Synthesis of Functionalized Oxacalix[4]arenes

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General information

^1H and ^{13}C NMR spectra were recorded on a Bruker Avance 400 spectrometer. Chemical shifts are reported in ppm versus tetramethylsilane with either tetramethylsilane or the residual solvent resonance used as an internal standard. Infrared spectra were recorded on a Mattson Satellite FT-IR spectrometer. Analytical chromatography (TLC) was performed on EM Reagents 0.25 mm silica gel 60-F plates.

Characterization Data

3a: Purified by flash column chromatography using a linear gradient 30-50% ethyl acetate in hexanes as the eluant (loaded from ethyl acetate in hexanes with minimum CH_2Cl_2 for solubility). ^1H NMR (400 MHz, $\text{DMSO}-d_6$): δ 8.96 (s, 2H), 7.64 (d, 4H, $J = 2.3$ Hz), 7.49 (t, 2H, $J = 2.3$ Hz), 7.23 (s, 2H), 3.87 (s, 6H); ^{13}C NMR (100 MHz, CDCl_3): δ 164.3, 155.7, 154.4, 135.6, 133.6, 126.2, 120.8, 116.6, 106.2, 53.2; IR (thin film): 3072, 2954, 2920, 2848, 1730, 1615, 1587, 1539, 1455, 1443, 1435, 1347, 1300, 1227, 1051, 999 cm^{-1} ; ESI(+) LRMS m/z 682 ($\text{M}+\text{NH}_4$) $^+$; TLC $R_f = 0.57$ (40% Ethyl acetate in hexanes).

3b: Purified by flash column chromatography using a linear gradient 20-30% ethyl acetate in hexanes as the eluant (loaded by pre-absorbing onto silica from acetone). ^1H NMR (400 MHz, $\text{DMSO}-d_6$): δ 8.92 (s, 2H), 7.04 (d, 4H, $J = 2.0$ Hz), 7.00 (t, 2H, $J = 2.0$ Hz), 6.82 (s, 2H), 2.34 (s, 6H); ^{13}C NMR (100 MHz, acetone- d_6): δ 156.4, 156.1, 144.8, 135.1, 125.8, 120.0, 109.5, 109.2, 21.3; IR (thin film): 3068, 2920, 2848, 1611, 1583, 1526, 1349, 1295, 1187, 1057, 969, 833 cm^{-1} ; ESI(+) LRMS m/z 594 ($\text{M}+\text{NH}_4$) $^+$; TLC $R_f = 0.30$ (30% Ethyl acetate in hexanes).

3c: Purified by flash column chromatography using a linear gradient 10-20% ethyl acetate in hexanes as the eluant (loaded by pre-absorbing onto silica from CH_2Cl_2). ^1H NMR (400 MHz, $\text{DMSO}-d_6$): δ 8.93 (s, 2H), 7.08 (d, 4H, $J = 2.1$ Hz), 7.04 (t, 2H, $J = 2.1$ Hz), 6.48 (s, 2H), 2.59 (t, 4H, $J = 7.7$ Hz), 1.55 (m, 4H), 1.31-1.23 (m, 8H), 0.86 (t, 6H, $J = 7.0$ Hz); ^{13}C NMR (100 MHz, CDCl_3): δ 156.8, 154.0, 149.9, 132.5, 126.3, 120.2, 111.2, 108.8, 35.8, 31.4, 30.8, 22.5, 14.2; IR (thin film): 3073, 2929, 2852, 1608, 1578, 1529, 1455, 1350, 1288, 1187, 1058, 997, 835 cm^{-1} ; ESI(+) LRMS m/z 706 ($\text{M}+\text{NH}_4$) $^+$; TLC $R_f = 0.70$ (30% Ethyl acetate in hexanes).

3d: Purification of this compound was not carried out beyond washing with methanol due to low solubility. The low solubility also precluded ^{13}C NMR analysis. ^1H NMR (400 MHz, $\text{DMSO}-d_6$): δ 10.03 (s, 2H) 8.98 (s, 2H), 7.68 (d, 4H, $J = 2.2$ Hz), 7.53 (t, 2H, $J = 2.2$ Hz), 7.30 (s, 2H). IR (KBr pellet): 3440, 3043, 2856, 2745, 1693, 1610, 1586, 1544, 1489, 1458, 1350, 1293, 1192, 1142, 1056 cm^{-1} ; ESI(-) LRMS m/z 639 ($\text{M}+\text{Cl}^-$).

3e: Purified by flash column chromatography using a linear gradient 3-5% MeOH in CH_2Cl_2 as the eluant. ^1H NMR (400 MHz, $\text{DMSO}-d_6$): δ 10.60 (s, 2H), 8.93 (s, 2H), 7.21 (d, 4H, $J = 8.2$ Hz), 6.97 (t, 2H, $J = 8.2$ Hz), 5.64 (s, 2H); ^{13}C NMR (100 MHz, acetone- d_6): δ 157.3, 142.5, 142.2, 132.7, 126.8, 122.8, 122.2, 102.6; IR (KBr pellet): 3496, 3106, 3058, 1621, 1603, 1583, 1530, 1494, 1474, 1355, 1282, 1214, 1188, 1054, 978, 834, 776,

738, 692 cm^{-1} ; ESI(-) LRMS m/z 579 (M-H) $^-$; TLC R_f = 0.29 (5% MeOH in CH_2Cl_2 + 1% acetic acid).

3f: Purified by flash column chromatography using a linear gradient 1-3% MeOH in CH_2Cl_2 + 0.5% acetic acid as the eluant. ^1H NMR (400 MHz, $\text{DMSO}-d_6$): δ 10.32 (s, 2H), 8.93 (s, 2H), 7.18 (s, 4H), 5.66 (s, 2H), 1.16 (s, 18H); ^{13}C NMR (100 MHz, $\text{acetone}-d_6$): δ 155.9, 144.9, 140.0, 138.1, 131.0, 125.1, 118.0, 101.1, 33.8, 29.9; IR (thin film): 3438, 3111, 2959, 2867, 1610, 1531, 1417, 1351, 1310, 1284, 1193, 1057, 1006, 834 cm^{-1} ; ESI(-) LRMS m/z 691 (M-H) $^-$; TLC R_f = 0.27 (5% MeOH in CH_2Cl_2 + 1% acetic acid).

3g: Purified by flash column chromatography using a linear gradient 1-3% MeOH in CH_2Cl_2 + 0.5% acetic acid as the eluant. ^1H NMR (400 MHz, $\text{DMSO}-d_6$): δ 11.70 (bs, 2H), 8.76 (s, 2H), 7.34 (s, 4H), 6.09 (s, 2H), 4.10 (q, 4H, J = 7.1 Hz), 1.22 (t, 6H, J = 7.1 Hz); ^{13}C NMR (100 MHz, $\text{DMSO}-d_6$): δ 163.2, 155.4, 146.2, 140.4, 131.7, 125.9, 122.9, 121.7, 101.2, 61.1, 13.8; IR (KBr pellet): 3404, 3270, 3114, 3081, 2985, 1717, 1692, 1618, 1581, 1533, 1434, 1350, 1325, 1283, 1213, 1094, 1054, 1017, 833, 769, 689 cm^{-1} ; ESI(-) LRMS m/z 723 (M-H) $^-$; TLC R_f = 0.23 (5% MeOH in CH_2Cl_2 + 1% acetic acid).

3h: Purified by flash column chromatography using a linear gradient 1-3% MeOH in CH_2Cl_2 + 0.5% acetic acid as the eluant. ^1H NMR (400 MHz, $\text{DMSO}-d_6$): δ 10.51 (bs, 2H), 8.89 (s, 2H), 6.74 (s, 2H), 6.57-6.56 (m, 6H); ^{13}C NMR (100 MHz, $\text{acetone}-d_6$): δ 162.0, 156.8, 156.5, 134.7, 125.7, 109.0, 107.0, 103.6; IR (KBr pellet): 3429, 3112, 3056, 1610, 1589, 1530, 1485, 1458, 1351, 1289, 1189, 1141, 1003, 854, 832 cm^{-1} ; ESI(-) LRMS m/z 579 (M-H) $^-$; TLC R_f = 0.18 (5% MeOH in CH_2Cl_2 + 1% acetic acid).

X-ray Crystallographic Data for 3b

The selected crystal was mounted with epoxy to the tip of a glass rod drawn out to a fiber. The X-ray intensity data for this colorless needle of $C_{26}H_{16}N_4O_{12}$ with approximate dimensions 0.95 x 0.08 x 0.04 mm were measured with phi and omega scans at 298 K on a Bruker SMART APEX CCD-based X-ray diffractometer system equipped with a Mo-target X-ray tube ($\lambda = 0.71073 \text{ \AA}$). The detector was placed at a distance of 5.00 cm from the crystal. A total of 1850 frames were collected (a hemisphere of data) with an exposure time of 30 sec/frame. The frames were integrated with the Bruker SAINT software package using a narrow-frame integration algorithm giving a total of 21,728 reflections to a maximum 2θ angle of 57° of which 5964 reflections were independent. The structure was solved (direct methods) and refined using the Bruker SHELXTL version 6.1 Software Package using literature scattering factors (Wilson, A. J. C., Ed. *International Tables for Crystallography*; Kluwer Academic Publishers: Dordrecht, The Netherlands, 1992; Vol. C.), and the orthorhombic space group $Pca2(1)$, with $Z = 4$. No absorption correction was applied. The final anisotropic full-matrix least-squares refinement of F^2 converged at $R1 = 7.11\%$, $wR2 = 14.04\%$ and a goodness-of-fit of 0.962. All non-hydrogen atoms were modeled anisotropically. Hydrogen atoms were placed at calculated distances. All hydrogen atoms use a riding model, which means that the positional and thermal parameters are derived from the atom each hydrogen atom is bound to, while maintaining the calculated or determined distance and optimal angles. The largest peak and hole in the final difference map were 0.296 and -0.264 e-/Å^3 , respectively. The calculated density is 1.524 g/cm^3 and $F(000)$ is 1184 e $^-$. Thermal ellipsoid drawings (15%) in this report were generated with the Bruker SHELXTL software.

Selected Distances and Angles for 3b

Angles between phenyl planes

C7+C8+C9+C10+C11+C12 and C19+C20+C21+C22+C23+C24	168.9°
C31+C32+C33+C34+C35+C36 and C43+C44+C45+C46+C47+C48	18.0°

Distances between the centers of phenyl planes

C7+C8+C9+C10+C11+C12 and C19+C20+C21+C22+C23+C24	4.557 Å
C31+C32+C33+C34+C35+C36 and C43+C44+C45+C46+C47+C48	7.522 Å

Experimental details for **3b**

Identification code	katz4; compound 3b
Empirical formula	C ₂₆ H ₁₆ N ₄ O ₁₂
Formula weight	576.43
Temperature	298(2) K
Wavelength	0.71073 Å
Crystal system	Orthorhombic
Space group	Pca2(1)
Unit cell dimensions	$a = 12.3501(14)$ Å $\alpha = 90^\circ$ $b = 18.786(2)$ Å $\beta = 90^\circ$ $c = 10.8270(12)$ Å $\gamma = 90^\circ$
Volume, Z	2512.0(5) Å ³ , 4
Density (calculated)	1.524 Mg/m ³
Absorption coefficient	0.124 mm ⁻¹
F(000)	1184
Crystal size	0.95 x 0.08 x 0.04 mm
θ range for data collection	1.08 to 28.30°
Limiting indices	$-15 < h < 16$, $-24 < k < 24$, $-14 < l < 14$
Reflections collected	21728
Independent reflections	5964 ($R_{\text{int}} = 0.1532$)
Completeness to $\theta = 28.27^\circ$	98.1 %
Absorption correction	None
Refinement method	Full-matrix least-squares on F ²
Data / restraints / parameters	5964 / 1 / 381
Goodness-of-fit on F ²	0.962
Final R indices [$I > 2\sigma(I)$]	R1 = 0.0711, wR2 = 0.1404

R indices (all data)	$R1 = 0.1187, wR2 = 0.1702$
Absolute structure parameter	0.4(14)
Largest diff. peak and hole	0.296 and $-0.264 \text{ e}^-/\text{\AA}$

X-ray Crystallographic Data for 3e•2CH₃CN

The selected crystal was mounted with epoxy to the tip of a glass rod drawn out to a fiber. The X-ray intensity data for this colorless plate of C₂₈H₁₈N₆O₁₄ with approximate dimensions 0.65 x 0.36 x 0.08 mm were measured with phi and omega scans at 298 K on a Bruker SMART APEX CCD-based X-ray diffractometer system equipped with a Mo-target X-ray tube ($\lambda = 0.71073 \text{ \AA}$). The detector was placed at a distance of 5.00 cm from the crystal. A total of 1850 frames were collected (a hemisphere of data) with an exposure time of 10 sec/frame. The frames were integrated with the Bruker SAINT software package using a narrow-frame integration algorithm giving a total of 25,817 reflections to a maximum 2θ angle of 56.54° of which 12,868 reflections were independent. The structure was solved (direct methods) and refined using the Bruker SHELXTL version 6.1 Software Package using literature scattering factors (Wilson, A. J. C., Ed. *International Tables for Crystallography*; Kluwer Academic Publishers: Dordrecht, The Netherlands, 1992; Vol. C.), and the monoclinic space group Pn, with Z = 4. No absorption correction was applied. The final anisotropic full-matrix least-squares refinement of F² converged at R1 = 5.23%, wR2 = 12.66% and a goodness-of-fit of 0.920. All non-hydrogen atoms were modeled anisotropically except the ill-behaved, disordered solvent atoms C52 and C54, which were modeled isotropically (the least squares refinement would not converge with those atoms modeled anisotropically either with or without modeling of the disorder). Hydrogen atoms were placed at calculated distances except the hydrogen-bonded hydrogen atoms on the phenolic oxygen atoms which were found. All hydrogen atoms use a riding model, which means that the positional and thermal parameters are derived from the carbon atom each hydrogen atom is bound to, while maintaining the calculated or determined distance and optimal angles. The largest peak and hole in the final difference map were 0.379 and $-0.223 \text{ e-/}\text{\AA}^3$, respectively. The calculated density is 1.486 g/cm^3 and F(000) is 1360 e-. Thermal ellipsoid drawings (15%) in this report were generated with the Bruker SHELXTL software.

Selected Distances and Angles for 3e•2CH₃ CN

Angles between phenyl planes

C7+C8+C9+C10+C11+C12 and C19+C20+C21+C22+C23+C24	8.9°
C31+C32+C33+C34+C35+C36 and C43+C44+C45+C46+C47+C48	10.4°
C1+C2+C3+C4+C5+C6 and C13+C14+C15+C16+C17+C18	124.6°
C25+C26+C27+C28+C29+C30 and C37+C38+C39+C40+C41+C42	124.7°

Distances between the centers of selected phenyl rings

C7+C8+C9+C10+C11+C12 and C19+C20+C21+C22+C23+C24	4.905 Å
C31+C32+C33+C34+C35+C36 and C43+C44+C45+C46+C47+C48	4.882 Å

Distances between phenolic hydrogen atoms and acetonitrile nitrogen atoms

H19 & N12	2.002 Å
H20 & N11	1.975 Å
H5 & N10	2.025 Å
H6A & N9	2.020 Å

Experimental details for 3e•2CH₃ CN

Identification code	katz2_m; compound 3e•2CH ₃ CN
Empirical formula	C ₂₈ H ₁₈ N ₆ O ₁₄
Formula weight	662.48
Temperature	298(2) K
Wavelength	0.71073 Å
Crystal system	Monoclinic
Space group	Pn
Unit cell dimensions	$a = 17.220(2)$ Å $\alpha = 90^\circ$ $b = 8.4231(10)$ Å $\beta = 110.017(2)^\circ$ $c = 21.729(3)$ Å $\gamma = 90^\circ$
Volume, Z	2961.3(6) Å ³ , 4
Density (calculated)	1.486 Mg/m ³
Absorption coefficient	0.122 mm ⁻¹
F(000)	1360

Crystal size	0.65 x 0.36 x 0.08 mm
θ range for data collection	1.31 to 28.27°
Limiting indices	$-22 < h < 22, -10 < k < 10, -28 < l < 28$
Reflections collected	25817
Independent reflections	12868 ($R_{\text{int}} = 0.0662$)
Completeness to $\theta = 28.27^\circ$	94.5 %
Absorption correction	None
Refinement method	Full-matrix least-squares on F^2
Data / restraints / parameters	12868 / 2 / 863
Goodness-of-fit on F^2	0.920
Final R indices [$I > 2\sigma(I)$]	$R1 = 0.0523, wR2 = 0.1266$
R indices (all data)	$R1 = 0.0825, wR2 = 0.1470$
Absolute structure parameter	-0.2(12)
Largest diff. peak and hole	0.379 and -0.223 e-/Å