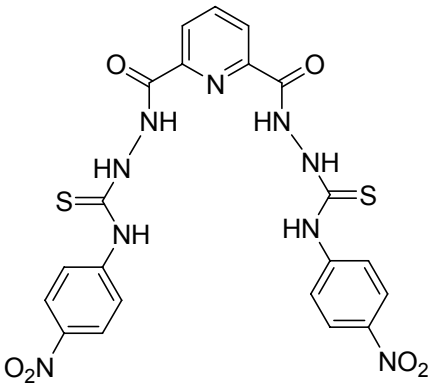
Colorimetric sensing of anions in aqueous solution using a charge neutral, cleft-like, amidothiourea receptor: Tilting the balance between hydrogen bonding and deprotonation in anion recognition

Rebecca M. Duke, John E. O'Brien, Thomas McCabe and Thorfinnur Gunnlaugsson*

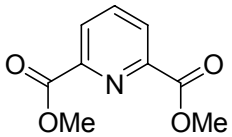
1. Synthesis and characterisation

1, 6 –Bis-[4-nitrophenyl(thioureidocarbomoyl)]-Pyridine (1)



2, 6-Pyridinedicarboxylic acid, dihydrazide (0.281 g, 1.03 mmol, 1 eq) and 4-nitrophenylisothiocyanate (0.518 g, 2.88 mmol, 2 eq) were refluxed together for 16 h. The precipitate was isolated by suction filtration and washed with acetonitrile to give a pale yellow solid, 0.784 g, 98%. m.p. 203.8-205.0 °C; δ_H (600 MHz, DMSO-*d*$_6$): δ_H 11.30 (2H, br s, N<u>H</u>NH$_{urea}$), 10. 37 (2H, br s, N<u>H</u>$_{urea}$), 10.20 (2H, br s, N<u>H</u>$_{urea}$), 8.31 (2H, br s, C<u>H</u>py), 8.30 (1H, br s, C<u>H</u>py), 8.22 (4H, br s, C<u>H</u>CNO$_2$), 7.92 (4H, br s, Hz, C<u>H</u>CNH,); δ_C (100 MHz DMSO-d$_6$) 181.1 (C=S), 162.8 (C=O), 147.8 (C<u>3</u>), 145.7 (<u>C</u>NH), 143.6 (<u>C</u>NO$_2$), 139.8 (<u>C</u>3/5), 125.6 (<u>C</u>4), 125.2 (<u>C</u>HCNH), 123.9 (<u>C</u>HCNO$_2$); δ_N (600 MHz DMSO-d$_6$) 129.6, 127.7, 126.2; IR υ_{max} (cm^{-1}) 3128, 2962, 1704, 1597, 1549, 1506, 1469, 1345, 1278, 1219, 1157, 1002, 887, 851, 745, 698. HRMS (ES$^+$): Calculated for $C_{21}H_{18}N_9O_6S_2$: 556.0821, Found: 556.0822 (M+H).

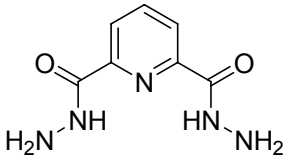
1, 6-Pyridinedimethylester



2, 6-Pyridinedicarboxylic acid (1.00 g, 5.98 mmol) was refluxed in a mixture of MeOH (50 mL) and 95% H_2SO_4 (5.86 g, 69.8 mmol, 3.18 mL) for 48h. The reaction mixture was neutralised with a saturated solution of $NaHCO_3$ and the methanol then removed under reduced pressure. The aqueous solution was extracted with chloroform (2 × 25 mL), the organic layer dried with $MgSO_4$ and the solvent removed under reduced pressure to give a white solid, 1.16 g, 66%. δ_H (400 MHz, DMSO-d$_6$) 8.36 (2H, d, *J* = 7.52 Hz, Ar-<u>H</u>), 8.05 (1H, t, *J* = 7.52 Hz, Ar-<u>H</u>), 4.05 (6H, s, OC<u>H</u>$_3$); δ_c (100MHz, $CDCl_3$) 164.6, 147.7, 137.9, 127.6,

52.7; IR (cm^{-1}) υ_{max} 1738, 1729, 1694, 1570, 1449, 1437, 1425, 1288, 1241, 1195, 1163, 1143, 1080, 1034, 993, 951, 861, 852, 811, 755, 721, 694.

2, 6-Pyridinedicarboxylic acid, dihydrazide



Pyridine-1,6-dimethylester (0.23 g, 1.11 mmol) and hydrazine monohydrate (1.18 g, 23.5 mmol, 1.14 mL) were heated at reflux in MeOH (20 mL) overnight. The precipitate was isolated by suction filtration and washed with MeOH (2 × 20ml) to give a white solid, 0.19 g, 86%. M.p. 299.3 °C; δ_H (400 MHz, DMSO-d_6) 10.64 (2H, br s, N<u>H</u>), 8.13 (3H, s, Ar-<u>H</u>), 4.63 (4H, br s, N<u>H</u>$_2$); δ_C (100 MHz DMSO-d_6) 161.9, 148.4, 139.3, 123.7; IR υ_{max} (cm^{-1}) 3270, 3185, 1689, 1632, 1512, 1439, 1256, 1120, 998, 963, 844, 728.

Figure S1. ^{1}H NMR of **1** in DMSO-d_6

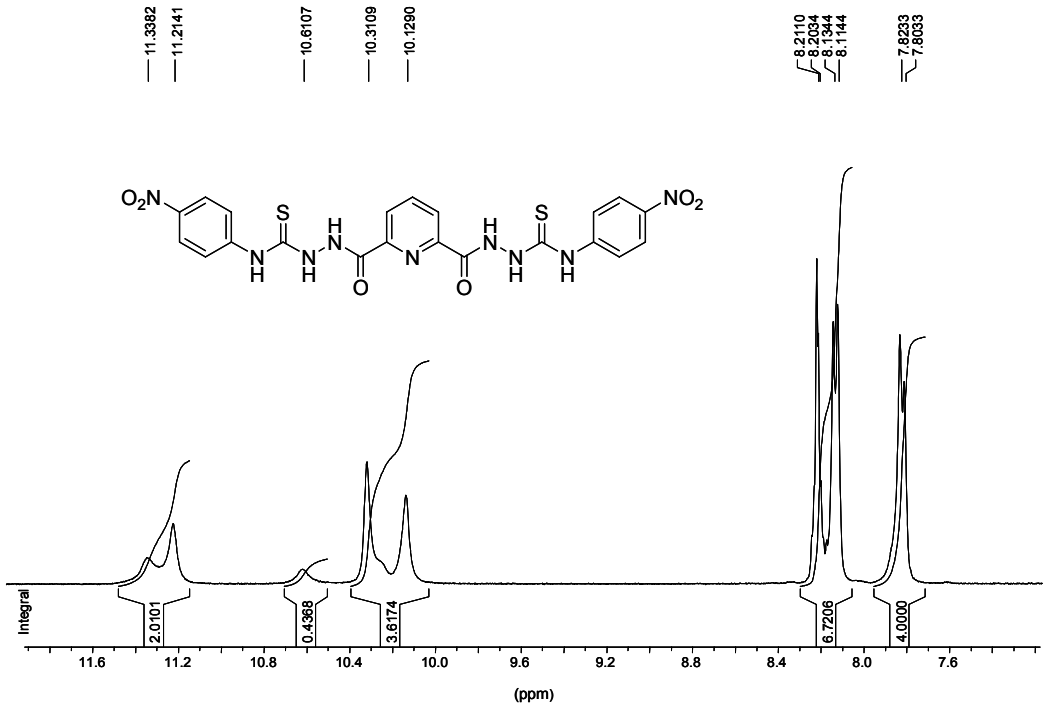


Figure S2. N^{15}-H^{1} Cosy of **1** in DMSO-d_6

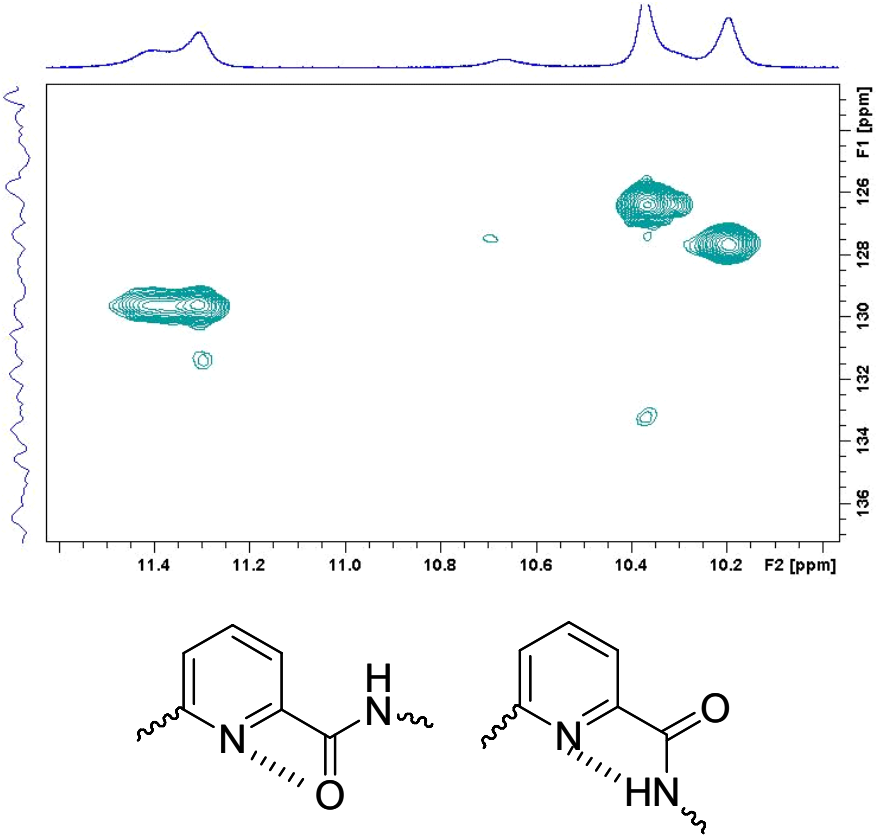


Figure S3. VT H NMR of **1** in DMSO-d_6

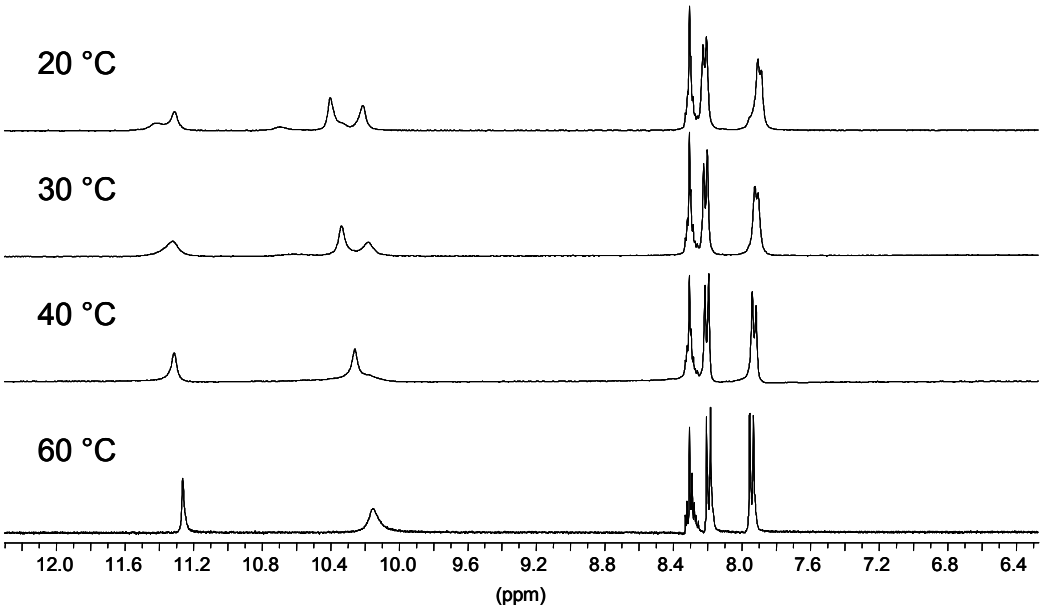


Figure S4. ^{1}H NMR of **1** in DMF-d_7

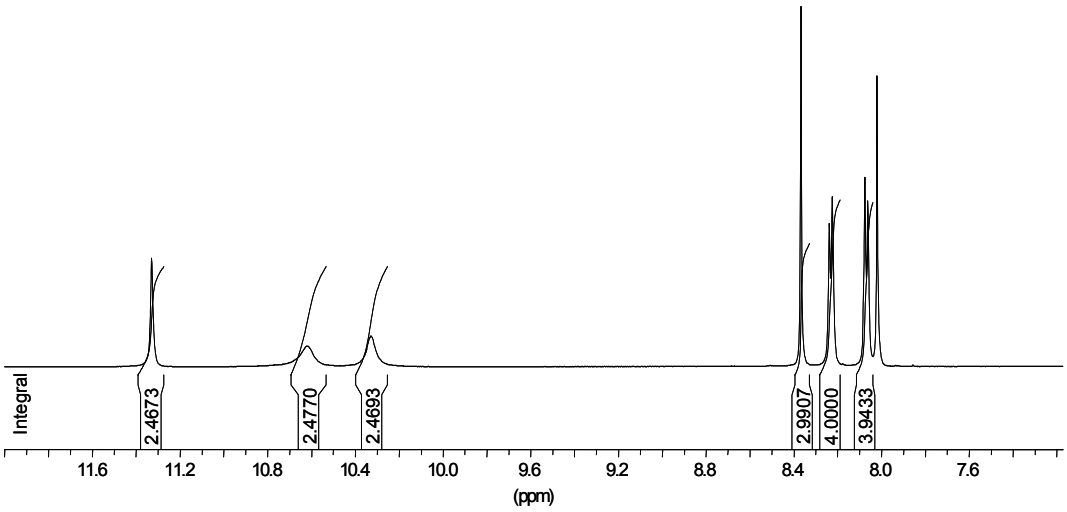


Figure S5. X-Ray crystal structure of **1** showing the unit cell, viewed down the crystallographic b*-axe. Short contacts shown are hydrogen bonding DMSO molecules.

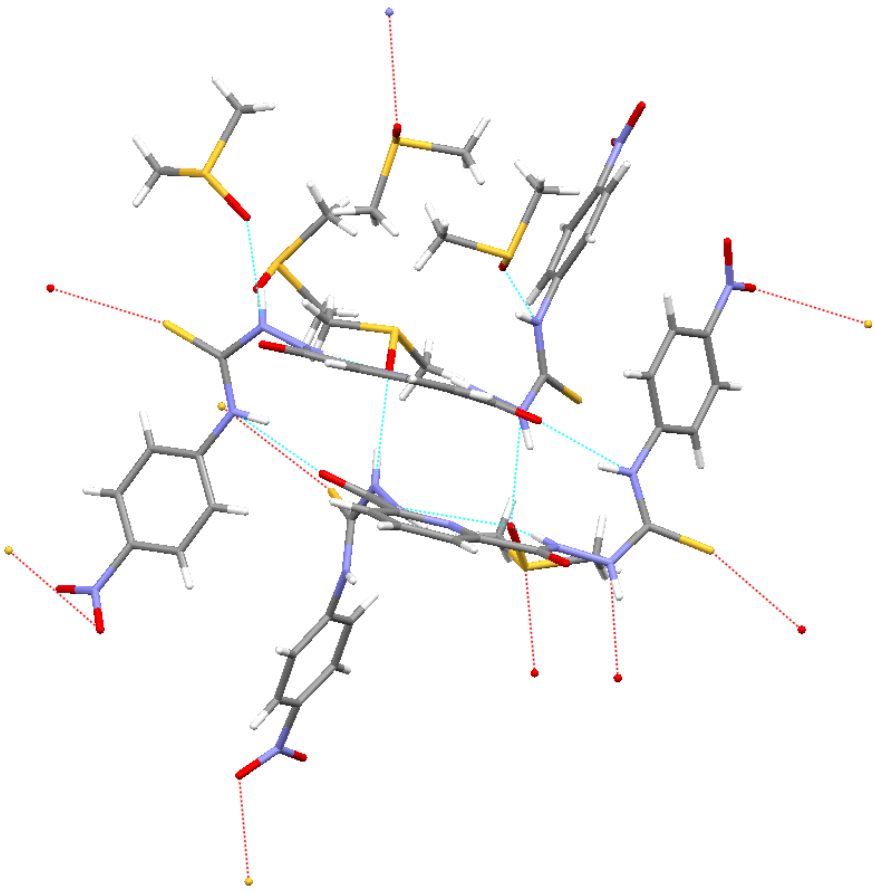


Figure S6. Changes in the UV-Vis of receptor 1 (1 x 10^{-5} M) in DMSO upon addition of various anions.

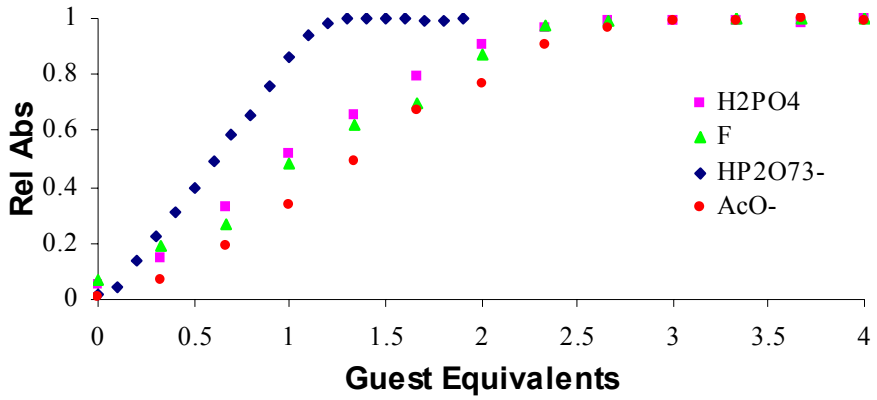


Figure S7. Relative changes in the absorption spectra of **1** upon titration with phosphate. Measured at 425 nm in 4:1 DMSO:H_20.

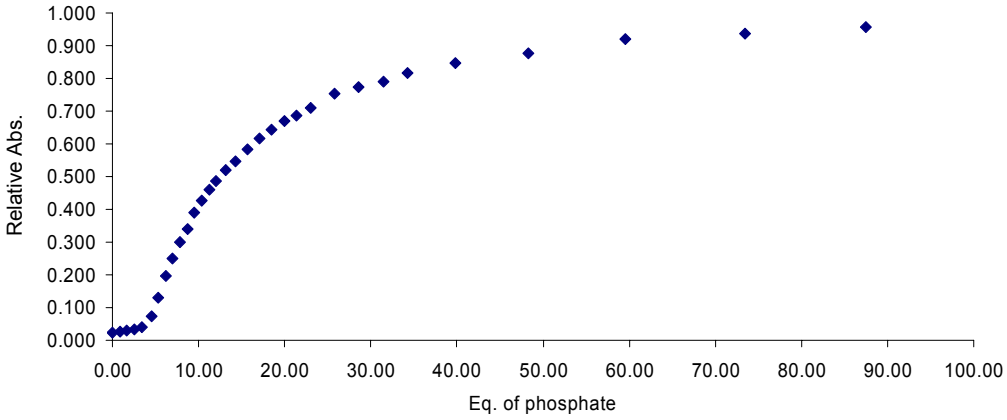


Figure S8. Changes in the UV-vis spectra of receptor **1** upon titration with TBA.Cl.

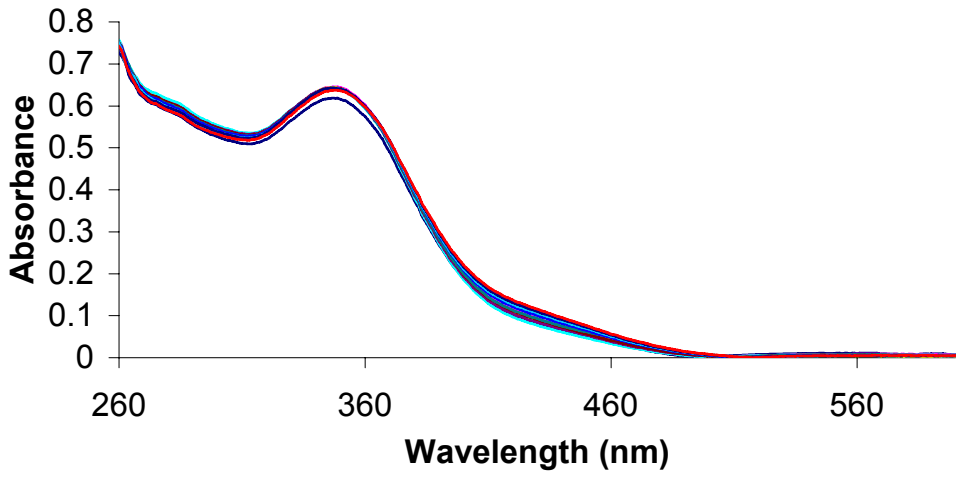


Figure S9. (A) Changes in the UV of receptor **1** at 425 nm upon addition of various TBA salts in 4:1 DMSO: H_2O. (B) Changes from 0 → 10 eq.

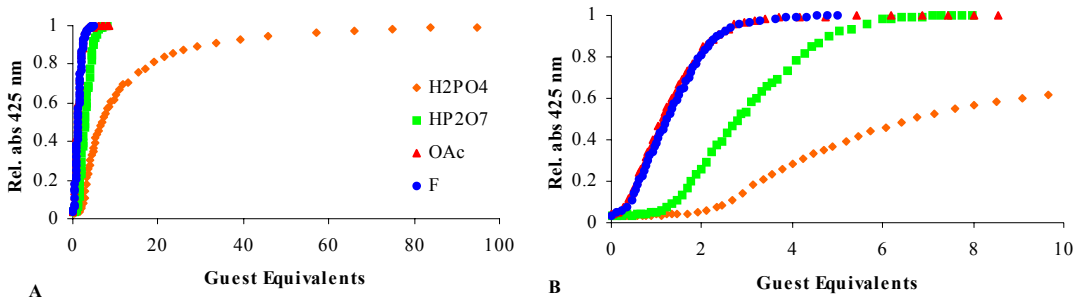


Figure S10a. Changes in the UV-Vis spectra of **1** in 4:1 DMSO:H_2O upon titration with AMP.

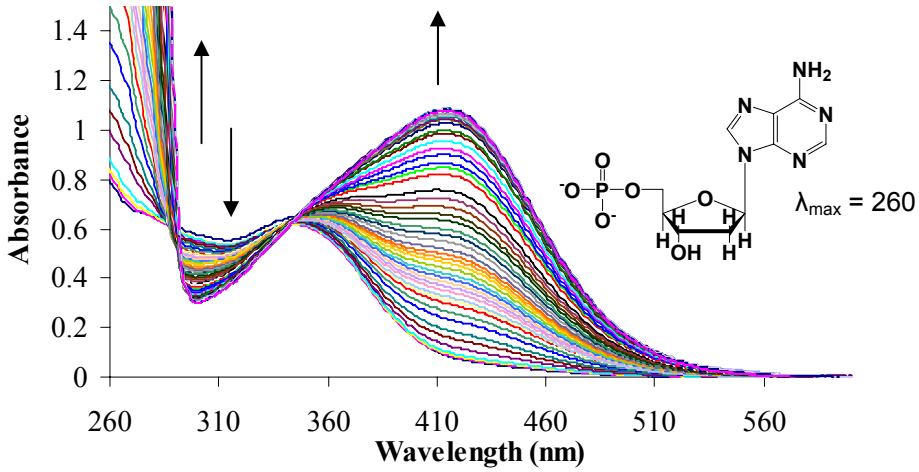


Figure S10b. Changes in the UV-Vis spectra of **1** in 4:1 DMSO:H_2O upon titration with AMP 425 nm.

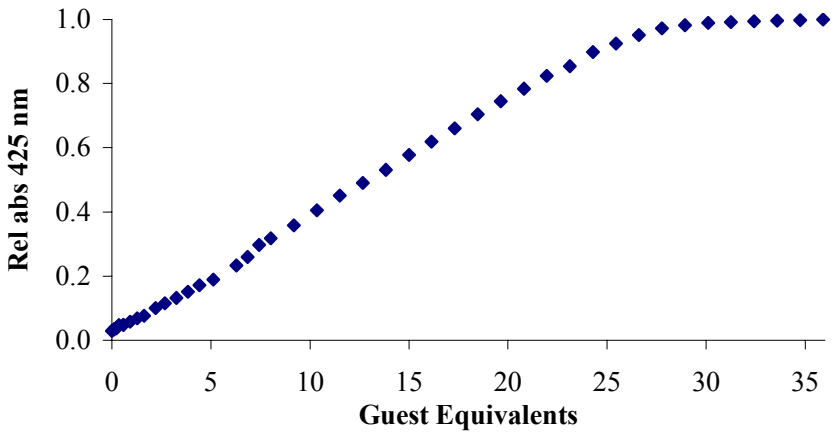


Figure S11. Changes in the UV-Vis spectra of **1** in 4:1 DMSO:H_2O upon titration with NaOH. Inset: Plot of changes at 425 nm against –log [anion].

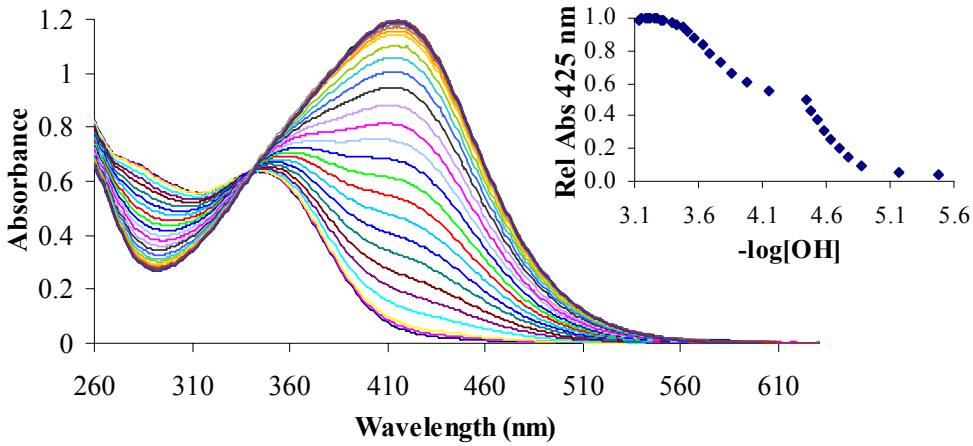


Figure S12a. Changes in the UV-Vis spectra of **1** [3.06 x 10^{-5} M] in 4:1 DMSO:H_2O upon titration with ADP.

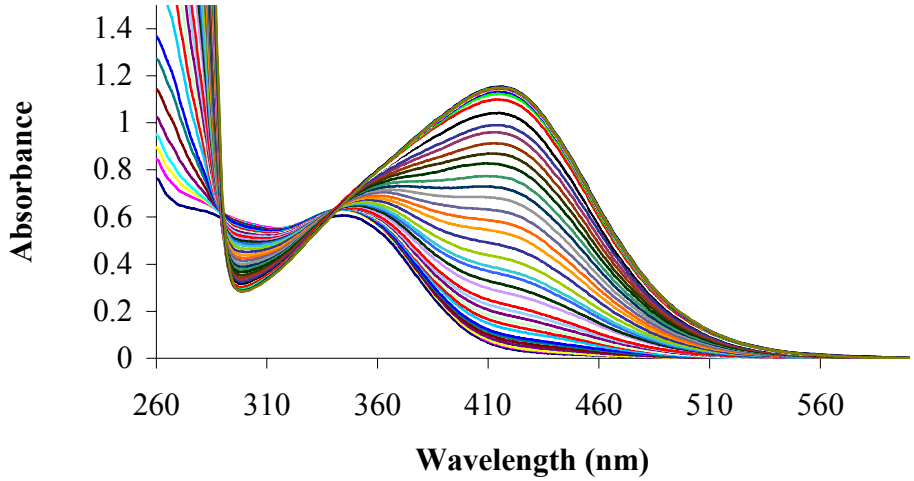


Figure S12b. Binding Isotherm with fit of **1** at 425 nm upon titration with Na_2ADP in 4: 1 DMSO: H_2O.

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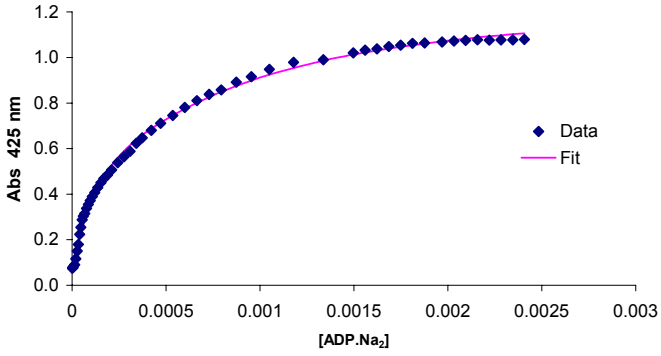

Figure S13a. The changes in the UV of **1** [3.01 x 10^{-5} M] upon addition of TBA.$HP_2O_7^{3-}$ (0→ 8 eq) in 4:1 DMSO: H_2O

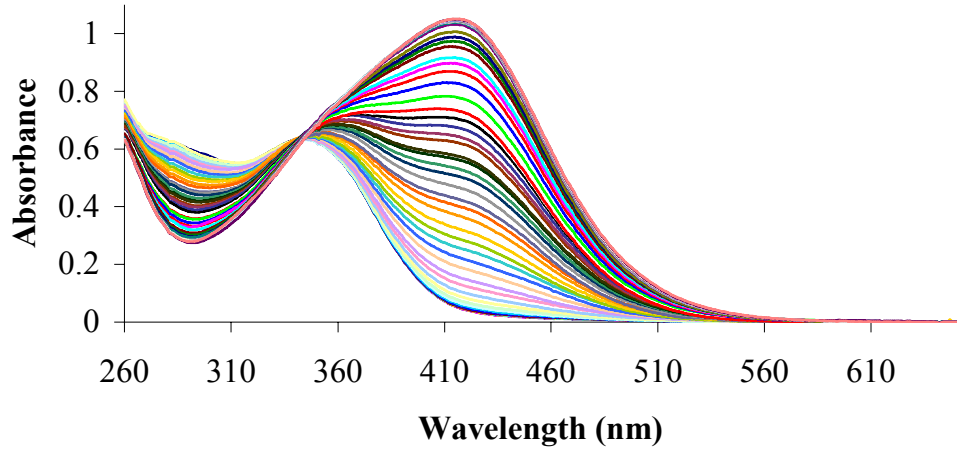

Figure S13b. Binding Isotherm with fit of **1** upon titration with TBA.$HP_2O_7^{3-}$.

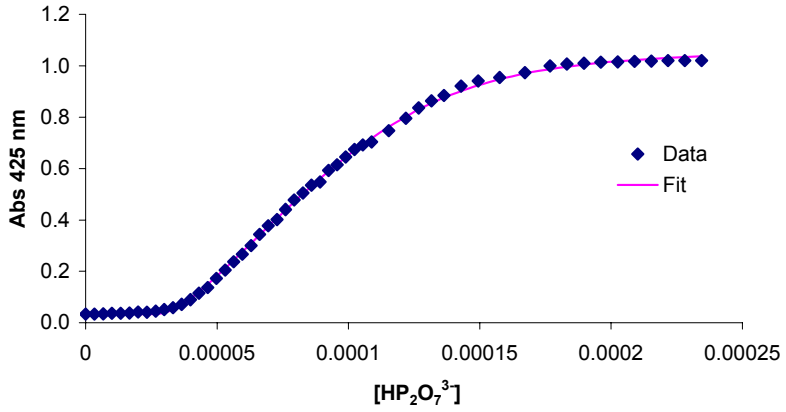

Figure S14. Addition of TBA.F.3H_2O to **1** [9.5 x 10^{-3}M] in DMSO-d_6

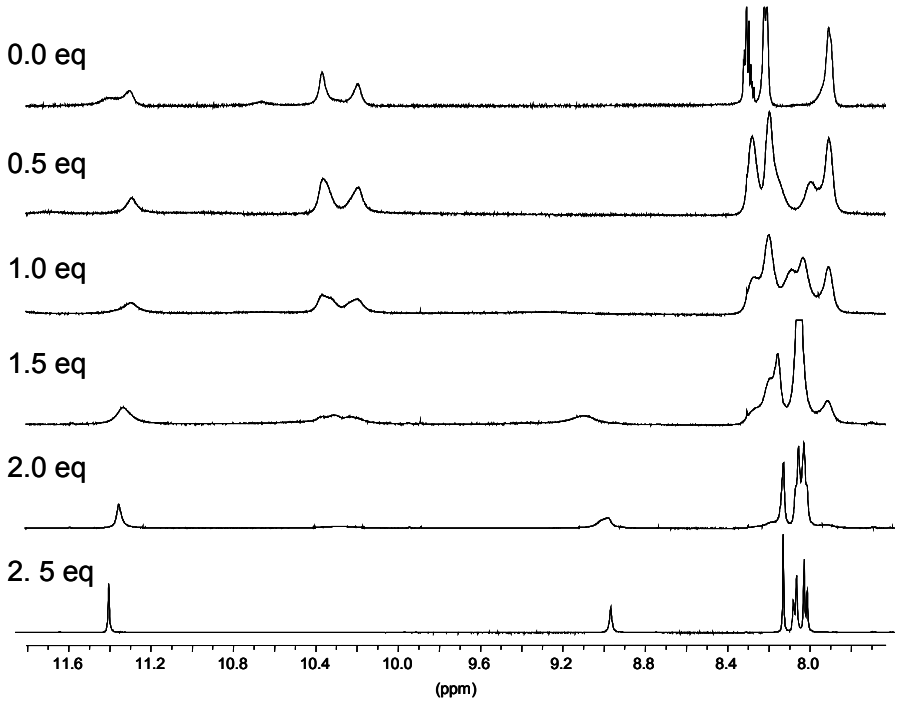

Figure S15. Addition of TBA.H_2PO_4 to **1** [9.5 x 10^{-3}M] in DMSO-d_6

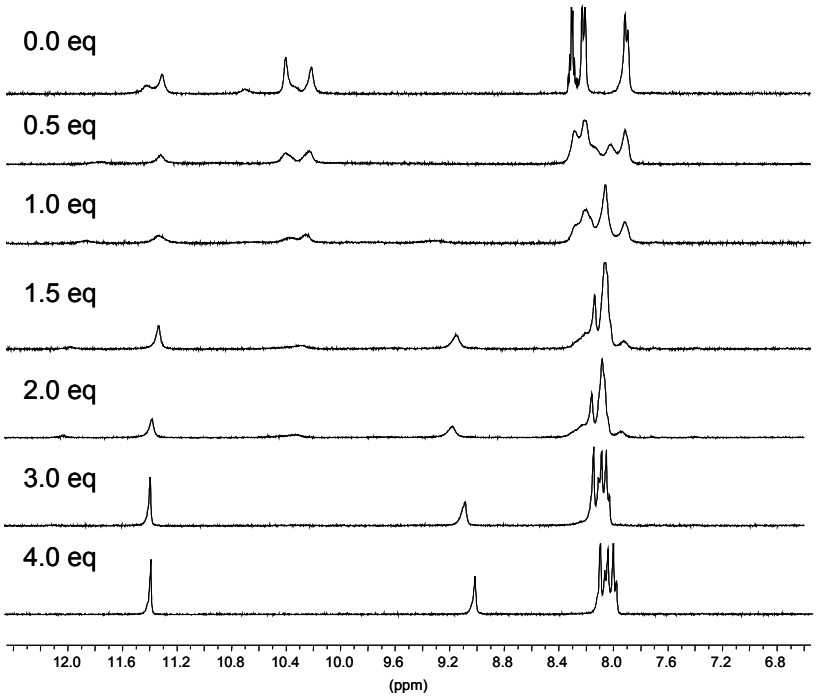

Figure S16. Addition of Na.AMP to **1** [3.4 x 10^{-3} M] in DMSO-d_6

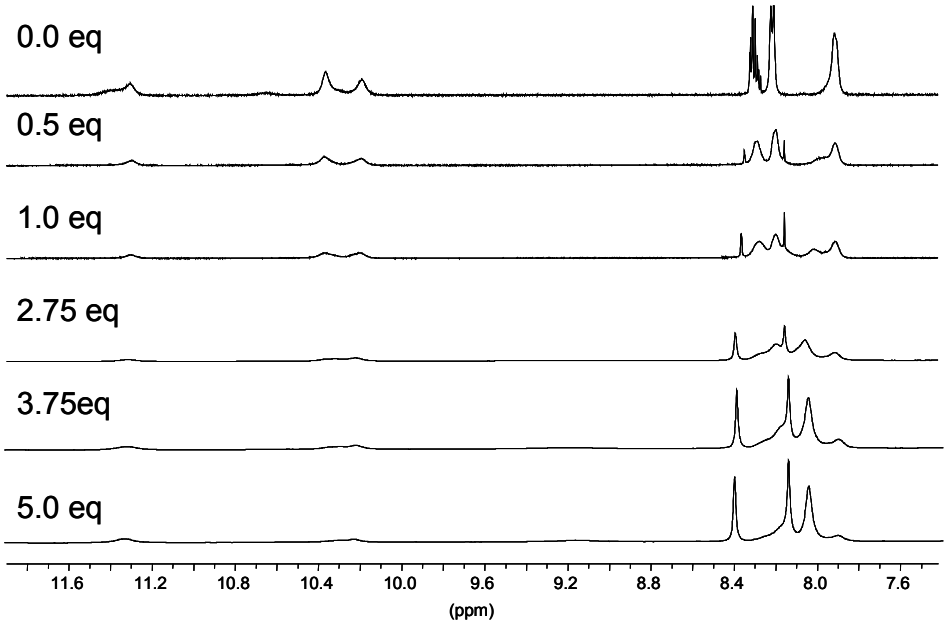

Figure S17. Addition of TMA.OH to **1** [3.9 x 10^{-3}M] in DMSO-d_6

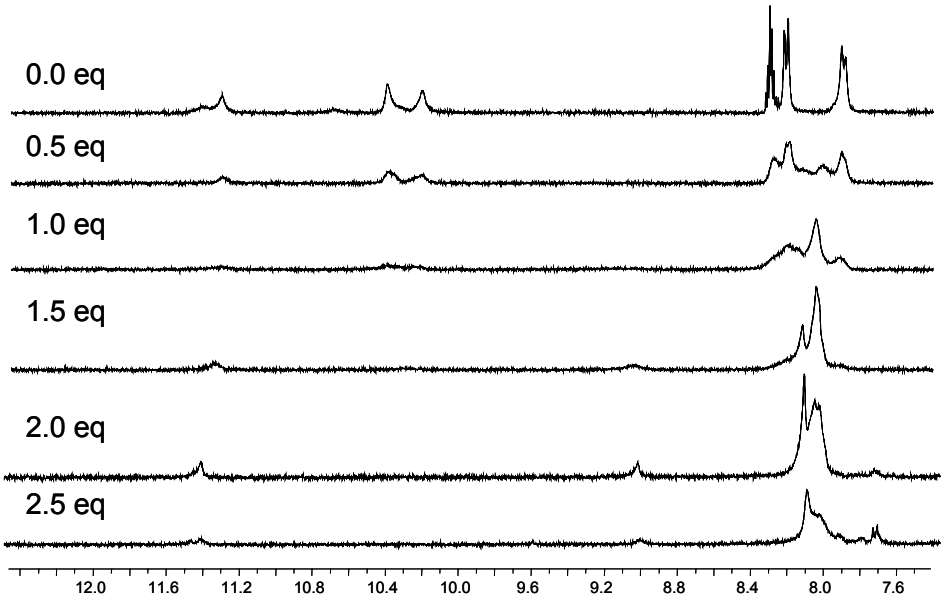

Figure S18. ^{1}H NMR titration of **1** with TBA.Cl in DMSO-d_6

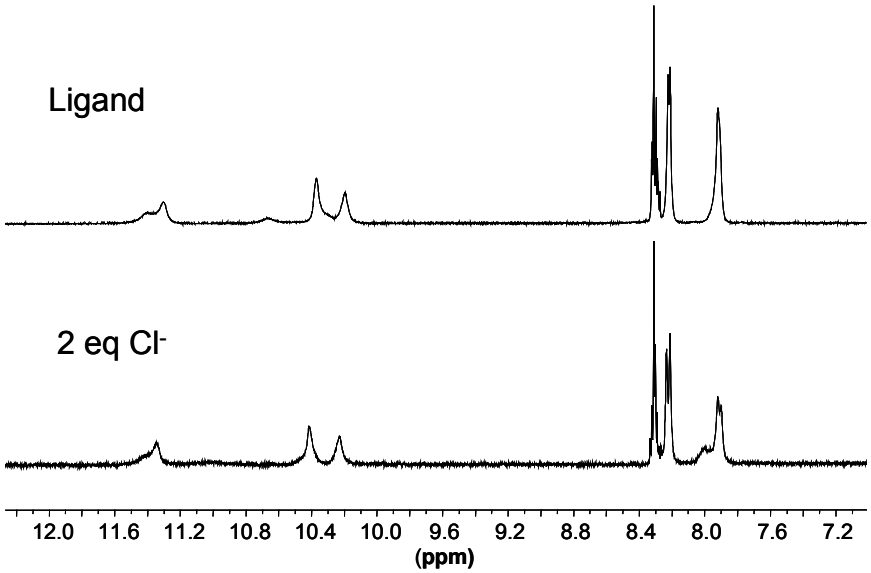

Figure S19. Selective ROESY experiments on **1** in DMSO-d_6

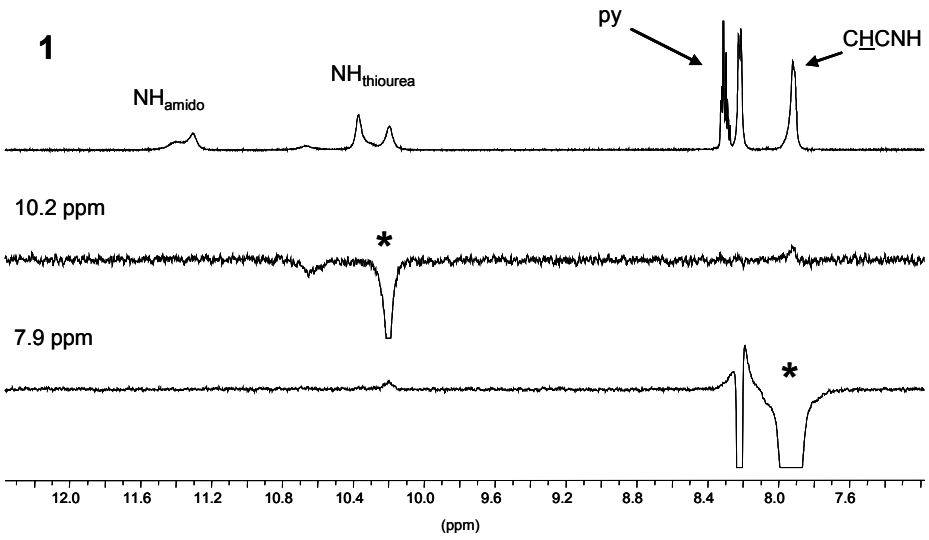

Figure S20. Irradiation of the NH proton at 11.3 ppm after the addition of 2.5 eq of TBA.F to **1**.

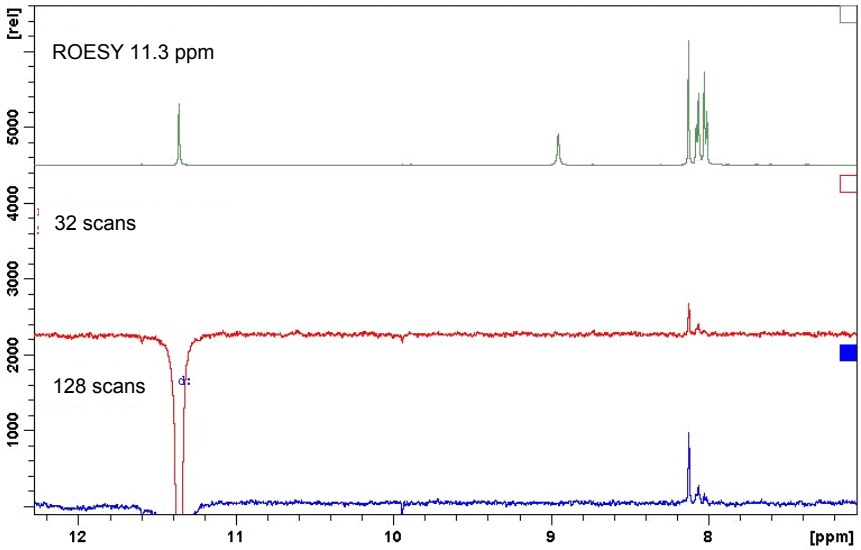

Figure S21. Irradiation of the NH proton at 8.9 ppm after the addition of 2.5 eq of TBA.F to **1**.