Supporting Information:

Fluorescence "Turn–On" Sensing of Carboxylate Anions with Oligothiophene-based *o*-(Carboxamido)trifluoroacetophenones

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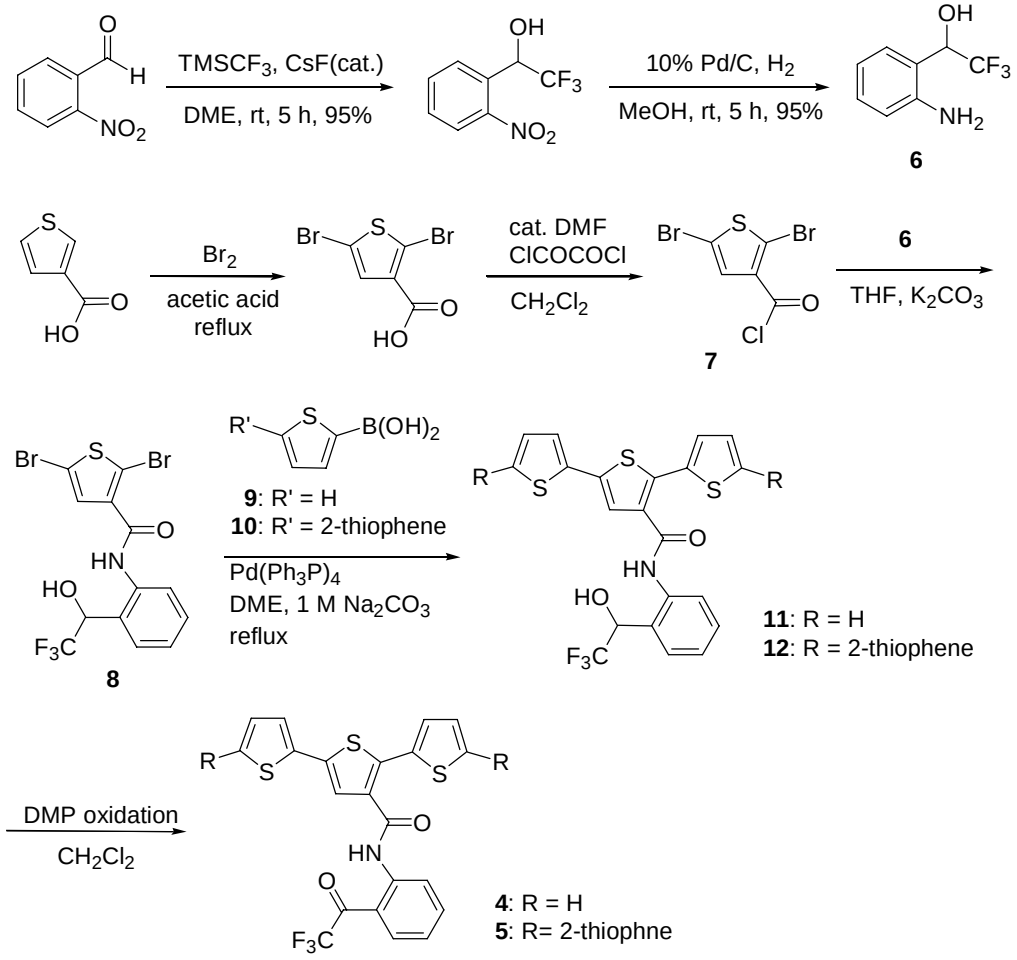
General Information.

All moisture or air sensitive experiments were performed under a positive pressure of argon and with flame dried glassware. Flash column chromatography was carried out using silica gel of 230-400 mesh size. Melting points were measured on a capillary melting point apparatus and were uncorrected. Chemical shifts for ^{1}H NMR were reported in parts per million downfield from tetramethylsilane (δ) as the internal standard. The following abbreviations were used for spin multiplicity: s = singlet, d = doublet, t= triplet, q = quartet, m = multiplet, br = broad. ^{19}F NMR spectra are reported using trifluoroacetic acid as an external reference. HRMS were performed by Korea Basic Science Center, Kyung-Pook National University, Korea.

Synthesis and characterization of the compounds 4 and 5.



1-(2-Aminophenyl)-2,2,2-trifluoroethanol (6).[1] To a stirred solution of the 2-nitrobenzaldehyde (151 mg, 1.0 mmol) and carefully dried cesium fluoride (*cat*.) in DME (5 mL) was added $TMSCF_3$ (2.0 M in THF, 0.06 mL, 1.2 mmol) at 0 °C under an argon atmosphere. After being stirred for 5 h at room temperature, the reaction mixture was treated with 10% *aq*. HCl (1 mL) and diluted with EtOAc (10 mL). An extractive workup with EtOAc and purification by column chromatography (Hexane: EtOAc, 4:1) afforded 2,2,2-trifluoro-1-(2-nitrophenyl)ethanol as a yellowish solid (210 mg, 95%) : ^{1}H NMR (300 MHz, $CDCl_3$) δ 8.0 (t, J = 7.8 Hz, 2H), 7.7 (t, J = 7.8 Hz, 1H), 7.6 (t, J = 7.5 Hz, 1H), 6.2 (q, J = 6.3 Hz, 1H), 4.1 (br s, 1H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 148.8, 134.5, 130.9, 130.0, 129.6, 126.4, 130.1, 126.4, 122.6, 118.9 (q, J = 280.8 Hz), 67.95, 67.52, 67.08 and 66.66 (q, J = 32.6 Hz); HRMS (EI) calc. for $C_8H_6F_3NO_3$ (M^+) 221.0300, found (*m*/*z*) 221.0296.

A solution of the nitro compound (221 mg, 1.0 mmol) in methanol (5 mL) was subjected to hydrogenolysis in the presence of 10 wt% Pd/C (25 mg) under hydrogen atmosphere (about 1 atm) at room temperature for 5 h. The reaction mixture was filtered through Celite and the filtrate was concentrated to give aniline **6** as a white solid (181 mg, 95%): ^{1}H NMR (300 MHz, $CDCl_3$ + CD_3OD) δ 7.2 (d, J = 7.8 Hz, 1H), 7.2 (t, J = 7.8 Hz, 1H), 6.8 (t, J = 7.5 Hz, 1H), 6.7 (d, J = 8.1 Hz, 1H), 5.1 (q, J = 7.5 Hz, 1H) and 3.7 (br, 2H); HRMS (EI^+) calc. for $C_8H_8F_3NO$ (M^+) 191.0558, found (*m*/*z*) 191.0550.

2,5-Dibromo-*N*-(2-(2,2,2-trifluoro-1-hydroxyethyl)phenyl)thiophene-3-carboxamide (8). Thiophene-3-carboxylic acid (2.56 g, 0.02 mol) and 50 mL of glacial acetic acid were put into a 100 mL three-necked flask equipped with a stirring bar, a condenser, and an addition funnel. To the mixture was added Br_2 (5.3 mL, 0.10 mol) dropwise at room temperature, and the resulting mixture was warmed to 60 °C and stirred for 8 h. After the reaction was complete, the mixture was poured into ice-cold water (200 mL) and treated with Na_2SO_3 to decompose the excess bromine. The reaction mixture was filtered to give a light yellow solid. This crude product was recrystallized from EtOH-H_2O (1:2; 600 mL) to give 2,5-dibromothiophene-3-carboxylic acid[2] as white solid (4.8 g, 84%): mp 177–179 °C; ^{1}H NMR: δ 10.88 (s), 7.41 (s); ^{13}C NMR: δ 165.3, 132.0, 130.8, 121.4, 111.7. Anal. calcd

for $C_5H_2O_2Br_2S$: C**,** 21.00; H, 0.71. Found: C, 21.20; H, 0.43.

2,5-Dibromothiophene-3-carboxylic acid (2.82 g, 9.9 mmol) was dissolved in dry CH_2Cl_2 (32 mL) and oxalyl chloride (0.72 mL, 19.7 mmol) was added, and the resulting mixture was stirred at room temperature for 12 h. The solvent was removed under reduced pressure, and the residue was dried under vacuum to give 2,5-dibromothiophene-3-carbonyl chloride **7**. To a solution of acid chloride **7** (1.88 g, 9.8 mmol) in dry THF (32 mL) was added K_2CO_3 (2.7 g, 19.6 mmol) followed by aniline **6** (3.0 g, 9.9 mmol) under an argon atmosphere, and the resulting mixture was stirred further for 6 h. The reaction mixture was concentrated under reduced pressure, and the residue was partitioned between CH_2Cl_2 (20 mL) and 10% aqueous HCl (20 mL). The organic layer was separated successively and dried over Na_2SO_4 and concentrated under reduced pressure to give a crude product, which was purified by column chromatography (Hexane/EtOAc = 4/1) to afford amide **8** as a white solid (2.9 g, 62 %): R_f = 0.31 (Hexane/EtOAc = 4/1); mp 153 °C; ^{1}H NMR (300 MHz, $CDCl_3$) δ 8.94 (s, 1H), 8.0 (d, J = 9.0 Hz, 1H), 7.38–7.47 (m, 2H), 7.21–7.27 (m, 2H), 5.18–5.22 (m, 1H), 3.72 (d, J = 3Hz, 1H); ^{13}C NMR (75 MHz, $CDCl_3$ + 4 drop of DMSO-d_6) δ 159.4, 137.4, 136.8, 130.3, 130.3, 130.0, 124.7, 124.5, 123.8, 123.7, 123.6, 123.5 (q, J = 7.5 Hz (coupled with –F), aromatic-C), 114.2, 112.1 130.6, 126.9, 123.1, 119.4 (q, J = 277.5 Hz (coupled with –F), –$\underline{C}F_3$), 73.5, 73.1, 72.6, 72.2 (q, J = 30.0Hz (coupled with –F), –$\underline{C}$(OH)CF_3); ^{19}F NMR (300 MHz, $CDCl_3$) δ –0.90, –0.93 (–C(OH)$C\underline{F}_3$); HRMS (FAB) calcd. for $C_{13}H_8Br_2F_3NO_2S$ (M+H) 457.8673, found 457.8672.

2-Thienylboronic acid (9).[3] A solution of thiophene (9.51 mL, 10.0 g, 0.119 mol) in dry THF (120 mL) cooled at –78 °C was treated dropwise with *n*-BuLi (95 mL, 1.24 mol/L, 0.118 mol). The reaction mixture was stirred at –78 °C for 30 min and then allowed to warm to –20 °C slowly. This 2-thienyllithium was again cooled to –78 °C and transferred by cannula into a solution of trisosopropylborate (38.0 mL, 31.0 g, 0.165 mol) in dry THF (80 mL) at –78 °C. The reaction mixture was stirred at –78 °C for 1 h before warming to room temperature. The mixture was then treated with 1 M aqueous HCl (200 mL) and the organic layer separated. The aqueous layer was then extracted with dichloromethane (5 ×

120 mL), and the combined organic layers were dried ($MgSO_4$) and concentrated under reduced pressure to afford a white solid. Recrystallized of the white solid from water gave thiopheneboronic acid **9** as a pure white solid (11.9 g, 78%): mp 125–127 °C.

2,2'-Bithiophene-5-boronic acid (10).[5] A solution of *n*-butyllithium (28 mL, 1.6 M in hexane, 45 mmol) was added dropwise to a stirred, cooled solution of bisthiophene (7.00 g, 42 mmol) in dry THF (200 mL) at –78 °C under nitrogen. The reaction mixture was stirred at the same temperature for 1 h and was treated with a solution of trimethylborate (10 g, 100 mmol) in dry THF (50 mL). The resulting mixture was allowed to attain room temperature and left overnight. 10% hydrochloric acid (300 mL) was added to the mixture, and the product was extracted with diethyl ether (2 × 50 mL). The combined organic layers were washed with water, dried over $MgSO_4$, filtered, and concentrated in vacuo. The crude product was purified by column chromatography on silica gel (gradient elution: dichloromethane → ethyl acetate) to give a colorless solid in 73% yield (6.40 g): mp: 92–95 °C. ^{1}H NMR ($CDCl_3$): δ 7.05 (dd, J = 2.5 Hz, 2.5 Hz, 1H), 7.26–7.32 (m, 3H), 7.58 (d, J = 2.5 Hz, 1H). MS (m/z): 210 (M^+).

***N*-(2-(2,2,2-Trifluoro-1-hydroxyethyl)phenyl)-2,5-di(thiophen-2-yl)thiophene-3-carboxamide (11).** To a solution of dibromothiophene **8 (**627 mg, 1.4 mmol) and $Pd(PPh_3)_4$ (94 mg, 0.08 mmol, 6 mol%) in DME (14 mL) were added (2-thiophene)boronic acid (**9**) (420 mg, 3.3 mmol) and an aqueous Na_2CO_3 solution (1.0 M, 10.0 mL), and the resulting mixture was heated under reflux for 5 h. The reaction mixture was concentrated and then diluted with dichloromethane (20 mL) and separated. The organic residue was washed with water (2 × 20 mL), dried (Na_2SO_4), and concentrated in vacuo to give a yellowish solid. Purification by column chromatography (Hexane/EtOAc = 4/1), followed by recrystallization from diethyl ether gave alcohol **11** as a bright yellow solid (536 mg, 84%): R_f = 0.23 (Hexane/EtOAc = 4/1); mp 165 °C; ^{1}H NMR (300 MHz, $CDCl_3$) δ 8.39 (s, 1H), 7.88 (d, J = 6.0 Hz, 1H), 7.39–7.47 (m, 5H) , 7.21-7.30 (m, 3H), 7.04–7.10 (m, 1H), 7.10–7.11 (m, 1H), 4.92–4.95 (m, 1H), 3.36 (s, 1H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 162.3,

136.6, 135.9, 135.6, 135.2, 133.2, 132.5, 129.6, 128.8, 128.4, 127.7, 127.6, 127.4, 125.1, 125.0, 124.2, 124.1, 123.7, 129.2, 125.8, 122.0, 118.3 [q, J = 285.0 Hz (coupled with –F), –$\underline{C}F_3$], 71.9, 71.5, 71.1, 70.6 [q, J = 30.0Hz (coupled with –F), –$\underline{C}(OH)CF_3$]; ^{19}F NMR (300 MHz, $CDCl_3$) δ –0.91, –0.94 (–C(OH)C$\underline{F}_3$); HRMS (FAB): calcd. for $C_{21}H_{14}F_3NO_2S_3$ (M + H) 466.0217, found 466.0221.

***N*-(2-(2,2,2-Trifluoro-1-hydroxyethyl)phenyl)-2,5-di(bithiophen-2-yl)thiophene-3-carboxamide (12).** Coupling dibromothiophene **8** with (bithiophene)boronic acid **10** according to the Suzuki-Miyaura coupling procedure described above afforded alcohol **12** as a reddish brown solid in 81% yield: R_f = 0.20 (Hexane/EtOAc = 4/1); ^{1}H NMR (300 MHz, $CDCl_3$) δ 8.66 (d, J = 18 Hz, 1H), 7.98 (d, J = 6.0 Hz, 1H), 7.00–7.51 (m, 14H), 4.96–5.04 (m, 1H), 3.44 (d, J = 36 Hz, 1H); ^{19}F NMR(300 MHz, $CDCl_3$) δ –1.10, –1.02 (–C (OH)C$\underline{F}_3$); HRMS (EI) calcd. for $C_{29}H_{18}F_3NO_2S_5$ (M^+) 628.9893, found (*m*/*z*) 628.9889.

***N*-(2-(2,2,2-Trifluoroacetyl)phenyl)-2,5-di(thiophen-2-yl)thiophene-3-carboxamide (4).** To a stirred solution of Dess-Martin periodinane[4] (1.272 g, 3 mmol) in dry dichloromethane (10 mL) was added a solution of alcohol **11** (424 mg, 1mmol) in dichloromethane (3 mL), and the resulting mixture was stirred at room temperature for 12 h. The reaction mixture was diluted with ethyl acetate (20 mL) and poured into a solution of sodium thiosulfate (10 mL, 0.26 M) dissolved in a saturated aqueous sodium bicarbonate solution. Extractive workup with ethyl acetate and purification by column chromatography (Hexane/EtOAc = 4/1) afforded terthiophene sensor **4** (242 mg, 57%) as a yellowish solid: R_f = 0.5 (Hexane/EtOAc = 4/1); mp 111 °C ;^{1}H NMR (300 MHz, $CDCl_3$) δ 11.19 (s, 1H), 8.95 (d, J = 6.0 Hz, 1H), 7.94–7.91 (m, 1H), 7.71 (td, J = 15.9, 1.2Hz, 1H), 7.48 (s, 1H), 7.36–7.35 (m, 2H), 7.29–7.17 (m, 3H), 7.06–7.00 (m, 2H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 183.82, 183.36, 182.90, 182.44 [q, J = 34.5Hz (coupled with –F), –$\underline{C}OCF_3$], 163.2, 143.7, 138.3, 138.2, 137.6, 136.3, 134.0, 133.7, 132.45, 132.39, 132.34, 132.29 [q, J = 3.75Hz (coupled with –F), aromatic-C], 129.7, 128.7, 128.3, 126.2, 125.4, 125.0, 123.6, 122.8, 122.1, 116.3, 122.8, 119.0, 115.1, 111.3 [q, J = 292.5Hz (coupled with –F), –$\underline{C}F_3$]; ^{19}F NMR (300 MHz,

$CDCl_3$) δ 6.51 (–COC<u>F</u>$_3$); HRMS (FAB) calcd. for $C_{21}H_{12}F_3NO_2S_3$ (M+H) 464.0061, found 464.0063.

***N*-(2-(2,2,2-Trifluoroacetyl)phenyl)-2,5-di(thiophen-2-yl)thiophene-3-carboxamide (5).** A reddish brown solid was obtained in 52 % yield after recrystalization (Hexane/EtOAc = 9/1) by following the oxidation procedure as above. mp 171 °C (decompose); ^{1}H NMR (300 MHz, $CDCl_3$) δ 11.34 (s, 1H), 8.96 (d, J = 9.0 Hz, 1H), 7.97 (d, J = 9.0 Hz, 1H), 7.75 (t, J = 6 Hz, 1H) , 7.48 (s, 1H), 6.91–7.40 (m, 11H); ^{13}C NMR (75 MHz, $CDCl_3$); δ <u>184.15, 183.70, 183.24, 182.79</u> [q, J = 34.5 Hz (coupled with –F), -<u>C</u>OCF$_3$], 163.3, 143.8, 140.7, 138.5, 138.3, 137.4, 137.3, 137.1, 134.9, 133.7, <u>132.63, 132.57, 132.52, 132.47</u> [q, J = 3.75 Hz (coupled with –F), aromatic-C], 130.4, 128.7, 128.6, 126.1, 125.8, 125.6, 125.2, 125.0, 124.9, 124.8, 124.7, 123.7, 122.2, 116.4, <u>122.5, 119.0, 115.2, 111.3</u> [q, J = 285 Hz (coupled with –F), –<u>C</u>F$_3$]; ^{19}F NMR (300 MHz, $CDCl_3$) δ 6.55 (-COC<u>F</u>$_3$); HRMS (FAB): calcd. for $C_{29}H_{16}F_3NO_2S_5$ (M+H) 627.9815, found 627.9812.

References

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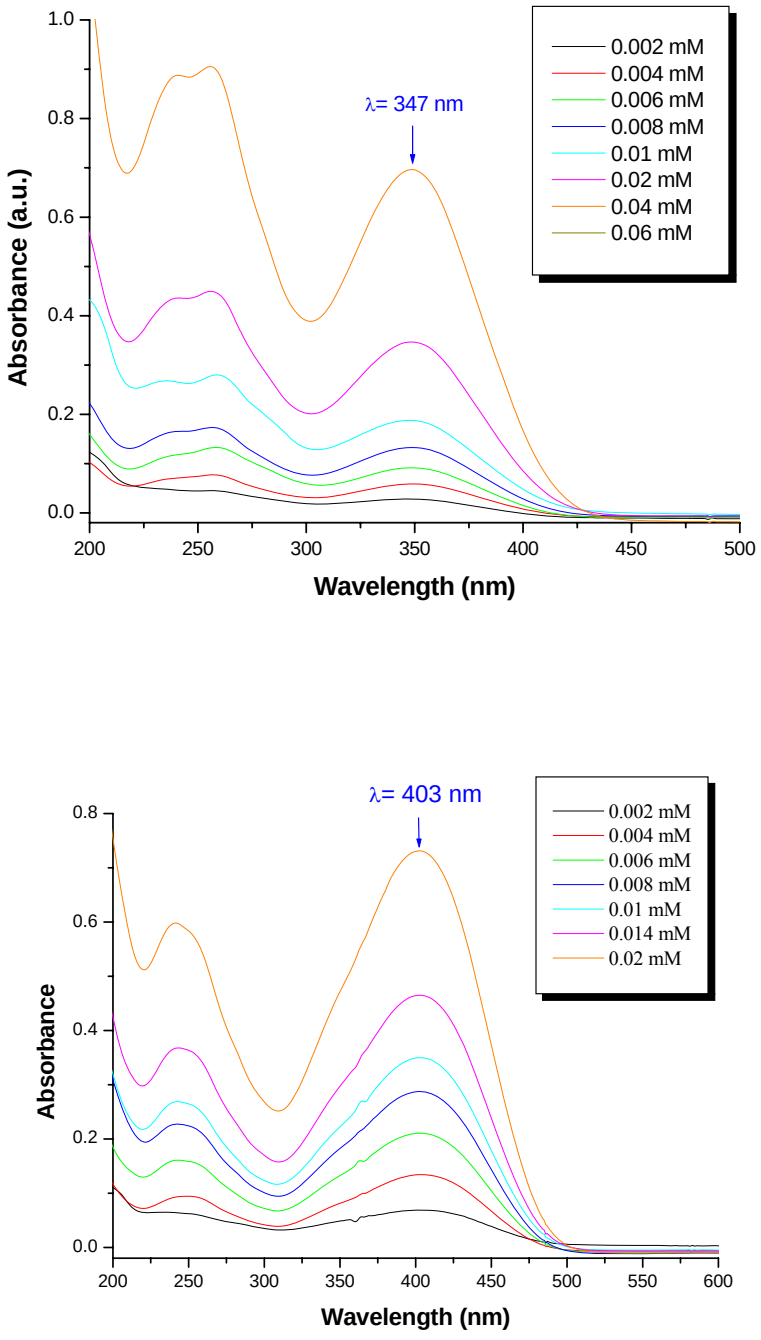


Figure S1. UV absorption spectrum of **4** (upper) and **5** (lower) in CH_3CN.

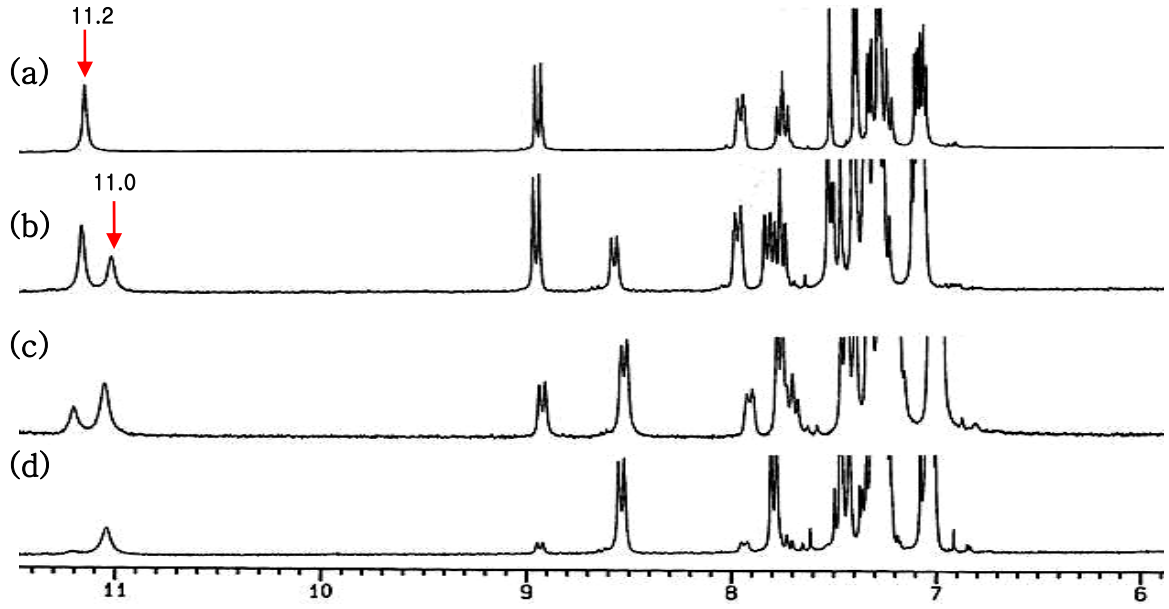


Figure S2. ^{1}H NMR spectra of (a) sensor **4** and its acetate mixtures: (b) 1.0 equiv, (c) 2.0 equiv, (d) 4.0 equiv of AcO^{-} (as Bu_4N^{+}-salt); taken in $CDCl_3$ at 25 °C. (Only NH and aromatic protons are shown).

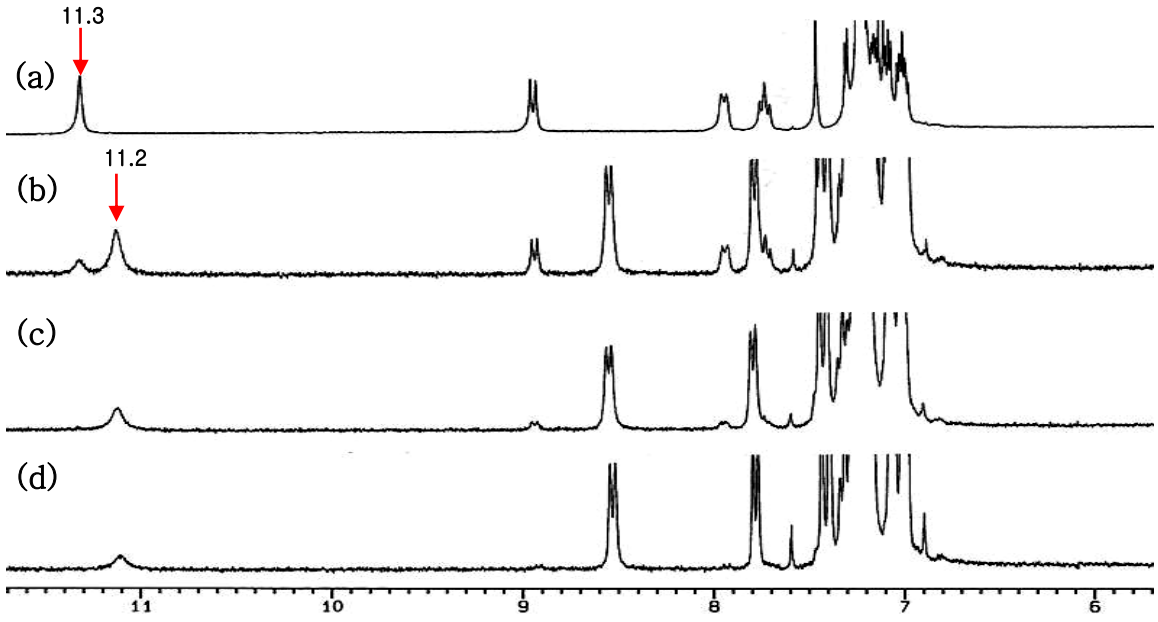


Figure S3. ^{1}H NMR spectra of (a) sensor **5** and its acetate mixtures: (b) 1.0 equiv, (c) 2.0 equiv, (d) 4.0 equiv of AcO^{-} (as Bu_4N^{+}-salt); taken in $CDCl_3$ at 25 °C. (Only NH and aromatic protons are shown).

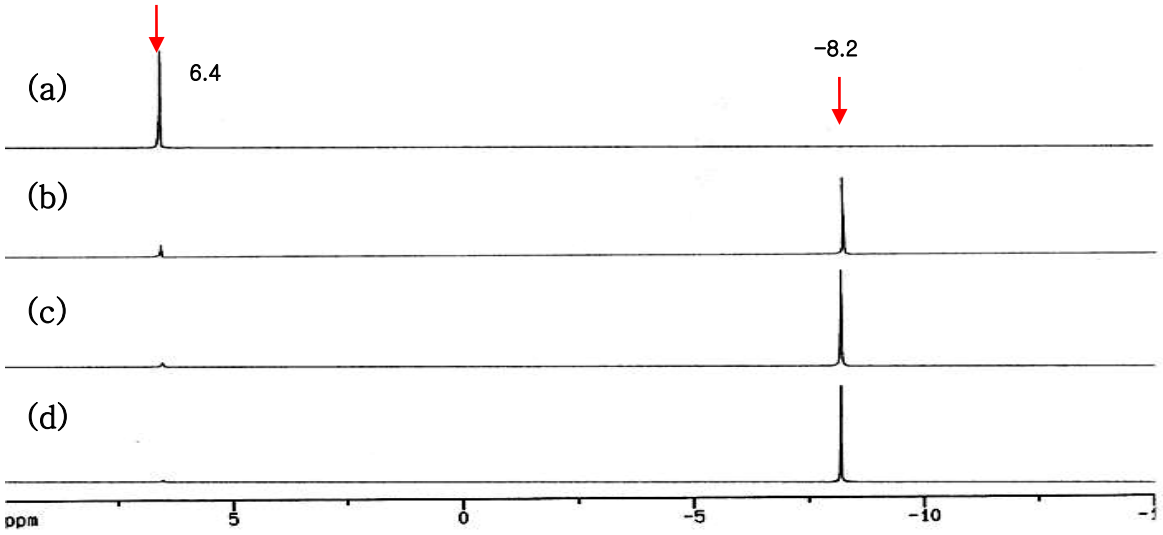


Figure S4. ^{19}F NMR spectra of (a) sensor **5** and its acetate mixtures: (b) 1.0 equiv, (c) 2.0 equiv, (d) 4.0 equiv of AcO^- (as Bu_4N^+-salt); taken in $CDCl_3$ at 25 °C.

Fluorescence titration experiments. Fluorescence titrations were carried out in 10 mm quartz cuvette at 25 ºC. Stock solutions of hosts and guests were prepared in acetonitrile. Test solutions were obtained by adding an appropriate aliquot of the stock solutions and diluting to 3 mL in the cuvette. Both excitation and emission slit widths were of 4 nm, respectively.

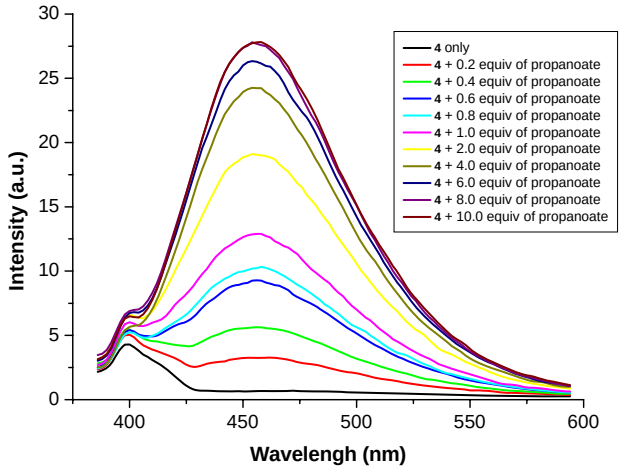


Figure S5. (a) Fluorescence titration of **4** (8.0 μM) with increasing amounts of propanoate.

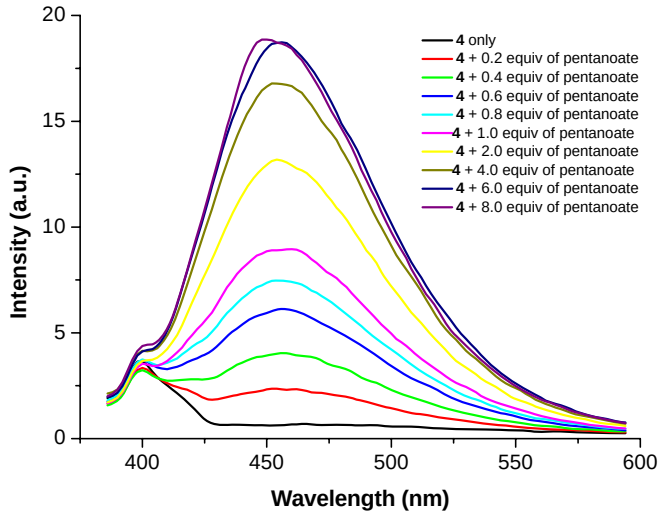


Figure S6. (a) Fluorescence titration of **4** (8.0 μM) with increasing amounts of pentanoate.

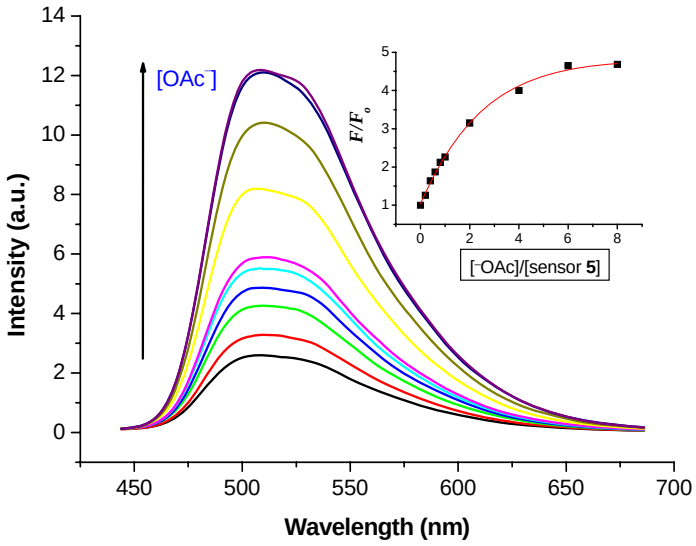


Figure S7. (a) Fluorescence titration of sensor **5** (4.0 μM) with increasing amounts of acetate ion. Inset: dependence of fluorescence intensity (F/F_o) with respect to [¯OAc]/[**5**].

Determination of the quantum yields. The quantum yields were determined by using quinine sulfate (1.0 *N* in sulfuric acid, 50 μM) as a fluorescence standard. The quantum yield of the unknown, Φ, is given by, $\Phi = \Phi_R\ (I/I_R)(OD_R/OD)(n^2/n_R^2)$, where I is the integrated fluorescence intensity, OD is the absorbance of a sample at the excitation wavelength, and n is the refractive index of solvent. The subscript R refers to the reference fluorophore, quinine sulfate in our case, of known quantum yield. The data obtained is summarized in the following Table 1 and Table 2.

Table 1. Quantum yields of acetate–**4** mixtures.

	OD	n	n^2	Φ
Quinine sulfate	0.071	1.333	1.777	0.550
4	0.114	1.342	1.801	0.0003
4 + 0.2 equiv	0.124	1.342	1.801	0.0009
4 + 0.4 equiv	0.129	1.342	1.801	0.0016
4 + 0.6 equiv	0.115	1.342	1.801	0.0023
4 + 0.8 equiv	0.132	1.342	1.801	0.0026
4 + 1.0 equiv	0.113	1.342	1.801	0.0036
4 + 2.0 equiv	0.107	1.342	1.801	0.0057
4 + 4.0 equiv	0.108	1.342	1.801	0.0071
4 + 6.0 equiv	0.106	1.342	1.801	0.0082
4 + 8.0 equiv	0.106	1.342	1.801	0.0081

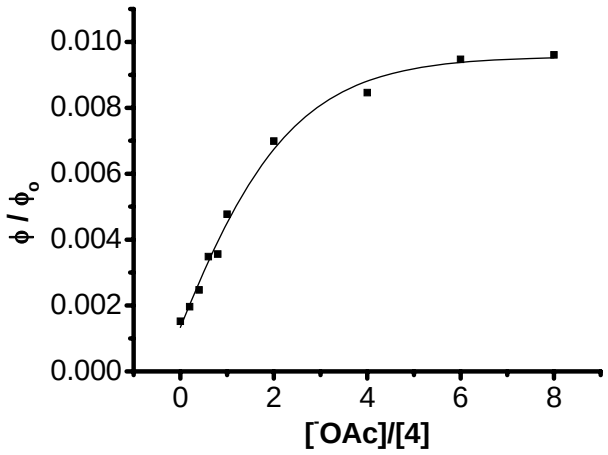


Figure S8. A plot of the relative quantum yield of a mixture of **4** and acetate over that of **4**, with respect to the molar ratio of acetate over **4**.

Table 2. Quantum yields of acetate–**5** mixtures.

	OD	n	n^2	Φ
Quinine sulfate	0.03862	1.333	1.777	0.550
5	0.06804	1.342	1.801	0.00454
5 + 0.2 equiv	0.0615	1.342	1.801	0.01318
5 + 0.4 equiv	0.06065	1.342	1.801	0.01607
5 + 0.6 equiv	0.0573	1.342	1.801	0.02371
5 + 0.8 equiv	0.06107	1.342	1.801	0.02653
5 + 1.0 equiv	0.06378	1.342	1.801	0.02902
5 + 2.0 equiv	0.07072	1.342	1.801	0.03612
5 + 4.0 equiv	0.05137	1.342	1.801	0.06207
5 + 6.0 equiv	0.05348	1.342	1.801	0.06727
5 + 8.0 equiv	0.04787	1.342	1.801	0.07961

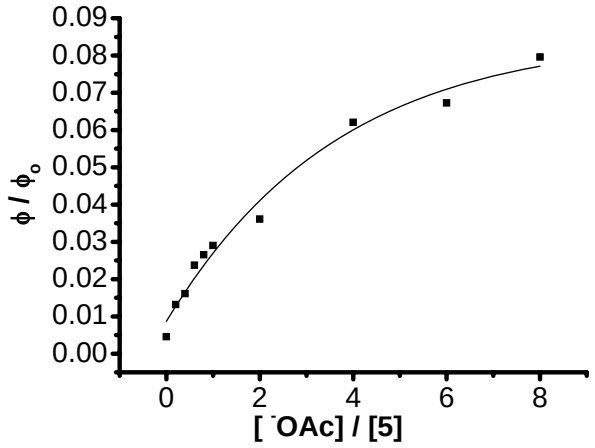


Figure S9. A plot of the relative quantum yield of a mixture of **5** and acetate over that of **5**, with respect to the molar ratio of acetate over **5**.

The isothermal titration calorimetry (ITC) analysis. The binding affinity and thermodynamic data were determined by ITC, using an isothermal titration calorimeter (MicroCal, Inc.).

A typical procedure: A solution of sensor **4** or **5** in acetonitrile (0.2 mM, 1.5 mL) was filled into the calorimetry cell. To this cell at operating temperature of 303 K was introduced 5.0 μL of an anionic analyte (3.0 mM) at each injection, in total 40 times. The Heat evolution at each titration was measured and expressed as "raw data" in terms of μcal/second plotted against time in minutes. Integration of the raw data in terms of kcal/mole of injection plotted against molar ratio, and analysis of this titration data by a nonlinear least squares curve fitting program (Orgin 7.0™) implemented with the instrument gave the binding stoichiometry, apparent binding affinity K_{ass}, and standard enthalpy change ΔH^{o}. In all titrations, the dilution of the analyte solution in neat solvent was corrected by running separate titration for each analyte, the result of which was subtracted from the raw titration data to produce the titration curve.

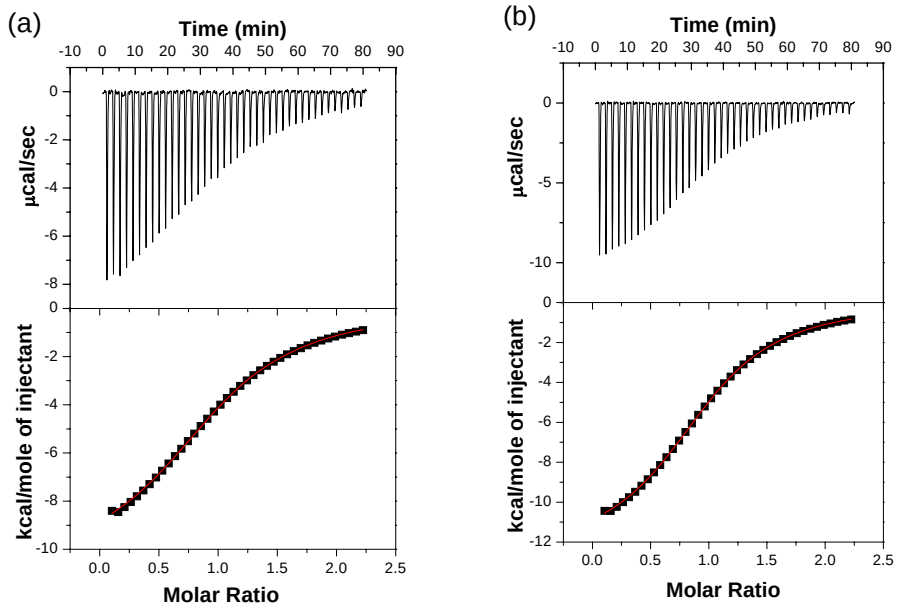
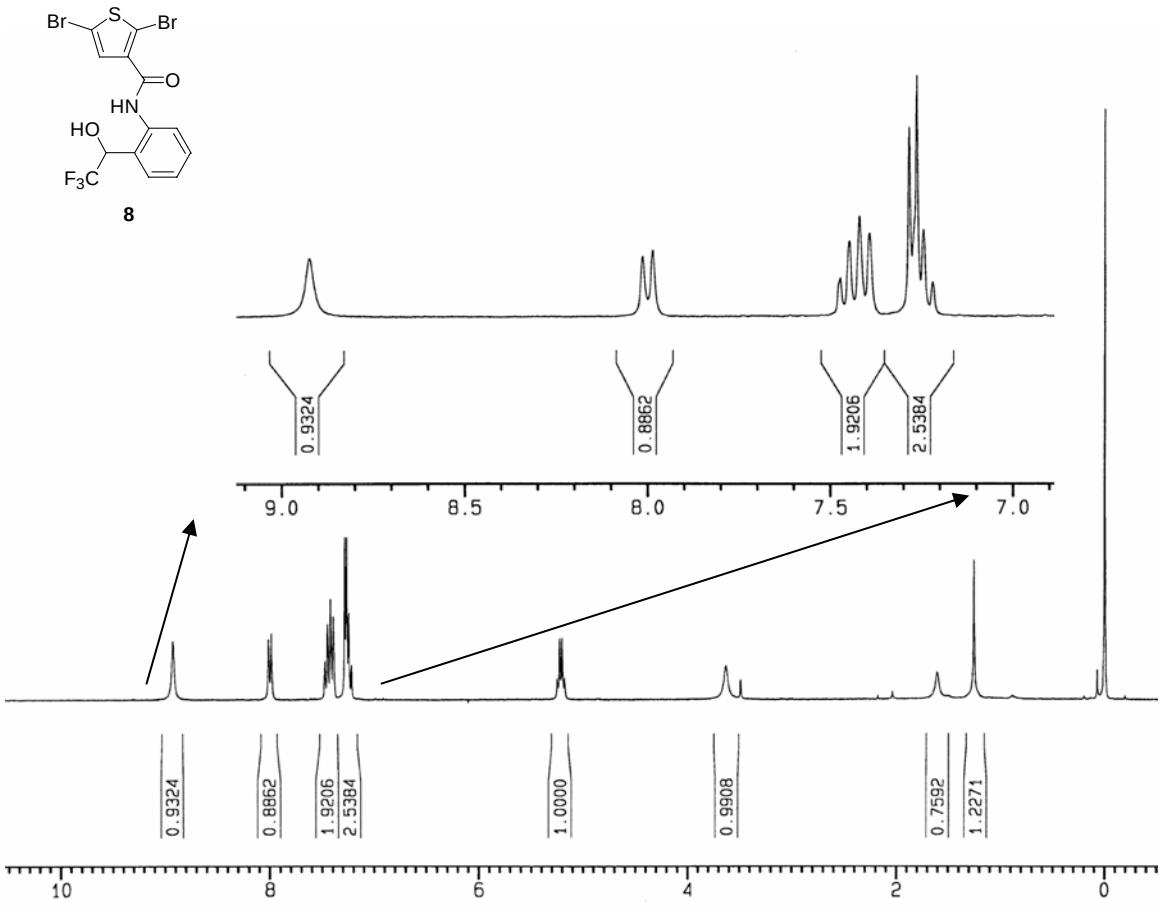
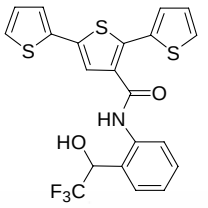


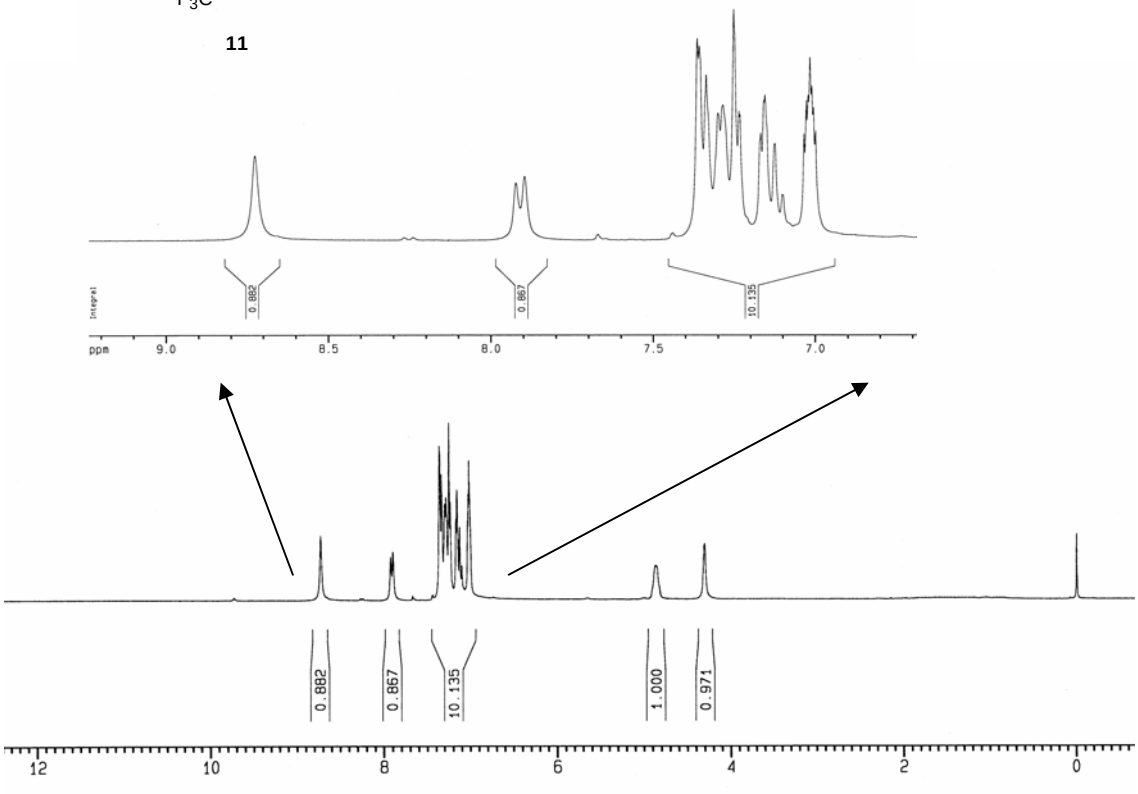
Figure S10. ITC titration data for **4** (a) and **5** (b) (0.2 mM, 1.5 mL) with $^{-}$OAc (3.0 mM, 5.0 μL × 40 times, as a Bu_4N^+ salt) in CH_3CN at 303 K.

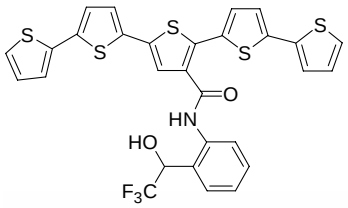
^{1}H NMR spectra of compounds **8**, **11, 12, 4**, and **5**.



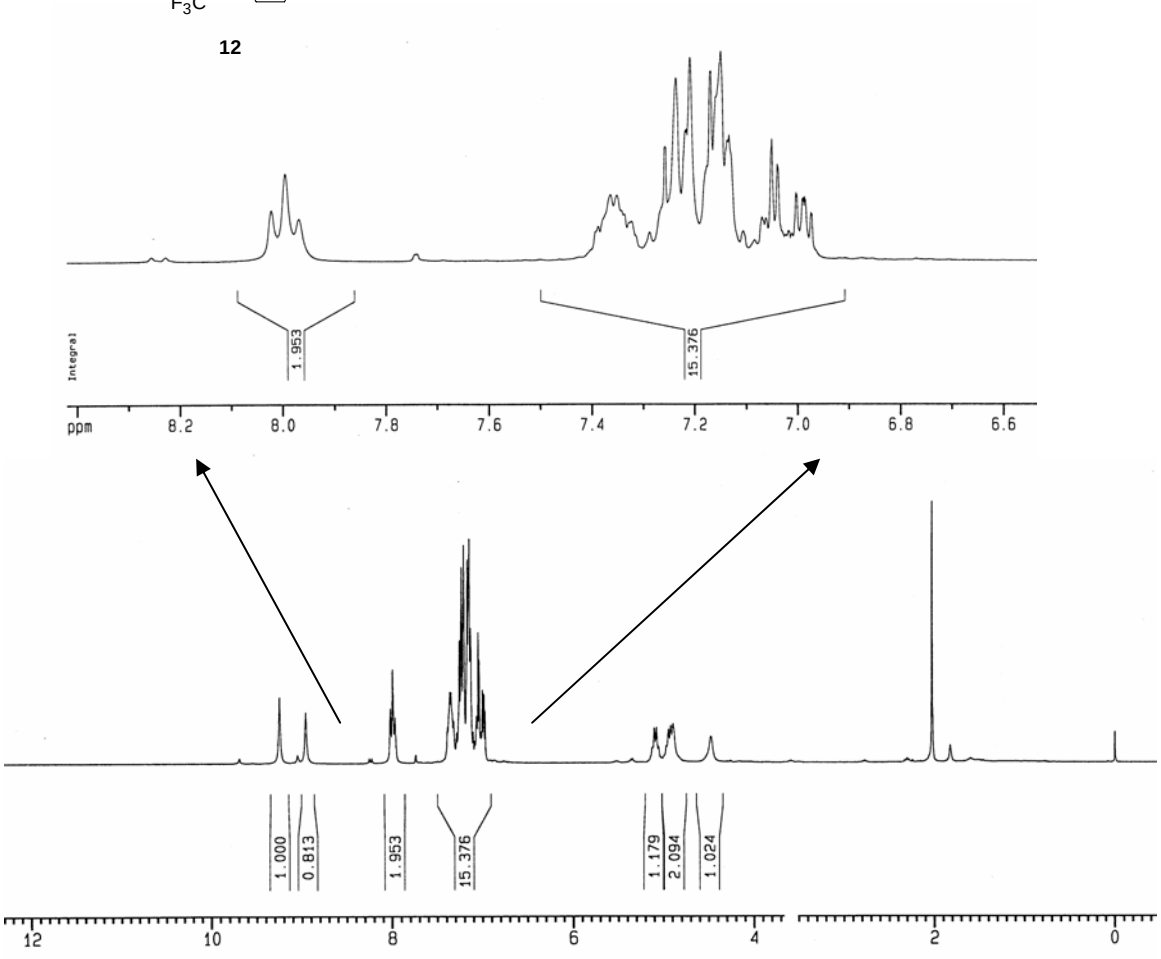


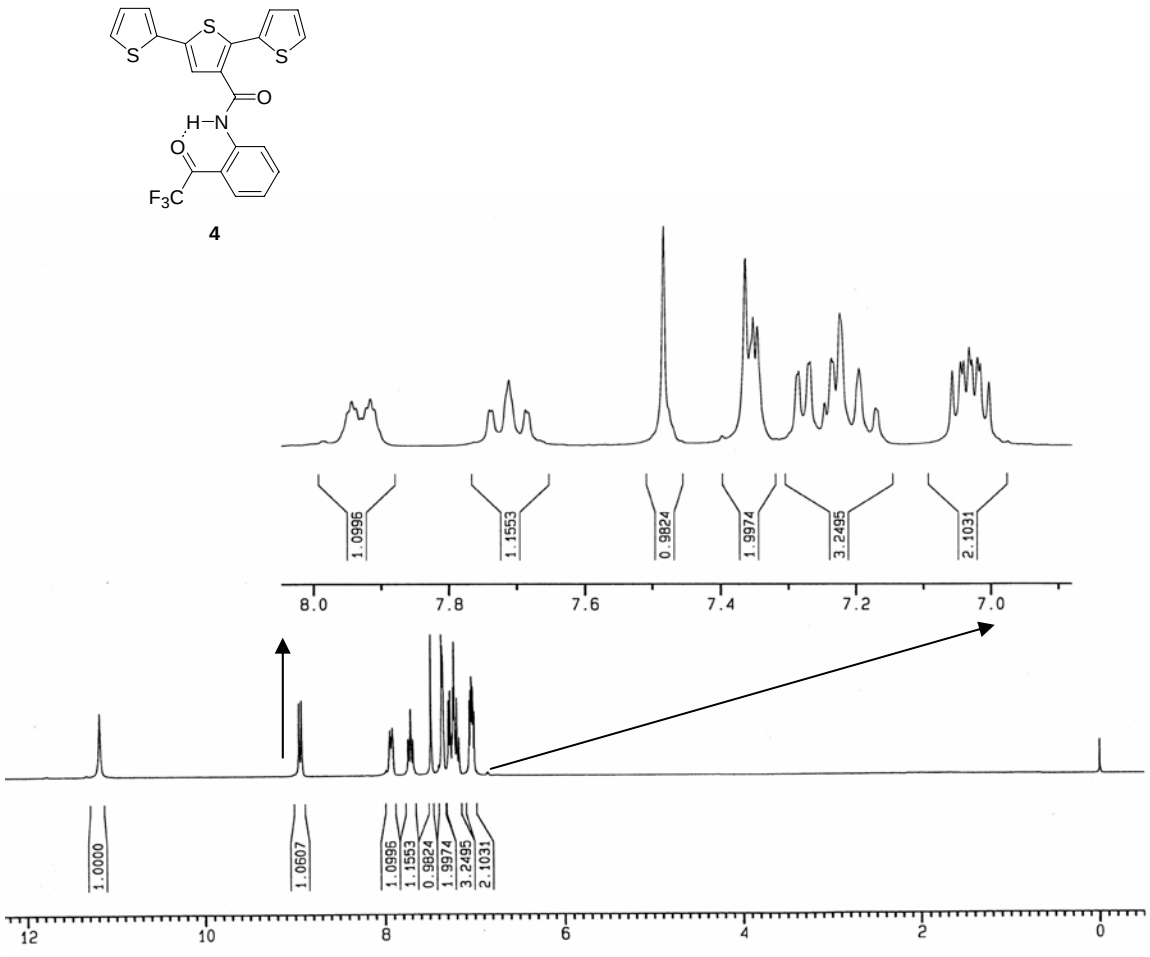
11



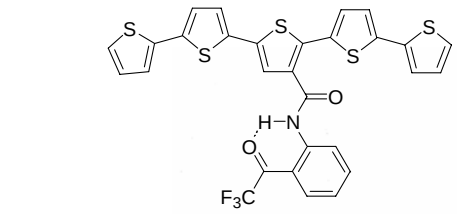

S
S
S
S
S
O
HN
HO
F3C

12


Integral
1.953
15.376
ppm
8.2
8.0
7.8
7.6
7.4
7.2
7.0
6.8
6.6
1.000
0.813
1.953
15.376
1.179
2.094
1.024
12
10
8
6
4
2
0


S
S
S
O
H–N
O
F3C
1.0996
1.1553
0.9824
1.9974
3.2495
2.1031
8.0
7.8
7.6
7.4
7.2
7.0
1.0000
1.0607
1.0996
1.1553
0.9824
1.9974
3.2495
2.1031
12
10
8
6
4
2
0

4


S
S
S
S
S
O
H–N
O
F3C

5

0.9938
1.0372
1.1060
1.0000
1.0373
6.1115
2.0967
2.1338
9.0
8.5
8.0
7.5
7.0
6.5
0.9681
0.9938
1.0372
1.1060
1.0000
1.0373
6.1115
2.0967
2.1338
12
10
8
6
4
2
0