppm.

The same procedure as above mentioned was used by using 4-aminoazobenzene (30.0 mmol, 5.91) to give 4-chlororoacetoamino-azobenzene as orange powder (72%). m.p. 145 °C. IR: ν_{max} = 3300(m), 2950(w), 1654(s), 1590(vs), 1520(vs), 1400(m), 1508(m), 836(vs), 773(s) cm^{-1}. ^{1}H NMR ($CDCl_3$). δ: 4.05 (s, 2H, OCH_2), 7.08–8.12 (m, 9H, ArH), 8.49 (s, 1H, NH) ppm.

Direct alkylation of calix[n]arenes with chloroacetoaminoazo-benzene (Method A)

4a: Under nitrogen atmosphere, the suspension of *p*-tert–butylcalix [4]arene **1a** (2.0 mmol, 1.30 g), K_2CO_3 (36.0 mmol, 5.00 g), KI (8.0 mmol, 1.30 g) in dry acetone (40 ml) was refluxed for about 1 h. The solution of 2,3'-dimethyl-4-chlororoacetoaminoazo-benzene (8.8 mmol, 2.65 g) in acetone (20 ml) was added dropwise to the system and the mixture was refluxed for an additional 5 days. Then the suspension was cooled to room temperature and the solid was filtered. The filtrate was evaporated under reduced pressure to give a crude residue, which was purified by column chromato-graphy over silica gel (ethyl acetate/petroleum ether 60–90 °C, 1/1) and recrystallised from ethanol to afford an orange solid as the product **4a** (1.30 g, 38.2%). m.p. 211–213 °C. UV ($\varepsilon_{\lambda I\times10^4}$): λ_{max} = 334.50 (1.49), 444.00 (0.12) nm. IR: ν_{max} = 3041(w), 2957(s), 1661(vs), 1590(w) 1470(s), 1449(m) 1315(m), 1139(m), 752(m) cm^{-1}. ^{1}H NMR ($CDCl_3$). δ: 1.26 (s, 36H, *t*-Bu); 2.19–2.74 (m, 24H, $ArCH_3$); 3.80 (s, 8H, $ArCH_2Ar$); 4.11–4.33 (m, 8H, $OCOCH_2$); 7.28–7.74 (m, 40H, ArH, NH) ppm. Anal. calcd. For $C_{96}H_{132}O_{24}$: C, 69.42; H, 7.97. Found: C, 69.33; H, 8.25.

4b: The same procedure as for the preparation of **4a** was used in using *p*-tert–butylcalix[6]arene (1.0 mmol, 0.97 g) to give **4b:** orange solid (1.09 g, 42.6%); m.p. 190–191 °C. UV ($\varepsilon_{\lambda I\times10^4}$): λ_{max} = 332.50 (9.33), 441.00 (0.66) nm. IR: ν_{max} = 3041(w), 2957(s), 1668(vs), 1590(w) 1470(s), 1435(m) 1259(m), 1189(m), 759(m) cm^{-1}. ^{1}H NMR ($CDCl_3$). δ: 1.27 (s, 54H, *t*-Bu); 2.45 and 2.75 (s, 36H, $ArCH_3$); 3.72 (s, 12H, $ArCH_2Ar$); 4.35–4.68 (m, 12H, $OCOCH_2$), 7.28–7.91 (m, 60H, ArH, NH) ppm. Anal. calcd. For $C_{96}H_{132}O_{24}$: C, 69.42; H, 7.97. Found: C, 69.33; H, 8.25.

4c: The same procedure as for the preparation of **4a** was used with *p*-tert–butylcalix[8]arene (1.0 mmol, 1.30 g) to give **4c:** orange solid (2.34 g**,** 68.8%); m.p. 204–206 °C. UV ($\varepsilon_{\lambda I\times10^4}$): λ_{max} = 335.00 (16.6), 442.00 (1.01) nm. IR: ν_{max} = 3041(w), 2957(s), 1661(vs), 1590(m) 1470(s), 1449(m) 1252(m), 1189(m), 752(m) cm^{-1}. ^{1}H NMR ($CDCl_3$). δ: 1.28 (s, 72H, *t*-Bu); 2.46, 2.76 (s, 72H, $ArCH_3$); 3.72 (s, 16H, $ArCH_2Ar$); 4.35–4.69 (m, 16H, $OCOCH_2$); 7.21–7.92 (m, 80H, ArH, NH) ppm. Anal. calcd. For $C_{96}H_{132}O_{24}$: C, 69.42; H, 7.97. Found: C, 69.33; H, 8.25.

4d: The same procedure as for the preparation of **4a** was used in the reaction of *p*-tert–butylcalix[4]arene (2.0 mmol, 1.30 g) with 4-chloroacetoaminoazobenzene (8.8 mmol, 2.55 g) to give **3d:** orange solid (0.84 g, 29.4%); m.p. 225–234 °C. UV ($\varepsilon_{\lambda I\times10^4}$): λ_{max} = 330.00 (10.9), 440.00 (0.67) nm. IR: ν_{max} = 2950(m), 1689(s), 1682(s), 1590(vs), 1527(s), 1476(s), 1400(m), 1290(m), 1196(m), 759(m) cm^{-1}. ^{1}H NMR ($CDCl_3$). δ: 1.28 (s, 36H, *t*-Bu); 3.86 (s, 16H, $ArCH_2Ar$); 4.30–4.80 (m, 8H, $OCOCH_2$); 7.10–7.90 (m, 48H, ArH, NH) ppm. Anal. calcd. For $C_{100}H_{100}N_{12}O_8$: C, 75.16; H, 6.31; N, 10.51. Found: C, 74.88; H, 6.25; N, 10.10.

4e: The same procedure as for the preparation of **4a** was used in the reaction of *p*-tert–butylcalix[6]arene (1.0 mmol, 0.97 g) with 4-chloroacetoamino azobenzene (6.6 mmol, 1.91 g) to give **4e:** orange solid (1.08 g, 48.0%); m.p. 169–171 °C. UV ($\varepsilon_{\lambda I\times10^4}$): λ_{max} = 332.00 (29.5), 441.00 (1.34) nm. IR: ν_{max} = 2954(m), 1675(m), 1590(vs), 1520(vs), 1400(m), 1231(s), 1146(s), 1013(m), 836(m), 759(m) cm^{-1}. ^{1}H NMR ($CDCl_3$). δ: 1.30 (s, 54H, *t*-Bu); 3.76 (s, 12H, $ArCH_2Ar$); 4.30–4.0 (m, 12H, $OCOCH_2$); 7.20–8.00 (m, 72H, ArH, NH) ppm. Anal. calcd. For $C_{150}H_{150}N_{18}O_{12}$: C, 75.16; H, 6.31; N, 10.51. Found: C, 75.57; H, 6.20; N, 9.88.

4f: The same procedure as for the preparation of **4a** was used in the reaction of *p*-tert–butylcalix[8]arene (1.0 mmol, 1.30 g) with 4-chloroacetoamino azobenzene (8.8 mmol, 2.55 g) to give **4f:** orange solid (1.46 g, 57.0%); m.p. 178–182 °C. UV ($\varepsilon_{\lambda I\times10^4}$): λ_{max} = 334.00 (14.9), 442.00 (0.85) nm. IR: ν_{max} = 2950(m), 1682(m), 1584(s), 1513(vs), 1406(m), 1260(s), 1231(s), 1140(s), 1006(m), 830(m), 759(m) cm^{-1}. cm^{-1}. ^{1}H NMR ($CDCl_3$). δ: 1.28 (s, 72H, *t*-Bu); 3.75 (s, 16H, $ArCH_2Ar$); 4.35–4.70 (m, 16H, $OCOCH_2$); 7.20–7.90 (m, 96H, ArH, NH) ppm. Anal. calcd. For $C_{200}H_{200}N_{24}O_{16}$: C, 75.16; H, 6.31; N, 10.51. Found: C, 75.46; H, 6.74; N, 9.79.

6a: The same procedure as for the preparation of **4a** was used with tetraphenylcalix[4]resorcinarene (1.0 mmol, 0.79 g) to give **6a:** orange solid (1.31 g, 45.0%); m.p. 212–214 °C. UV ($\varepsilon_{\lambda I\times10^4}$): λ_{max} = 334.50 (19.0), 442.00 (1.00) nm. IR: ν_{max} = 3041(w), 1661(vs), 1590(w) 1477(m), 1449(m) 1414(m), 1315(m), 1189(m), 1139(m), 815(m), 752(m) cm^{-1}. ^{1}H NMR ($CDCl_3$). δ: 2.45, 2.75 (s, s, 48H, $ArCH_3$); 4.34–4.69 (m, 16H, $OCOCH_2$); 6.25 (s, 4H, ArCHAr); 7.28–7.91

(m, 92H, ArH, NH) ppm. Anal. calcd. For $C_{180}H_{160}N_{24}O_{16}$: C, 75.41; H, 3.94; N, 11.72. Found: C, 74.16; H, 3.53; N, 11.53.

6b: The same procedure as for the preparation of **4a** was used with tetra(-4-hydroxyphenyl)calix[4]resorcinarene (1.0 mmol, 0.85 g) to give **6b:** orange solid (1.50 g**,** 37.2%); m.p. 210–212 °C. UV ($\varepsilon_{\lambda I \times 10^4}$): λ_{max} = 334.00 (18.0), 448.00 (0.15) nm. IR: ν_{max} = 3041(w), 1661(vs), 1590(w) 1477(m), 1449(m) 1414(m), 1315(m), 1252(m), 1139(m), 815(m), 752(m) cm^{-1}. ^1H NMR ($CDCl_3$). δ: 2.45, 2.76 (s, s, 48H, $ArCH_3$); 4.34–4.69 (m, 16H, $OCOCH_2$); 6.25 (s, 4H, ArCHAr); 7.28–7.91 (m, 92H, ArH, NH) ppm. Anal. calcd. For $C_{240}H_{220}N_{36}O_{24}$: C, 72.20; H, 5.55; N, 12.63. Found: C, 71.99; H, 6.34; N, 11.37.

Reaction of calix[n]arylacetyl chloride with aminoazobenzene (Method B)

3d: A mixture of *p*-tert-butylcalix[4]arylacetic acid (0.5 mmol, 0.44 g), thionyl chloride (5.0 ml) and benzene (20 ml) was refluxed for 3 h to give a clear yellowish solution. Then volatile material was evaporated under reduced pressure. The residue was redissolved in dry chloroform (20 ml). A solution of triethylamine (3.0 ml) and 2,3'-dimethyl-4-aminoazobenzene (2.1 mmol, 0.414 g) in chloroform (15 ml) was added at room temperature. The mixture was stirred for an additional 6 h. Then the resulting solution was washed with water. The organic layer was separated and evaporated to a residue, which was purified by column chromatography over silica gel (ethyl acetate/ petroleum ether 60–90 °C, 1/1) and recrystallised from ethanol to afford orange solid as the product **3d** (0.575 g, 72.1%). This had a similar melting point and ^1H NMR spectrum to that of the sample prepared from the method A.

3e: The same procedure as for the preparation of **3d** was used will *p*-tert-butylcalix[6]arylacetyl acid (0.35 mmol, 0.462 g) to give **3e** as orange solid (0.37 g, 43.1%). This had a similar melting point and ^1H NMR spectrum to that of the sample prepared from the method A.

3f: The same procedure as for the preparation of **3d** was used with *p*-tert-butylcalix[8]arylacetyl acid (0.35 mmol, 0.615 g) to give **3f** as orange solid (0.458 g, 41.0%). This had a similar melting point and ^1H NMR spectrum with that of the sample prepared from the method A.

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