

[6 + 3] Annulations of Morita–Baylis–Hillman Carbonates and Dicyanoheptafulvene

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Contents

General methods	2
Other heptafulvene substrate scope of [6 + 3] annulations	3
General Procedure for [6+3]-Cycloaddition	3
General Procedure for Asymmetric [6+3]-Cycloaddition	4
HPLC Chromatograms of Chiral Products	4-6
Analytic and Characterization Data for [6+3] Cycloadducts	6-12
Transformations of the Products	13
¹ H and ¹³ C NMR and 2D Spectra of All Products	14-35

General methods

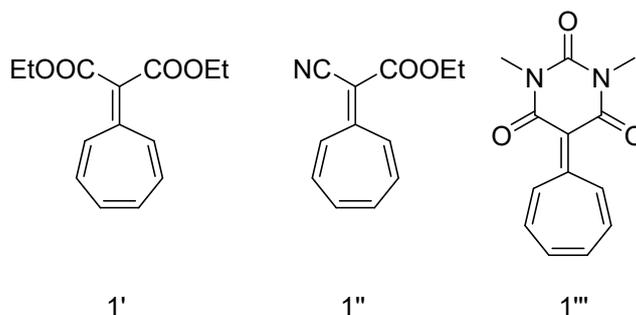
¹H NMR data were obtained for ¹H at 400 MHz or 600 MHz, and for ¹³C at 100 MHz or 150 MHz. Chemical shifts were given in parts per million (δ) from tetramethylsilane with the solvent

resonance as the internal standard in CDCl₃ solution. ESI HRMS was recorded on a Waters SYNAPT G2. UV detection was monitored at 220 nm or 254 nm. Optical rotation was measured in CHCl₃ solution at 15 °C. Column chromatography was performed on silica gel (200-300 mesh) eluting with ethyl acetate and petroleum ether. TLC was performed on glass-backed silica plates. UV light, I₂, and solution of potassium permanganate were used to visualize products. All chemicals were used without purification as commercially available unless otherwise noted. Petroleum ether (PE) and ethyl acetate (EtOAc) were distilled. THF was freshly distilled from sodium/benzophenone. Unless otherwise noted, experiments involving moisture and/or air sensitive components were performed under a positive pressure of argon in oven-dried glassware equipped with a rubber septum inlet. Accurate mass measurements were performed using an Agilent instrument with the ESI-MS technique. Melting points were determined by an X-4 digital micro melting point apparatus. X-ray crystallographic data were collected using a MM007HF Saturn 724⁺. HPLC analysis was performed on Agilent 1100 series, UV detection monitored at 254 nm, using a Chiralcel AD-H column with hexane and i-PrOH as the eluent. Dried solvents and liquid reagents were transferred by oven-dried syringes. Morita–Baylis–Hillman carbonates 1,^{1a-b} biscyano heptafulvene 2,² were prepared according to the literature procedures. The triphenylphosphine was commercial available. The Chiral phosphine was synthesized according to the literature.³

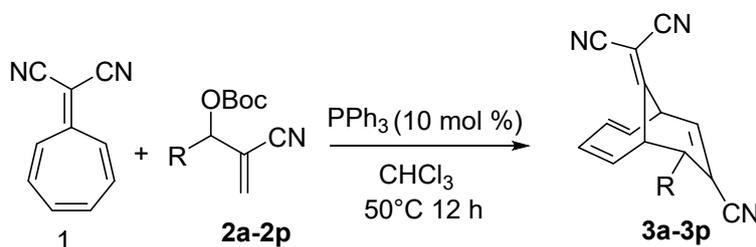
- (1) (a) F. Zhong; J. Luo; G. Chen; X. Dou and Y. Lu; *J. Am. Chem. Soc.*, 2012, **134**, 10222; (b) G. Zhu; J. Yang; G. Bao; M. Zhang; J. Li; Y. Li; W. Sun; L. Hong and R. Wang; *Chem. Commun.*, 2016, **52**, 7882.
- (2) (a) R. Mose; G. Preegel; J. Larsen; S. Jakobsen; E.-H. Iversen and K.-A. Jørgensen; *Nat. Chem.*, 2017, **9**, 487; (b) T. Nozoe; T. Mukaj; K. Osaka and N. Shishido.; *Bull. Chem. Soc. Jpn.*; 1961, **34**, 1384.
- (3) X. Su, W. Zhou, Y. Li and J. Zhang; *Angew. Chem. Int. Ed.*, 2015, **54**, 6874.

Other heptafulvene substrate scope of [6 + 3] annulations

The other heptafulvenes such as diethyl 2-(cyclohepta-2,4,6-trien-1-ylidene)malonate (1') and ethyl 2-cyano-2-(cyclohepta-2,4,6-trien-1-ylidene)acetate (1'') had been attempted in this reaction. Unfortunately, both heptafulvenes 1' and 1'' did not work. 5-(cyclohepta-2,4,6-trien-1-ylidene)-1,3-dimethylpyrimidine-2,4,6(1H,3H,5H)-trione(1''') was also tested, trace product (approximately 5% yield) was observed in this reaction.

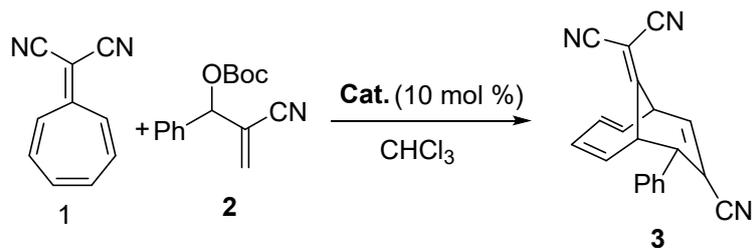


General procedure for [6 + 3] annulation reaction of MBH carbonates and the dicyanoheptafulvene



To a stirred mixture of dicyanoheptafulvene **1** (0.1 mmol), MBH carbonates **2a-2p** (0.1 mmol) in solvent of CHCl₃ (1.0 mL) was added catalyst PPh₃ (10 mol %) at room temperature. The resulting mixture was stirred for 12 h at 50°C. The mixture was allowed to cool down to room temperature. H₂O (5.0 mL) was added. The mixture was extracted with DCM (5.0 mL×3). The combined organic phases were dried over Na₂SO₄, filtered, and concentrated under reduced pressure. The obtained residue was purified by flash chromatography on a silica gel with EtOAc/petroleum ether to afford the product **3a-3p**.

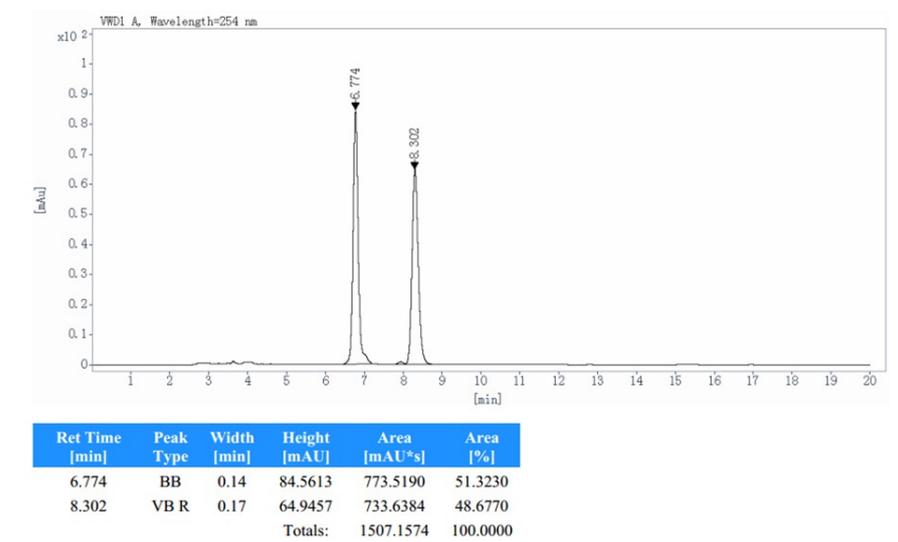
General Procedure for Asymmetric [6+3]-Cycloaddition



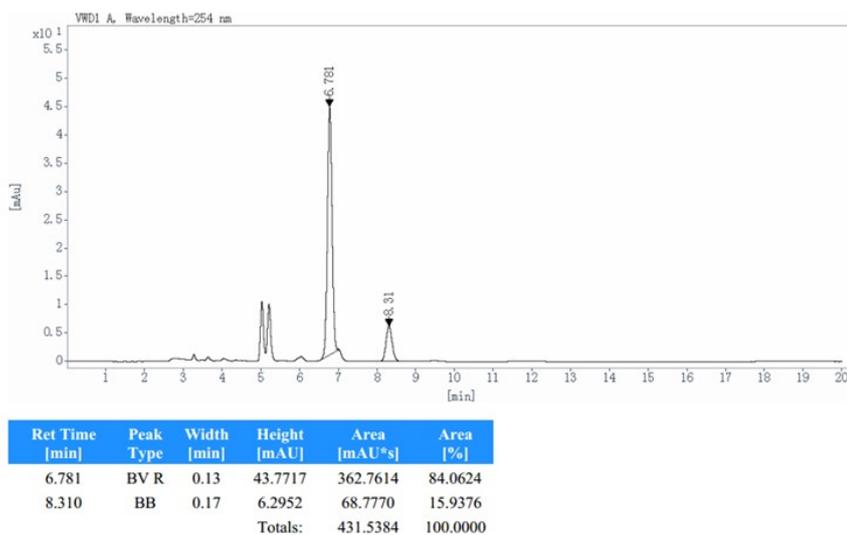
To a stirred mixture of dicyanoheptafulvene **1** (0.1 mmol), MBH carbonates **2** (0.1 mmol) in solvent of CHCl_3 (1.0 mL) was added catalyst **C1-C8** (10 mol %) at room temperature. The resulting mixture was stirred for 12 h at room temperature. H_2O (5.0 mL) was added. The mixture was extracted with DCM (5.0 mL \times 3). The combined organic phases were dried over Na_2SO_4 , filtered, and concentrated under reduced pressure. The obtained residue was purified by flash chromatography on a silica gel with EtOAc/petroleum ether =1/10 to afford the product

HPLC Chromatograms of Chiral Products

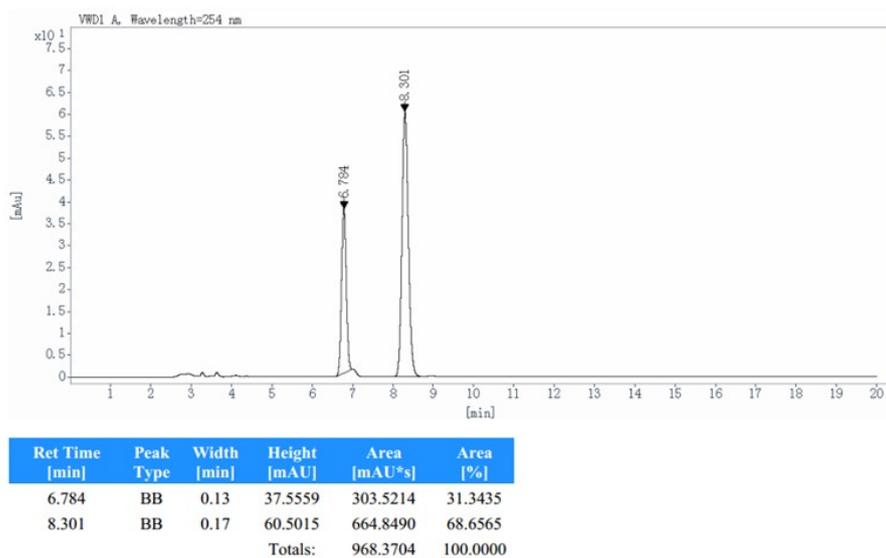
HPLC chromatogram of racemic product 3a



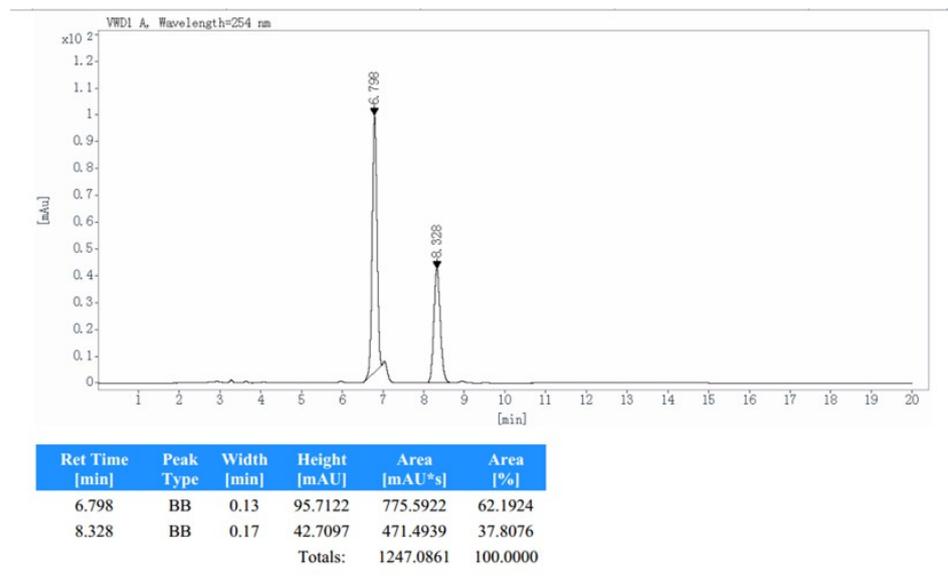
HPLC chromatogram of product 3a obtained with chiral catalyst **C1**



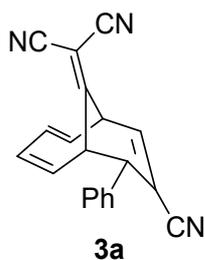
HPLC chromatogram of product 3a obtained with chiral catalyst C3



HPLC chromatogram of product 3a obtained with chiral catalyst C6



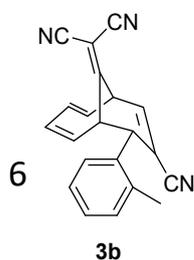
¹H and ¹³C NMR and 2D NMR Spectra of All Products



Purification by flash chromatography on silica gel (EtOAc/petroleum ether = 1/10) gave product, white solid, 92% yield, mp = 112–114 °C, R_f = 0.20 (EtOAc/petroleum ether = 1/10), 2-((1S,6R,9S)-8-cyano-9-phenylbicyclo[4.3.1]deca-2,4,7-trien-10-ylidene)malononitrile ESI-HRMS: calcd. for $C_{20}H_{13}N_3+Na^+$ 318.1002, found 318.1000. ¹H NMR (400 MHz, $CDCl_3$) δ 7.46 – 7.38 (m, 3H), 7.27 – 7.24 (m, 1H), 6.51 (dd, J = 4.0 Hz, 2.0 Hz, 1H), 6.19 (dd, J = 10.0 Hz, 7.2 Hz, 1H), 6.10 (dd, J = 11.6 Hz, 7.2 Hz, 1H), 6.03 (t, J = 9.0 Hz, 1H), 5.30 – 5.24 (m, 1H), 4.59 – 4.54 (m, 1H), 4.14 – 4.13 (m, 2H). ¹³C NMR (100 MHz, $CDCl_3$) δ 174.1(C-5), 140.5(C-10), 135.2*, 129.7*, 129.6*, 128.9*, 126.1**, 125.8(C-2), 121.0(C-1), 116.5(C-3), 114.2(C-11), 110.7(C-13), 110.3(C-14), 84.7(C-12), 50.3(C-8), 48.8(C-6), 43.3(C-4).

* This four peaks were included six carbons in the phenyl group.

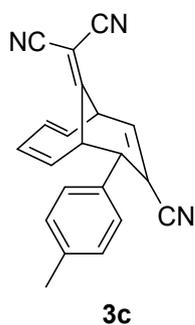
** This was two carbon, C-7 and C-9



Purification by flash chromatography on silica gel (EtOAc/petroleum ether = 1/10) gave product, white solid, 81% yield, mp = 127–129 °C, R_f = 0.20

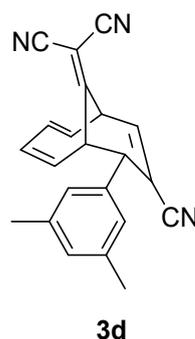
(EtOAc/petroleum ether =1/10), 2-((1S,6R,9S)-8-cyano-9-(o-tolyl)bicyclo[4.3.1]deca-2,4,7-trien-10-ylidene)malononitrile, ESI-HRMS: calcd. for $C_{21}H_{15}N_3+Na^+$ 332.1158, found 332.1158.

1H NMR (400 MHz, $CDCl_3$) δ 7.32 – 7.25 (m, 1H), 7.15 – 7.08 (m, 1H), 6.54 (dd, $J = 4.4, 2.9$ Hz, 1H), 6.21 (dd, $J = 10.3, 7.4$ Hz, 1H), 6.11 (dd, $J = 11.8, 7.4$ Hz, 1H), 6.03 (t, $J = 9.8$ Hz, 1H), 5.25 (dd, $J = 11.8, 5.7$ Hz, 1H), 4.58 (dd, $J = 6.5, 4.3, 2.1$ Hz, 1H), 4.47 – 4.34 (m, 1H), 4.24 – 4.10 (m, 1H), 2.44 (s, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 174.4, 140.1, 138.4, 134.9, 130.6, 129.6, 127.4, 126.4, 125.5, 120.9, 116.5, 114.6, 110.7, 110.3, 84.5, 50.3, 48.9, 43.3, 21.4.



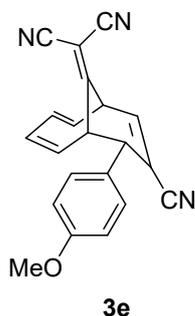
Purification by flash chromatography on silica gel (EtOAc/petroleum ether = 1/10) gave product, white solid, 86% yield, mp = 126–128 °C, $R_f = 0.20$ (EtOAc/petroleum ether =1/10), 2-((1S,6R,9S)-8-cyano-9-(p-tolyl)bicyclo[4.3.1]deca-2,4,7-trien-10-ylidene)malononitrile, ESI-HRMS: calcd. for $C_{21}H_{15}N_3+Na^+$ 332.1158, found 332.1163. 1H NMR (400 MHz, $CDCl_3$) δ 7.24 (d, $J = 8.0$ Hz, 2H), 7.13 (d, $J = 8.4$ Hz, 2H), 6.51 (dd, $J = 4.4$

Hz, 2.8 Hz, 1H), 6.20 (dd, $J = 10.4, 7.6$ Hz, 1H), 6.10 (dd, $J = 11.6$ Hz, 7.6 Hz, 1H), 6.03 (t, $J = 10.0$ Hz, 1H), 5.31 (dd, $J = 11.6$ Hz, 5.6 Hz, 1H), 4.59 – 4.55 (m, 1H), 4.14 – 4.08 (m, 2H), 2.38 (s, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 174.2, 159.9, 140.1, 130.8, 129.6, 127.0, 126.3, 125.7, 120.9, 116.5, 114.8, 114.3, 110.7, 110.2, 84.5, 55.4, 49.8, 49.1, 43.3.

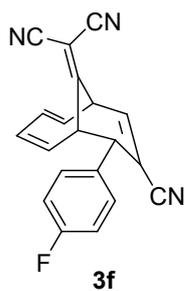


Purification by flash chromatography on silica gel (EtOAc/petroleum ether = 1/10) gave product, white solid, 82% yield, mp = 151–153 °C, $R_f = 0.18$ (EtOAc/petroleum ether =1/10), 2-((1S,6R,9S)-8-cyano-9-(3,5-dimethylphenyl)bicyclo[4.3.1]deca-2,4,7-trien-10-ylidene)malononitrile, ESI-HRMS: calcd. for $C_{22}H_{17}N_3+Na^+$ 346.1315, found 346.1316. 1H NMR (400 MHz, $CDCl_3$) δ 7.03 (s, 1H), 6.84 (s, 2H), 6.58 – 6.45 (m, 1H), 6.21 (dd, $J = 10.2, 7.5$ Hz, 1H), 6.11 (dd, $J = 11.7, 7.5$ Hz, 1H), 6.04 (t, $J = 9.8$ Hz, 1H),

5.33 (dd, $J = 11.8, 5.8$ Hz, 1H), 4.69 – 4.46 (m, 1H), 4.15 (t, $J = 5.0$ Hz, 1H), 4.10 – 3.97 (m, 1H), 2.36 (s, 6H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 174.4, 140.1, 138.4, 134.9, 130.6, 129.6, 127.4, 126.4, 125.5, 120.9, 116.5, 114.6, 110.7, 110.3, 84.5, 50.3, 48.9, 43.3, 21.4.



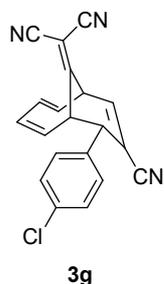
Purification by flash chromatography on silica gel (EtOAc/petroleum ether = 1/5) gave product, white solid, 80% yield, mp = 143–145 °C, R_f = 0.23 (EtOAc/petroleum ether = 1/5), 2-((1S,6R,9S)-8-cyano-9-(4-methoxyphenyl)bicyclo[4.3.1]deca-2,4,7-trien-10-ylidene)malononitrile, ESI-HRMS: calcd. for $C_{21}H_{15}N_3O+Na^+$ 348.1107, found 348.1105. 1H NMR (400 MHz, $CDCl_3$) δ 7.17 (d, J = 8.4 Hz, 2H), 6.95 (d, J = 8.8 Hz, 2H), 6.50 (dd, J = 4.0 Hz, 2.8 Hz, 1H), 6.20 (dd, J = 10.4 Hz, 7.6 Hz, 1H), 6.11 (dd, J = 11.6 Hz, 7.6 Hz, 1H), 6.03 (t, J = 9.6 Hz, 1H), 5.33 (dd, J = 11.6 Hz, 5.6 Hz, 1H), 4.59 – 4.55 (m, 1H), 4.12 – 4.09 (m, 2H), 3.84 (s, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 174.2, 140.2, 138.8, 132.0, 129.6, 129.5, 126.3, 125.7, 120.9, 116.5, 114.6, 110.7, 110.2, 84.6, 50.1, 49.0, 43.3, 21.2.



Purification by flash chromatography on silica gel (EtOAc/petroleum ether = 1/10) gave product, white solid, 78% yield, mp = 120–122 °C, R_f = 0.16 (EtOAc/petroleum ether = 1/10), 2-((1S,6R,9S)-8-cyano-9-(4-fluorophenyl)bicyclo[4.3.1]deca-2,4,7-trien-10-ylidene)malononitrile, ESI-HRMS: calcd. for $C_{20}H_{12}FN_3+Na^+$ 336.0907, found 336.0908. 1H NMR (400 MHz, $CDCl_3$) δ 7.25 – 7.23 (m, 2H), 7.17-7.12 (m, 2H), 6.54 (dd, J = 4.0 Hz, 1.6 Hz, 1H), 6.21 (dd, J = 10.0 Hz, 7.2 Hz, 1H), 6.13 (dd, J = 11.6 Hz, 7.6 Hz, 1H), 6.06 (t, J = 10 Hz, 1H), 5.28 (dd, J = 11.6 Hz, 4.8 Hz, 1H), 4.61 – 4.57 (m, 1H), 4.14 (s, 2H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 173.6(C-5), 162.9* ($^1J_{CF}$ = 257.5 Hz), 140.5(C-10), 131.4* ($^3J_{CF}$ = 8.3 Hz), 130.9(C-15), 129.6(C-7), 126.1(C-9), 125.8(C-2), 121.1(C-1), 116.3(C-3), 116.2(C-11), 115.9(C-13), 114.2(C-14), 110.4* ($^2J_{CF}$ = 47.7 Hz), 84.9(C-12), 49.7(C-8), 48.7(C-6), 43.3(C-4).

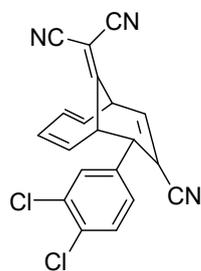
* This three peaks were included five carbons in the phenyl group.

^{19}F NMR (400 MHz, $CDCl_3$) δ -112.29.



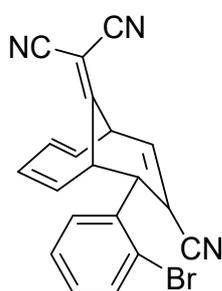
Purification by flash chromatography on silica gel (EtOAc/petroleum ether = 1/10) gave product, white solid, 73% yield, mp = 148–150 °C, R_f = 0.35 (EtOAc/petroleum ether = 1/5), 2-((1S,6R,9S)-9-(4-chlorophenyl)-8-cyanobicyclo[4.3.1]deca-2,4,7-trien-10-ylidene)malononitrile, ESI-HRMS: calcd. for $C_{20}H_{12}ClN_3+Na^+$ 352.0612, found 352.0609. 1H NMR (400 MHz, $CDCl_3$) δ 7.43 (d, J = 8.4 Hz, 2H), 7.21 (d, J = 8.4 Hz, 2H), 6.60 – 6.49 (m, 1H), 6.21 (dd, J = 10.4 Hz, 7.6 Hz, 1H), 6.15 – 6.10 (m, 1H), 6.06 (t, J = 9.8 Hz, 1H), 5.28 – 5.24 (m, 1H), 4.59 –

4.58 (m, 1H), 4.13 (s, 2H). ^{13}C NMR (100 MHz, CDCl_3) δ 173.4, 140.7, 135.1, 133.7, 130.9, 129.5, 129.2, 126.2, 125.6, 121.1, 116.2, 113.8, 110.6, 110.1, 85.0, 49.8, 48.5, 43.3.



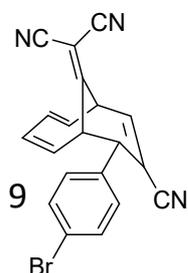
3h

Purification by flash chromatography on silica gel (EtOAc/petroleum ether = 1/10) gave product, white solid, 69% yield, mp = 161–163 °C, R_f = 0.25 (EtOAc/petroleum ether = 1/5), 2-((1S,6R,9S)-8-cyano-9-(3,4-dichlorophenyl)bicyclo[4.3.1]deca-2,4,7-trien-10-ylidene)malononitrile, ESI-HRMS: calcd. for $\text{C}_{20}\text{H}_{11}\text{Cl}_2\text{N}_3 + \text{Na}^+$ 386.0222, found 386.0216. ^1H NMR (600 MHz, CDCl_3) δ 7.54 (d, J = 8.0 Hz, 1H), 7.38 (s, 1H), 7.12 (d, J = 8.0 Hz, 1H), 6.57 (s, 1H), 6.26 – 6.20 (m, 1H), 6.19 – 6.14 (m, 1H), 6.08 (t, J = 9.6 Hz, 1H), 5.27 (dd, J = 11.1, 4.8 Hz, 1H), 4.60 (d, J = 4.5 Hz, 2H), 4.38 – 3.72 (m, 3H). ^{13}C NMR (100 MHz, CDCl_3) δ 172.9, 141.0, 135.4, 133.5, 133.3, 131.5, 130.9, 129.5, 128.9, 126.5, 125.1, 121.3, 116.0, 113.2, 110.5, 110.0, 85.3, 49.4, 48.1, 43.2.



3i

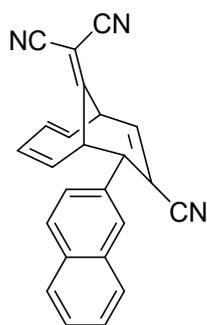
Purification by flash chromatography on silica gel (EtOAc/petroleum ether = 1/10) gave product, white solid, 71% yield, mp = 155–157 °C, R_f = 0.30 (EtOAc/petroleum ether = 1/5), 2-((1S,6R,9R)-9-(2-bromophenyl)-8-cyanobicyclo[4.3.1]deca-2,4,7-trien-10-ylidene)malononitrile, ESI-HRMS: calcd. for $\text{C}_{20}\text{H}_{12}\text{BrN}_3 + \text{Na}^+$ 396.0107, found 396.0109. ^1H NMR (400 MHz, CDCl_3) δ 7.69 (d, J = 8.0 Hz, 1H), 7.41 (t, J = 7.5 Hz, 1H), 7.32 – 7.25 (m, 1H), 7.22 (d, J = 7.7 Hz, 1H), 6.68 – 6.44 (m, 1H), 6.21 (dd, J = 10.0, 7.7 Hz, 1H), 6.10 (dd, J = 13.1, 9.0 Hz, 1H), 6.04 (d, J = 9.9 Hz, 1H), 5.17 (dd, J = 11.7, 5.7 Hz, 1H), 4.70 (s, 1H), 4.59 (dd, J = 5.4, 3.1 Hz, 1H), 4.44 (t, J = 4.6 Hz, 1H). ^{13}C NMR (100 MHz, CDCl_3) δ 173.0, 141.0, 134.0, 133.7, 131.4, 130.4, 129.7, 127.4, 126.3, 125.9, 125.1, 121.0, 116.3, 113.8, 110.4, 110.2, 85.1, 49.7, 45.6, 43.4.



3j

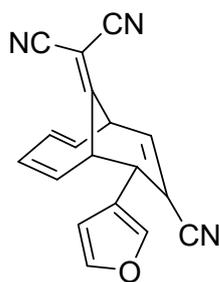
Purification by flash chromatography on silica gel (EtOAc/petroleum ether = 1/10) gave product, white solid, 69% yield, mp = 152–154 °C, R_f = 0.30 (EtOAc/petroleum ether = 1/5), 2-((1S,6R,9S)-9-(4-bromophenyl)-8-

cyanobicyclo[4.3.1]deca-2,4,7-trien-10-ylidene)malononitrile, ESI-HRMS: calcd. for $C_{20}H_{12}BrN_3 + Na^+$ 396.0107, found 396.0109. 1H NMR (400 MHz, $CDCl_3$) δ 7.59 (m, $J = 13.2$ Hz, 2H), 7.15 (m, $J = 8.8$ Hz, 2H), 7.22 (d, $J = 7.7$ Hz, 1H), 6.19 (dd, $J = 10.3, 7.5$ Hz, 1H), 6.10 (dd, $J = 11.8, 7.4$ Hz, 1H), 6.03 (t, $J = 9.8$ Hz, 1H), 5.35 – 5.19 (m, 1H), 4.56 (d, $J = 13.2$ Hz, 1H), 4.14 (d, $J = 1.4$ Hz, 2H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 173.3, 140.7, 134.2, 132.1, 131.2, 129.5, 126.2, 125.6, 123.2, 121.1, 116.2, 113.7, 110.6, 110.1, 85.0, 49.8, 48.4, 43.2



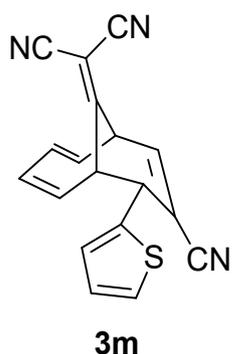
3k

Purification by flash chromatography on silica gel (EtOAc/petroleum ether = 1/10) gave product, white solid, 84% yield, mp = 166–168 °C, $R_f = 0.18$ (EtOAc/petroleum ether = 1/10), 2-((1S,6R,9S)-8-cyano-9-(naphthalen-2-yl)bicyclo[4.3.1]deca-2,4,7-trien-10-ylidene)malononitrile, ESI-HRMS: calcd. for $C_{24}H_{15}N_3 + Na^+$ 368.1158, found 368.1149. 1H NMR (600 MHz, $CDCl_3$) δ 7.92 (d, $J = 8.5$ Hz, 1H), 7.90 – 7.87 (m, 2H), 7.75 (s, 1H), 7.61 – 7.51 (m, 2H), 7.34 (d, $J = 8.4$ Hz, 1H), 6.64 – 6.54 (m, 1H), 6.22 (dd, $J = 22.4, 11.2$ Hz, 1H), 6.12 (dd, $J = 11.6, 7.6$ Hz, 1H), 6.07 (t, $J = 9.8$ Hz, 1H), 5.29 (dd, $J = 11.7, 5.7$ Hz, 1H), 4.62 (dd, $J = 5.8, 3.3$ Hz, 1H), 4.32 (s, 1H), 4.26 (d, $J = 4.9$ Hz, 1H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 140.6, 133.2, 133.1, 132.6, 129.6, 129.2, 128.7, 128.1, 127.8, 126.9, 126.8, 126.7, 126.1, 125.9, 121.0, 116.5, 114.3, 110.7, 110.2, 84.8, 50.5, 50.0, 43.4.

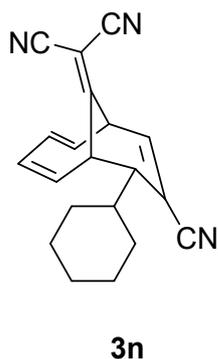


3l

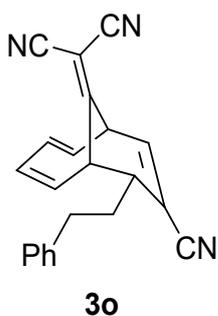
Purification by flash chromatography on silica gel (EtOAc/petroleum ether = 1/10) gave product, yellow solid, 66% yield, mp = 103–105 °C, $R_f = 0.20$ (EtOAc/petroleum ether = 1/5), 2-((1S,6R,9R)-8-cyano-9-(furan-3-yl)bicyclo[4.3.1]deca-2,4,7-trien-10-ylidene)malononitrile, ESI-HRMS: calcd. For $C_{18}H_{12}N_3O + Na^+$ 308.0794, found 308.0795. 1H NMR (400 MHz, $CDCl_3$) δ 7.52 (d, $J = 6.4$ Hz, 1H), 6.44 (dd, $J = 3.9, 3.0$ Hz, 1H), 6.40 (s, 1H), 6.24 – 6.18 (m, 1H), 6.15 (dd, $J = 11.4, 7.5$ Hz, 1H), 6.03 (t, $J = 9.7$ Hz, 1H), 5.61 (dd, $J = 11.6, 5.5$ Hz, 1H), 4.74 – 4.39 (m, 1H), 4.22 – 3.92 (m, 1H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 173.4, 143.8, 141.7, 139.3, 129.7, 126.2, 125.9, 120.9, 120.0, 116.2, 114.3, 110.8, 110.6, 110.1, 84.8, 48.6, 43.1, 41.2.



Purification by flash chromatography on silica gel (EtOAc/petroleum ether = 1/10) gave product, yellow solid, 59% yield, mp = 112–114 °C, R_f = 0.25 (EtOAc/petroleum ether = 1/5), 2-((1S,6R,9R)-8-cyano-9-(thiophen-2-yl)bicyclo[4.3.1]deca-2,4,7-trien-10-ylidene)malononitrile, ESI-HRMS: calcd. for $C_{18}H_{12}N_3S + H^+$ 324.0566, found 324.0577. 1H NMR (400 MHz, $CDCl_3$) δ 7.38 (d, J = 4.9 Hz, 1H), 7.08 (dd, J = 9.0, 4.1 Hz, 2H), 6.49 – 6.42 (m, 1H), 6.22 (dd, J = 9.9, 7.6 Hz, 1H), 6.16 (dd, J = 11.4, 7.5 Hz, 1H), 6.03 (t, J = 9.7 Hz, 1H), 5.59 (dd, J = 11.5, 5.7 Hz, 1H), 4.65–4.49 (m, 1H), 4.46–4.38 (m, 1H), 4.19 (t, J = 5.0 Hz, 1H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 173.2, 139.4, 136.8, 129.8, 128.9, 127.4, 126.6, 126.1, 125.9, 120.7, 116.0, 114.3, 110.5, 110.1, 85.4, 48.9, 45.3, 43.1.

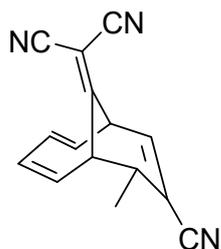


Purification by flash chromatography on silica gel (EtOAc/petroleum ether = 1/15) gave product, white solid, 81% yield, mp = 121–123 °C, R_f = 0.32 (EtOAc/petroleum ether = 1/10), 2-((1S,6R,9R)-8-cyano-9-cyclohexylbicyclo[4.3.1]deca-2,4,7-trien-10-ylidene)malononitrile, ESI-HRMS: calcd. for $C_{20}H_{19}N_3 + Na^+$ 324.1471, found 324.1475. 1H NMR (400 MHz, $CDCl_3$) δ 6.26 (s, 1H), 6.22 – 6.07 (m, 3H), 5.97 (t, J = 9.5 Hz, 1H), 5.83 (dd, J = 11.1, 4.8 Hz, 1H), 4.47 (d, J = 8.5 Hz, 2H), 4.15 (s, 2H), 2.45 (s, 1H), 2.25 (d, J = 11.7 Hz, 2H), 2.09 – 1.09 (m, 11H). ^{13}C NMR (150 MHz, $CDCl_3$) δ 174.9, 139.7, 130.1, 126.5, 125.8, 121.0, 117.3, 115.7, 110.7, 110.3, 83.4, 48.2, 45.5, 43.6, 38.8, 32.9, 30.5, 26.4, 26.1, 26.0.



Purification by flash chromatography on silica gel (EtOAc/petroleum ether = 1/15) gave product, white solid, 95% yield, mp = 128–130 °C, R_f = 0.30 (EtOAc/petroleum ether = 1/10), 2-((1S,6R,9R)-8-cyano-9-phenethylbicyclo[4.3.1]deca-2,4,7-trien-10-ylidene)malononitrile, ESI-HRMS: calcd. for $C_{22}H_{17}N_3 + Na^+$ 346.1315, found 346.1317. 1H NMR (400 MHz, $CDCl_3$) δ 7.32 (m, 5H), 6.25 (s, 1H), 6.18 (d, J = 10.1

Hz, 2H), 5.98 (t, $J = 9.2$ Hz, 1H), 5.89 – 5.77 (m, 1H), 4.45 (d, $J = 8.4$ Hz, 1H), 4.20 (s, 1H), 2.99 (dd, $J = 13.2, 6.0$ Hz, 1H), 2.92 – 2.70 (m, 1H), 2.59 (s, 1H), 2.35 (m, 1H), 2.04 (dd, $J = 13.4, 9.3$ Hz, 1H). ^{13}C NMR (100 MHz, CDCl_3) δ 176.1, 164.3, 136.0, 135.5, 129.3, 128.7, 128.5, 128.3, 128.3, 126.9, 125.0, 124.5, 111.4, 110.7, 83.5, 67.0, 42.6, 42.4, 34.9, 26.9.

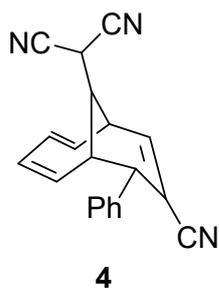


3p

Purification by flash chromatography on silica gel (EtOAc/petroleum ether = 1/15) gave product, white solid, 93% yield, mp = 103–105 °C, $R_f = 0.35$ (EtOAc/petroleum ether = 1/10), 2-((1S,6R,9R)-8-cyano-9-methylbicyclo[4.3.1]deca-2,4,7-trien-10-ylidene)malononitrile, ESI-HRMS: calcd. for $\text{C}_{15}\text{H}_{11}\text{N}_3 + \text{Na}^+$ 256.0845, found 256.0849. ^1H NMR (400 MHz, CDCl_3) δ 6.26 (s, 1H), 6.16 (d, $J = 10.0$ Hz, 1H), 5.98 (t, $J = 8.9$ Hz, 1H), 5.89 – 5.78 (m, 1H), 4.49 (d, $J = 7.3$ Hz, 1H), 3.99 (s, 1H), 2.88 (s, 1H), 1.48 (d, $J = 7.1$ Hz, 1H). ^{13}C NMR (150 MHz, CDCl_3) δ 174.3, 137.7, 129.5, 126.4, 124.9, 120.9, 116.2, 116.1, 110.7, 110.1, 84.1, 47.7, 43.1, 37.8, 16.8.

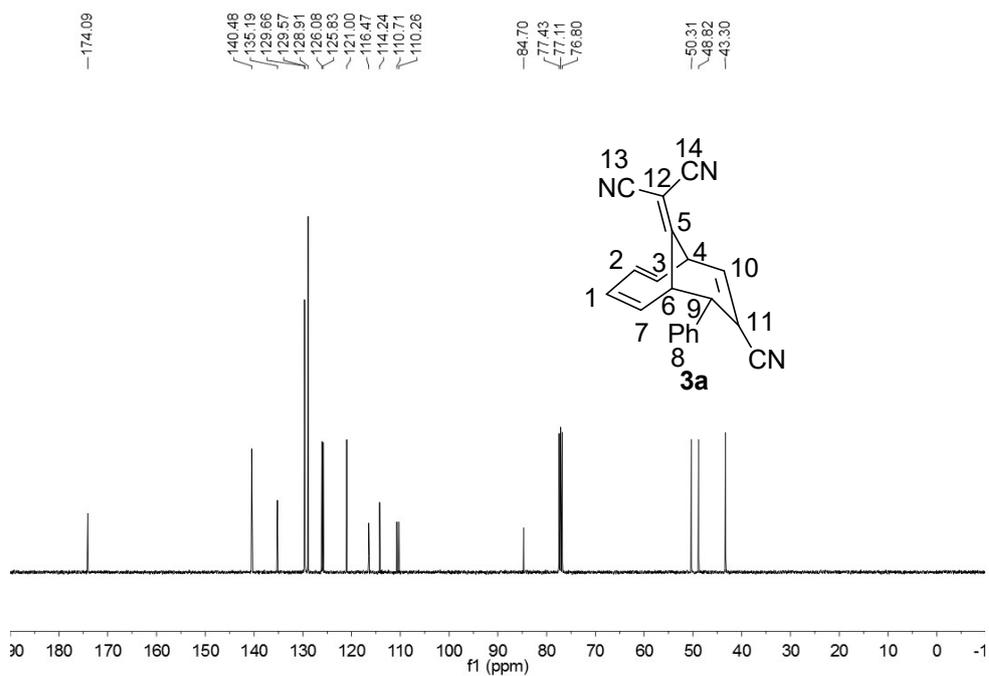
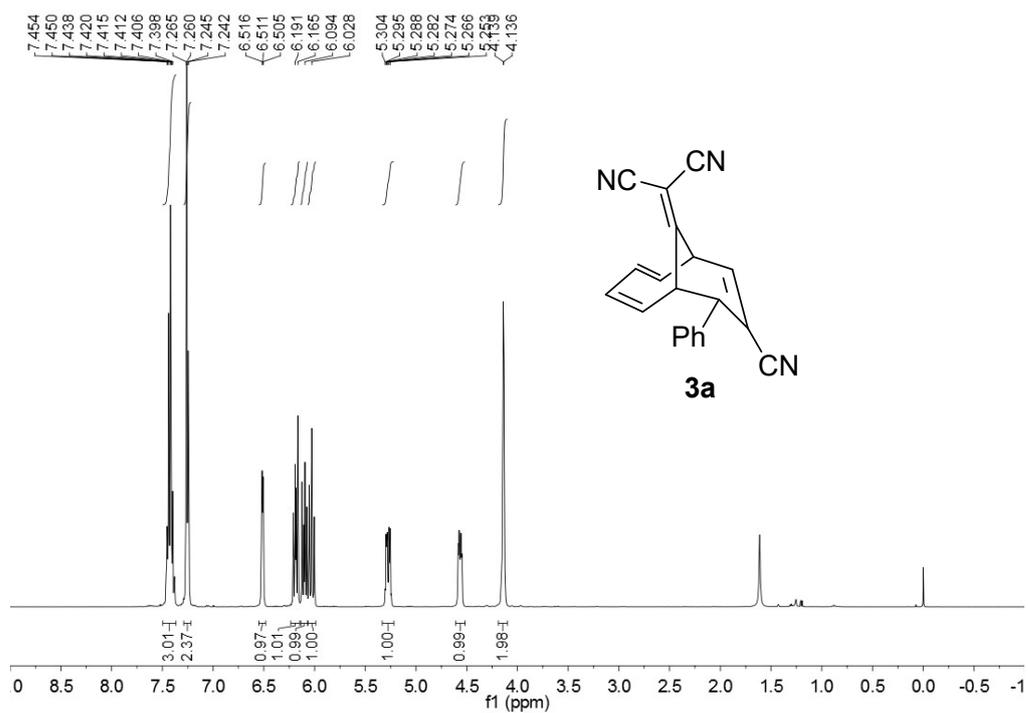
The transformations with the products

Hantzsch ester (253 mg, 1.00 mmol) was added to a stirred solution of product 3a (59 mg, 0.20 mmol) in $\text{CHCl}_3/\text{EtOH}$ (1:1, 10.0 mL). The solution was stirred at 50 °C and monitored by TLC. After 48 h, the mixture was concentrated and purified by flash chromatography on silica gel to give the reduced product, white solid (petroleum ether/EtOAc = 10:1).

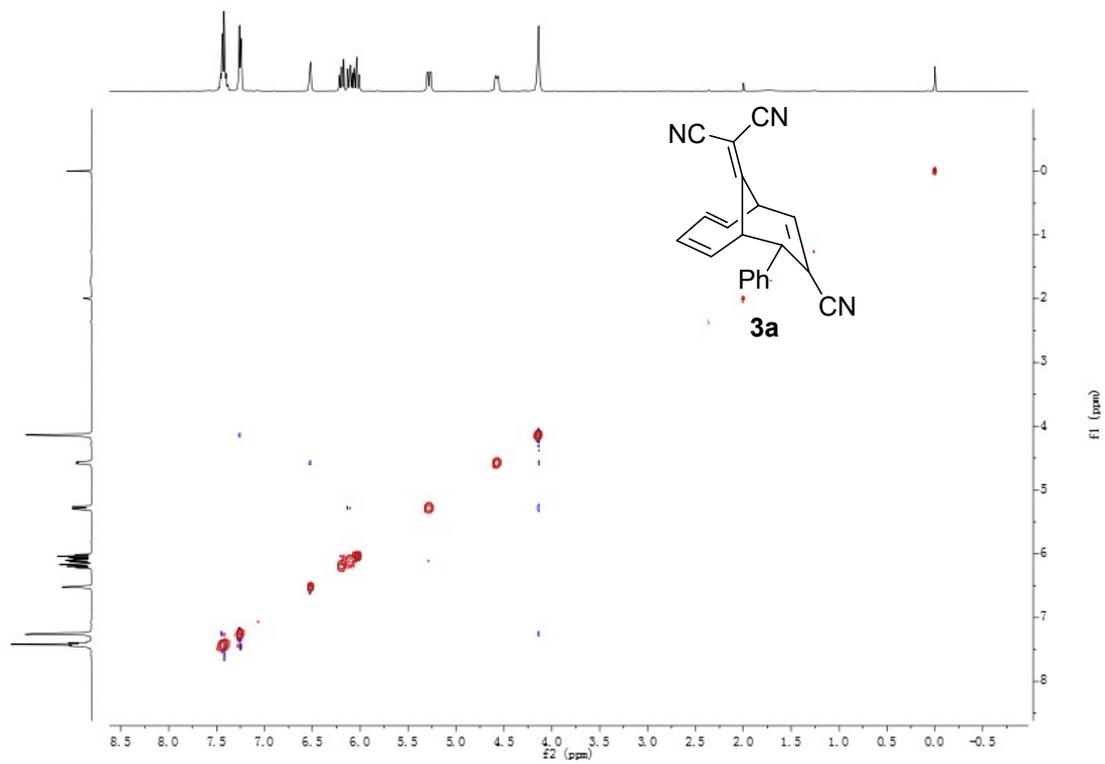


Purification by flash chromatography on silica gel (EtOAc/petroleum ether = 1/10) gave product, white solid, 82% yield. mp = 118–120 °C, R_f = 0.20 (EtOAc/petroleum ether = 1/10), 2-((1R,6S,9S,10R)-8-cyano-9-phenylbicyclo[4.3.1]deca-2,4,7-trien-10-yl)malononitrile, ESI-HRMS: calcd. For $\text{C}_{20}\text{H}_{15}\text{N}_3 + \text{Na}^+$ 320.1158, found 320.1163. ^1H NMR (400 MHz, CDCl_3) δ 7.45–7.30 (m, 3H), 7.19 (d, J = 6.9 Hz, 2H), 6.65 (dd, J = 5.2, 2.5 Hz, 1H), 6.21 (dd, J = 10.8, 7.6 Hz, 1H), 6.04 (dd, J = 12.3, 7.5 Hz, 1H), 5.96–5.82 (m, 1H), 5.18 (dd, J = 12.3, 6.5 Hz, 1H), 4.11–3.99 (m, 1H), 3.75 (dd, J = 5.4, 2.5 Hz, 1H), 3.62 (d, J = 11.8 Hz, 1H), 3.23 (s, 1H), 2.97 (d, J = 7.3 Hz, 1H). ^{13}C NMR (150 MHz, CDCl_3) δ 142.92, 137.39, 131.44, 130.37, 129.37, 128.59, 128.20, 126.62, 124.78, 117.24, 114.06, 111.62, 111.41, 50.24, 42.23, 38.09, 24.60.

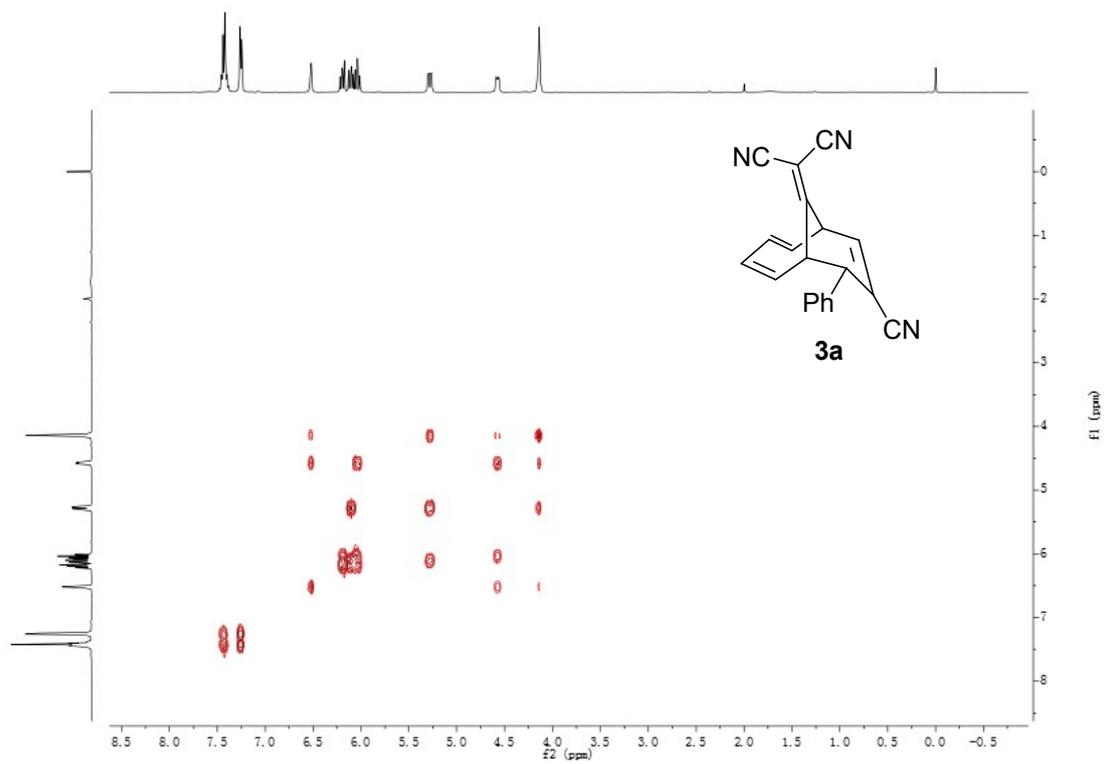
^1H and ^{13}C NMR and 2D Spectra of All Products



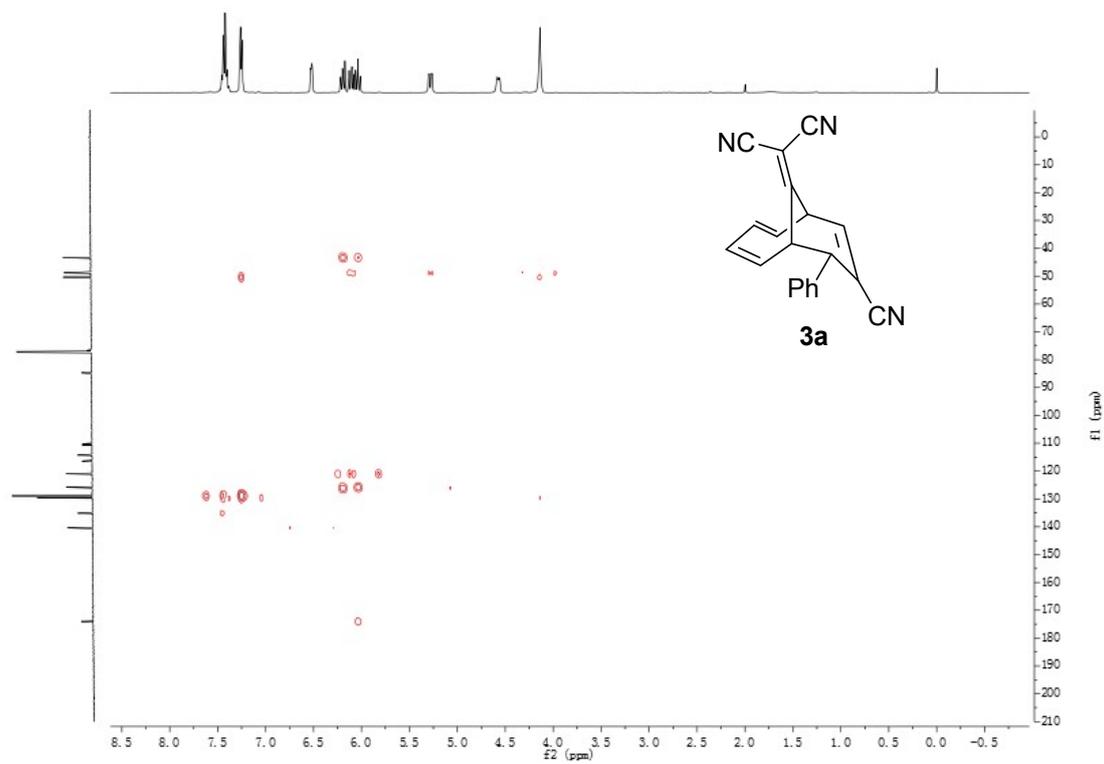
NOE of 3a



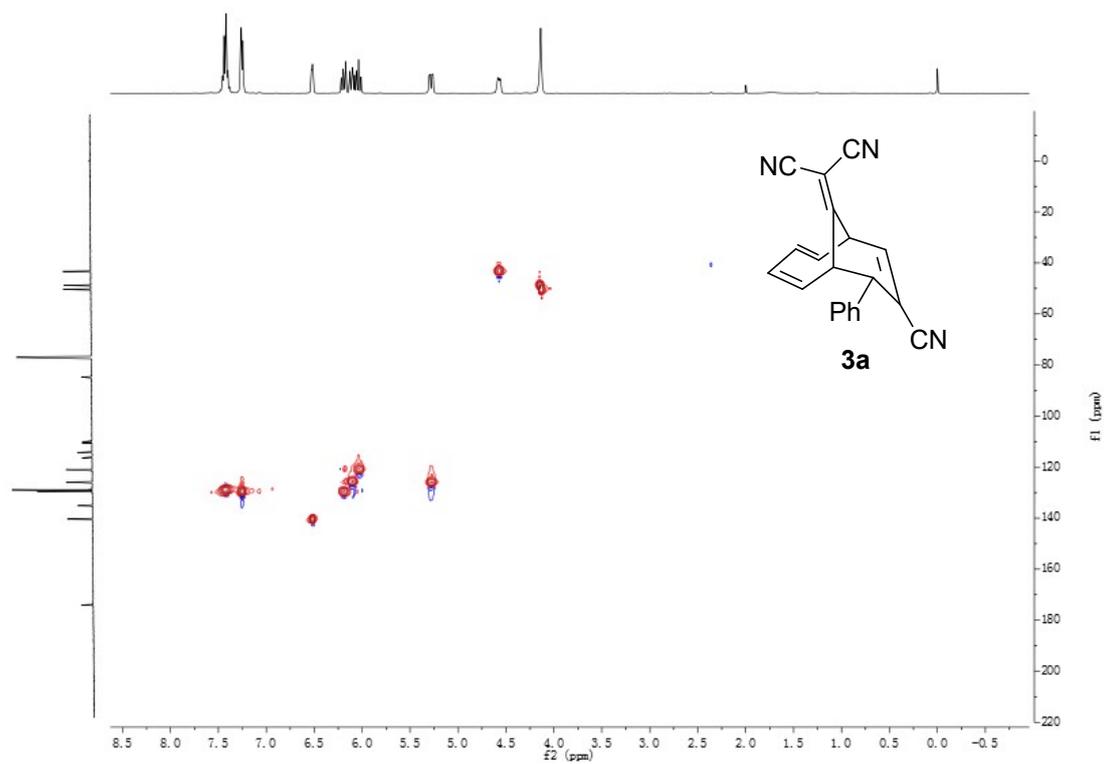
COSY of 3a

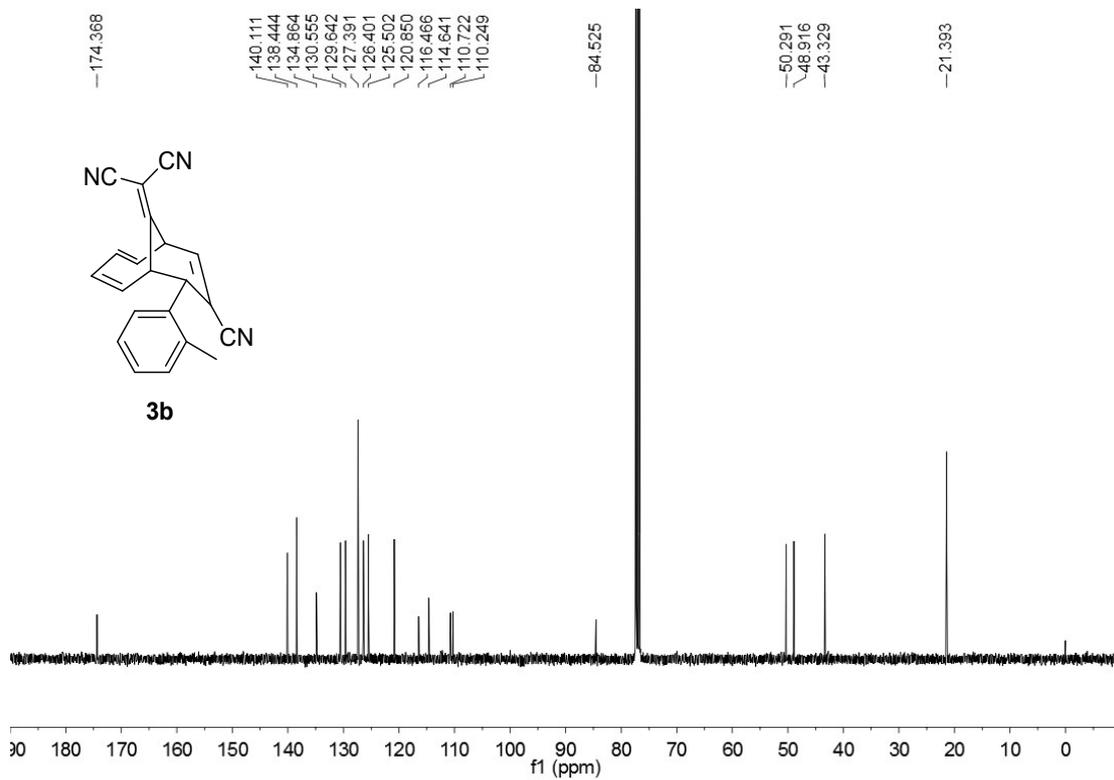
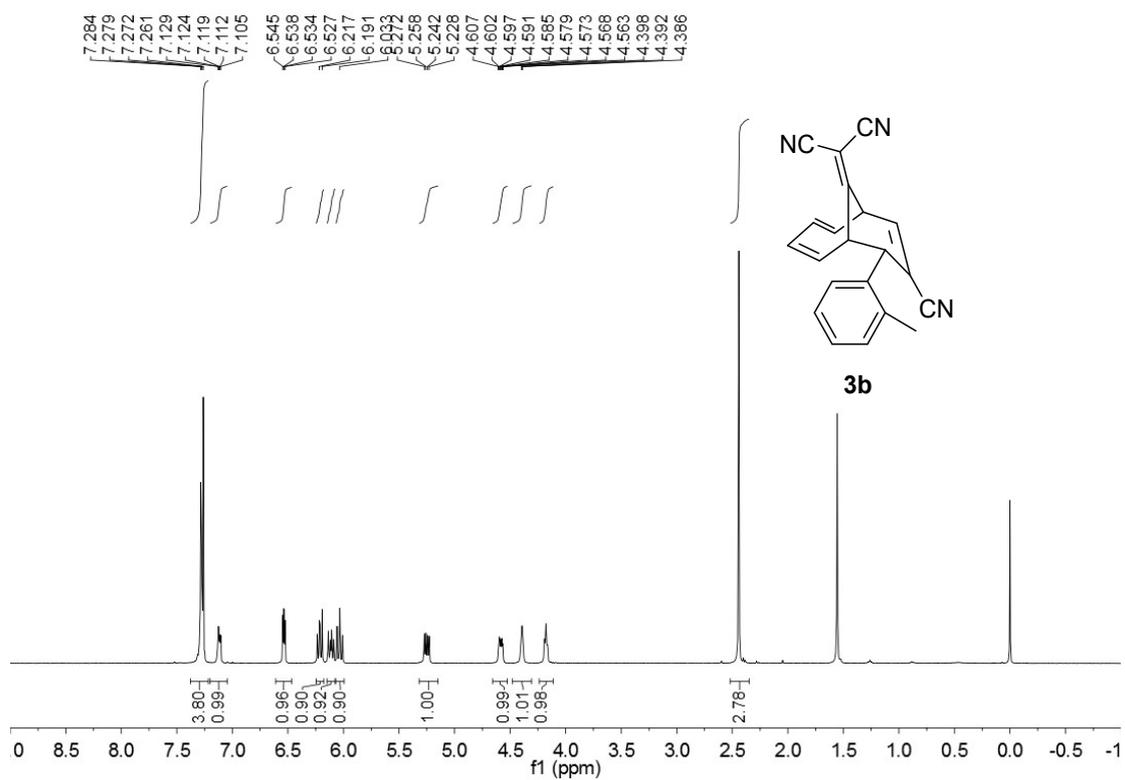


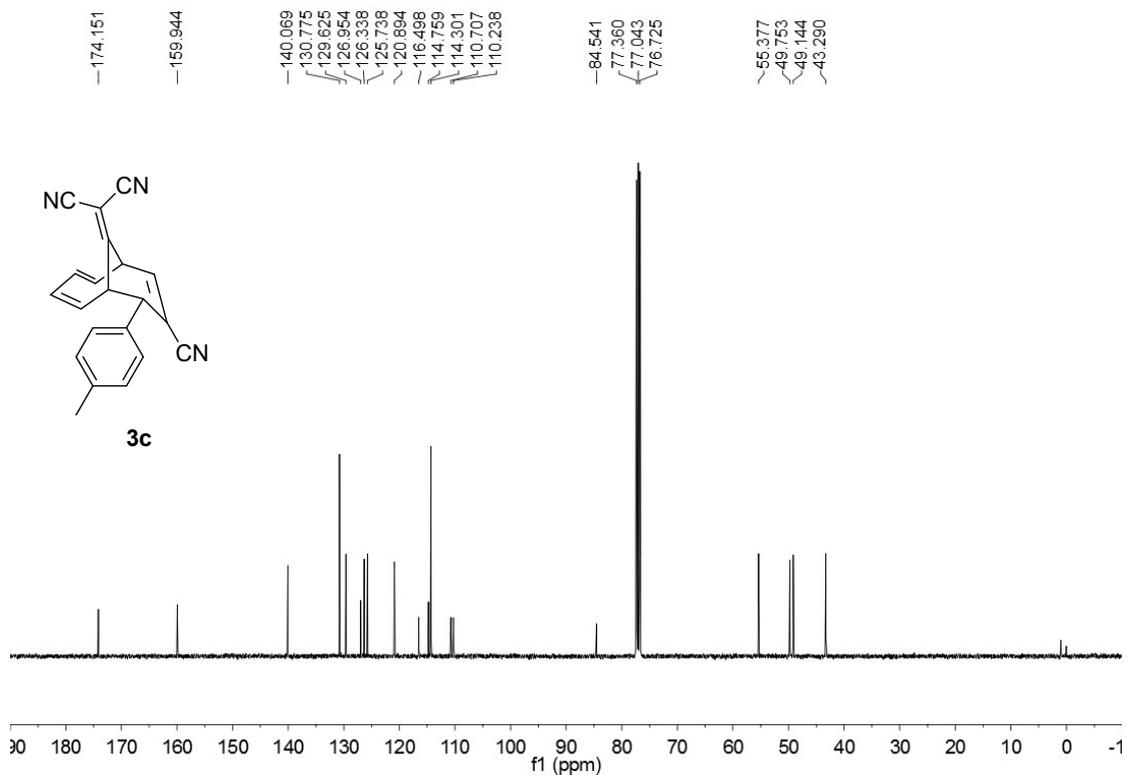
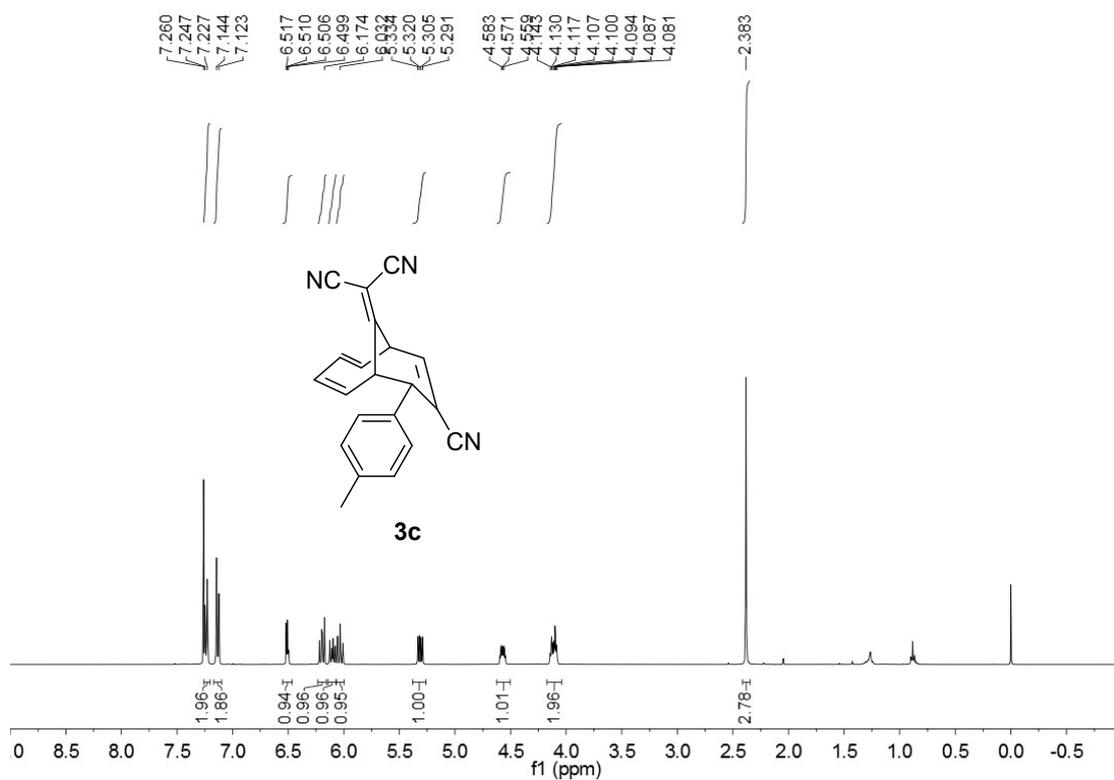
HMBC of 3a

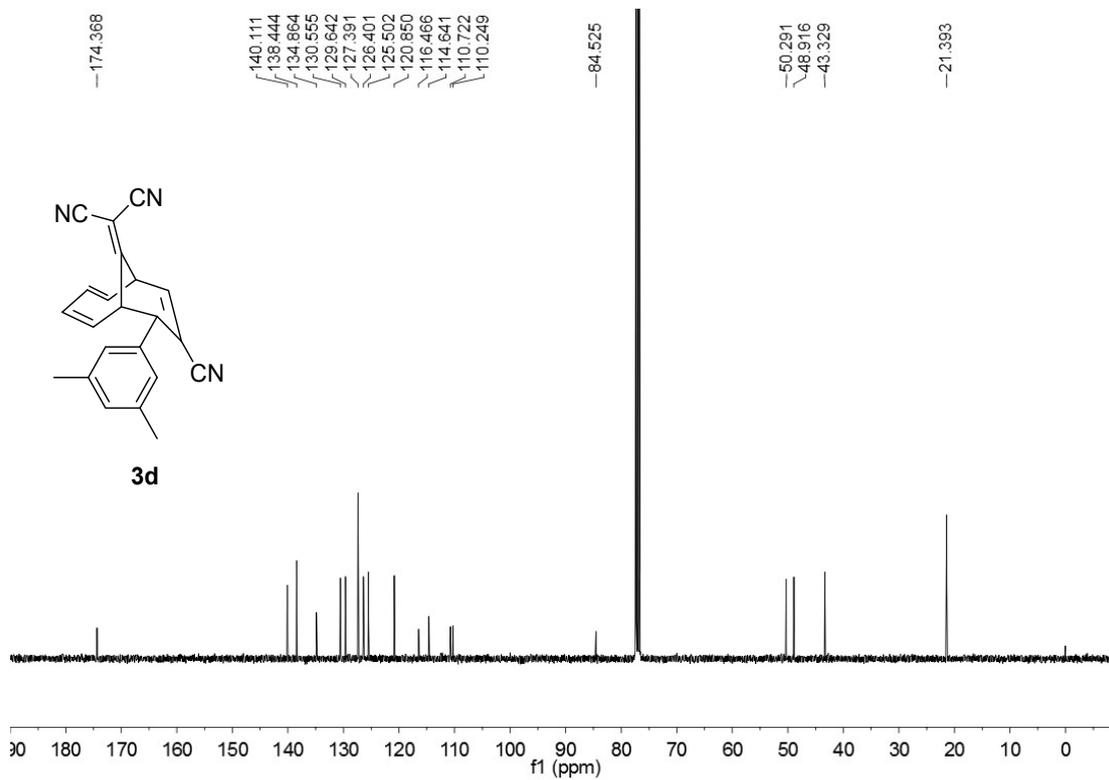
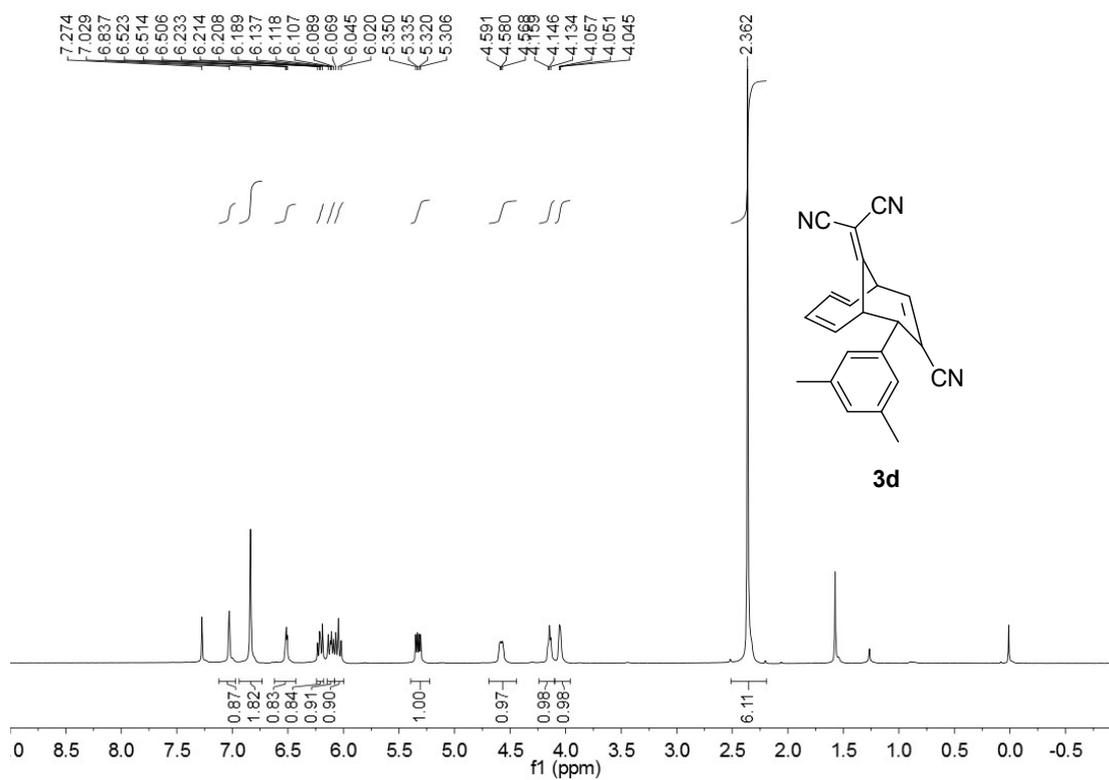


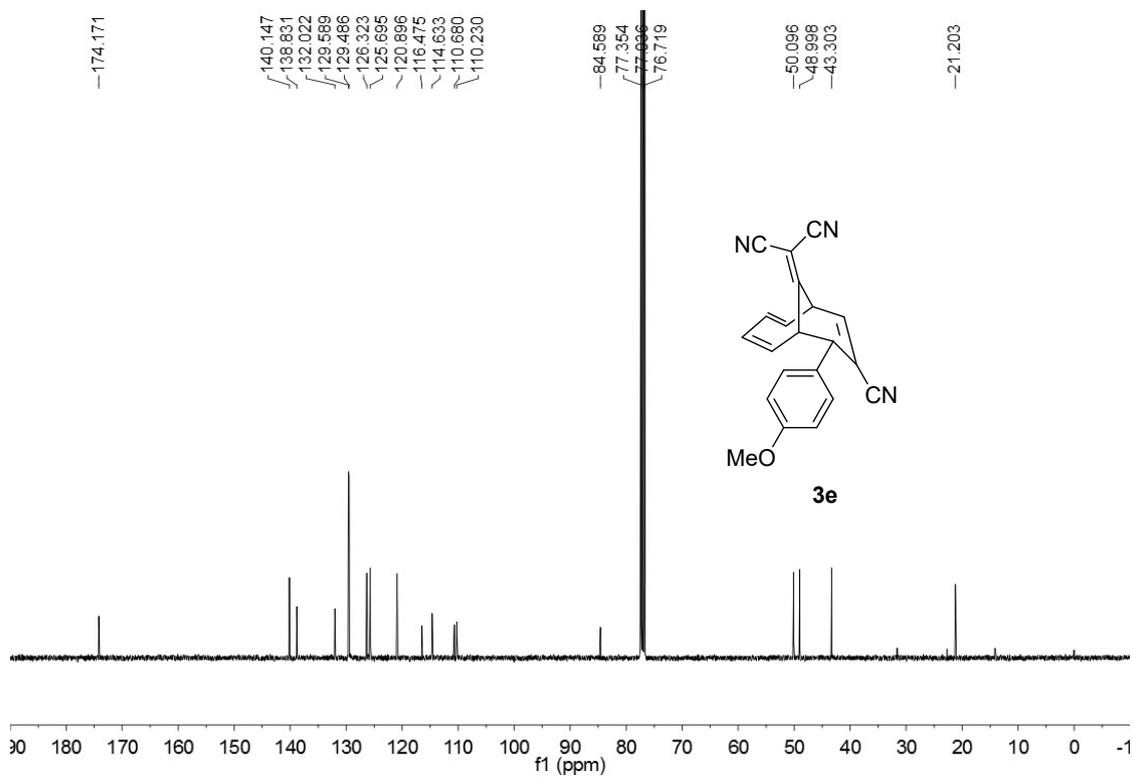
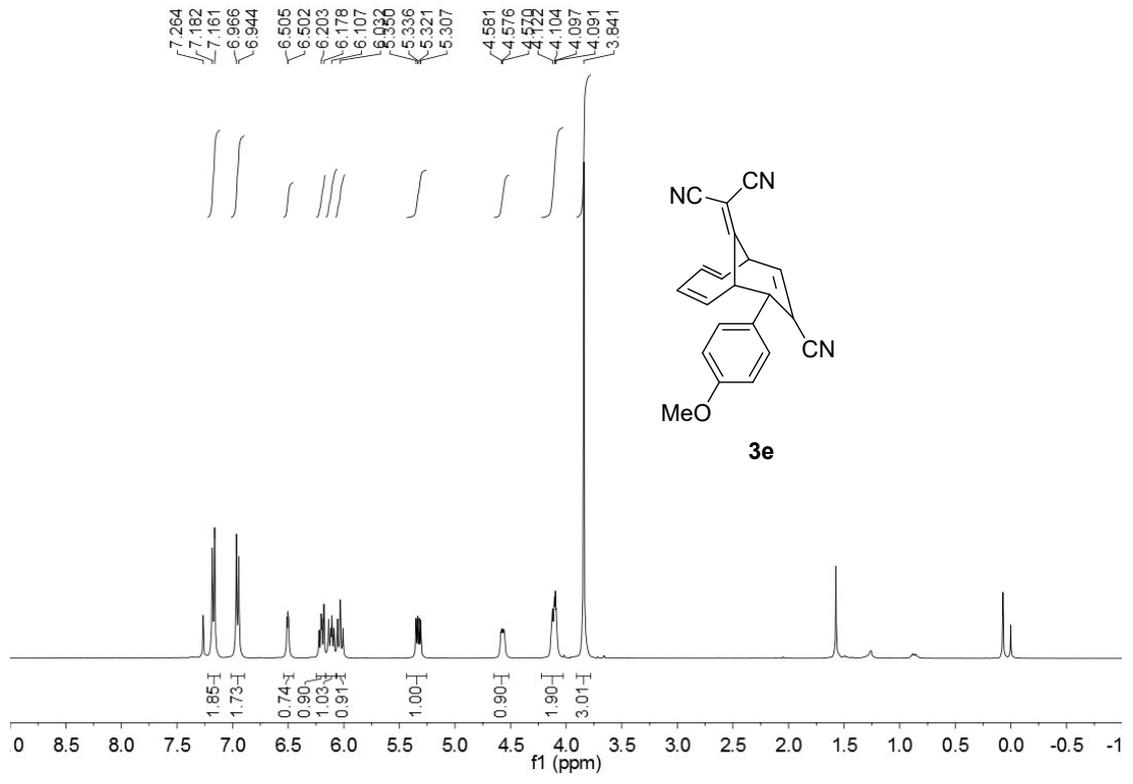
HSQC of 3a

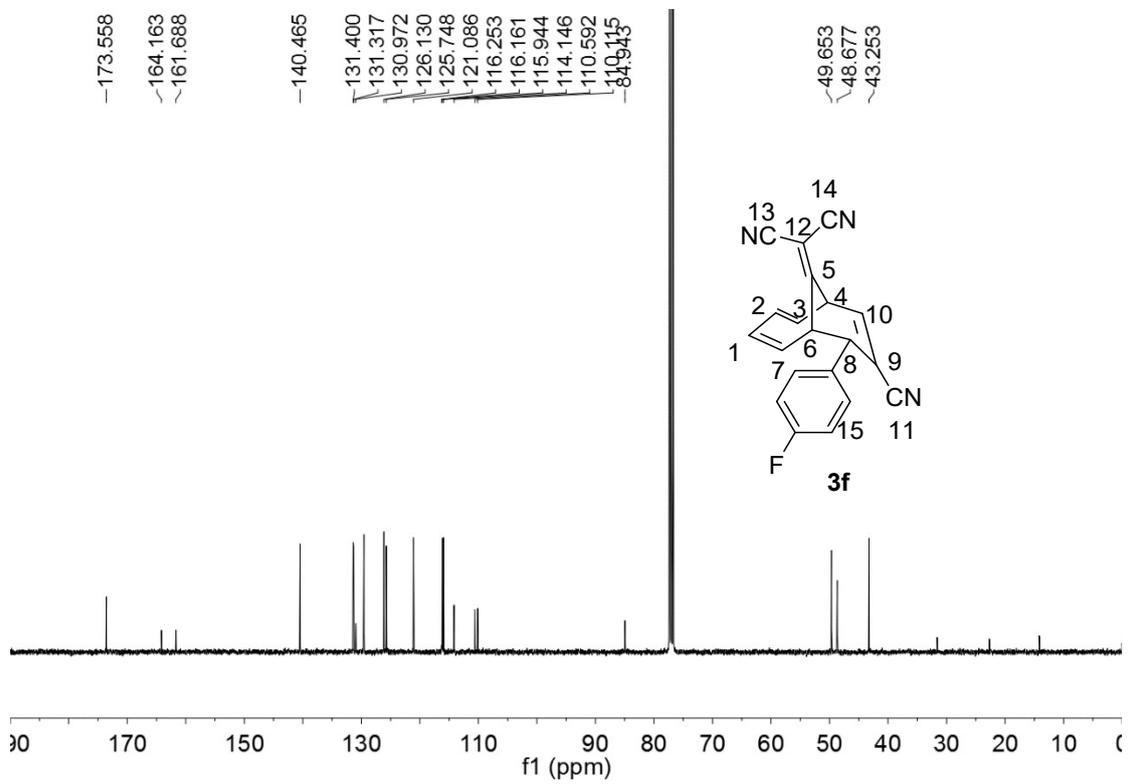
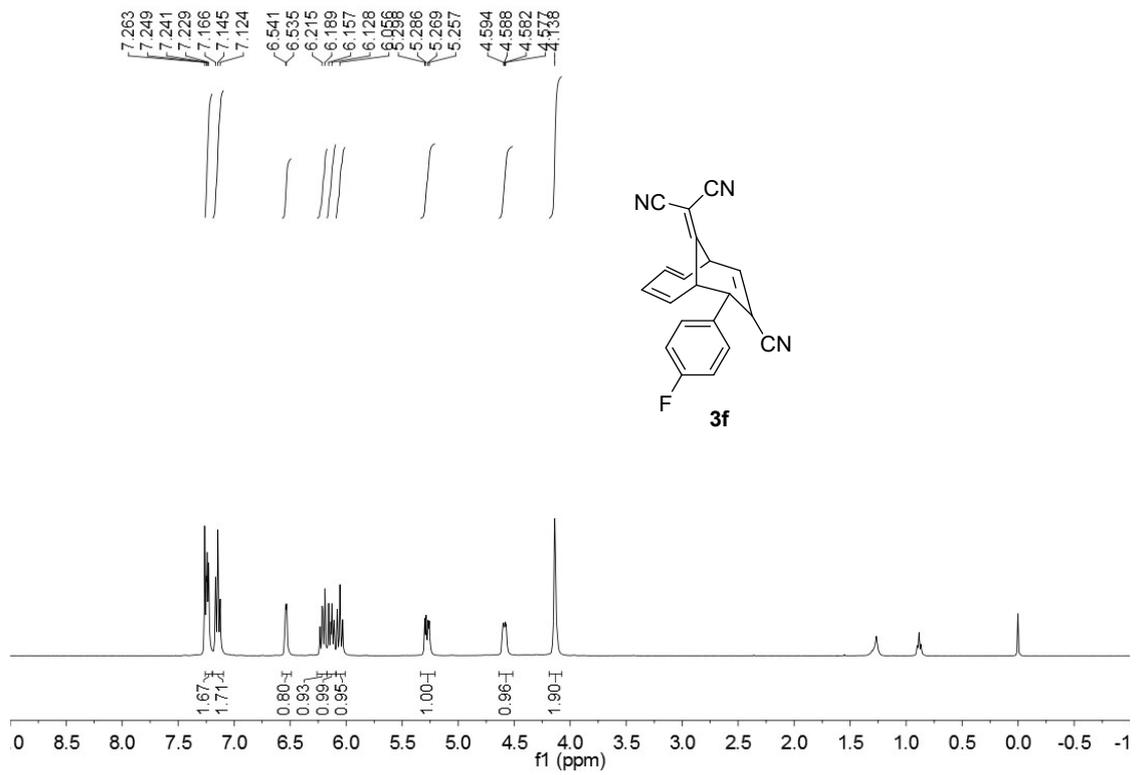




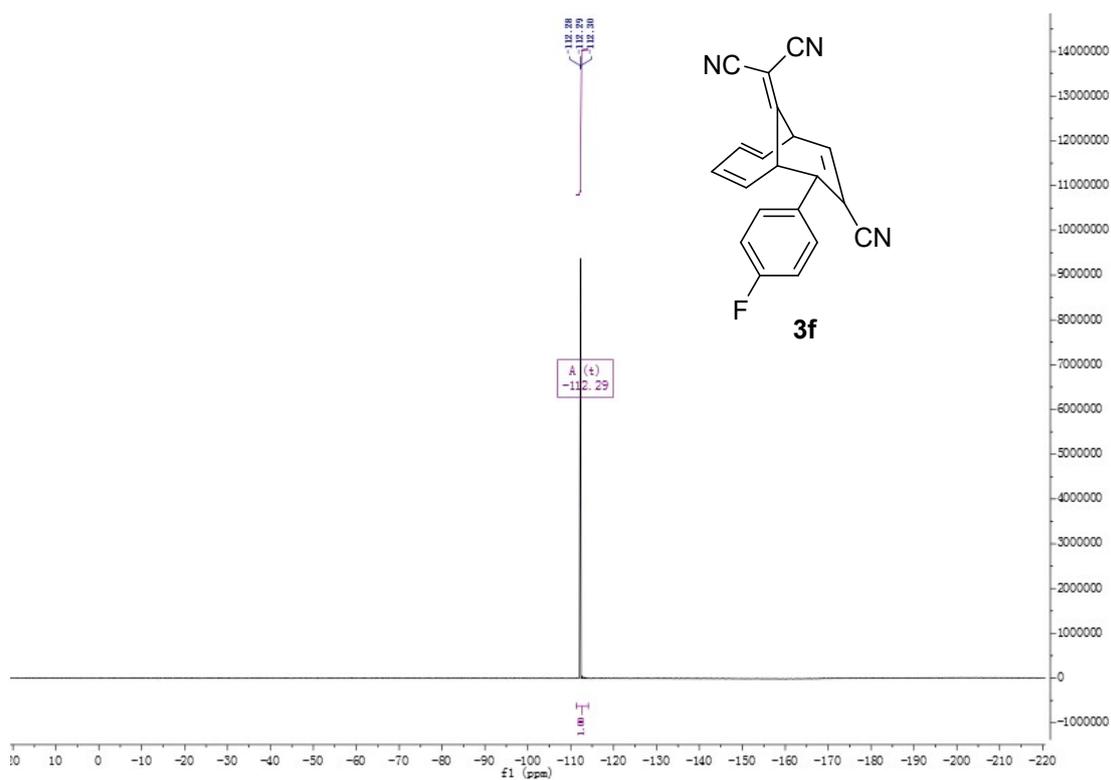




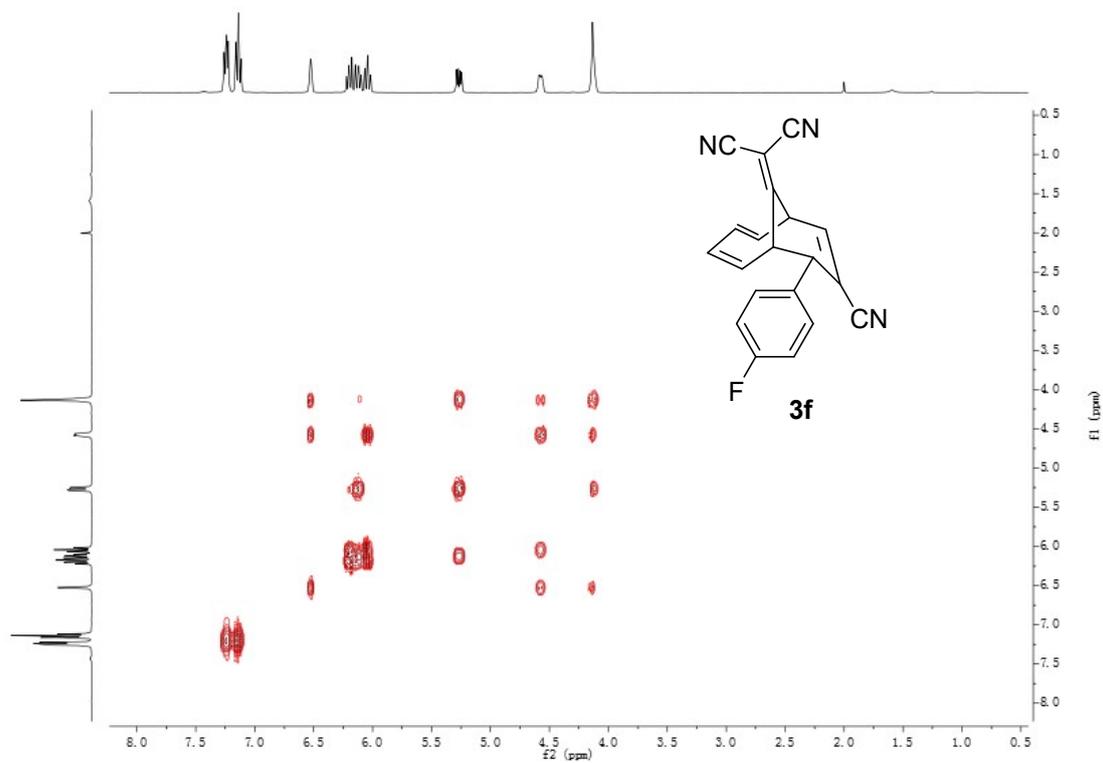




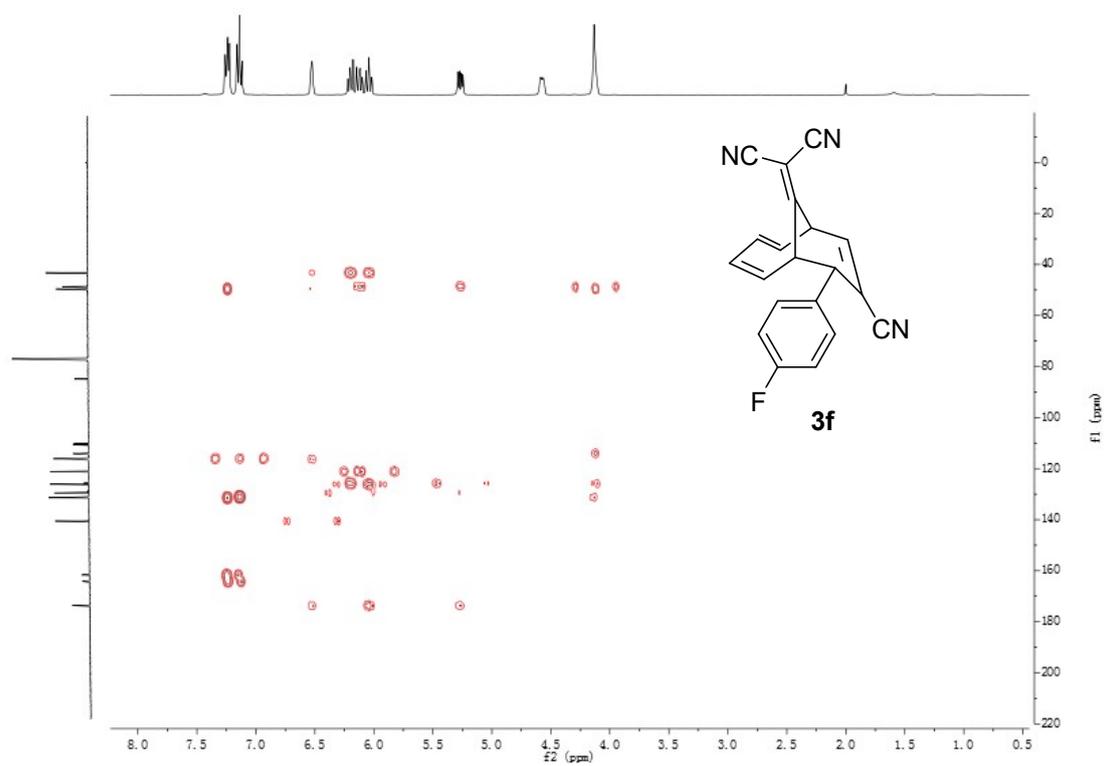
¹⁹F of 3f



COSY of 3f



HMBC OF 3f



HSQC of 3f

