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SUPPLEMENTARY INFORMATION

Target-selective photodegradation of oligosaccharides by a fullerene-boronic acid hybrid upon visible light irradiation

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Supplementary methods.

^{11}B NMR binding assay: All ^{11}B NMR measurements were performed on a JEOL ECA-500 (160 MHz for ^{11}B). The ^{11}B NMR spectra were measured with a 0.1 M solution of boric acid in D_2O (δ = 0.00 ppm) as external standard. To avoid the broad signal from the boron incorprtated in glasses, measurements were carried out in a 5 mm tube made of poly(tetrafluoroethylene). The sample temperature was regulated at 25 ± 1 ºC. For ^{11}B NMR binding assay, a 5.0×10^{-2} M solution of fullerene-boronic acid hybrid **2** in DMSO-d_6 (solution A) and 1.0×10^{-1} M solution of each glycoside in 0.1 M phosphate buffer (pH 7.4) (solution B) were prepared. And then, solution B was titrated into solution A in order to make mixtures with a constant concentration of the hybrid **2** and a range of concentration of each glycoside. In general, five different concentrations were made.

The equilibrium constant for the complexation of the hybrid **2** with a glycoside is defined[1] as

$$K = [\text{complexed boron}]_{area}/([S][\text{free boron}]_{area}) \quad (1)$$

$$[S] = [S_0] - [\text{complexed boron}], \quad [S_0] \text{ denotes the total sugar.} \quad (2)$$

A plot of [complexed boron]/[free boron] versus [S] for determination of K for the hybrid **2** with Gal*f*(β1-6)Gal*f*β-OMe (**4**) is shown in Fig. S1.

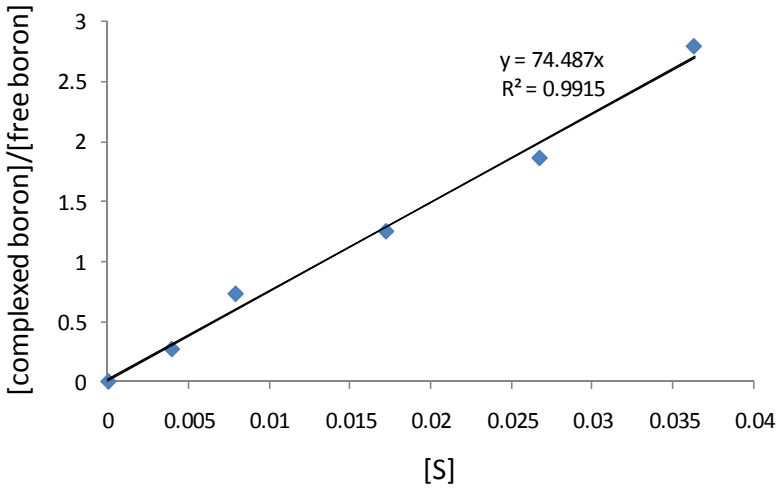

Fig. S1 A [complexed boron]/[free boron] versus [S] plot for determination of K for the hybrid **2** (5.0 mM) with Gal*f*(β1-6)Gal*f*β-OMe (**4**) (5-40 mM) in 30% DMSO-d_6/0.1 M phosphate buffer (pH 7.4).

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Photodegradation of γ-CD by fullerene-derivative 1: γ–CD (**3**) (30 μM) was incubated with **1** (15, 30, 90 or 300 μM) in 0.1 M phosphate buffer (30 μL, pH 7.4) at 25 ºC for 2 h under irradiation with a UV lamp (365 nm, 100 W) or a visible lamp (diffuse sunlight, 100 W) placed 10 cm from the vessel, and analyzed by HPLC (TSK-GEL amide-80, 4.6 × 250 mm; 40 ºC; detection by RI).

Photodegradation of glycosides by fullerene-boronic acid hybrid 2: Each glycoside (1.0 mM) was incubated with **2** in 10% DMF/0.1 M phosphate buffer (100 μL, pH 7.4) at 25 ºC for 2 h under irradiation with a visible lamp (diffused sun light, 100 W) placed 10 cm from the mixture. Each degradation percentage was determined by HPLC (Mightysil RP-18 GP 5 μm, 4.6 × 150 mm; 40 ºC; detection by UV (215 nm or 254 nm); 35:65 MeOH/H_2O; flow rate 1.0 mL min^{-1} for **5**, **6**, **7** and **8**; 50:50 MeOH/H_2O; flow rate 0.5 mL min^{-1} for **4**; 47:53 MeOH/H_2O; flow rate 0.5 mL min^{-1} for **9**; 43:57 MeOH/H_2O; flow rate 0.5 mL min^{-1} for **10**; 70:30 MeOH/H_2O; flow rate 1.0 mL min^{-1} for **11**).

EPR spectrometry: EPR experiments were carried out with a E-500 CW/EPR (Bruker) and recorded under the following conditions: temperature 296 K, microwave frequency 9.39 GHz, microwave power 16 mW, field modulation 0.1 mT at 100 kHz. DMPO was used as a spin-trapping agent. Fullerene-boronic acid hybrid **2** (200 μM) and DMPO (500 mM) were incubated in 30% DMF/0.1 M phosphate buffer (pH 7.4) containing 1 mM DETAPAC and 10 mM NADH under irradiation with a visible lamp (diffused sun light, 100 W) placed 40 cm from a flat cell.

ESI-TOF MS analysis of photodegradation products: ESI-TOF MS analysis was performed after incubation of Gal*f*β(1-6)Gal*f*β-OMe (**4**) (1.0 mM) and the hybrid **2** (1.0 mM) in 10% DMF/0.1 M phosphate buffer (100 μL) at 25 ºC for 10 min under irradiation with a visible lamp (diffused sun light, 100 W) placed 10 cm from the mixture, and subsequent acetylation of the products (Fig. S2).

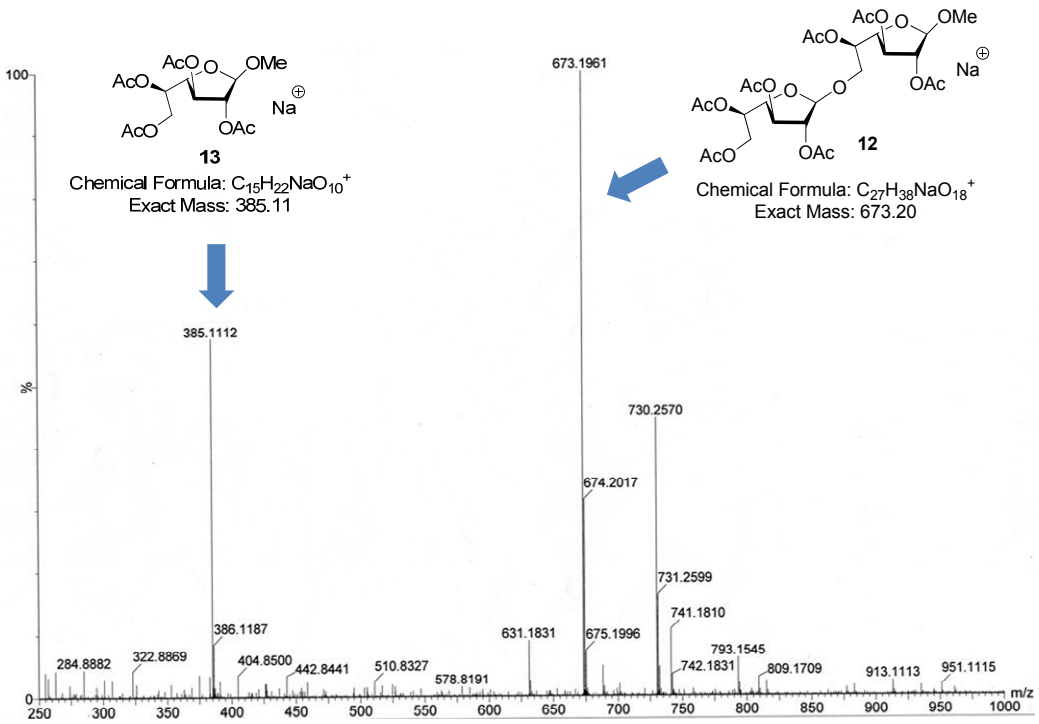

Fig. S2 ESI-TOF MS spectrum chart of the products generated by photodegradation of Gal*f*β(1-6)Gal*f*β-OMe (**4**) by the hybrid **2**, and subsequent acetylation.

General methods for chemical synthesis.

^{1}H- and ^{13}C-NMR spectra were recorded on a JEOL ECA-500 (500 MHz for ^{1}H, 125 MHz for ^{13}C) spectrometer in the indicated solvent. ESI-TOF Mass spectra were measured on a Waters LCT premier XE. UV/vis spectra were recorded on a JASCO V-550 spectrometer. The reactions were monitored by thin layer chromatography carried out on Merck TLC 60F-254 (0.25 mm) using UV light and *p*-anisaldehyde or 10% ethanolic phosphomonolybdic acid as developing agent. Column chromatography separations were performed using silica gel 60 N (spherical, neutral) (Kanto Chemical Co., Inc.). Reverse phase column chromatography separations were performed using Wakosil 40C18 (Wako). Air- and/or moisture-sensitive reactions were carried out under an atmosphere of argon using oven-dried glassware. In general, organic solvents were purified and dried using an appropriate procedure, and evaporation and concentration were carried out under reduced pressure below 30 ºC, unless otherwise noted.

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Synthesis of the fullerene-boronic acid hybrid 2.

1-[*N*-(*tert*-Butyldimethylsilanoxyethyl)amino] acetic acid *tert*-butyl ester (16): To a solution of 2-aminoethanol (**14**) (2.05 g, 33.5 mmol) in dry CH_2Cl_2 (30.0 mL) were added TBSCl (5.57 g, 36.8 mmol) and imidazole (4.56 g, 67.0 mmol) at 0 ºC. After being stirred at room temperature for 5 h, the reaction mixture was poured into ice-cooled water (6 mL). The mixture was extracted with three portions of AcOEt (15 mL). The combined extracts were washed with brine (15 mL), dried over anhydrous Na_2SO_4, filtered, and then concentrated under reduced pressure to yield **15**[2] (4.99 g) as a yellow oil. The residue was used in the next reaction without further purification. To a solution of the crude residue (4.99 g) and Et_3N (5.94 mL, 42.8 mmol) in dry THF (30.0 mL) was dropwisely added *tert*-butyl bromoacetate (4.22 mL, 31.3 mmol) at 0 ^oC. After being stirred at room temperature for 14 h, the reaction mixture was poured into ice-cooled water (6 mL). The mixture was extracted with three portions of AcOEt (20 mL). The combined extracts were washed with brine (20 mL), dried over anhydrous Na_2SO_4, filtered and then concentrated under reduced pressure. The residue was subjected to silica gel column chromatography (20 g, 20:1 $CHCl_3$/MeOH) to give **16** (6.03 g, 62% yield in 2 steps) as a pale yellow oil.; TLC ($CHCl_3$:MeOH, 10:1 v/v): R_f = 0.50; ^{1}H NMR (500 MHz, $CDCl_3$): δ 3.75 (t, J = 5.5 Hz, 2H), 3.38 (s, 2H), 2.85 (s, 1H), 2.76 (t, J = 5.5 Hz, 2H), 1.47 (s, 9H), 0.90 (s, 9H), 0.07 (s, 6H); ^{13}C NMR (125 MHz, $CDCl_3$): δ 171.11, 81.37, 62.46, 51.67, 51.21, 28.20, 26.03, 18.41, -5.25.; HRMS (ESI-TOF) (*m/z*): $[M+H]^+$ calcd. for $C_{14}H_{32}NO_3Si$, 290.2152; found, 290.2137.

***trans*-2,5-Di-*tert*-butoxycarbonyl-[*N*-(2-*tert*-butyldimethylsilyloxyethyl)pyrrolidino][3,4:1,2][60]fullerene (19):** To a solution of buckminster fullerene (**17**) (2.16 g, 3.00 mmol) in dry PhMe (630 mL) were added *tert*-butyl glyoxylate **18**[3] (312 mg, 2.40 mmol) and **16** (695 mg, 2.40 mmol), and then the resultant mixture was refluxed for 18 h. After cooling of the reaction mixture to room temperature, the solvent was removed under reduced pressure. The residue was subjected to silica

gel column chromatography (PhMe) to give **19** (1.52 g, 57% yield) as a dark brown solid: *Rf* 0.40 (PhMe); ^{1}H-NMR (500 MHz, $CDCl_3$): δ 5.94 (2H, s), 4.25 (1H, m), 4.15 (1H, m), 3.44-3.35 (2H, m), 1.49 (18H, s), 0.98 (9H, s), 0.19 (6H, s); ^{13}C-NMR (125 MHz, $CDCl_3$): δ 169.00, 153.36, 150.34, 146.32, 145.38, 145.33, 145.28, 145.05, 144.99, 144.63, 144.50, 144.44, 144.26, 144.18, 143.49, 143.47, 142.02, 141.69, 141.58, 141.14, 141.08, 140.95, 140.82, 140.75, 140.71, 138.91, 138.22, 136.09, 135.21, 81.81, 74.05, 70.63, 62.72, 49.64, 27.29, 25.07, 17.38, -6.09, -6.15; HRMS (ESI-TOF) *m/z* 1122.2676 (1122.2689 calcd. for $C_{80}H_{40}NO_5Si$, $[M+H]^+$).

***trans*-2,5-Di-*tert*-butoxycarbonyl-[*N*-(2-hydroxyethyl)pyrrolidino][3,4:1,2][60]fullerene (20):** To a solution of **19** (916 mg, 0.750 mmol) in dry CH_2Cl_2 (120 mL) was added trifluoroacetic acid (120 μL) at 0 °C. After being stirred for 10 min., the reaction mixture was poured into saturated $NaHCO_3$ aq. The mixture was washed with brine, dried over anhydrous Na_2SO_4, and concentrated in *vacuo*. The residue was subjected to silica gel column chromatography ($CHCl_3$) to give **11** (669 mg, 89% yield) as a dark brown solid: *Rf* 0.20 ($CHCl_3$); ^{1}H-NMR (500 MHz, $CDCl_3$): δ 5.86 (2H, s), 4.14 (1H, ddd, *J* = 3.0, 10.0, 11.5 Hz), 3.96 (1H, ddd, *J* = 3.0, 4.0, 11.5 Hz), 3.55 (1H, ddd, *J* = 4.0, 10.0, 11.5 Hz), 3.43 (1H, ddd, *J* = 3.0, 4.0, 13.5 Hz), 2.20 (br-s, 1H), 1.51 (s, 18H); ^{13}C-NMR (125 MHz, $CDCl_3$): δ 170.08, 153.94, 150.92, 147.44, 146.44, 146.36, 146.18, 146.10, 145.97, 145.66, 145.64, 145.55, 145.35, 145.29, 144.55, 144.52, 143.11, 142.78, 142.66, 142.23, 142.15, 142.04, 141.92, 141.78, 141.74, 140.07, 139.35, 137.13, 136.26, 83.68, 74.35, 71.64, 59.86, 50.78, 28.25; HRMS (ESI-TOF) (*m/z*) 1008.1840 (1008.1811 calcd. for $C_{74}H_{26}NO_5$, $[M+H]^+$).

Protected fullerene-boronic acid hybrid S1: To a solution of **20** (683 mg, 678 μmol) and 3-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)benzoic acid (**21**) (505 mg, 2.03 mmol) in dry CH_2Cl_2 (30.0 mL) were added EDC (580 mg, 2.71 mmol) and DMAP (41.4 mg, 339 μmol) at 0 °C. After being stirred at room temperature for 10 h, the reaction mixture was poured into ice-cooled water (6 mL). The mixture was extracted with two portions of $CHCl_3$ (15 mL). The combined

extracts were washed with brine (15 mL), dried over anhydrous Na_2SO_4, filtered, and concentrated under reduced pressure. The residue was subjected to silica gel column chromatography (200 g, $CHCl_3$) to give protected fullerene-boronic acid hybrid **S1** (559 mg, 67% yield) as a black solid.; TLC ($CHCl_3$:AcOEt 2:1 v/v): R_f = 0.62; ^{1}H-NMR (500 MHz, $CDCl_3$): δ 8.59 (s, 1H), 8.30 (d, *J* = 7.6 Hz, 1H), 8.00 (d, *J* = 7.6 Hz, 1H), 7.47 (t, *J* = 7.6 Hz, 1H), 5.95 (s, 2H), 5.04 (dt, *J* = 5.7, 11.2 Hz, 1H), 4.85 (ddd, *J* = 5.7, 3.6, 11.2 Hz, 1H), 3.77 (ddd, *J* = 5.7, 6.1, 13.8 Hz, 1H), 3.62 (dt, *J* = 6.1, 13.8 Hz, 1H), 1.46 (s, 18H), 1.33 (s, 12H); ^{13}C-NMR (125 MHz, $CDCl_3$): δ 169.82, 166.74, 154.30, 151.25, 147.51, 146.51, 146.42, 146.21, 146.15, 146.13, 145.80, 145.66, 145.61, 145.41, 145.36, 144.66, 144.61, 143.17, 142.83, 142.73, 142.32, 142.25, 142.14, 142.0, 141.98, 141.86, 141.83, 140.10, 139.45, 139.38, 137.30, 136.40, 136.31, 132.70, 129.75, 127.92, 84.17, 83.38, 74.83, 71.77, 64.29, 47.57, 28.34, 24.99, 24.95.; HRMS (ESI-TOF) (*m/z*): $[M+H]^+$ calcd. for $C_{87}H_{41}BNO_8$, 1238.2925; found, 1238.2970.

Fullerene-boronic acid hybrid 2: To a solution of the protected fullerene-boronic acid hybrid **S1** (112 mg, 90.3 μmol) in TFA (2.00 mL) was added H_2O (200 μL) at 0 °C. After being stirred at room temperature for 14 h, the reaction mixture was concentrated under reduced pressure. The residue was subjected to silica gel column chromatography (50 g, 50:10:1 toluene/AcOEt/AcOH) to give **2** (23.6 mg, 25% yield) as a brown solid.; TLC ($CHCl_3$:MeOH:AcOH 10:1:0.1 v/v/v): R_f = 0.48; ^{1}H-NMR (500 MHz, $CDCl_3$:CD_3OD 9:1 v/v): δ 8.69 (s, 1H), 8.21 (d, *J* = 7.5 Hz, 1H), 7.95 (s, 1H), 7.47 (t, *J* = 7.5 Hz, 1H), 6.06 (s, 2H), 5.06 (m, 1H), 4.84 (m, 1H), 3.89 (m, 1H), 3.72 (m, 1H); ^{13}C-NMR (125 MHz, $CDCl_3$): δ 172.96, 167.40, 153.81, 151.23, 147.46, 146.44, 146.37, 146.17, 146.11, 145.68, 145.62, 145.51, 145.35, 145.29, 144.59, 144.53, 143.06, 142.75, 142.66, 142.25, 142.19, 142.25, 142.19, 141.98, 141.91, 141.88, 141.76, 140.04, 139.53, 137.10, 136.35, 135.06, 129.34, 128.04, 74.93, 71.49, 68.03, 64.11, 58.06, 47.56; HRMS (ESI-TOF) (*m/z*): $[M+H]^+$ calcd. for $C_{73}H_{15}BNO_8$, 1044.0891; found, 1044.0911.

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UV/vis spectrum charts of 1 and 2.

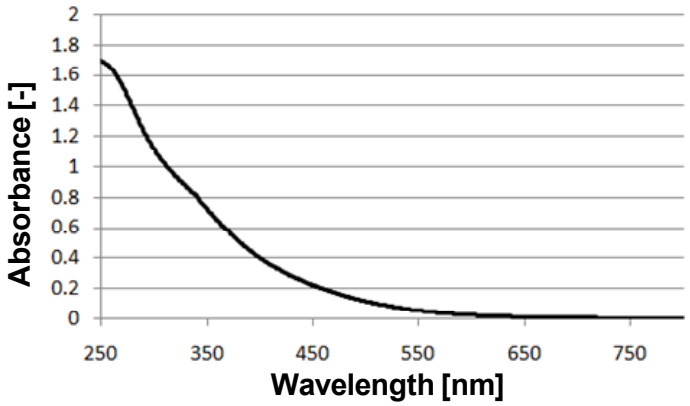

Fig. S3 UV/vis spectrum of the fullerene derivative **1** (50 µM) in 0.1 M phosphate buffer (pH 7.4).

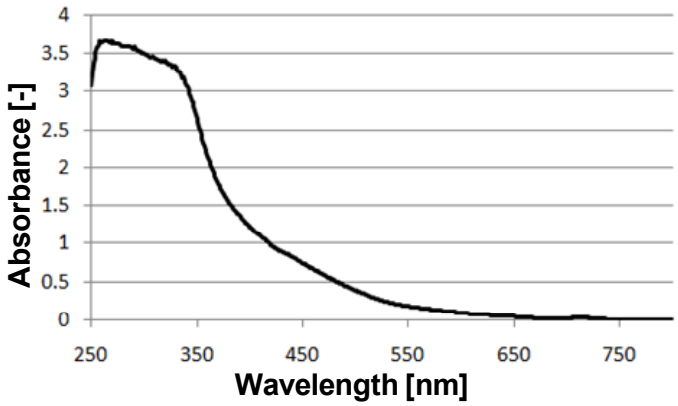

Fig. S4 UV/vis spectrum of the fullerene-boronic acid hybrid **2** (50 µM) in 10% DMF/0.1 M phosphate buffer (pH 7.4).

A presumed pathway of the photodegradation of 4 by 2.

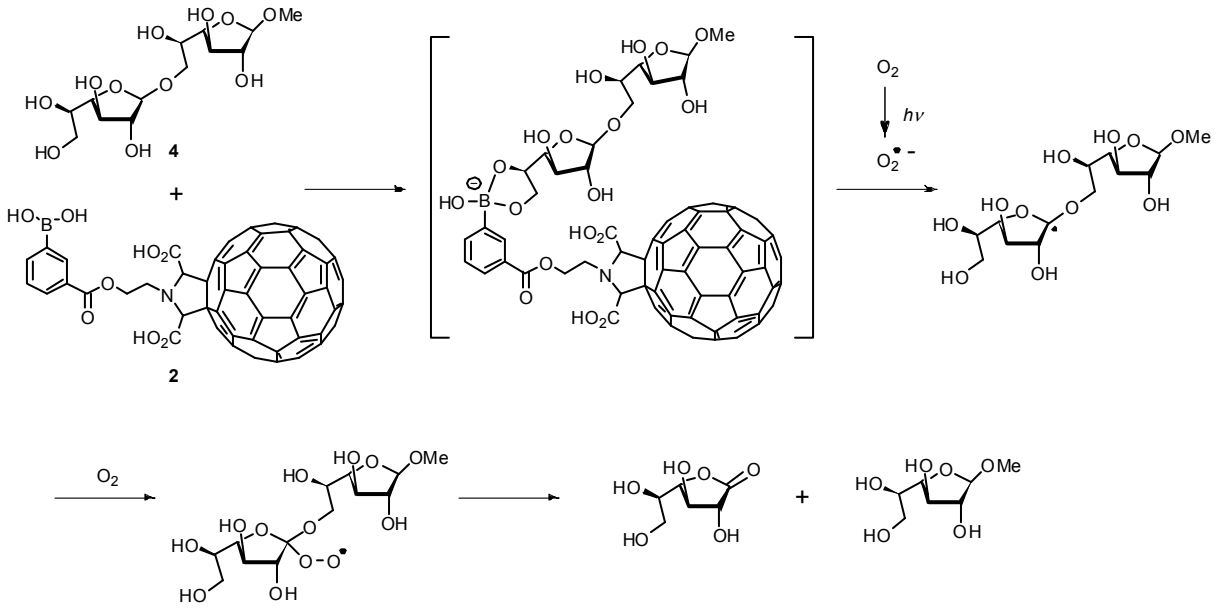

Fig. S5 A presumed pathway of the photodegradation of D-galactofuranoside **4** by a radical species produced by photoexcitation of hybrid **2** and O_2 (only oxidative cleavage of glycosidic bond is shown).

^{1}H- and ^{13}C-NMR spectrum charts of new compounds.

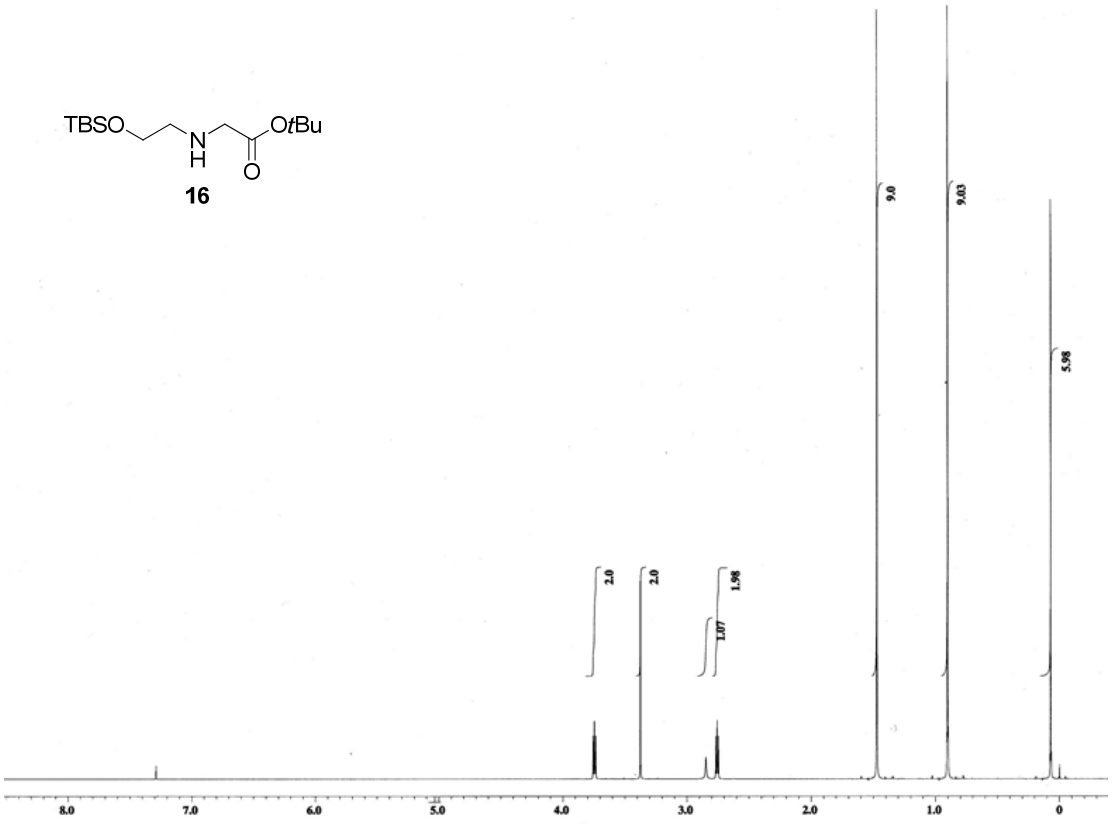

Fig. S5 ^{1}H-NMR spectrum of **16**.

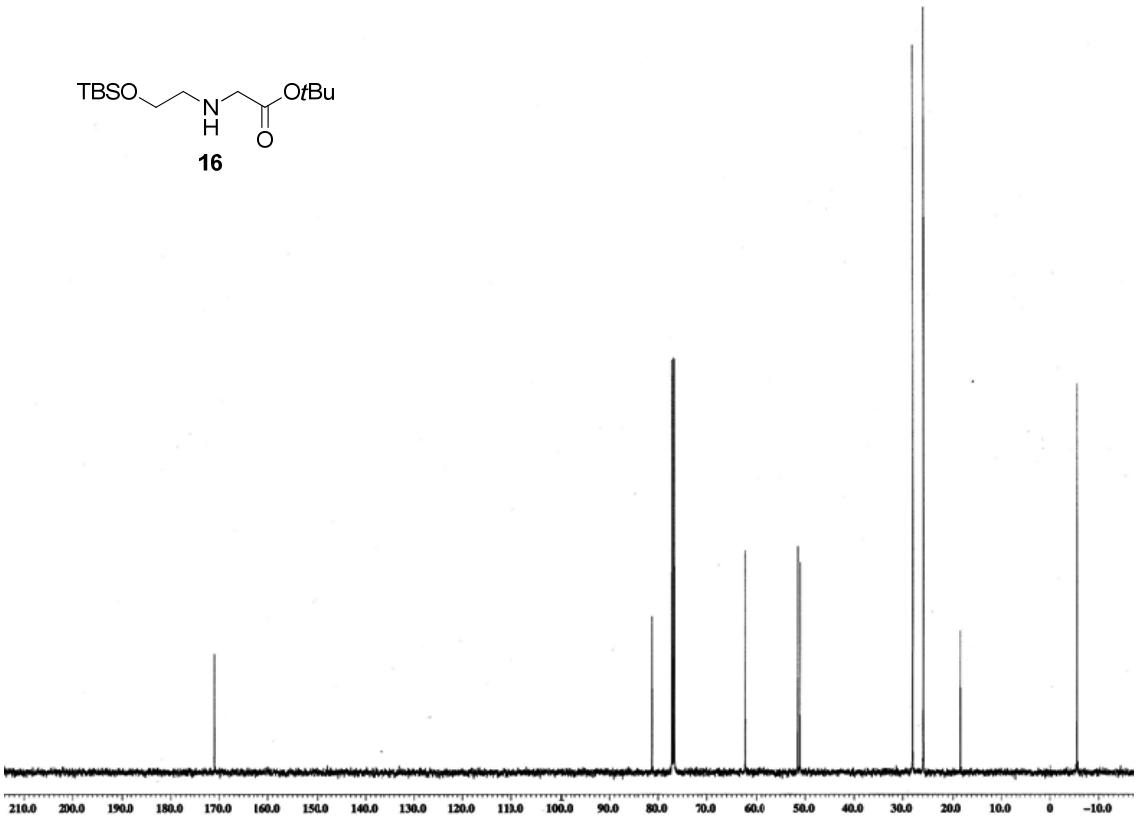

Fig. S6 ^{13}C-NMR spectrum of **16**.

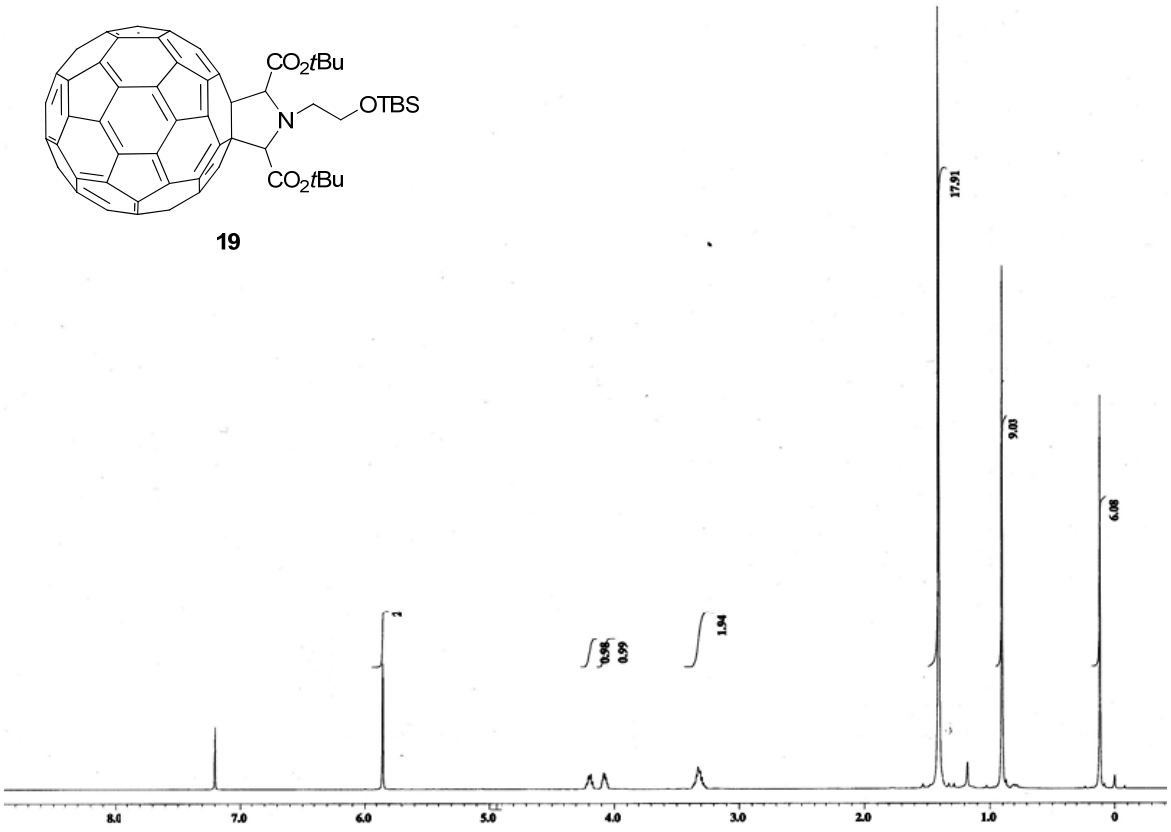

Fig. S7 ^{1}H-NMR spectrum of **19**.

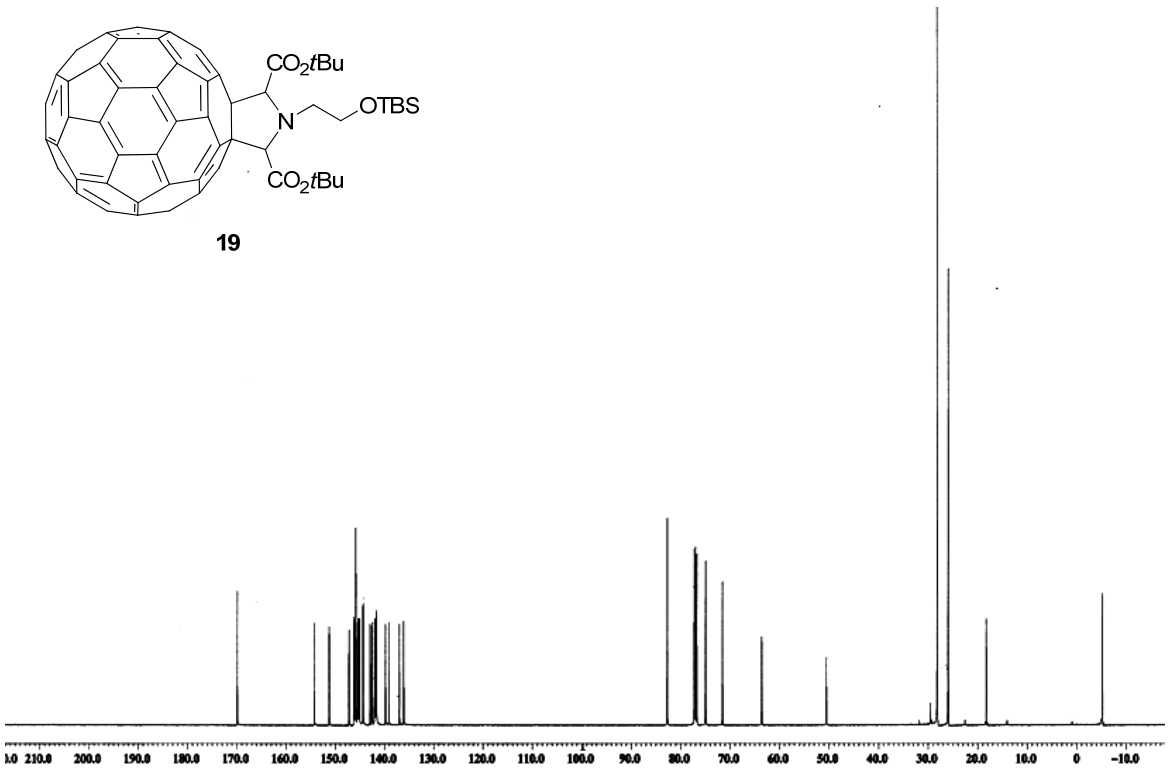

Fig. S8 ^{13}C-NMR spectrum of **19**.

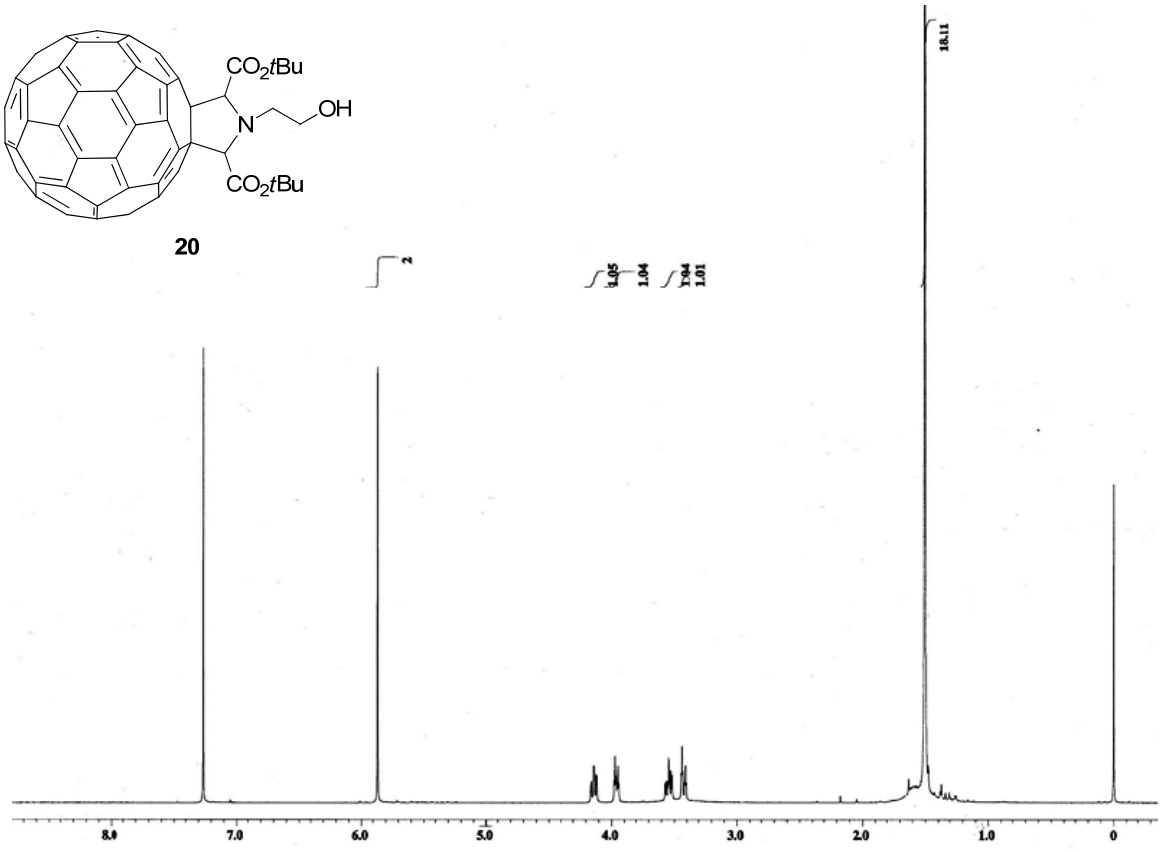

Fig. S9 ^{1}H-NMR spectrum of **20**.

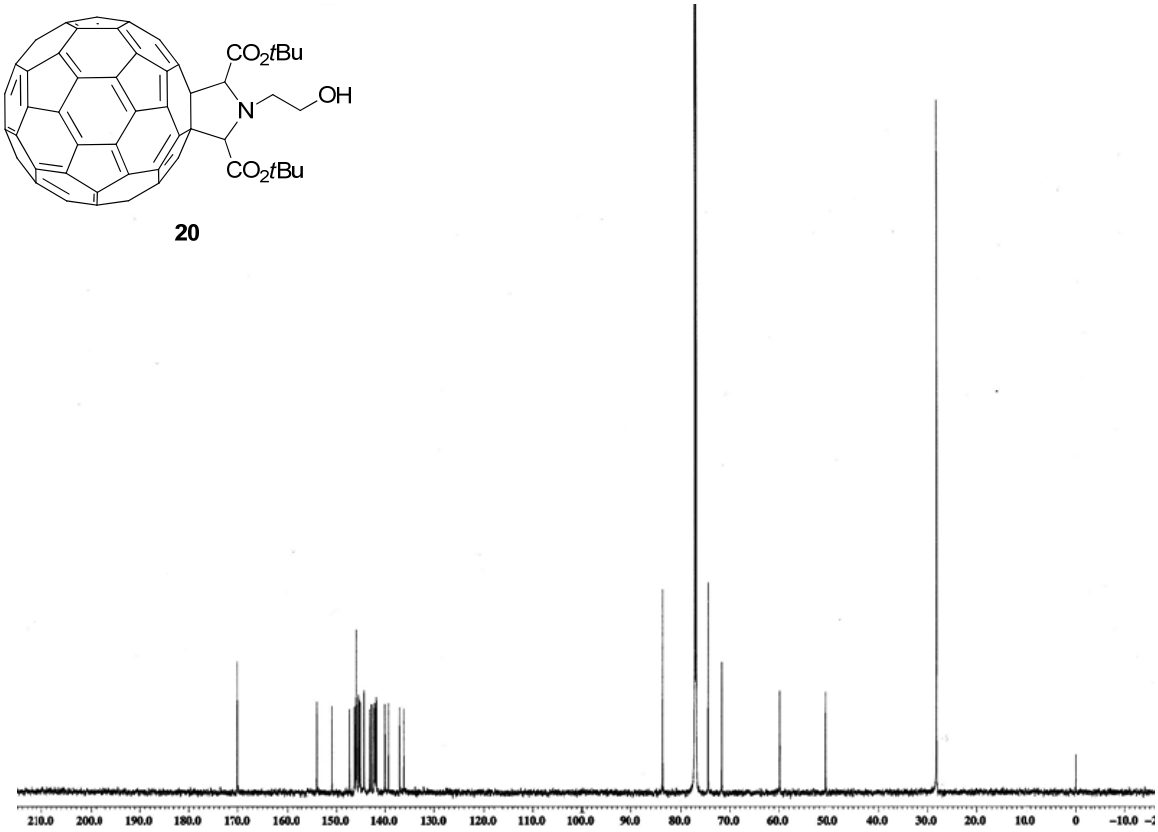

Fig. S10 ^{1}H-NMR spectrum of **20**.

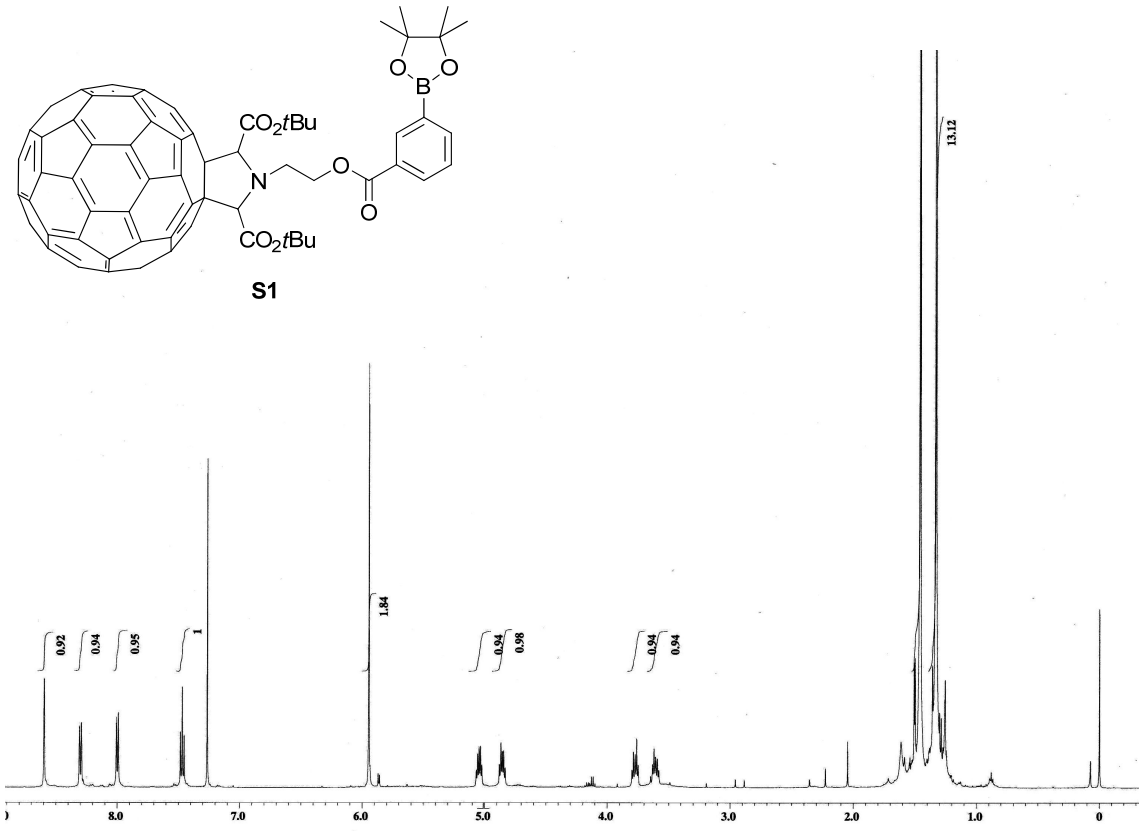

Fig. S11 ^{1}H-NMR spectrum of **S1**.

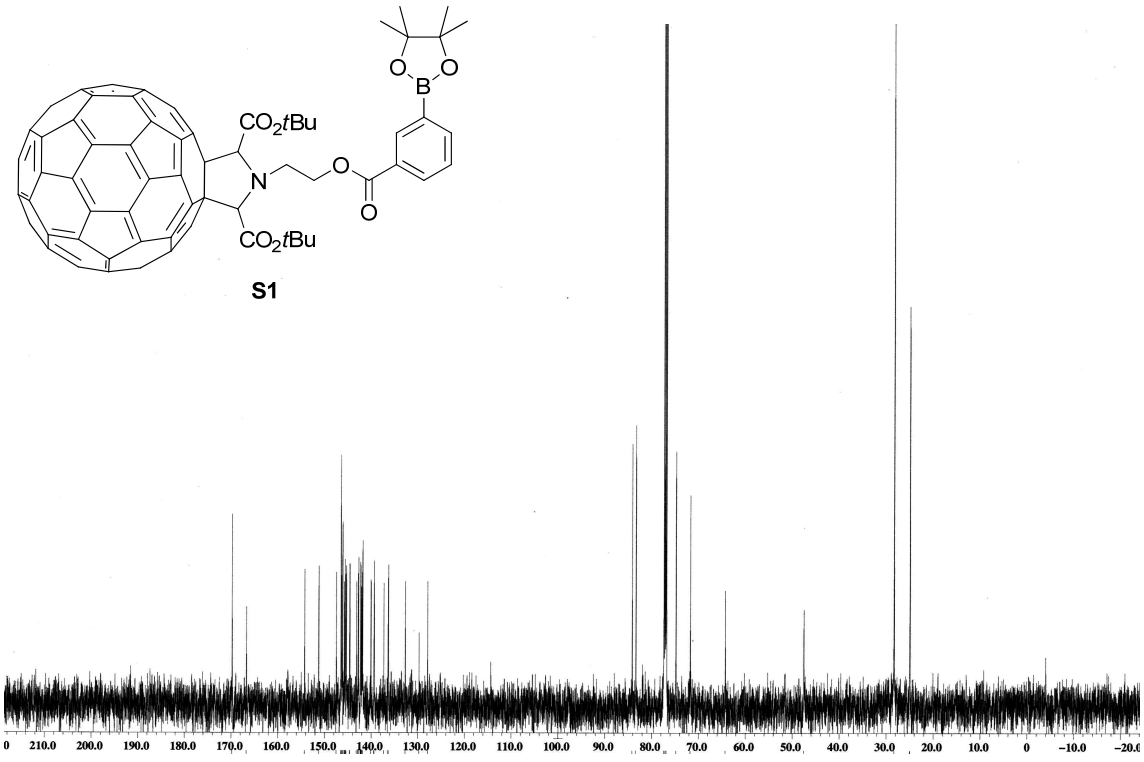

Fig. S12 ^{13}C-NMR spectrum of **S1**.

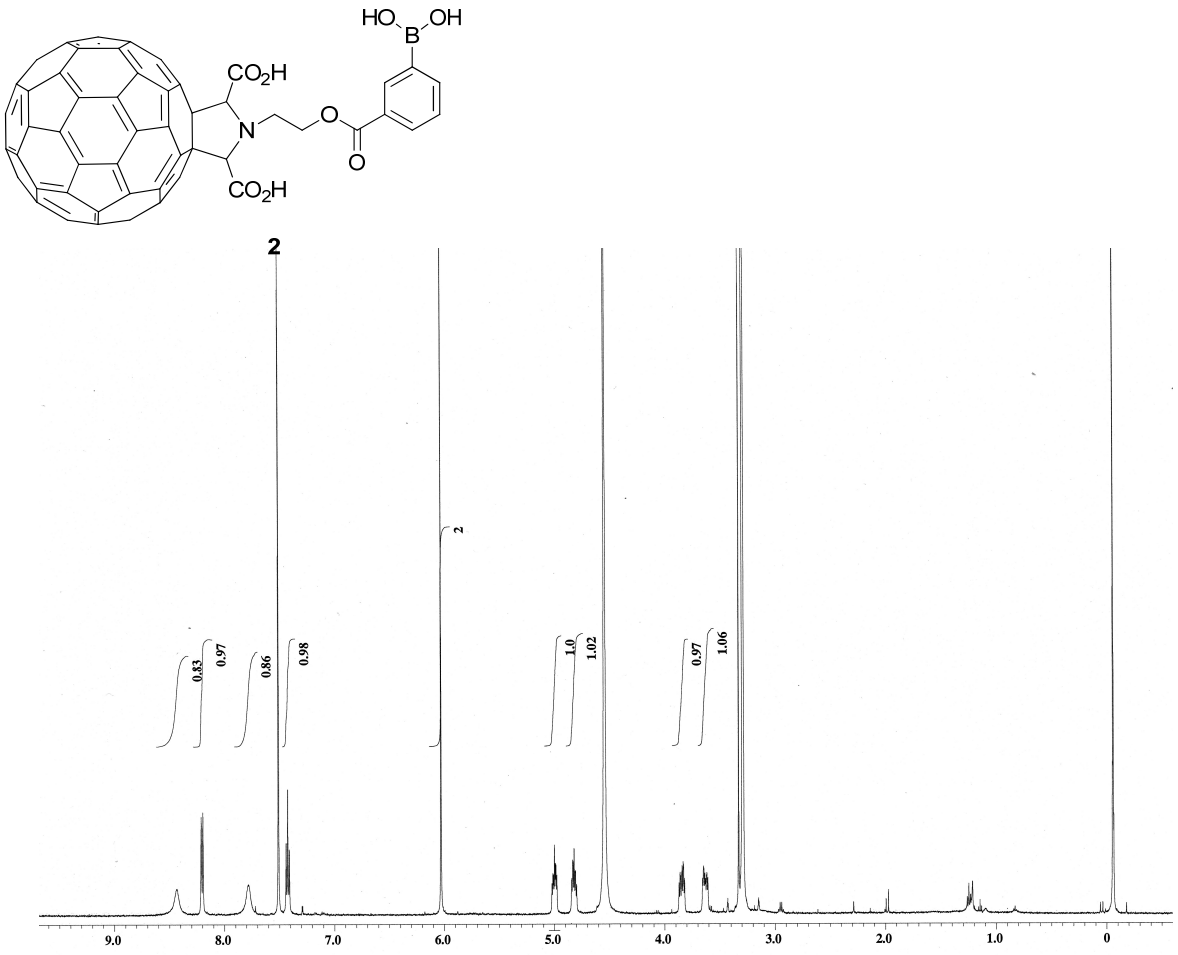

Fig. S13 ^{1}H-NMR spectrum of **2**.

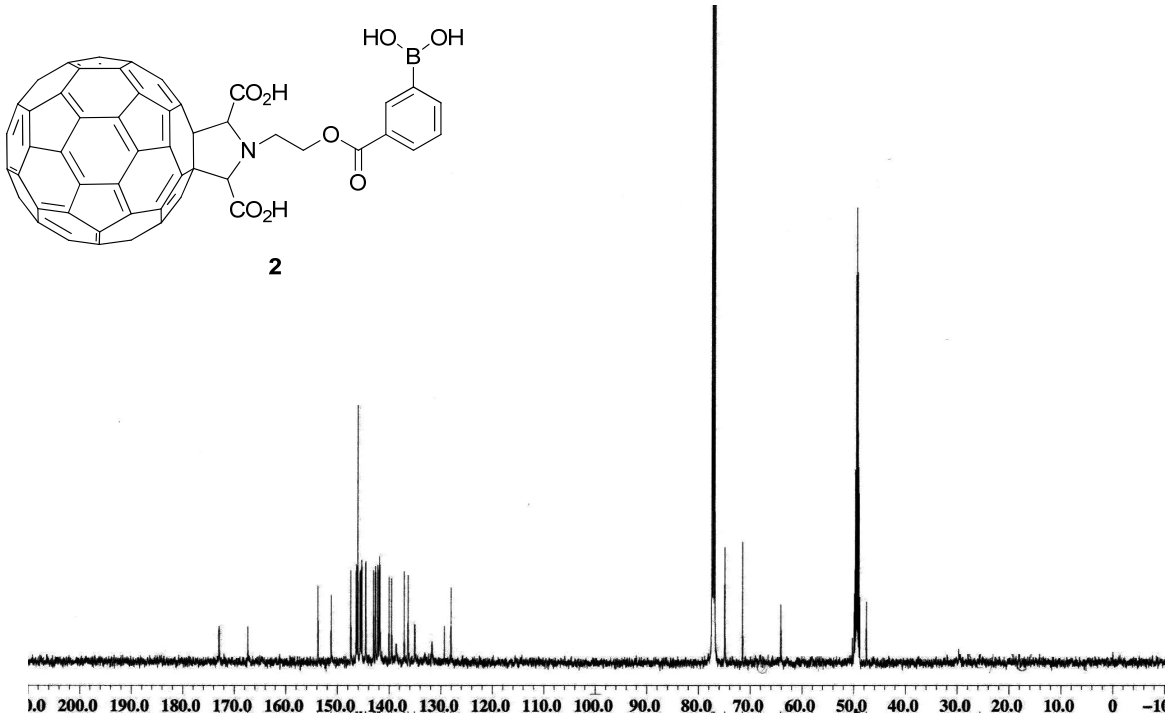

Fig. S14 ^{13}C-NMR spectrum of **2**.

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