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Supporting Information

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Water and Hydrogen Halides Serve the Same Structural Role in a Series of 2+2 Hydrogen Bonded Dimers Based on 2,6-Bis(2-anilinoethynyl)pyridine Sulfonamide Receptors

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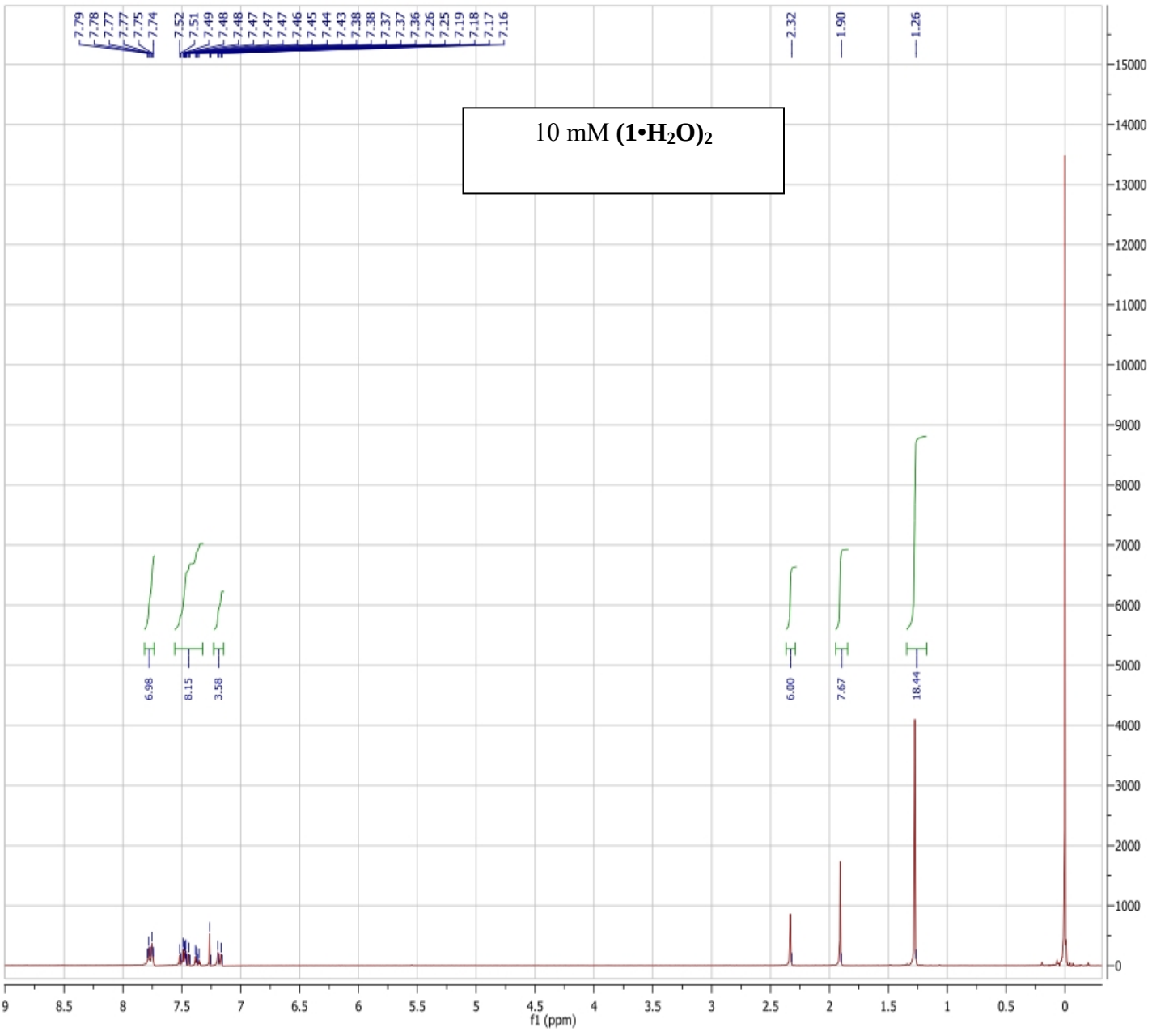
EXPERIMENTAL

General: All solvents were dried over 3Å molecular sieves unless otherwise stated. All other materials were obtained from TCI-America, Sigma-Aldrich, Acros and Strem and used as received. ^{1}H and ^{13}C NMR spectra were recorded using a Varian Inova 300 (^{1}H 299.95 MHz, ^{13}C 75.43 MHz) or Inova 500 (^{1}H 500.10 MHz, ^{13}C 125.75 MHz) spectrometer. Chemical shifts (δ) expressed as ppm downfield from tetramethylsilane using either the residual solvent peak as an internal standard ($CDCl_3$ ^{1}H: 7.27 ppm) or using $CDCl_3$ spiked with 1% trimethylsilane for the ^{1}H NMR spectra. For the ^{13}C NMR spectra the middle $CDCl_3$ peak (δ 77.00 ppm) was used as the internal standard. Signal patterns are indicated as b, broad; s, singlet; d, doublet; t, triplet; m, multiplet. Coupling constants (*J*) are given in hertz. UV-Vis spectra were recorded using a Hewlett-Packard 8453 spectrophotometer and extinction coefficients are expressed in $M^{-1}cm^{-1}$. Mass spectra were recorded using an Agilent 1100 Series LC/MSD. Emission spectra were recorded on a Hitachi F-4500 fluorescence spectrophotometer. Melting points were determined with a Meltemp II apparatus or a TA Instruments DSC 2920 Modulated DSC.

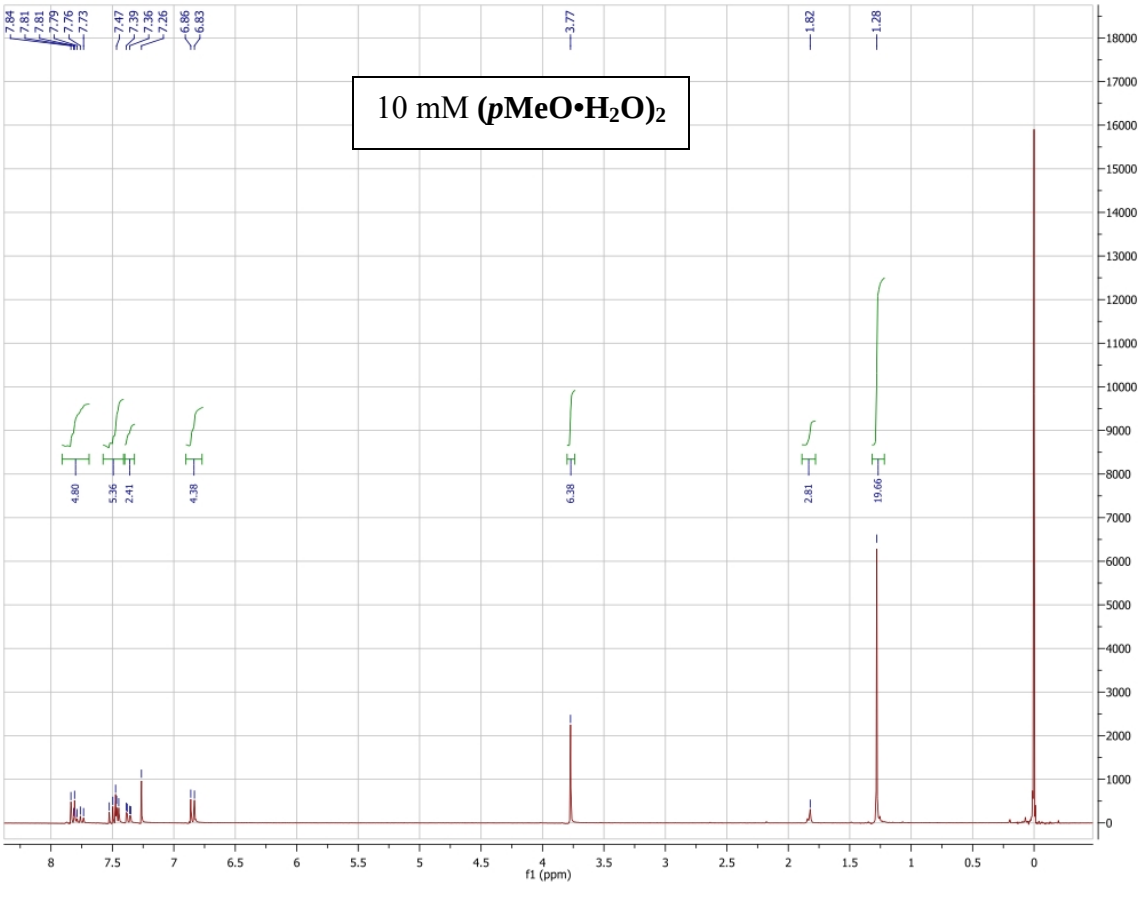
General Preparation of Sulfonamides. A solution of arene **3** (1 equiv) and sulfonyl chloride (5 equiv) in pyridine (8-15 mM) was stirred for 3 h under an N_2 environment. Following concentration in vacuo, the crude oil was filtered through a 2.5 cm silica plug and then chromatographed on silica gel.

$(1•H_2O)_2$. Arene **3** (150 mg, 0.36 mmol) was reacted with *p*-toluenesulfonyl chloride according to General Preparation for Sulfonamides (above). Purification by chromatography (1:1 hexanes:EtOAc) afforded **$(1•H_2O)_2$** (249 mg, 95%) as a pale yellow solid. Recrystallization by diffusion (hexanes:EtOAc) afforded colorless crystals. Mp: 133-135 °C. ^{1}H NMR (300 MHz, $CDCl_3$): δ 7.85-7.71 (m, 5H), 7.52-7.43 (m, 6H), 7.35 (dd, *J* = 8.5, 2.3 Hz, 2H), 7.15 (d, *J* = 8.5 Hz, 4H), 2.34 (s, 6H), 1.26 (s, 18H). ^{13}C NMR (75 MHz, $CDCl_3$): δ 147.53, 143.73, 142.85, 136.93, 136.49, 135.84, 129.54 (2C), 127.89, 127.25, 126.29, 120.52, 112.89, 93.20, 85.56, 34.29, 31.03, 21.45. UV-Vis (CH_2Cl_2): λ_{max} (ε) 234 (58,000), 287 (31,000), 330 (27,600) nm. Fluorescent emission ([**$(1•H_2O)_2$**] ≤ 0.057 mM in $CHCl_3$; 354 nm excitation): λ_{max} 388 nm. IR (neat): ν 3266, 2961, 2899, 2877, 2213, 1555, 1156 cm^{-1}. MS (CI pos) *m/z* (%): 732 (M^++2, 21), 731 (MH^+, 56), 730 (M^+, 100); $C_{43}H_{43}N_3O_4S_2$ (729.95).

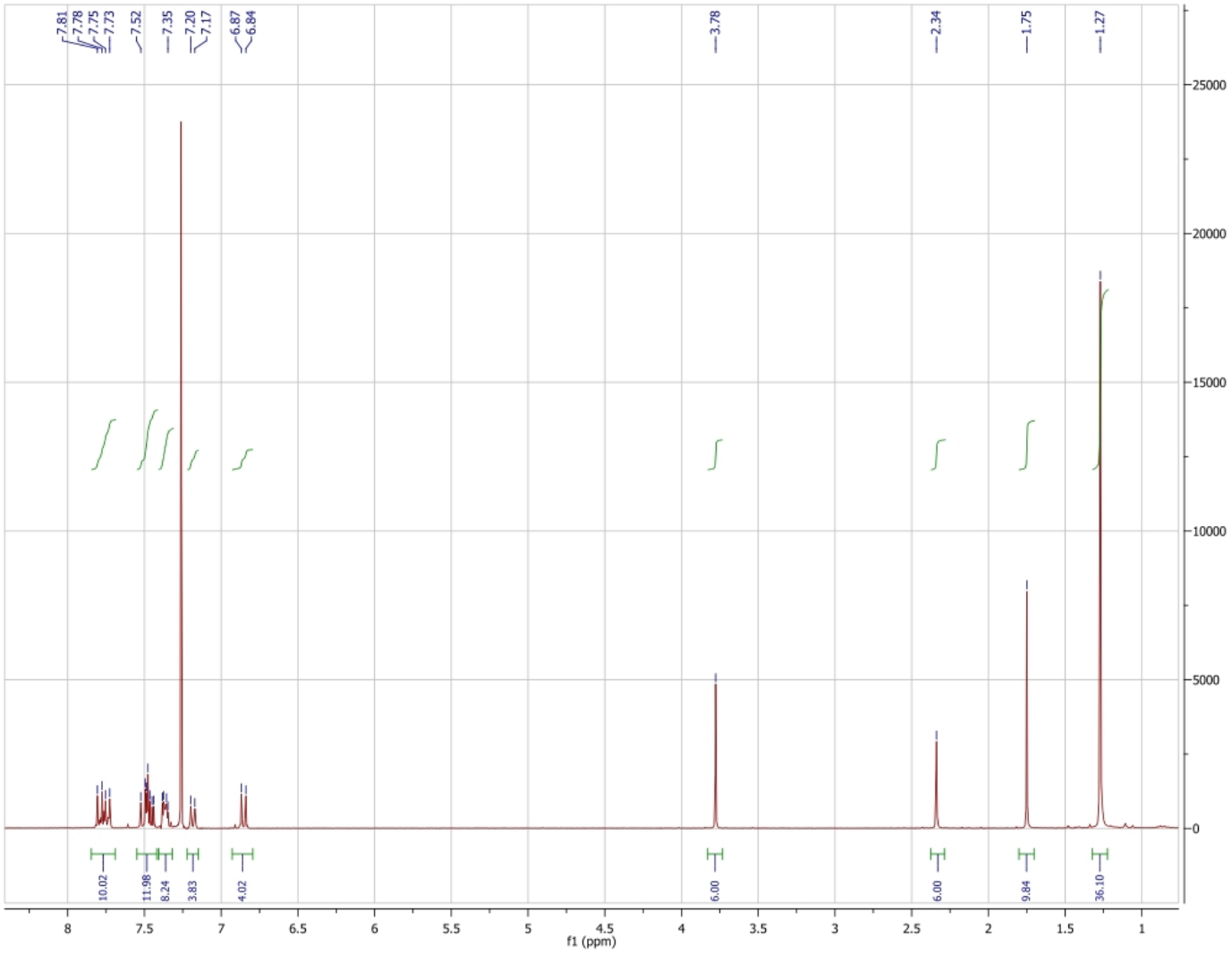


(2•H_2O)$_2$. Arene **3** (150 mg, 0.36 mmol) was reacted with *p*-nitrobenzenesulfonyl chloride according to General Preparation for Sulfonamides (above). Purification by chromatography (20:1 CH_2Cl_2:EtOAc) afforded **(2•H_2O)$_2$** (285 mg, 93%) as a pale yellow solid. Recrystallization by diffusion (pentane:$CHCl_3$ or hexanes:EtOAc) afforded pale yellow crystals. Mp: 136-139 °C. ^{1}H NMR (300 MHz, $CDCl_3$): δ 8.15 (d, J = 8.7 Hz, 4H), 8.03 (d, J = 8.7 Hz, 4H), 7.74 (t, J = 7.8 Hz, 1H), 7.55 (d, J = 8.7 Hz, 2H), 7.48-7.37 (m, 6H), 1.29 (s, 18H). ^{13}C NMR (75 MHz, $CDCl_3$): δ 150.10, 149.33, 145.32, 142.68, 137.20, 134.63, 129.82, 128.68, 128.28, 126.31, 124.12, 123.31, 114.59, 92.68, 85.71, 34.51, 31.05. UV-Vis (CH_2Cl_2): λ_{max} (ε) 242 (56,200), 285 (35,500), 319 (23,000) nm. Fluorescent emission ([**(2•H_2O)$_2$**] ≤ 0.057 mM in $CHCl_3$; 364 nm excitation): λ_{max} 428 nm. IR (neat): ν 3271, 2964, 2869, 2213, 1348, 1171 cm^{-1}. MS (CI pos) *m/z* (%): 794 (M^++2, 24), 793 (MH^+, 53), 792 (M^+, 100), 608 (17), 607 (44); $C_{41}H_{37}N_5O_8S_2$ (791.89).

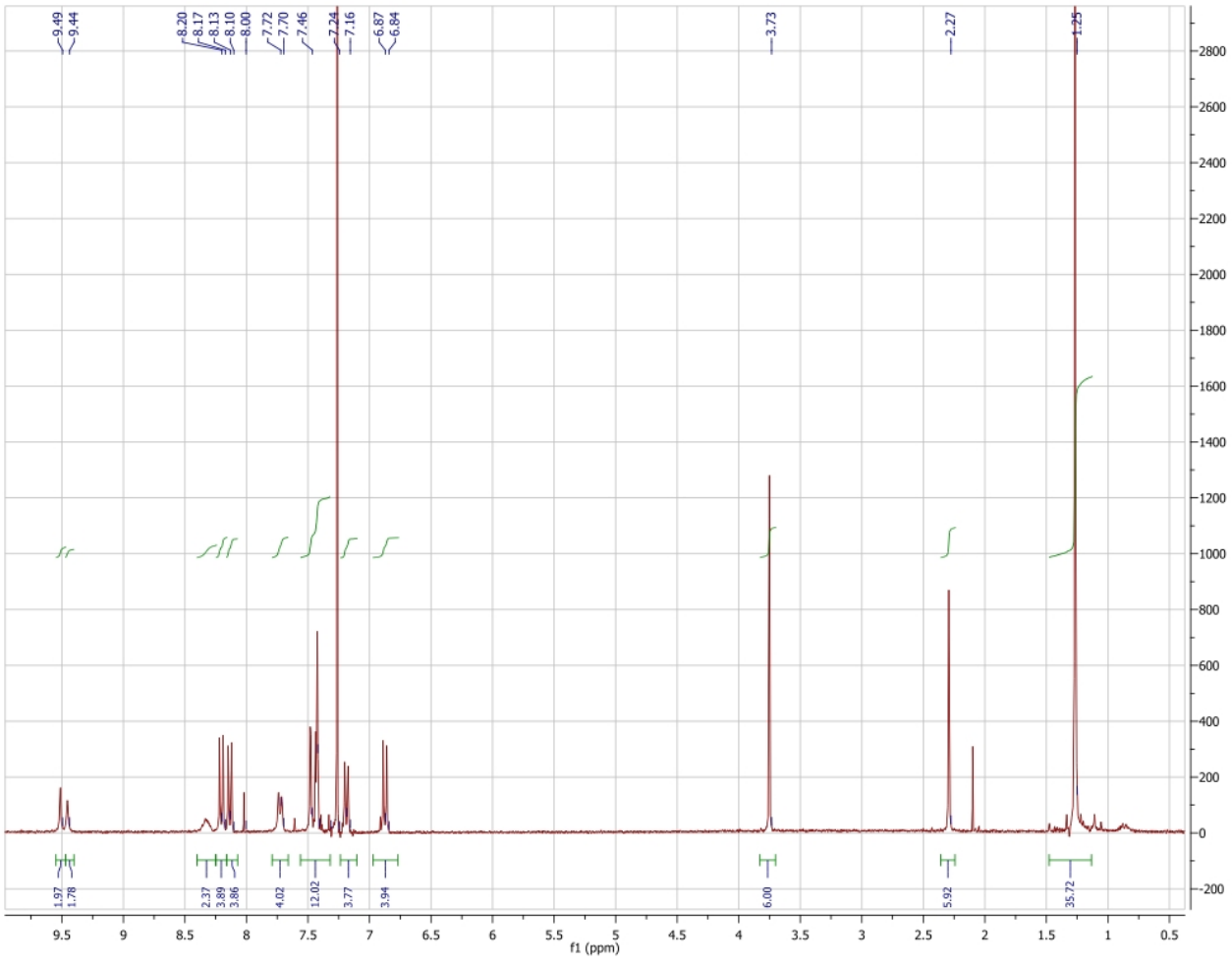
(*p*MeO•H_2O)$_2$. Arene **3** (110 mg, 0.26 mmol) was reacted with *p*-methoxybenzenesulfonyl chloride according to General Preparation for Sulfonamides (above). Purification by chromatography (20:1 CH_2Cl_2:EtOAc) afforded **(*p*MeO•H_2O)$_2$** (185 mg, 93%) as a white crystalline solid. Recrystallization by diffusion (hexanes:CH_2Cl_2) afforded colorless crystals. Mp: 141-143 °C. ^{1}H NMR (300 MHz, $CDCl_3$): δ 7.77 (d, J = 9 Hz, 4H), 7.76 (t, J = 9 Hz, 1H), 7.53-7.45 (m, 5H), 7.37 (dd, J = 9, 3 Hz, 2H), 6.84 (d, J = 9 Hz, 4H), 3.77 (s, 6H), 1.28 (s, 18H). ^{13}C NMR (75 MHz, $CDCl_3$): δ 163.06, 147.62, 142.93, 136.75, 135.70, 130.85, 129.60, 129.43, 127.85, 126.44, 120.64, 114.09, 113.02, 93.28, 85.33, 55.45, 34.31, 31.03. UV-Vis (CH_2Cl_2): λ_{max} (ε) 239 (71,700), 292 (30,200), 343 (23,000) nm. Fluorescent emission ([**(*p*MeO•H_2O)$_2$**] ≤ 0.05 mM in $CHCl_3$; 353 nm excitation): λ_{max} 389 nm. IR (neat): ν 3248, 2962, 2902, 2870, 2214, 1498, 1161 cm^{-1}. MS (CI pos) *m/z* (%): 764 (M^++2, 22), 763 (MH^+, 49), 762 (M^+, 100); $C_{43}H_{43}N_3O_6S_2$ (761.95).



[**1•H_2O**]•[***p*MeO•H_2O**]. **1•H_2O** (3.650 mg, 0.00488 mmol) and ***p*MeO•H_2O** (3.740 mg, 0.00480 mmol) were dissolved in seperate portions of $CDCl_3$ with 1 % TMS (1 mL) passed through basic alumina and dried with 3 Å molecular sieves. Aliquots (400 µL) from each solution were transfered to an NMR tube via syringe and thoroughly mixed. ^1H NMR spectra were recorded on a Varian 300 MHz spectrometer. Proton signals were referenced to the 1 % TMS included in the $CDCl_3$. ^1H NMR (300 MHz, $CDCl_3$): δ 7.81-7.73 (m, 10H), 7.52-7.44 (m, 12H), 7.38-7.33 (m, 8H), 7.18 (d, *J* = 9 Hz, 4H), 6.85 (d, *J* = 9 Hz, 6H), 7.18 (d, *J* = 6 Hz, 3H) 2.29 (s, 6H), 1.26 (s, 18H).

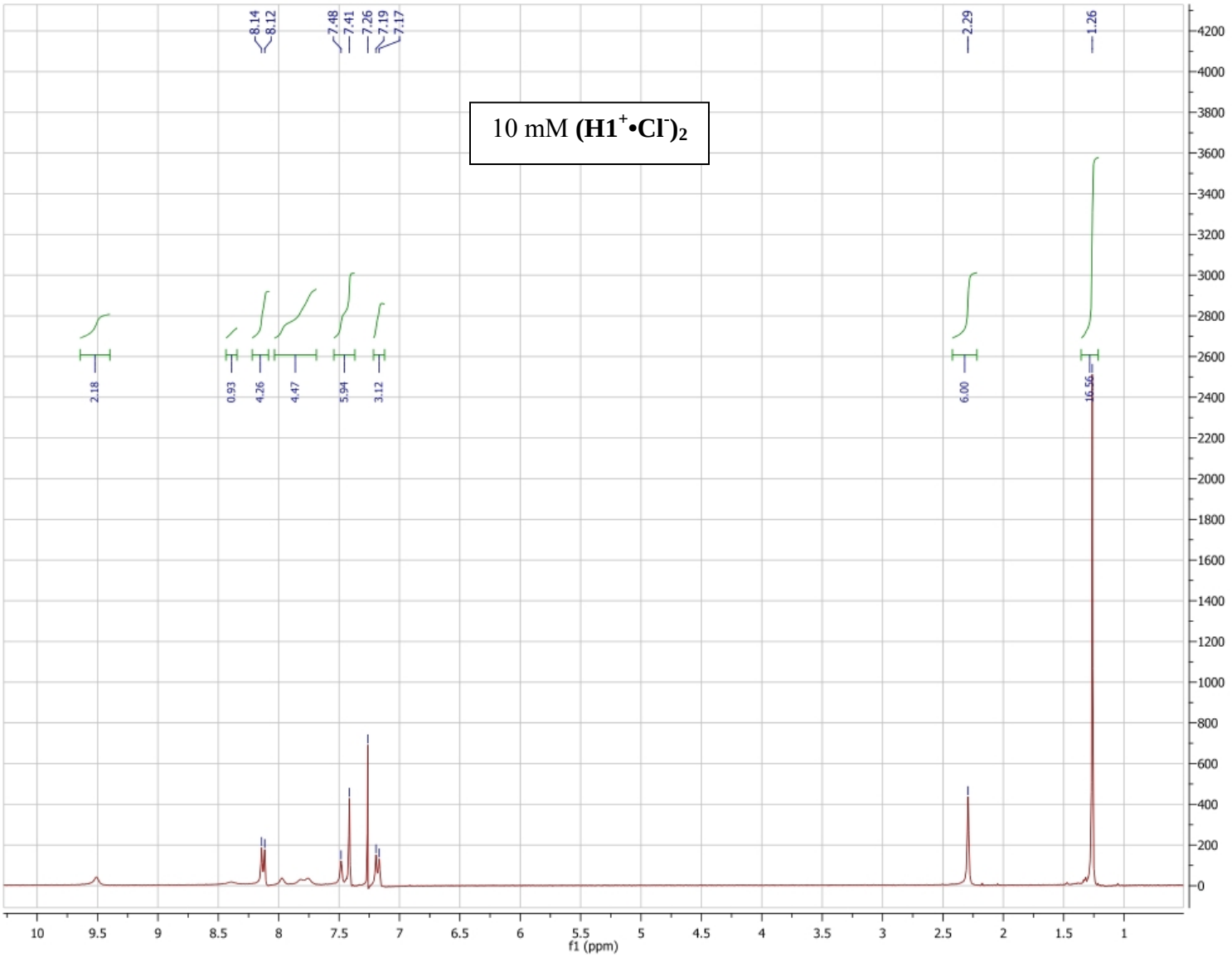


[**H1**$^{+}$**•Cl**$^{-}$]**•[H*p*MeO**$^{+}$**•Cl**$^{-}$]**.** The stock solutions from the preparation of [**1•H$_2$O**]**•[*p*MeO•H$_2$O**] (above) were combined and protonated with HCl gas (see below, **General salt preparation**). ^{1}H NMR spectra were recorded on a Varian 300 MHz spectrometer. Proton signals were referenced to the 1% TMS included in the $CDCl_3$. ^{1}H NMR (300 MHz, $CDCl_3$): δ 9.49 (s, 2H), 9.44 (s, 2H), 8.30 (b, 2H), 8.18 (d, *J* = 9 Hz, 4H), 8.12 (d, *J* = 9 Hz, 4H), 7.71 (d, *J* = 6 Hz, 4H) 7.46 (m, 12H), 7.17 (d, *J* = 6 Hz, 4 H), 6.85 (d, *J* = 6 Hz, 4H), 3.73 (s, 6H), 2.27 (s, 6H), 1.25 (s, 36H) .

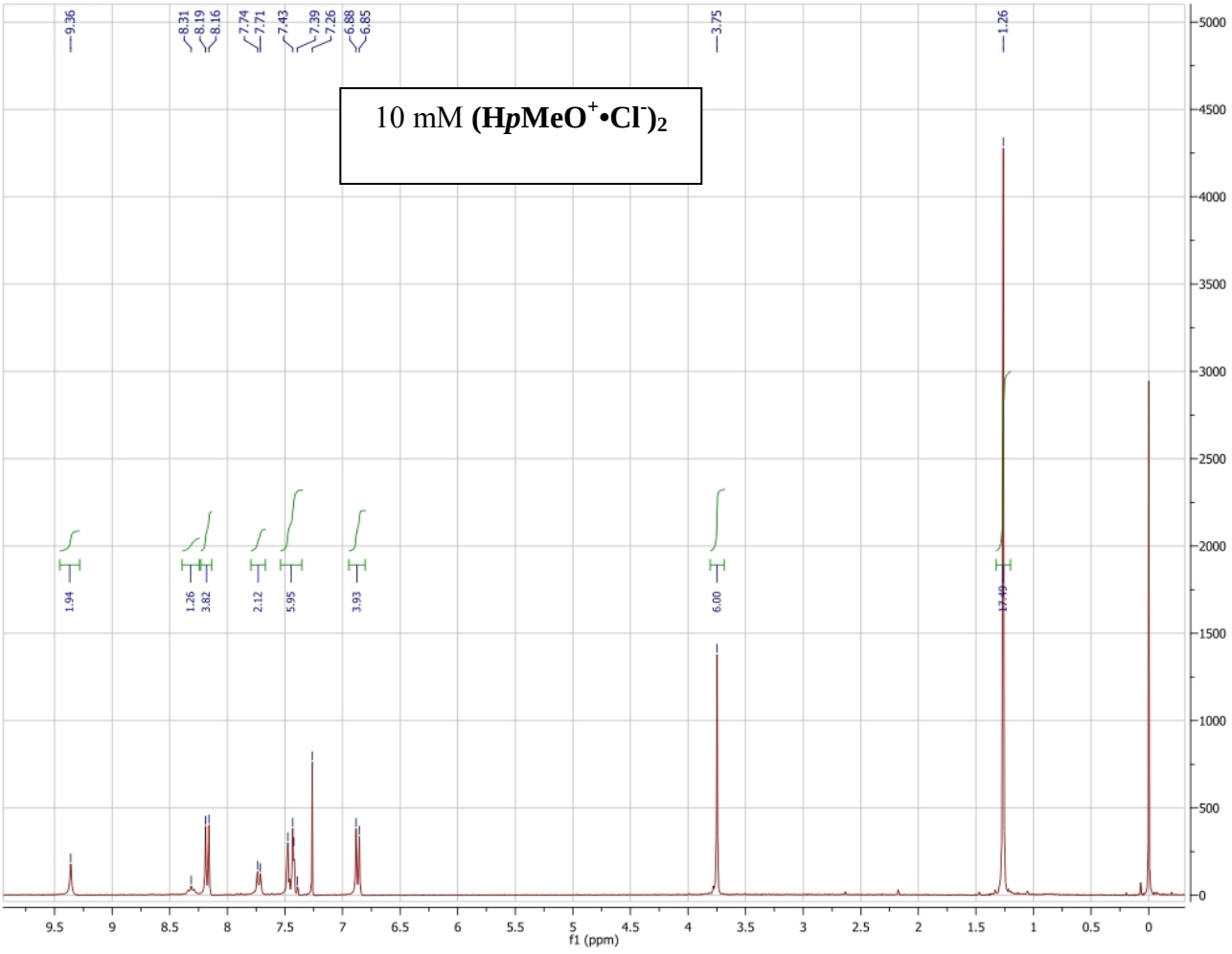


General salt preparation. A 10 mM stock solution of sulfonamide receptor dissolved in $CDCl_3$ with 1% TMS that had been passed through basic alumina and stored over 3 Å molecular seives was prepared. With a 9 inch pipet and 10 ml pipet bulb HCl gas is passed through the sulfonamide solution 20 times. The resulting bright yellow solution is diluted to the original volume and an appropriate aliqout is removed for study.

$(H1^+•Cl^-)_2$. 10 mM stock solutions of $(H1^+•Cl^-)_2$ were prepared according to the **General salt preparation** (above). ^{1}H NMR (300 MHz, $CDCl_3$): δ 9.51 (b, 2H), 8.40 (b, 1H), 8.13 (d, *J* = 6 Hz, 4H), 8.00-7.75 (b, 4H), 7.48-7.41 (m, 6H), 7.18 (d, *J* = 6 Hz, 3H) 2.29 (s, 6H), 1.26 (s, 18H).

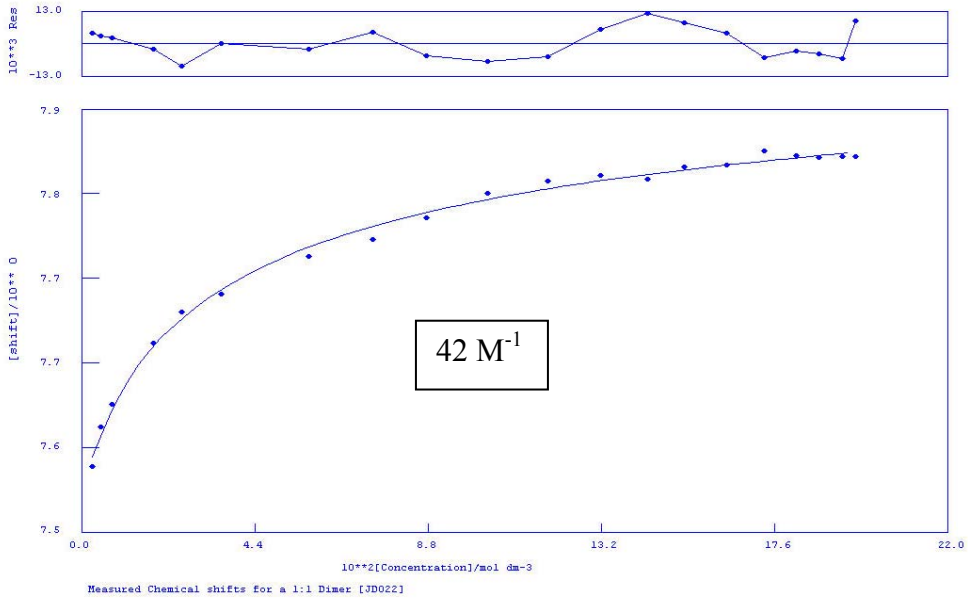


(H*p*MeO$^+$•Cl$^-$)$_2$. 10 mM stock solutions of (**H*p*MeO$^+$**•Cl$^-$)$_2$ were prepared according to the **General salt preparation** (above).^{1}H NMR (300 MHz, $CDCl_3$): δ 9.36 (b, 2H), 8.31 (t, 1H), 8.17 (d, *J* = 9 Hz, 4H), 7.72 (d, *J* = 9 Hz, 4H), 7.40 (m, 6H), 6.86 (d, *J* = 9 Hz, 4H) 3.75 (s, 6H), 1.26 (s, 18H).



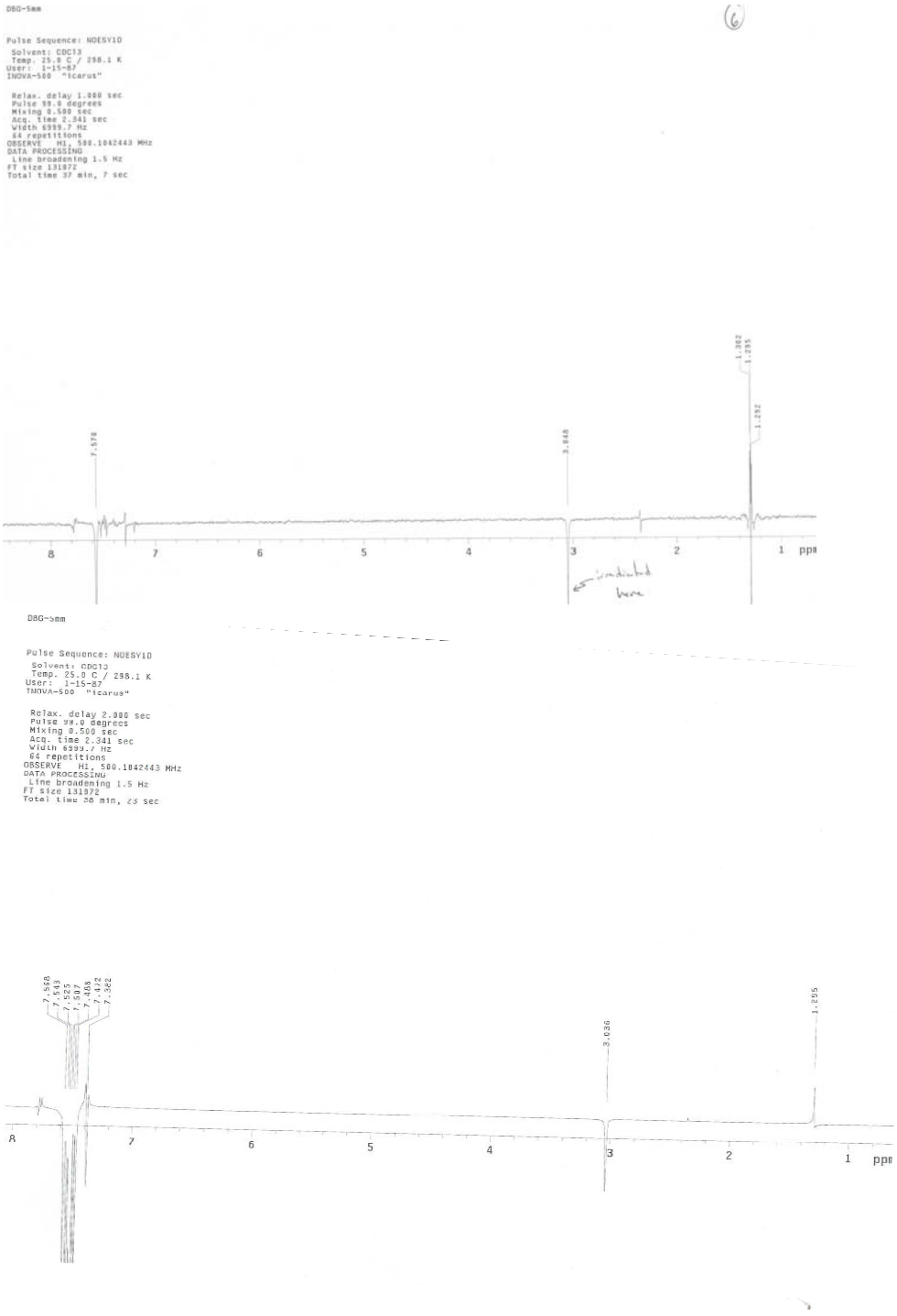
Dilution experiment.

(1•H_2O)$_2$ (88.260 mg, 0.180 mmol) was dissolved in $CDCl_3$ (600 µl) saturated with H_2O. $CDCl_3$ saturated with H_2O was prepared by mixing equal parts (v/v) $CDCl_3$ and H_2O for 30 minutes followed by separation of the two layers. Aliquots of $CDCl_3$ saturated with H_2O were added to the initial solution of receptor (197 mM) until the end point of the titration is reached (minimal change in chemical shift observed per per aliquot of $CDCl_3$). All additions were performed through septa with a Hamilton gas tight microsyringe at room temperature. ^{1}H NMR spectra were recorded after each addition on a Varian 300 MHz spectrometer. Proton signals were referenced to the residual $CHCl_3$ signal. The dimerization constant K_{dim} was calculated by plotting the change in the shift of the sulfonamide proton versus the total concentration and the resulting data was fit to a 1:1 dimerization with the non-linear regression curve fitting software WinEQNMR.



vol removed prior to addition	file	vol added (ml)	Vol prior to addition	Total vol in NMR tube after	[R]	NH peak
0	JD022_0	0	0	0.6	1.967E-01	7.855
0	JD022_1	0.01	0.6	0.61	1.934E-01	7.855
0	JD022_2	0.02	0.61	0.63	1.873E-01	7.854
0	JD022_3	0.02	0.63	0.65	1.815E-01	7.856
0	JD022_4	0.03	0.65	0.68	1.735E-01	7.86
0	JD022_5	0.04	0.68	0.72	1.639E-01	7.847
0	JD022_6	0.05	0.72	0.77	1.532E-01	7.845
0	JD022_7	0.05	0.77	0.82	1.439E-01	7.834
0	JD022_8	0.075	0.82	0.895	1.318E-01	7.837
0	JD022_9	0.1	0.895	0.995	1.186E-01	7.832
0	JD022_10	0.15	0.995	1.145	1.031E-01	7.82
0	JD022_11	0.2	1.145	1.345	8.773E-02	7.797
0	JD022_12	0.25	1.345	1.595	7.398E-02	7.777
0	JD022_13	0.45	1.595	2.045	5.770E-02	7.761
1.25	JD022_14	0.5	0.795	1.295	3.542E-02	7.725
0	JD022_15	0.5	1.295	1.795	2.556E-02	7.708
0	JD022_16	0.7	1.795	2.495	1.839E-02	7.679
1.75	JD022_17	1	0.745	1.745	7.850E-03	7.621
0	JD022_18	1	1.745	2.745	4.990E-03	7.599
1	JD022_19	1.3	1.745	3.045	2.860E-03	7.562

NOESY1D experiment. $(1•H_2O)_2$ (88.260 mg, 0.180 mmol) was dissolved in $CDCl_3$ (600 µl) saturated with H_2O. $CDCl_3$ saturated with H_2O was prepared by mixing equal parts (v/v) $CDCl_3$ and H_2O for 30 minutes followed by separation of the two layers. ^1H NMR spectra were recorded on a Varian 500 MHz spectrometer. Proton signals were referenced to the residual $CHCl_3$ signal. NOEs between the water and sulfonamide protons were observed by irradiating either the guest water protons (3.042 ppm) or the hydrogen bonding sulfonamide protons (7.570 ppm) and observing signal enhancement from the other protons.



Crystal growth conditions. Sulfonamide receptors were dissolved in a 10x75 mm test tube with EtOAc to a concentration > 10 mM (for halide salts HX gas was passed through the EtOAc solution of receptor). Alternatively, 1 drop of concentrated HX is added and the resulting yellow solution is thoroughly mixed). Hexanes cooled to 0^oC were layered on top of receptor solutions and set aside. After 3 days colorless (neutral receptor complex) or yellow (protonated receptor complex) single crystals were harvested for x-ray diffraction studies. Refer to cif files for exact structural details.

Single Crystal X-ray Diffraction Experimental: X-Ray diffraction data for $(\mathbf{1}\bullet H_2O)_2$, $(\mathbf{2}\bullet H_2O)_2$, $(\mathbf{H2}^+\bullet Cl^-)_2$, $(\mathbf{H1}^+Cl^-)\bullet(\mathbf{1}\bullet H_2O)$ and $(\mathbf{H1}^+\bullet Br^-)_2$ were collected on a Bruker SMART APEX diffractometer using MoK_α radiation (λ = 0.7107 Å). Data have been corrected for absorption using the SADABS v2.02 area-detector absorption correction program.[1] The structures were solved by direct methods and refined based on $|F|^2$. All non-hydrogen atoms were refined with anisotropic displacement parameters. Hydrogen atoms in the investigated structures were found from the residual density maps and refined with isotropic thermal parameters except those in terminal *t*-Bu groups in $(\mathbf{H2}^+\bullet Cl^-)_2$, $(\mathbf{H1}^+Cl^-)\bullet(\mathbf{1}\bullet H_2O)$ and $(\mathbf{H1}^+\bullet Br^-)_2$, which were placed in calculated positions and refined in a rigid group model with isotropic thermal parameters U(H) = 1.5Ueq (C). One of the H atoms at the bridging solvent molecule in $(\mathbf{1}\bullet H_2O)_2$ is disordered over two positions in a 1:1 ratio. Only one position for this H atom is shown in Fig. 1 for clarity. The O atoms of the bridging water molecule and the Cl atom in $(\mathbf{H1}^+\bullet Cl^-)\bullet(\mathbf{1}\bullet H_2O)$ are disordered over two positions corresponding to opposite orientations of the dimeric units. These O and Cl atoms were refined in the same positions with occupation factors μ=1/2. The H atoms attached to the O atom in the bridging water molecules were not found from the F-map. All calculations were performed with the SHELXTL v.6.1 program package.[2]

References:

[1] G. M. Sheldrick, *SADABS: Area Detector Absorption Correction*; University of Göttingen: Göttingen, Germany, 2001.
[2] G. M. Sheldrick, SHELXTL: Program Library for Structure Solution and Molecular Graphics, 5.10; Bruker AXS: Madison, WI, 2000).