Supporting Information

A Novel Nanostructured Supramolecular Hydrogel Self-assembled from Tetraphenylethylene-capped Dipeptides

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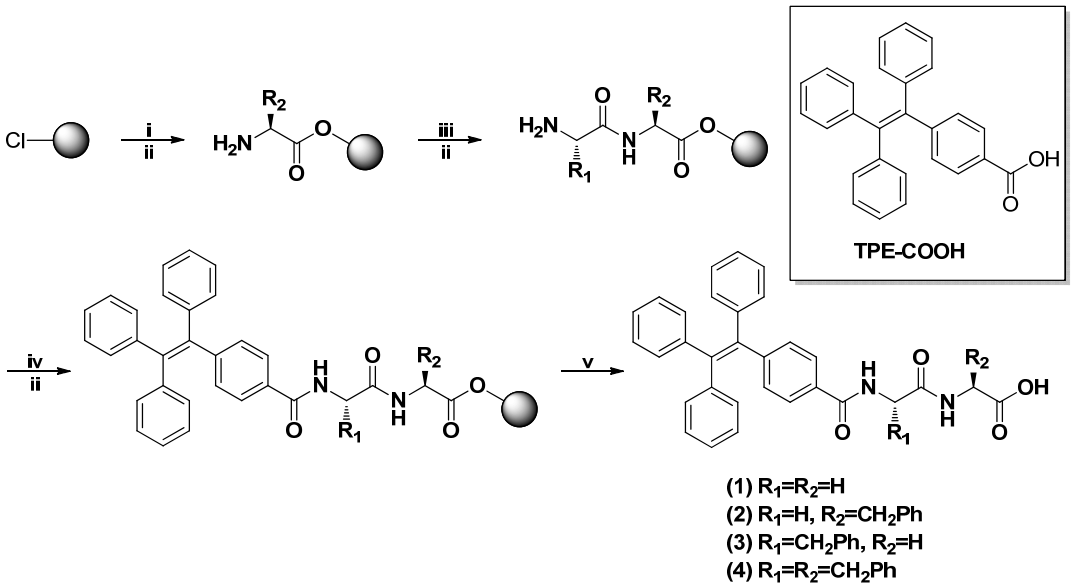

i) Fmoc-L-Gly-OH, DIEA; ii) 20 % piperidine; iii) Fmoc-L-Gly-OH, DIEA; iv) TPE-COOH, HBTU, DIEA; v) TFA

Synthesis of TPE-GG (1). The peptide/dye conjugate derivative of 1 was prepared through SPPS using 2-chlorotrityl chloride resin, Fmoc-glycine, and 4-(1,2,2-triphenylvinyl)benzoic acid (TPE-COOH). The resin (0.6 g) was swelled in anhydrous CH_2Cl_2 for 30 min and then Fmoc-glycine (0.2973 g, 1.000 mmol) was loaded onto the resin in anhydrous *N*,*N*-dimethylformamide and *N*,*N*-diisopropylethylamine (DIEA; 0.415 mL, 2.500 mmol) for 1 h. For deprotection of the Fmoc group, piperidine (20% in DMF) was added and the sample left for 20 min; this procedure was repeated twice (each time for 2 min). Fmoc-glycine (0.2973 g, 1.000 mmol) was coupled to the free amino group using *O*-(benzotriazol-1-yl)-*N*,*N*,*N*′,*N*′-tetramethyluraniumhexafluorophosphate (HBTU) (0.3793 g, 1.000 mmol) and *N*,*N*-diisopropylethylamine (DIEA) (0.4150 mL, 2.500 mmol) as coupling agents for 30 min. Again, the sample was treated with piperidine

(20% in DMF) for 20 min; this procedure was repeated twice (each time for 2 min). Finally, 4-(1,2,2-triphenylvinyl)benzoic acid (TPE-COOH) (0.7586 g, 2.000 mmol) was coupled to the free amino group using HBTU (0.7586 g, 2.000 mmol) and DIEA (0.415 mL, 2.500 mmol) as coupling agents. After the reaction mixture had been stirred overnight, the peptide derivative was cleaved through treatment with CF_3CO_2H overnight. The resulting solution was dried by air and then DI water was added to precipitate the target product. The solid was dried under vacuum to remove residual solvent (white solid: 0.111 g). ^{1}H NMR (300 MHz, [D_6]DMSO, 25 °C): δ= 3.78 (d, *J*=5.4 Hz, 2H; CH_2), 3.89 (d, *J*=5.8 Hz, 2H; CH_2), 6.95-7.25 (m, 17H; CH), 7.70 (d, *J*=8.1 Hz, 2H; CH), 8.21 (t, *J*=5.8 Hz, 1H; NH), 8.74 (t, *J*=5.4 Hz 1H; NH); ^{13}C NMR (75 MHz, [D_6]DMSO): δ=41.6, 43.3, 127.7, 127.8, 127.9, 128.8, 128.9, 129.0, 131.4, 131.5, 131.6, 132.8, 140.8, 142.4, 143.7, 143.8, 147.3, 167.0, 170.3, 172.1, 41.6; MS [FAB^-]: calcd. m/z 490.19, obsvd. 489.3 $[M - H]^-$. HRMS (FAB^+) $C_{31}H_{26}N_2O_4$: calcd. 490.1893; found 490.1895.

Synthesis of TPE-GF (2). The peptide/dye conjugate derivative of 2 was prepared through SPPS using 2-chlorotrityl chloride resin, Fmoc-glycine, and Fmoc-L-phenylalanine and 4-(1,2,2-triphenylvinyl)benzoic acid (TPE-COOH). The resin (0.6 g) was swelled in anhydrous CH_2Cl_2 for 30 min and then Fmoc-L-phenylalanine (0.3874 g, 1.000 mmol) was loaded onto the resin in

anhydrous *N*,*N*-dimethylformamide and *N*,*N*-diisopropylethylamine (DIEA; 0.415 mL, 2.500 mmol) for 1 h. For deprotection of the Fmoc group, piperidine (20% in DMF) was added and the sample left for 20 min; this procedure was repeated twice (each time for 2 min). Fmoc-glycine (0.2973 g, 1.000 mmol) was coupled to the free amino group using *O*-(benzotriazol-1-yl)-*N*,*N*,*N*′,*N*′-tetramethyluraniumhexafluorophosphate (HBTU) (0.3793 g, 1.000 mmol) and *N*,*N*-diisopropylethylamine (DIEA) (0.415 mL, 2.500 mmol) as coupling agents for 1 h. Again, the sample was treated with piperidine (20% in DMF) for 20 min; this procedure was repeated twice (each time for 2 min). Finally, 4-(1,2,2-triphenylvinyl)benzoic acid (TPE-COOH) (0.752 g, 2.000 mmol) was coupled to the free amino group using HBTU (0.7586g , 2.000 mmol) and DIEA (0.830 mL, 5.000 mmol) as coupling agents. After the reaction mixture had been stirred overnight, the peptide derivative was cleaved through treatment with CF_3CO_2H overnight. The resulting solution was dried by air and then DI water was added to precipitate the target product. The solid was dried under vacuum to remove residual solvent (off-white solid: 0.140 g). ^{1}H NMR (300 MHz, [D_6]DMSO, 25 °C): δ=2.85-3.10 (m, 2H; CH_2), 3.80-3.90 (m, 2H; CH_2), 4.40-4.50 (m, 1H; CH), 6.90-7.40 (m, 22H; CH), 7.60 (d, *J*=8.1 Hz, 2H; CH), 8.30-8.40 (m, 1H; NH), 8.58 (d, *J*=8.4 Hz, 1H; NH) ; ^{13}C NMR (75 MHz, [D_6]DMSO): δ=36.8, 42.2, 53.3, 126.4, 126.7, 126.8,

126.9, 127.8, 127.9, 128.2, 129.1, 130.6, 131.8, 137.4, 139.8, 141.5, 142.7, 142.9, 146.3, 165.9, 168.9, 172.7; MS [FAB$^-$]: calcd. m/z 580.24, obsvd. 579.3 [M – H]$^-$. HRMS (FAB$^+$) $C_{38}H_{32}N_2O_4$: calcd. 580.2362; found 580.2362.

Synthesis of TPE-FG (3). The peptide/dye conjugate derivative of 3 was prepared through SPPS using 2-chlorotrityl chloride resin, Fmoc-glycine, and Fmoc-L-phenylalanine and 4-(1,2,2-triphenylvinyl)benzoic acid (TPE-COOH). The resin (0.6 g) was swelled in anhydrous CH_2Cl_2 for 30 min and then Fmoc-glycine (0.2973 g, 1.000 mmol) was loaded onto the resin in anhydrous *N*,*N*-dimethylformamide and *N*,*N*-diisopropylethylamine (DIEA; 0.415 mL, 2.500 mmol) for 1 h. For deprotection of the Fmoc group, piperidine (20% in DMF) was added and the sample left for 20 min; this procedure was repeated twice (each time for 2 min). Fmoc-L-phenylalanine (0.3874 g, 1.000 mmol) was coupled to the free amino group using *O*-(benzotriazol-1-yl)-*N*,*N*,*N*′,*N*′-tetramethyluraniumhexafluorophosphate (HBTU) (0.3793 g, 1.000 mmol) and *N*,*N*-diisopropylethylamine (DIEA) (0.415 mL, 2.500 mmol) as coupling agents for 1 h. Again, the sample was treated with piperidine (20% in DMF) for 20 min; this procedure was repeated twice (each time for 2 min). Finally, 4-(1,2,2-triphenylvinyl)benzoic acid (TPE-COOH) (0.752 g, 2.000 mmol) was coupled to the free amino group using HBTU (0.7586g , 2.000 mmol) and

DIEA (0.830 mL, 5.000 mmol) as coupling agents. After the reaction mixture had been stirred overnight, the peptide derivative was cleaved through treatment with CF_3CO_2H overnight. The resulting solution was dried by air and then DI water was added to precipitate the target product. The solid was dried under vacuum to remove residual solvent (off-white solid: 0.284 g). ^{1}H NMR (300 MHz, [D_6]DMSO, 25 °C): δ=2.90-3.20 (m, 2H; CH_2), 3.75-3.85 (m, 2H; CH_2), 4.65-4.80 (m, 1H; CH), 6.90-7.40 (m, 22H; CH), 7.60 (d, *J*=8.1 Hz, 2H; CH), 8.30-8.40 (m, 1H; NH), 8.58 (d, *J*=8.4 Hz, 1H; NH) ; ^{13}C NMR (75 MHz, [D_6]DMSO): δ=37.0, 41.0, 54.7, 126.2, 126.7, 127.0, 127.8, 127.88, 127.95, 128.0, 129.1, 130.4, 130.6, 131.8, 138.5, 139.8, 141.4, 142.9, 146.3, 165.8, 171.1, 171.7; MS [FAB$^-$]: calcd. m/z 580.24, obsvd. 579.9 [M – H]$^-$. HRMS (FAB$^+$) $C_{38}H_{32}N_2O_4$: calcd. 580.2362; found 580.2368.

Synthesis of TPE-FF (4). The peptide/dye conjugate derivative of 4 was prepared through SPPS using 2-chlorotrityl chloride resin, Fmoc-L-phenylalanine and 4-(1,2,2-triphenylvinyl)benzoic acid (TPE-COOH). The resin (0.6 g) was swelled in anhydrous CH_2Cl_2 for 30 min and then Fmoc-L-phenylalanine (0.3874 g, 1.000 mmol) was loaded onto the resin in anhydrous *N*,*N*-dimethylformamide and *N*,*N*-diisopropylethylamine (DIEA; 0.415 mL, 2.500 mmol) for 1 h. For deprotection of the Fmoc group, piperidine (20% in DMF) was added and the sample left for 20 min; this procedure was repeated twice (each time for 2 min). Fmoc-L-phenylalanine

(0.3874 g, 1.000 mmol) was coupled to the free amino group using *O*-(benzotriazol-1-yl)-*N*,*N*,*N*′,*N*′-tetramethyluraniumhexafluorophosphate (HBTU) (0.3793 g, 1.000 mmol) and *N*,*N*-diisopropylethylamine (DIEA) (0.415 mL, 2.500 mmol) as coupling agents for 1 h. Again, the sample was treated with piperidine (20% in DMF) for 20 min; this procedure was repeated twice (each time for 2 min). Finally, 4-(1,2,2-triphenylvinyl)benzoic acid (TPE-COOH) (0.564 g, 1.500 mmol) was coupled to the free amino group using HBTU (0.5689g , 1.500 mmol)and DIEA (1.245 mL, 0.622 mmol) as coupling agents. After the reaction mixture had been stirred overnight, the peptide derivative was cleaved through treatment with CF_3CO_2H overnight. The resulting solution was dried by air and then DI water was added to precipitate the target product. The solid was dried under vacuum to remove residual solvent (off-white solid: 0.284 g). ^{1}H NMR (300 MHz, [D_6]DMSO, 25 °C): δ=2.85-3.20 (m, 4H; CH_2), 4.10-4.20 (s, 1H; CH), 4.58 (t, *J*=6.25 1H; CH), 6.95-7.30 (m, 19H; CH), 7.57 (d, 2H; CH), 8.7 (d, *J*=8.4 Hz, H; NH); ^{13}C NMR (75 MHz, [D_6]DMSO): δ= 36.6, 37.3, 55.0, 125.7, 126.1, 126.7, 126.8, 127.1, 127.7, 127.85, 127.91, 127.97, 128.05, 129.1, 129.6, 130.4, 130.6, 131.8, 138.6, 138.7, 139.8, 141.5, 142.8, 142.87, 142.90, 146.4, 165.8, 170.2, 174.6; MS [FAB^-]: calcd. m/z 670.28, obsvd. 669.40 [M – H]$^-$. HRMS (FAB^+) $C_{45}H_{38}N_2O_4$: calcd. 670.2832; found 670.2830.

Inverted Tube Method. Gelation was performed by weighing a compound (6.0 mg) in a screw-capped 2-mL vial (diameter: 10 mm). Sodium hydroxide solution was added to the suspension to adjust pH; alternating vortex and ultrasonication were applied until a clear solution was obtained. This solution was then neutralized by a dropwise addition of hydrochloric acid for gelation.

Transmission Electron Microscopy. Images were obtained with a Hitachi HT7700 transmission electron microscope at an accelerating voltage of 100 kV. Hydrogels were applied directly onto 200 mesh carbon-coated copper grids. Excess amount of the hydrogel was carefully removed by capillary action (filter paper), and the grids were then immediately stained with uranyl acetate for 30 s. Excess stain was removed by capillary action, and the grids were allowed to air dry.

Rheological tests. Rheological tests were conducted using an Anton Paar rheometer and a 25-mm parallel plate. The hydrogel sample (400μL, 1 wt %) was placed on the parallel plate for the angular frequency sweep test (test range: 0.25 to 100 $rads^{-1}$; 13 points per decade; sweep mode, “log”; temperature, 25 °C) and oscillatory strain (test range: 0.1% to 15%; frequency, 1 $rads^{-1}$; 21 points per decade; sweep mode, “log”; temperature, 25 °C).

Computational details

The geometries of the dimer and tetramer were optimized by DFT/6-31G* and semi-empirical Austin Model 1 methods, respectively.[S1] The visualization of weak interactions of the dimer was conducted using Multiwfn 2.6 software[S2] in real space. The graphic displays of π–π interactions were then drawn using VMD 1.9. This visualization method was successfully and widely used in many other works.[S3-S5]

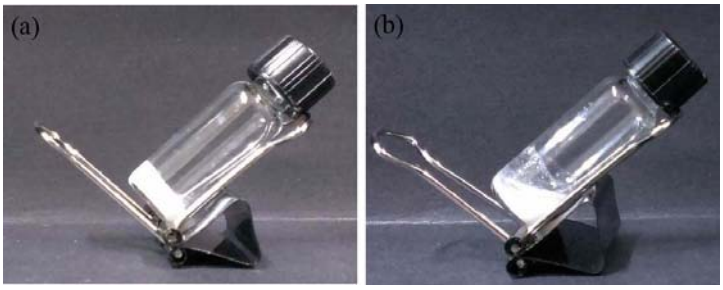

Fig. S1. Optical images of **1** at (a) room temperature and (b) gel-to-solution transition when the temperature was higher than 55 ^{o}C.

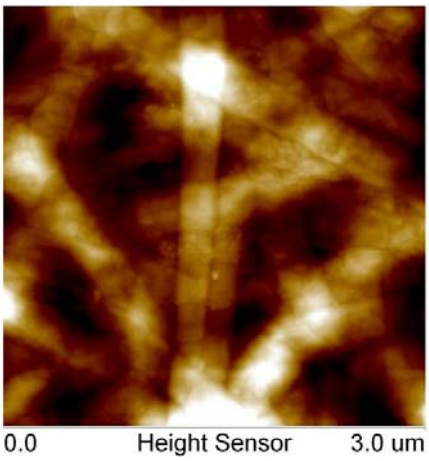

Fig. S2. AFM image of self-assembled nanobelt of **1**.

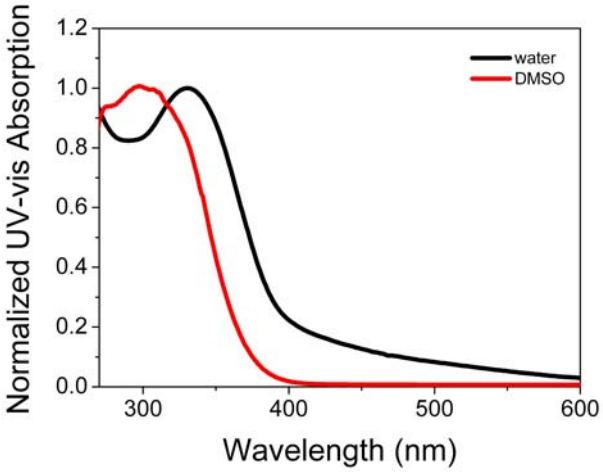

Fig. S3. Normalized UV-vis absorption spectrum of **1** in water (black line) and DMSO (red line).

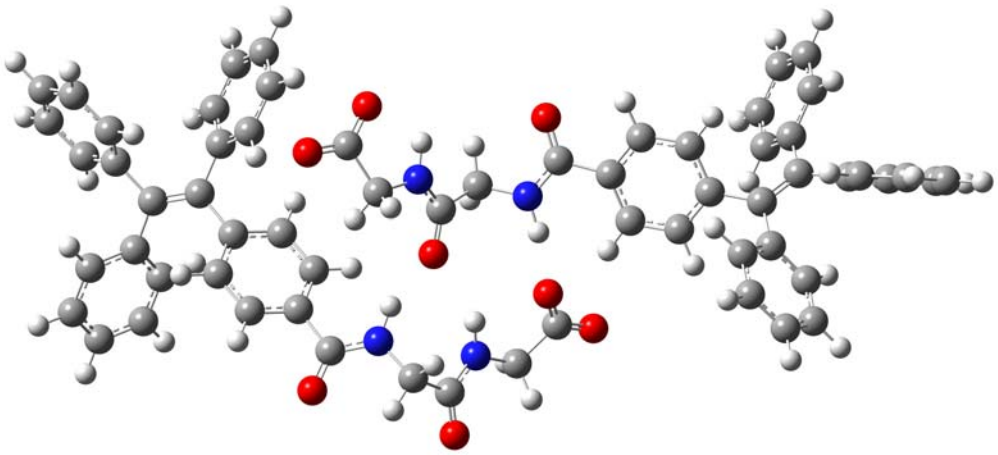

Fig. S4. Optimized geometry of a dimer of **1** calculated at quantum-chemical DFT/6-31G* level of theory; hydrogen bonds: green dashed line. C: gray, H: white, N: blue, O: red.

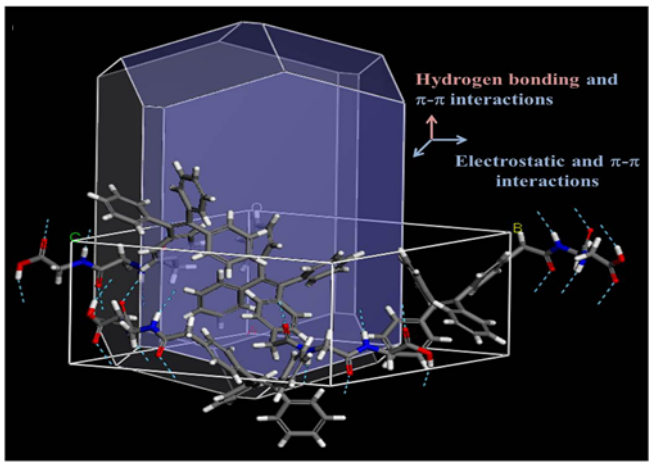

Fig. S5. The theoretically predicted crystal habit (Bravais-Friedel-Donnay Harker method, BFDH) exhibits an elongation along the extended hydrogen bonding direction. C: gray, H: white, N: blue, O: red.

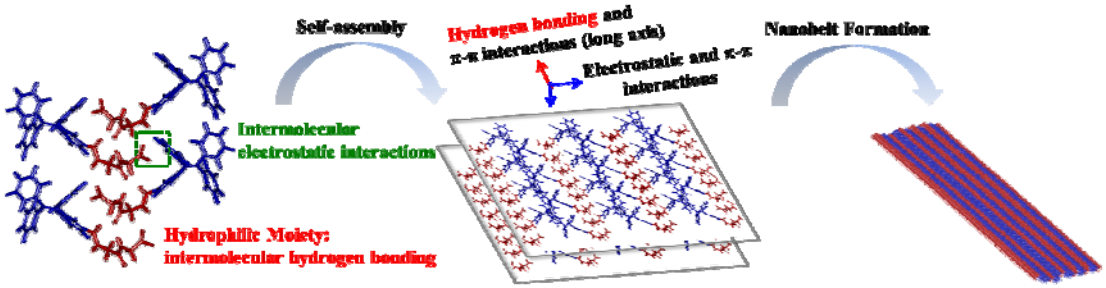

Fig. S6. Proposed formation of self-assembled nanobelt of **1**.

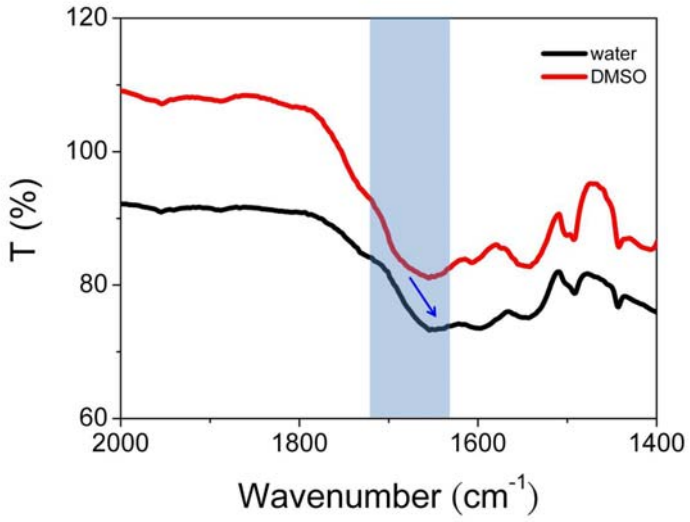

Fig. S7. FT-IR spectrum of **1** in water (black line) and DMSO (red line).

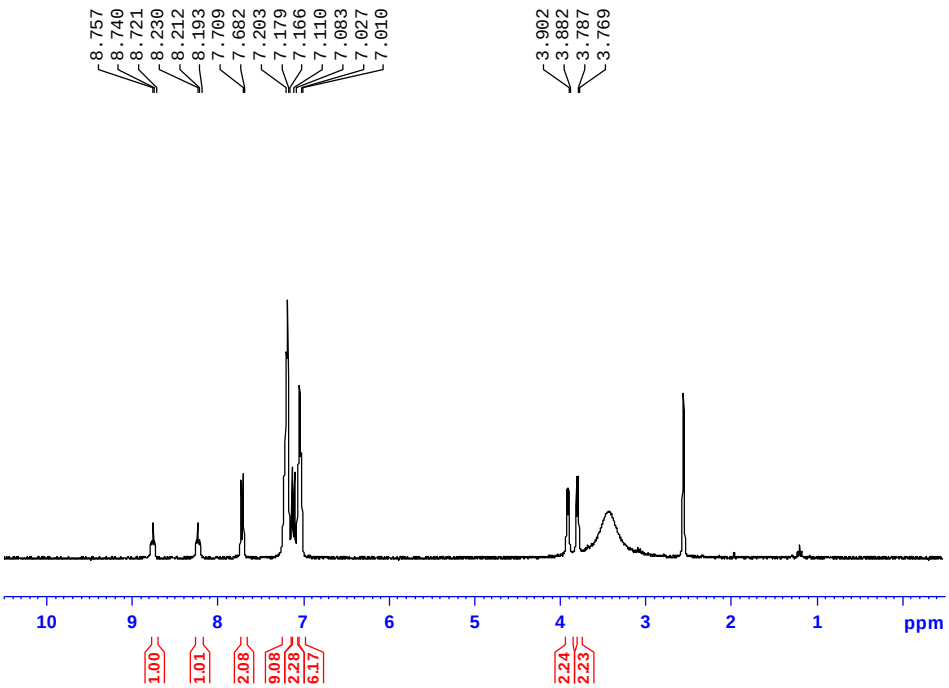

Fig. S8. ^{1}H NMR spectrum of **1** in [D_6]DMSO.

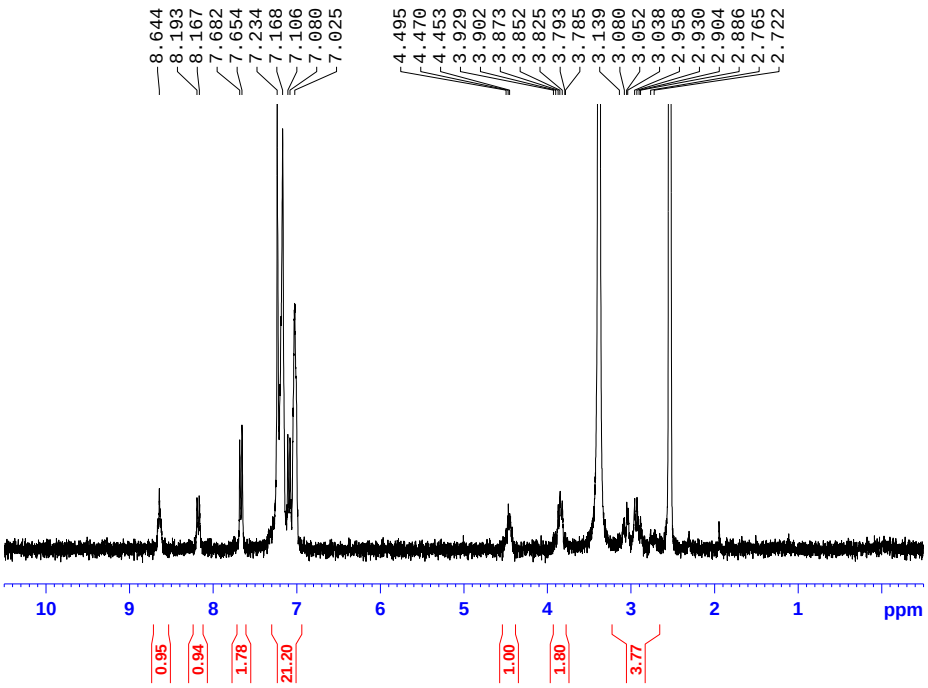

Fig. S9. ^{1}H NMR spectrum of **2** in [D_6]DMSO.

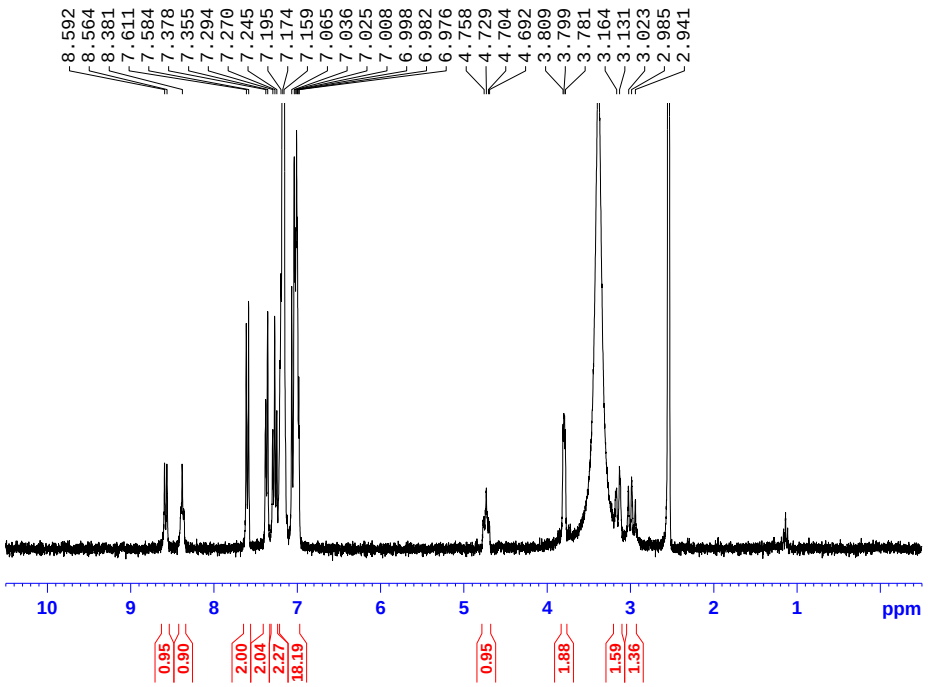

Fig. S10. ^{1}H NMR spectrum of **3** in [D_6]DMSO.

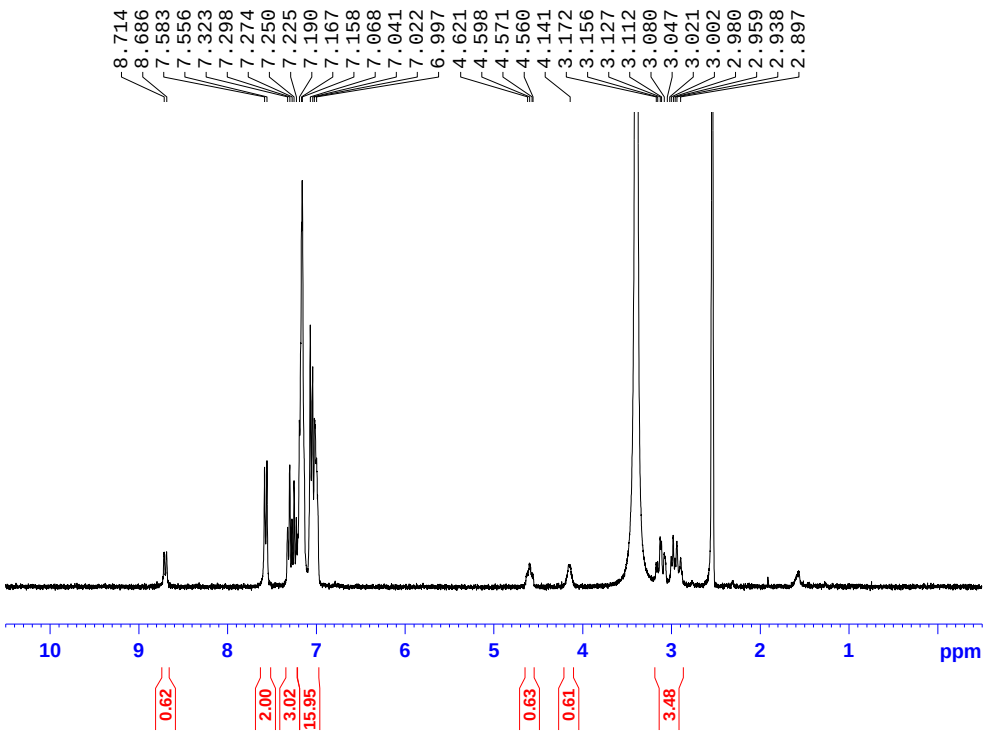

Fig. S11. ^{1}H NMR spectrum of **4** in [D_6]DMSO.

Reference

[S1] W. Qu, H. Tan, G. Chen and R. Liu, *Phys. Chem. Chem. Phys.* **2003**, *5*, 2327.

[S2] T. Lu and F. Chen, *J. Comput. Chem.* **2012**, *33*, 580.

[S3] E. R. Johnson, S. Keinan, P. Mori-Sa´nchez, J. Contreras- Garcı´a, A. J. Cohen and W. Yang, *J. Am. Chem. Soc.* **2010**, *132*, 6498.

[S4] J. Contreras-Garcı´a, E. R. Johnson, S. Keinan, R. Chaudret, J.-P. Piquemal, D. N. Beratan and W. Yang, *J. Chem. Theory Comput.* **2011**, *7*, 625.

[S5] M.-Y. Yeh and H.-C. Lin, *Phys. Chem. Chem. Phys.* **2014**, *16*, 24216.