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Microwave irradiation assisted synthesis, alkylation reaction, and configuration analysis of aryl pyrogallol[4]arenes

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Abstract—A series of aryl pyrogallol[4]arenes were efficiently synthesized in excellent yields by cyclocondensation of pyrogallol with aromatic aldehydes under microwave irradiation. The structures of aryl pyrogallol[4]arenes were confirmed by characterization of their acylated derivatives. Under microwave irradiation, alkylation reactions of aryl pyrogallol[4]arenes with some alkylating reagents such as *n*-butyl iodide, benzyl chloride, and ethyl α-chloroacetate were also finished quickly to yield fully *O*-alkylated products. The ^{1}H NMR spectra and crystal structures showed that the acylated and alkylated aryl pyrogallol[4]arenes existed mainly in *rctt* (cis–trans–trans) configuration.

1. Introduction

Pyrogallol[4]arene,[1] also called as hydroxyresorci[4]arene,[2] is a subgroup of calixarenes. Because of their favorable cyclic shape, 12 hydroxyl groups, and high polarity, pyrogallol[4]arenes have been used extensively as starting material for carcerand synthesis,[3,4] self-assembly to molecular vesicle, capsules, and other supramolecular architectures[5–7] as well as in liquid-crystal material,[8] and in complexation studies.[9,10] Pyrogallol[4]arene can be easily prepared similar to resorcinarenes in fairly high yields by acid condensation of pyrogallol with aldehydes.[11] The first synthesis of pyrogallol[4]arene was reported in 1980.[12] Since then a series of pyrogallol[4]arenes have been synthesized with emphasis of using aliphatic aldehydes to give alkyl pyrogallol[4]arenes.[8,9,13–17] While the study of aryl pyrogallol[4]arenes derived from the reaction of aromatic aldehydes has attracted very little attention because aryl pyrogallol[4]arenes usually have very poor solubility in common solvents and thus are difficult for chemical modification and to be used as building blocks.[18] Iwanek[19] developed a Lewis acid-catalyzed template synthesis of methylene bridged methoxypyrogallol[4]arene in crown conformer from reaction of 1,2,3-trimethoxybenzene with trioxane. A larger cyclic ethyl pyrogallol[6]arene is also separated as a minor product in acid condensation process of pyrogallol with proponaldehyde.[20]

Recently preparation of calixarenes by using benign procedures effectively embracing the principles of green chemistry has been witnessed with much great progress. Lewis acid such as ytterbium triflate has been utilized to provide an atom economic synthesis of resorcinarenes.[21,22] Scott[23] and Raston[24] reported solvent-free synthesis of aryl calix[4]resorcinarenes and *C*-methylcalix[4]resorcinarene by simply grinding together resorcinol with aldehydes in the presence of a catalytic amount of *p*-toluenesulfonic acid. The boron trifluoride catalyzed reaction of 3-alkoxyphenol with aldehydes provides an efficient method for preparing tetraalkyloxyresorcinarenes.[25] Hamdi[26] initiated microwave-assisted synthesis of calix[4]resorcinarenes by cyclocondensation of various aldehydes with resorcinol catalyzed with 12-tungstophosphoric acid. Viswanathan also reported efficient synthesis of chiral calixasalens, which displayed calixarene-like crystal structures with microwave irradiation.[27] These green routes provide fast, simple, high-yielding, and non-polluting synthetic methodology of resorcinarenes and these efficient processes should be potentially applicable to the preparation of other calixarene systems. In continuation of our effects to develop more efficient procedure for new synthetic methods and functional modification of calixarenes, herein we wish to report microwave irradiation assisted synthesis of aryl pyrogallol[4]arenes and their O-alkylation reactions.

2. Results and discussion

The synthesis of aryl pyrogallol[4]arenes was conducted by heating a mixture of equal molar amounts of pyrogallol with aromatic aldehydes in 2-ethoxyethanol in the presence of concentrated HCl under microwave irradiation for 3–5 min. The general procedure of the synthetic reactions is outlined in Scheme 1. All aromatic aldehydes reacted very

Keywords: Calixarene; Pyrogallol[4]arene; Pyrogallol; Microwave; Alkylation; Crystal structure.
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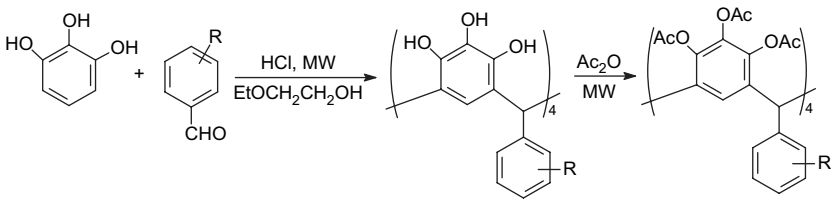


Scheme 1. Synthesis and acylation of aryl pyrogallol[4]arenes.

smoothly under irradiation for about 3 min and gave good yields of aryl pyrogallol[4]arenes **3a**–**3e** (66–89%). Salicylaldehyde and *p*-hydroxybenzaldehyde, which have not previously been used in the preparation of pyrogallol[4]arenes, also gave high yields of pyrogallol[4]arenes with four additional hydroxyl groups. Comparing with conventional heating, microwave heating gives nearly same yields and the reaction can be finished in very short time, which demonstrates that aryl pyrogallol[4]arenes can be prepared simply and efficiently under microwave irradiation condition.

Because of having at least 12 hydroxyl groups these aryl pyrogallol[4]arenes **3a**–**3e** have very poor solubility in common organic solvents. It is very difficult for us to get accepted characterization data for them. For confirming their structures, it is better to convert the hydrophilic hydroxyl groups into ester groups, which can be done conveniently by refluxing aryl pyrogallol[4]arenes **3a**–**3e** in acetic anhydride. The formed acyl derivatives **4a**–**4e** have very good solubility in organic solvents and therefore all necessary analytical data such as IR, ^{1}H and ^{13}C NMR spectra as well as elemental analysis were achieved for them. In their IR spectra, the acetyl C═O groups show a very strong absorption band at 1780 cm^{-1} with the disappearance of hydroxyl absorption at 3200–3500 cm^{-1}, which indicated that all hydroxyl groups in **3a**–**3e** have been transformed into ester groups. The ^{1}H NMR spectra of **4a**–**4f** in $CDCl_3$ usually show one singlet peak for bridging methyne protons at about 5.4 ppm and two singlet signs in 1:1 ratio for proton of pyrogallol ring at about 6.0 and 6.3 ppm, which clearly indicates two kinds of pyrogallol rings existed in the molecule and **4a**–**4f** should be in thermodynamically stable *rctt* (cis–trans–trans) isomer. The proton of acyl groups usually shows a group of peaks at 1.90–2.20 ppm, which is concordance with the fact that the 12 acyl groups existed in slightly different environments (Figs. 1 and 2).

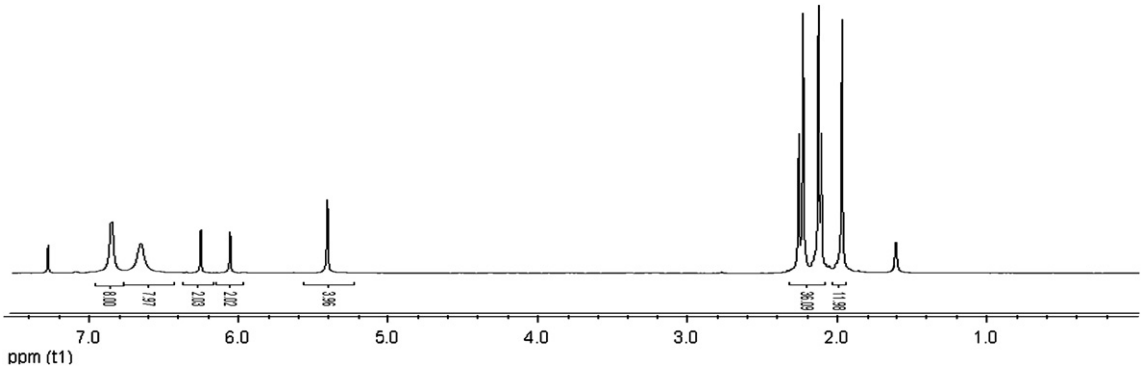


Figure 1. ^{1}H NMR spectrum of compound **4b**.

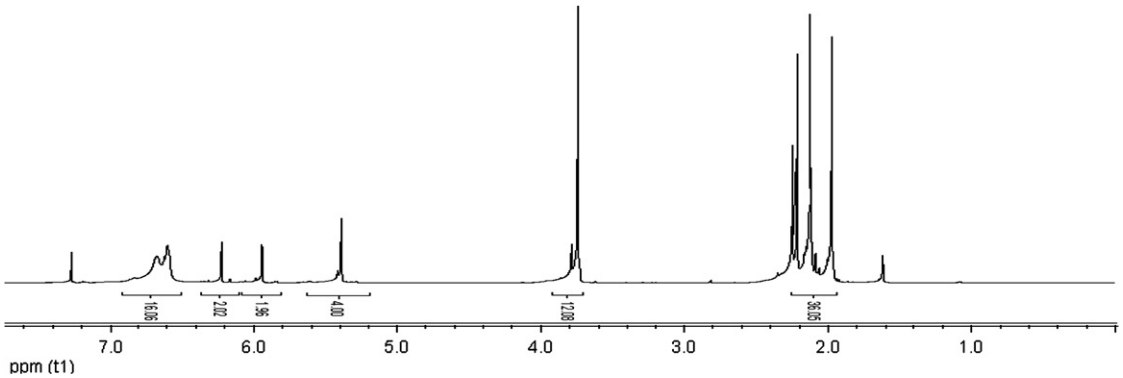


Figure 2. ^{1}H NMR spectrum of compound **4c**.

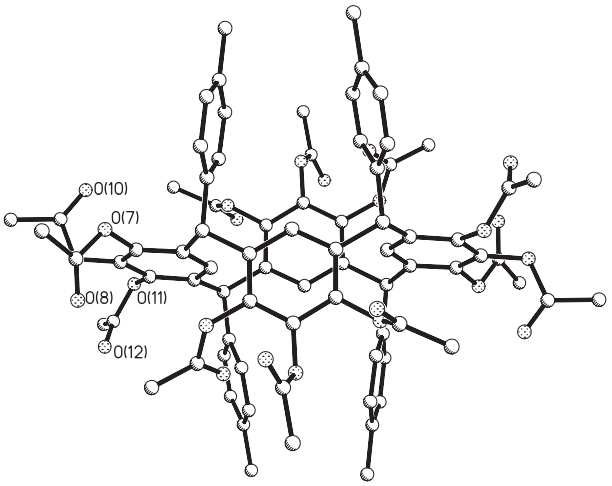


Figure 3. Crystal structure of acylated *p*-methylphenyl pyrogallol[4]-arene **4b**.

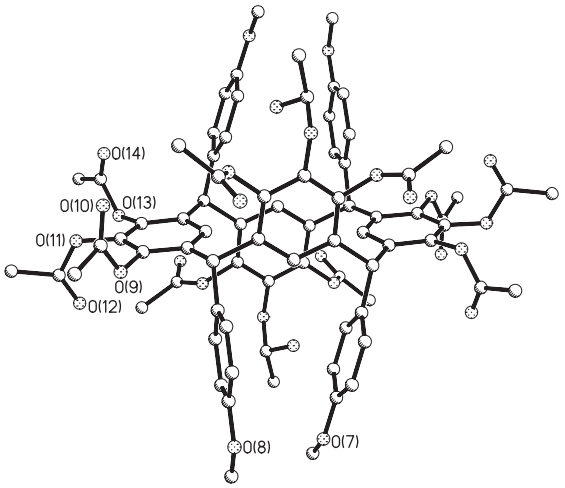


Figure 4. Crystal structure of acylated *p*-methoxyphenyl pyrogallol[4]-arene **4c**.

The X-ray single crystal analysis of two representative compounds **4b** and **4c** confirms the structures of the aryl pyrogallol[4]arenes. The crystal structures are shown in Figures 3 and 4 and the crystal data are listed in Table 1. It is interesting to find that *p*-methylphenyl and *p*-methoxyphenyl pyrogallol[4]arenes **4b** and **4c** are both in *rctt* (cis–trans–trans) configuration isomer, which supports the results of the ^{1}H NMR analysis. The four pyrogallol units in the calixarene ring were divided into two groups with two pyrogallol rings at almost perpendicular direction and other two pyrogallol rings nearly in horizontal position. The stretching direction of two perpendicular pyrogallol rings is opposite. One pyrogallol ring is upper standing and the other is upside down. The four side *p*-methylphenyl or *p*-methoxyphenyl groups are also divided into two groups with two neighboring phenyl groups at C1 and C20 locating in upper direction, while other two phenyl groups at C13 and C32 stretching to down direction.

Table 1. Crystal data and structure refinement details of pyrogallol[4]arenes

	4b	**4c**	**5a**	**5c**	**5d**
Empirical formula	$C_{84}H_{76}Cl_{12}O_{24}$	$C_{82}H_{74}Cl_6O_{28}$	$C_{138}H_{114}Cl_6O_{12}$	$C_{140}H_{120}O_{16}$	$C_{100}H_{134}O_{12}$
Formula weight	1894.84	1720.12	2177.00	2058.36	1528.07
Temperature (K)	273(2)	273(2)	273(2)	293(2)	273(2)
Wavelength (Å)	0.71073	0.71073	0.71073	0.71073	0.71073
Crystal system, space group	Triclinic, *P*-1	Triclinic, *P*-1	Monoclinic, *P*2(1)/*n*	Triclinic, *P*-1	Triclinic, *P*-1
Unit cell dimensions	11.9764(16)	12.403(2)	12.9584(11)	14.113(2)	13.300(2)
	14.792(2)	12.6998(19)	27.628(2)	26.291(4)	18.758(4)
	15.545(2)	15.774(2)	16.5237(14)	20.786(2)	21.464(4)
	61.992(2)	66.691(2)	90.00	90	67.617(3)
	74.241(2)	78.585(2)	92.2270(10)	131.635(6)	77.221(3)
	78.256(2)	68.983(2)	90.00	90	82.474(4)
Volume (Å^3)	3890.4	2125.5(6)	5911.3(9)	5764.3(13)	4822.1(15)
Z	2	2	4	2	1
Calculated density (g cm^{-3})	1.350	1.344	1.223	1.186	1.052
Absorption coefficient (mm^{-1})	0.093	0.281	0.207	0.077	0.067
F(000)	976	892	2280	2176	1660
Crystal size (mm)	0.40×0.30×0.30	0.20×0.20×0.10	0.30×0.30×0.25	0.30×0.10×0.10	0.30×0.20×0.20
θ range for data collection	2.05–25.00	2.07–25.00	2.09–25.00	1.97–25.00	1.99–25.00
hkl ranges	−12 to14, −17 to 17, −18 to 16	−9 to14, −14 to 15, −17 to 18	−15 to14, −32 to 30, −19 to 19	−16 to 15, −31 to 31, −11 to 24	$-15\leq h\leq 11$, $-22\leq k\leq 15$, $-25\leq l\leq 23$
Reflections collected/unique	8070/4789 [*R*(int)=0.0202]	7365/3267 [*R*(int)=0.0104]	10,395/6487 [*R*(int)=0.0272]	10,137/3883 [*R*(int)=0.0995]	25,237/16,703 [*R*(int)=0.0601]
Completeness to theta=27.50 (%)	98.2	98.4	99.7	99.7	98.4
Absorption correction	None	None	None	None	None
Refinement method	Full-matrix least-squares on F^2	Full-matrix least-squares on F^2	Full-matrix least-squares on F^2	Full-matrix least-squares on F^2	Full-matrix least-squares on F^2
Data/restraints/parameters	8070/0/550	7365/6/532	10,392/99/692	16,858/9/665	16,703/68/1018
Goodness-of-fit on F^2	1.046	1.228	1.004	0.930	0.917
Final *R* indices [$I>2\sigma(I)$]	R_1=0.1197, wR_2=0.2732	R_1=0.2126, wR_2=0.4223	R_1=0.1254, wR_2=0.2988	R_1=0.2056, wR_2=0.2234	R_1=0.1110, wR_2=0.2909
R indices (all data)	R_1=0.0760, wR_2=0.2310	R_1=0.1276, wR_2=0.3555	R_1=0.0861, wR_2=0.2574	R_1=0.0780, wR_2=0.1782	R_1=0.3339, wR_2=0.4413
Largest diff. peak and hole (eÅ^{-3})	0.491 and −0.533	1.003 and −0.557	0.939 and −0.645	0.415 and −0.256	0.340 and −0.388

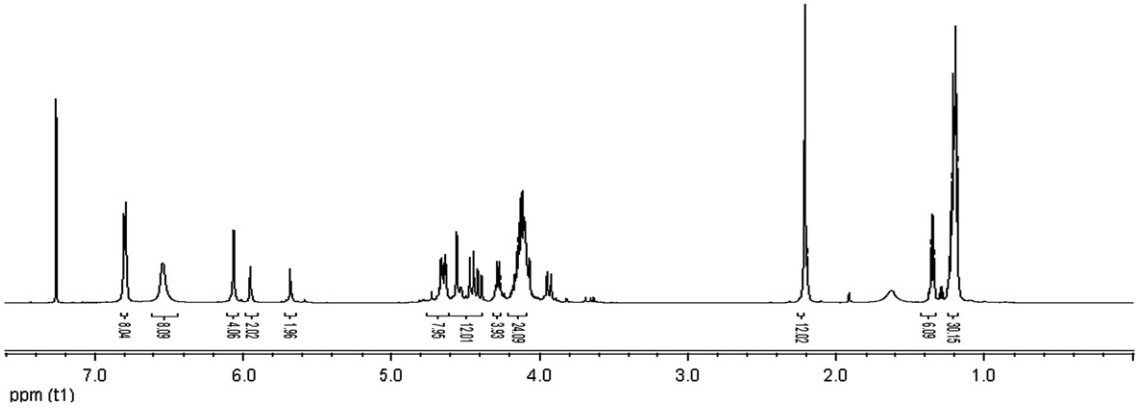
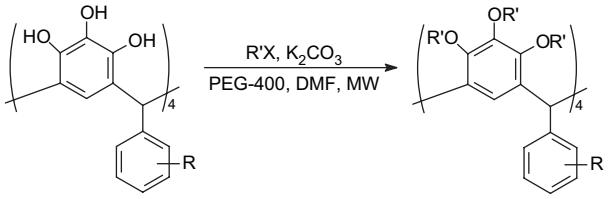


Figure 5. ^{1}H NMR spectrum of compound **5h**.

The O-alkylation of phenolic hydroxyl groups is the most popular modification procedure for *p-tert*-butylcalixarenes and resorcinarenes. It should be also suitable for the preparation of functional derivatives of pyrogallol[4]arene.[28] Aryl resorcinarenes and pyrogallol[4]arenes have been successfully alkylated by reaction with ethyl α-bromoacetate in the refluxing system of K_2CO_3/acetone for relatively longer time (5–7 days) to give the fully *O*-alkylated products in lower yield (11–27%).[29] The rapid heating induced by microwave irradiation leads to the formation of products under mild reaction conditions with short reaction times, thus avoiding decomposing or side reactions and, in many cases, increasing the yields. Now there have been a lot of examples about alkylation reactions under microwave irradiation.[30] So we try to carry microwave irradiation assisted O-alkylation of aryl pyrogallol[4]arenes with some typical alkylating reagents. The reaction was carried out by heating a mixture of aryl pyrogallol[4]arenes (**3a**–**3c**), potassium carbonate, and alkylating reagents in DMF in the presence of polyethylene glycol under microwave irradiation for about 3 min. After workup the fully O-alkylation products (**5a**–**5i**) were separated in moderate yields. All testing alkylating reagents such as *n*-butyl iodide, benzyl chloride, and ethyl α-chloroacetate gave the expected fully alkylation products with high purity in very short time compared with the results of conventional heating reactions. Thus this method is very suitable for rapid preparation of some functional pyrogallol[4]arenes. The structure of all products was characterized with IR, ^{1}H and ^{13}C NMR spectroscopy, and elemental analysis. As for example in ^{1}H NMR spectroscopy of **5h** (Fig. 5), the –OCH_2CO– groups show a mixed peak at about 4.30–4.80 ppm and methylene of OCH_2CH_3 groups displays a broad peak at about 4.10 ppm. The sign of bridging methyne appears at about 6.8 ppm, which is much down shifted with the data of acylated derivatives (**4b**). The four protons of pyrogallol ring show two single peaks in 1:1 ratio at about 6.0 and 5.7 ppm, which also indicates two kinds of pyrogallol rings existed in the molecule and **5h** occurs in cis–trans–trans (*rctt*) configuration isomer. The ^{1}H NMR spectra of *O*-benzylated and *O*-butylated derivatives all gave two singlets in 1:1 ratio for protons of pyrogallol ring, which suggest that they all exist in cis–trans–trans (*rctt*) configuration isomer (Scheme 2).

The X-ray single crystal structure of **5a**, **5c**, and **5d** are shown in Figures 6–8 and their crystal data are also listed



Scheme 2. Alkylation reactions of pyrogallol[4]arenes.

in Table 1. It is clearly seen from Figures 6 and 7 that there are 12 benzyl groups in the outer spherical positions of **5a** and **5c**, which confirmed the correct structure of the *O*-alkylated products. Compounds **5a** and **5c** both exist in *rctt* isomer or in chair form. The four pyrogallol units in the ring were divided into two groups with two pyrogallol rings at almost perpendicular direction and other two being nearly in horizontal. The stretching direction of two perpendicular pyrogallol rings is opposite. One is upper standing and the other is upside down. The four phenyl groups in **5a** and four *p*-methoxyphenyl groups in **5c** are also divided in two groups with two phenyl groups at C1 and C20 locating in upper direction, while other two phenyl groups at C13 and C32 stretching to down direction. The fully *n*-butylated **5d** also exists in *rctt* configuration with 12 *n*-butyl groups stretching to all directions.

In conclusion, we have provided microwave irradiation assisted preparation of aryl pyrogallol[4]arenes and their functional *O*-alkylating derivatives in moderate yields. The procedure is simple, efficient and time saving, and the

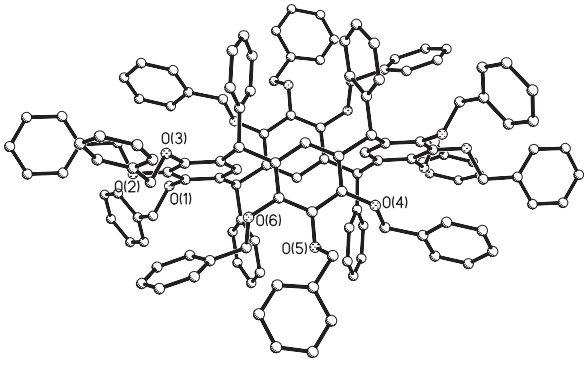


Figure 6. Crystal structure of benzylated phenylpyrogallol[4]arene **5a**.

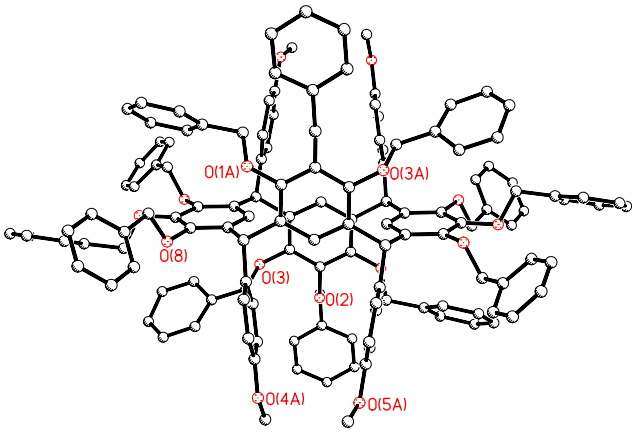


Figure 7. Crystal structure of benzylated *p*-methoxyphenyl pyrogallol[4]-arene **5c**.

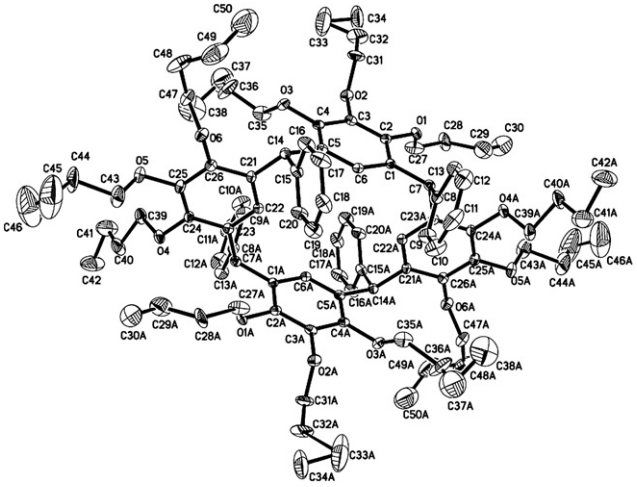


Figure 8. Crystal structure of *n*-butylated phenylpyrogallol[4]arene **5d**.

isolation of products is simple and dispenses with extensive recrystallization or chromatographic purification steps. The larger quantity of functional pyrogallol[4]arenes can be conveniently obtained in short time and it would offer great potentials in the study of aryl pyrogallol[4]arenes. The single crystal structure analysis of five representative compounds indicates that aryl pyrogallol[4]arenes usually exist in cis–trans–trans configuration isomer.

3. Experimental

3.1. Materials and apparatus

Melting points were obtained on a hot-plate microscope apparatus and were uncorrected. ^{1}H and ^{13}C NMR spectra were recorded with a Bruker AV-600 spectrophotometer. IR spectra were obtained on a Nicolet FT-IR 740 spectrometer (KBr disc). Elemental analysis was obtained on Perkin Elmer 1102b Instrument. X-ray data were collected on a Bruker Smart APEX-2 diffractometer. Microwave heating is conducted with Lingjiang LMMC-201 Microwave reactor (Nanjing, China). All reagents (pyrogallol, aromatic aldehydes, benzyl chloride, *n*-butyl iodide, and ethyl α-chloroacetate) and solvents (acetone, chloroform, dichloromethane, dimethyl sulfoxide, alcohol, and ethyl ether) were commercial reagents with analytical grade and used as received. Further purification and drying by standard method were employed and distilled prior to use when necessary.

3.2. General procedure for the synthesis of acylated aryl pyrogallol[4]arenes

The mixture of pyrogallol (1.26 g, 10.0 mmol), aldehydes **2a**–**2f** (10.0 mmol), 2-ethoxyethanol (2.0 mL), and concentrated HCl (2.0 mL) was heated by microwave irradiation for about 2 min with a fixed power of 130 W. After cooling to room temperature, 50 mL of H_2O was added to the mixture, the precipitate was filtered, and washed with water and ethanol to give pink solid products **3a**–**3f**. Then a mixture of aryl pyrogallol[4]arenes **3a**–**3f** (1.0 mmol) in acetic anhydride (15.0 mL) and pyridine (0.5 mL) was refluxed for 8 h. After cooling, the mixture was poured into 100 mL of water, the organic residue extracted with chloroform (30 mL), and dried with Na_2SO_4. Evaporation of the solvent gives colorless or yellow solid, which was purified by recrystallization with chloroform and ethyl alcohol.

3.2.1. Compound 4a. R=H, 83.2%, mp>250 °C; ^{1}H NMR ($CDCl_3$, 600 MHz) δ 6.99–7.04 (m, 12H, ArH), 6.77 (s, 8H, ArH), 6.29 (s, 2H, ArH), 5.96 (s, 2H, ArH), 5.45 (s, 4H, CH), 2.28 (s, 6H, $COCH_3$), 2.13–2.15 (br, 18H, $COCH_3$), 1.98 (s, 12H, $COCH_3$); ^{13}C NMR ($CDCl_3$, 600 MHz) δ 167.5, 166.8, 166.2, 140.5, 140.2, 138.1, 136.3, 135.9, 133.4, 133.3, 129.1, 128.8, 128.4, 126.7, 126.5, 45.1, 20.2, 20.0, 19.8; IR (KBr) ν 2937 (w), 1780 (vs), 1428 (m), 1372 (s), 1203 (vs), 1041 (s), 900 (w), 872 (w), 696 (m) cm^{-1}. Anal. Calcd for $C_{76}H_{64}O_{24}$: C, 67.06; H, 4.74; Found: C, 66.85; H, 4.67.

3.2.2. Compound 4b. R=*p*-CH_3, 88.7%, mp>250 °C; ^{1}H NMR ($CDCl_3$, 600 MHz) δ 6.86 (s, 8H, ArH), 6.66 (s, 8H, ArH), 6.26 (s, 2H, ArH), 6.06 (s, 2H, ArH), 5.42 (s, 4H, CH), 2.13–2.27 (m, 36H, $COCH_3$), 1.99 (s, 12H, $ArCH_3$); ^{13}C NMR ($CDCl_3$, 600 MHz) δ 167.5, 166.9, 166.4, 140.4, 140.1, 136.2, 135.8, 135.7, 135.2, 133.5, 129.1, 128.9, 126.4, 44.7, 21.1, 20.2, 20.2, 20.0, 19.9; IR (KBr) ν 2927 (w), 1783 (vs), 1635 (s), 1442 (s), 1376 (m), 1280 (s), 1210 (s), 1198 (vs), 1083 (s), 721 (m) cm^{-1}. Anal. Calcd for $C_{80}H_{72}O_{24}$: C, 67.79; H, 5.12; Found: C, 67.71; H, 4.73.

3.2.3. Compound 4c. R=*p*-OCH_3, 87.9%, mp>250 °C; ^{1}H NMR ($CDCl_3$, 600 MHz) δ 6.60–6.80 (m, 16H, ArH), 6.23 (s, 2H, ArH), 5.95 (s, 2H, ArH), 5.40 (s, 4H, CH), 3.76 (s, 12H, OCH_3), 1.99–2.27 (m, 36H, $COCH_3$); ^{13}C NMR ($CDCl_3$, 600 MHz) δ 167.6, 166.9, 166.3, 166.2, 158.1, 140.3, 140.1, 136.1, 135.8, 133.8, 133.5, 130.3, 130.1, 128.9, 126.4, 113.7, 54.8, 44.6, 20.2, 20.2, 20.0, 19.9; IR (KBr) ν 2935 (w), 1780 (vs), 1485 (w), 1435 (m), 1365 (m), 1196 (vs), 1168 (s), 1153 (s), 1027 (m), 821 (m) cm^{-1}. Anal. Calcd for $C_{80}H_{72}O_{28}$: C, 64.86; H, 4.90; Found: C, 65.12; H, 4.83.

3.2.4. Compound 4d. R=*p*-Cl, 81.5%, mp>250 °C; ^{1}H NMR ($CDCl_3$, 600 MHz) δ 7.08–7.19 (m, 16H, ArH), 6.21 (s, 2H, ArH), 5.90 (s, 2H, ArH), 5.43 (s, 4H, CH), 2.01–2.27 (m, 36H, $COCH_3$); ^{13}C NMR ($CDCl_3$, 600 MHz) δ 167.5, 166.7, 166.3, 140.7, 140.5, 136.6, 136.0, 133.0, 132.8, 130.4, 128.4, 126.5, 44.3, 20.2, 20.1, 20.0, 19.9; IR (KBr) ν 2936 (w), 1780 (vs), 1485 (w), 1435 (m), 1365 (m), 1196 (vs),

1168 (s), 1153 (s), 1027 (m), 721 (m) cm^{-1}. Anal. Calcd for $C_{76}H_{60}Cl_4O_{24}$: C, 60.89; H, 4.04; Found: C, 60.67; H, 4.35.

3.2.5. Compound 4e. R=*o*-$OCOCH_3$, 88.9%, mp>250 °C; ^1H NMR ($CDCl_3$, 600 MHz) δ 6.76–7.02 (m, 12H, ArH), 6.46–6.50 (m, 4H, ArH), 6.12–6.20 (m, 2H, ArH), 5.76 (s, 2H, ArH), 5.54 (s, 4H, CH), 2.04–2.27 (m, 48H, $COCH_3$); ^{13}C NMR ($CDCl_3$, 600 MHz) δ 169.4, 169.3, 167.4, 167.3, 166.4, 148.6, 148.1, 140.7, 140.6, 136.2, 132.5, 131.9, 130.9, 130.5, 127.7, 126.0, 122.4, 121.6, 39.1, 20.6, 20.5, 20.1, 20.1, 19.9, 19.8; IR (KBr) ν 2931 (w), 1783 (vs), 1635 (vs), 1481 (m), 1442 (s), 1376 (m), 1319 (m), 1207 (m), 1076 (m), 1040 (m), 870 (m) cm^{-1}. Anal. Calcd for $C_{84}H_{72}O_{32}$: C, 63.32; H, 4.55; Found: C, 63.54; H, 4.69.

3.2.6. Compound 4f. R=*p*-$OCOCH_3$, 81.5%, mp>250 °C; ^1H NMR ($CDCl_3$, 600 MHz) δ 6.90 (d, J=8.4 Hz, 9H, ArH), 6.87 (d, J=7.8 Hz, 3H, ArH), 7.79 (s, 3H, ArH), 7.71 (s, 4H, ArH), 6.25 (s, 1H, ArH), 6.19 (s, 1H, ArH), 6.02 (s, 2H, ArH), 5.48 (s, 4H, CH), 2.13–2.33 (m, 36H, $COCH_3$), 1.96–2.00 (br, 2H, $COCH_3$); ^{13}C NMR ($CDCl_3$, 600 MHz) δ 168.8, 168.7, 167.6, 167.4, 166.8, 166.7, 149.5, 140.8, 140.7, 140.4, 137.2, 136.5, 135.5, 133.2, 133.0, 132.3, 132.2, 130.1, 129.3, 129.2, 129.0, 128.2, 126.4, 125.3, 121.6, 121.3, 44.2, 21.3, 21.3, 20.1, 20.0, 19.9; IR (KBr) ν 2931 (w), 1787 (vs), 1506 (m), 1477 (w), 1442 (m), 1372 (s), 1315 (w), 1196 (vs), 1076 (m), 1034 (s), 907 (w), 851 (w) cm^{-1}. Anal. Calcd for $C_{84}H_{72}O_{32}$: C, 63.32; H, 4.55; Found: C, 63.27; H, 4.71.

3.3. General procedure for alkylation of aryl pyrogallol[4]arenes

To a 50 mL of flask were added aryl pyrogallol[4]arenes **3a** or **3b** or **3c** (1.0 mmol), potassium carbonate (12.0 mmol), *N*,*N*-dimethylformamide (2.0 mL), polyethylene glycol 400 (2.0 mL), and alkyl halide (24.0 mmol). The mixture was heated by microwave irradiation for about 3 min (130 W). After cooling, the reaction mixture was poured into 50 mL water and extracted with $CHCl_3$. The organic layer was dried with $MgSO_4$. After evaporating the solvent the residue was recrystallized with chloroform–ethanol to give the white solid sample for analysis.

3.3.1. Compound 5a. R=H, R′=CH_2Ph, 32.4%, mp 219–220 °C; ^1H NMR ($CDCl_3$, 600 MHz) δ 7.06–7.25 (m, 60H, ArH), 6.86 (m, 12H, ArH), 6.75 (s, 8H, ArH), 6.47 (s, 2H, CH), 6.11 (s, 4H, ArH), 5.71 (s, 2H, CH), 5.29 (s, 2H, OCH_2), 5.27 (s, 2H, OCH_2), 5.03 (s, 4H, OCH_2), 4.70–4.76 (m, 6H, OCH_2), 4.60 (t, J=9.6 Hz, 6H, OCH_2), 4.34 (s, 2H, OCH_3), 4.32 (s, 2H, OCH_3); ^{13}C NMR ($CDCl_3$, 600 MHz) δ 149.4, 149.1, 146.2, 145.9, 142.4, 138.1, 137.8, 133.7, 133.1, 128.8, 128.5, 128.2, 128.1, 128.0, 127.8, 127.5, 127.3, 75.8, 75.1, 74.3, 74.1, 65.1, 44.5, 15.31; IR (KBr) ν 2924 (w), 2857 (w), 1633 (s), 1435 (m), 1383 (vs), 1315 (w) cm^{-1}. Anal. Calcd for $C_{136}H_{112}O_{12}$: C, 84.27; H, 5.82; Found: C, 84.03; H, 5.87.

3.3.2. Compound 5b. R=*p*-CH_3, R′=CH_2Ph, 35.6%, mp 244–245 °C; ^1H NMR ($CDCl_3$, 600 MHz) δ 7.22–7.36 (m, 60H, ArH), 6.65–6.69 (m, 16H, ArH), 6.44 (s, 2H, CH), 6.08 (s, 4H, ArH), 5.82 (s, 2H, CH), 5.26 (s, 4H, OCH_2), 5.02 (s, 4H, OCH_2), 4.55–4.73 (m, 12H, OCH_2), 4.34–4.35 (m, 4H, OCH_2), 2.13 (s, 12H, $ArCH_3$); ^{13}C NMR ($CDCl_3$, 600 MHz) δ 149.3, 149.1, 146.2, 146.0, 139.4, 138.2, 137.9, 137.7, 137.5, 134.9, 133.9, 133.2, 128.7, 128.4, 128.3, 128.2, 128.1, 128.0, 127.8, 127.6, 127.3, 75.8, 75.0, 74.3, 74.1, 44.1, 21.0; IR (KBr) ν 2924 (w), 2856 (w), 1635 (s), 1498 (m), 1383 (vs), 1311 (w) cm^{-1}. Anal. Calcd for $C_{140}H_{120}O_{12}$: C, 84.31; H, 6.06; Found: C, 84.56; H, 6.34.

3.3.3. Compound 5c. R=*p*-OCH_3, R′=CH_2Ph, 31.2%, mp 220–221 °C; ^1H NMR ($CDCl_3$, 600 MHz) δ 7.06–7.25 (m, 60H, ArH), 6.64 (s, 8H, ArH), 6.40 (s, 8H, ArH), 6.14 (s, 2H, CH), 6.01 (s, 4H, ArH), 5.61 (s, 2H, CH), 5.22 (s, 4H, OCH_2), 4.99 (s, 4H, OCH_2), 4.66–4.78 (m, 12H, OCH_2), 4.40 (m, 4H, OCH_2), 3.50 (s, 12H, OCH_3); ^{13}C NMR ($CDCl_3$, 600 MHz) δ 157.6, 149.2, 148.9, 138.2, 137.9, 137.7, 137.3, 134.5, 133.8, 133.5, 128.5, 128.2, 128.2, 128.1, 128.0, 127.9, 127.7, 127.6, 127.3, 76.0, 75.1, 74.2, 54.0, 43.8; IR (KBr) ν 2924 (w), 2853 (w), 1635 (s), 1384 (vs), 1084 (w) cm^{-1}. Anal. Calcd for $C_{140}H_{120}O_{16}$: C 81.69; H, 5.88; Found: C, 81.37; H, 5.59.

3.3.4. Compound 5d. R=H, R′=*n*-Bu, 45.3%, mp 149–150 °C; ^1H NMR ($CDCl_3$, 600 MHz) δ 6.78 (s, 12H, ArH), 6.59 (s, 8H, ArH), 6.06 (s, 2H, CH), 5.83 (s, 4H, ArH), 5.37 (s, 2H, CH), 3.83–3.99 (m, 16H, OCH_2), 3.16–3.32 (m, 8H, OCH_2), 0.69–1.72 (m, 84H, $CH_2CH_2CH_3$); ^{13}C NMR ($CDCl_3$, 600 MHz) δ 149.7, 149.6, 145.8, 145.4, 143.2, 132.9, 132.0, 129.0, 127.4, 126.7, 125.4, 123.8, 73.1, 73.0, 72.9, 72.7, 44.0, 32.7, 32.5, 32.5, 32.4, 19.5, 19.2, 19.1, 19.0, 14.2, 14.0, 13.9; IR (KBr) ν 2959 (w), 2933 (w), 2873 (w), 1633 (m), 1463 (w), 1384 (vs), 1314 (w), 1093 (w) cm^{-1}. Anal. Calcd for $C_{100}H_{136}O_{12}$: C, 78.49; H, 8.96; Found: C, 78.22; H, 8.85.

3.3.5. Compound 5e. R=*p*-CH_3, R′=*n*-Bu, 41.5%, mp 118–119 °C; ^1H NMR ($CDCl_3$, 600 MHz) δ 6.54–6.66 (m, 16H, ArH), 6.09 (s, 2H, CH), 5.85 (s, 4H, ArH), 5.53 (s, 2H, CH), 3.70–4.02 (m, 16H, OCH_2), 3.24–3.40 (m, 8H, OCH_2), 2.18 (s, 12H, $ArCH_3$), 0.82–1.78 (m, 84H, $CH_2CH_2CH_3$); ^{13}C NMR ($CDCl_3$, 600 MHz) δ 149.6, 149.4, 145.4, 140.2, 134.2, 133.1, 132.1, 129.0, 127.9, 73.1, 72.7, 43.7, 32.7, 32.6, 32.5, 21.0, 19.5, 19.3, 19.1, 19.0, 14.2, 14.0, 13.9; IR (KBr) ν 2939 (w), 2930 (w), 2871 (w), 1631 (m), 1515 (m), 1463 (w), 1436 (w), 1384 (vs), 1313 (w), 1090 (w) cm^{-1}. Anal. Calcd for $C_{104}H_{144}O_{12}$: C, 78.75; H, 9.15; Found: C, 78.63; H, 8.97.

3.3.6. Compound 5f. R=*p*-OCH_3, R′=*n*-Bu, 47.3%, mp 128–129 °C; ^1H NMR ($CDCl_3$, 600 MHz) δ 6.42–6.57 (m, 16H, ArH), 6.08 (s, 2H, CH), 5.84 (s, 4H, ArH), 5.45 (s, 2H, CH), 3.91–4.02 (m, 12H, $ArCH_3$), 3.71–3.78 (m, 16H, OCH_2), 3.24–3.43 (m, 8H, OCH_2), 0.84–1.79 (m, 84H, $CH_2CH_2CH_3$); ^{13}C NMR ($CDCl_3$, 600 MHz) δ 155.8, 148.1, 144.4, 144.0, 134.0, 131.7, 130.9, 128.5, 125.3, 122.2, 111.3, 71.7, 71.6, 71.5, 71.3, 53.4, 41.8, 31.3, 31.2, 31.1, 18.1, 17.8, 17.7, 17.6, 12.8, 12.6, 12.5; IR (KBr) ν 2954 (w), 2872 (w), 1635 (s), 1514 (w), 1436 (w), 1384 (vs), 1175 (w), 1084 (w) cm^{-1}. Anal. Calcd for $C_{104}H_{144}O_{16}$: C, 75.69; H, 8.80; Found: C, 75.87; H, 9.14.

3.3.7. Compound 5g. R=H, R′=CH_2CO_2Et, 27.9%, mp 118–119 °C; ^1H NMR ($CDCl_3$, 600 MHz) δ 6.97 (m, 12H, ArH), 6.66 (s, 8H, ArH), 6.12 (s, 4H, ArH), 5.96 (s, 2H, CH), 5.56 (s, 2H, CH), 4.28–4.71 (m, 24H, OCH_2CO),

4.02–4.15 (m, 24H, OCH_2), 1.38 (t, J=7.3 Hz, 6H, CH_3), 1.19–1.24 (m, 30H, CH_3); ^{13}C NMR ($CDCl_3$, 600 MHz) δ 169.1, 168.8, 168.7, 148.6, 148.5, 143.8, 142.7, 141.2, 133.3, 132.6, 128.8, 128.0, 127.1, 126.2, 123.8, 70.2, 69.9, 60.7, 60.7, 43.9, 14.2, 14.1, 14.0; IR (KBr) ν 2935 (w), 1766 (vs), 1731 (s), 1604 (w), 1442 (s), 1379 (m), 1287 (m), 1210 (s), 1090 (s), 1055 (m), 703 (m) cm^{-1}. Anal. Calcd for $C_{100}H_{112}O_{36}$: C, 63.55; H, 5.97; Found: C, 63.82; H, 6.27.

3.3.8. Compound 5h. R=*p*-CH_3, R′=CH_2CO_2Et, 20.8%, mp 150–151 °C; ^1H NMR ($CDCl_3$, 600 MHz) δ 6.81 (s, 8H, ArH), 6.54 (s, 8H, ArH), 6.07 (s, 4H, ArH), 5.96 (s, 2H, CH), 5.69 (s, 2H, CH), 4.27–4.67 (m, 24H, $COOCH_2$), 4.08–4.16 (m, 24H, OCH_2), 2.21 (s, 12H, $ArCH_3$), 1.37 (t, J=7.2 Hz, 6H, CH_3), 1.20–1.24 (br, 30H, CH_3); ^{13}C NMR ($CDCl_3$, 600 MHz) δ 169.1, 168.9, 148.5, 148.5, 143.8, 142.8, 138.1, 135.3, 133.7, 132.7, 128.8, 128.6, 127.1, 123.8, 70.2, 69.9, 60.7, 43.5, 21.1, 14.3, 14.18; IR (KBr) ν 2937 (w), 1752 (vs), 1442 (s), 1280 (m), 1210 (s), 1083 (s) cm^{-1}. Anal. Calcd for $C_{104}H_{120}O_{36}$: C, 64.19; H, 6.21; Found: C, 64.45; H, 6.48.

3.3.9. Compound 5i. R=*p*-OCH_3, R′=CH_2CO_2Et, 25.3%, mp 178–179 °C; ^1H NMR ($CDCl_3$, 600 MHz) δ 6.35 (s, 16H, ArH), 5.85 (s, 4H, ArH), 5.71 (s, 2H, CH), 5.36 (s, 2H, CH), 4.05–4.45 (m, 24H, $COOCH_2$), 3.79–3.97 (m, 24H, OCH_2), 3.53 (s, 12H, OCH_3), 1.14 (t, J=7.2 Hz, 6H, CH_3), 0.99–1.02 (br, 30H, CH_3); ^{13}C NMR ($CDCl_3$, 600 MHz) δ 169.1, 168.8, 157.9, 148.5, 148.7, 133.6, 133.3, 133.0, 129.7, 113.4, 70.3, 69.9, 60.8, 60.8, 60.7, 54.8, 43.1, 14.1, 14.0; IR (KBr) ν 2931 (w), 1766 (vs), 1611 (m), 1583 (w), 1513 (s), 1470 (s), 1428 (s), 1386 (m), 1252 (s) cm^{-1}. Anal. Calcd for $C_{104}H_{120}O_{40}$: C, 62.14; H, 6.02; Found: C, 62.39; H, 5.86.

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Supplementary data

Crystallographic data (CCDC-646541 for **4b**, CCDC-646542 for **4c**, CCDC-646543 for **5a**, CCDC-646544 for **5c**, CCDC-646545 for **5d**) have been deposited at the Cambridge Crystallographic Database Centre. Supplementary data associated with this article can be found in the online version, at doi:10.1016/j.tet.2007.07.043.

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