Selective Recognition and Sensing of Biologically Important Phosphates Using Triptycene-Based Anion Receptors

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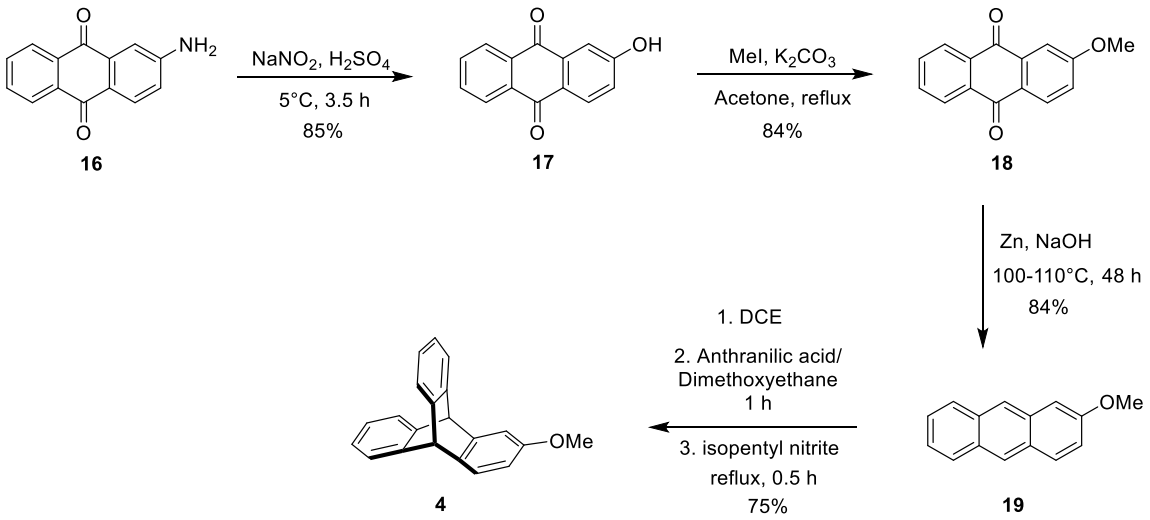
Contents:

1. General information

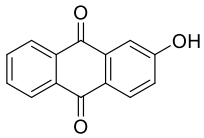
All reagents were purchased from Sigma-Aldrich, Ambeed and Fluorochem, and used without further purification. The ^{1}H, ^{13}C and ^{31}P NMR spectra were recorded on Varian Gemini 200, Bruker Avance III HD 400, and Varian-Agilent 600. Chemical shifts are reported in ppm. The splitting pattern of multiplets is described by abbreviations (s – singlet, bs – broad singlet, d – doublet, t – triplet, q – quartet, dd – doublet of doublets, m – complex multiplicity). Coupling constants values (*J*) are reported in Hz. Column chromatography was performed with Merck Kieselgel 60 (230-400 mesh). TLC was carried out on Merck Kieselgel F254 plates. Melting points were determined using a Boëtius M HMK hot-stage apparatus and were uncorrected. High resolution Mass spectrometry analysis was performed using Synapt G2-S mass spectrometer (Waters) equipped with the electrospray (ESI) ion source and quadrupole-Time-of-flight (qTOF) mass analyzer. Acetonitrile (Honeywell, LC-MS Chromasolv™, purity ⩾ 99.9%) was used as a solvent and mobile phase with the flow rate 100 µl/min. Sample was dissolved and injected directly into the ESI source. Injection volume was 1 µl depending on concentration. The measurement was performed in the positive ion mode with the resolving power of TOF analyzer 30000 FWHM. The lock-spray spectrum of Leucine-enkephalin was generated by the lock-spray source and the correction was performed for the recorded spectrum. The exact mass measurement was performed within 3 mDa mass error. Nitrogen was used as desolvation and cone gas, and their flow values were set to 600 L/h and 100 L/h respectively. Desolvation gas temperature was set to 350°C. Nebulizer gas pressure was set to 5.0 bar. Capillary voltage was set to 3.0 kV, and sampling cone voltage and source offset were set to 30-50 V. The instrument was controlled and data were processed using the MassLynx V4.1 software package (Waters).

2. Synthesis of compounds

2.1. Synthesis of compound 4

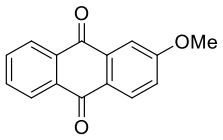


2-Hydroxyantraquinone (17)



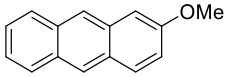
2-Aminoanthraquinone **16** (10.00 g, 45 mmol) was dissolved in 98% H_2SO_4 (130 mL). To the stirred solution, $NaNO_2$ (3.8 g, 55 mmol) was added in small portions, while keeping the temperature below 5 °C. After completion of addition, the reaction mixture was stirred additionally for 3.5 h and then it was poured into ice-cold water (500 mL) and the solution was refluxed for 30 min. The yellow–brown precipitate was filtered off and dissolved in aqueous NaOH solution (1 M, 90 mL) and was filtered and subsequently acidified with 6 M $HCl_{(aq)}$ until the disappearance of red color. This suspension was refluxed for 10 min and the solid was collected by filtration, to give 2-hydroxyanthraquinone **17** (8.6 g, 85%) in form of yellow solid, mp 304-305 °C. ^{1}H NMR (400 MHz, DMSO-d_6) δ 11.03 (s, 1H), 8.18 – 8.12 (m, 2H), 8.08 (d, J = 8.5 Hz, 1H), 7.92 – 7.84 (m, 2H), 7.50 (d, J = 2.6 Hz, 1H), 7.24 (dd, J = 8.5, 2.6 Hz, 1H). ^{13}C NMR (101 MHz, DMSO-d_6) δ 182.6, 181.1, 163.1, 135.2, 134.5, 133.9, 133.1, 133.0, 129.8, 126.6, 126.5, 125.1, 121.5, 112.2. HRMS (ESI) m/z: $[M-H]^-$ calcd for $C_{14}H_7O_3$, 223.0395; found, 223.0401.

2-Methoxyanhtraquinone (18)



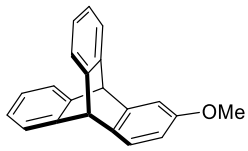
2-Hydroxyanthraquinone **17** (17.90 g, 80 mmol) and K_2CO_3 (33.20 g, 240 mmol) were placed in a two–necked flask, suspended in 400 mL of acetone and brought to a reflux under argon atmosphere and to this reaction mixture, MeI (15 mL, 33.90 g, 240 mmol) was added in three 5 mL portions at 1 h intervals, following the reaction progress by TLC (dichloromethane). After the complete conversion of the substrate, the post-reaction mixture was concentrated under reduced pressure, and water (150 mL) was added. The resulting solution was extracted with dichloromethane (3x100 mL), and combined organic phases were washed with 10% aqueous NaOH solution, 10% H_2SO_4, brine, dried over Na_2SO_4 and evaporated to afford 2-methoxyanthraquinone **18** (16.00 g, 84%) yellow crystals, mp 192-193 °C. ^{1}H NMR (400 MHz, Chloroform-*d*) δ 8.32 – 8.27 (m, 2H), 8.26 (d, *J* = 8.7 Hz, 1H), 7.80 – 7.75 (m, 2H), 7.73 (d, *J* = 2.7 Hz, 1H), 7.27 (dd, *J* = 8.7, 2.7 Hz, 1H), 3.99 (s, 3H). ^{13}C NMR (101 MHz, Chloroform-*d*) δ 183.4, 182.3, 164.5, 135.8, 134.3, 133.8, 133.8, 133.8, 129.9, 127.3, 127.3, 127.3, 121.3, 110.1, 56.1. HRMS (ESI) m/z: $[M]^+$ calcd for $C_{15}H_{10}O_3$, 238.0630; found, 238.0630.

2-Methoxyanthracene (19)



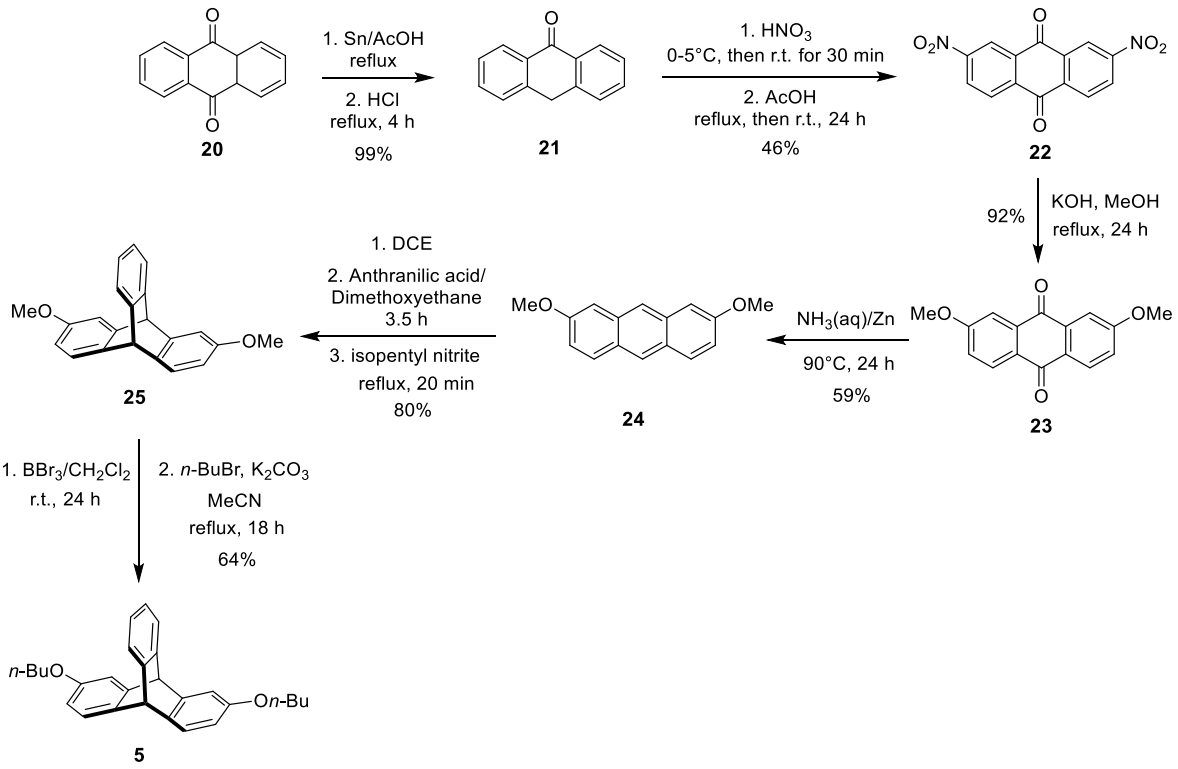
2-Methoxyanthraquinone **18** (16.00 g, 67.2 mmol), Zn powder (23 g, 350,0 mmol) and aqueous solution of NaOH (10%, 320 mL) were heated at 100-110 °C for 48 h under argon atmosphere.[1] After the complete conversion of the substrate, distilled water (320 mL) was added, and the resulting mixture was extracted with dichloromethane (3 x 300 mL). Combined organic phases were dried over Na_2SO_4 and evaporated. The resulting solid was recrystallized from dichloromethane to afford 2-methoxyanthracene **19** (11.70 g, 84%) as colorless plates. mp 174-175 °C. ^{1}H NMR (400 MHz, Chloroform-*d*) δ 8.35 (s, 1H), 8.28 (s, 1H), 8.00 – 7.92 (m, 2H), 7.90 (d, *J* = 9.1 Hz, 1H), 7.50 – 7.37 (m, 2H), 7.21 (d, *J* = 2.5 Hz, 1H), 7.17 (dd, *J* = 9.1, 2.5 Hz, 1H), 3.97 (s, 3H). ^{13}C NMR (101 MHz, Chloroform-*d*) δ 157.3, 132.9, 132.4, 130.5, 130.0, 128.5, 128.4, 127.7, 126.4, 125.7, 124.6, 124.3, 120.7, 103.7, 55.4. HRMS (ESI) m/z: $[M+H]^+$ calcd for $C_{15}H_{13}O$, 209.0966; found, 209.0973.

2-Methoxytriptycene (4)

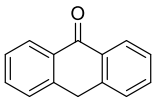


2-Methoxyanthracene **19** (4.16 g, 20 mmol) and anhydrous 1,2-dichloroethane (50 mL) were placed in a three–necked flask and brought to reflux under argon atmosphere. Solution of anthranilic acid (5.52 g, 40 mmol) in anhydrous 1,2-dimethoxyethane (22 mL) was added dropwise over 1 h. Concurrently, isopentyl nitrite (6.85 mL, 53 mmol) was added in 5 equal portions, ensuring that there was always an excess of the nitrite was present in the reaction mixture (adding the first portion before starting the addition of anthranilic acid solution). The reaction mixture was refluxed further for 30 min, and the resulting solution was evaporated under reduced pressure. The dark-brown oil obtained was diluted with dichloromethane and filtered through a short pad of silica gel and the filtrate was evaporated under reduced pressure. The colorless crystals obtained were collected by filtration, washed with hot ethanol, and dried to obtain 2-methoxytriptycene **4** (9.20 g, 75 %) colorless crystals, mp 161-162 °C. ^{1}H NMR (400 MHz, Chloroform-*d*) δ 7.46 – 7.39 (m, 4H), 7.32 (d, *J* = 8.1 Hz, 1H), 7.06 (d, *J* = 2.5 Hz, 1H), 7.05 – 7.00 (m, 4H), 6.54 (dd, *J* = 8.1, 2.5 Hz, 1H), 5.418 (s, 1H), 5.417 (s, 1H), 3.77 (s, 3H).^{13}C NMR (101 MHz, Chloroform-*d*) δ 157.4, 146.9, 145.8, 145.2, 137.8, 125.3, 125.2, 124.2, 123.7, 123.5, 111.0, 109.3, 55.5, 54.4, 53.3. HRMS (ESI) m/z: $[M+Na]^+$ calcd for $C_{21}H_{16}ONa$, 307.1093; found, 307.1093.

2.2. Synthesis of compound 5

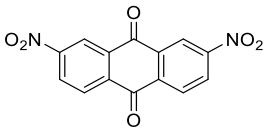


Anthrone (21)



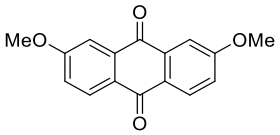
Anthraquinone **20** (41.64 g, 200 mmol) and granulated tin (40.00 g, 336 mmol) were taken up in acetic acid (300 mL) and brought to reflux. Over 2 h concentrated hydrochloric acid (100 mL) was added to the refluxing solution in 5 mL portions. After the complete addition of the hydrochloric acid, the reaction mixture was further refluxed for 2 h, then, cooled to RT and subsequently water (100 mL) was added. The precipitated light yellow solid was filtered on a Schott funnel and dissolved in dichloromethane (300 mL). This solution was washed with water (2x100 mL) and saturated $NaHCO_3$ solution (100 mL). The organic phase was dried over Na_2SO_4 and evaporated, yielding anthrone **21** (38.34 g, 198 mmol, 99%) as yellow needles, mp 149-150 °C, ^{1}H NMR (400 MHz, Chloroform-*d*) δ 8.40 – 8.34 (m, 2H), 7.63 – 7.56 (m, 2H), 7.50 – 7.43 (m, 4H), 4.36 (s, 2H). ^{13}C NMR (101 MHz, Chloroform-*d*) δ 184.4, 140.6, 132.9, 132.2, 128.6, 127.8, 127.2, 32.5. HRMS (ESI) m/z: $[M+H]^+$ calcd for $C_{14}H_{11}O$, 195.0810; found, 195.0812.

2,7-Dinitroanthraquinone (22)



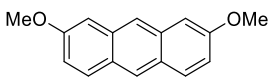
Fuming nitric acid (75 mL) was cooled down to 0 °C and anthrone **21** (20.00 g, 103 mmol) was added in small portions so that the temperature of the acid does not exceed 5 °C. After the complete addition of the anthrone **21**, the reaction mixture was stirred for 30 min at RT and was poured into glacial acetic acid (400 mL), which was brought to reflux. The acetic acid mixture was refluxed until nitrogen dioxide stopped evolving. The mixture was stirred overnight at RT and the light yellow precipitate was filtered, washed with methanol and dried, yielding crude 2,7-dinitroanthraquinone (24.6 g) contaminated with the 2,6- isomer. The crude product was recrystallized from DMSO, filtered, washed with methanol and dried, yielding pure 2,7-dinitroanthraquinone **22** (14.20 g, 46%) in form of fine light yellow needles, ^{1}H NMR (400 MHz, DMSO-d_6) δ 8.84 (d, J = 2.2 Hz, 2H), 8.71 (d, J = 8.5 Hz, 2H), 8.48 (d, J = 8.5 Hz, 2H). ^{13}C NMR (101 MHz, DMSO-d_6) δ 180.3, 179.8, 150.8, 136.9, 134.3, 129.1, 128.6, 121.4. HRMS (ESI) m/z: $[M]^+$ calcd for $C_{14}H_6N_2O_6$, 298.0226; found, 298.0224.

2,7-Dimethoxyanthraquinone (23)



2,7-dinitroanthraquinone **22** (14.00 g, 47 mmol) was taken up in a solution of KOH (14.0 g, 250 mmol) in MeOH (450 mL) and refluxed overnight. The reaction mixture was cooled down to RT and filtered. The solid was washed copiously with MeOH and hexane, and air-dried, yielding 2,7-dimethoxyanthraquinone as a light yellow solid. The crude product was purified by recrystallization from acetic acid, yielding 2,7-dimethoxyanthraqunone **23** (11.60 g, 92%) in form of fine orange-yellow needles. mp 208-209 °C. ^{1}H NMR (400 MHz, DMSO-d_6) δ 8.13 (dd, J = 8.7, 1.8 Hz, 2H), 7.60 – 7.55 (m, 2H), 7.46 – 7.39 (m, 2H), 3.96 (s, 6H), ^{13}C NMR (101 MHz, DMSO-d_6) δ 180.3, 180.3, 163.6, 135.0, 129.3, 126.4, 120.7, 110.2, 56.0. HRMS (ESI) m/z: $[M+Na]^+$ calcd for $C_{16}H_{12}O_4Na$, 291.0633; found, 291.0632.

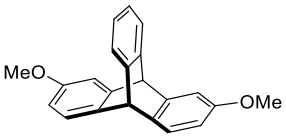
2,7-Dimethoxyanthracene (24)



2,7-Dimethoxyanthraquinone **23** (3.00 g, 10.0 mmol) was suspended in aqueous ammonia (100 mL, 12.5%). The mixture was heated to 80°C and zinc (25.00 g, 382.3 mmol) was added in portions over the

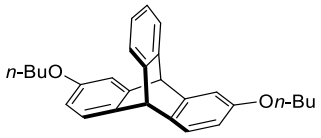
course of 1 h. The color of the mixture changes to cherry-red. The mixture was heated to 90 °C and stirred at this temperature overnight under argon. The mixture was cooled to RT and filtered, and the residue was washed copiously with water and dichloromethane. The organic phase was dried over Na_2SO_4 and evaporated. The crude product was purified using column chromatography (hexane/dichloromethane, 2:1), yielding 2,7-dimethoxyanthracene **24** (1.40 g, 59%) in form of colorless crystals. mp 208-211 °C. ^{1}H NMR (400 MHz, DMSO-d_6) δ 8.39 (s, 1H), 8.23 (s, 1H), 7.94 (d, J = 9.2 Hz, 2H), 7.30 (d, J = 2.5 Hz, 2H), 7.11 (dd, J = 9.2, 2.5 Hz, 2H), 3.91 (s, 6H). ^{13}C NMR (101 MHz, DMSO-d_6) δ 157.0, 132.9, 129.8, 126.3, 126.1, 122.1, 119.2, 103.4, 55.2. HRMS (ESI) m/z: $[M+H]^+$ calcd for $C_{16}H_{15}O_2$, 239.1072; found, 239.1078.

2,7-Dimethoxytriptycene (25)



2,7-Dimethoxyanthracene **24** (1.82 g, 7.6 mmol) was dissolved in anhydrous DCE (30 mL) and heated to reflux under argon. A solution of anthranilic acid (3.14 g, 22.9 mmol) in anhydrous DME was added dropwise over the course of 3.5 h. Isopentyl nitrite (3.58 g, 30.6 mmol, 4.1 mL) was added in 4 portions in 1 h intervals, with the first portion being added concurrently with the start of the addition of the anthranilic acid solution. After the addition of the anthranilic acid solution was finished, the reaction mixture was refluxed for additional 20 min, and was then evaporated. The product was purified using column chromatography (hexane/dichloromethane, 2:1), yielding 2,7-dimethoxytriptycene **25** (1.92 g, 6.1 mmol, 80%) as a yellow solid. mp 141-142 °C. ^{1}H NMR (400 MHz, Chloroform-d) δ 7.40 – 7.32 (m, 2H), 7.26 (d, J = 8.1 Hz, 2H), 7.03 – 6.96 (m, 4H), 6.50 (dd, J = 8.1, 2.5 Hz, 2H), 5.32 (s, 1H), 5.31 (s, 1H), 3.74 (s, 6H). ^{13}C NMR (101 MHz, Chloroform-d) δ 157.3, 146.8, 146.3, 145.1, 138.3, 125.4, 125.1, 123.9, 123.7, 123.3, 111.0, 109.4, 55.6, 54.7, 52.6. HRMS (ESI) m/z: $[M+H]^+$ calcd for $C_{22}H_{19}O_2$, 315.1385; found, 315.1393.

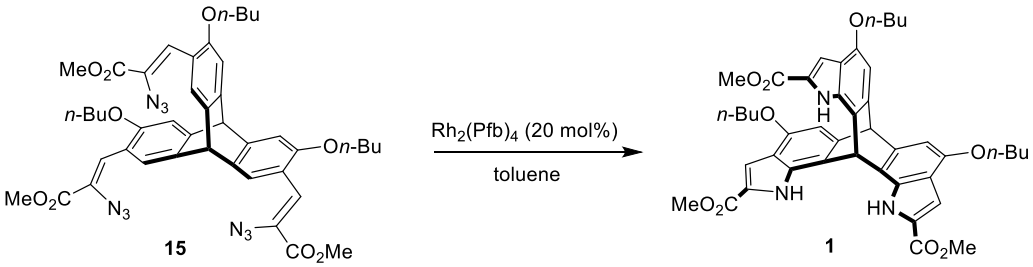
2,7-Dibutoxytriptycene (5)



2,7-Dimethoxytriptycene **25** (1.92 g, 6.1 mmol) was dissolved in anhydrous dichloromethane (20 mL) and cooled down to 0 °C. A 1M solution of BBr_3 (12.1 mL, 12.1 mmol) was added dropwise to the mixture, which was then allowed to warm up to RT and was stirred overnight. The reaction mixture was poured to ice water (100 mL) and extracted with ethyl acetate (2 x 50 mL) the combined organic phases

were washed with water (3 x 50 mL) and brine (50 mL). The organic phase was dried over Na_2SO_4 and evaporated, yielding a brown solid (1.90 g) which was used in the next step without further purification. It was dissolved in acetonitrile (50 mL) and *n*-butyl bromide (3.33 g, 2.62 mL, 24.3 mmol) along with K_2CO_3 (3.36 g, 24.3 mmol) was added, and the mixture was brought to reflux under argon atmosphere for 18 h. The mixture was evaporated and dichloromethane (100 mL) was added. The dichloromethane solution was washed with water (50 mL), saturated $NaHCO_3$ solution (50 mL) and brine (50 mL), and was dried over Na_2SO_4. Evaporation of the solution yielded a dark brown oil, which was purified using column chromatography (hexanes/dichloromethane, 2:1), yielding 2,7-dibutoxytriptycene **5** (1.55 g, 64%) as a yellow oil. ^{1}H NMR (400 MHz, Chloroform-*d*) δ 7.37 – 7.30 (m, 2H), 7.22 (d, *J* = 8.1 Hz, 2H), 7.01 – 6.93 (m, 4H), 6.47 (dd, *J* = 8.1, 2.5 Hz, 2H), 5.28 (s, 1H), 5.25 (s, 1H), 3.88 (t, *J* = 6.5 Hz, 4H), 1.75 – 1.65 (m, 4H), 1.50 – 1.38 (m, 4H), 0.94 (t, *J* = 7.4 Hz, 6H). ^{13}C NMR (101 MHz, Chloroform-*d*) δ 156.9, 146.7, 146.4, 145.2, 138.1, 125.4, 125.0, 123.9, 123.7, 123.2, 111.6, 110.0, 68.0, 54.7, 52.6, 31.5, 19.4, 13.9. HRMS (ESI) m/z: $[M+H]^+$ calcd for $C_{28}H_{31}O_2$, 399.2324; found, 399.2327.

2.3. Synthesis of compound 1 under flow conditions



1.3.1. Description of the Flow setup

Compound **15** and rhodium(II) perfluorobutyrate were dissolved in anhydrous toluene in separate flasks under argon atmosphere. The two solutions were transferred to separate syringes. As shown in the figure below, one syringe contains the yellow solution of compound **15**, and the other contains the green solution of the rhodium(II) perfluorobutyrate catalyst. The two solutions are added a by a syringe pump with a proper flow rate through a mixer to polyetheretherketone (PEEK) or stainless steel reactor being heated in an oil bath. The crude of the reaction mixture is collected in a separate flask as shown below in the **Photo S1**. The volumes of the iron and PEEK reactors were 0.1 mL and 0.35 mL respectively.

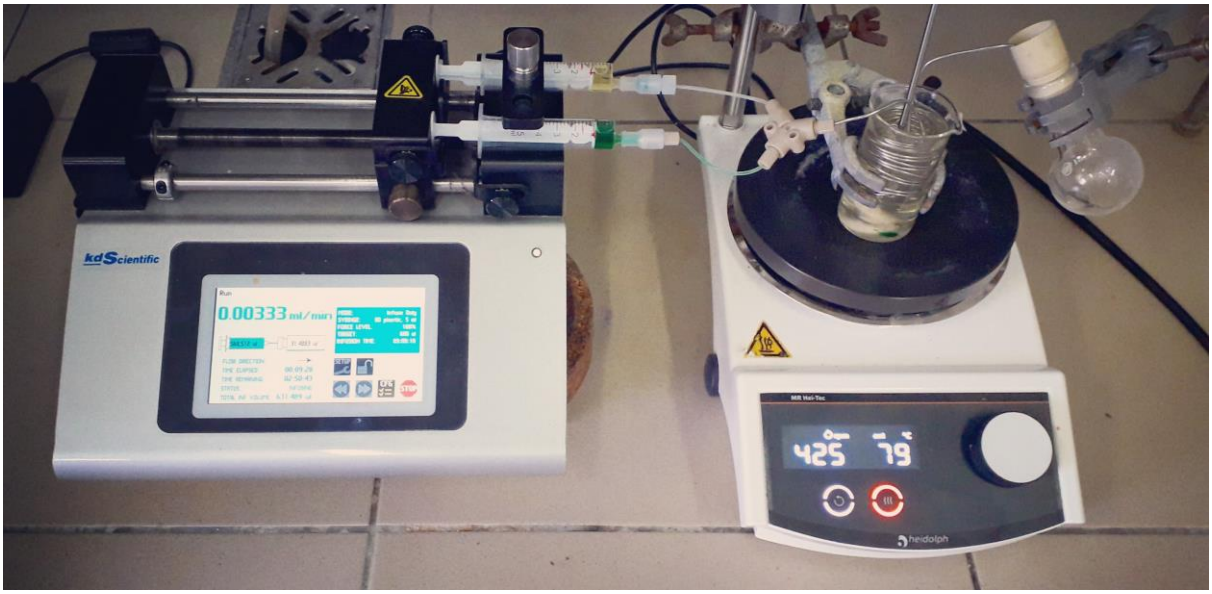


Photo S1. Photo of the assembled flow setup.

1.3.2. Experimental results of the Flow setup

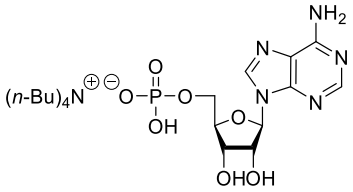
Entry	Tube	Temperature (°C)	Concentration (mM)	Flow (µL/h)	Residence Time (h)	Yield (%)
1	Iron	60	25	100.0	1.0	0
2	Iron	80	76	28.8	3.5	14
3	PEEK	80	32	87.5	4.0	33

1.3.3. Procedure of synthesis of compound 1 (entry 3)

Compound **15** (110.0 mg, 0.130 mmol) was dissolved in 2.0 mL anhydrous toluene and Rhodium(II) perfluorobutyrate (27.5 mg, 0.026 mmol) was dissolved in 2 mL anhydrous toluene. Both solutions were transferred into two separate syringes. The reaction is performed using setup described above. The flow rate was 87.5 µL/h, and the total flow time was 45.7 h. (Note: additional 4 h flow time was applied to compensate the dead volume of the reactor which is 0.35 mL). The reaction mixture was evaporated and purified using column chromatography (hexanes/ethyl acetate, 9:1 to hexanes/ethyl acetate, 8:2), yielding compound **1** (32.3 mg, 33%). The spectra were identical to those described previously.[2]

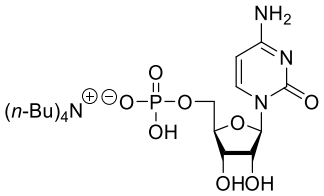
2.4. Synthesis of tetrabutyl ammonium salts

TBA^+ AMP^- (26)



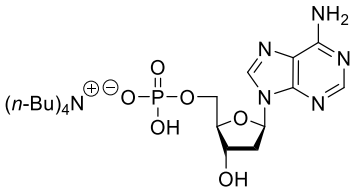
AMP (200 mg, 0.570 mmol) was dissolved in MeOH (5.0 mL). Then, a solution of tetrabutyl ammonium hydroxide in MeOH/toluene (1:1) (0.11 M, 5.00 mL, 0.550 mmol) was added and the reaction mixture was stirred for 0.5 h. The reaction mixture turned from white turbid to colorless solution after few min. The reaction mixture was then filtrated on cotton to remove the slightly excess of undissolved AMP. Then, the product was co-evaporated under reduced pressure with dichloromethane to remove toluene and to obtain the salt **26** (0.32 g, quant.) as white powder. ^{1}H NMR (400 MHz, DMSO-d_6) δ 8.48 (s, 1H), 8.13 (s, 1H), 7.20 (s, 2H), 5.90 (d, J = 6.6 Hz, 1H), 4.73 (dd, J = 6.6, 4.8 Hz, 1H), 4.26 (dd, J = 4.8, 2.4 Hz, 1H), 4.05 – 3.97 (m, 1H), 3.85 – 3.69 (m, 2H), 3.24 – 3.07 (m, 8H), 1.65 – 1.45 (m, 8H), 1.38 – 1.21 (m, 8H), 0.93 (t, J = 7.3 Hz, 12H). ^{13}C NMR (101 MHz, DMSO-d_6) δ 156.1, 153.0, 150.1, 139.9, 118.8, 86.8, 84.9, 74.6, 71.4, 64.3, 57.9, 23.4, 19.4, 13.7. ^{31}P NMR (162 MHz, DMSO-d_6) δ 0.72. HRMS (ESI) m/z: $[AMP]^-$ calcd for $C_{10}H_{13}N_5O_7P$, 346.0553; found, 346.0551.

TBA^+ CMP^- (27)



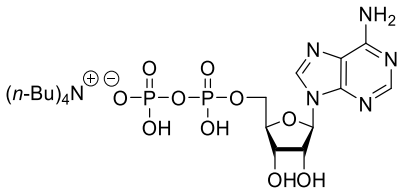
CMP (250 mg, 0.770 mmol) was dissolved in MeOH (6.5 mL). Then, a solution of tetrabutyl ammonium hydroxide in MeOH/toluene (1:1) (0.11 M, 6.63 mL, 0.730 mmol) was added and the reaction was stirred for 1 h. The reaction mixture turned from white turbid to colorless solution after few min. The reaction mixture was then filtrated on cotton to remove the slightly excess of undissolved phosphate. Then, the product was co-evaporated under reduced pressure with dichloromethane to remove toluene and to obtain the salt **27** (0.40 g, 98%) as white powder. ^{1}H NMR (400 MHz, DMSO-d_6) δ 7.92 (d, J = 7.4 Hz, 1H), 7.24 (s, 1H), 6.96 (s, 1H), 5.85-5.80 (m, 1H), 5.73 (d, J = 7.4 Hz, 1H), 4.06 – 4.01 (m, 2H), 3.89 – 3.85 (m, 1H), 3.83 – 3.73 (m, 2H), 3.22 – 3.09 (m, 8H), 1.63 – 1.49 (m, 8H), 1.36 – 1.24 (m, 8H), 0.93 (t, J = 7.3 Hz, 12H). ^{13}C NMR (101 MHz, DMSO-d_6) δ 165.6, 155.7, 141.6, 94.4, 88.1, 83.3, 74.2, 70.3, 63.4, 57.6, 23.1, 19.2, 13.5. ^{31}P NMR (162 MHz, DMSO) δ 0.47. HRMS (ESI) m/z: $[CMP]^-$ calcd for $C_9H_{13}N_3O_8P$, 322.0440; found, 322.0439.

TBA$^+$ deoxyAMP$^-$ (28)



DeoxyAMP (45 mg, 0.136 mmol) was dissolved in MeOH (2 mL). Then, a solution of tetrabutyl ammonium hydroxide in MeOH/toluene (1:1) (0.11 M, 1.16 mL, 0.128 mmol) was added and the reaction was stirred for 1 h. The reaction mixture turned from white turbid to colorless solution after few min. The reaction mixture was then filtrated on cotton to remove the slightly excess of undissolved phosphate. Then, the product was co-evaporated under reduced pressure with dichloromethane to remove toluene and to obtain the salt **28** (65 mg, 89%) as white powder. ^{1}H NMR (400 MHz, DMSO-d_6) δ 8.42 (s, 1H), 8.13 (s, 1H), 7.19 (s, 2H), 6.36 – 6.29 (m, 1H), 4.53 – 4.46 (m, 1H), 3.93 – 3.87 (m, 1H), 3.78 – 3.70 (m, 2H), 3.21 – 3.10 (m, 8H), 2.72 – 2.63 (m, 1H), 2.29 – 2.21 (m, 1H), 1.62 – 1.50 (m, 8H), 1.37 – 1.25 (m, 8H), 0.93 (t, J = 7.3 Hz, 12H).^{13}C NMR (101 MHz, DMSO-d_6) δ 156.1, 152.9, 149.4, 139.7, 118.9, 86.8, 83.2, 71.5, 64.3, 57.9, 57.8, 23.3, 19.4, 13.7. ^{31}P NMR (162 MHz, DMSO) δ 0.15. HRMS (ESI) m/z: [deoxyAMP]$^-$ calcd for $C_{10}H_{13}N_5O_6P$, 330.0603; found, 330.0602.

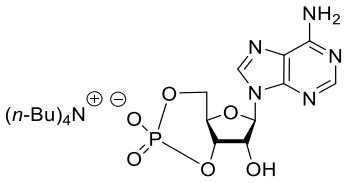
TBA$^+$ ADP$^-$ (29)



ADP (50 mg, 0.117 mmol) was dissolved in MeOH (1 mL), then a solution of tetrabutyl ammonium hydroxide in MeOH/toluene (1:1) (0.11 M, 1.02 mL, 0.112 mmol) was added and the reaction mixture was stirred for 1 h. The reaction mixture stayed turbid. Then, distilled water (2 mL) was added to homogenize the reaction mixture, which was left for stirring for additional 2 h at RT. The reaction mixture was then filtrated on cotton. Then, the product was co-evaporated under reduced pressure with dichloromethane to remove toluene and water and to obtain the salt **29** (65 mg, 87%) as white powder. ^{1}H NMR (400 MHz, DMSO-d_6) δ 8.41 (d, J = 7.0 Hz, 1H), 8.14 (s, 1H), 7.23 (s, 2H), 5.91 (d, J = 5.5 Hz, 1H), 4.61 – 4.47 (m, 1H), 4.30 – 4.22 (m, 1H), 4.07 – 4.01 (m, 1H), 4.00 – 3.92 (m, 2H), 3.20 – 3.07 (m, 8H), 1.65 – 1.48 (m, 8H), 1.38 – 1.25 (m, 8H), 0.93 (t, J = 7.3 Hz, 12H). ^{13}C NMR (101 MHz, DMSO-d_6) δ 155.9, 152.5, 149.7, 139.3, 118.6, 86.6, 83.8, 73.8, 70.5, 64.9, 57.5, 23.0, 19.2, 13.4. ^{31}P

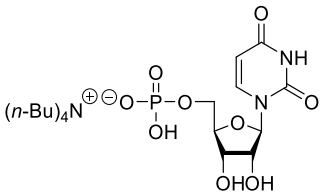
NMR (162 MHz, DMSO) δ -9.66, -11.00. HRMS (ESI) m/z: $[ADP]^-$ calcd for $C_{10}H_{14}N_5O_{10}P_2$, 426.0216; found, 426.0211.

TBA^+ $cAMP^-$ (30)



cAMP (100 mg, 0.304 mmol) was dissolved in MeOH (8 mL), then a solution of tetrabutyl ammonium hydroxide in MeOH/toluene (1:1) (0.16 M, 1.87 mL, 0.299 mmol) was added and the reaction mixture was stirred for 1 h. The reaction mixture stayed turbid. Then, distilled water (1 mL) was added to homogenize the reaction mixture, which was left for stirring for additional 2 h at RT. Then, the product was co-evaporated under reduced pressure with dichloromethane to remove toluene and water and to obtain the salt **30** (0.16 g, 95%) as white powder. ^{1}H NMR (400 MHz, DMSO-d_6) δ 8.24 (s, 1H), 8.17 (s, 1H), 7.29 (s, 2H), 5.88 (s, 1H), 5.77 (d, J = 4.4 Hz, 1H), 4.63 – 4.56 (m, 1H), 4.55 – 4.49 (m, 1H), 4.09 – 3.87 (m, 3H), 3.21 – 3.10 (m, 8H), 1.64 – 1.48 (m, 8H), 1.37 – 1.20 (m, 8H), 0.93 (t, J = 7.3 Hz, 12H). ^{13}C NMR (101 MHz, DMSO) δ 155.9, 152.7, 148.9, 139.7, 118.9, 91.6, 77.1, 72.1, 72.0, 65.8, 57.5, 23.1, 19.2, 13.4. ^{31}P NMR (162 MHz, DMSO) δ -3.94. HRMS (ESI) m/z: $[cAMP]^-$ calcd for $C_{10}H_{11}N_5O_6P$, 328.0447; found, 328.0450.

TBA^+ UMP^- (31)



UMP (80 mg, 0.247 mmol) was dissolved in MeOH (4 mL), then a solution of tetrabutyl ammonium hydroxide in MeOH/toluene (1:1) (0.15 M, 1.60 mL, 0.240 mmol) was added and the reaction mixture was stirred for 1 h. Then, the product was co-evaporated under reduced pressure with dichloromethane to obtain the salt **31** (0.13 g, 96%) as white powder.^{1}H NMR (400 MHz, DMSO-d_6) δ 11.20 (s, 1H), 7.99 (d, J = 8.1 Hz, 1H), 5.80 (d, J = 6.4 Hz, 1H), 5.60 (d, J = 8.1 Hz, 1H), 4.26 – 4.15 (m, 1H), 4.14 – 4.04 (m, 1H), 3.97 – 3.87 (m, 1H), 3.84 – 3.67 (m, 2H), 3.25 – 3.07 (m, 8H), 1.66 – 1.46 (m, 8H), 1.40 – 1.19 (m, 8H), 0.93 (t, J = 7.3 Hz, 12H). ^{13}C NMR (101 MHz, DMSO) δ 163.5, 151.1, 141.4, 102.1, 87.3, 84.2, 73.5, 70.8, 63.8, 57.7, 23.2, 19.3, 13.5. ^{31}P NMR (162 MHz, DMSO) δ 0.75. HRMS (ESI) m/z: $[UMP]^-$ calcd for $C_9H_{12}N_2O_9P$, 323.0280; found, 323.0278.

3. ^{1}H, ^{13}C and ^{31}P NMR Spectra

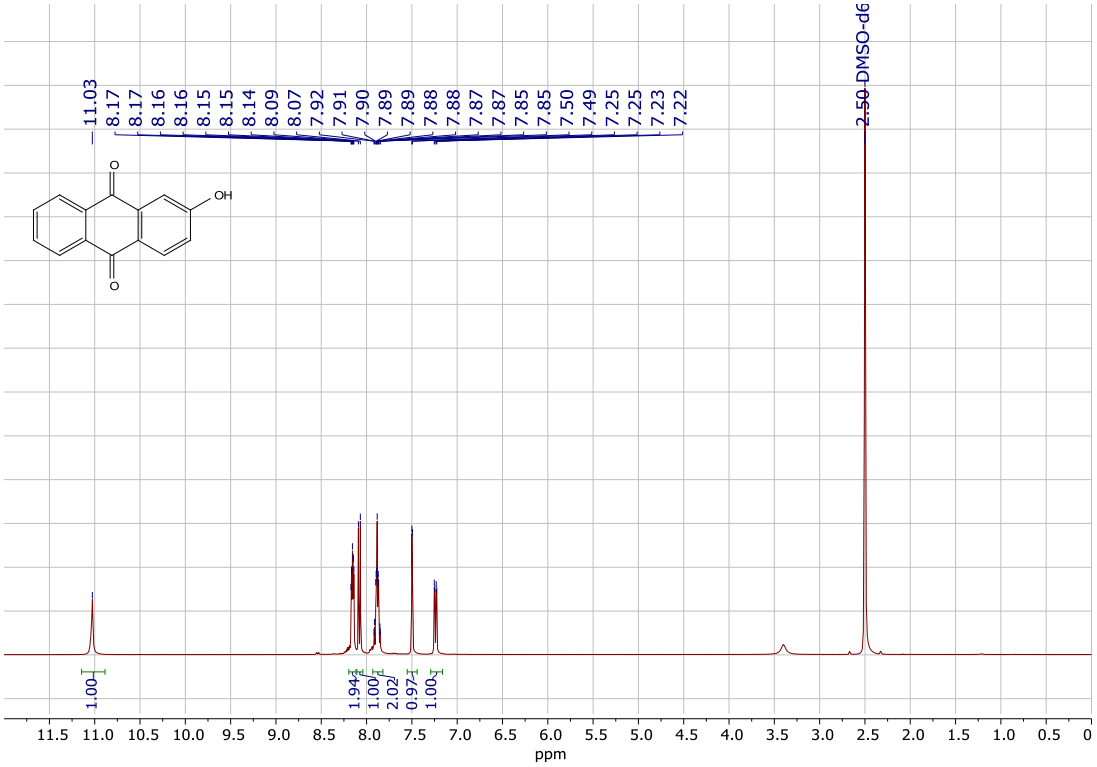


Fig. S1. ^{1}H NMR spectrum of **17** in DMSO-d_6

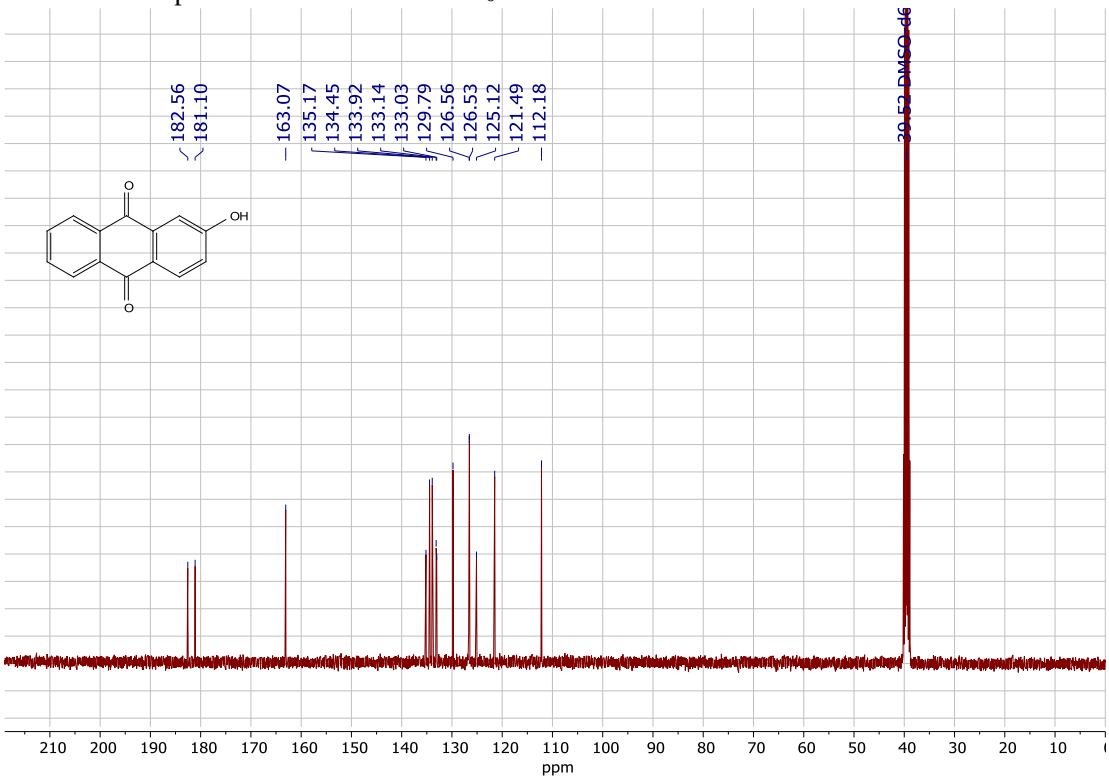


Fig. S2. ^{13}C NMR spectrum of **17** in DMSO-d_6

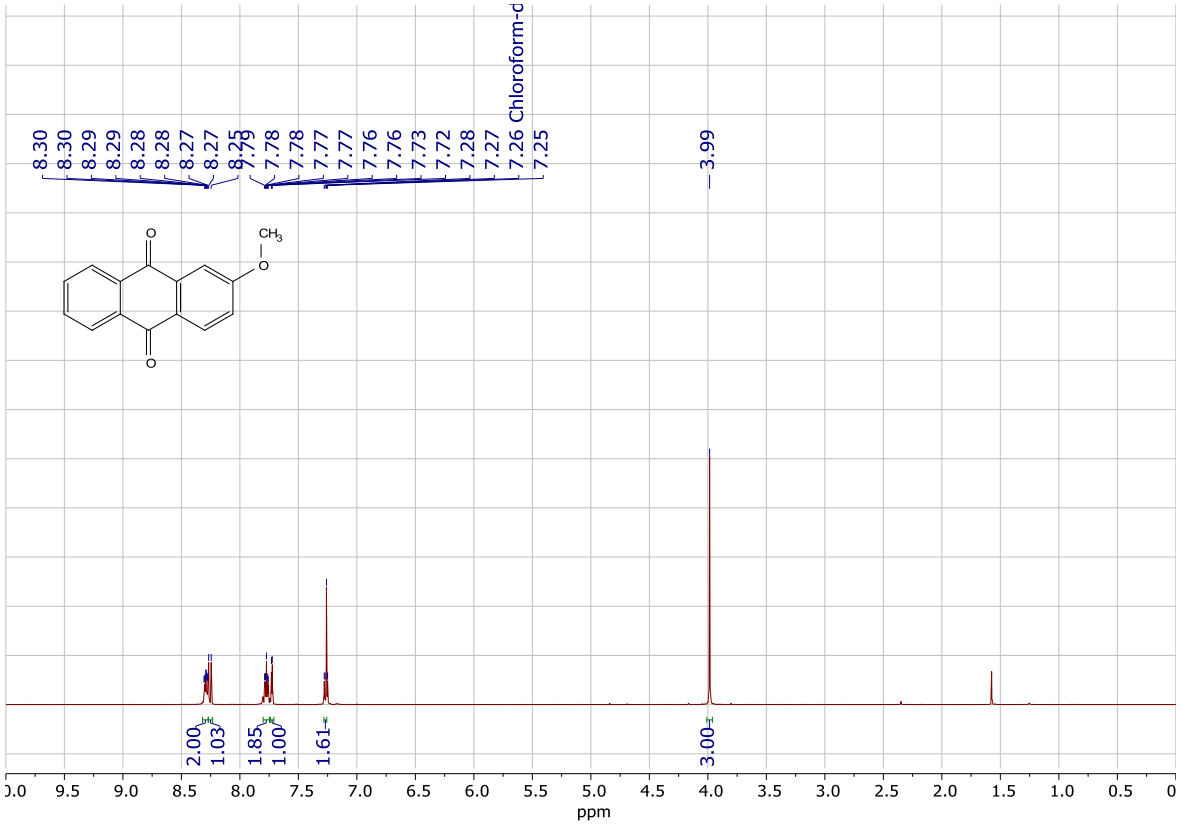


Fig. S3. [1]H NMR spectrum of **18** in Chloroform-*d*

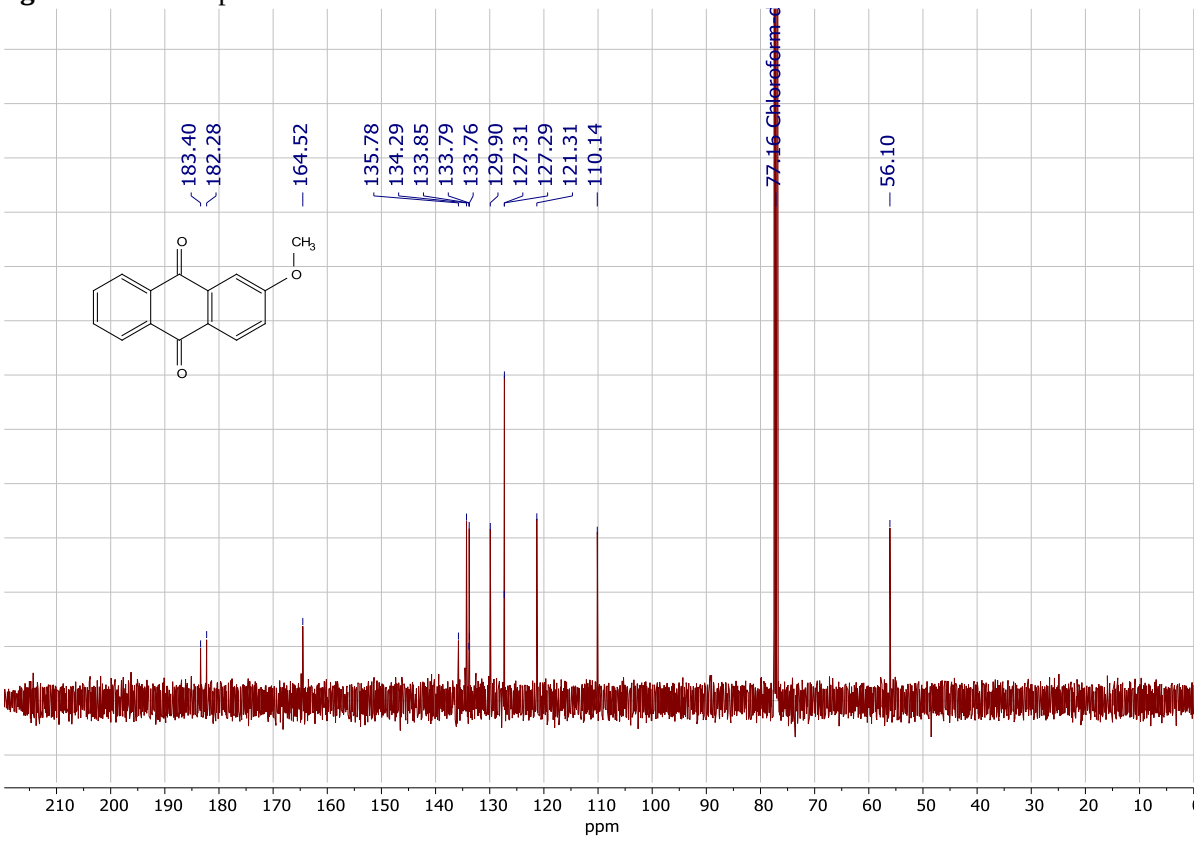


Fig. S4. [13]C NMR spectrum of **18** in Chloroform-*d*

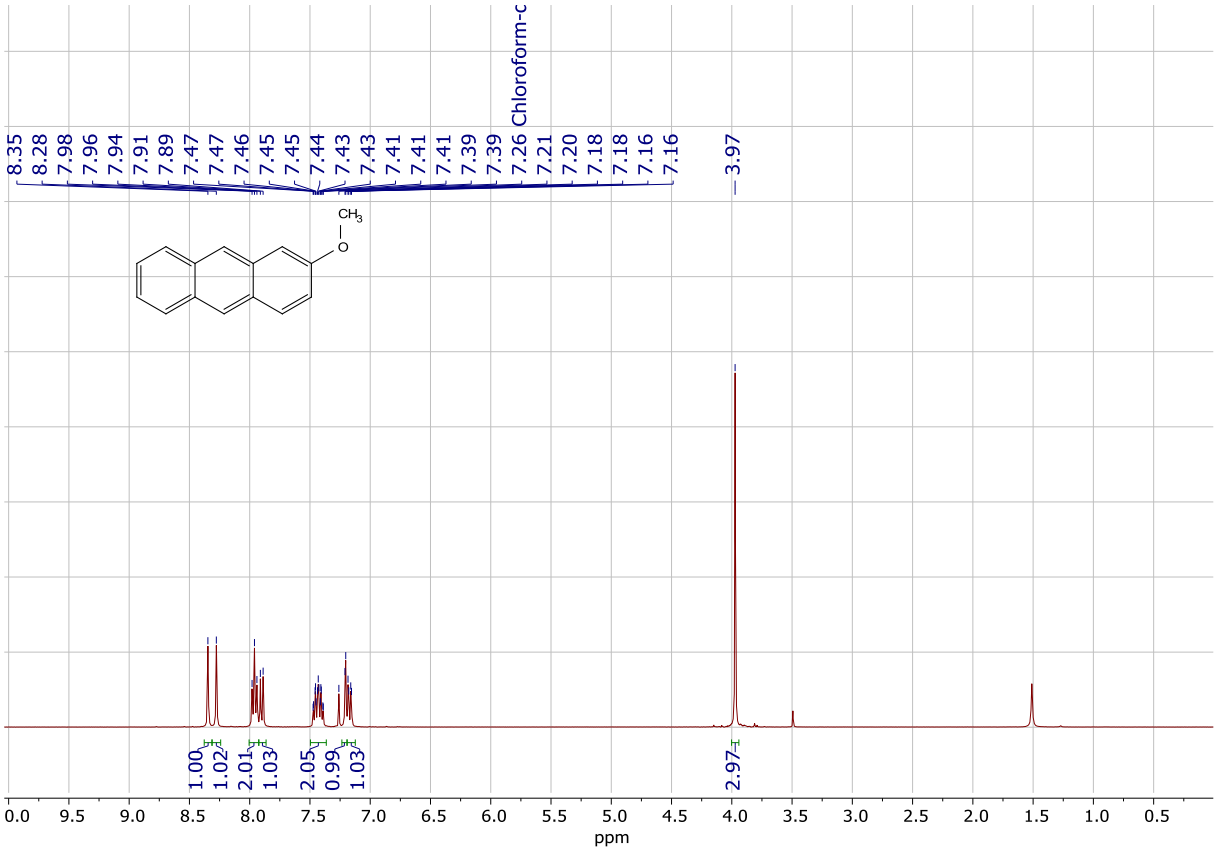


Fig. S5. ^{1}H NMR spectrum of **19** in Chloroform-*d*

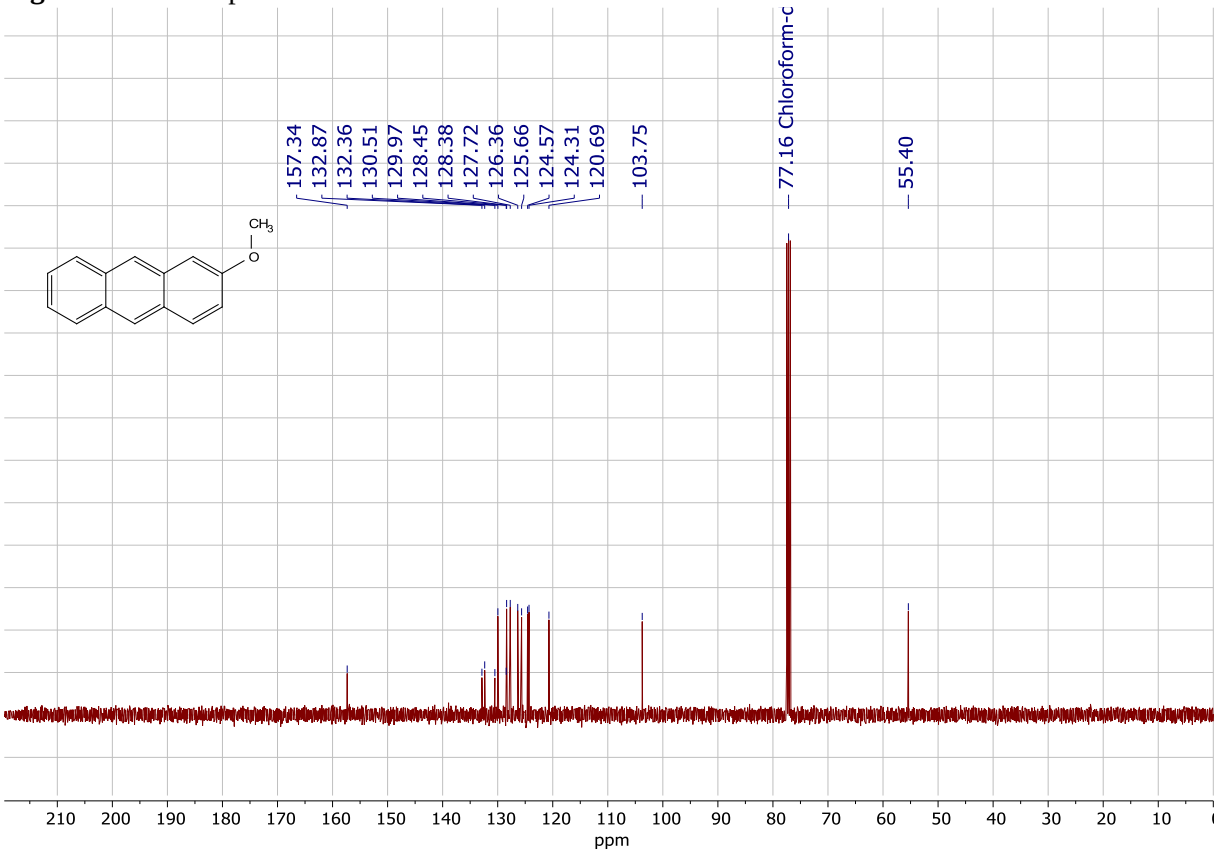


Fig. S6. ^{13}C NMR spectrum of **19** in Chloroform-*d*

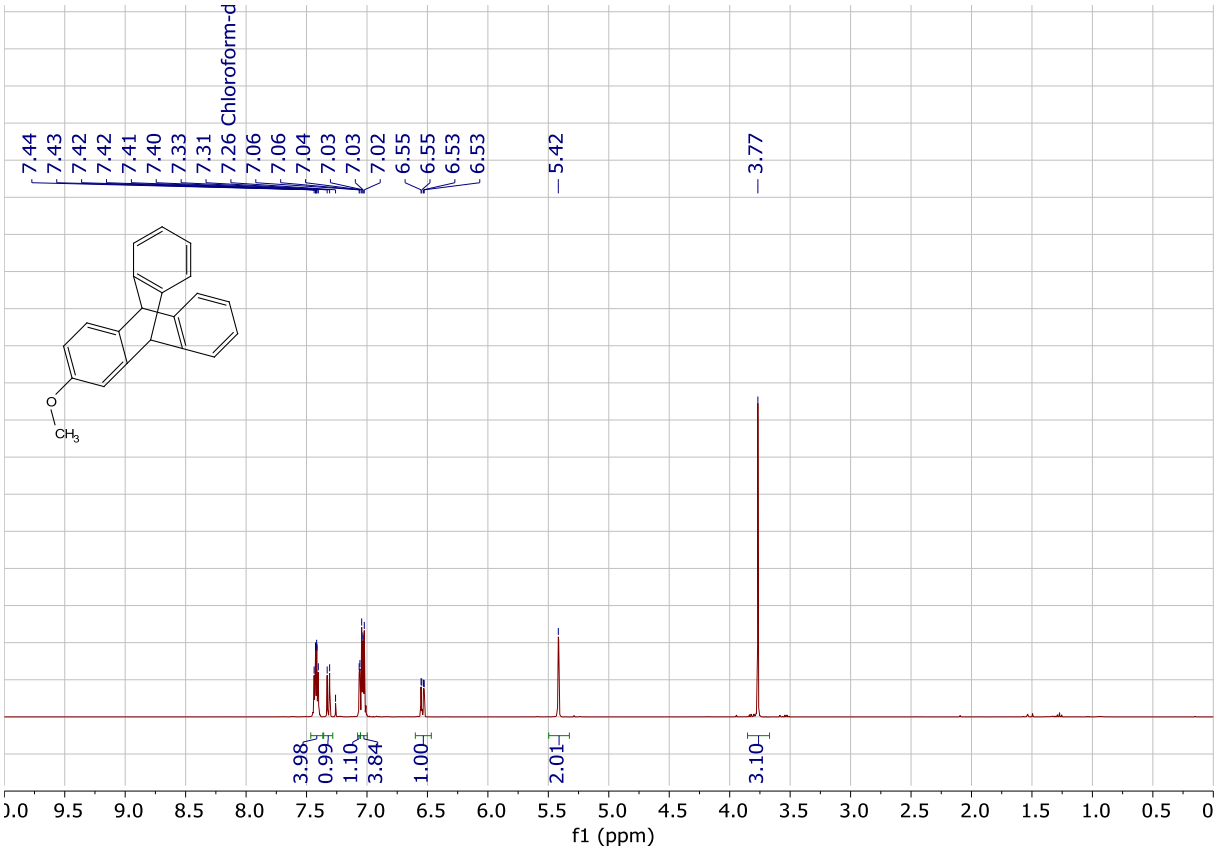


Fig. S7. ^{1}H NMR spectrum of **4** in Chloroform-*d*

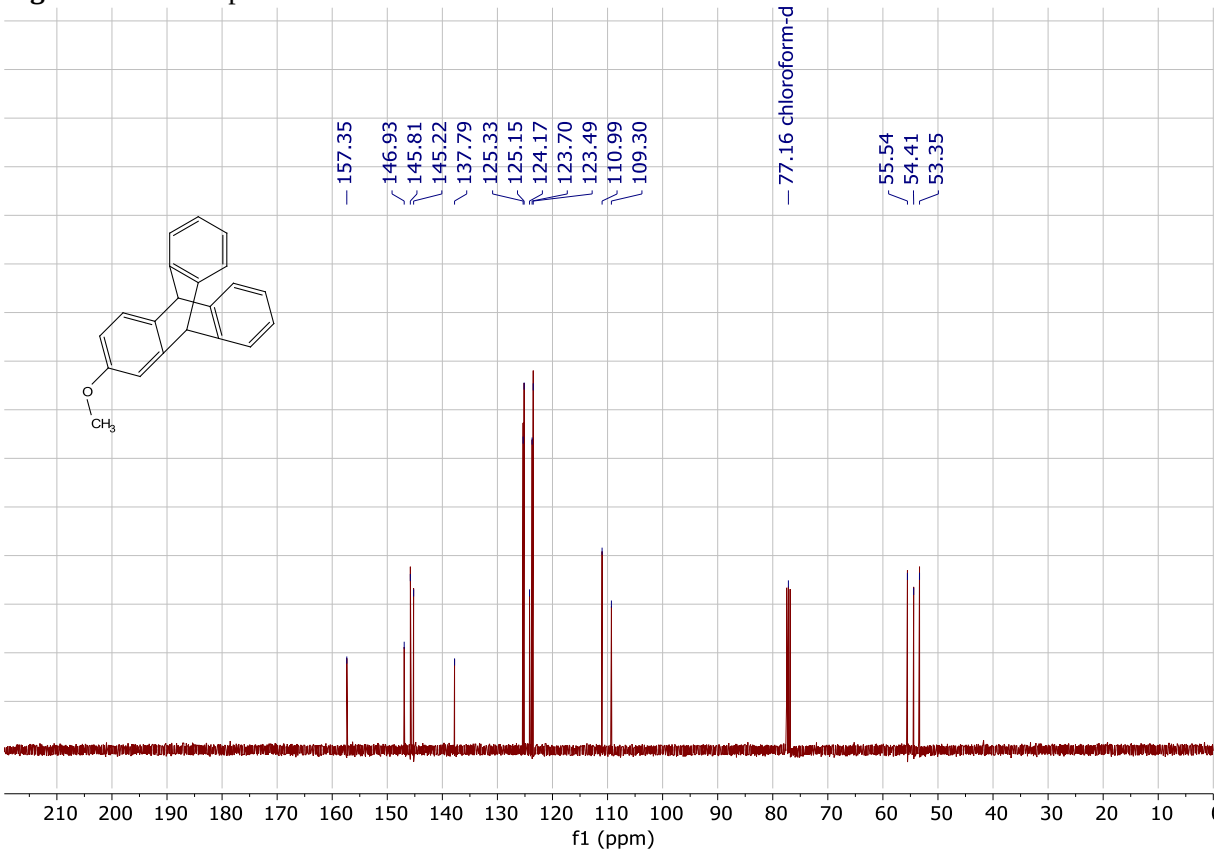


Fig. S8. ^{13}C NMR spectrum of **4** in Chloroform-*d*

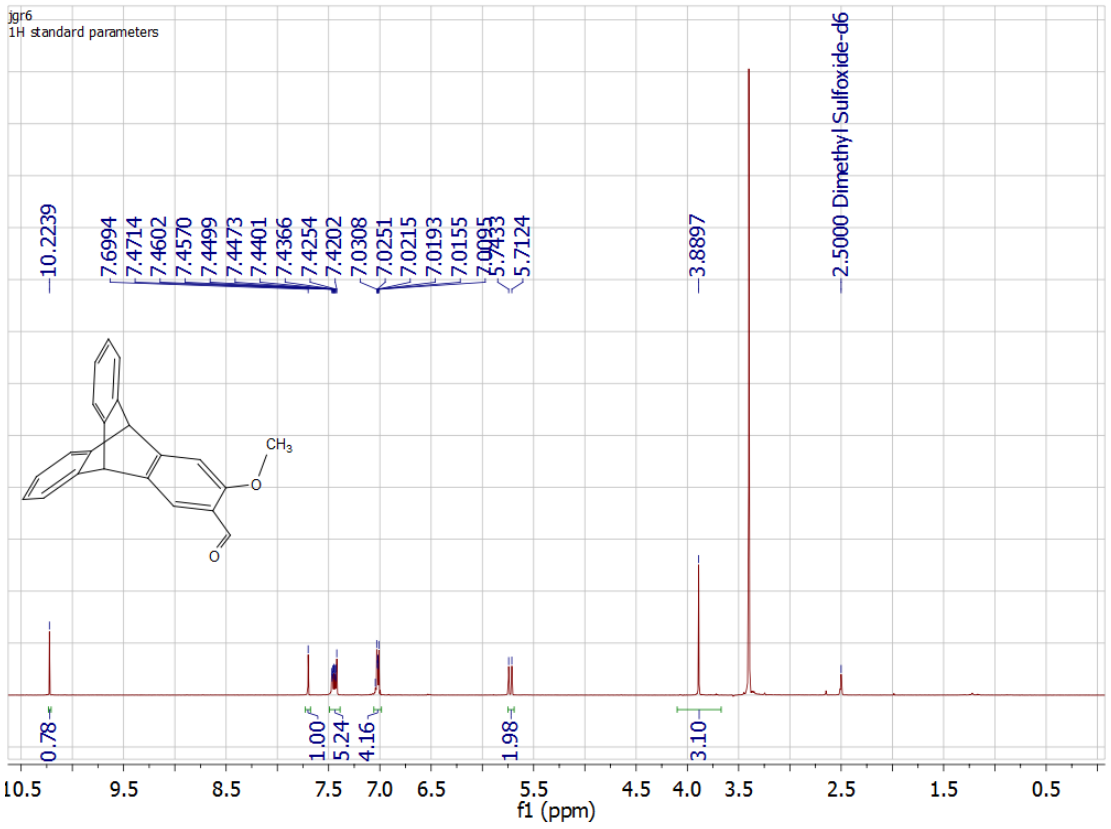


Fig. S9. ^{1}H NMR spectrum of **7** in DMSO-d_6

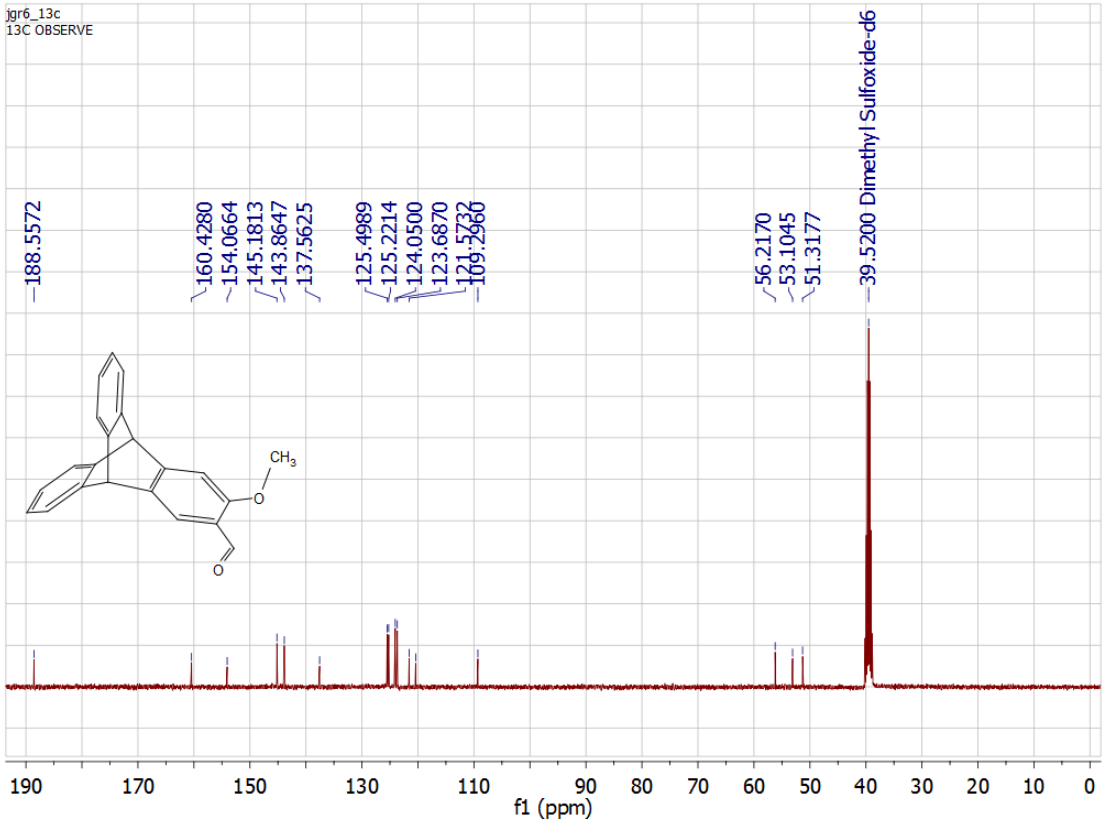


Fig. S10. ^{13}C NMR spectrum of **7** in DMSO-d_6

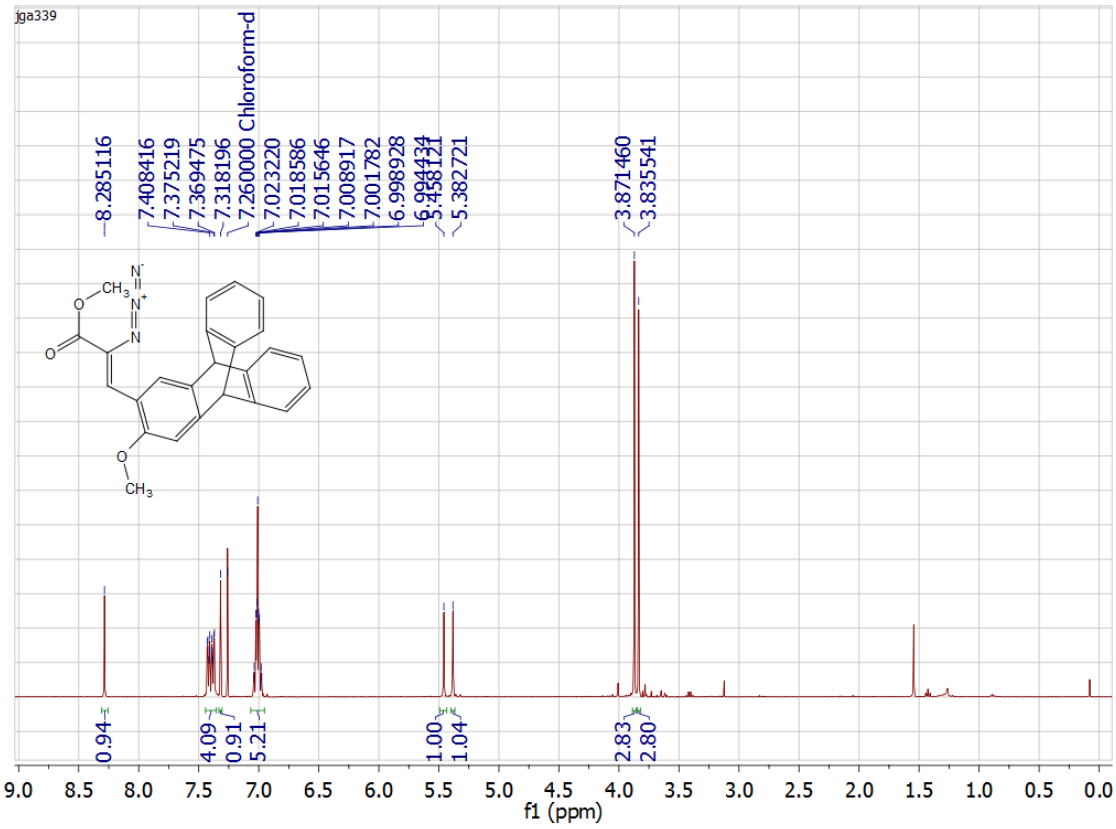


Fig. S11. [1]H NMR spectrum of **10** in Chloroform-*d*

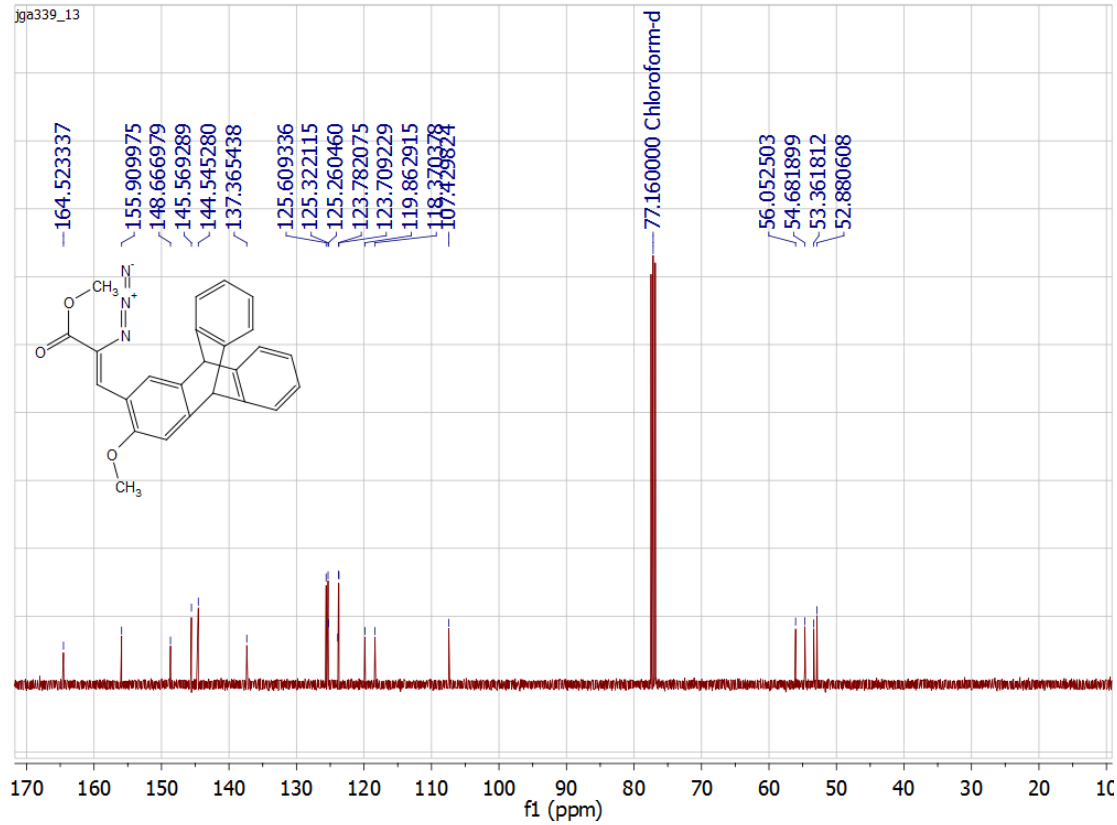


Fig. S12. [13]C NMR spectrum of **10** in Chloroform-*d*

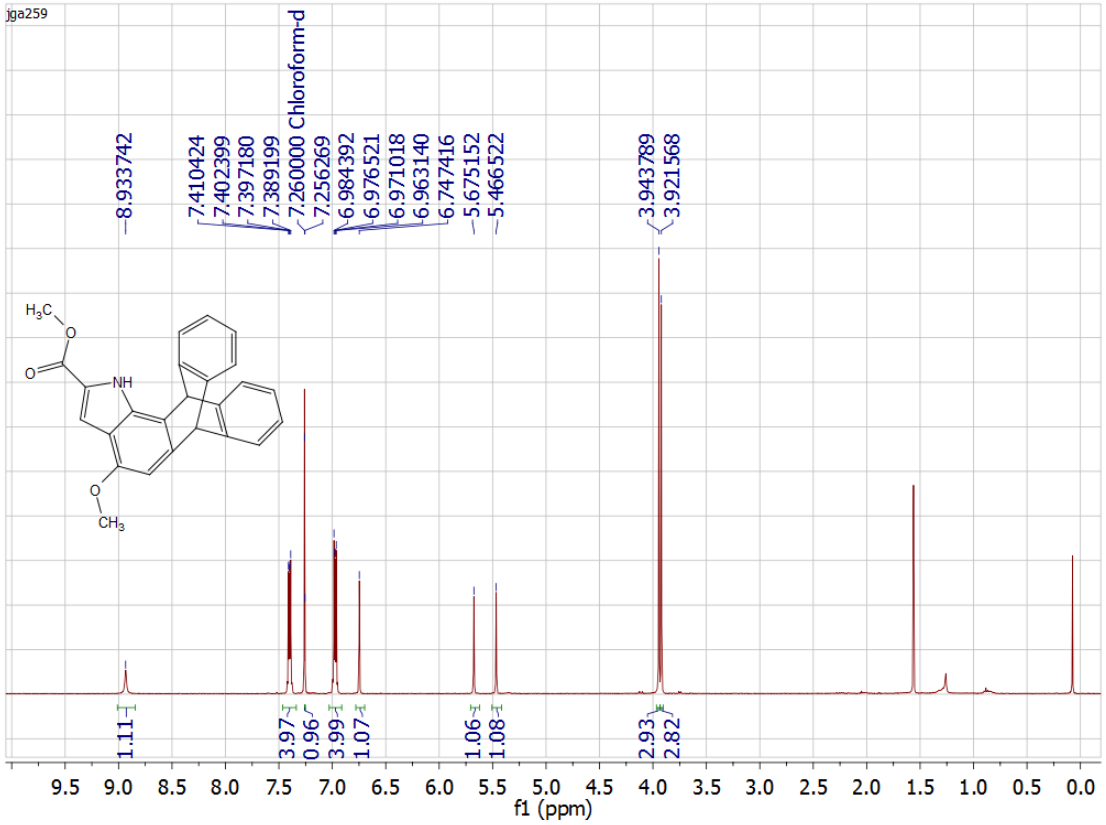


Fig. S13. [1]H NMR spectrum of **13** in Chloroform-*d*

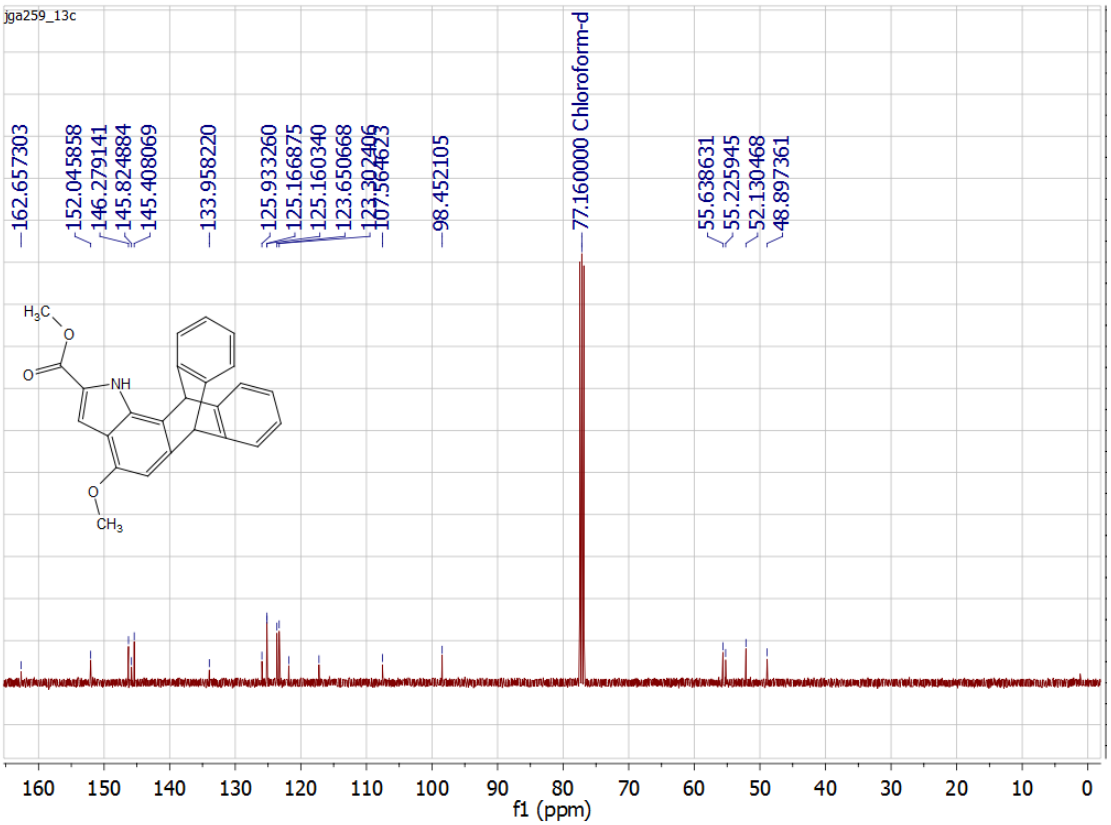


Fig. S14. [13]C NMR spectrum of **13** in Chloroform-*d*

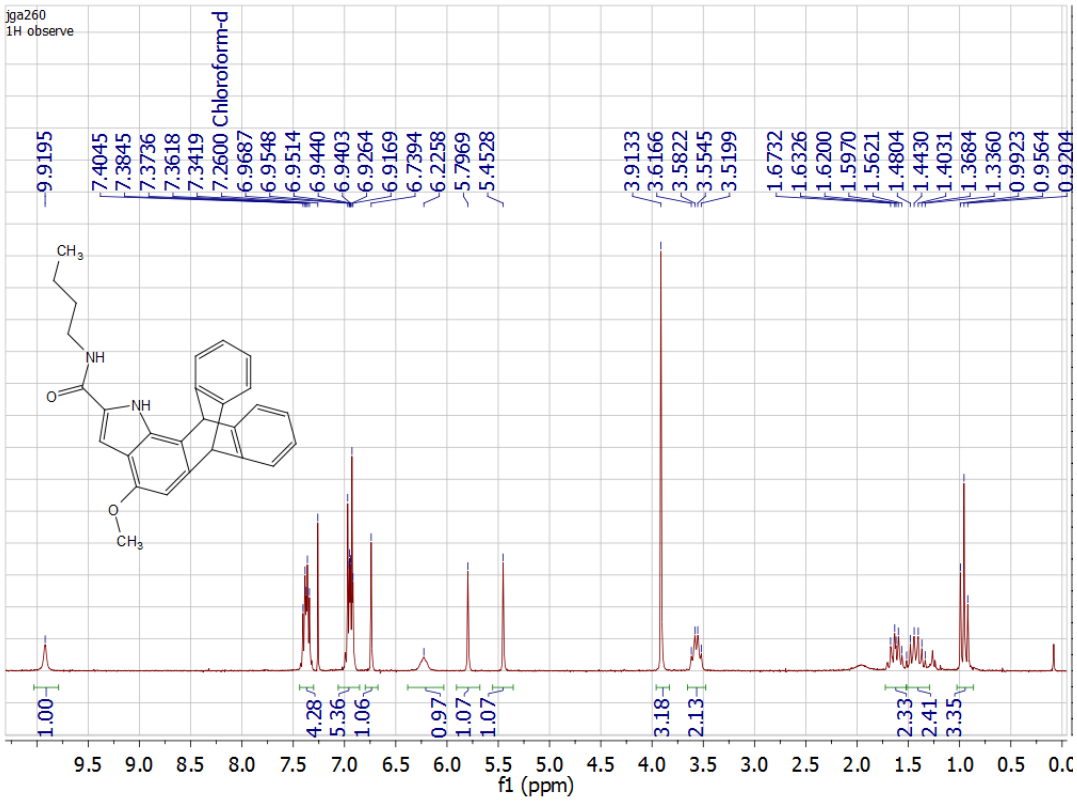


Fig. S15. ^{1}H NMR spectrum of **3** in Chloroform-*d*

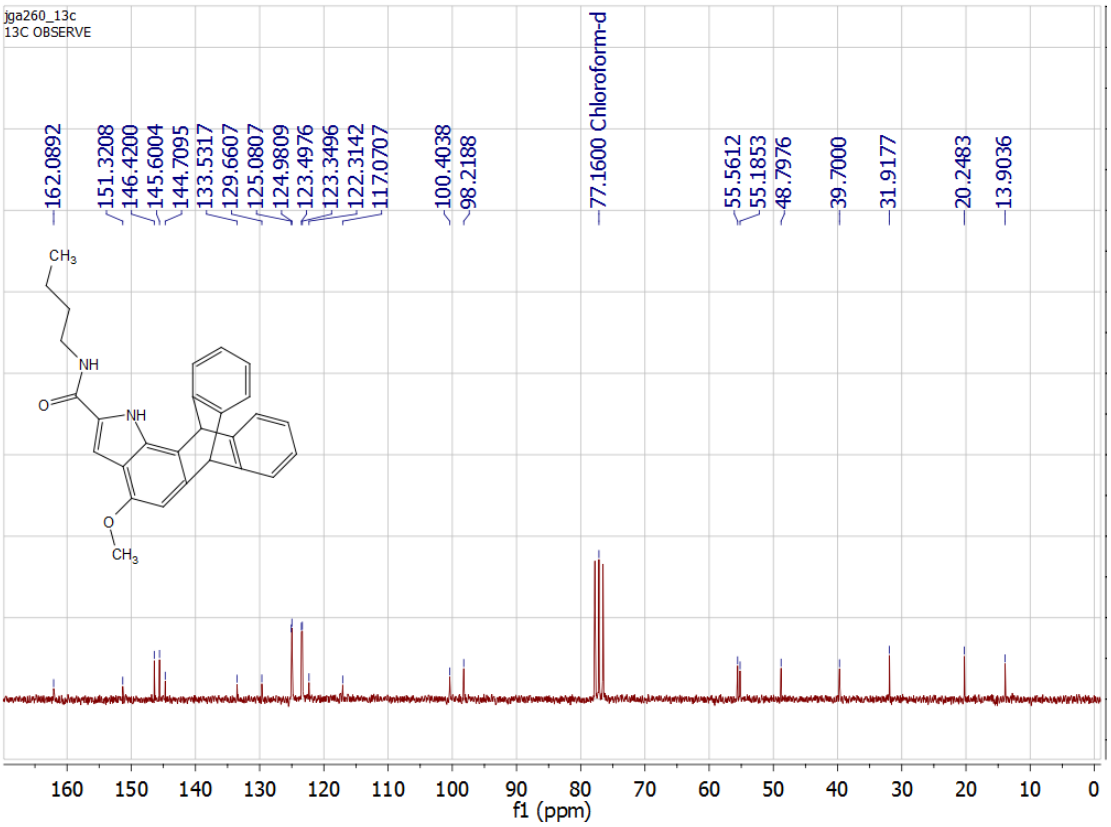


Fig. S16. ^{13}C NMR spectrum of **3** in Chloroform-*d*

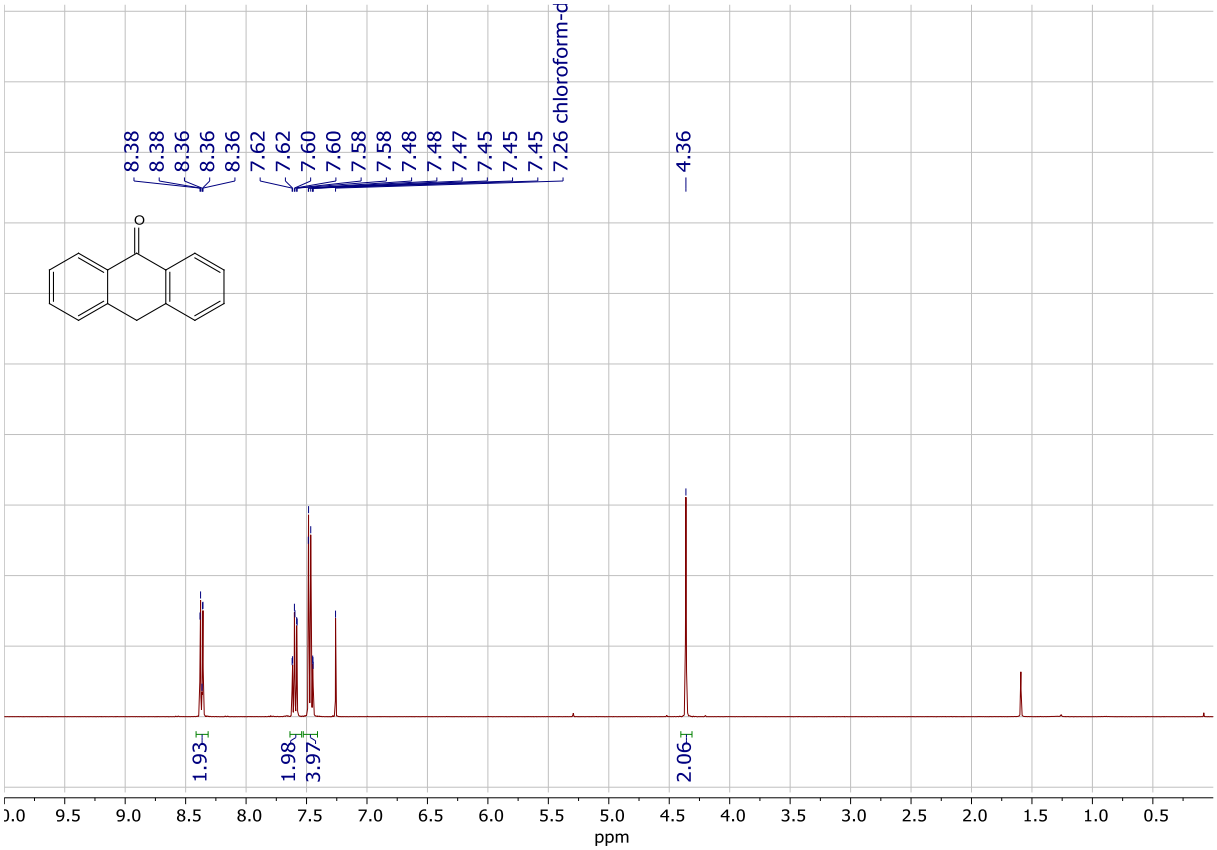


Fig. S17. [1]H NMR spectrum of **21** in Chloroform-*d*

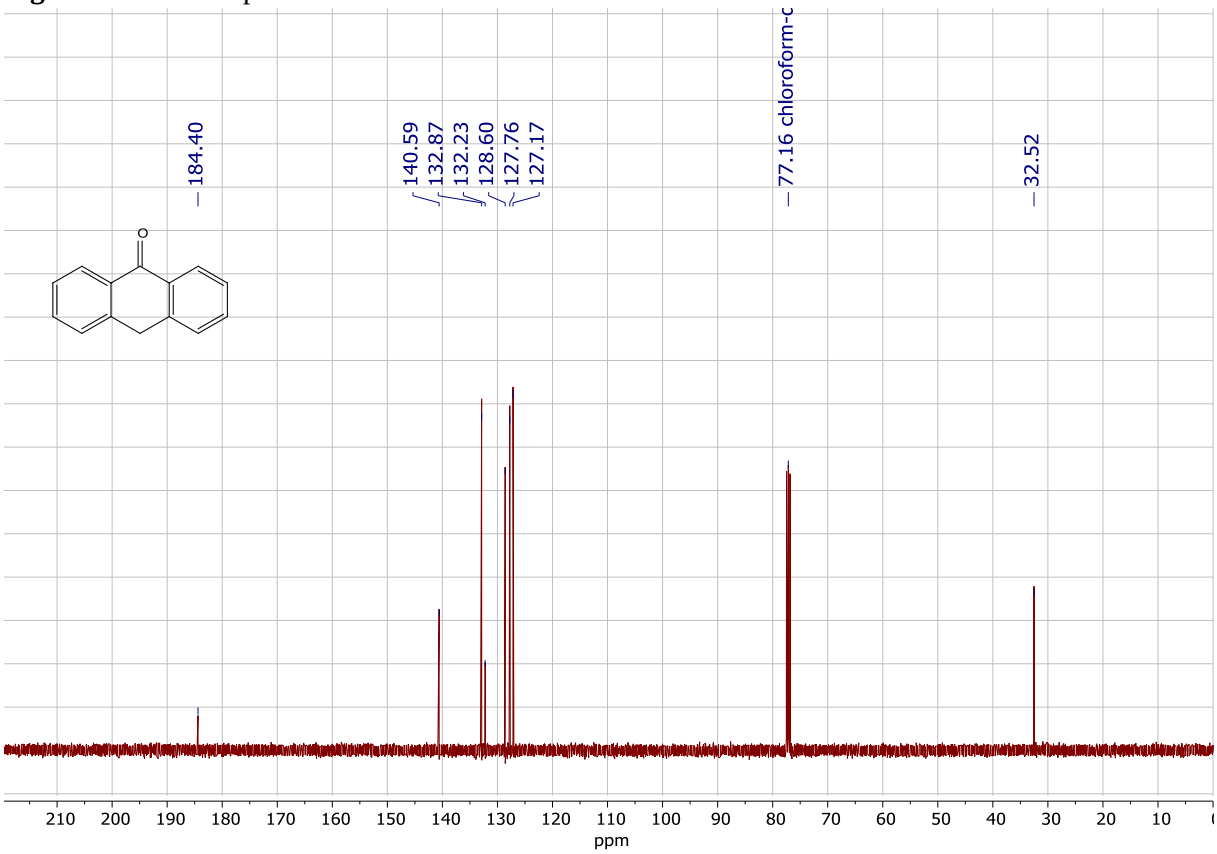


Fig. S18. [13]C NMR spectrum of **21** in Chloroform-*d*

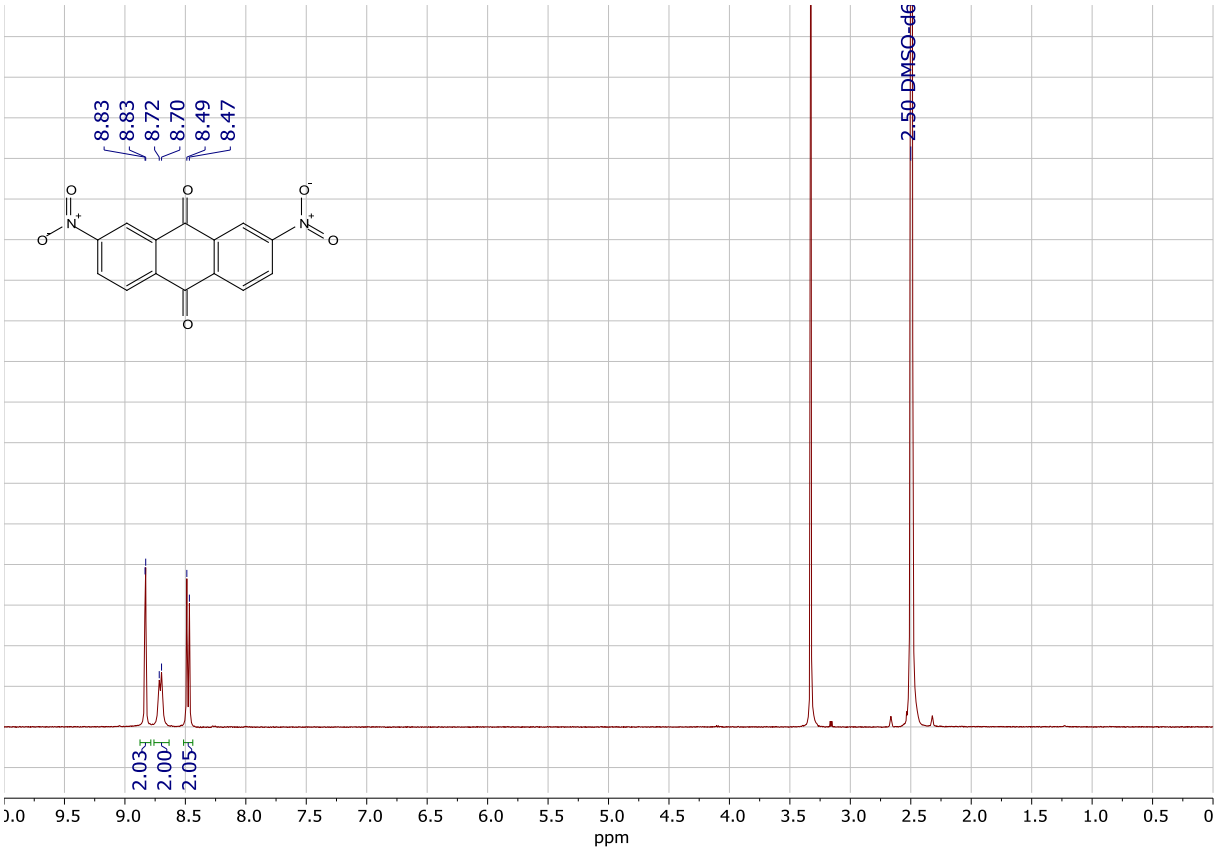


Fig. S19. ^{1}H NMR spectrum of **22** in DMSO-d_6

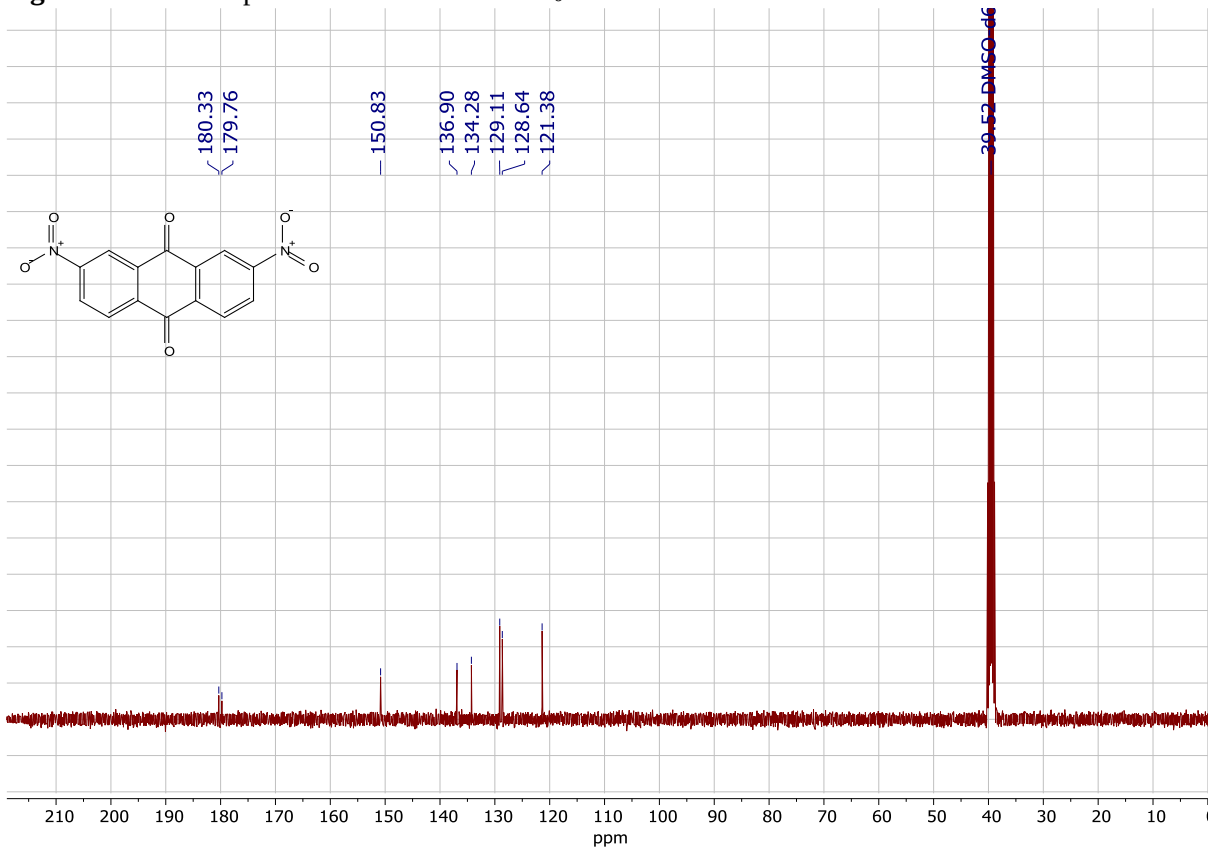


Fig. S20. ^{13}C NMR spectrum of **22** in DMSO-d_6

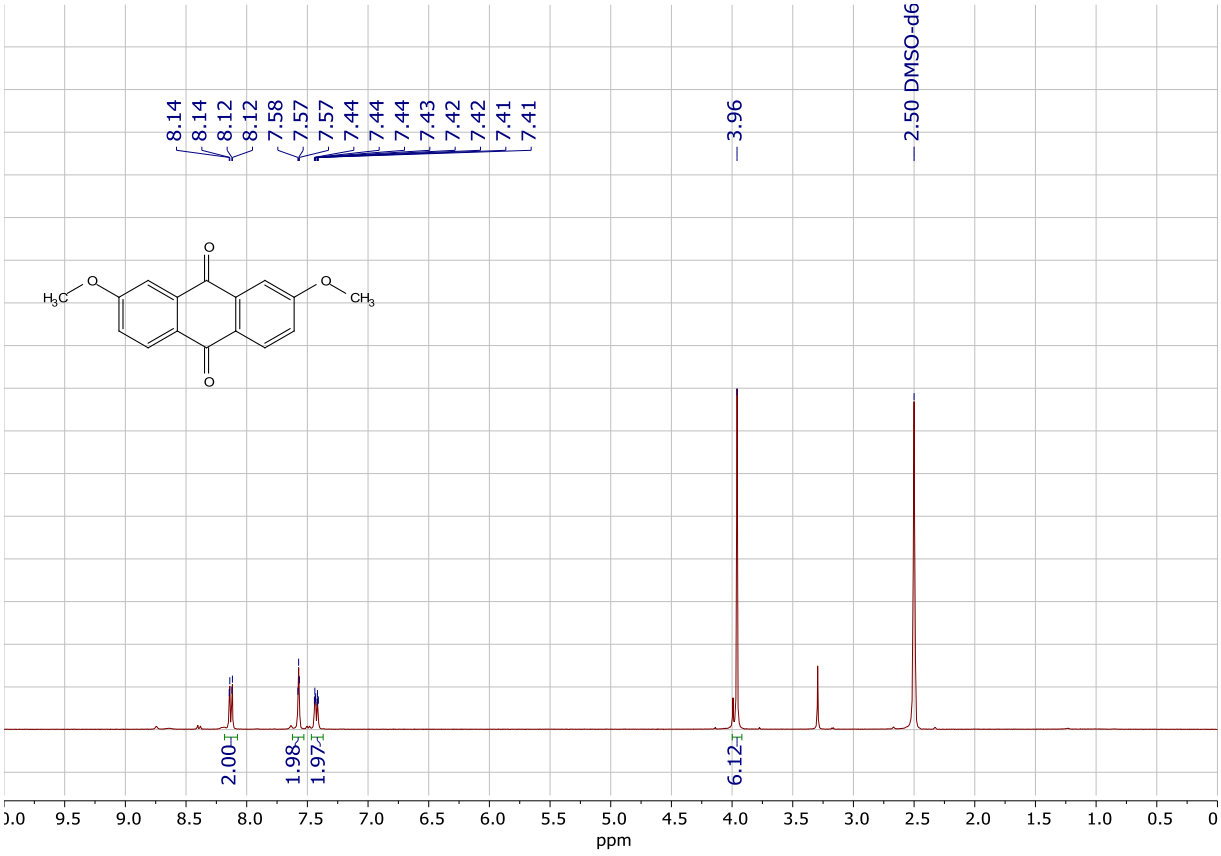


Fig. S21. ^{1}H NMR spectrum of **23** in DMSO-d_6

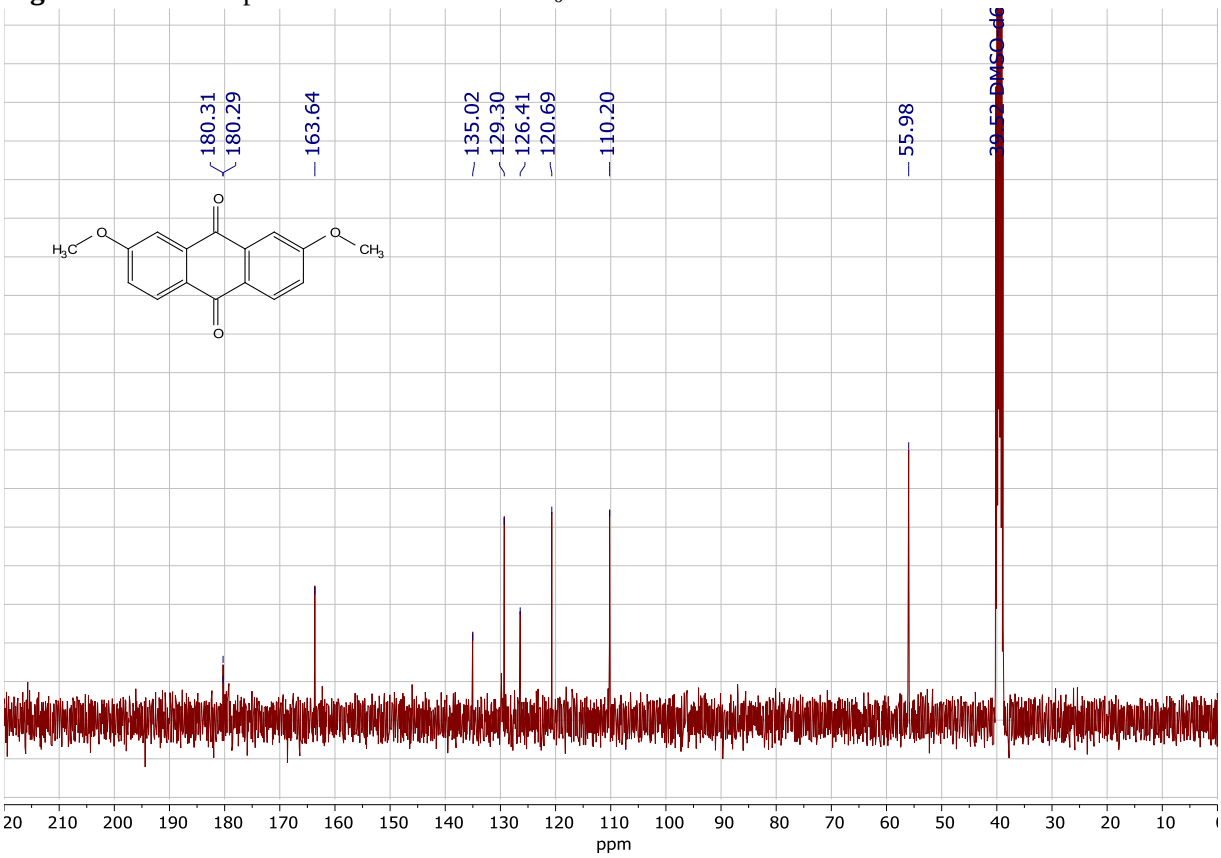


Fig. S22. ^{13}C NMR spectrum of **23** in DMSO-d_6

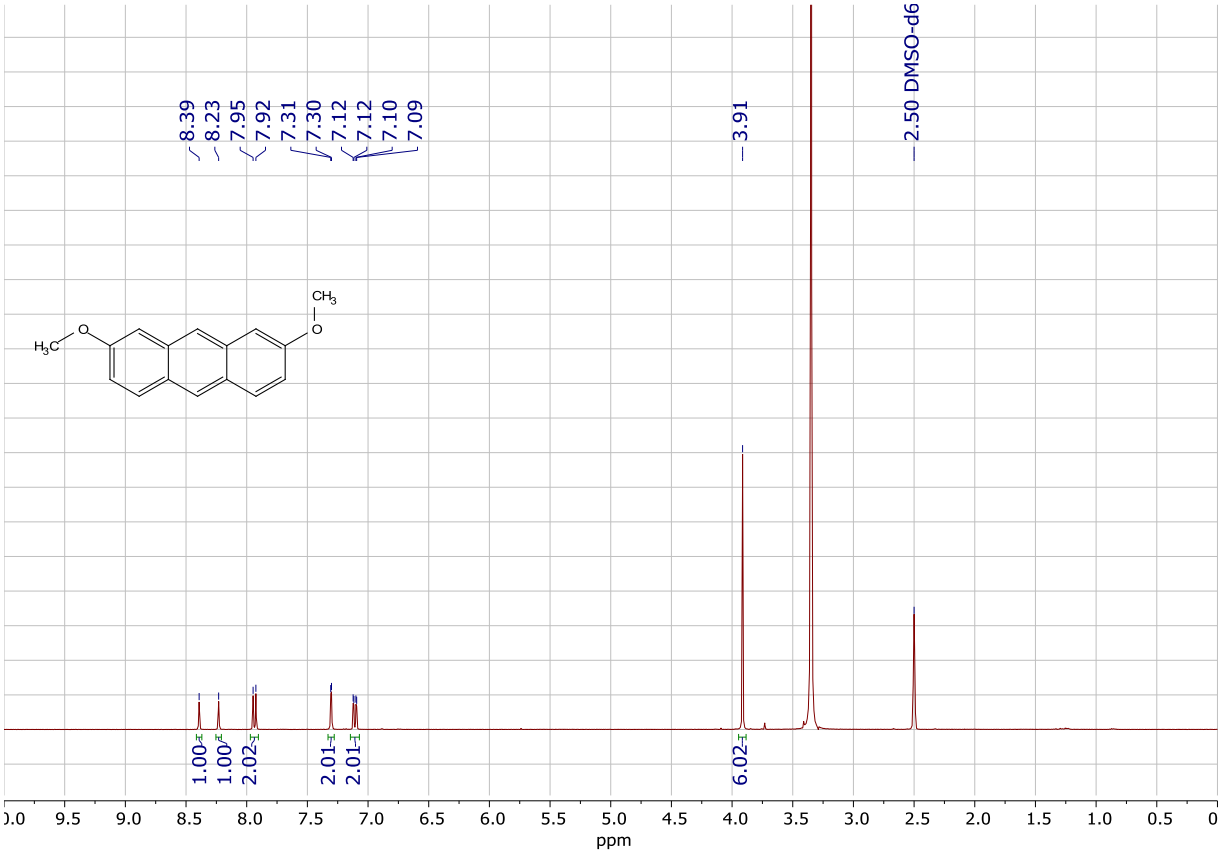


Fig. S23. ^{1}H NMR spectrum of **24** in DMSO-d_6

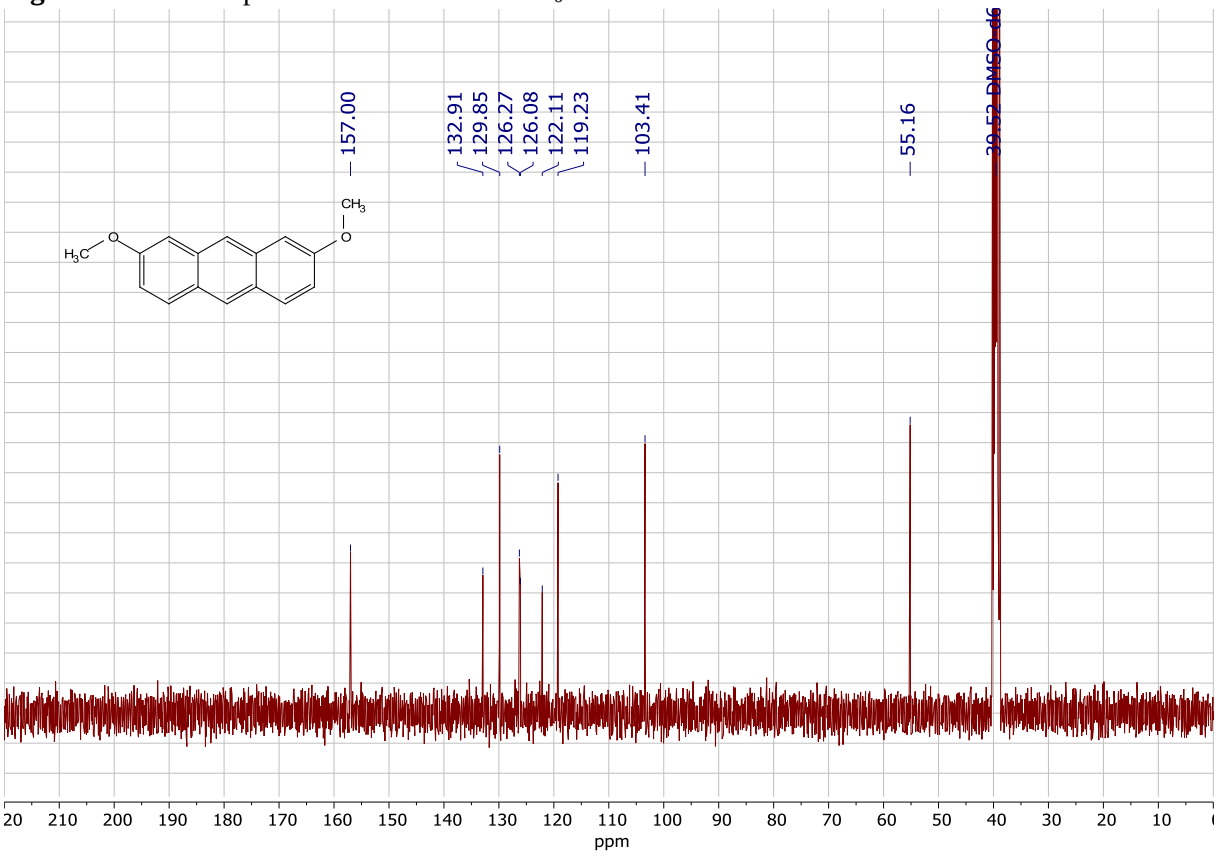


Fig. S24. ^{13}C NMR spectrum of **24** in DMSO-d_6

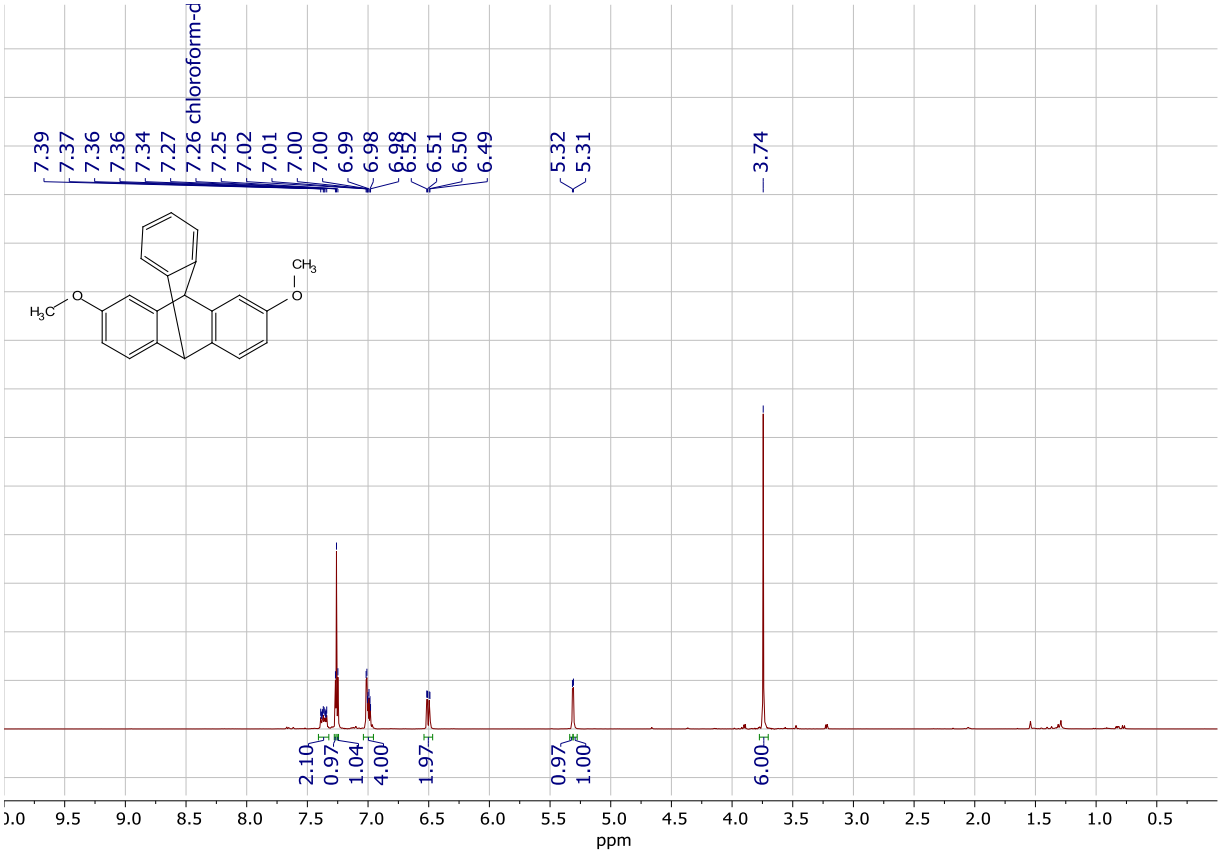


Fig. S25. [1]H NMR spectrum of **25** in Chloroform-*d*

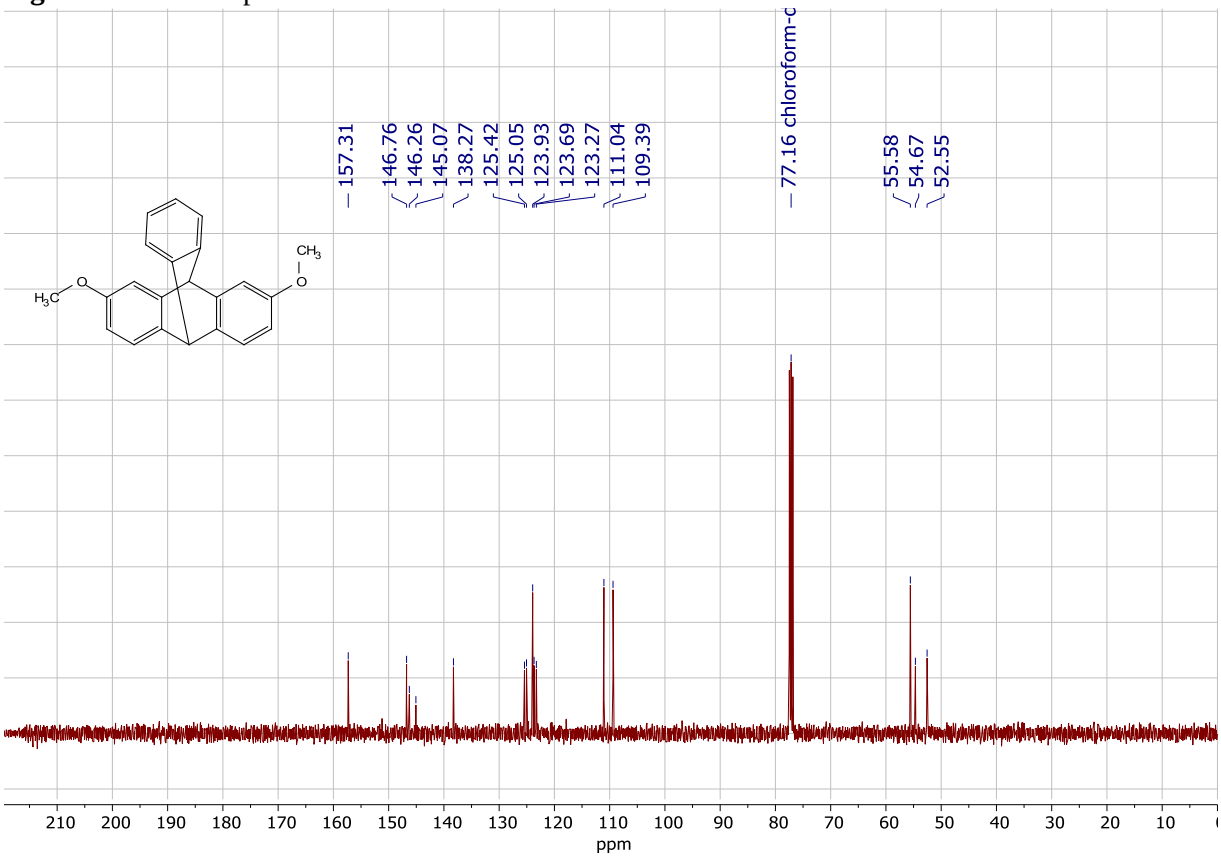


Fig. S26. [13]C NMR spectrum of **25** in Chloroform-*d*

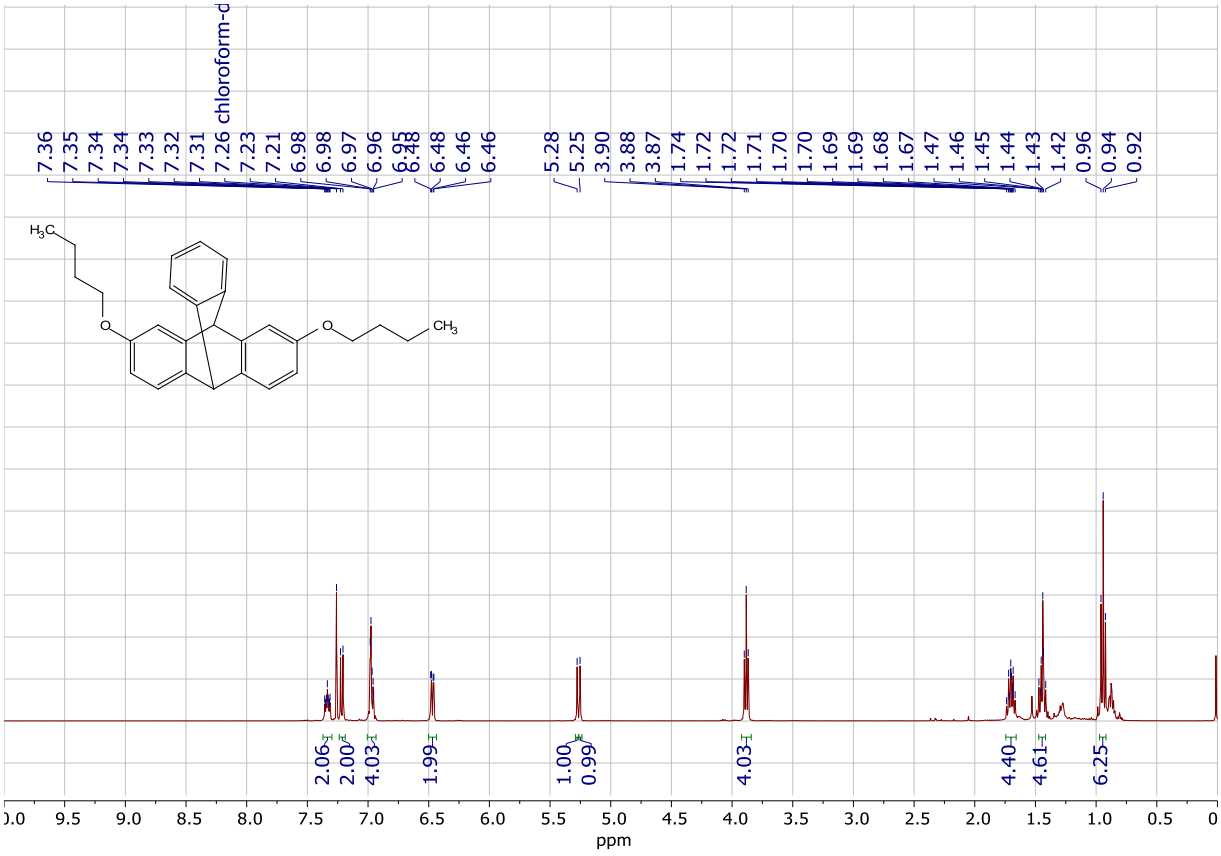


Fig. S27. [1]H NMR spectrum of **5** in Chloroform-*d*

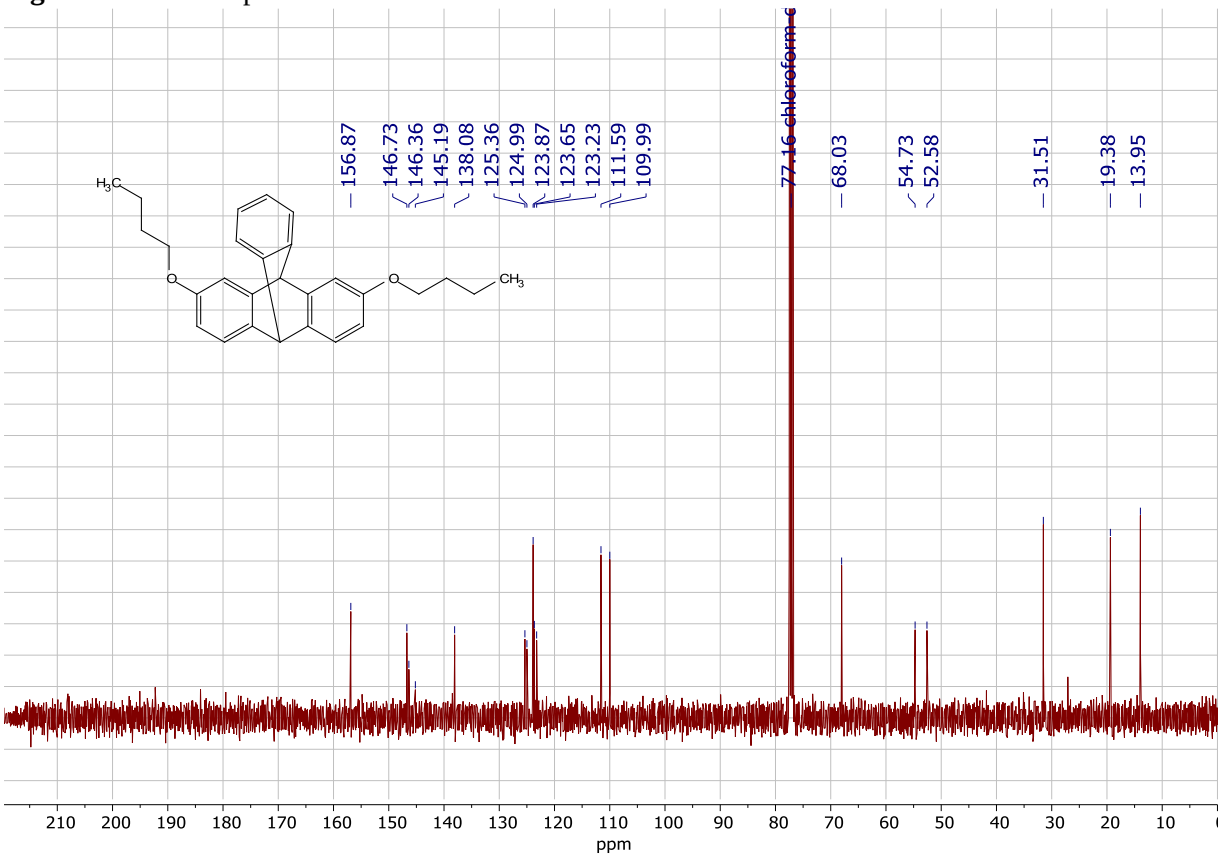


Fig. S28. [13]C NMR spectrum of **5** in Chloroform-*d*

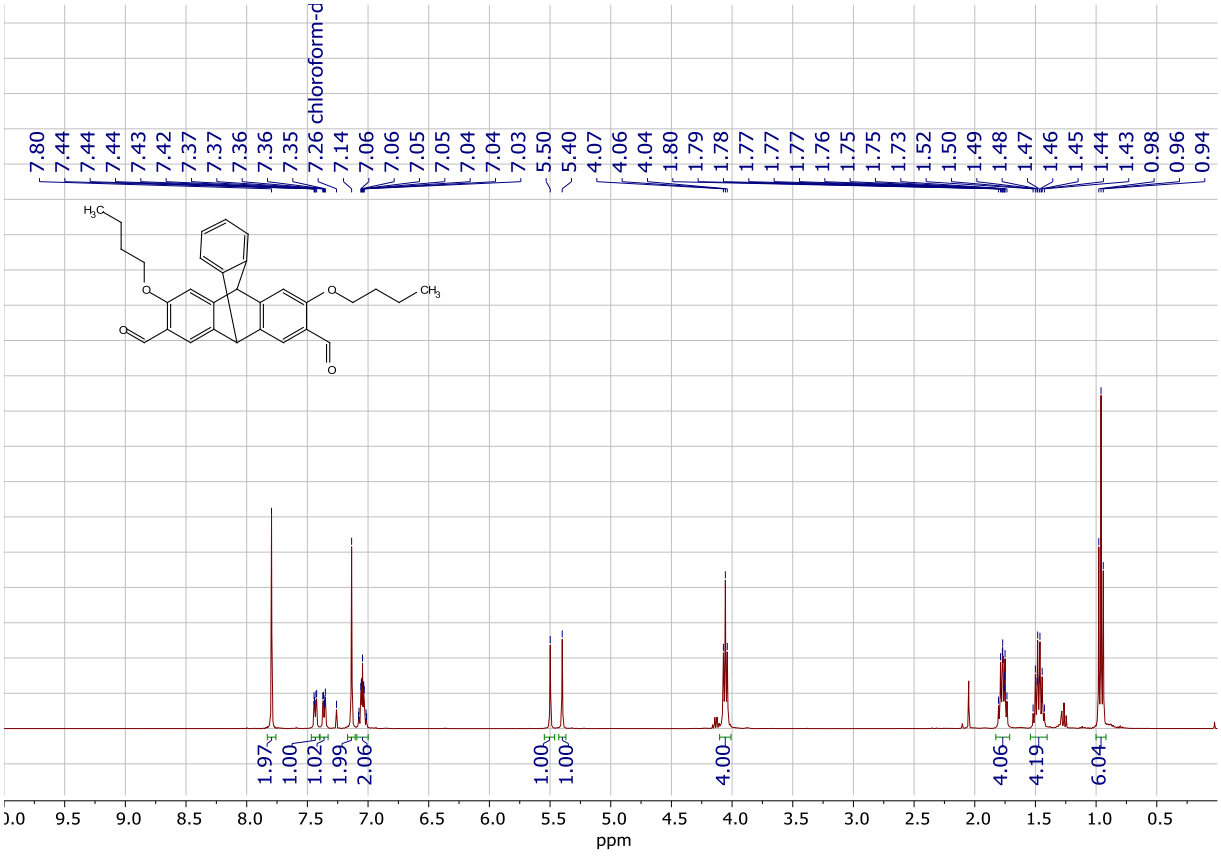


Fig. S29. [1]H NMR spectrum of **8** in Chloroform-*d*

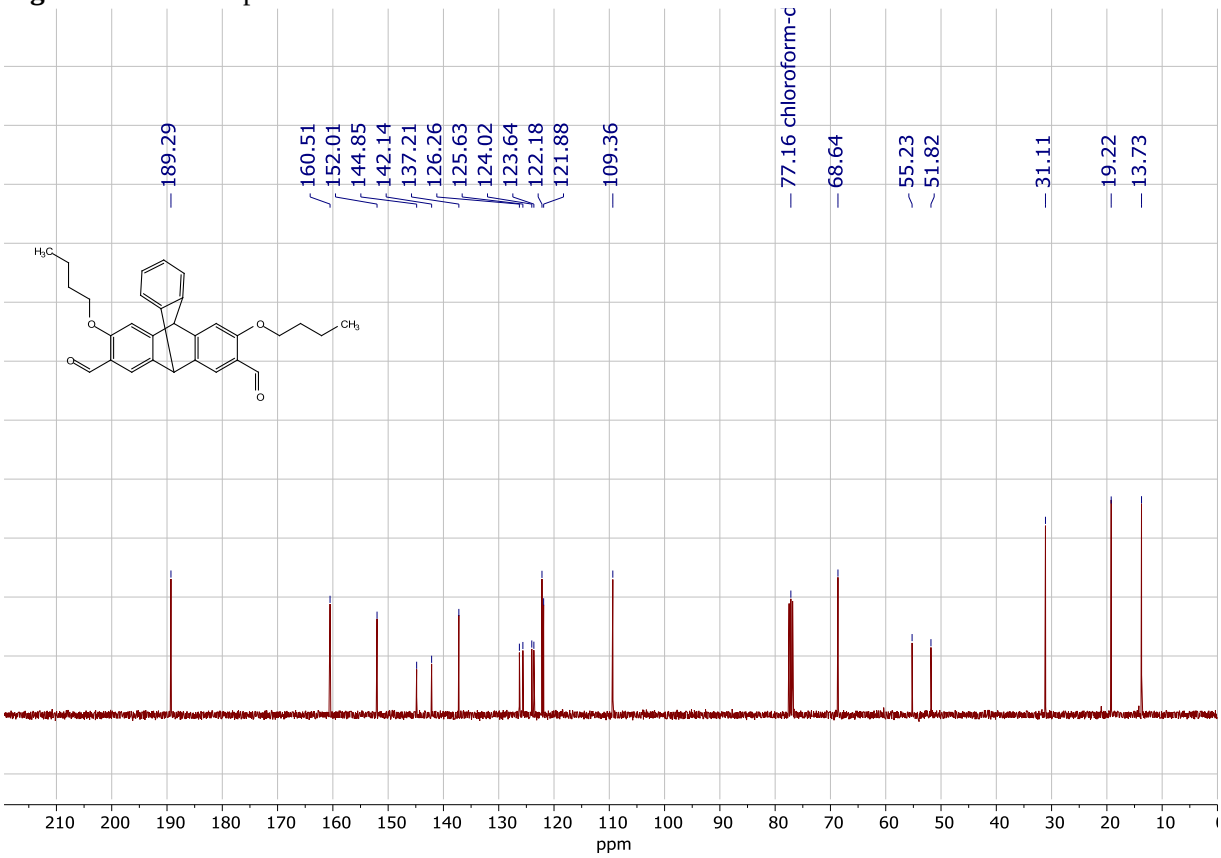


Fig. S30. [13]C NMR spectrum of **8** in Chloroform-*d*

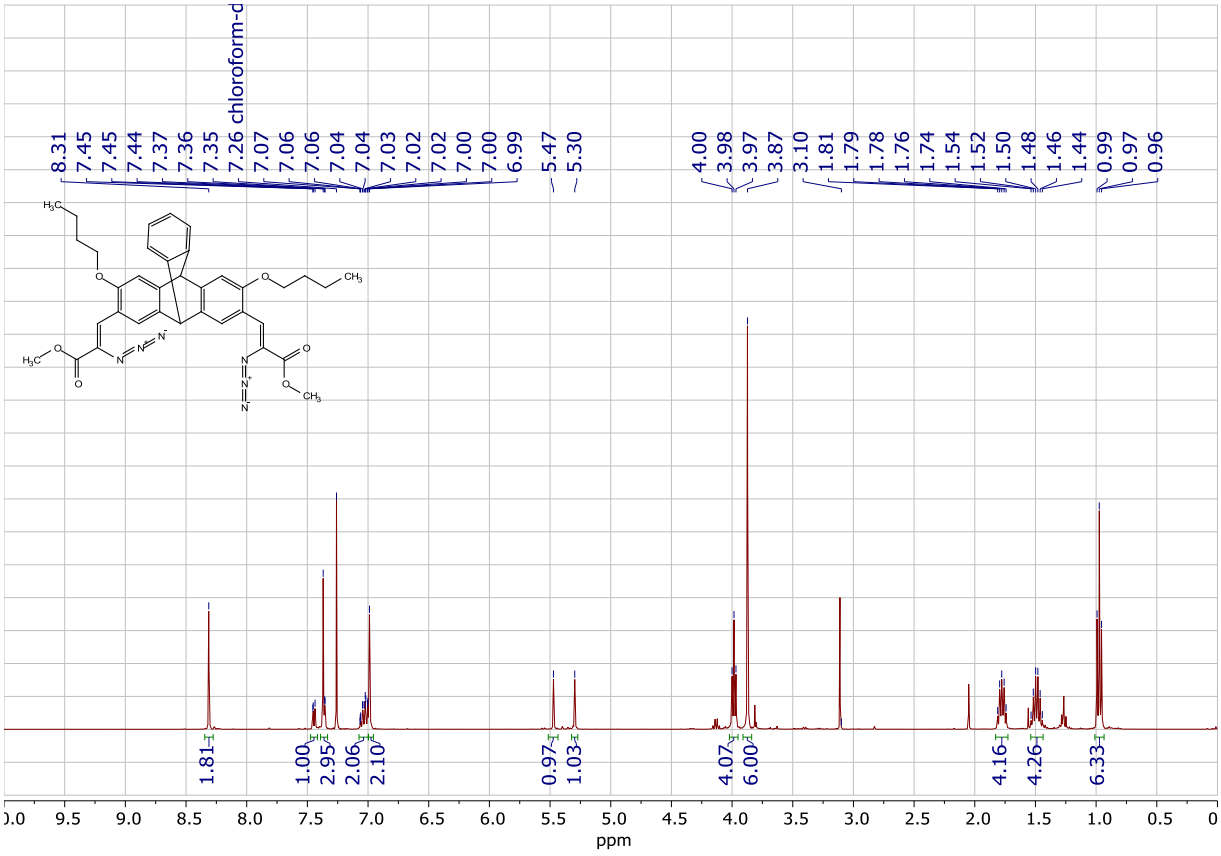


Fig. S31. [1]H NMR spectrum of **11** in Chloroform-*d*

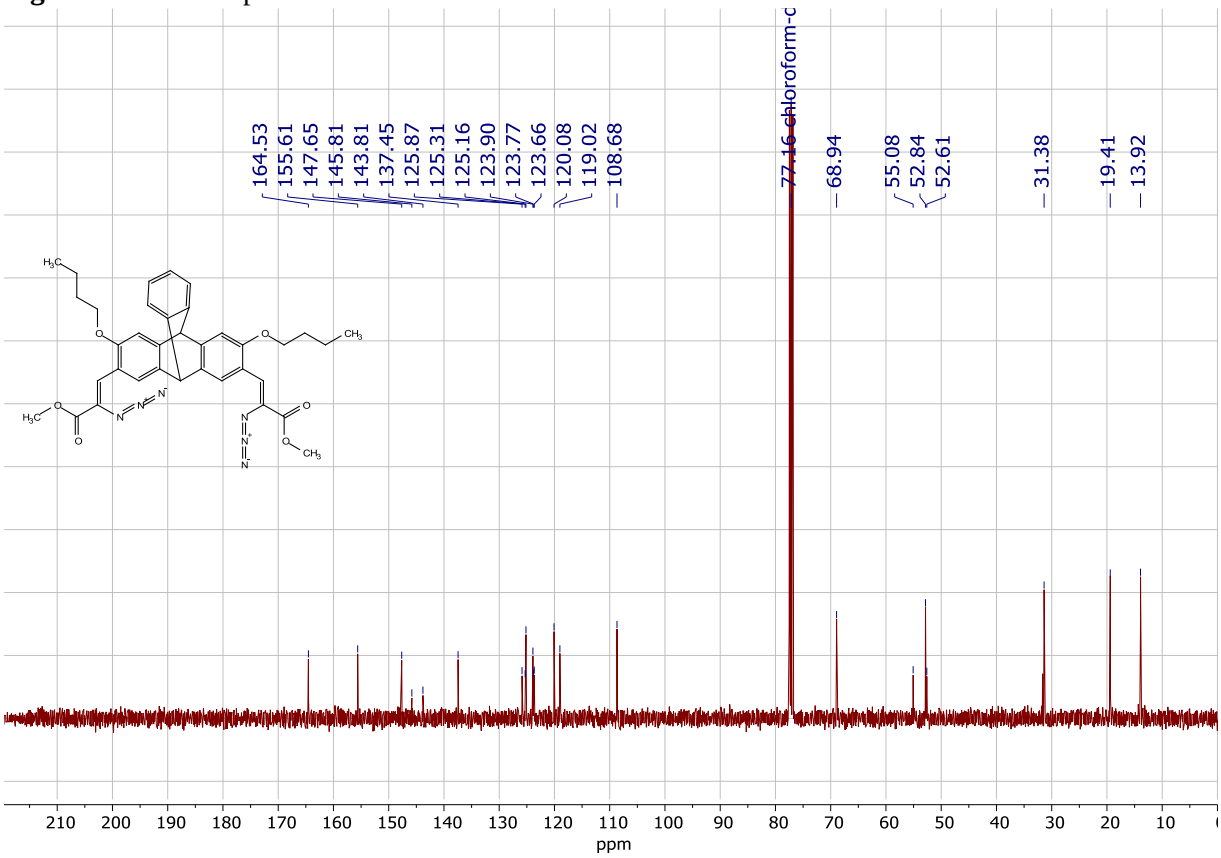


Fig. S32. [13]C NMR spectrum of **11** in Chloroform-*d*

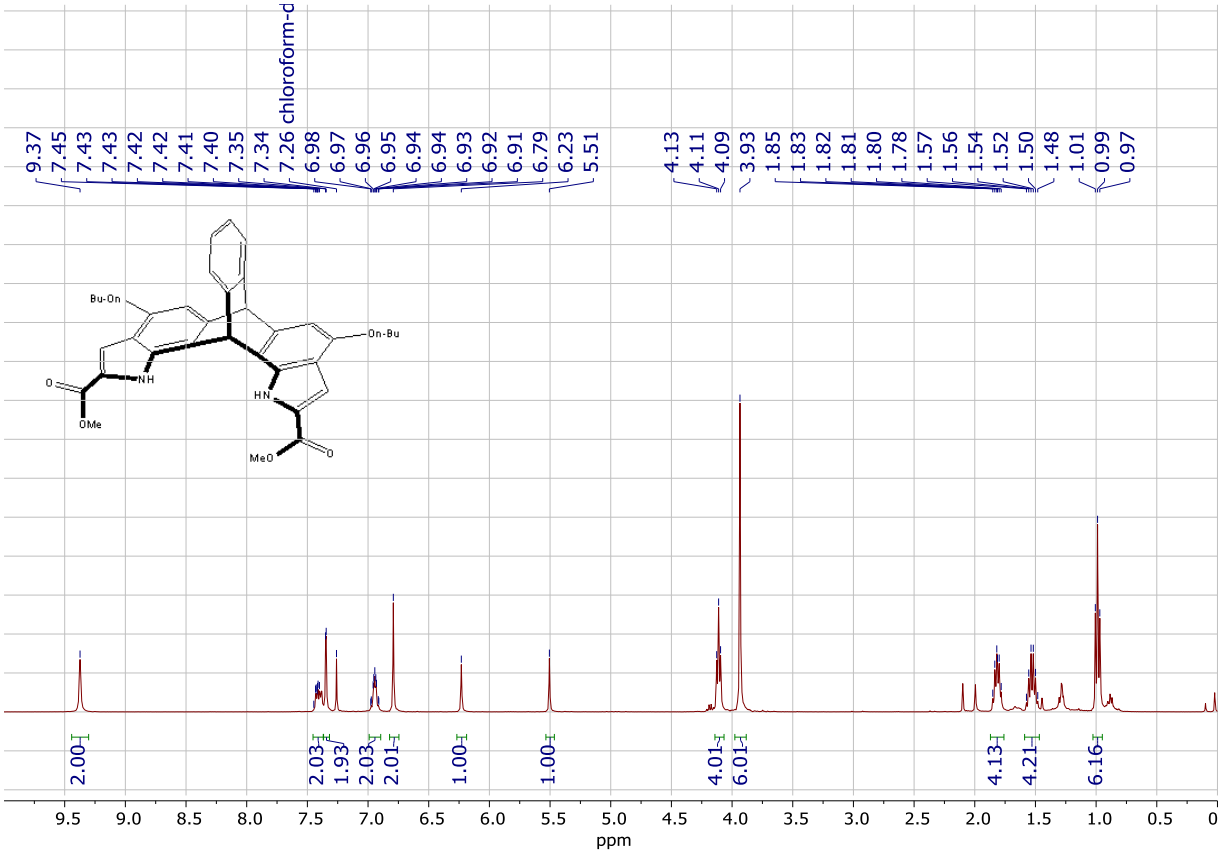


Fig. S33. [1]H NMR spectrum of **14** in Chloroform-*d*

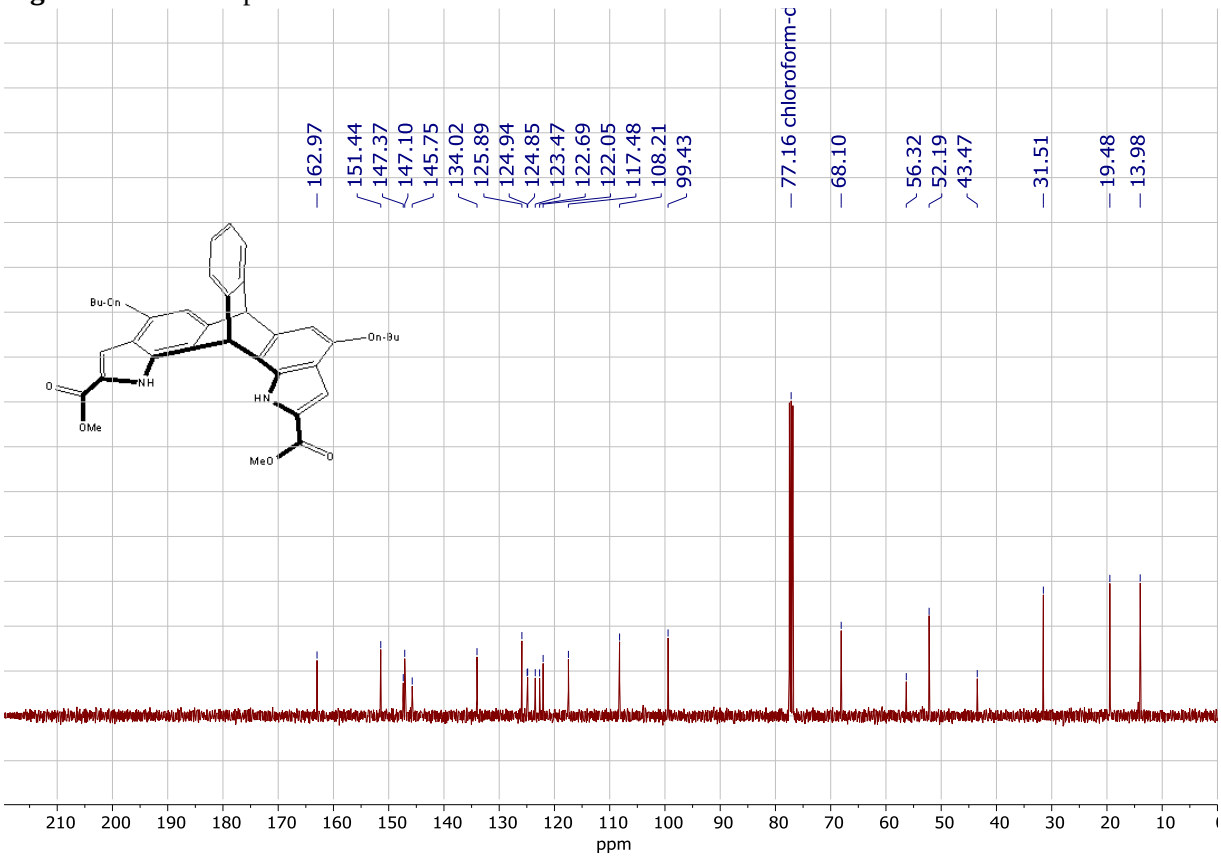


Fig. S34. [13]C NMR spectrum of **14** in Chloroform-*d*

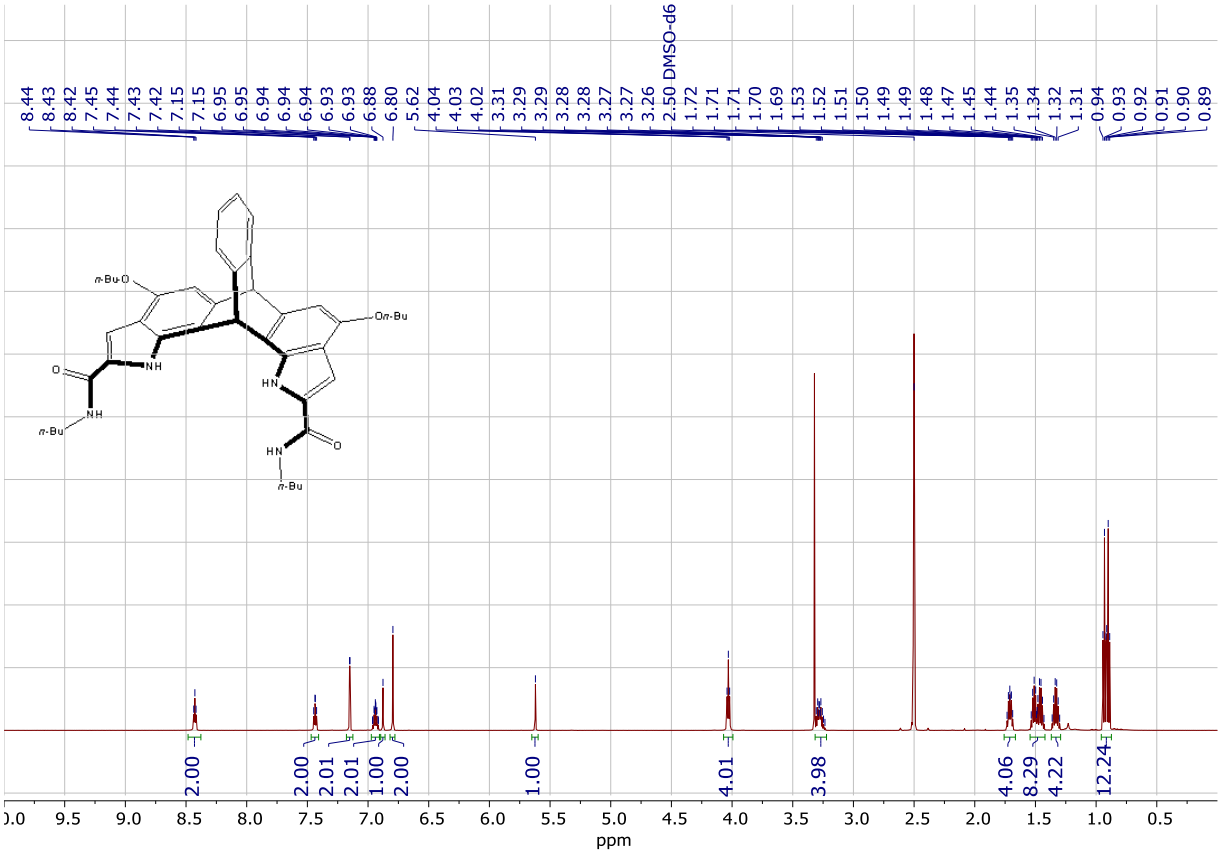


Fig. S35. [1]H NMR spectrum of **2** in DMSO-d_6

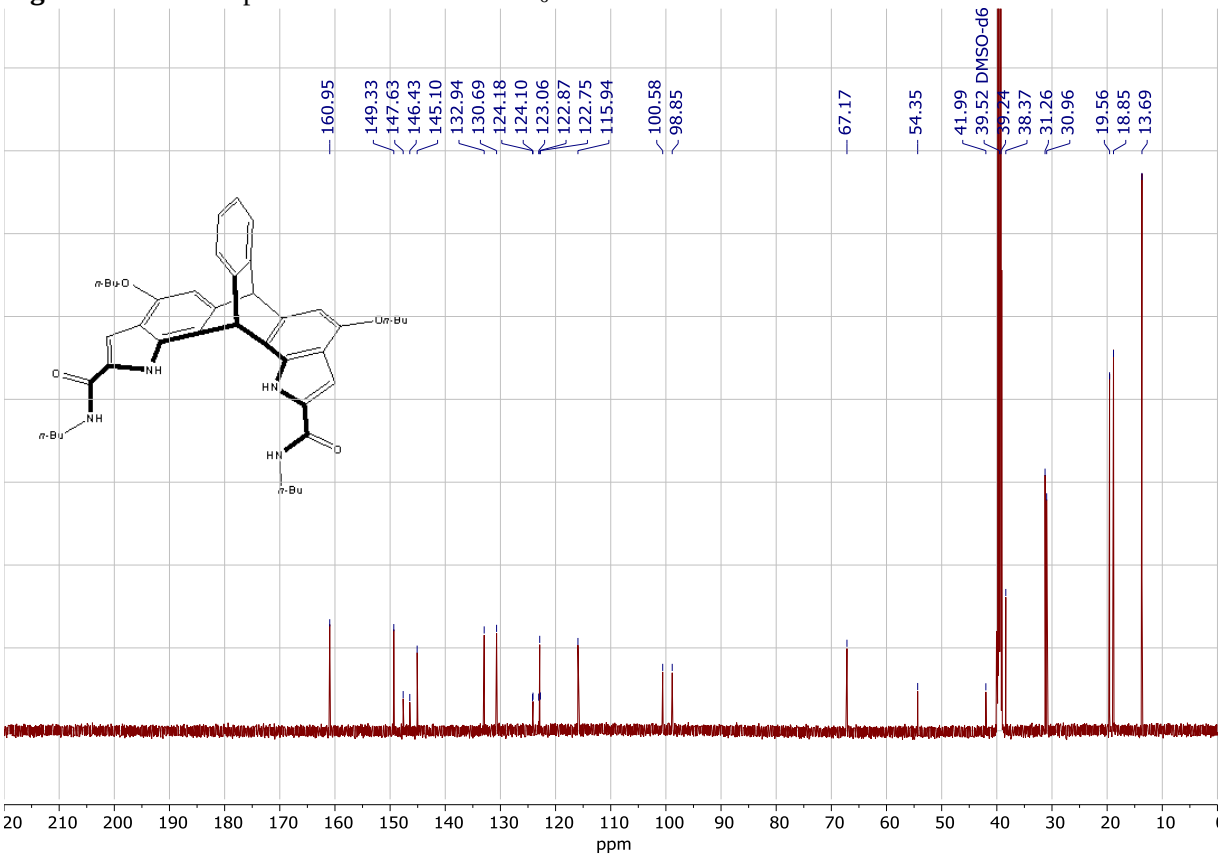


Fig. S36. [13]C NMR spectrum of **2** in DMSO-d_6

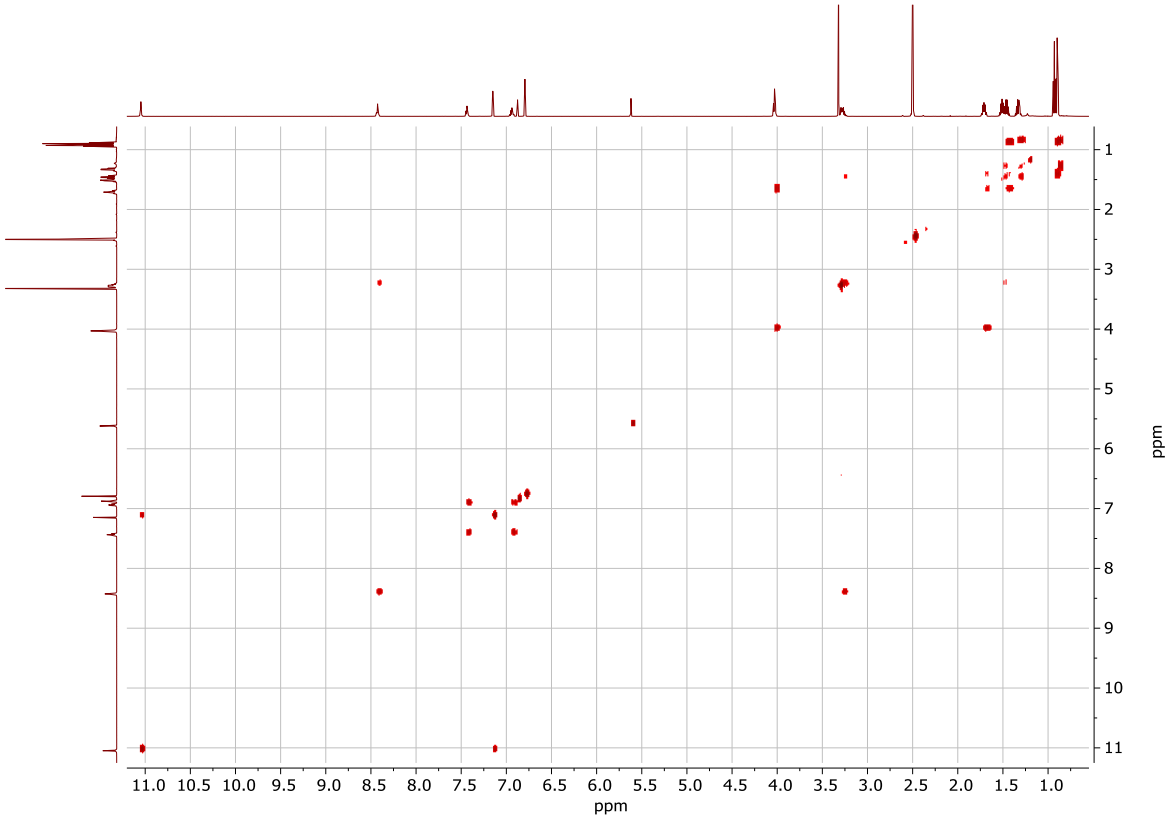


Fig. S37. COSY NMR spectrum of **2** in DMSO-d_6

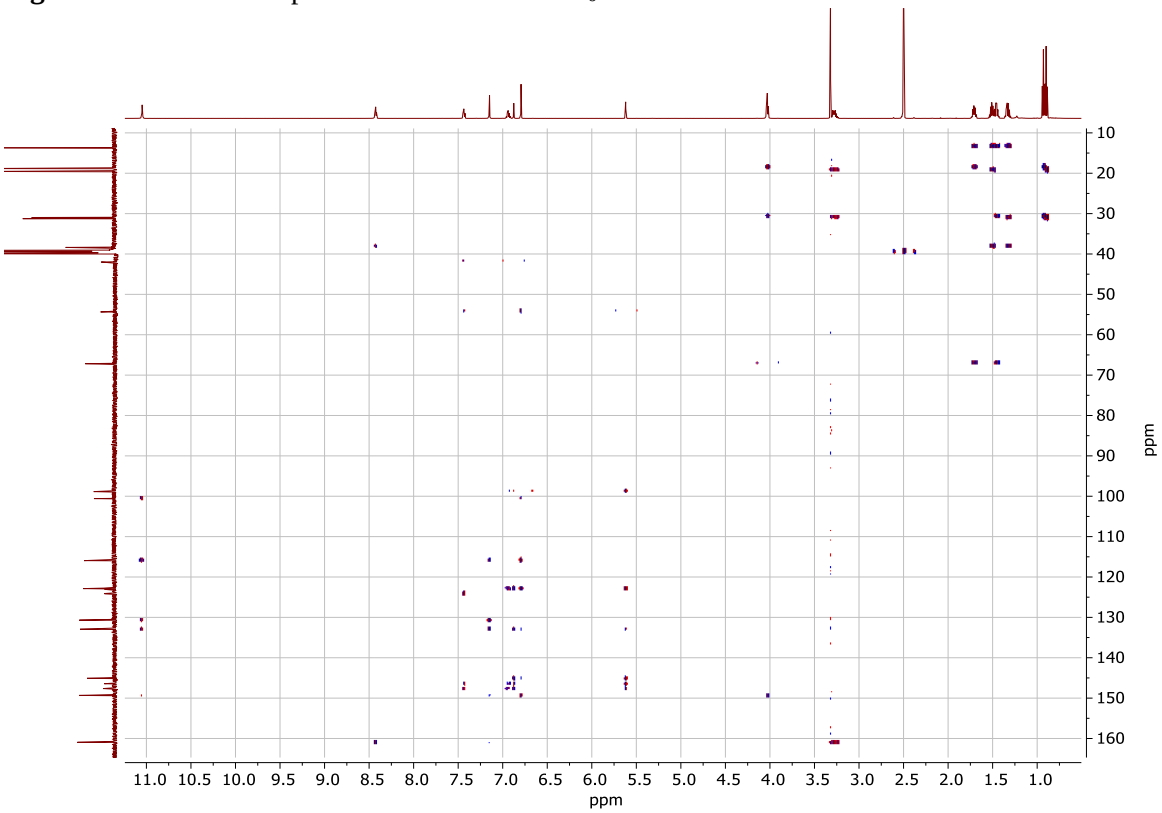


Fig. S38. HMBC NMR spectrum of **2** in DMSO-d_6

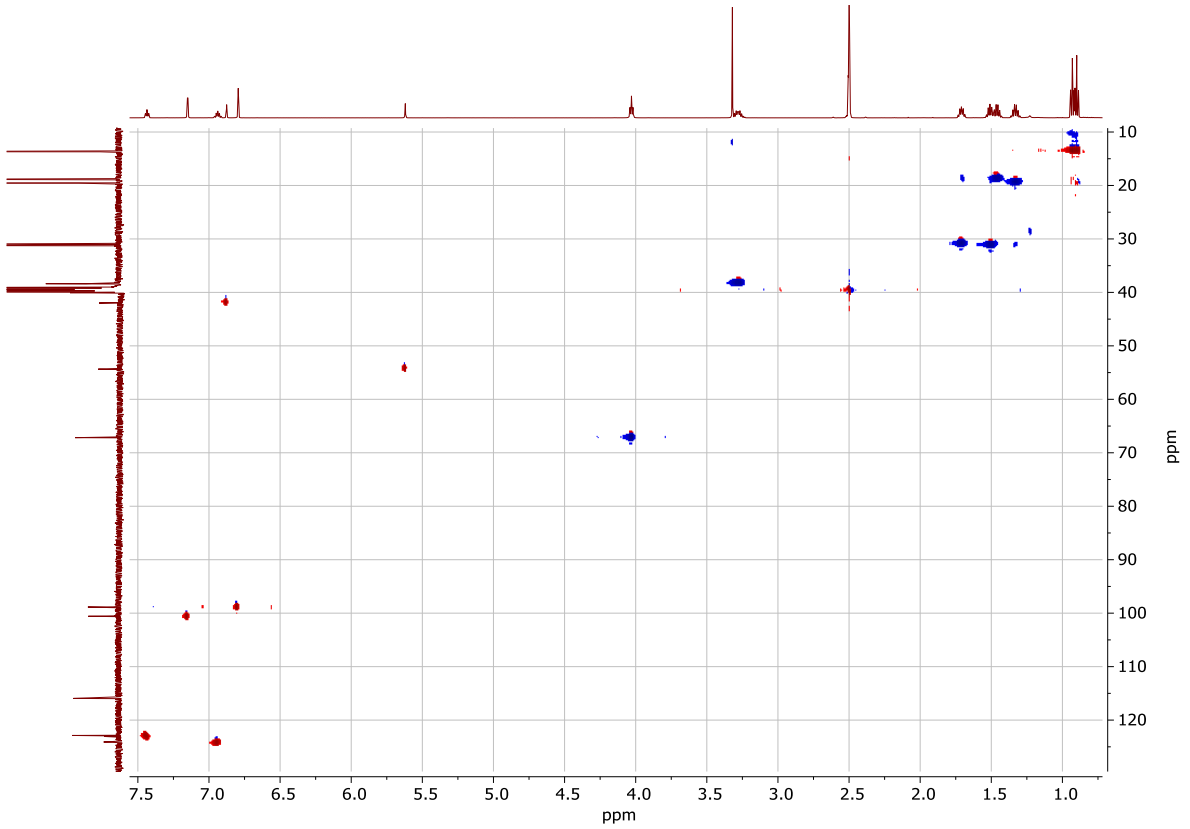


Fig. S39. HSQC NMR spectrum of **2** in DMSO-d_6

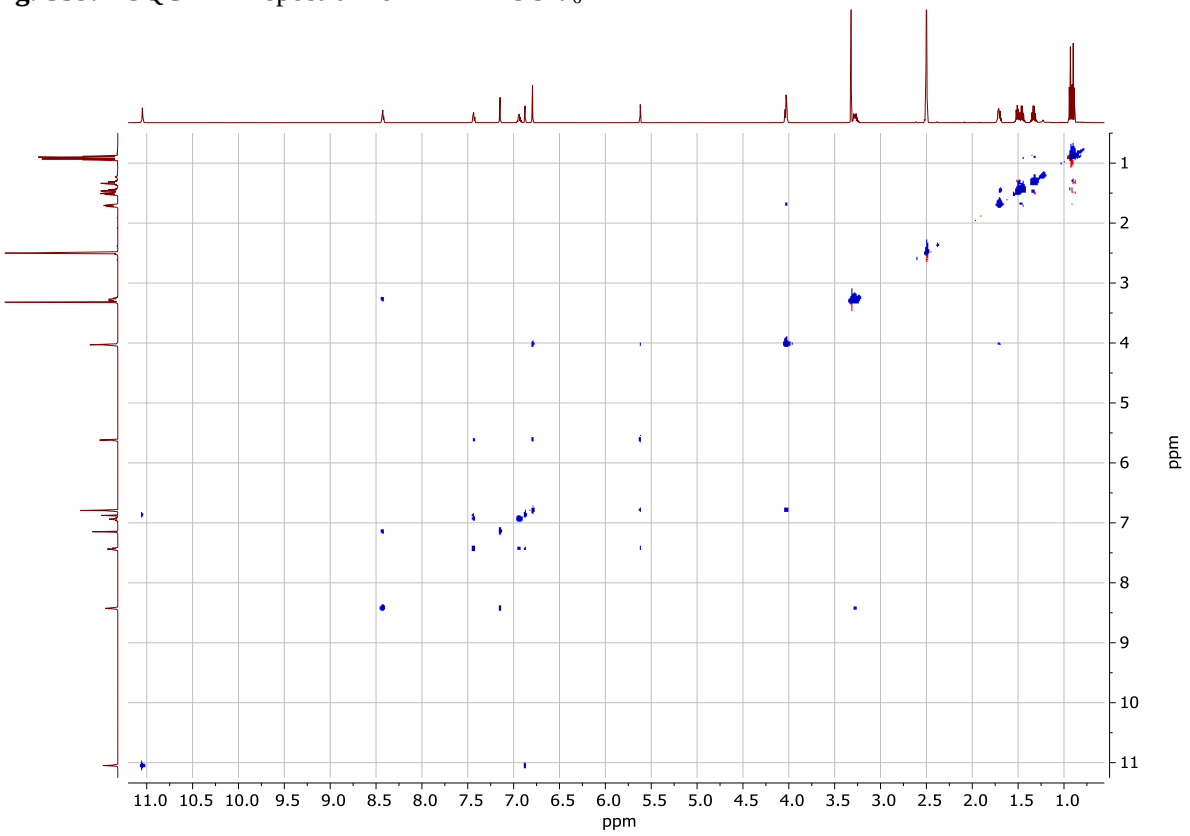


Fig. S40. NOESY NMR spectrum of 2 in DMSO-d_6

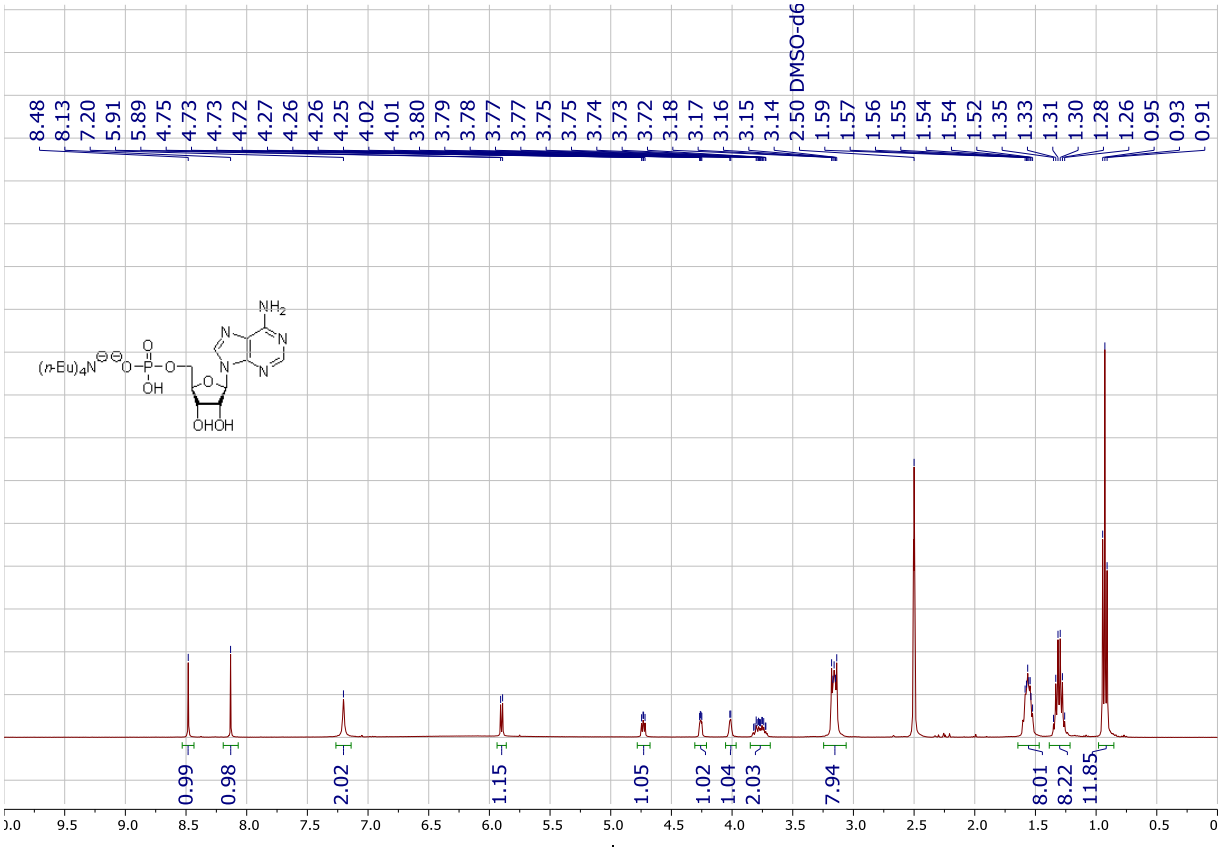


Fig. S41. [1]H NMR spectrum of **26** in DMSO-d_6

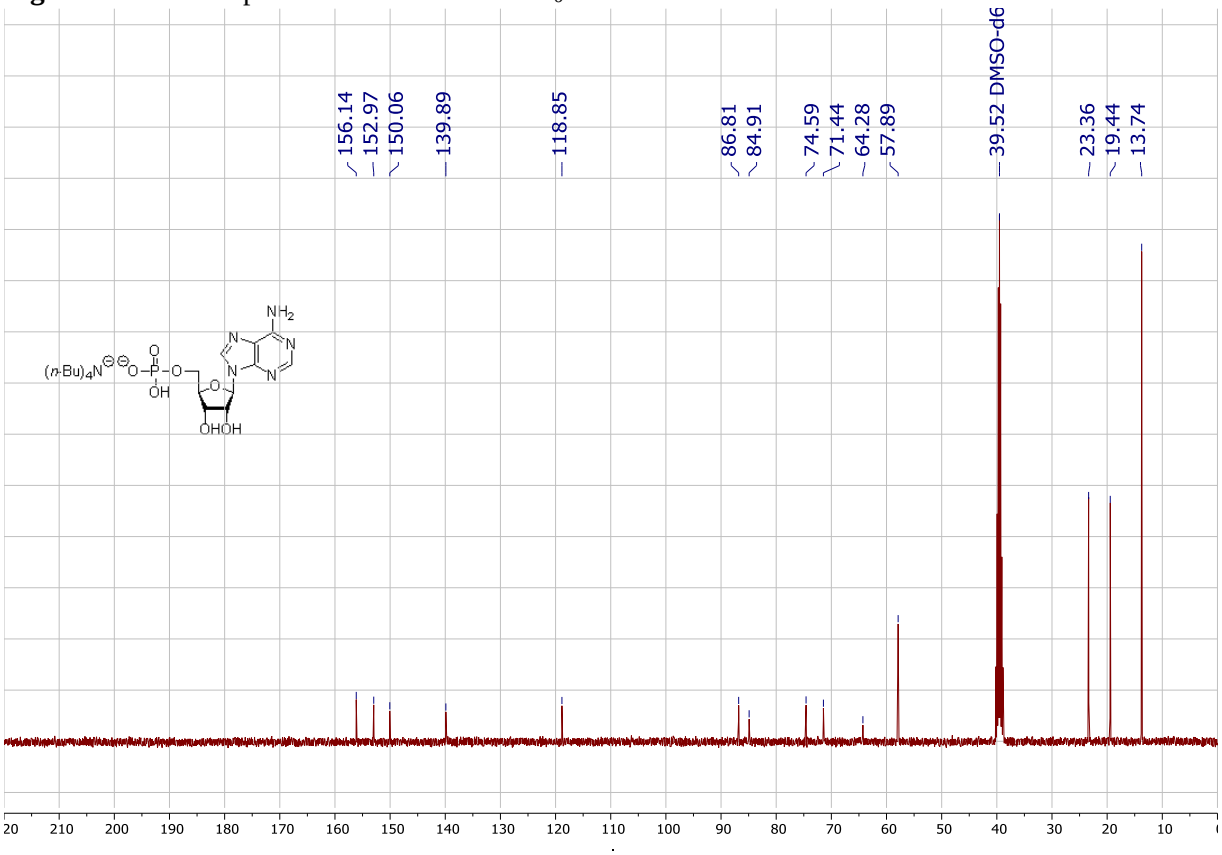


Fig. S42. [13]C NMR spectrum of **26** in DMSO-d_6

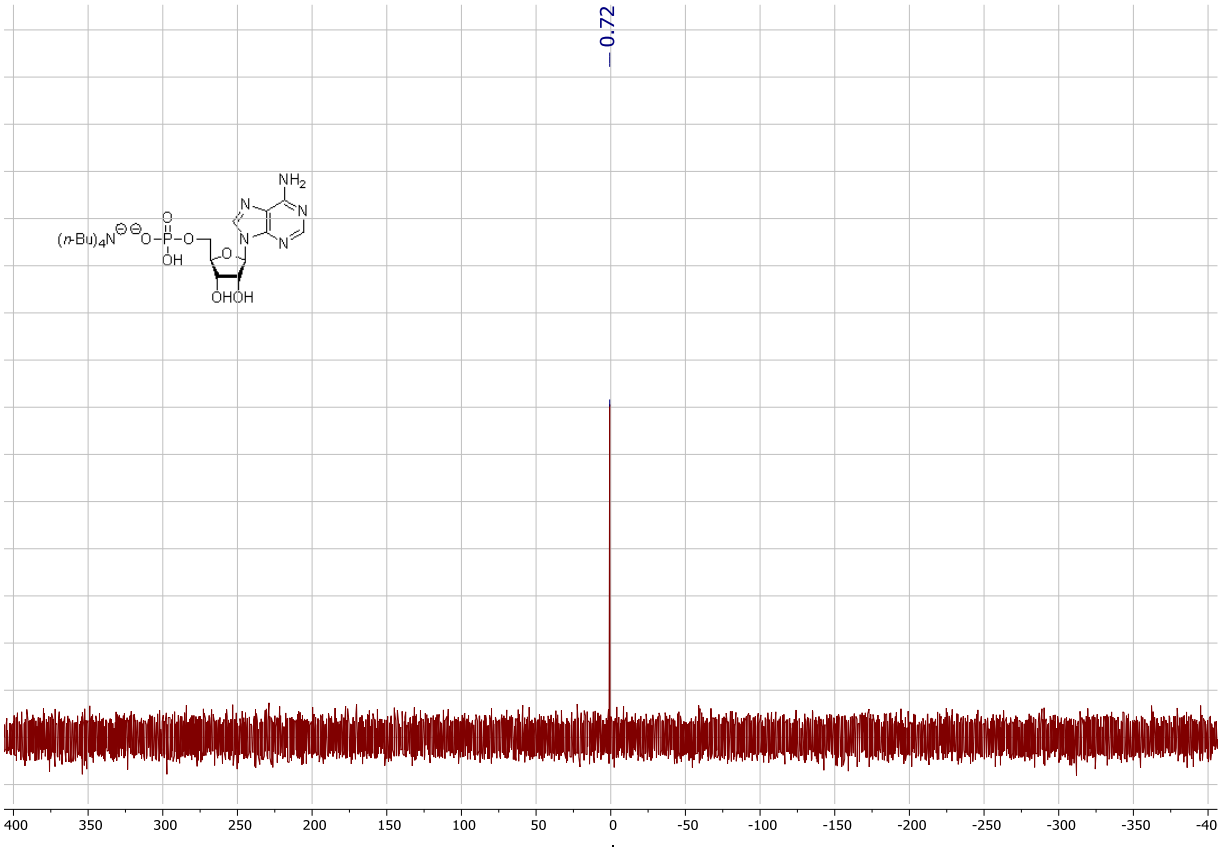


Fig. S43. ^{31}P NMR spectrum of **26** in DMSO-d_6

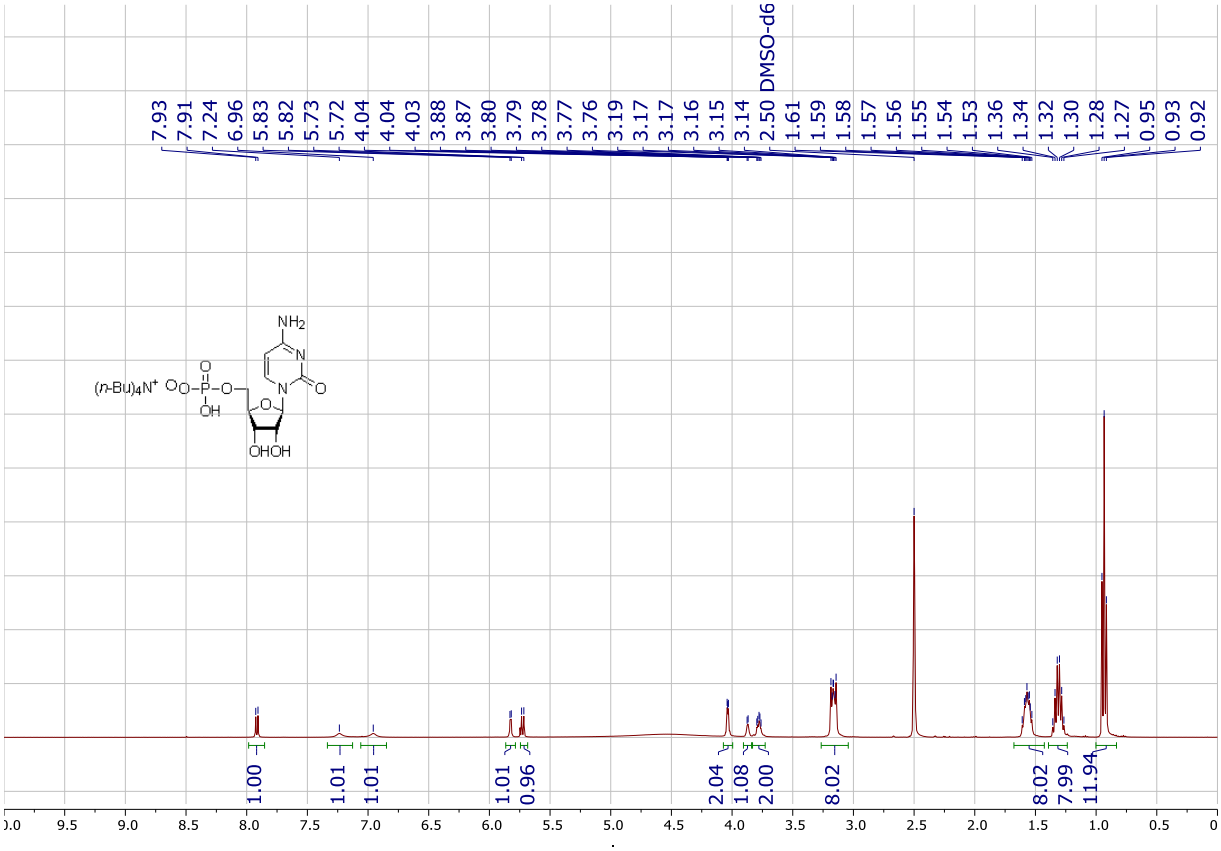


Fig. S44. ^{1}H NMR spectrum of **27** in DMSO-d_6

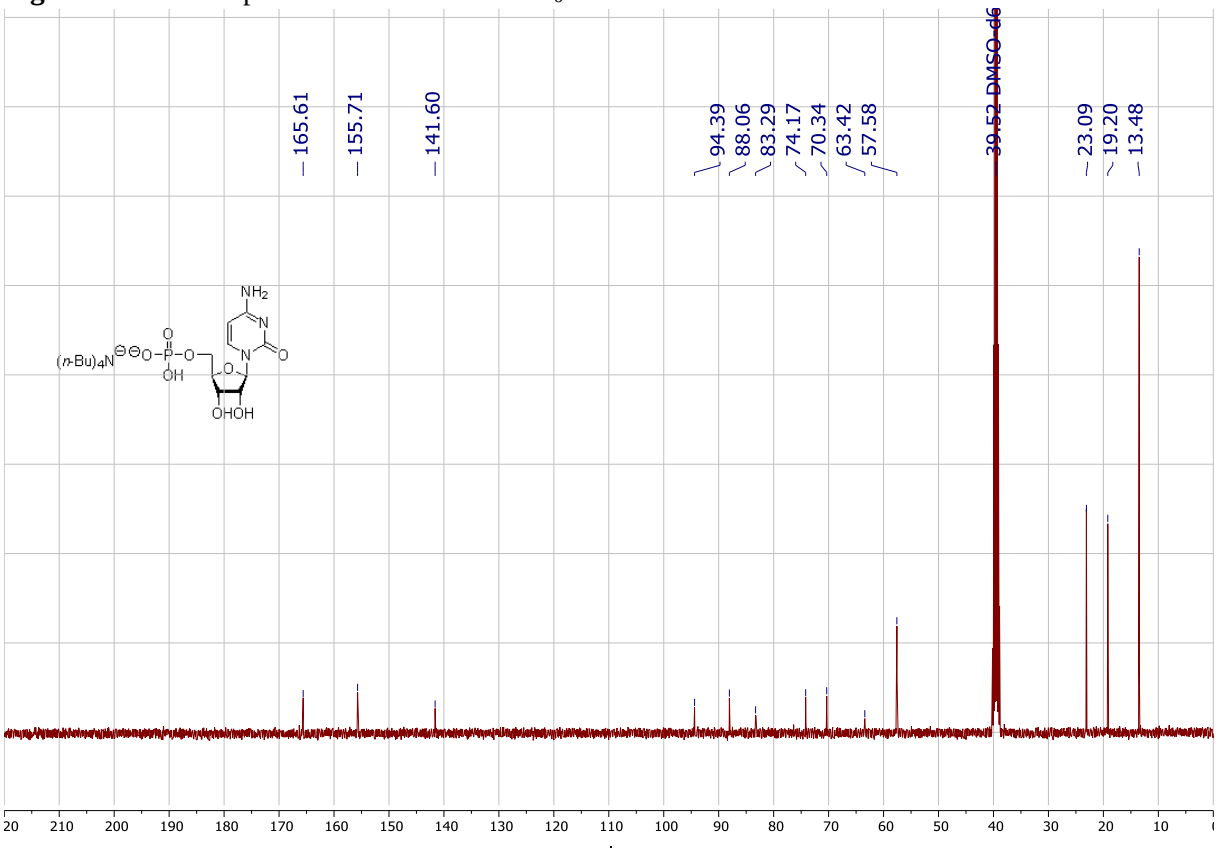


Fig. S45. ^{13}C NMR spectrum of **27** in DMSO-d_6

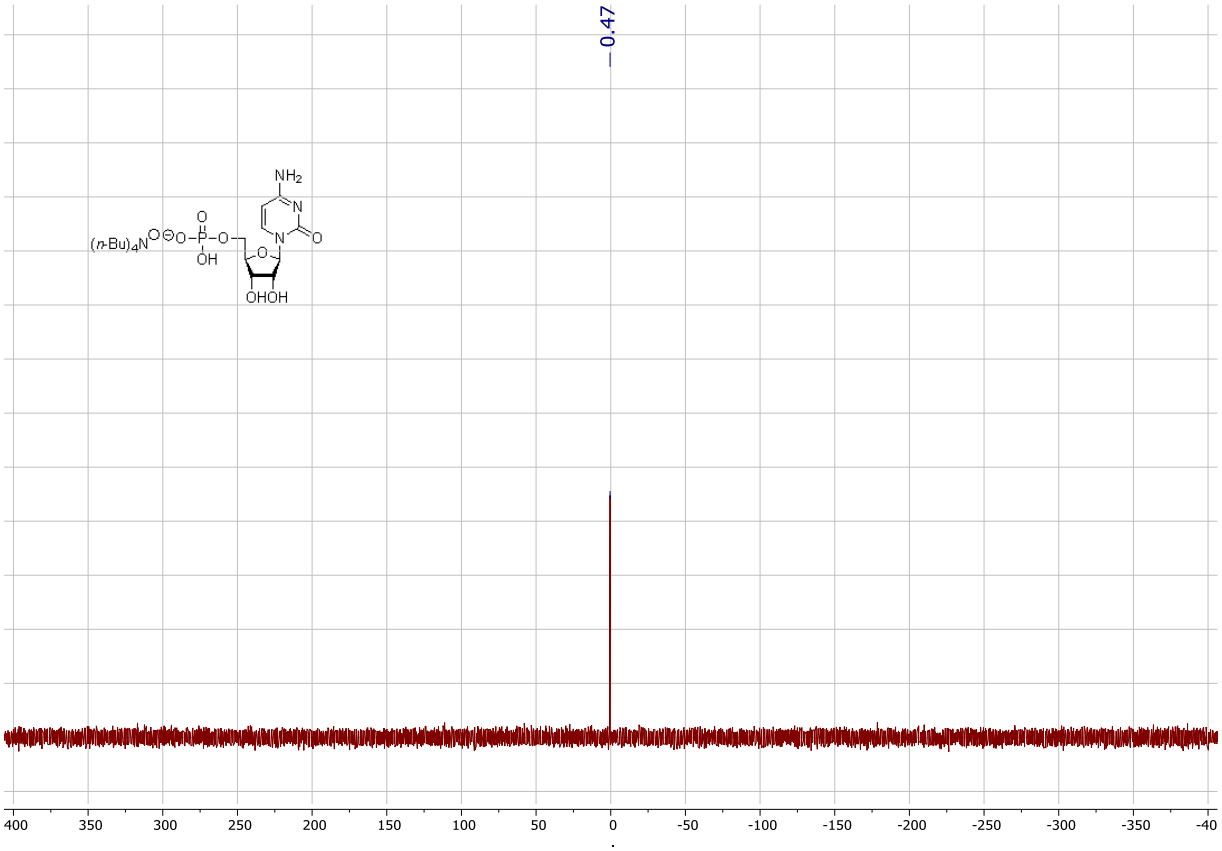


Fig. S46. ^{31}P NMR spectrum of **27** in DMSO-d_6

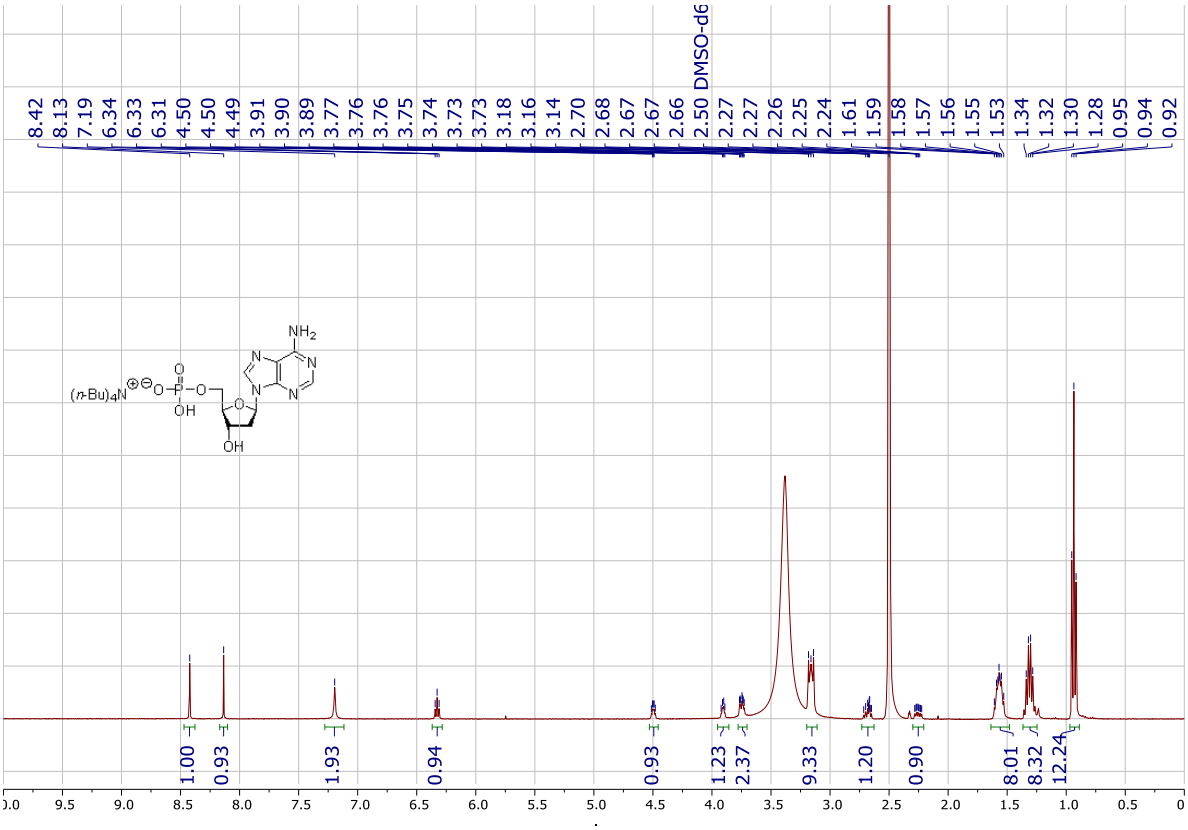


Fig. S47. ^{1}H NMR spectrum of **28** in DMSO-d_6

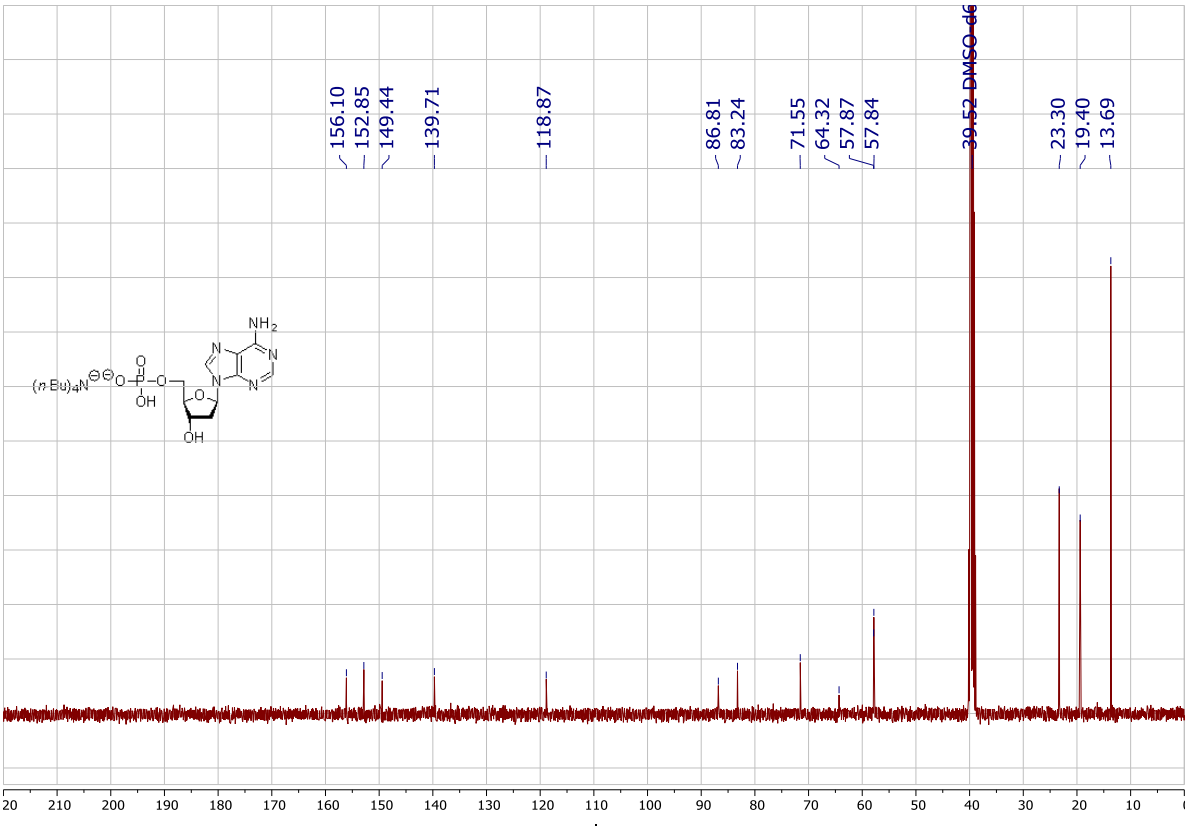


Fig. S48. ^{13}C NMR spectrum of **28** in DMSO-d_6

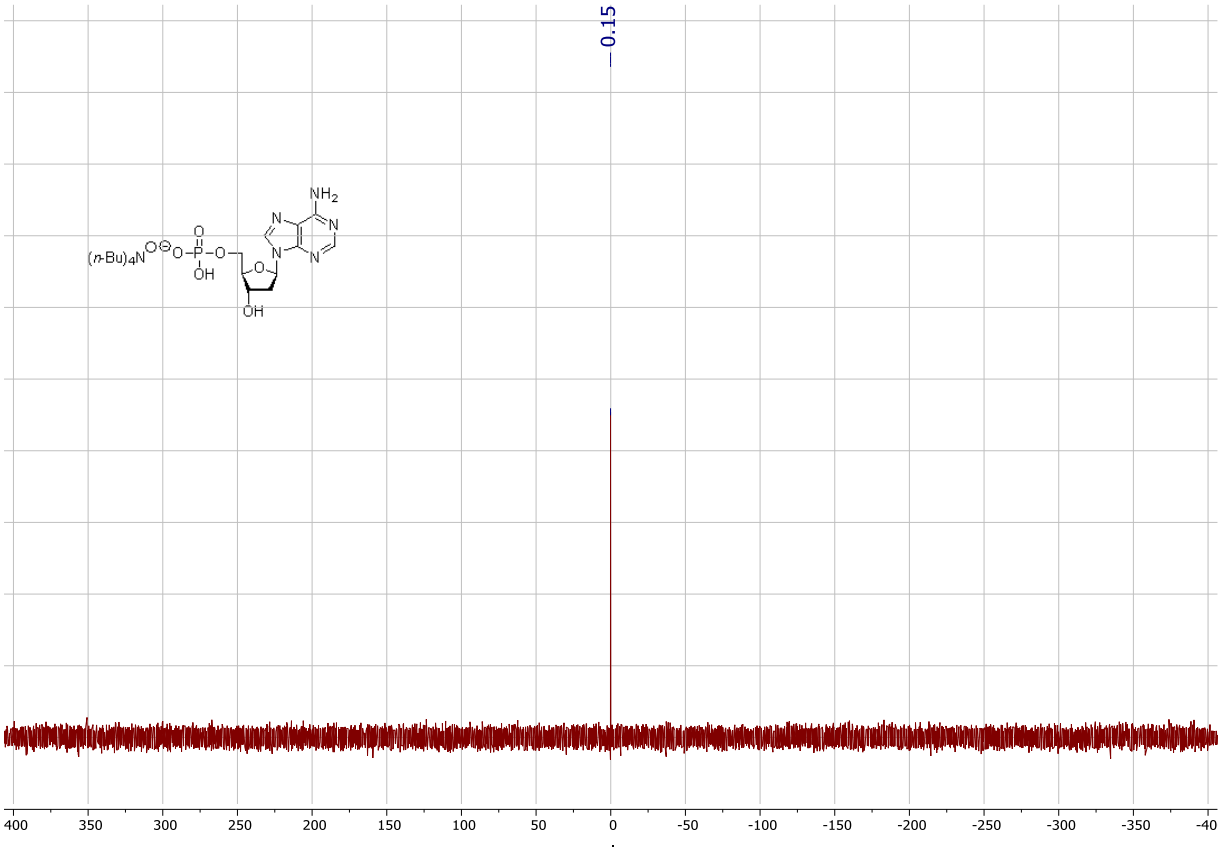


Fig. S49. ^{31}P NMR spectrum of **28** in DMSO-d_6

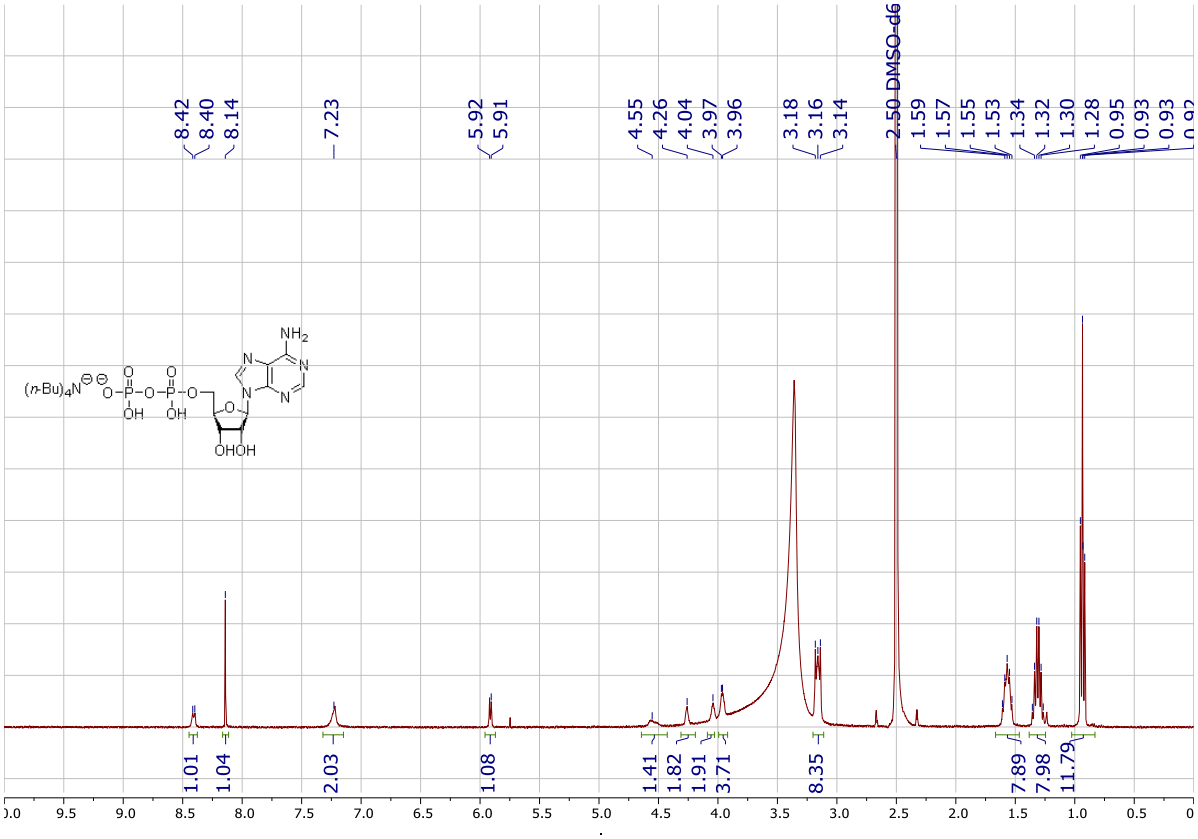


Fig. S50. ^{1}H NMR spectrum of **29** in DMSO-d_6

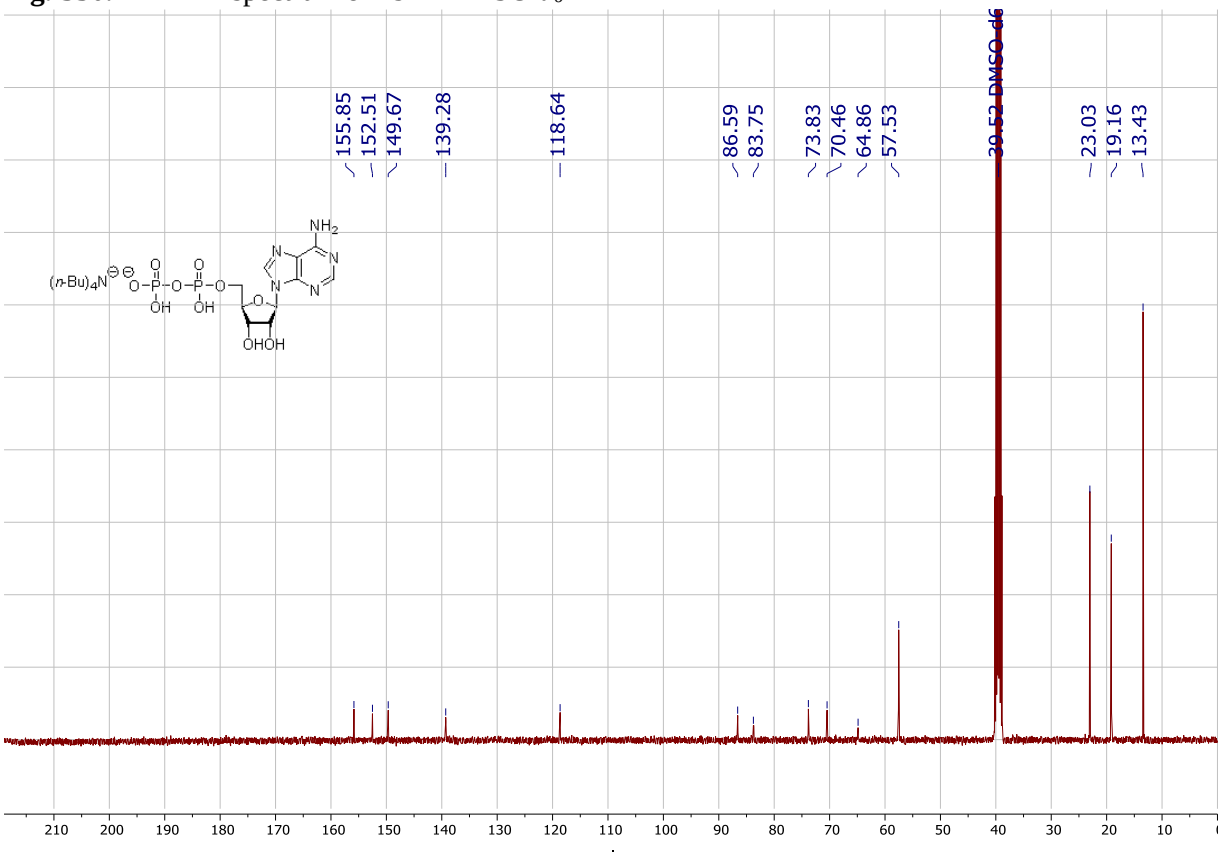


Fig. S51. ^{13}C NMR spectrum of **29** in DMSO-d_6

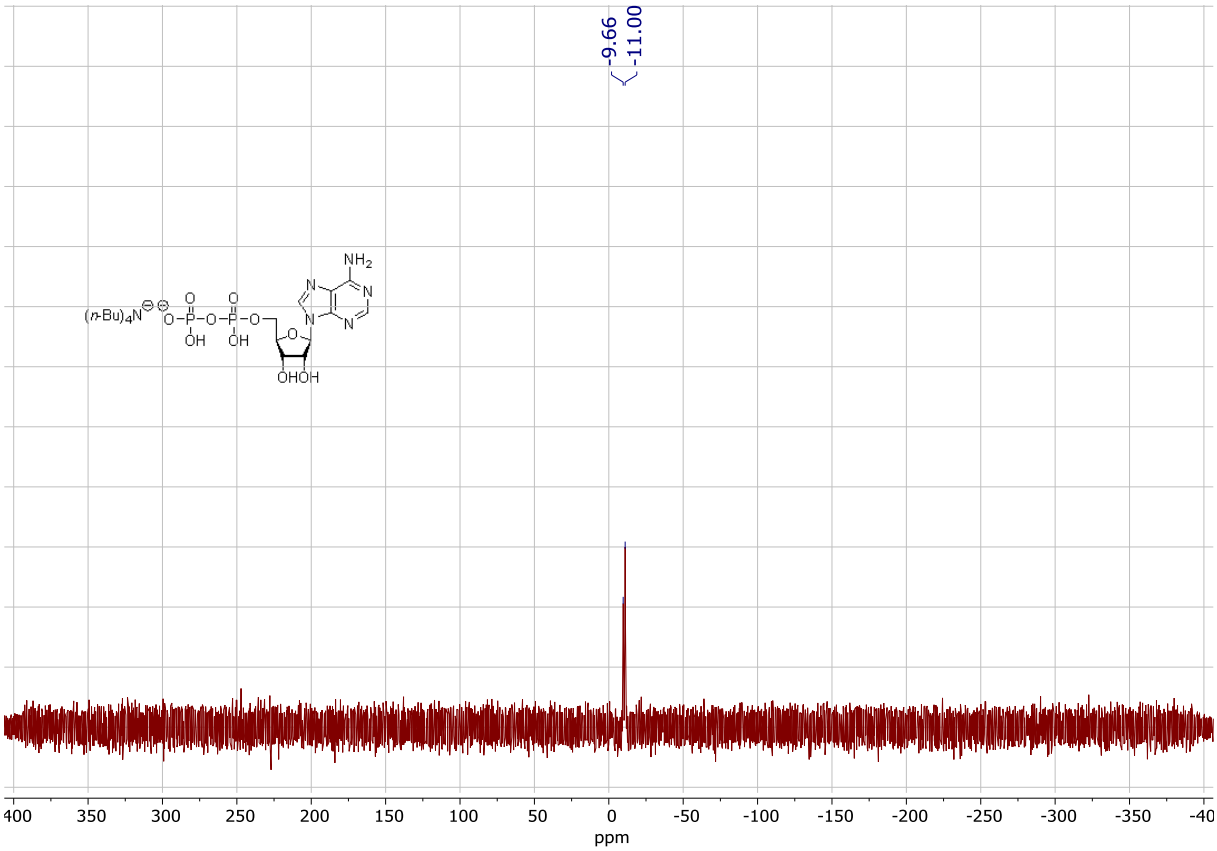


Fig. S52. ^{31}P NMR spectrum of **29** in DMSO-d_6

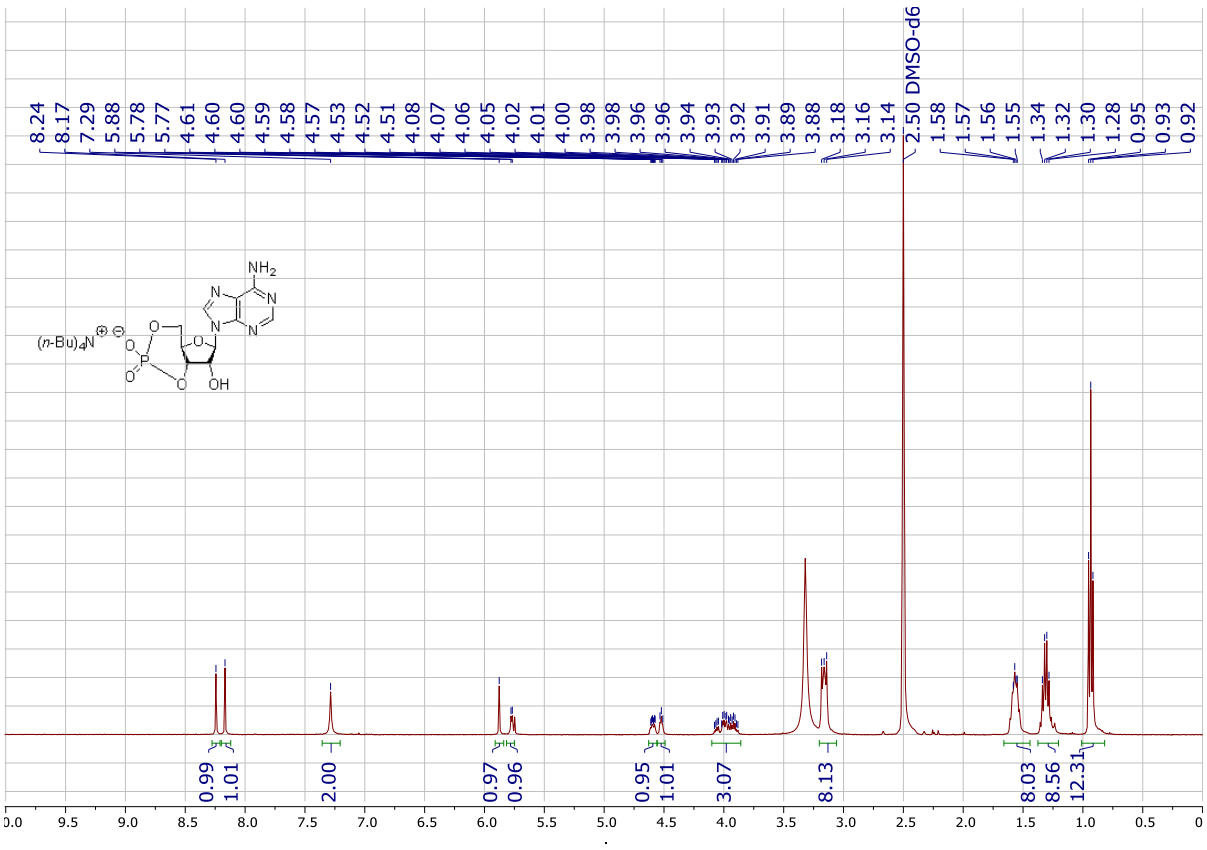


Fig. S53. [1]H NMR spectrum of **30** in DMSO-d_6

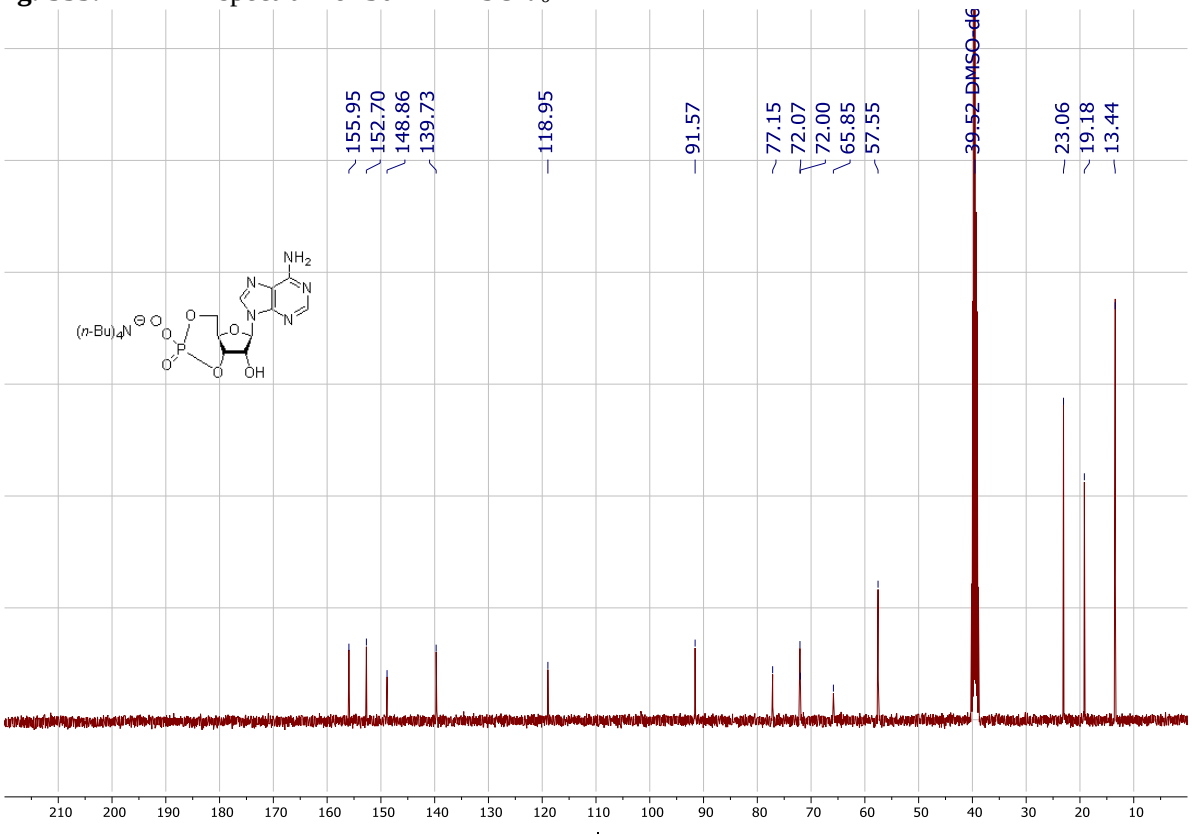


Fig. S54. [13]C NMR spectrum of **30** in DMSO-d_6

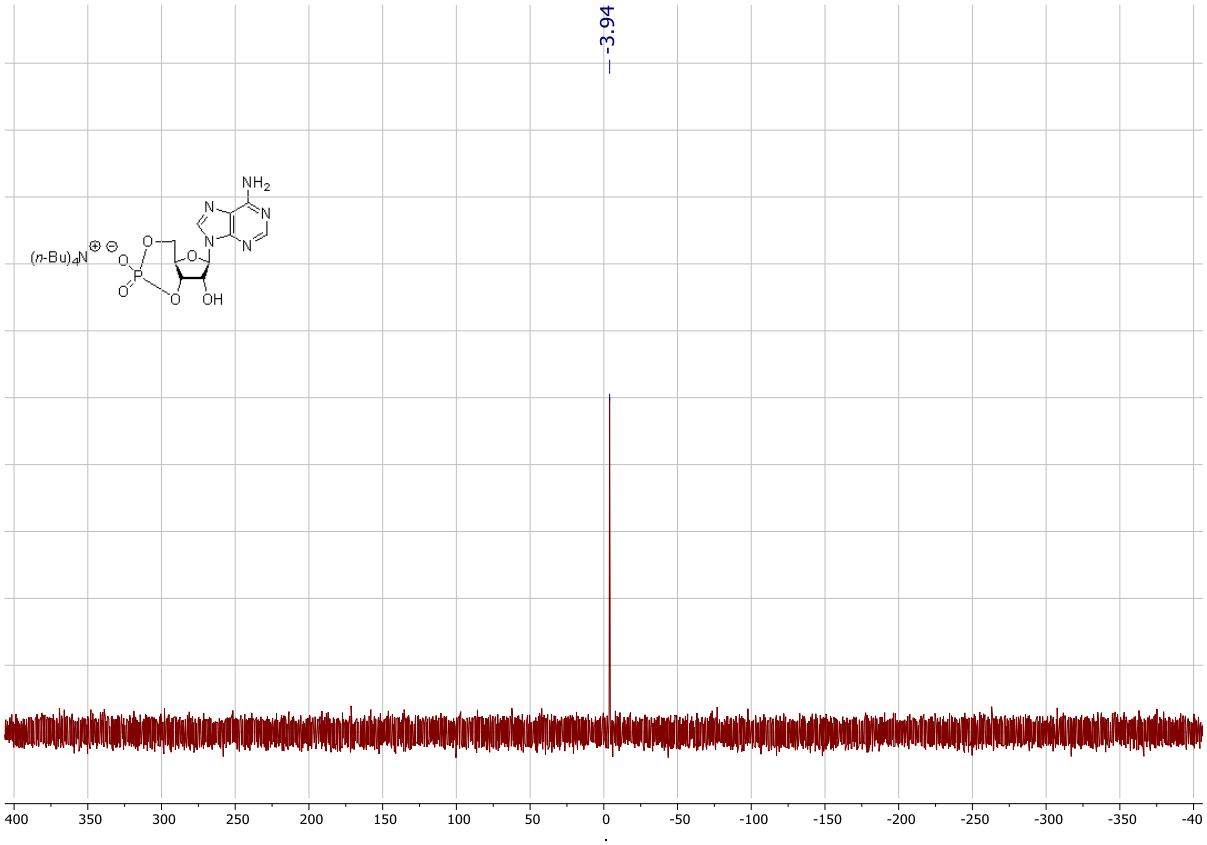


Fig. S55. ^{31}P NMR spectrum of **30** in DMSO-d_6

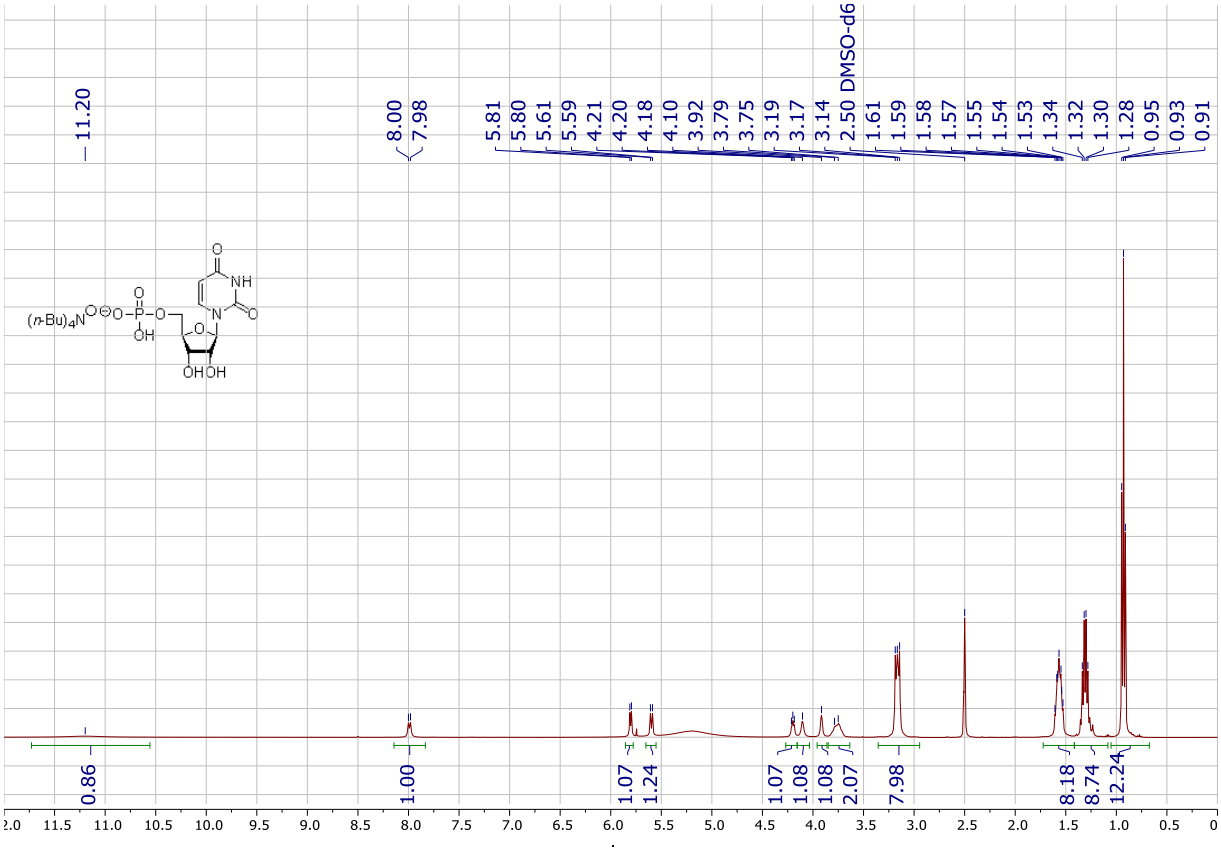


Fig. S56. ^{1}H NMR spectrum of **31** in DMSO-d_6

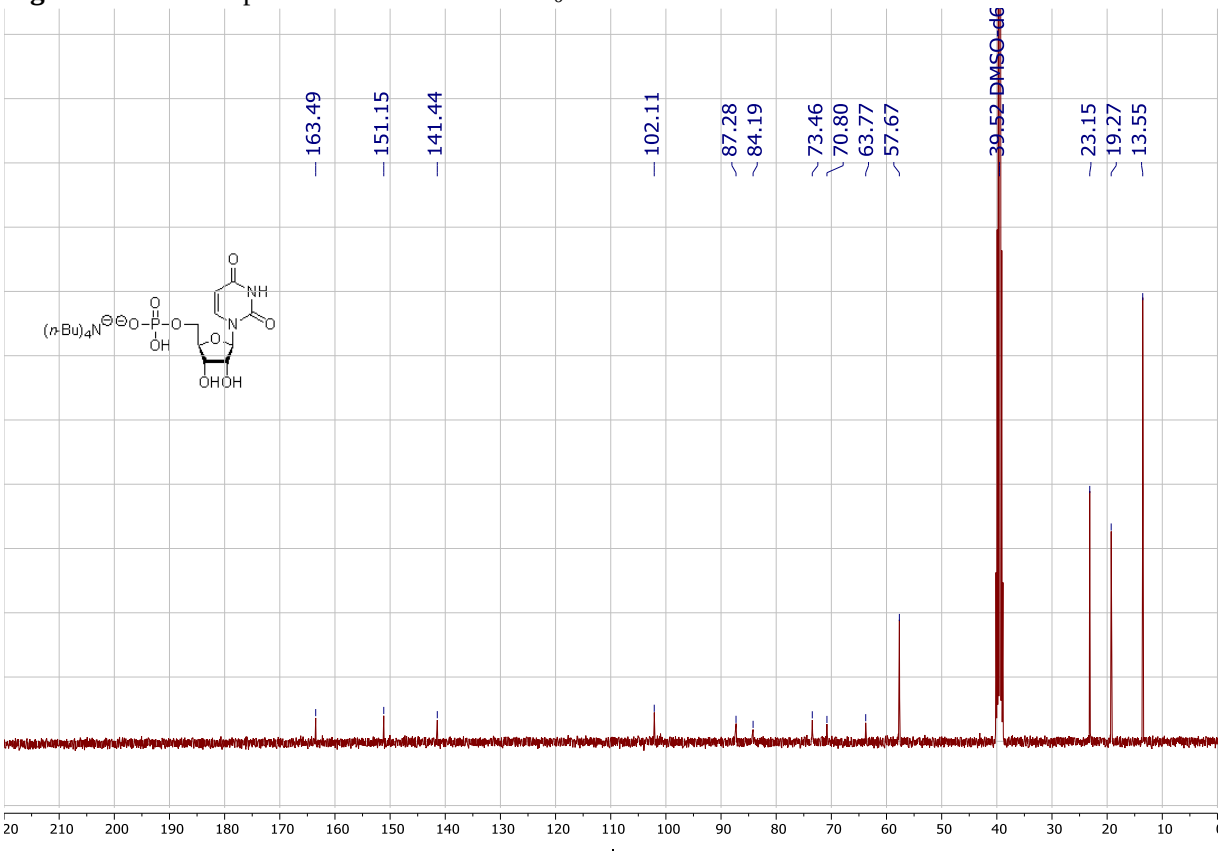


Fig. S57. ^{13}C NMR spectrum of **31** in DMSO-d_6

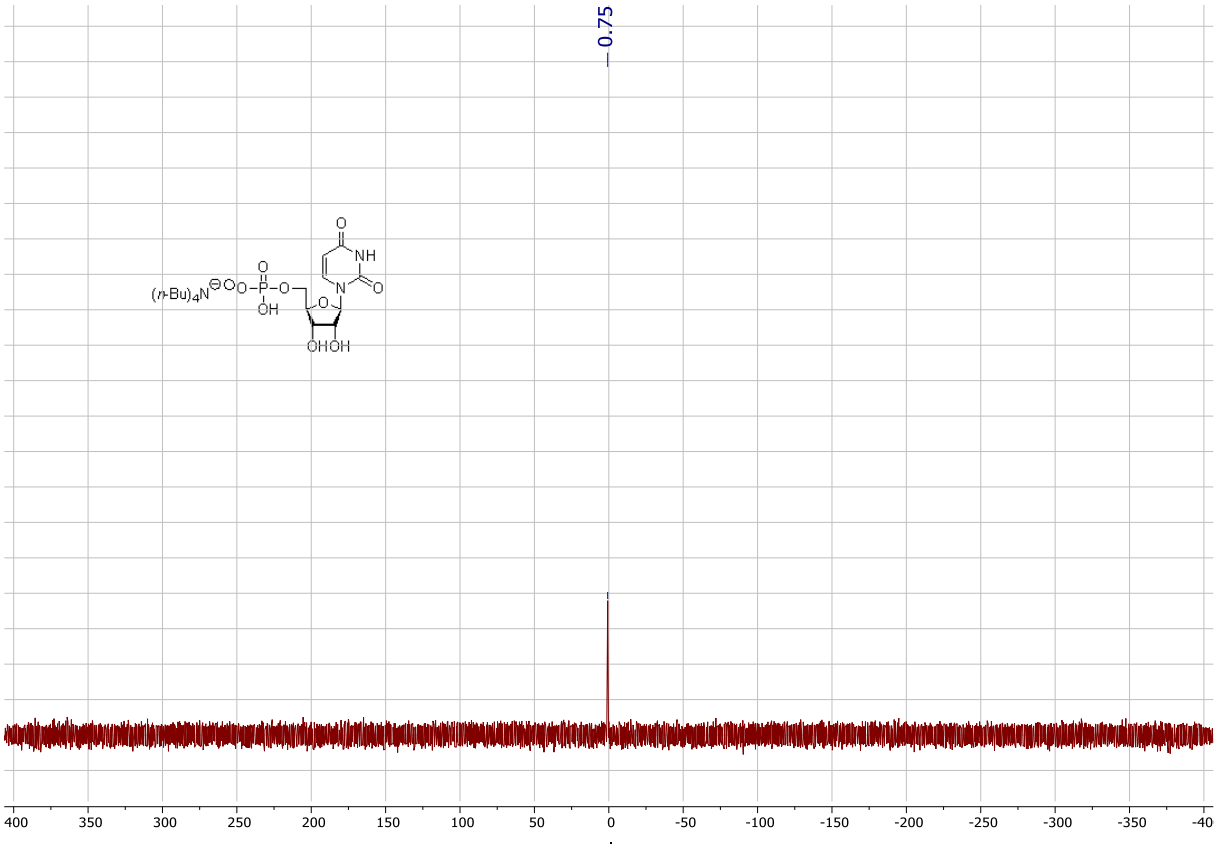


Fig. S58. ^{31}P NMR spectrum of **31** in DMSO-d_6

4. X-ray single-crystal data for compounds 1 and 3

4.1. Experimental of compound 3 (CCDC 1405451)

The X-ray measurement of **3** was performed at 100(2) K on a Bruker D8 Venture Photon100 diffractometer equipped with a TRIUMPH monochromator and a MoKα fine focus sealed tube (λ = 0.71073 Å). A total of 2898 frames were collected with Bruker APEX2 program.[3] The frames were integrated with the Bruker SAINT software package[4] using a narrow-frame algorithm. The integration of the data using a triclinic unit cell yielded a total of 72833 reflections to a maximum θ angle of 25.25° (0.83 Å resolution), of which 18001 were independent (average redundancy 4.046, completeness = 99.7%, R_{int} = 3.65%, R_{sig} = 3.66%) and 13563 (75.35%) were greater than $2\sigma(F^2)$. The final cell constants of a = 15.7796(14) Å, b = 16.5721(15) Å, c = 20.6662(18) Å, α = 80.044(2)°, β = 79.078(2)°, γ = 71.2037(19)°, volume = 4986.9(8) $Å^3$, are based upon the refinement of the XYZ-centroids of 9334 reflections above 20 σ(I) with 4.555° < 2θ < 51.68°. Data were corrected for absorption effects using the multi-scan method (SADABS).[5] The ratio of minimum to maximum apparent transmission was 0.890. The calculated minimum and maximum transmission coefficients (based on crystal size) are 0.9640 and 0.9770.

The structure was solved and refined using SHELXTL Software Package[6-7] using the space group P -1, with Z = 2 for the formula unit, $C_{116}H_{116}N_8O_{11.20}S_2$. The final anisotropic full-matrix least-squares refinement on F^2 with 1392 variables converged at R1 = 4.66%, for the observed data and wR2 = 12.32% for all data. The goodness-of-fit was 1.021. The largest peak in the final difference electron density synthesis was 0.451 $e^-/Å^3$ and the largest hole was -0.355 $e^-/Å^3$ with an RMS deviation of 0.048 $e^-/Å^3$. On the basis of the final model, the calculated density was 1.242 g/cm^3 and F(000), 1979 e^-.

The independent part of the unit cell contains: four ligand molecules, two of them with disordered over three positions aliphatic chain; two disordered DMSO molecules and partially occupied two water molecules (occupancy sum equal to 1.2). The disorder of the molecules was modeled with series of geometric restrains for distances angles and thermal atomic parameters. In the structure water and DMSO molecules share common space but the sum occupancy of these species never exceeds 1.

The non-hydrogen atoms were refined anisotropically except atoms with occupancy equal or less than 0.2. All hydrogen atoms were placed in calculated positions and refined within the riding model. The hydrogen atoms of partial occupancy water molecules were n it assigned. The temperature factors of these hydrogen atoms were not refined and were set to be equal to either 1.2 or 1.5 times larger than U_{eq} of the corresponding heavy atom. The atomic scattering factors were taken from the International Tables.[8] Molecular graphics was prepared using program Diamond 3.2.[9] Thermal ellipsoids parameters are presented at 50% probability level.

Acknowledgements

The X-ray structure was determined in the Advanced Crystal Engineering Laboratory (aceLAB) at the Chemistry Department of the University of Warsaw by dr Łukasz Dobrzycki.

4.2. Experimental of compound 1 (CCDC 2152150)

The X-ray measurement of **1** was performed at 103(2) K on a Bruker D8 Venture Photon II diffractometer equipped with a TRIUMPH monochromator and a MoKα fine focus sealed tube (λ = 0.71073 Å). A total of 1432 frames were collected with Bruker APEX2 program.[10] The frames were integrated with the Bruker SAINT software package[11] using a narrow-frame algorithm. The integration of the data using a monoclinic unit cell yielded a total of 108454 reflections to a maximum θ angle of 25.05° (0.84 Å resolution), of which 12270 were independent (average redundancy 8.839, completeness = 99.9%, R_{int} = 8.79%, R_{sig} = 4.94%) and 7378 (60.13%) were greater than $2\sigma(F^2)$. The final cell constants of a = 17.0525(8) Å, b = 19.6640(9) Å, c = 22.1200(11) Å, β = 110.6794(15)°, V = 6939.4(6) Å^3, are based upon the refinement of the XYZ-centroids of 9899 reflections above 20 $\sigma(I)$ with 4.586° < 2θ < 48.84°. Data were corrected for absorption effects using the Multi-Scan method (SADABS).[12] The ratio of minimum to maximum apparent transmission was 0.945. The calculated minimum and maximum transmission coefficients (based on crystal size) are 0.978 and 0.995.

The structure was solved and refined using SHELXTL Software Package[13,14] using the space group $P2_1/n$, with Z = 2 for the formula unit, $C_{142}H_{214}F_6N_{16}O_{12}Si$. The final anisotropic full-matrix least-squares refinement on F^2 with 944 variables converged at $R1$ = 7.70%, for the observed data and $wR2$ = 23.61% for all data. The goodness-of-fit was 1.035. The largest peak in the final difference electron density synthesis was 0.457 e$^-$/Å^3 and the largest hole was -0.362 e$^-$/Å^3 with an RMS deviation of 0.054 e$^-$/Å3. On the basis of the final model, the calculated density was 1.187 g/cm3 and F(000), 2684 e$^-$.

The structure in the asymmetric part contains SiF_6^{2-} ion located on the center of symmetry, one tetrabutylammonium cation, ligand and acetonitrile solvent molecule. In the structure most of the molecules, except the solvent, are disordered over up to four alternative sites. The occupancy ratios of disordered fragments were refined. Because the refined occupancy was rounded in the cif file up to three decimal places there is some discrepancy between the atom count resulting in three Alerts level G in checkcif report. To preserve reasonable geometry of the molecules a number of restraints was used during the refinement process.

All non-hydrogen atoms with occupancy higher than 0.5 were refined anisotropically. All hydrogen atoms were placed in calculated positions and refined within the riding model. The temperature factors of hydrogen atoms were not refined and were set to be equal to either 1.2 or 1.5 times larger than U_{eq} of the corresponding heavy atom. The atomic scattering factors were taken from the International Tables.[8]

Molecular graphics was prepared using program Mercury 3.9.[15] Thermal ellipsoids parameters are presented at 50% probability level.

5. Binding studies of ligands 3, 2 and 1

5.1. Binding studies of ligand 3

5.1.1. General remarks

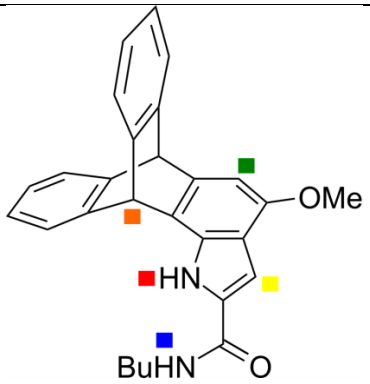
Tetrabutylammonium salts were used as a source of anions. Tetrabutylammonium acetate, Tetrabutylammonium benzoate, Tetrabutylammonium chloride, Tetrabutylammonium phosphate and are commercially available from Sigma-Aldrich. Distilled water was added to the commercially available DMSO-d_6 of 99.8% isotopic purity (purchased Eurisotope) to obtain the appropriate water concentration.

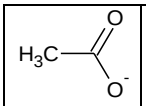
5.1.2. ^{1}H NMR titration experiments

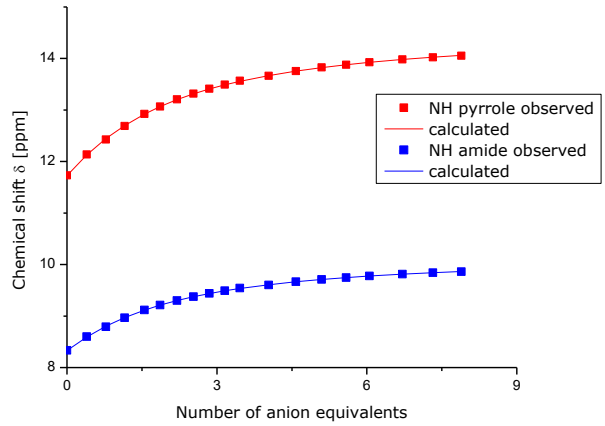
The ca. 1x10^{-2} M DMSO solution of a receptor **3** was titrated in an NMR tube with the 0.1-0.2 M solution of a respective tetrabutylammonium salt. The solution of the salt contained a certain amount of the receptor in order to keep its concentration constant during the titration. 19 data points were recorded. It was important to choose such concentration of the salt so that most of the data points could occur in close proximity of the inflection point of the respective titration curve. Such a procedure allows for more precise calculation of the binding constants, which were calculated by taking into account changes in the chemical shifts of ligand NH protons. A nonlinear curve fitting for 1:1 binding model was carried out with the HypNMR program.[16-17]

TBA$^+$ AcO$^-$

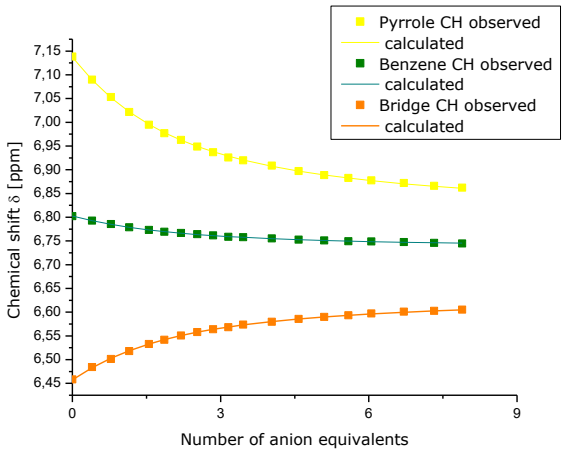
Table S1. The details of ^{1}H NMR titration experiment: concentrations used, titration curves and the results of data fitting for receptor **3** with TBA$^+$ AcO$^-$ in DMSO-d_6+0.5% H_2O.[a]

Ligand								
Solvent	DMSO-d_6 + 0.5% H_2O							
Anion	C_{ligand} [mol·dm^{-3}]	C_{anion} [mol·dm^{-3}]	K [M^{-1}]	$\Delta\delta_{max}$ [ppm]				
				NH pyrrole	NH amide	CH pyrrole	CH benzene	CH bridge

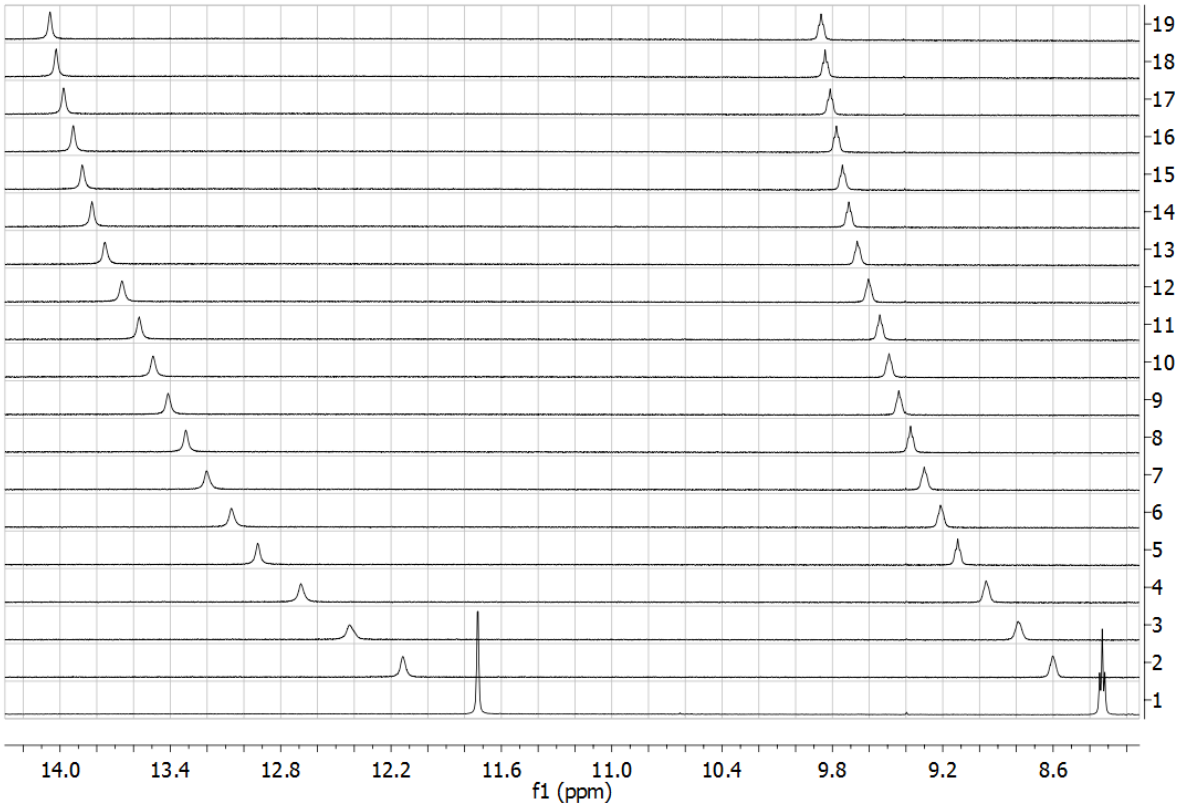
	0.01241	0.09788	51	2.850	1.875	-0.3369	-0.0700	0.1801



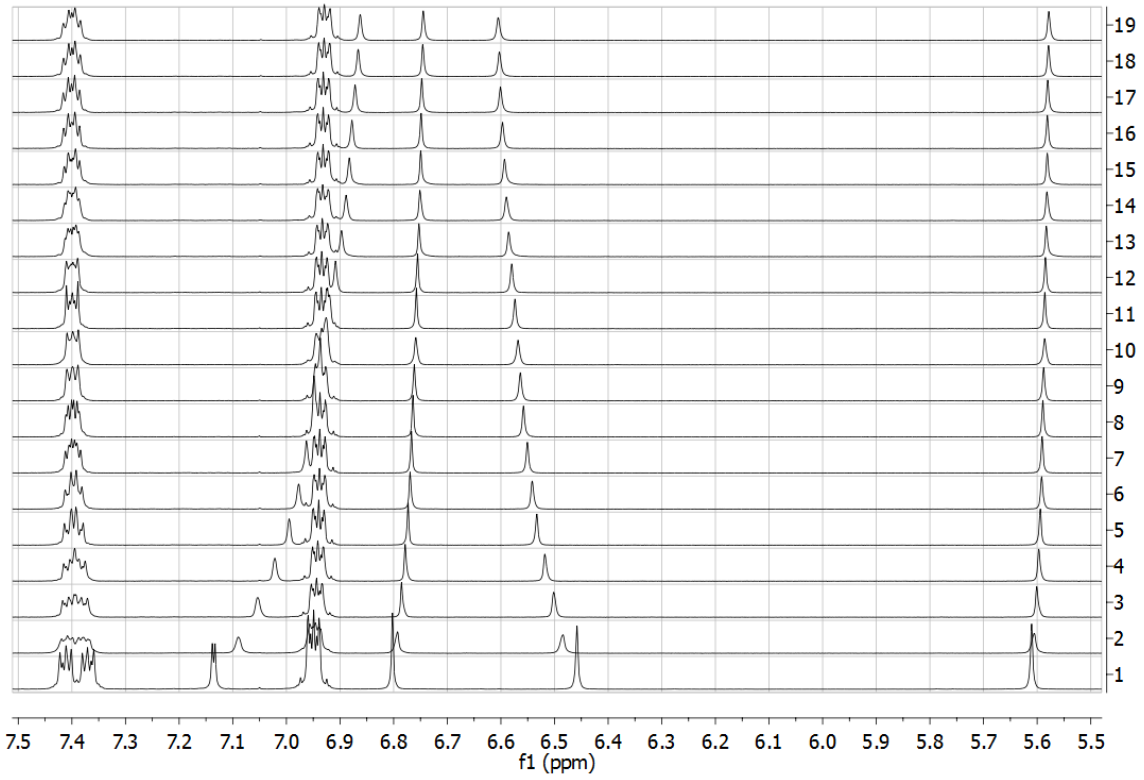
Changes in ^{1}H NMR signal shifts of the ligand NH protons upon addition of the anion



Changes in ^{1}H NMR signal shifts of the ligand aromatic and bridgehead and CH protons upon addition of the anion



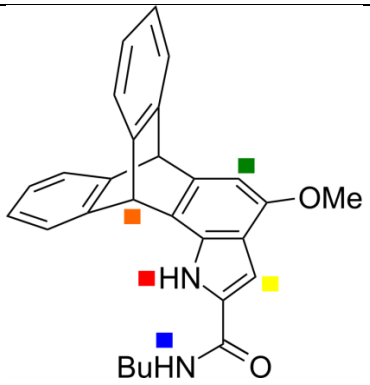
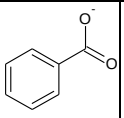
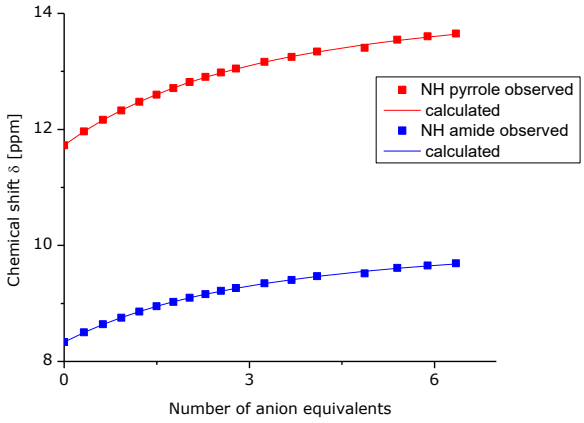
Changes in ^{1}H NMR signal shifts of the ligand amide NH protons upon addition of the anion

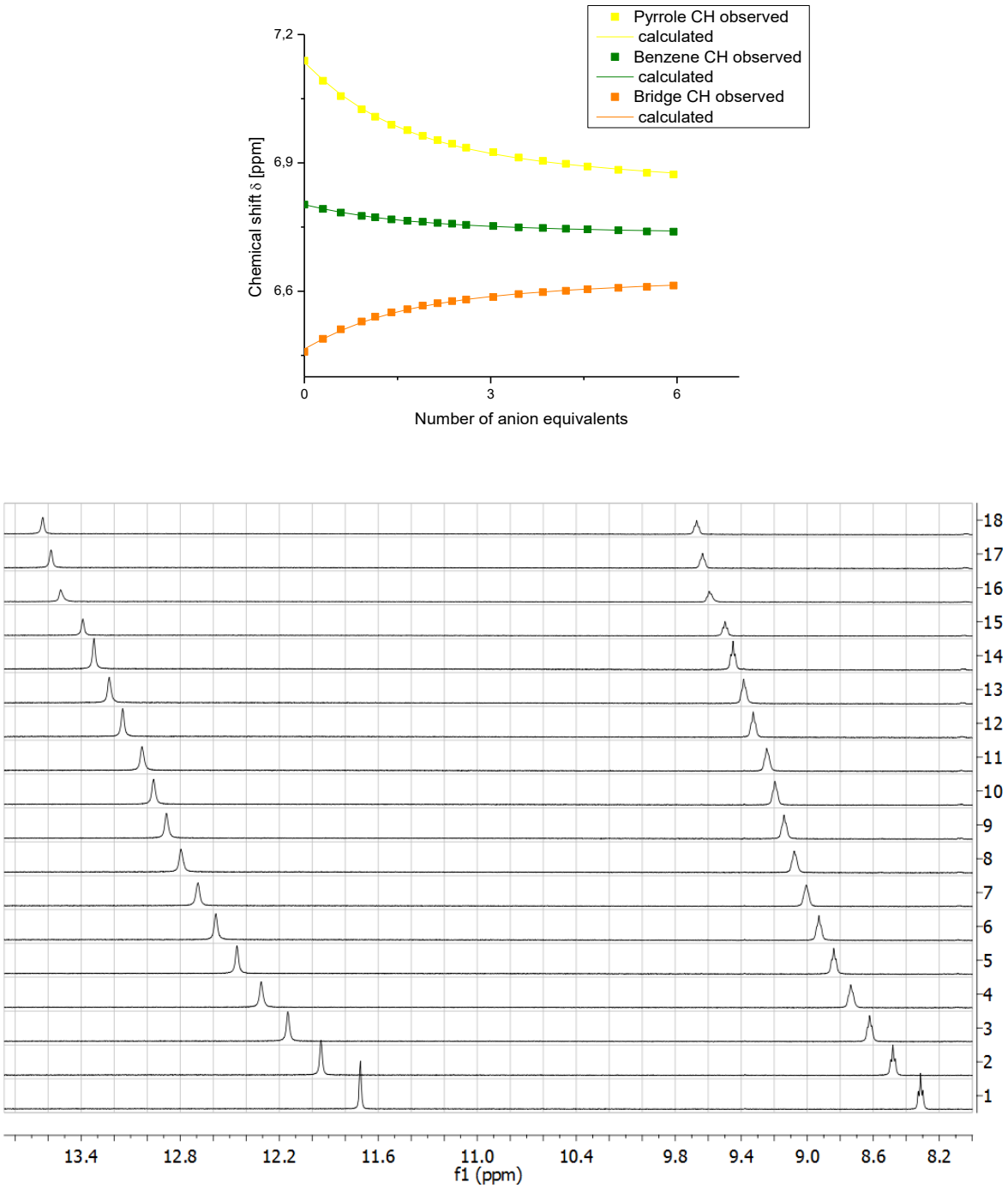


Changes in ^{1}H NMR signal shifts of the ligand aromatic and bridgehead CH protons upon addition of the anion

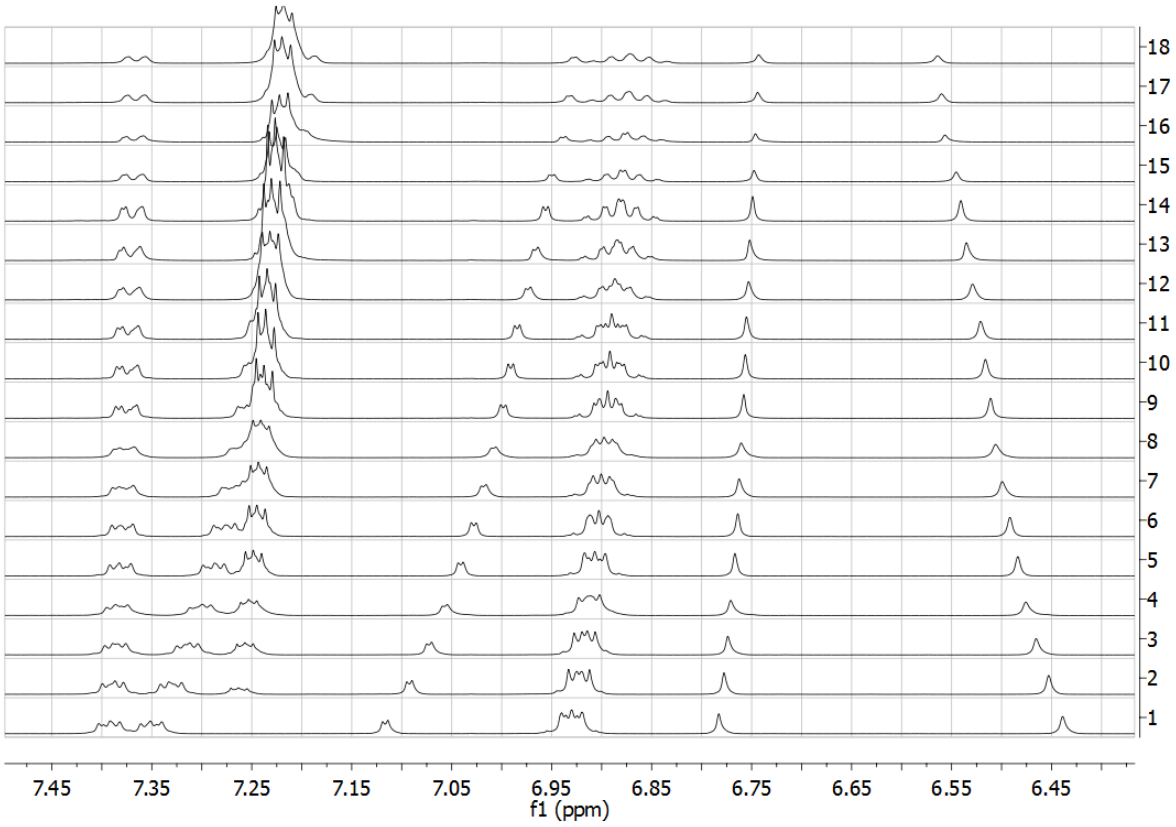
TBA$^+$ BzO$^-$

Table S2. The details of ^{1}H NMR titration experiment: concentrations used, titration curves and the results of data fitting for receptor **3** with TBA$^+$ BzO$^-$ in DMSO-d_6+0.5% H_2O.[a]

Ligand								
Solvent	DMSO-d_6 + 0.5% H_2O							
Anion	C_{ligand} [mol·dm^{-3}]	C_{anion} [mol·dm^{-3}]	K [M^{-1}]	$\Delta\delta_{max}$ [ppm]				
				NH pyrrole	NH amide	CH pyrrole	CH benzene	CH bridge
	0.01234	0.07335	32	2.786	1.964	-0.2710	-0.0560	0.1825
	 Changes in ^{1}H NMR signal shifts of the ligand amide NH protons upon addition of the anion							



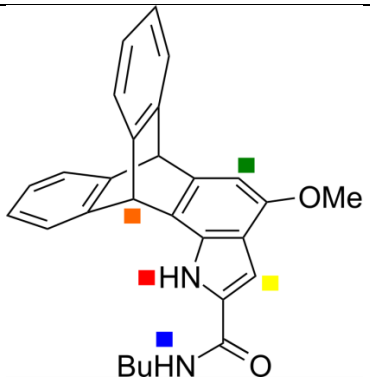
Changes in ^{1}H NMR signal shifts of the ligand amide NH protons upon addition of the anion



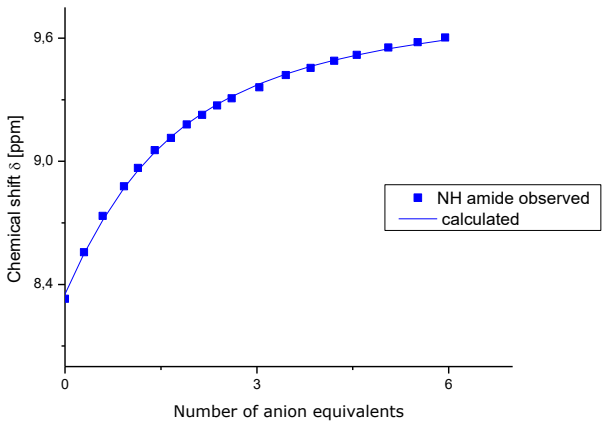
Changes in ^{1}H NMR signal shifts of the ligand aromatic and bridgehead CH protons upon addition of the anion

$TBA^+ H_2PO_4^-$

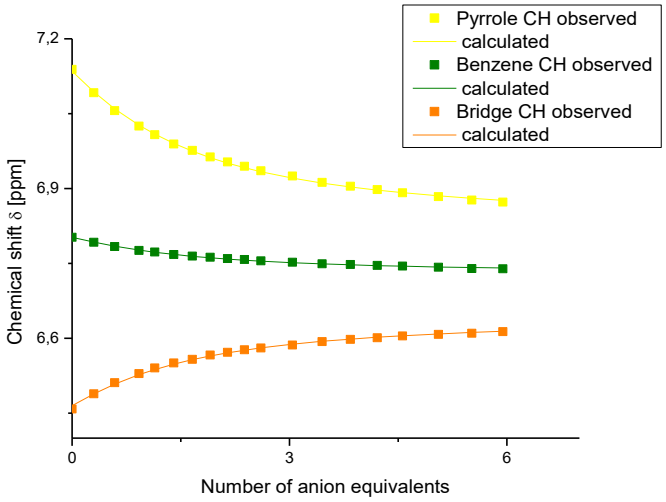
Table S3. The details of ^{1}H NMR titration experiment: concentrations used, titration curves and the results of data fitting for receptor **3** with $TBA^+ H_2PO_4^-$ in DMSO-d_6+0.5% H_2O.[a]

Ligand								
Solvent	DMSO-d_6 + 0.5% H_2O							
Anion	C_{ligand} [mol·dm^{-3}]	C_{anion} [mol·dm^{-3}]	K [M^{-1}]	$\Delta\delta_{max}$ [ppm]				
				NH pyrrole	NH amide	CH pyrrole	CH benzene	CH bridge

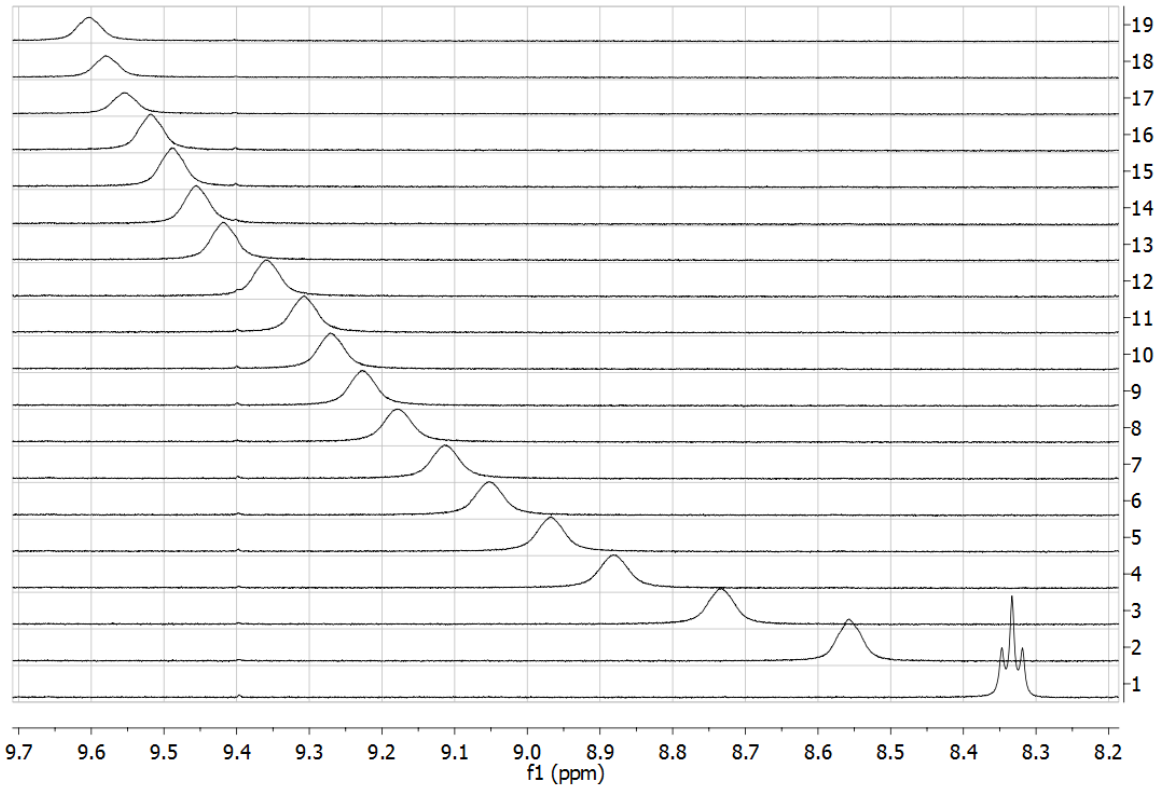
$H_2PO_4^-$	0.01234	0.07335	73	-	1.506	-0.3148	-0.0751	0.1814



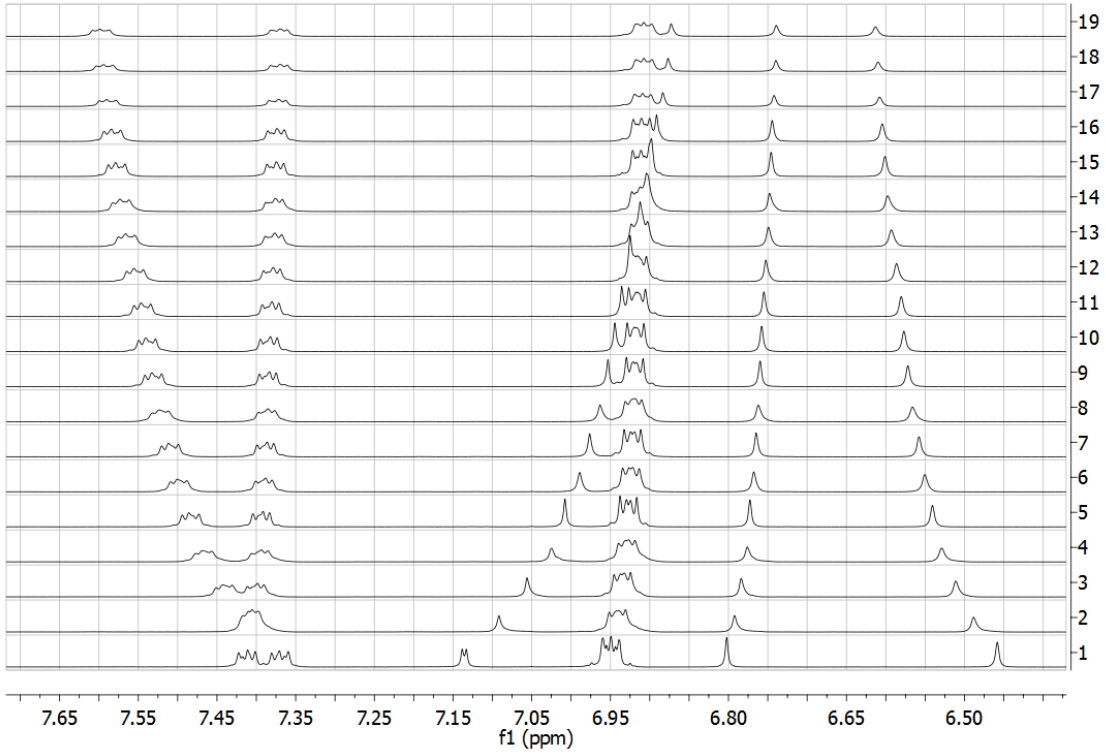
Changes in ^{1}H NMR signal shifts of the ligand amide NH protons upon addition of the anion



Changes in ^{1}H NMR signal shifts of the ligand aromatic and bridgehead CH protons upon addition of the anion



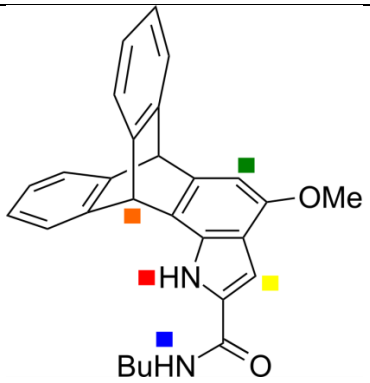
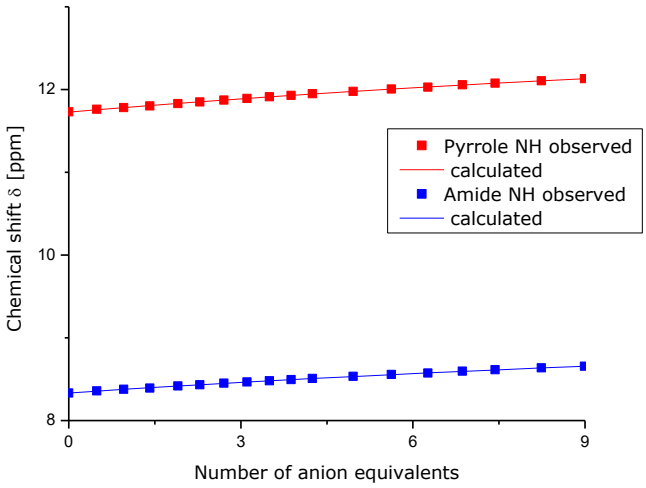
Changes in ^{1}H NMR signal shifts of the ligand amide NH protons upon addition of the anion



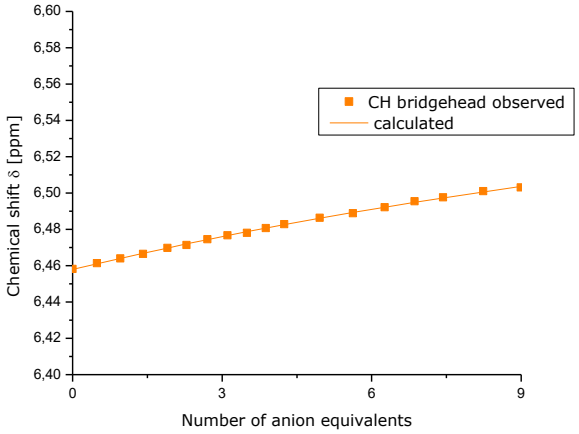
Changes in ^{1}H NMR signal shifts of the ligand aromatic and bridgehead CH protons upon addition of the anion

TBA$^+$ Cl$^-$

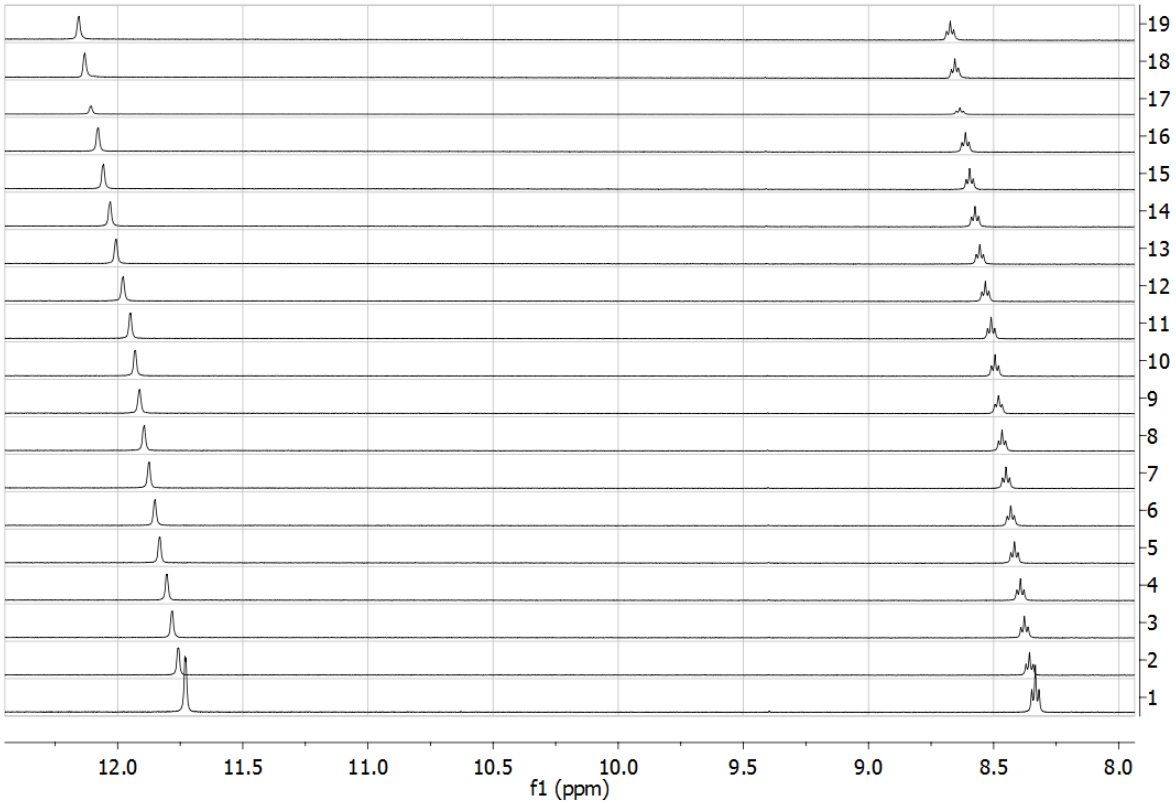
Table S4. The details of ^{1}H NMR titration experiment: concentrations used, titration curves and the results of data fitting for receptor **3** with TBA$^+$ Cl$^-$ in DMSO-d_6+0.5% H_2O.[a]

Ligand								
Solvent	DMSO-d_6 + 0.5% H_2O							
Anion	C_{ligand} [mol·dm^{-3}]	C_{anion} [mol·dm^{-3}]	K [M^{-1}]	$\Delta\delta_{max}$ [ppm]				
				NH pyrrole	NH amide	CH pyrrole	CH benzene	CH bridge
Cl$^-$	0.01201	0.11639	3.0	1.670	1.336	-	-	0.1892
								

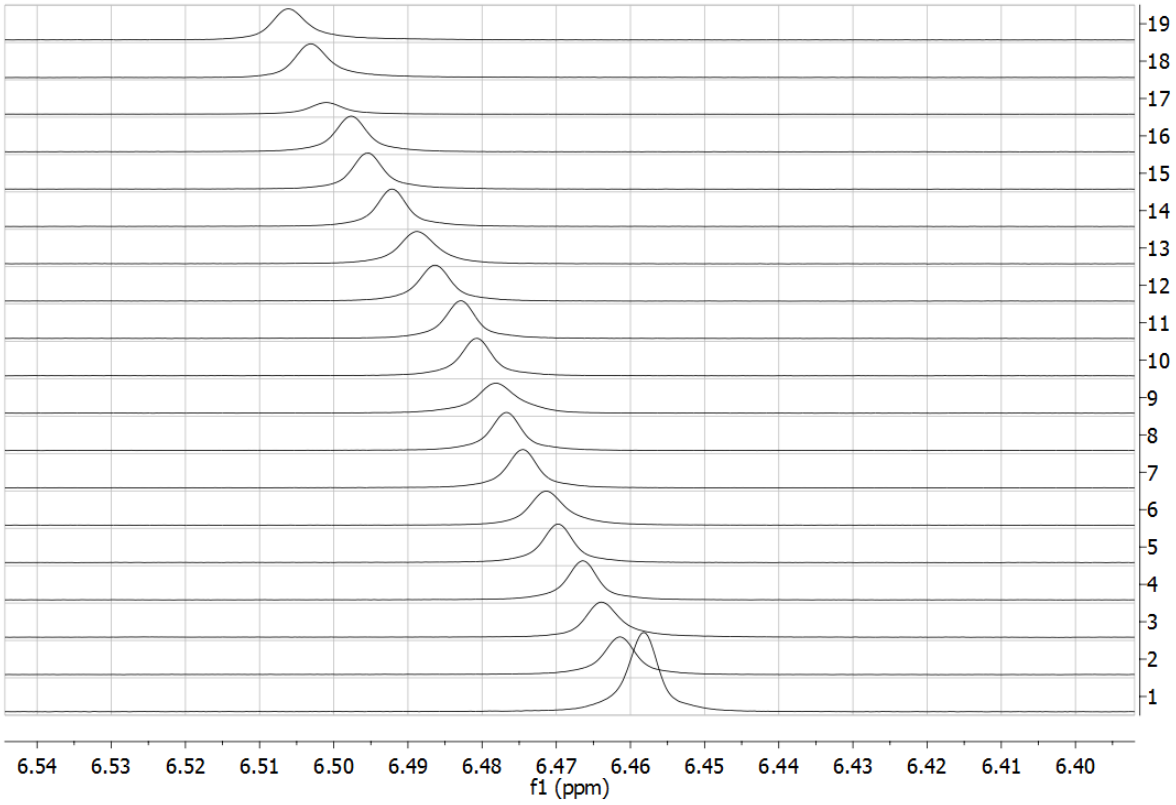
Changes in ^{1}H NMR signal shifts of the ligand NH protons upon addition of the anion



Changes in ^{1}H NMR signal shifts of the ligand bridgehead CH protons upon addition of the anion



Changes in ^{1}H NMR signal shifts of the ligand amide NH protons upon addition of the anion



Changes in ^{1}H NMR signal shifts of the ligand bridgehead CH protons upon addition of the anion

5.2. Binding studies of ligand 2

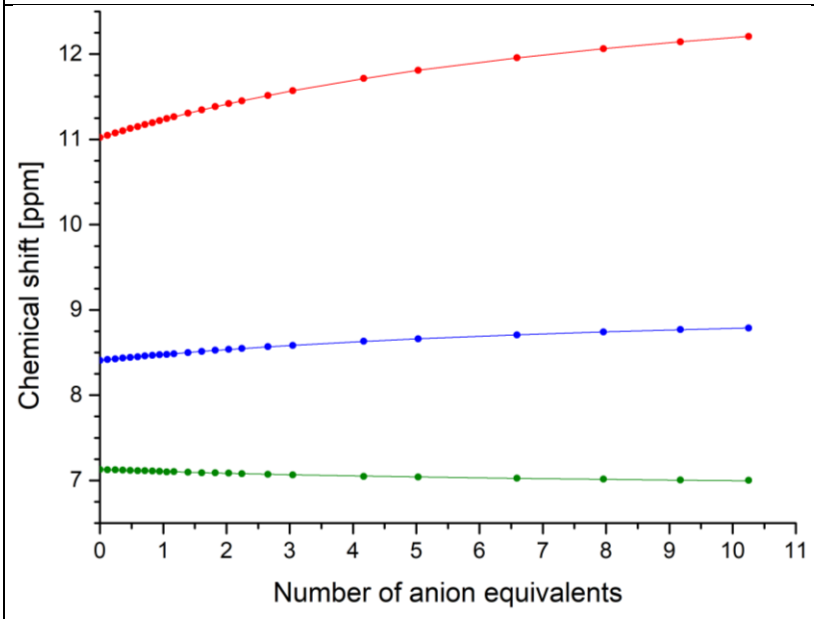
5.2.1. General remarks

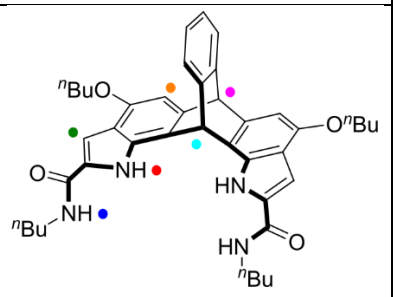
As the source of anions commercially available *n*-tetrabutylammonium (TBA) salts were used. The aqueous DMSO-d_6 mixtures were obtained by adding an appropriate amount of distilled water to a septum-sealed vial of DMSO-d_6 purchased from Eurisotop. The ca. $2 \cdot 10^{-3}$ M solution of receptor was titrated in a NMR septum-sealed tube with a ca. $5 \cdot 10^{-2}$ M solution of the appropriate TBA salts.

5.2.2. ^{1}H NMR titration experiments (DMSO-d$_6$+5% H$_2$O)

TBA+ AcO-

Table S5. The details of ^{1}H NMR titration experiment: concentrations used. titration curves and the results of data fitting for receptor **2** with TBA^+ AcO^- in DMSO-d_6+5% H_2O.[a]





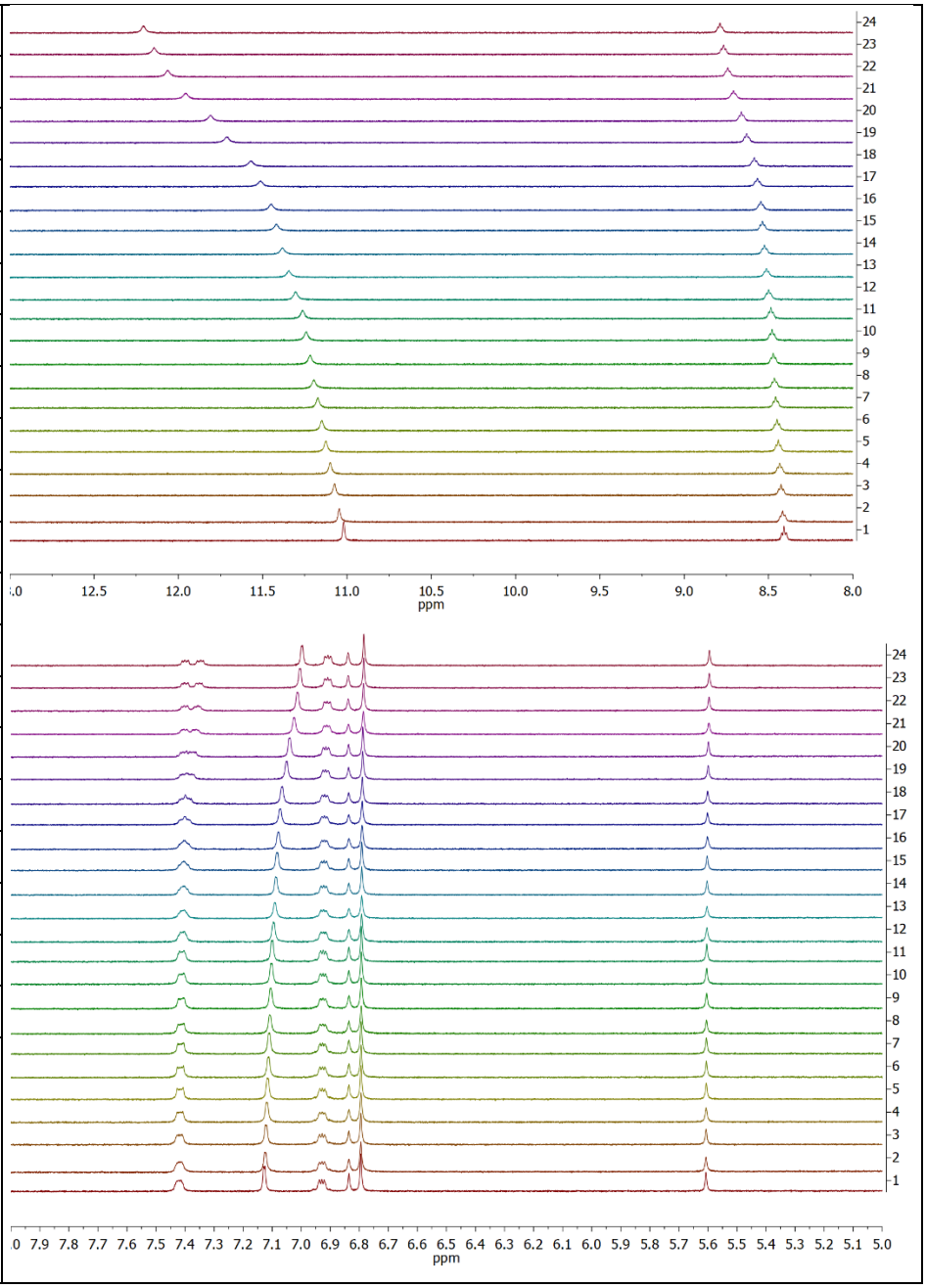
Concentration [mol·dm^{-3}]	
Ligand	Anion
0.00245	0.07161
Binding model (receptor:anion)	
1:1	

Log β	Stability constant [M^{-1}]
1.68(3)	47.8

[a] Nonlinear curve fitting was performed using *HypNMR 2008* program.

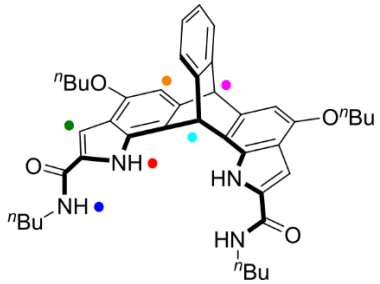
Table S6. ^{1}H NMR changes during titration of receptor **2** with TBA^+ $H_2PO_4^-$ in DMSO-d_6+5% H_2O.[a]

Spectrum number	Number of anion equivalents	
1	0.00	
2	0.12	
3	0.24	

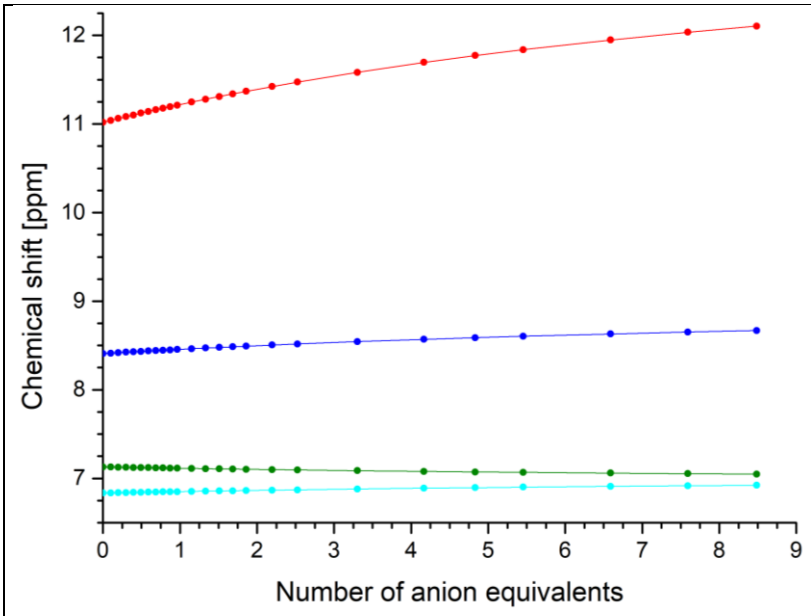
4	0.36	
5	0.48	
6	0.60	
7	0.71	
8	0.83	
9	0.94	
10	1.05	
11	1.17	
12	1.39	
13	1.61	
14	1.82	
15	2.04	
16	2.25	
17	2.65	
18	3.05	
19	4.17	
20	5.03	
21	6.59	
22	7.96	
23	9.17	
24	10.25	

TBA$^+$ BzO$^-$

Table S7. The details of ^{1}H NMR titration experiment: concentrations used. titration curves and the results of data fitting for receptor **2** with TBA$^+$ BzO$^-$ in DMSO-d_6+5% H_2O.[a]



Concentration [mol·dm^{-3}]



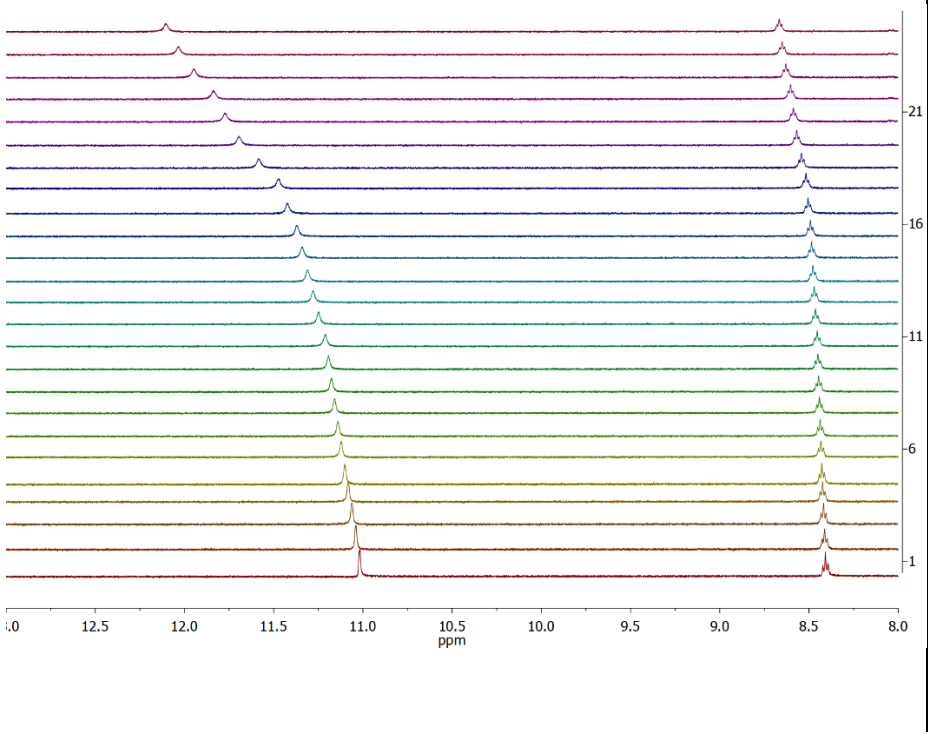
Ligand	Anion
0.00245	0.06202
Binding model (receptor:anion)	
1:1	

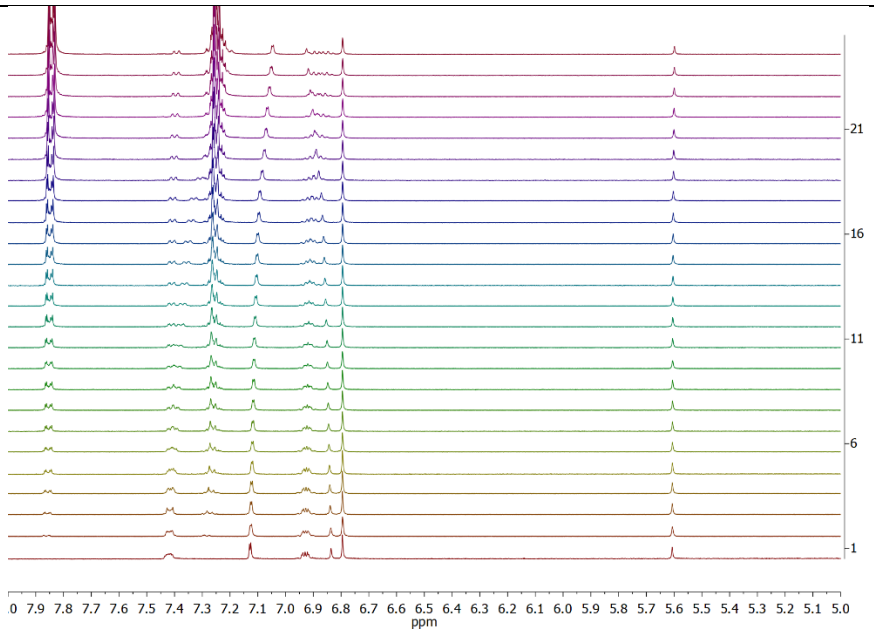
Log β	Stability constant [M^{-1}]
1.559(2)	36.4

[a] Nonlinear curve fitting was performed using *HypNMR 2008* program.

Table S8. ^{1}H NMR changes during titration of receptor **2** with TBA^{+} BzO^{-} in DMSO-d_6+5% H_2O.[a]

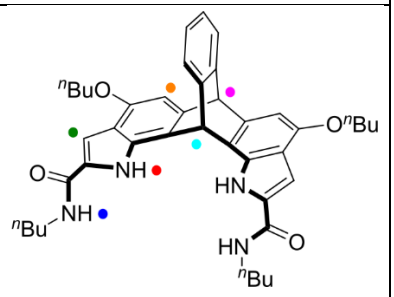
Spectrum number	Number of anion equivalents
1	0.00
2	0.10
3	0.21
4	0.31
5	0.41
6	0.52
7	0.62
8	0.72
9	0.82
10	0.91
11	1.01
12	1.20



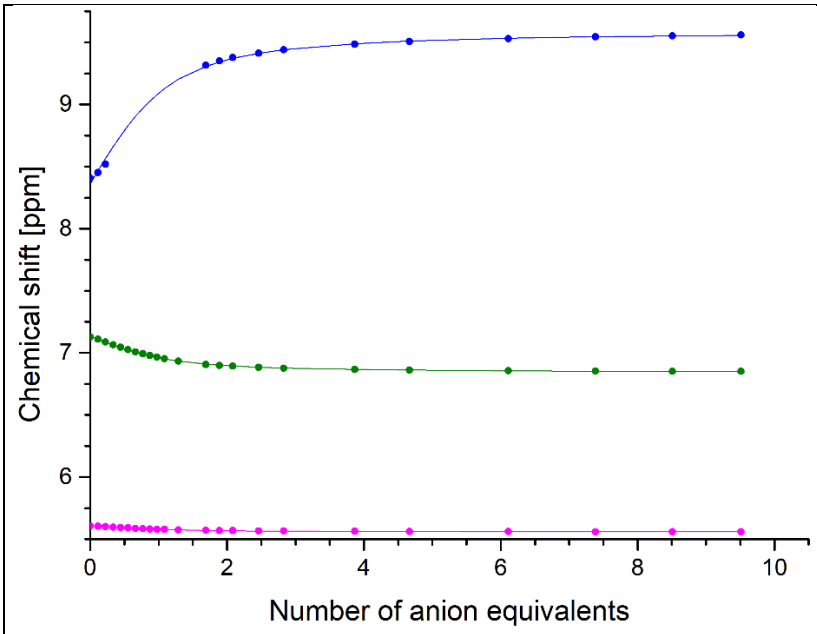
13	1.39	
14	1.58	
15	1.76	
16	1.94	
17	2.30	
18	2.64	
19	3.46	
20	4.36	
21	5.06	
22	5.71	
23	6.89	
24	7.94	
25	8.88	

TBA^+ $H_2PO_4^-$

Table S9. The details of ^{1}H NMR titration experiment: concentrations used, titration curves and the results of data fitting for receptor **2** with TBA^+ $H_2PO_4^-$ in DMSO-d_6+5% H_2O.[a]



Concentration [mol·dm^{-3}]	
Ligand	Anion
0.00257	0.06643
Binding model (receptor:anion)	



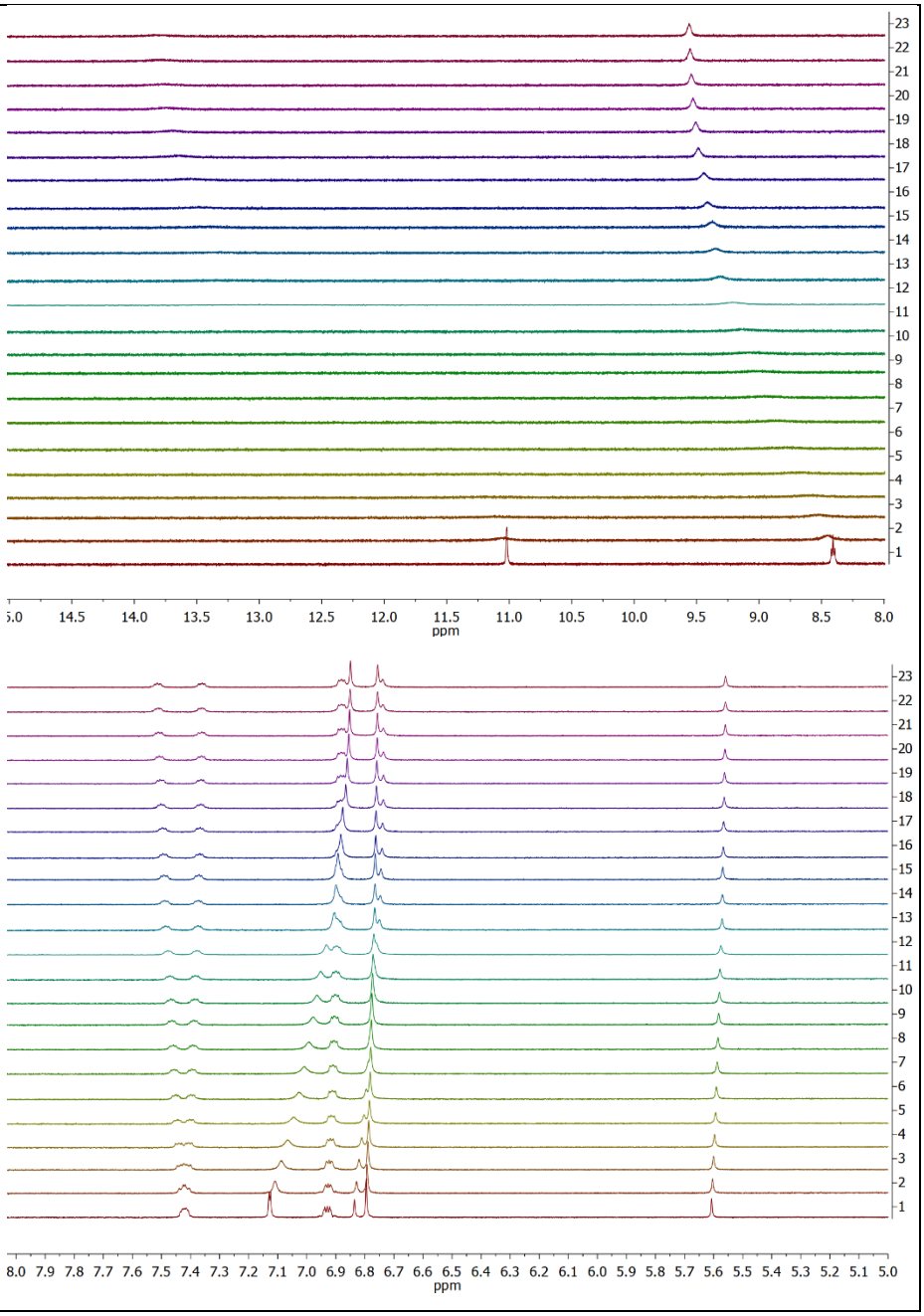
1:1

Log β	Stability constant [M^{-1}]
3.16 (2)	1445

[a] Nonlinear curve fitting was performed using *HypNMR 2008* program.

Table S10. ^{1}H NMR changes during titration of receptor **2** with TBA^{+} $H_2PO_4^{-}$ in DMSO-d_6+5% H_2O.[a]

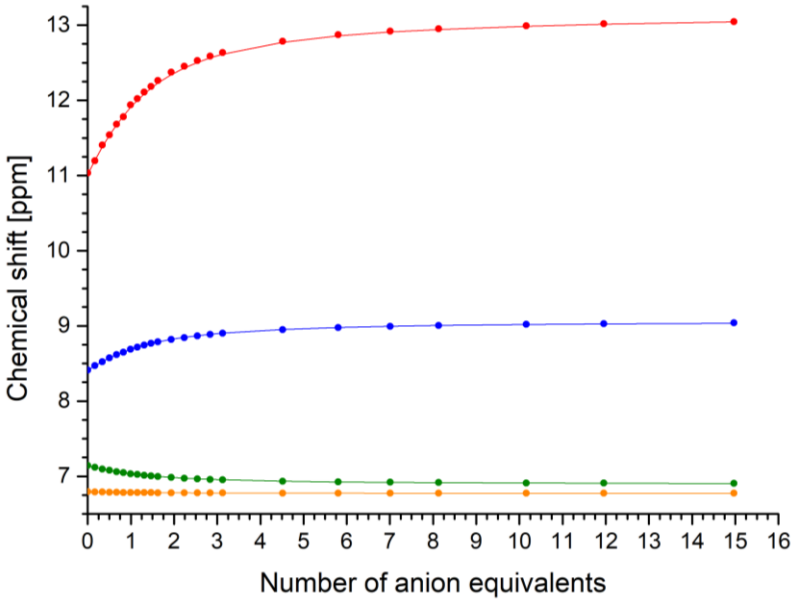
Spectrum number	Number of anion equivalents
1	0.00
2	0.11
3	0.22
4	0.33
5	0.44
6	0.55
7	0.66
8	0.77
9	0.87

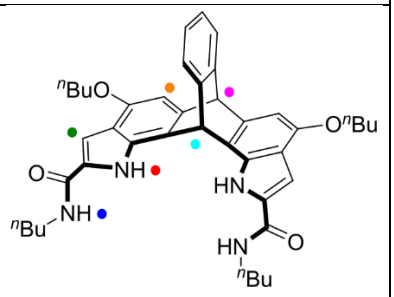
10	0.98	
11	1.08	
12	1.29	
13	1.69	
14	1.89	
15	2.08	
16	2.46	
17	2.83	
18	3.87	
19	4.67	
20	6.11	
21	7.38	
22	8.51	
23	9.51	

5.2.3. ^{1}H NMR titration experiments (DMSO-d_6+0.5% H_2O)

TBA^+ AcO^-

Table S11. The details of ^{1}H NMR titration experiment: concentrations used. titration curves and the results of data fitting for receptor **2** with TBA^+ AcO^- in DMSO-d_6+0.5% H_2O.[a]





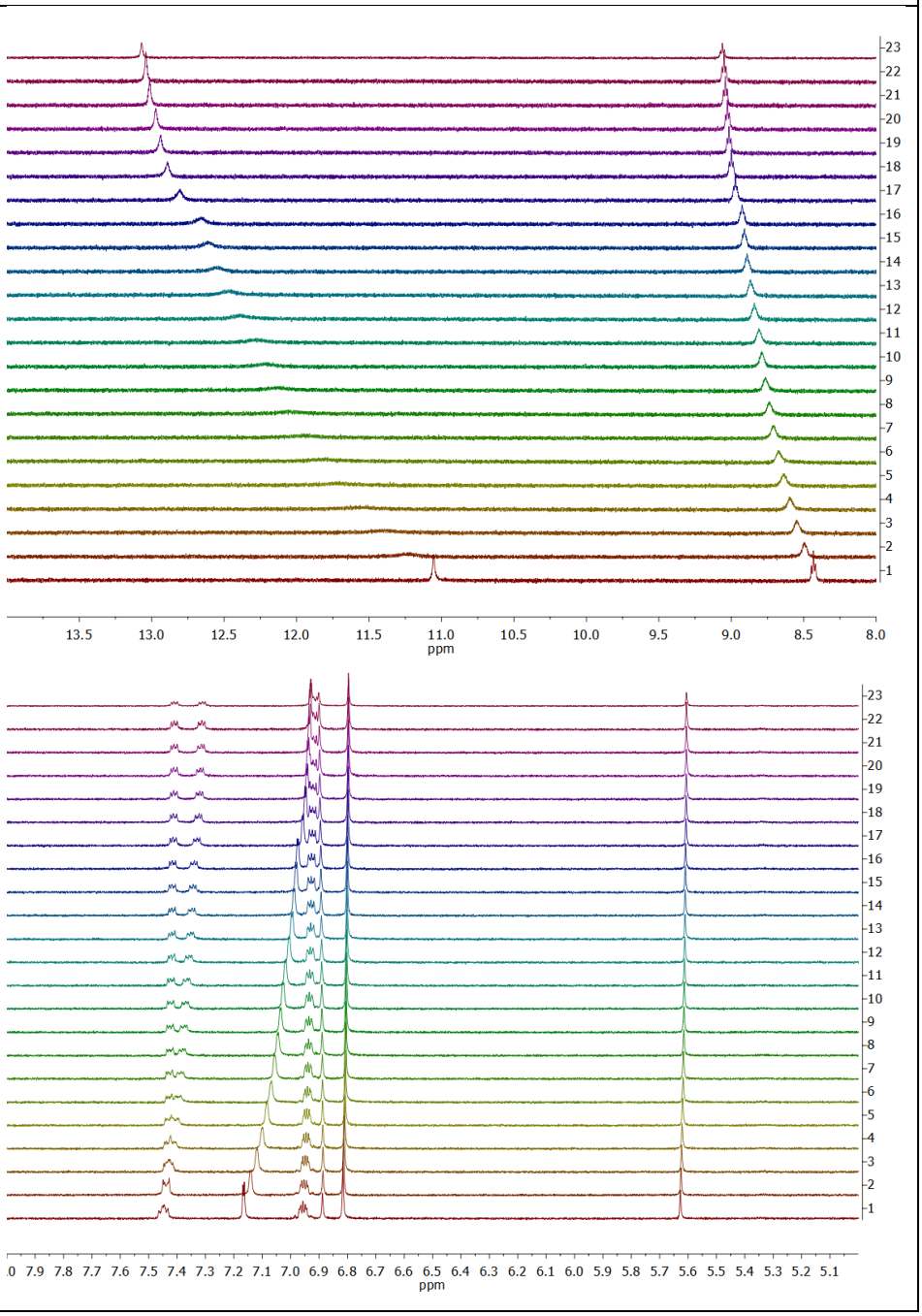
Concentration [mol·dm^{-3}]	
Ligand	Anion
0.00233	0.09461
Binding model (receptor:anion)	
1:1	

Log β	Stability constant [M^{-1}]
2.745(4)	555.9

[a] Nonlinear curve fitting was performed using *HypNMR 2008* program.

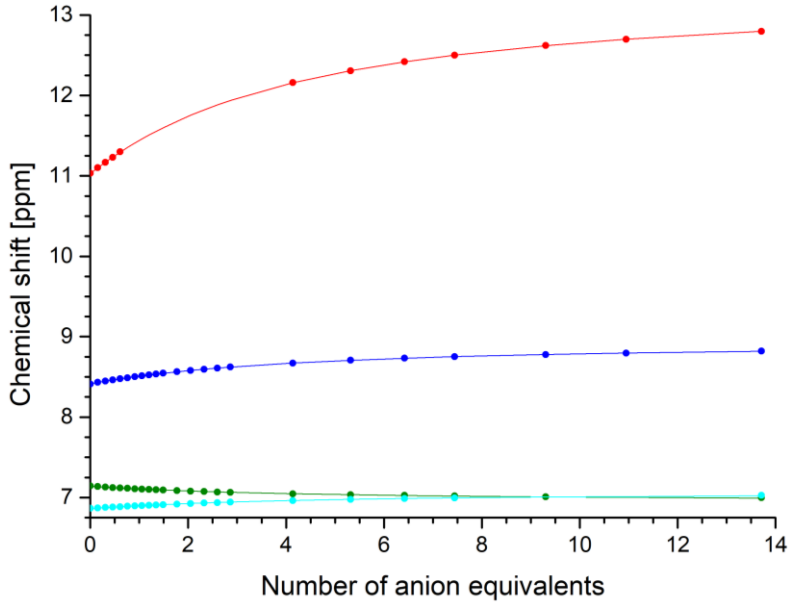
Table S12. ^{1}H NMR changes during titration of receptor **2** with TBA^{+} AcO^{-} in DMSO-d_6+0.5% H_2O.[a]

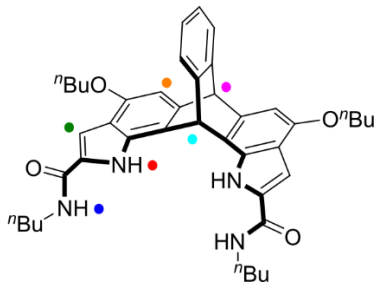
Spectrum number	Number of anion equivalents
1	0.00
2	0.17
3	0.34
4	0.50
5	0.67
6	0.83
7	0.99
8	1.15
9	1.31
10	1.47
11	1.63
12	1.94
13	2.24
14	2.54
15	2.84
16	3.13
17	4.52
18	5.81
19	7.01
20	8.13
21	10.16
22	11.95
23	14.97



TBA^+ BzO^-

Table S13. The details of ^1H NMR titration experiment: concentrations used. titration curves and the results of data fitting for receptor **2** with TBA^+ BzO^- in DMSO-d_6+0.5% H_2O.[a]





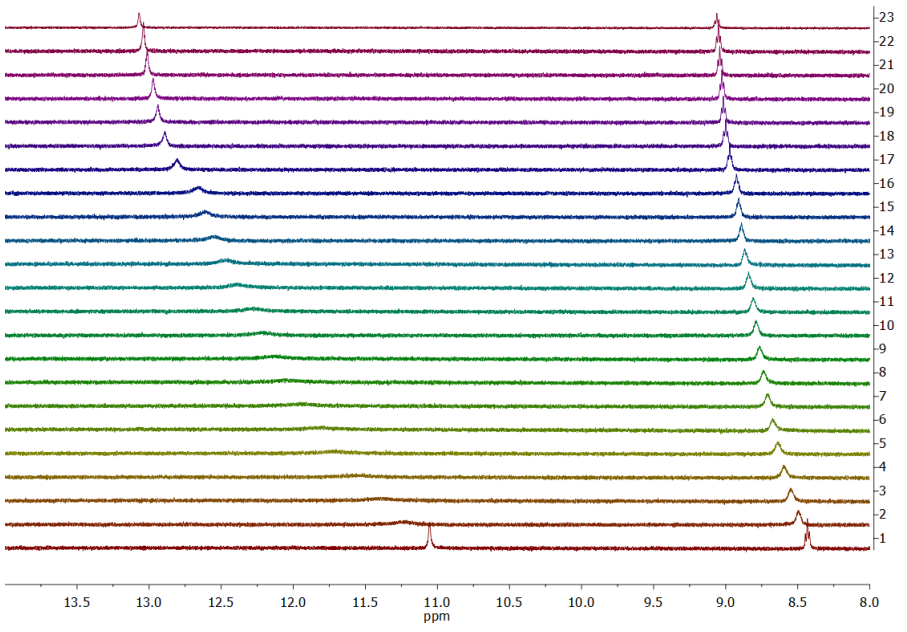
Concentration [mol·dm^{-3}]	
Ligand	Anion
0.00233	0.09461
Binding model (receptor:anion)	
1:1	

Log β	Stability constant [M^{-1}]
2.062(3)	115.3

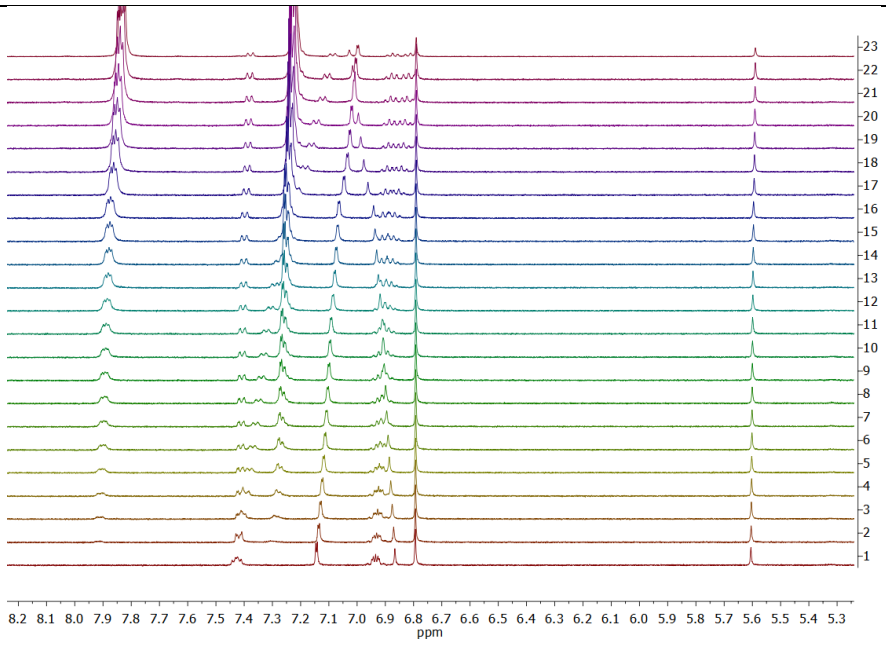
[a] Nonlinear curve fitting was performed using *HypNMR 2008* program.

Table S14. ^1H NMR changes during titration of receptor **2** with TBA^+ BzO^- in DMSO-d_6+0.5% H_2O.[a]

Spectrum number	Number of anion equivalents
1	0.00
2	0.17
3	0.34
4	0.50
5	0.67
6	0.83
7	0.99
8	1.15
9	1.31
10	1.47
11	1.63
12	1.94

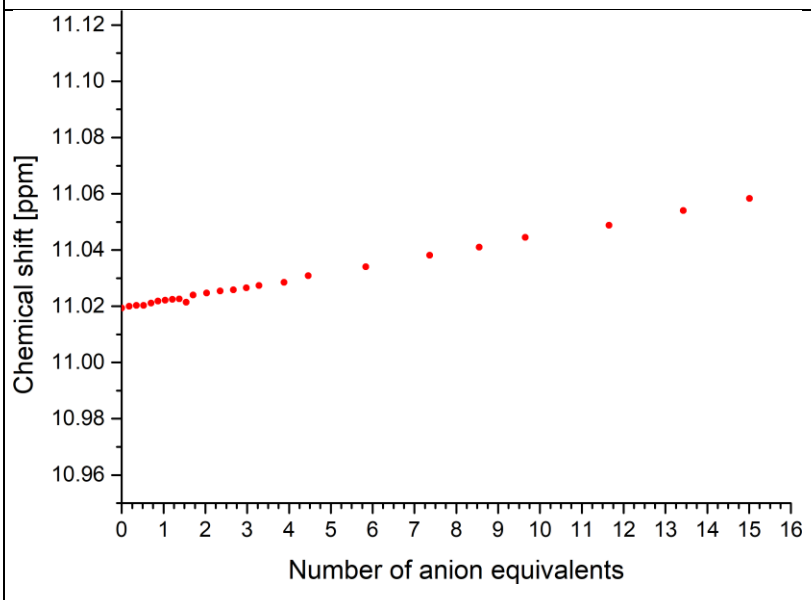


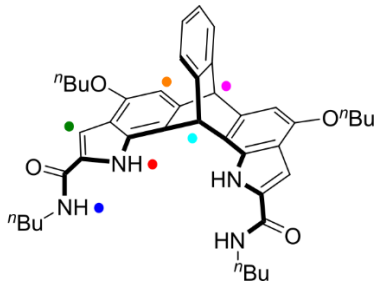
13	2.24
14	2.54
15	2.84
16	3.13
17	4.52
18	5.81
19	7.01
20	8.13
21	10.16
22	11.95
23	14.97



TBA$^+$ Cl$^-$

Table S15. The details of ^{1}H NMR titration experiment: concentrations used. titration curves and the results of data fitting for receptor **2** with TBA$^+$ Cl$^-$ in DMSO-d_6+0.5% H_2O.[a]





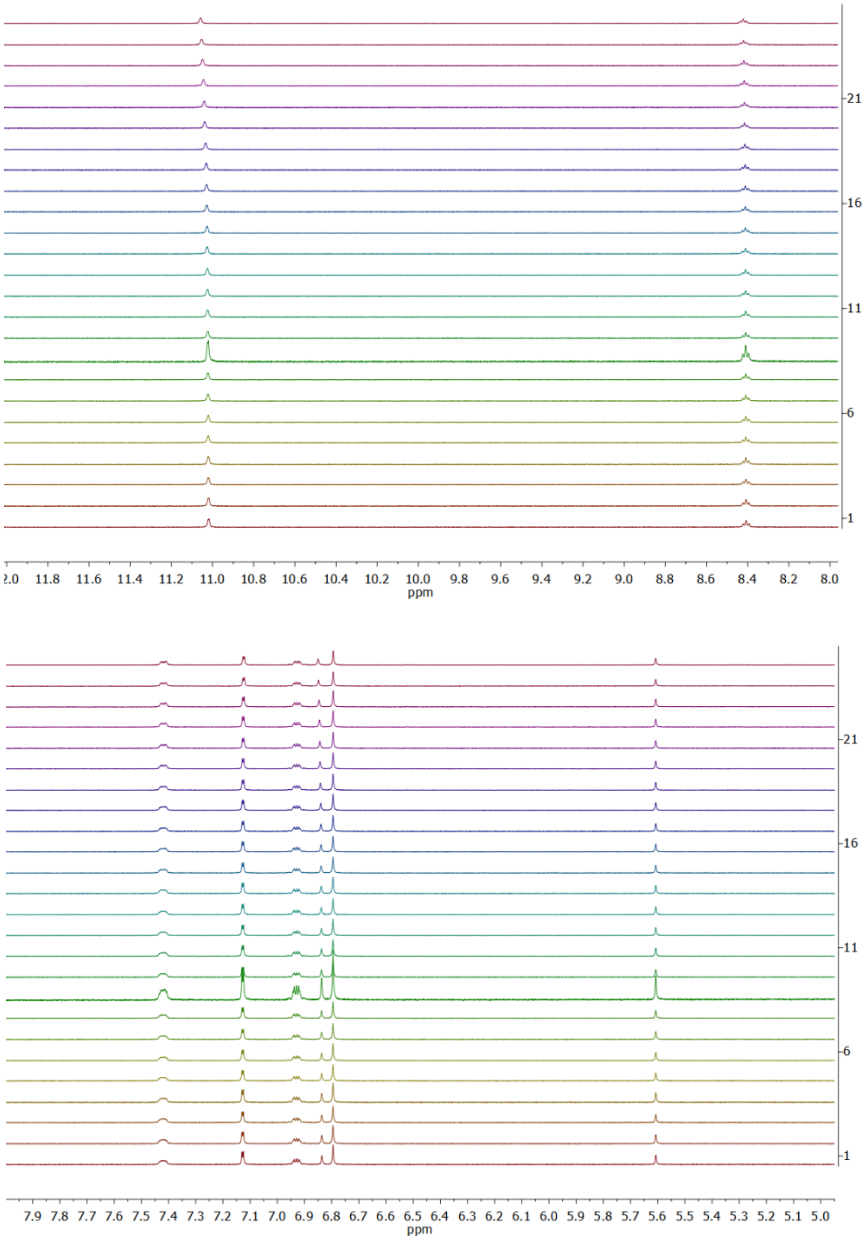
Concentration [mol·dm^{-3}]	
Ligand	Anion
0.00245	0.10484
Binding model (receptor:anion)	
-	

Log β	Stability constant [M^{-1}]
-	-

[a] Changes in chemical shift too small for accurate stability constant determination.

Table S16. ^{1}H NMR changes during titration of receptor **2** with TBA^{+} Cl^{-} in DMSO-d_6+0.5% H_2O.[a]

Spectrum number	Number of anion equivalents
1	0.00
2	0.18
3	0.35
4	0.53
5	0.70
6	0.87
7	1.04
8	1.21
9	1.38
10	1.54
11	1.71
12	2.03
13	2.36
14	2.67
15	2.98
16	3.29
17	3.88
18	4.46
19	5.84
20	7.37
21	8.55
22	9.65
23	11.65
24	13.43
25	15.01



5.3. Binding studies of ligand 1

5.3.1. General remarks

As the source of anions commercially available *n*-tetrabutylammonium (TBA) salts were used. The aqueous DMSO-d_6 mixtures were obtained by adding an appropriate amount of distilled water to a septum-sealed vial of DMSO-d_6 purchased from Eurisotop. The ca. $2 \cdot 10^{-3}$ M solution of receptor was titrated in a NMR septum-sealed tube with a ca. $5 \cdot 10^{-2}$ M solution of the appropriate TBA salts.

5.3.2. ^{1}H NMR titration experiments (DMSO-d$_6$+5% H_2O)

TBA^+ UMP^-

Table S17. The details of ^{1}H NMR titration experiment: concentrations used. titration curves and the results of data fitting for receptor **1** with TBA^+ UMP^- in DMSO-d_6+0.5% H_2O.

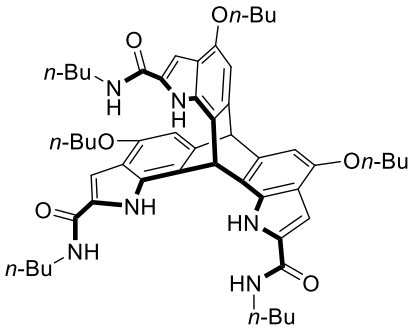
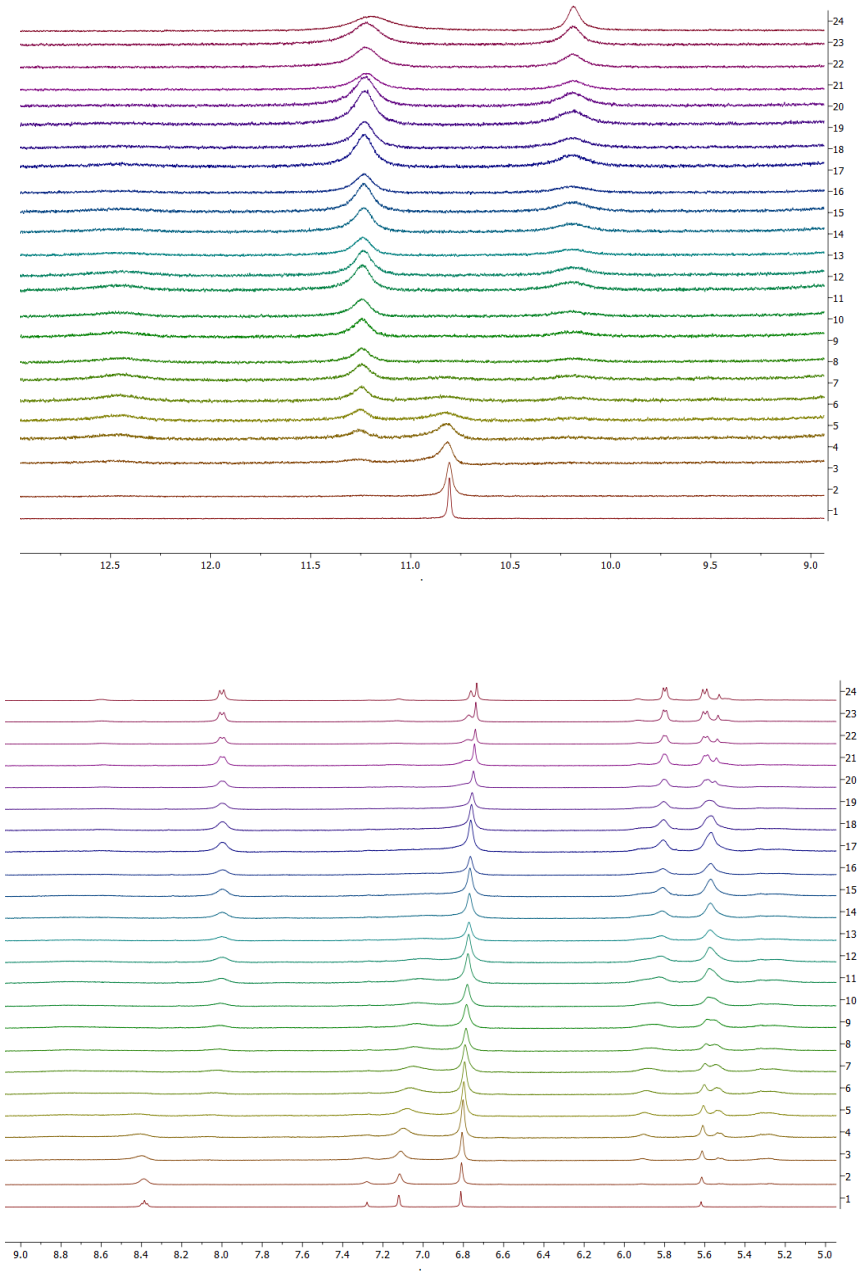
Slow biding equilibrium		
	Concentration [mol·dm^{-3}]	
	Ligand	Anion
	0.00370	0.03686
	Binding model (receptor:anion)	
	-	
Log β	Stability constant [M^{-1}]	
-	-	

Table S14. ^{1}H NMR changes during titration of receptor **1** with TBA^{+} UMP^{-} in DMSO-d_6+0.5% H_2O.[a]

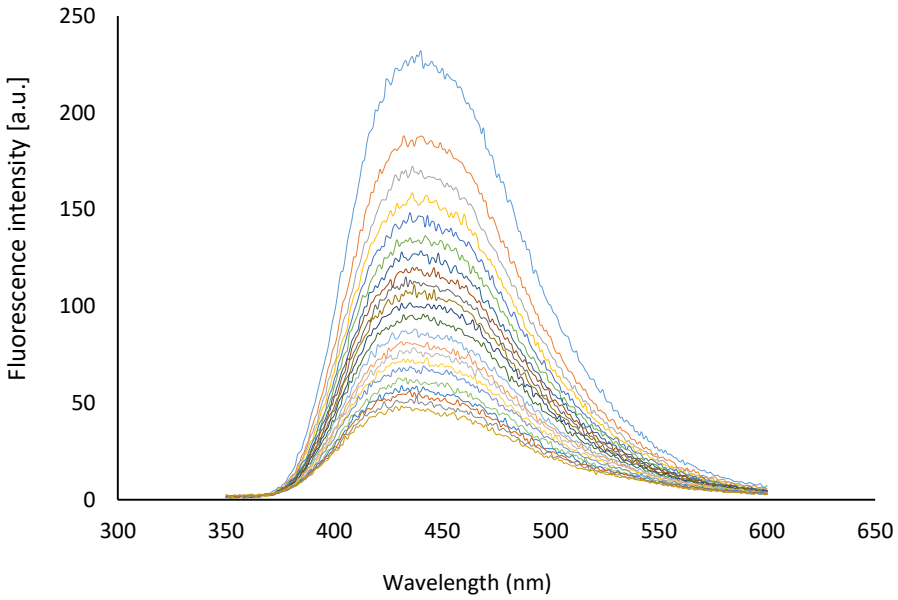
Spectrum number	Number of anion equivalents
1	0.00
2	0.20
3	0.38
4	0.56
5	0.74
6	0.91
7	1.07
8	1.22
9	1.37
10	1.52
11	1.66
12	1.80
13	1.93
14	2.06
15	2.18
16	2.30
17	2.42
18	2.64
19	2.85
20	3.32
21	3.74
22	4.10
23	4.43
24	4.98

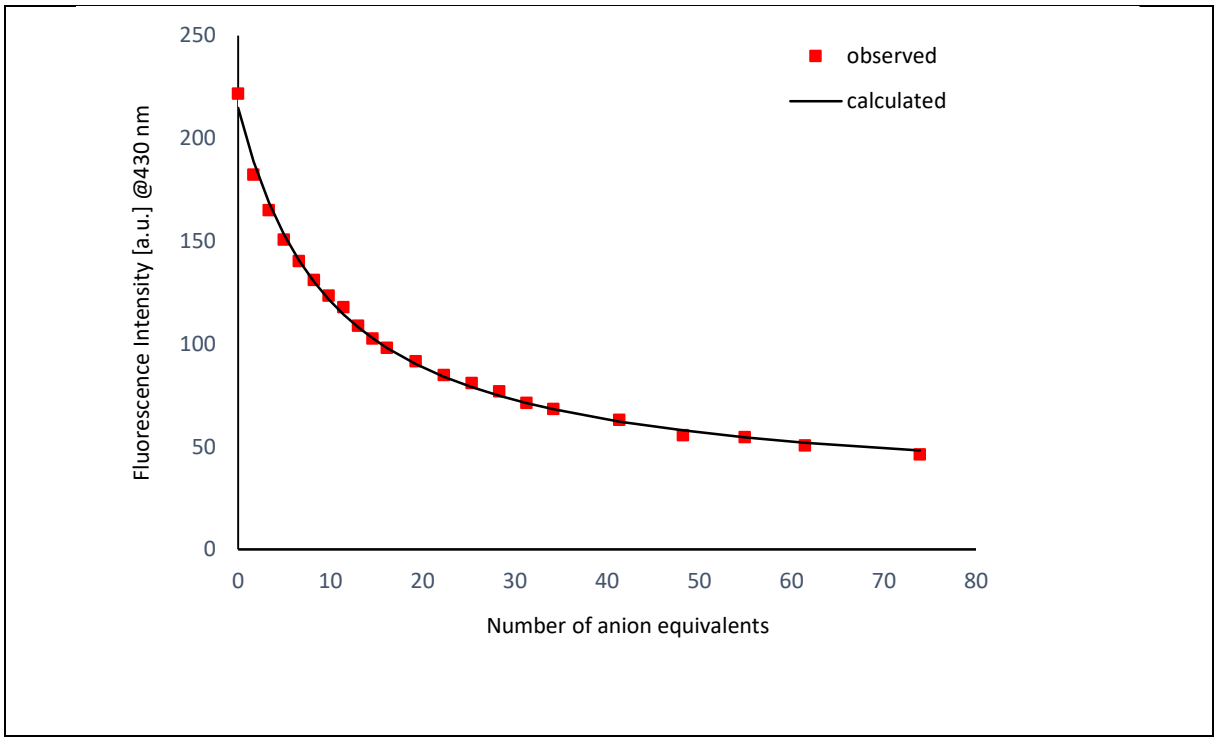


5.3.3. Fluorescence titration experiments of ligand 1

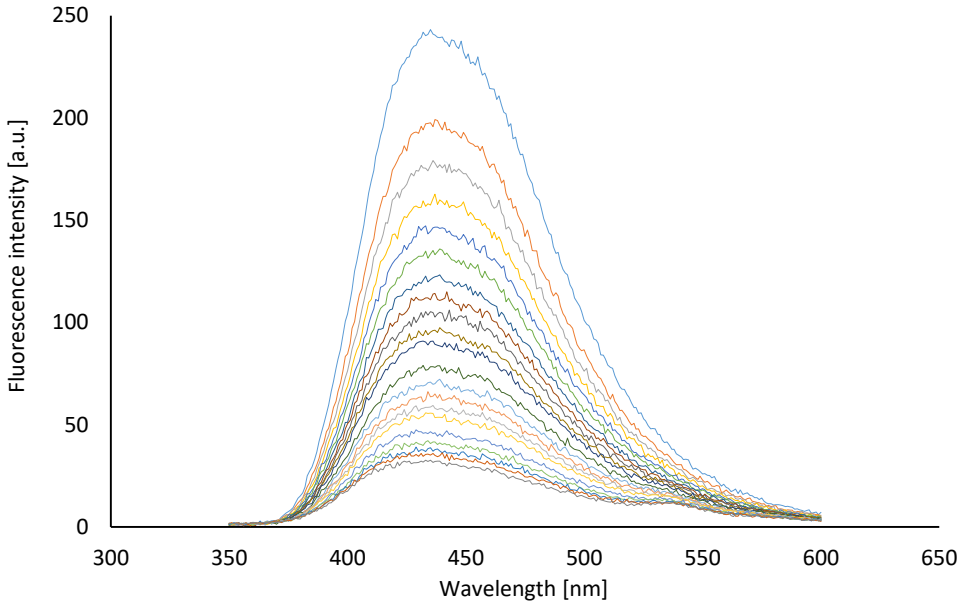
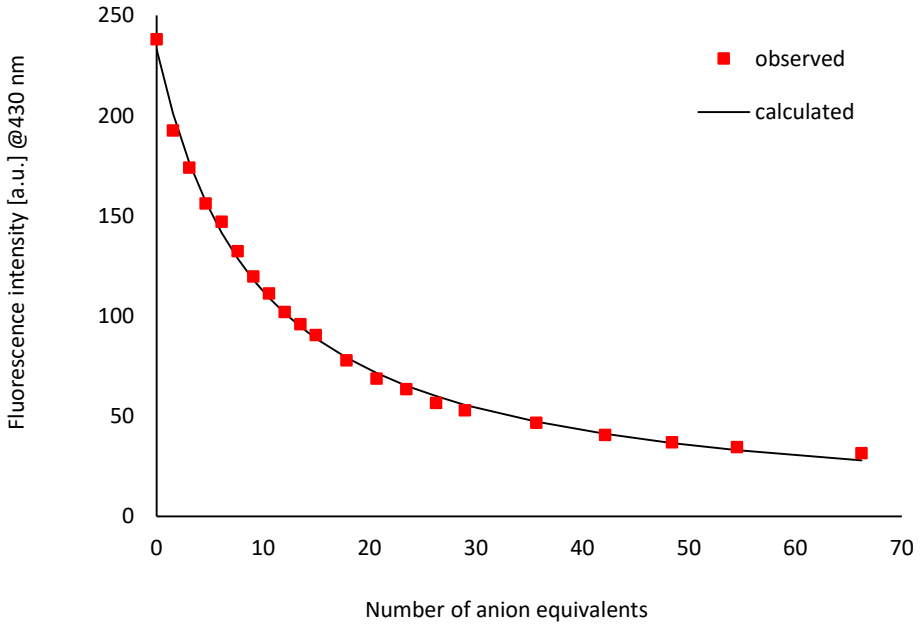
Fluorescence titration experiments were performed in 1 cm cell. To 3 mL solution of ligand (C = ~10^{-5} M) in 99.5% DMSO+0.5% H_2O (V/V), 0.5 to 1 mL of the solution of the respective Anions was added in 10-50 portions. After addition of each anion portion the fluorescence spectrum was recorded in range from 350 to 600 nm, using excitation of 310 nm on Varian Eclipse Fluorescence Spectrophotometer. The association constants were calculated from the changes in fluorescence. Non-linear cure fitting for 1:1 binding model was performed using the *HypNMR2008* program.

TBA^+ AMP^-

Receptor **1**
Anion: TBA^+ AMP^- K = 6637 M^{-1} Model of binding 1/1



250
200
150
100
50
0
Fluorescence Intensity [a.u.] @430 nm
0
10
20
30
40
50
60
70
80
Number of anion equivalents
observed
calculated

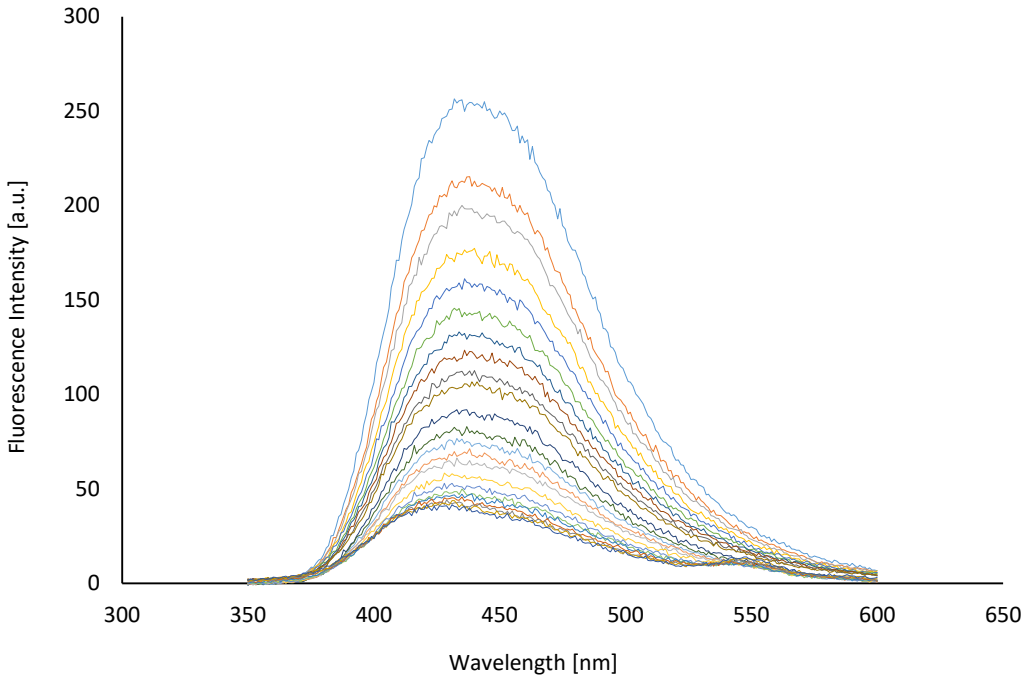
TBA^+ CMP^-

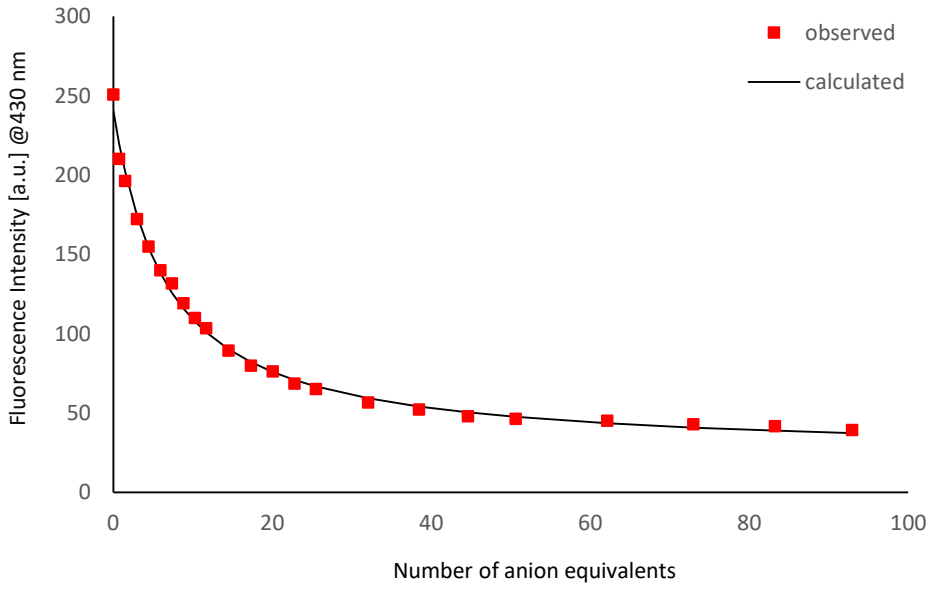
Receptor **1**
Anion: TBA^+ CMP^- K = 7170 M^{-1} Model of binding 1/1



TBA^+ $deoxyAMP^-$

Receptor **1**

Anion: TBA^+ $deoxyAMP^-$ K = 9576 M^{-1} Model of binding 1/1

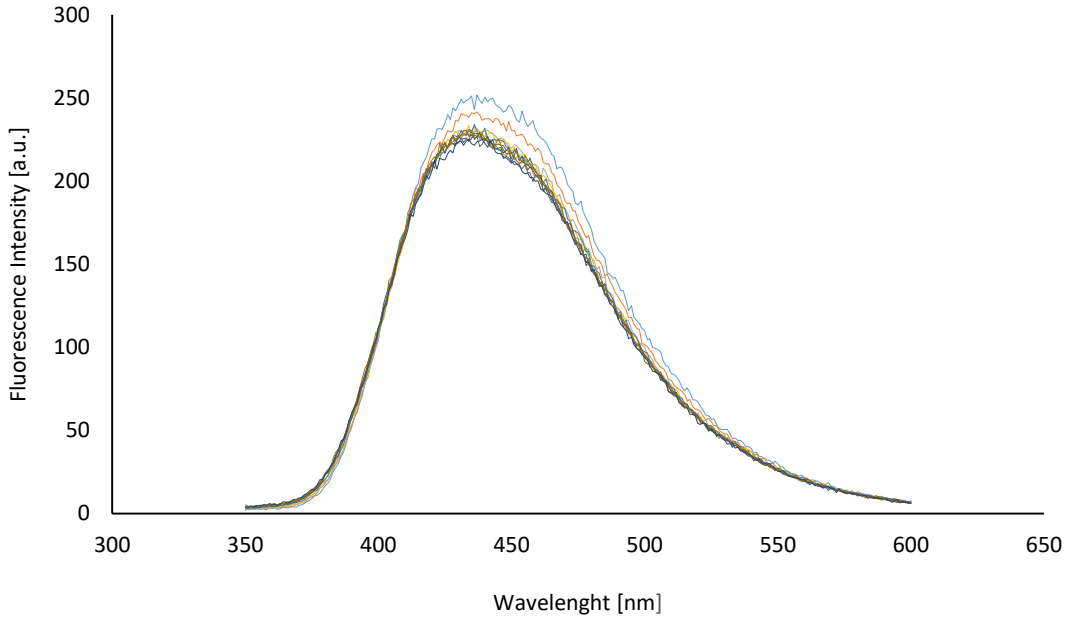


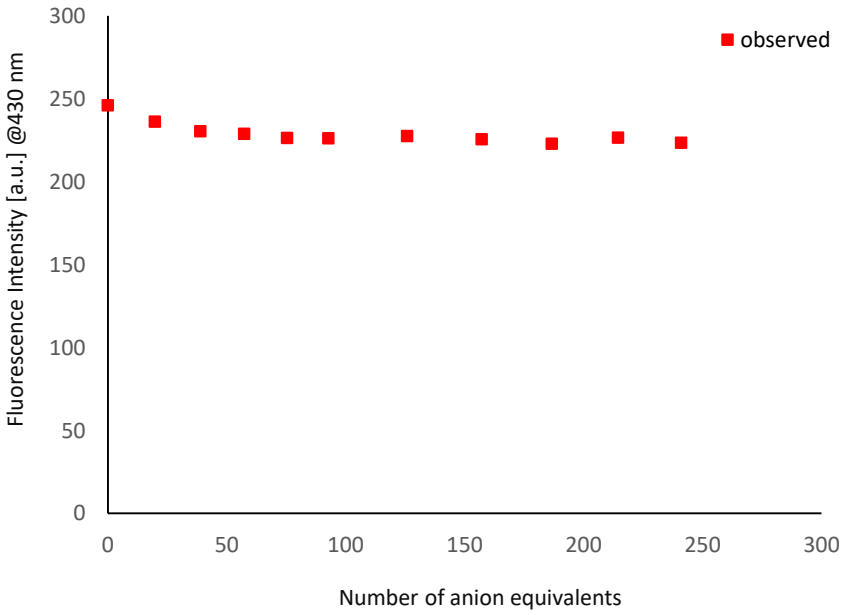


TBA^+ ADP^-

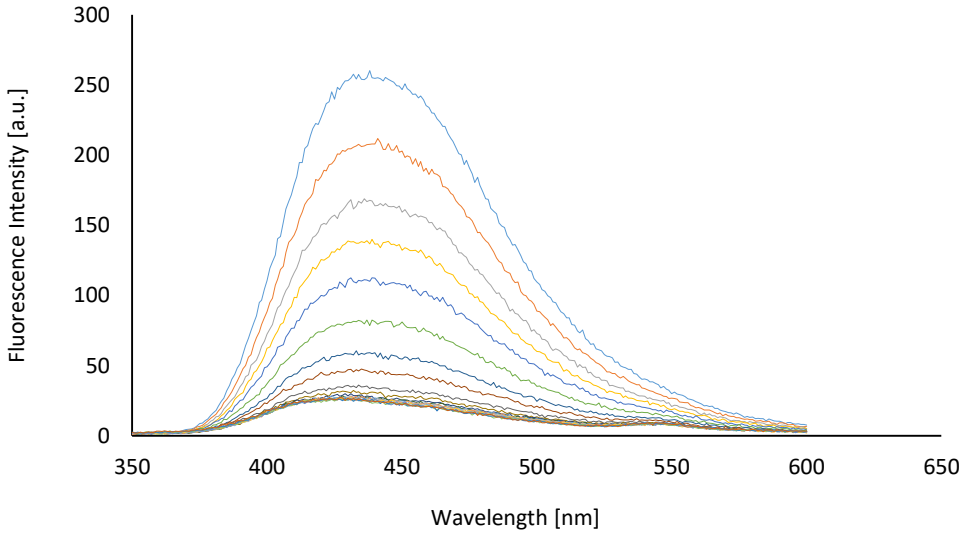
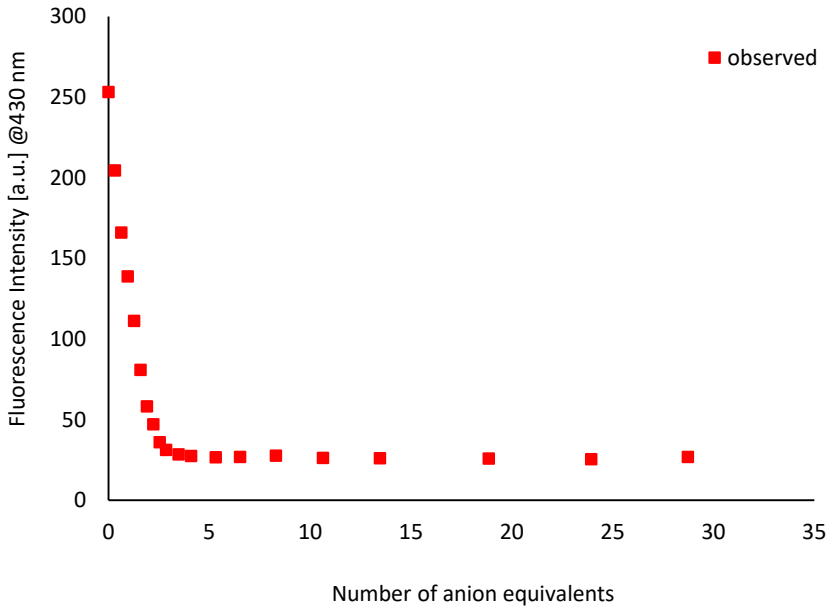
Receptor **1**

Anion: TBA^+ ADP^-





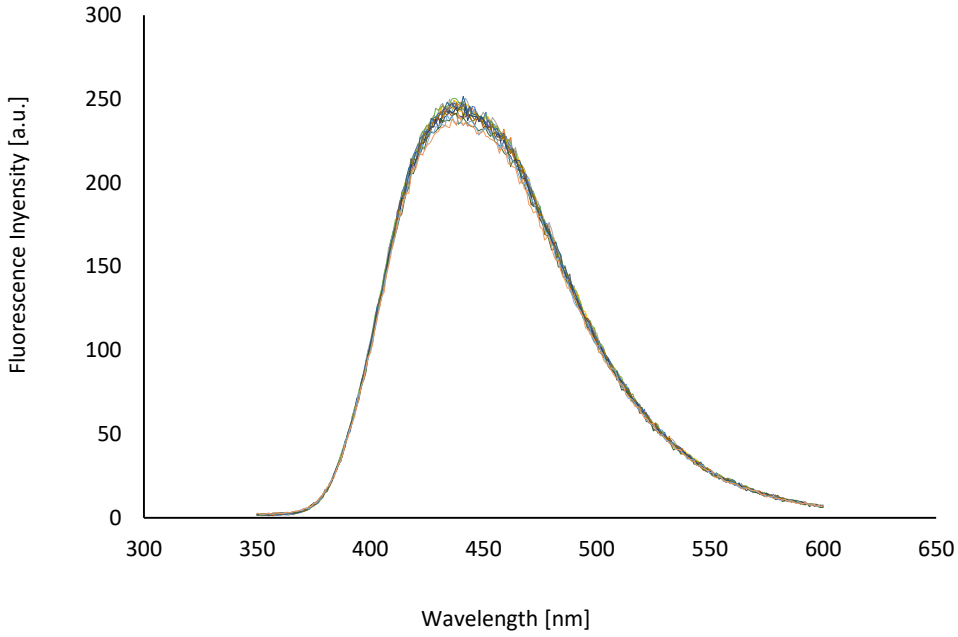
TBA^+ UMP^-

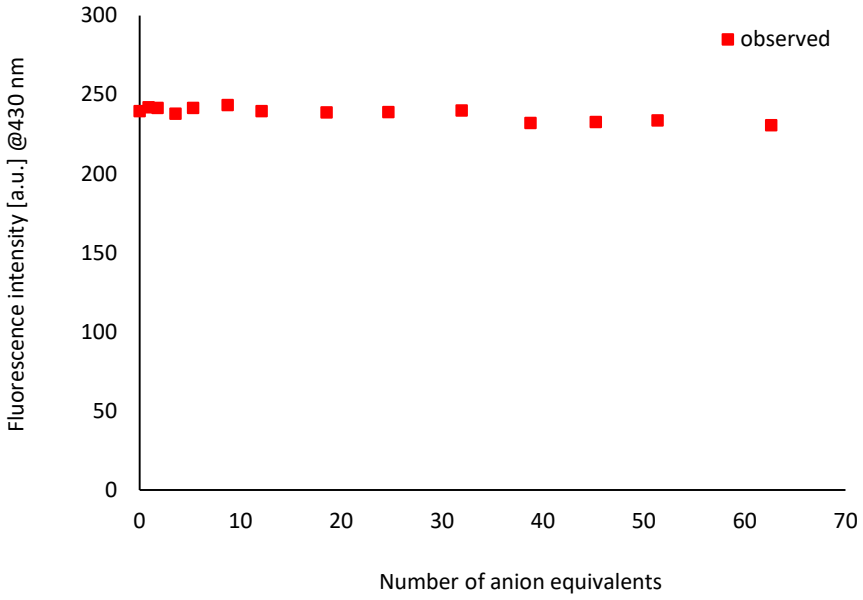
Receptor **1**
Anion: TBA^+ UMP^-



TBA^+ $cyclicAMP^-$

Receptor **1**

Anion: TBA^+ $cyclicAMP^-$

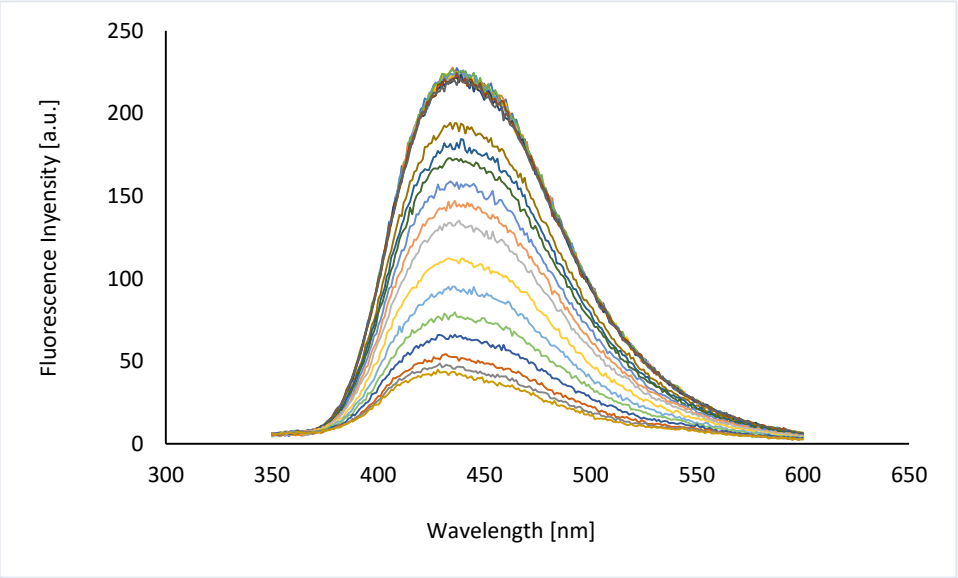


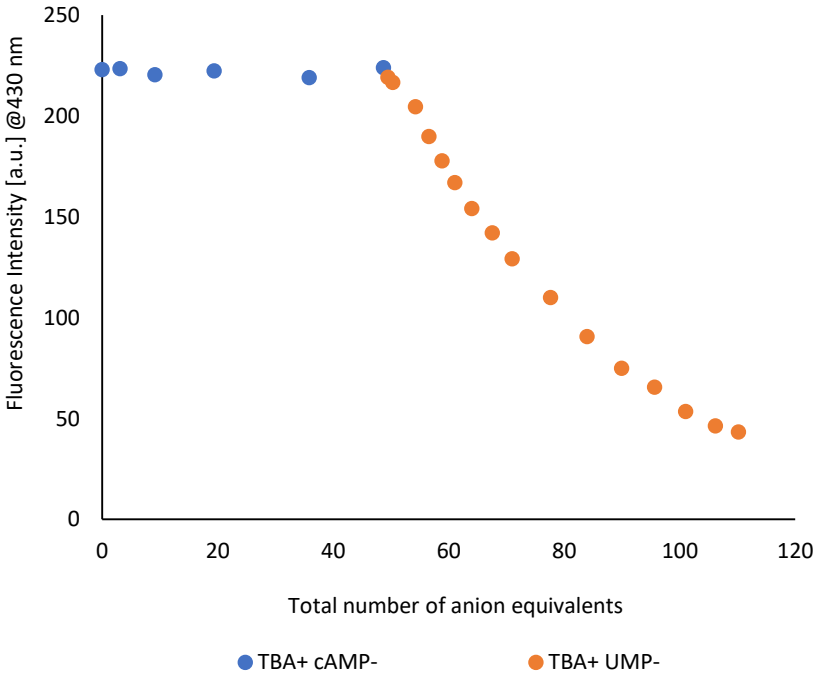


TBA^+ $cAMP^-$ and TBA^+ UMP^-

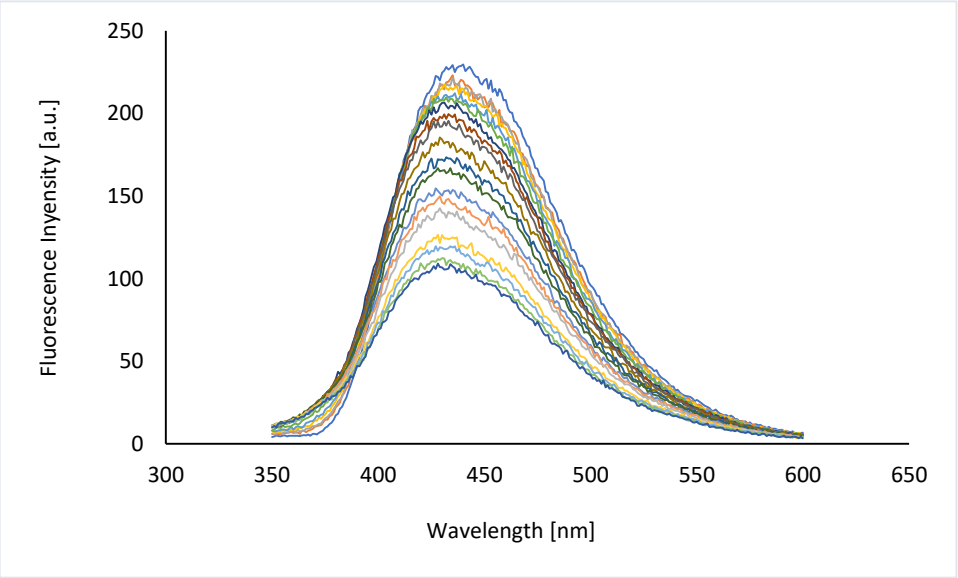
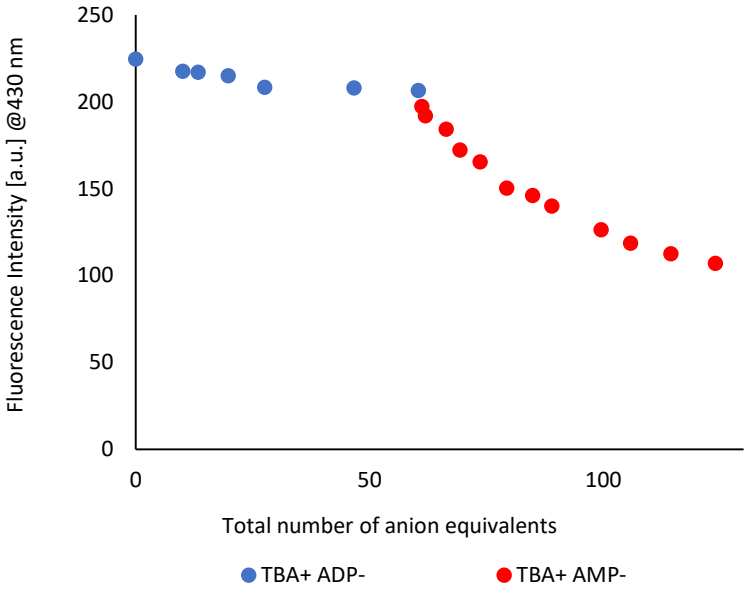
Receptor **1**

Anion: TBA^+ cyclicAMP$^-$ and TBA^+ UMP^-





TBA^+ ADP^- and TBA^+ AMP^-

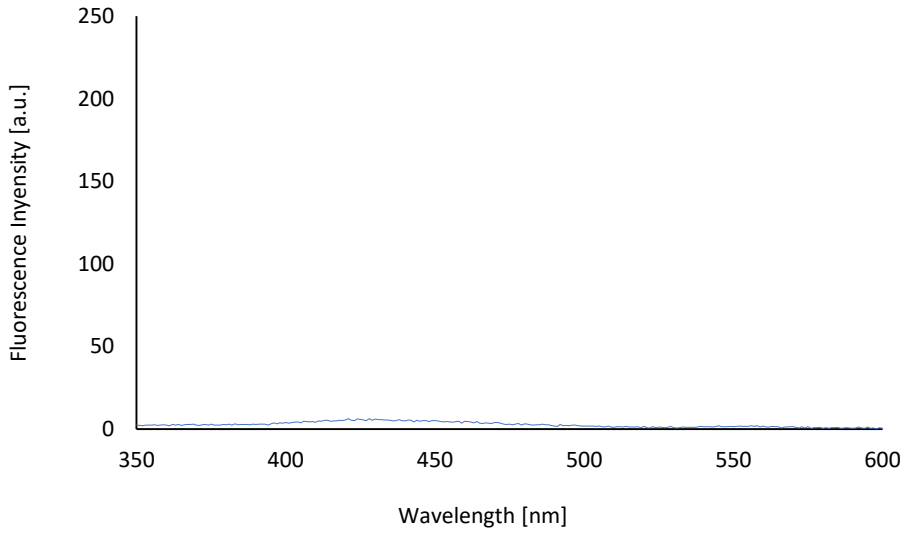
Receptor **1**
Anion: TBA^+ ADP^- and TBA^+ AMP^-



6. Fluorescence spectra of tetrabutyl ammonium salts

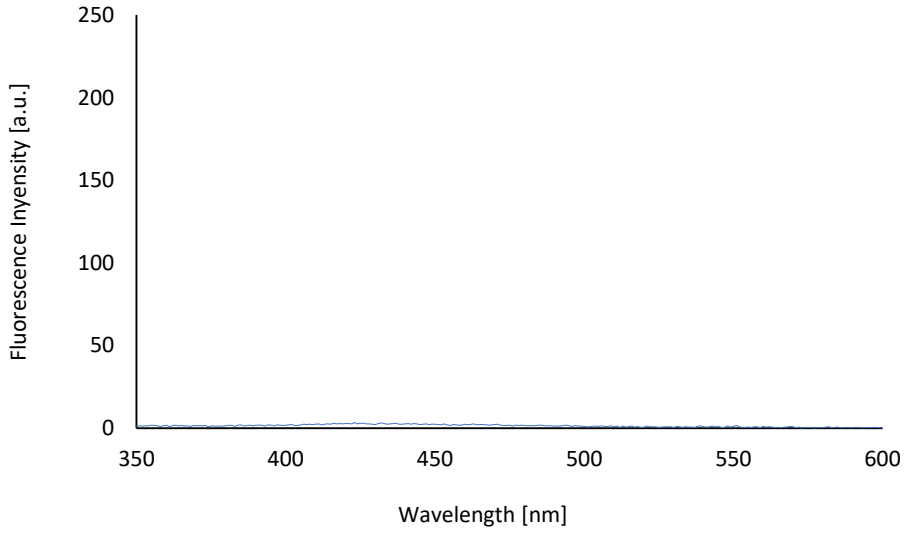
General remarks

Fluorescence emission spectra were measured in 1.0 cm cell. Solutions of tetrabutyl ammonium salts in 99.5% DMSO+0.5% H_2O (V/V) were prepared (C = 5×10^{-5} M). The emission spectra were recorded in range from 350 to 600 nm, using excitation of 310 nm on Varian Eclipse Fluorescence Spectrophotometer.

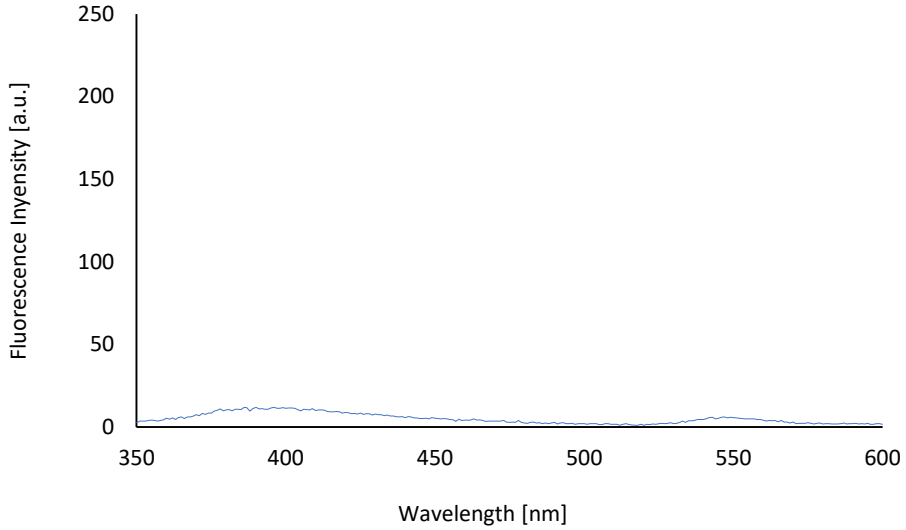
TBA^+ AMP^- (26)



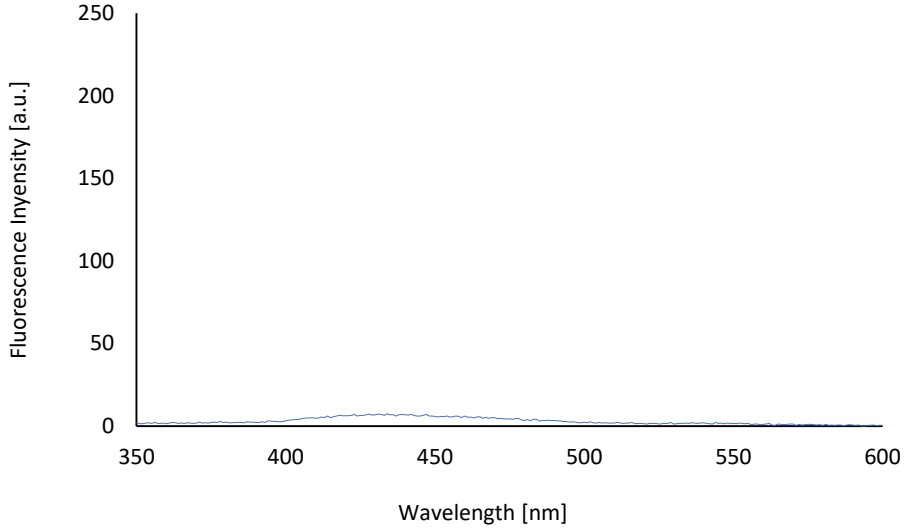
TBA^+ CMP^- (27)



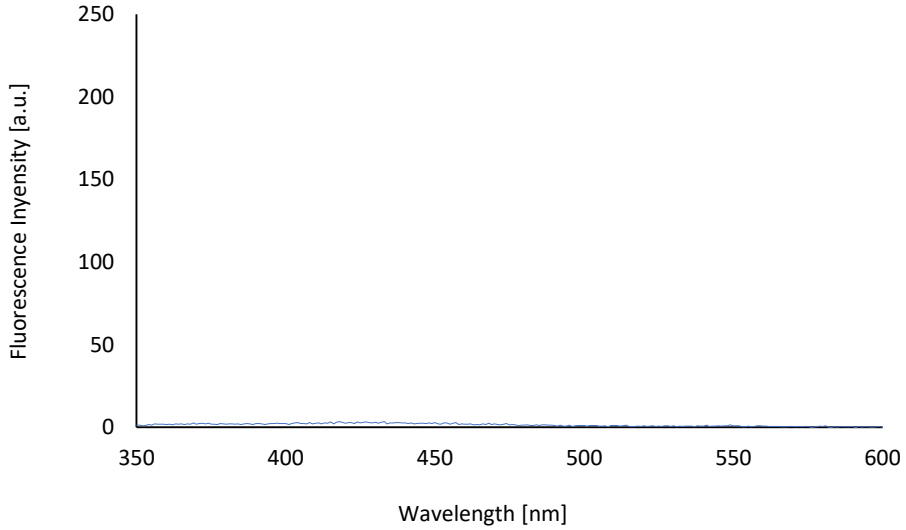
TBA^+ ADP^- (29)



TBA^+ $cAMP^-$ (30)



TBA^+ UMP^- (31)

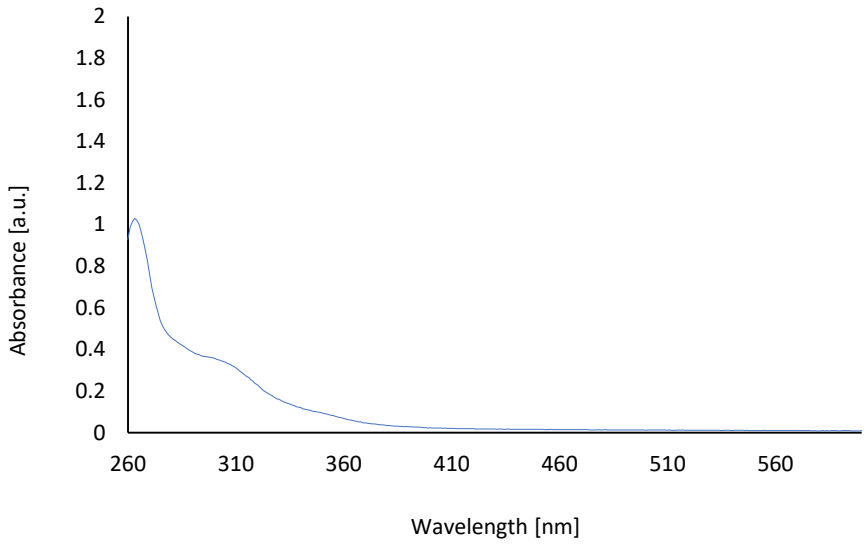

250
200
150
100
50
0
Fluorescence Inyensity [a.u.]
350
400
450
500
550
600
Wavelength [nm]

7. UV-VIS spectra of tetrabutyl ammonium salts and receptor 1

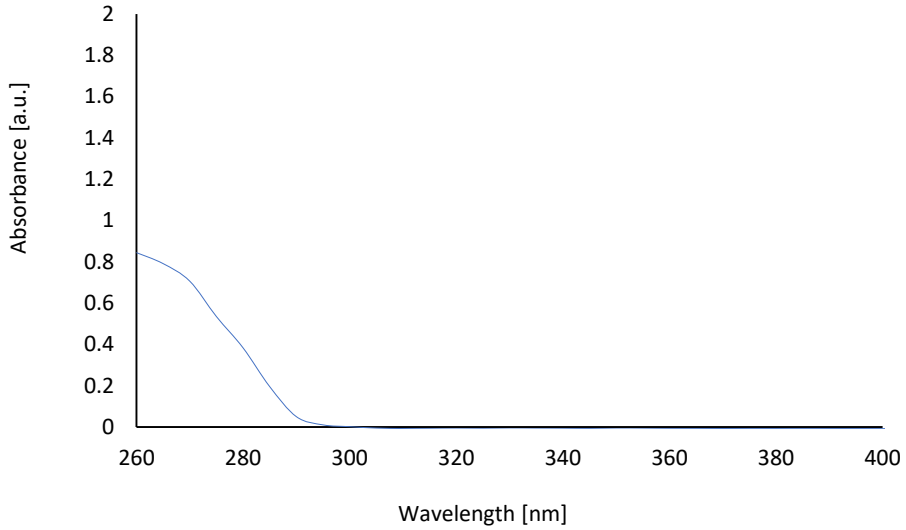
General remarks

UV-VIS spectra were measured in 1.0 cm cell. Solutions of tetrabutyl ammonium salts and receptor 1 were prepared in 99.5% DMSO+0.5% H_2O (V/V). The concentration of salts were prepared C = 5×10^{-5} M. The concentration of receptor **1** was C = 2×10^{-5} M. The UV-VIS spectra were recorded on Agilent Cary 60 UV-VIS Spectrophotometer.

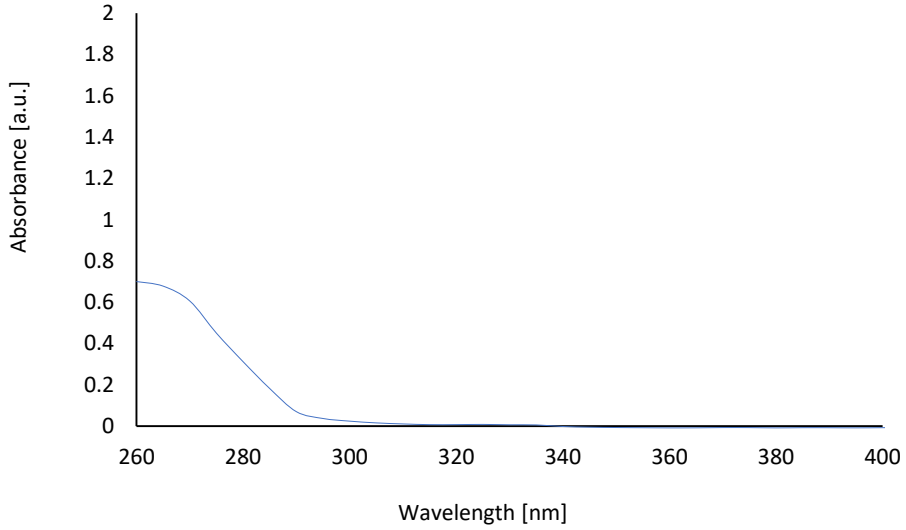
Receptor (1)



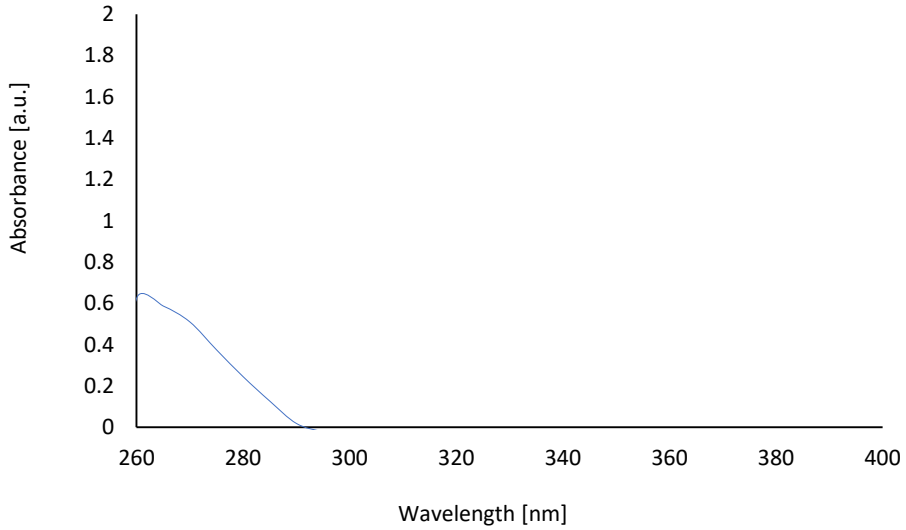
TBA^+ AMP^- (26)



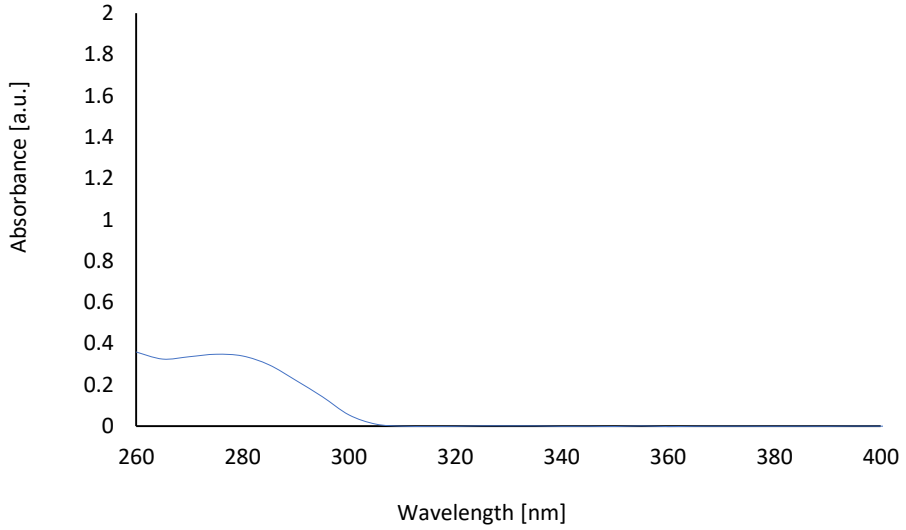
TBA^+ ADP^- (29)



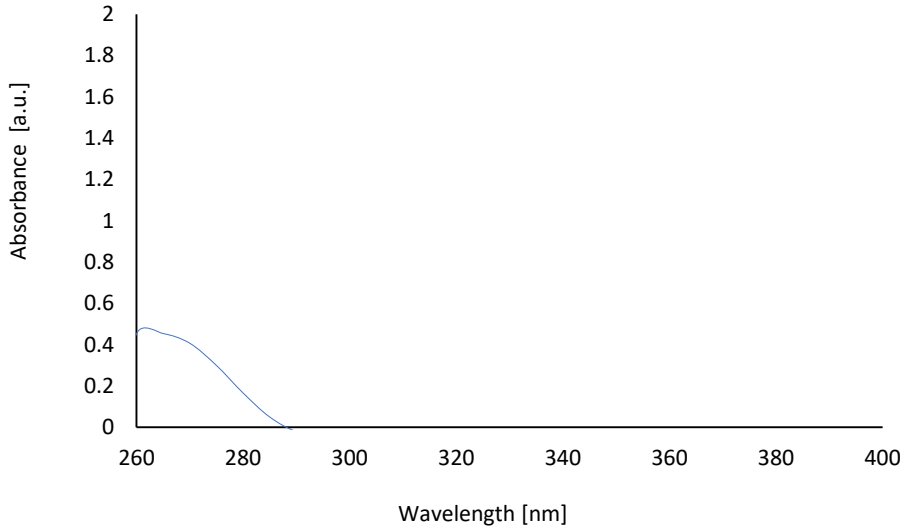
TBA^+ $cAMP^-$ (30)



TBA^+ CMP^- (27)



TBA^+ UMP^- (31)


Absorbance [a.u.]
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
260
280
300
320
340
360
380
400
Wavelength [nm]

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17. Frassineti, C.; Alderighi, L.; Gans, P.; Sabatini, A.; Vacca, A.; Ghelli, S., Determination of protonation constants of some fluorinated polyamines by means of C-13 NMR data processed by the new computer program HypNMR2000. Protonation sequence in polyamines. *Anal. Bioanal. Chem.* **2003,** *376*, 1041-1052.