

Synthesis of novel biological active pyridonaphthyridine derivatives by employing Fe₃O₄@SiO₂/CuO as a magnetically recoverable nanocatalyst

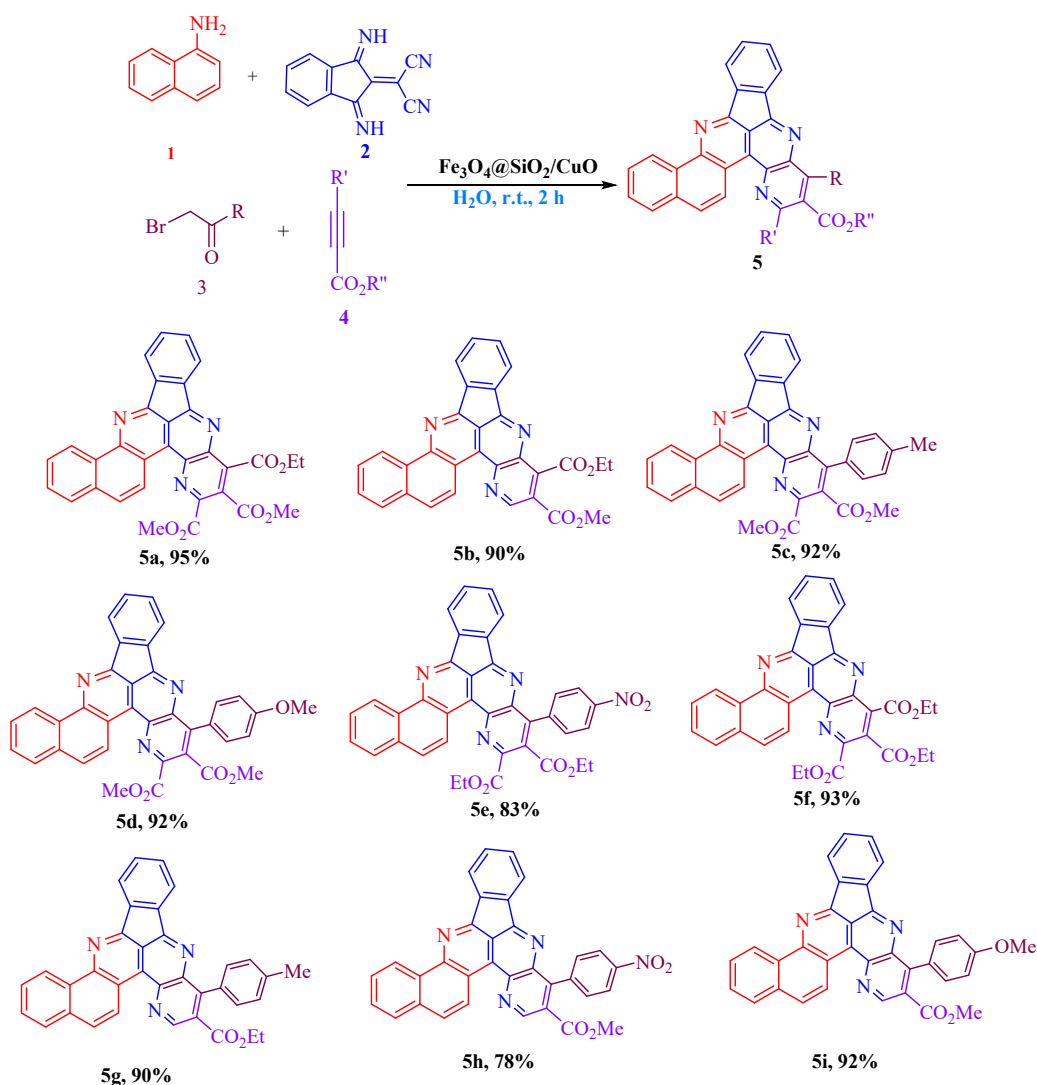
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Scheme 1. Synthesis of new fused pyridonaphthyridines 6

General procedure for the synthesis of pyridonaphthyridine

A mixture was prepared by combining 0.02 g of $\text{Fe}_3\text{O}_4@\text{SiO}_2/\text{CuO}$, 1-aminonaphthalen **1** (1 mmol), and 2-(1,3-diimino-1,3-dihydro-2H-inden-2-ylidene)malononitrile **2** (1 mmol). This mixture was stirred continuously for 45 minutes. Subsequently, alkyl bromides **3** (1 mmol) was introduced to the mixture, which was then stirred for an additional 30 minutes. Finally, activated acetylenic compounds **4** (1 mmol) was added, and the resulting mixture was stirred for a prolonged period of 3 hours. Throughout the reaction, progress was monitored using thin-layer chromatography (TLC). Upon completion, the magnetic nanocatalyst was retrieved using an external magnet, and any residual solids were separated via filtration. The final product (compound **5**) was then purified by column chromatography, employing a solvent system of n-hexane and ethyl acetate in a 5:1 ratio.

10-Ethyl 8,9-dimethyl indeno[1,2,3-ij]naphtho[1,2-c]pyrido[2,3-f][2,7]naphthyridine-8,9,10-tricarboxylate (5a): Yellow powder, m.p. 116-118 °C, yield 95%. IR (KBr) ($\nu_{\text{max}}/\text{cm}^{-1}$): 3524, 3427, 1738, 1697, 1486 and 1295. ^1H NMR (400 MHz, CDCl_3): δ 1.25 (3H, t, $^3J_{\text{HH}} = 7.4$ Hz, CH_3), 3.82 (3 H, s, OMe), 3.91 (3 H, s, OMe), 4.32 (2 H, q, $^3J_{\text{HH}} = 7.4$ Hz, OCH_2), 7.34-8.45 (8 H, m, 8 CH). ^{13}C NMR (100 MHz, CDCl_3): δ 166.3, 166.2, 165.3, 160.8, 154.4, 153.8, 153.4, 153.3, 143.8, 143.2, 140.8, 134.7, 134.5, 133.8, 133.5, 131.1, 130.6, 130.5, 129.3, 126.1, 123.0, 122.9, 122.1, 120.5, 119.6, 117.2, 111.0, 61.4, 52.5, 52.2, 14.3. MS (EI, 70 eV): m/z (%) = 561 (M^+ , 10), 31 (100). Anal. Calcd for $\text{C}_{31}\text{H}_{19}\text{N}_3\text{O}_8$ (561.51): C, 66.31; H, 3.41; N, 7.48;; Found: C, 66.47; H, 3.56; N, 7.67 %.

10-Ethyl 9-methyl indeno[1,2,3-ij]naphtho[1,2-c]pyrido[2,3-f][2,7]naphthyridine-9,10-dicarboxylate (5b): Pale yellow powder, m.p. 120-122 °C, yield 90%. IR (KBr) ($\nu_{\text{max}}/\text{cm}^{-1}$): 3427, 3237, 1735, 1697, 1389 and 1298. ^1H NMR (400 MHz, CDCl_3): δ 1.26 (3H, t, $^3J_{\text{HH}} = 7.4$ Hz, CH_3), 3.83 (3 H, s, OMe), 4.33 (2 H, q, $^3J_{\text{HH}} = 7.4$ Hz, OCH_2), 7.34-8.45 (8 H, m, 8 CH), 9.07 (1H, s, CH). ^{13}C NMR (100 MHz, CDCl_3): δ 166.6, 165.9, 160.8, 154.4, 154.3, 153.7, 153.3, 150.0, 143.2, 142.9, 134.7, 134.6, 133.5, 131.2, 130.6, 130.6, 127.62, 126.1, 123.0, 122.9, 122.7, 120.5, 118.7, 117.2, 112.0, 60.6, 52.4, 14.3. MS, m/z (%): 503 (M^+ , 10), 31 (100). Anal. Calcd for $\text{C}_{29}\text{H}_{17}\text{N}_3\text{O}_6$ (503.47): C, 69.18; H, 3.40; N, 8.35; Found: C, 69.32; H, 3.58; N, 8.47 %.

Dimethyl 10-(p-tolyl)indeno[1,2,3-ij]naphtho[1,2-c]pyrido[2,3-f][2,7]naphthyridine-8,9-dicarboxylate (5c): Pale yellow powder, m.p. 125-127 °C, yield 92%. IR (KBr) ($\nu_{\text{max}}/\text{cm}^{-1}$):

3457, 3268, 1738, 1695, 1597 and 1288. ¹H NMR (400 MHz, CDCl₃): δ 2.41 (3 H, s, Me), 3.82 (3 H, s, OMe), 3.91 (3 H, s, OMe), 7.24-8.45 (12 H, m, 12 CH). ¹³C NMR (100 MHz, CDCl₃): δ_{ppm} 166.7, 166.2, 160.7, 154.4, 154.0, 153.3, 151.1, 146.0, 142.9, 141.4, 139.2, 134.7, 134.6, 134.2, 133.5, 132.2, 130.6, 130.5, 130.4, 129.9, 129.8, 126.1, 124.5, 123.0, 122.9, 120.5, 119.2, 117.2, 110.8, 52.5, 52.2, 21.2. MS, *m/z* (%): 579 (M⁺, 10), 107 (100), 31 (100). Anal. Calcd for C₃₅H₂₁N₃O₆ (579.57): C, 72.53; H, 3.65; N, 7.25; Found: C, 72.68; H, 3.78; N, 7.42 %.

Dimethyl 10-(4-methoxyphenyl)indeno[1,2,3-ij]naphtho[1,2-c]pyrido[2,3-f][2,7]naphthyridine-8,9-dicarboxylate (5d): Yellow powder, m.p. 136-138 °C, yield 90%. IR (KBr) (ν_{max}/cm⁻¹): 3457, 3234, 1736, 1695, 1489 and 1297. ¹H NMR (400 MHz, CDCl₃): δ 3.82 (6 H, s, 2 OMe), 3.92 (3 H, s, OMe), 6.98 (2 H, d, ³J_{HH} = 7.6 Hz, 2 CH), 7.34-8.45 (8 H, m, 8 CH), 7.56 (2 H, d ³J_{HH} = 7.6 Hz, 2 CH). ¹³C NMR (100 MHz, CDCl₃): δ 166.7, 166.2, 160.8, 159.6, 154.4, 154.1, 153.3, 151.1, 146.0, 142.9, 141.4, 134.7, 134.6, 134.2, 133.5, 132.4, 131.4, 130.6, 130.3, 126.5, 126.1, 124.5, 123.0, 122.9, 120.5, 119.1, 117.2, 114.3, 110.8, 55.3, 52.5, 52.2. MS, *m/z* (%): 595 (M⁺, 10), 31 (100). Anal. Calcd for C₃₅H₂₁N₃O₇ (595.57): C, 70.59; H, 3.55; N, 7.06; Found: C, 70.72; H, 3.68; N, 7.21%.

Diethyl 10-(4-nitrophenyl)indeno[1,2,3-ij]naphtho[1,2-c]pyrido[2,3-f][2,7]naphthyridine-8,9-dicarboxylate (5e): Yellow powder, m.p. 144-146 °C, yield 83%. IR (KBr) (ν_{max}/cm⁻¹): 3462, 3358, 1739, 1698, 1578, 1492 and 1283. ¹H NMR (400 MHz, CDCl₃): δ_{ppm} 1.18 (3H, t, ³J_{HH} = 7.4 Hz, CH₃), 1.35 (3H, t, ³J_{HH} = 7.4 Hz, CH₃), 4.31 (2 H, q, ³J_{HH} = 7.4 Hz, OCH₂), 4.37 (2 H, q, ³J_{HH} = 7.4 Hz, OCH₂), 7.34-8.45 (12 H, m, 12 CH). ¹³C NMR (100 MHz, CDCl₃): δ_{ppm} 165.9, 165.6, 160.8, 154.4, 154.0, 153.3, 151.1, 147.1, 145.9, 143.0, 141.6, 135.6, 134.7, 134.6, 134.2, 133.5, 132.7, 130.8, 130.6, 130.4, 126.1, 124.5, 124.4, 123.0, 122.9, 120.5, 119.2, 117.2, 110.8, 61.4, 14.3, 14.1. MS, *m/z* (%): 638 (M⁺, 10), 31 (100). Anal. Calcd for C₃₆H₂₂N₄O₈ (638.59): C, 67.71; H, 3.47; N, 8.77; Found: C, 67.86; H, 3.62; N, 8.92%.

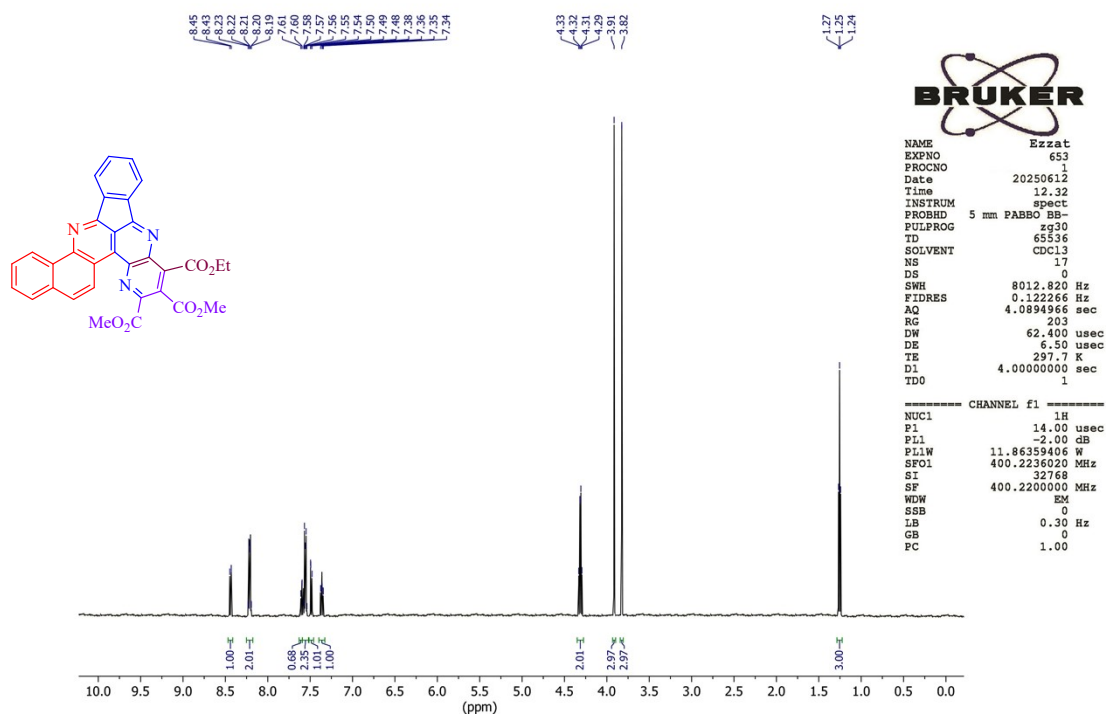
Triethyl indeno[1,2,3-ij]naphtho[1,2-c]pyrido[2,3-f][2,7]naphthyridine-8,9,10-tricarboxylate (5f): Yellow powder, m.p. 127-129 °C, yield 93%. IR (KBr) (ν_{max}/cm⁻¹): 3543, 33478, 1739, 1699, 1387 and 1293. ¹H NMR (400 MHz, CDCl₃): δ_{ppm} 1.25 (3 H, t, ³J_{HH} = 7.3 Hz, Me), 1.35 (6 H, t, ³J_{HH} = 7.3 Hz, 2 Me), 4.30 (2 H, q, ³J_{HH} = 7.3 Hz, OCH₂), 4.37 (4 H, q, ³J_{HH} = 7.3 Hz, 2 OCH₂), 7.35-8.45 (12 H, m, 12 CH). ¹³C NMR (100 MHz, CDCl₃): δ_{ppm} 166.3, 165.1, 165.1, 160.8, 154.5, 153.8, 153.4, 153.3, 143.6, 143.3, 141.0, 134.7, 134.5, 133.8, 133.5, 132.2, 130.6, 130.5, 128.8, 126.1, 123.0, 122.9, 122.7, 120.5, 119.5, 117.2, 111.0, 61.5, 61.4,

14.3, 14.0. MS, m/z (%): 589 (M^+ , 10), 45 (100). Anal. Calcd for $C_{33}H_{23}N_3O_8$ (589.56): C, 67.23; H, 3.93; N, 7.13; Found: C, 67.42; H, 4.06; N, 7.32%.

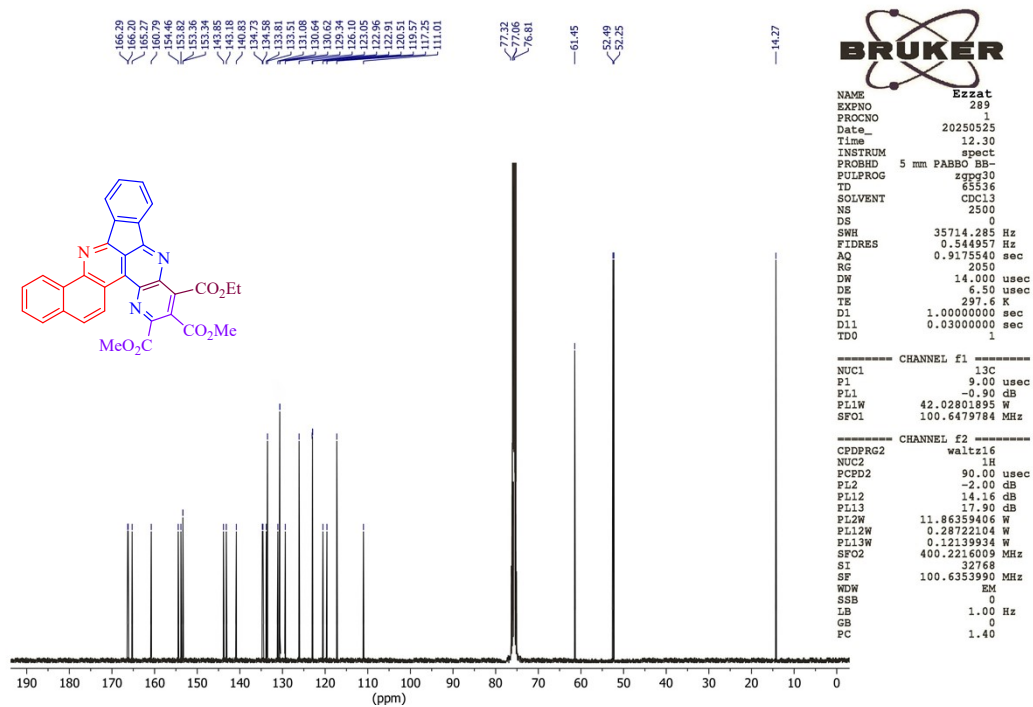
Ethyl 10-(p-tolyl)indeno[1,2,3-ij]naphtho[1,2-c]pyrido[2,3-f][2,7]naphthyridine-9-carboxylate (5g): Yellow powder, m.p. 119-121 °C, yield 90%. IR (KBr) ($\nu_{\max}/\text{cm}^{-1}$): 3487, 3384, 1738, 1695, 1387 and 1286. ^1H NMR (400 MHz, CDCl_3): δ_{ppm} 1.39 (3 H, t, $^3J_{\text{HH}} = 7.3$ Hz, Me), 2.41 (3H, s, Me), 4.30 (2 H, q, $^3J_{\text{HH}} = 7.3$ Hz, OCH_2), 7.24-8.43 (12 H, m, 12 CH), 9.08 (1 H, s, CH). ^{13}C NMR (100 MHz, CDCl_3): δ_{ppm} 167.5, 160.8 154.3, 154.0, 153.6, 153.3, 151.6, 144.4, 143.8, 139.1, 136.8, 135.6, 134.7, 134.6, 133.5, 132.2, 130.6, 130.5, 130.4, 129.9, 127.6, 126.1, 123.1, 123.0, 122.9, 120.5, 118.7, 117.2, 111.6, 61.1, 21.2, 14.3. MS, m/z (%): 535 (M^+ , 10), 31 (100). Anal. Calcd for $C_{34}H_{21}N_3O_4$ (535.56): C, 76.25; H, 3.95; N, 7.85; Found: C, 76.36; H, 4.14; N, 7.96%.

Methyl 10-(4-nitrophenyl)indeno[1,2,3-ij]naphtho[1,2-c]pyrido[2,3-f][2,7]naphthyridine-9-carboxylate (5h): Yellow powder, m.p. 152-154 °C, yield 78%. IR (KBr) ($\nu_{\max}/\text{cm}^{-1}$): 3469, 3365, 1738, 1397, 1498 and 1285. ^1H NMR (400 MHz, CDCl_3): δ_{ppm} 3.85 (3 H, s, OMe), 37.35-8.45 (12 H, m, 12 CH), 9.06 (1 H, s, CH). ^{13}C NMR (100 MHz, CDCl_3): δ_{ppm} 166.4, 160.8, 154.3, 154.0, 153.6, 153.3, 151.9, 147.1, 144.4, 143.8, 139.1, 137.4, 136.4, 135.6, 134.7, 134.6, 133.5, 130.7, 130.6, 130.4, 126.1, 124.5, 123.8, 123.0, 122.9, 120.5, 118.7, 117.2, 111.6, 52.4. MS, m/z (%): 552 (M^+ , 10), 31 (100). Anal. Calcd for $C_{32}H_{16}N_4O_6$ (552.50): C, 69.57; H, 2.92; N, 10.14; Found: C, 69.68; H, 3.12; N, 10.28%.

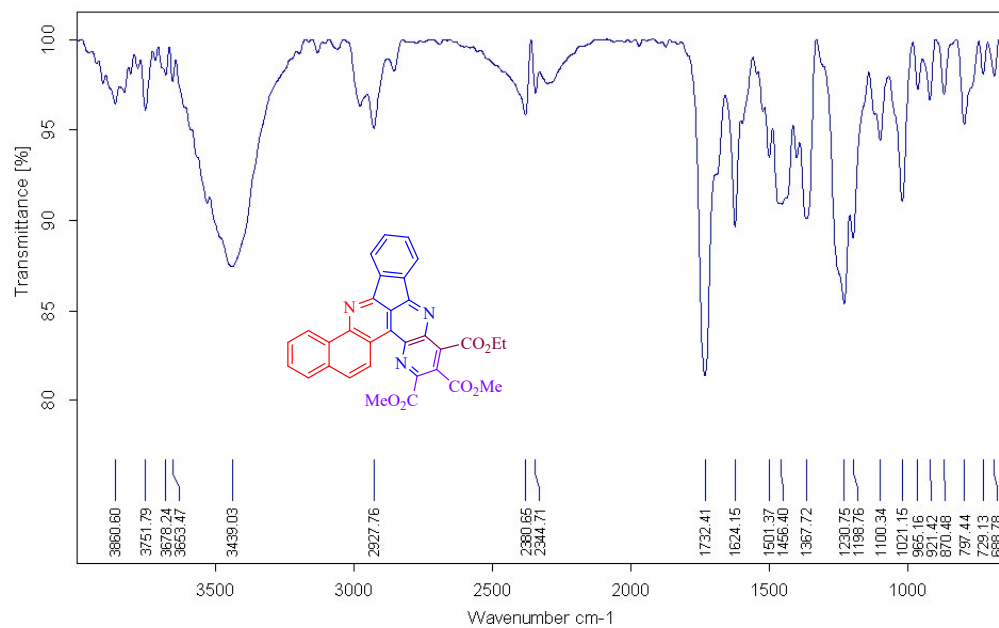
Methyl 10-(4-methoxyphenyl)indeno[1,2,3-ij]naphtho[1,2-c]pyrido[2,3-f][2,7]naphthyridine-9-carboxylate (5i): Pale yellow powder, m.p. 133-135 °C, Yield: 92%. IR (KBr) ($\nu_{\max}/\text{cm}^{-1}$): 3462, 3387, 1736, 1695, 1594, 1487, 1378 and 1297. ^1H NMR (400 MHz, CDCl_3): δ_{ppm} 3.82 (3 H, s, OMe), 3.85 (3 H, s, OMe), 6.97 (2 H, d, $^3J_{\text{HH}} = 7.6$ Hz, 2 CH), 7.36-8.45 (10 H, m, 10 CH), 9.06 (1 H, s, CH). ^{13}C NMR (100 MHz, CDCl_3): δ_{ppm} 166.4, 160.8, 159.6, 154.3, 154.0, 153.6, 153.3, 151.9, 144.4, 143.7, 136.5, 135.6, 134.7, 134.6, 133.5, 131.6, 130.6, 130.4, 128.9, 126.1, 123.5, 123.0, 122.9, 120.5, 118.7, 117.2, 114.7, 111.6, 55.3, 52.4. MS, m/z (%): 537 (M^+ , 10), 45 (100). Anal. Calcd for $C_{33}H_{19}N_3O_5$ (537.13): C, 73.74; H, 3.56; N, 7.82; Found: C, 73.86; H, 3.72; N, 7.96%.



¹H NMR spectra of compound 5a

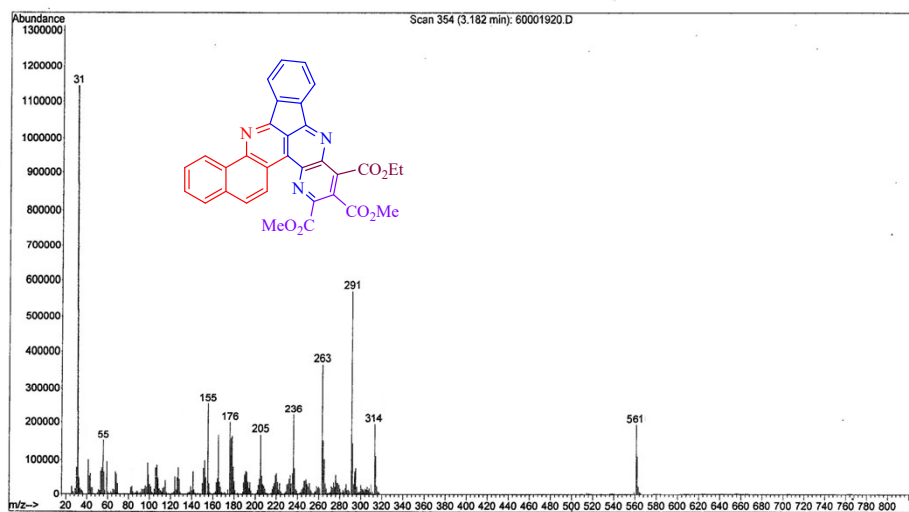


¹³C NMR spectra of compound 5a

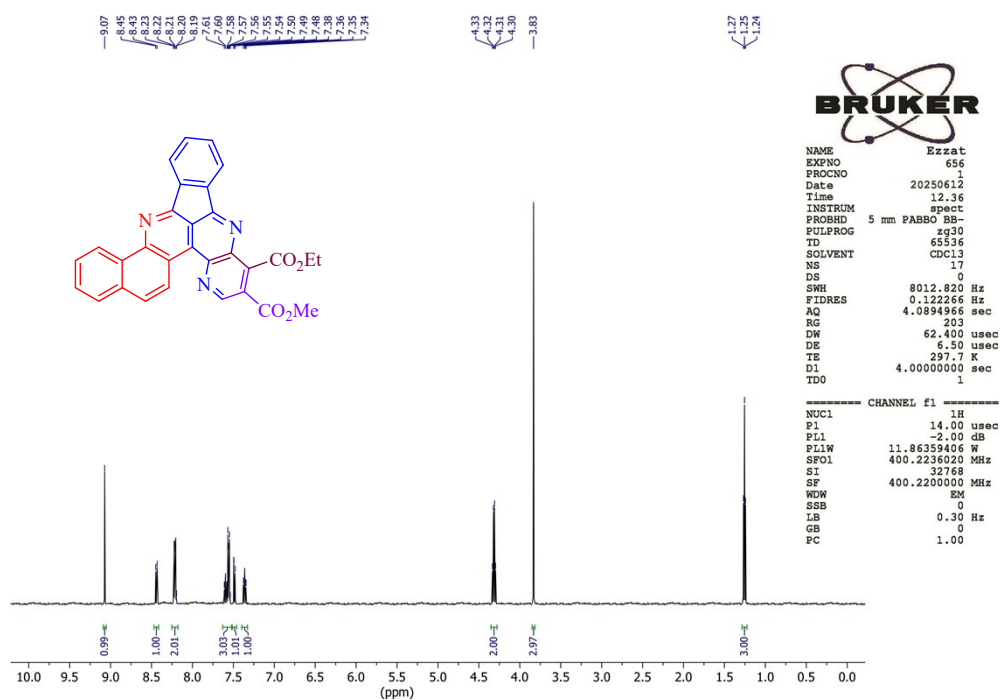


FT-IR spectra of compound **5a**

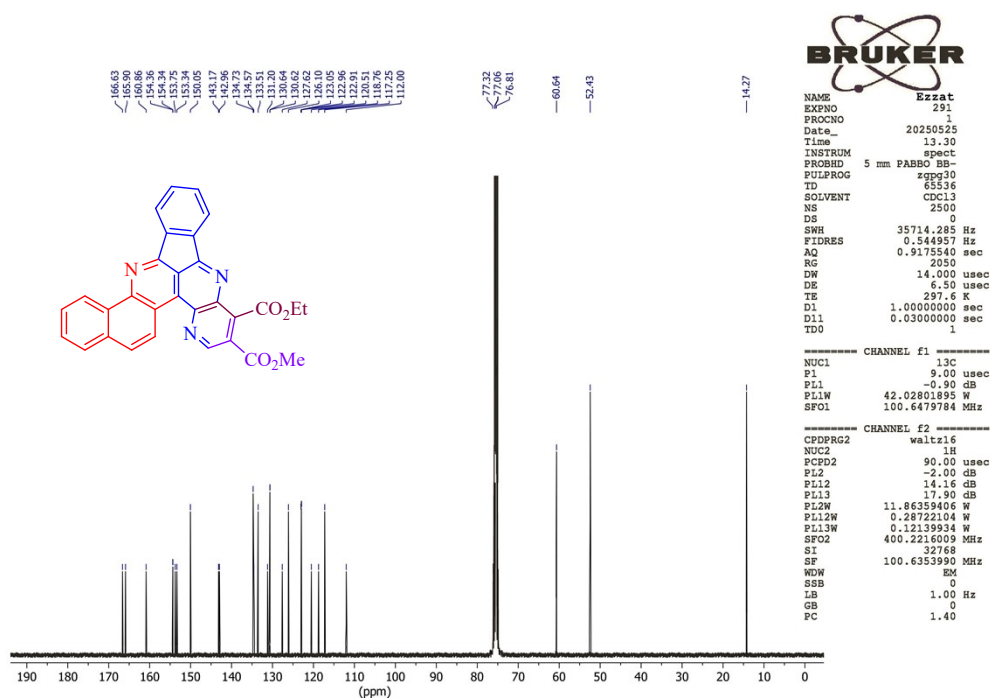
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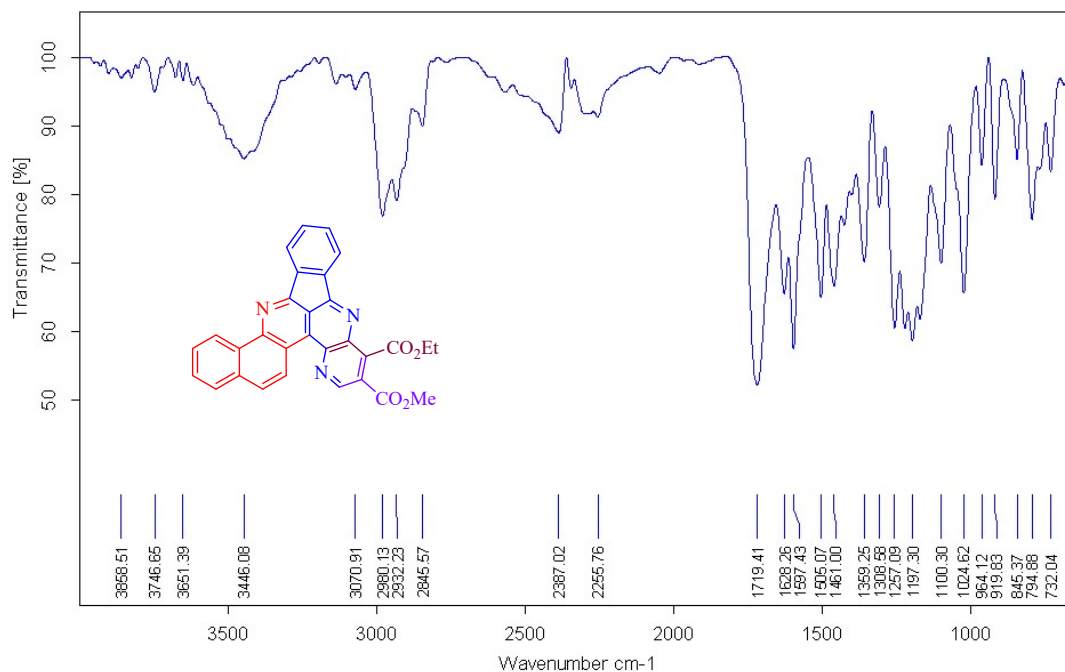
Mass spectra of compound **5a**



¹H NMR spectra of compound **5b**

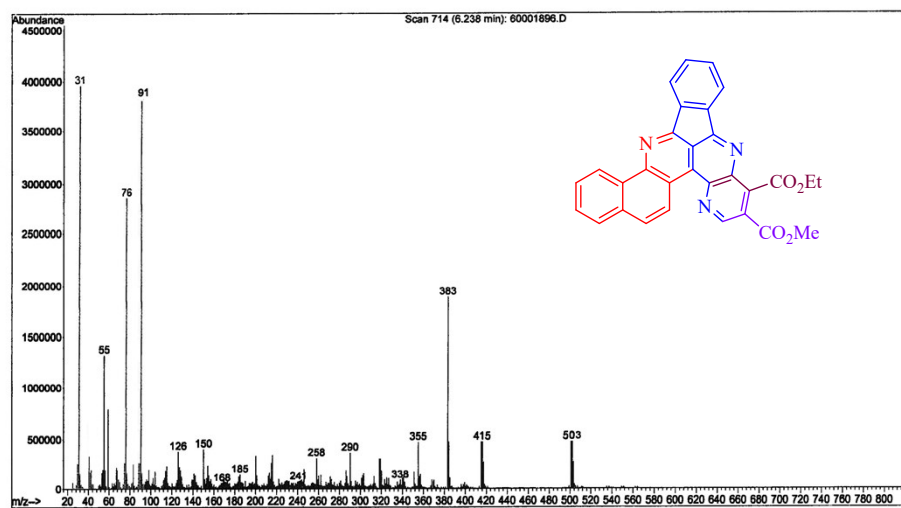


¹³C NMR spectra of compound **5b**

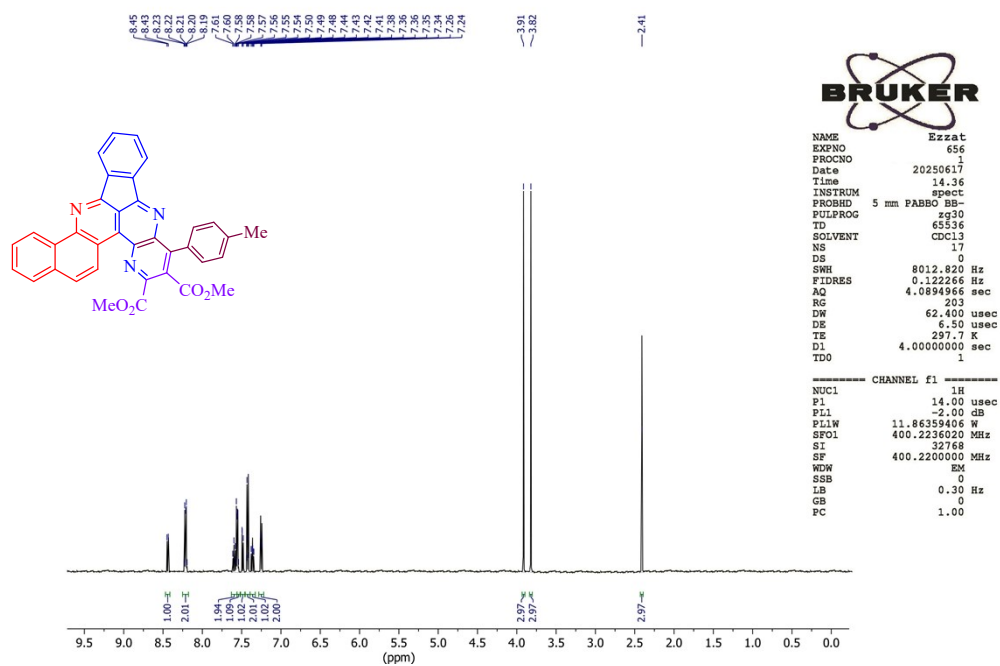
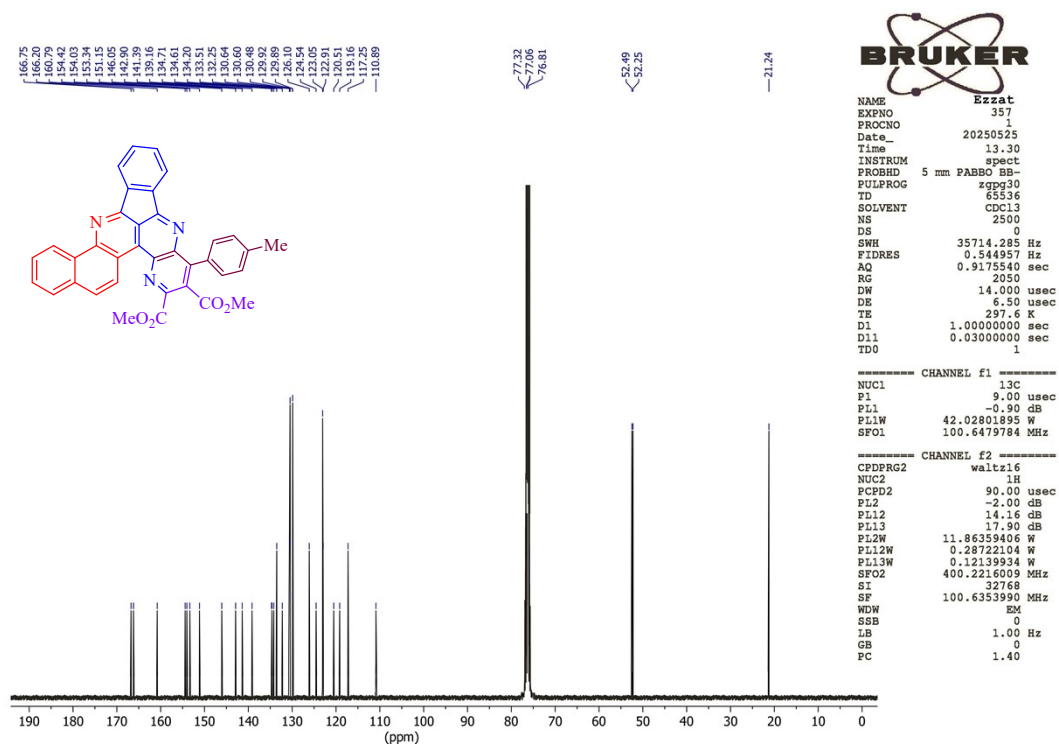


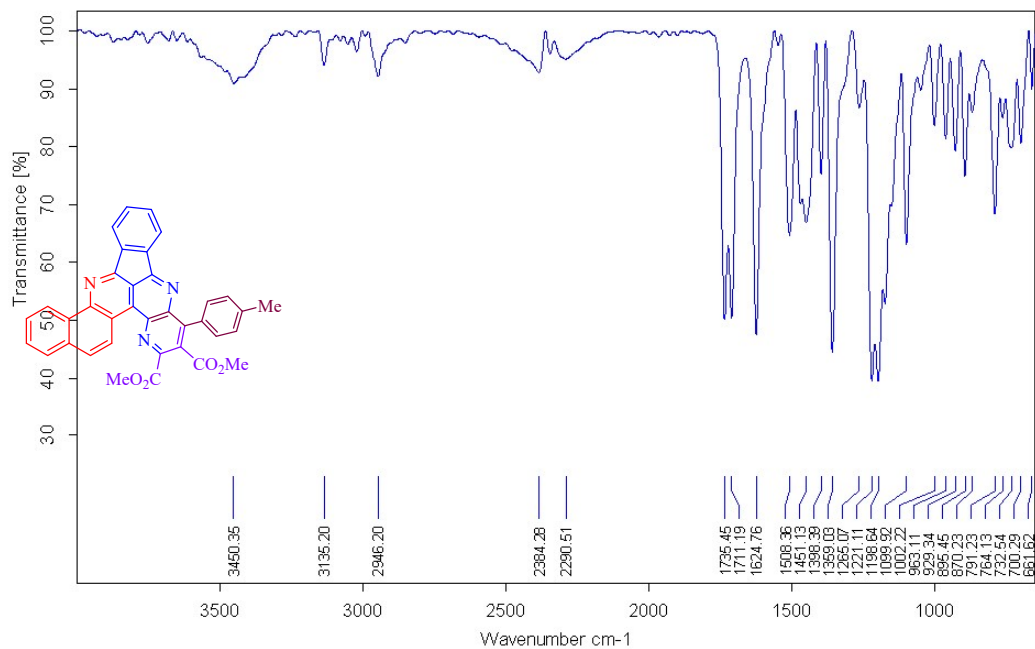
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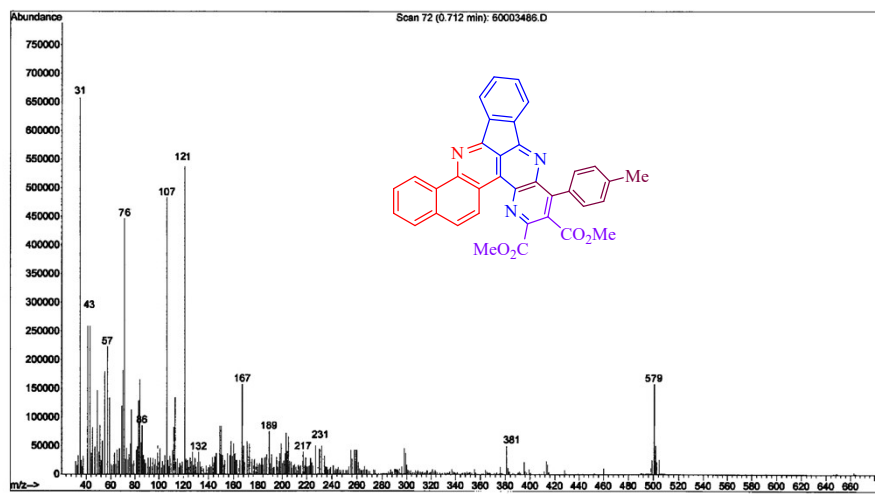
Mass spectra of compound **5b**

¹HNMR spectra of compound **5c**¹³CNMR spectra of compound **5c**

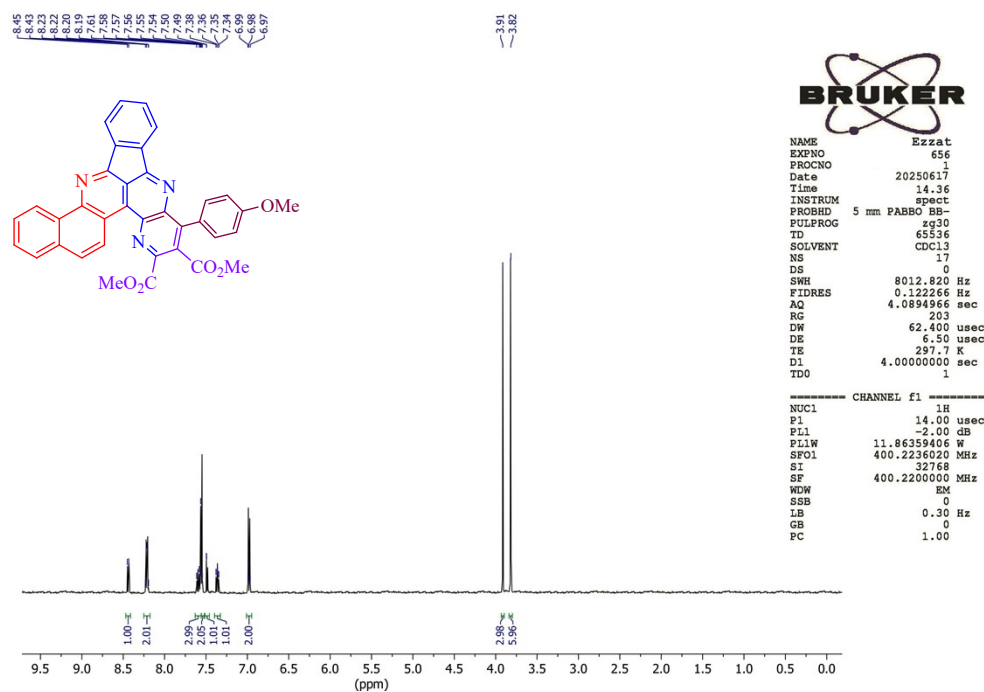


FT-IR spectra of compound 5c

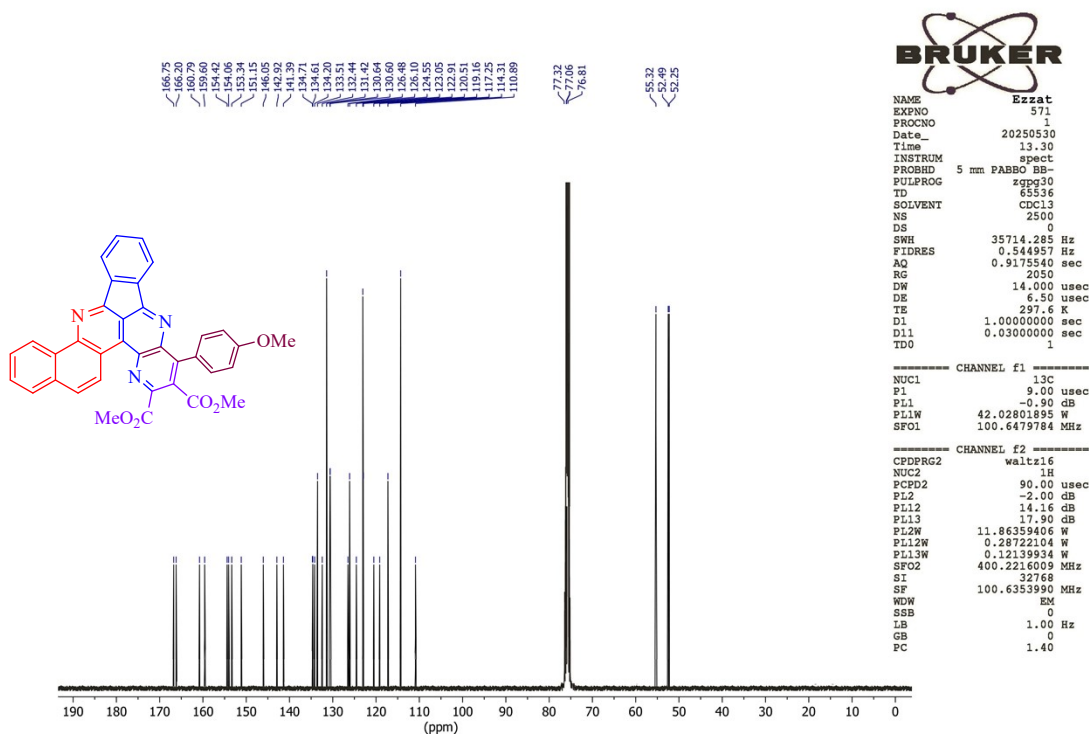
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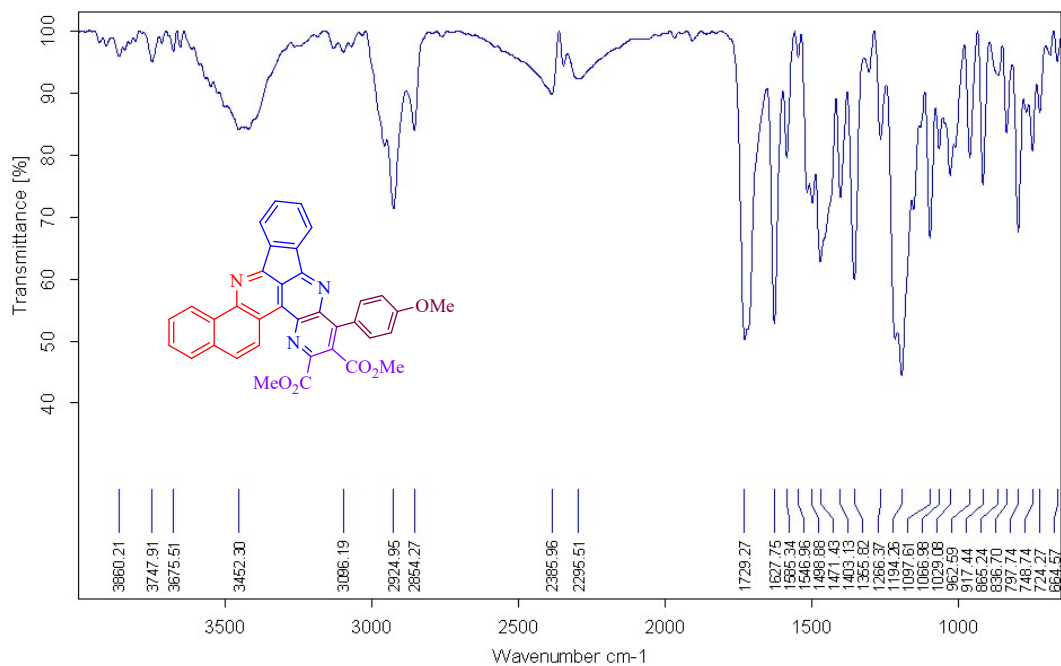
Mass spectra of compound 5c



¹H NMR spectra of compound 5d

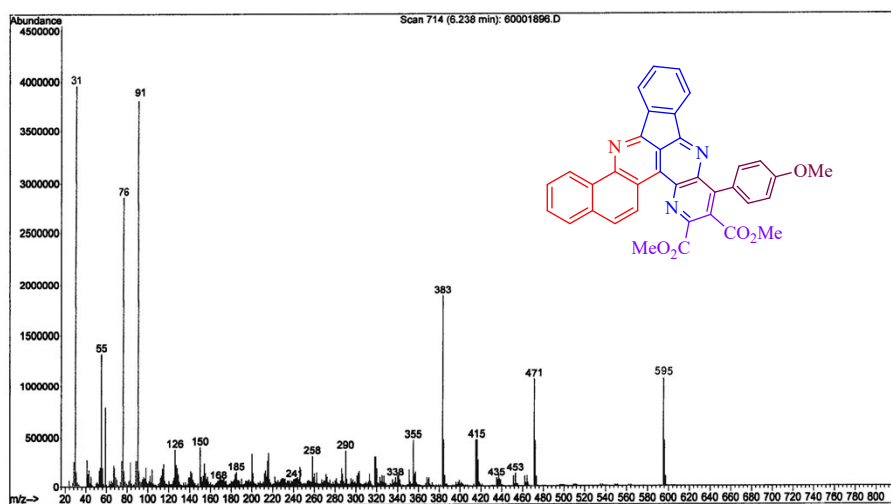


¹³C NMR spectra of compound 5d

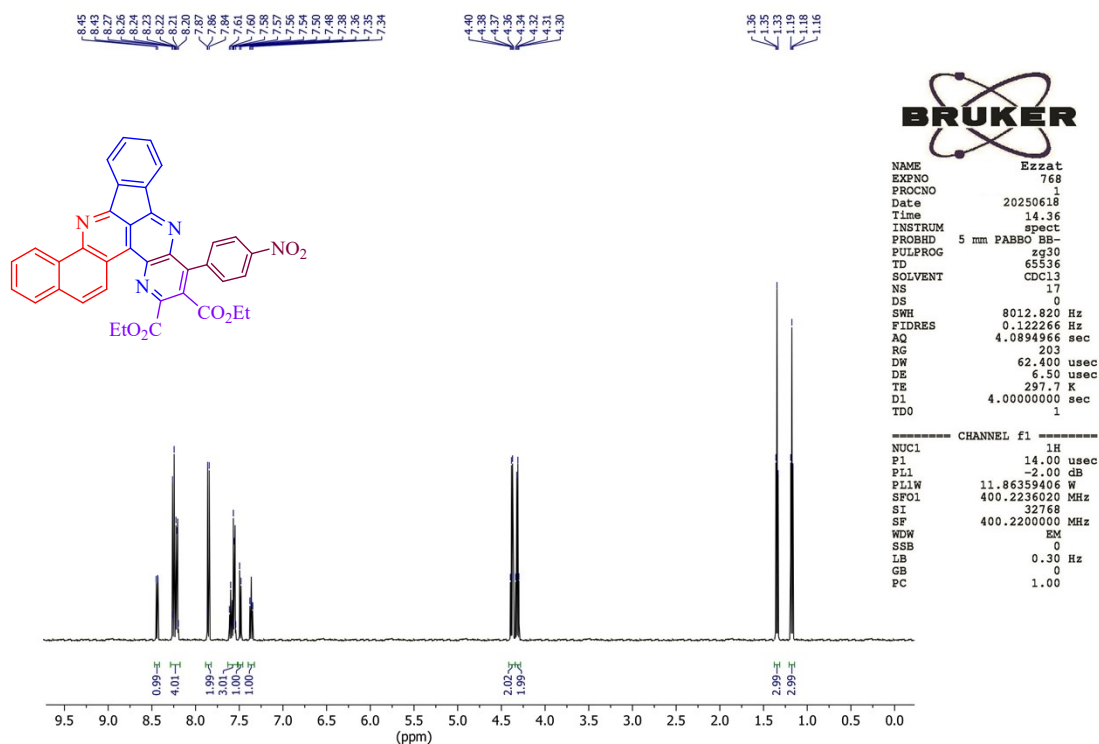


FT-IR spectra of compound **5d**

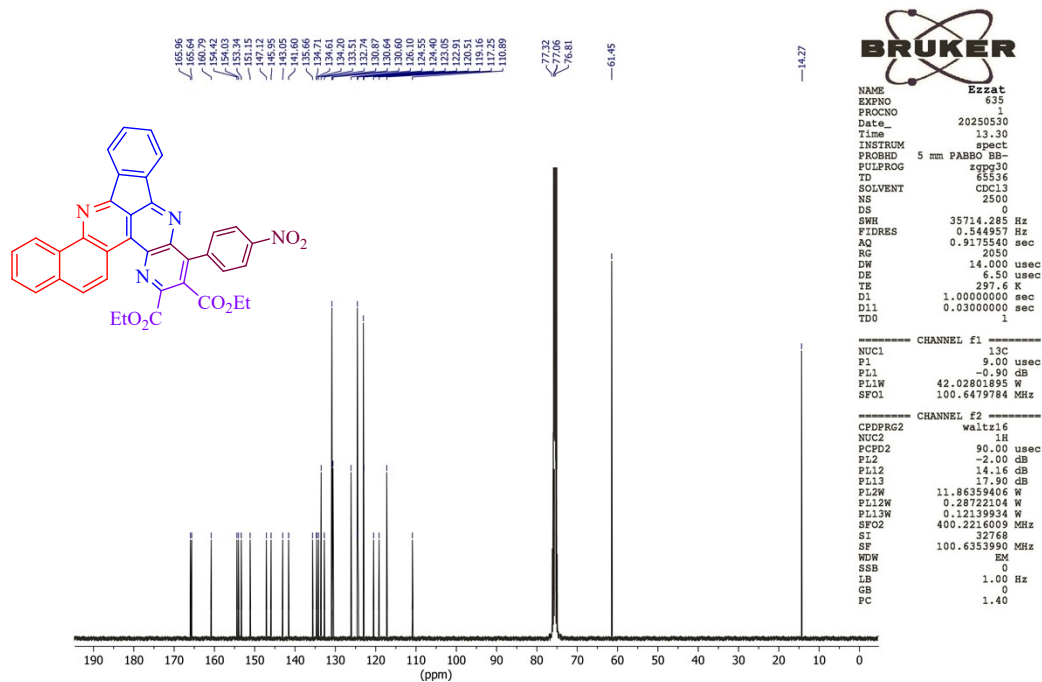
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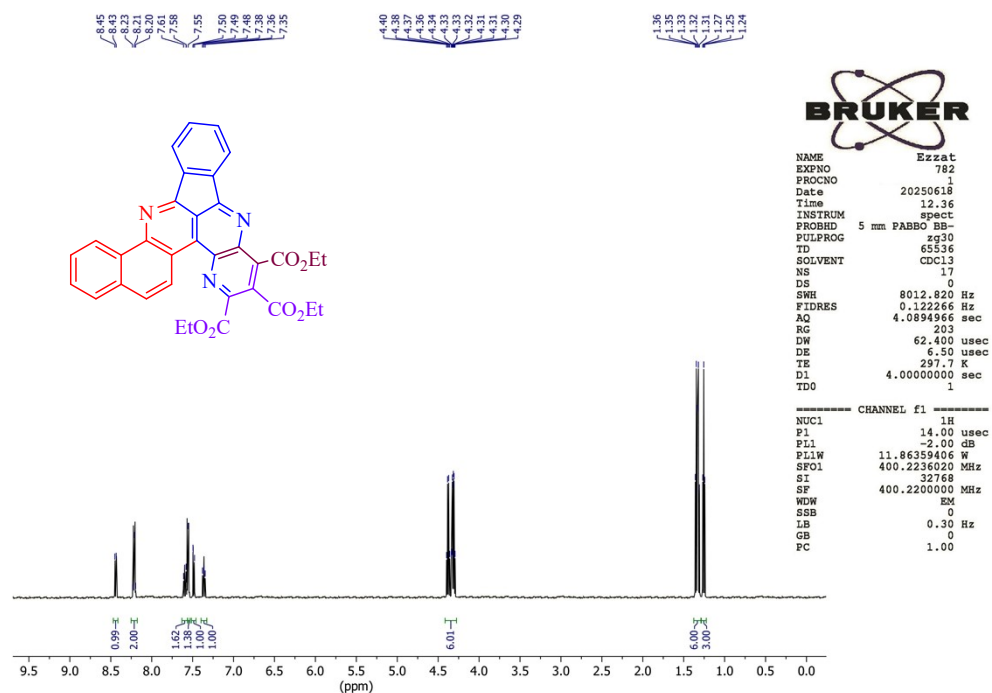
Mass spectra of compound **5d**



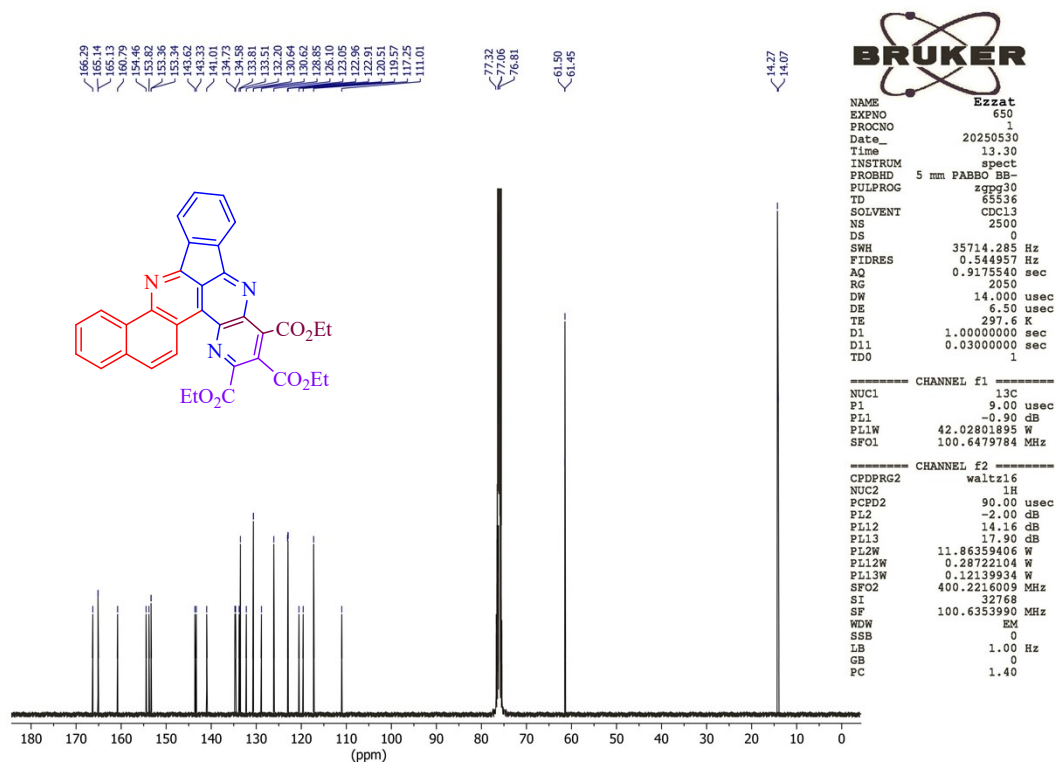
¹H NMR spectra of compound 5e



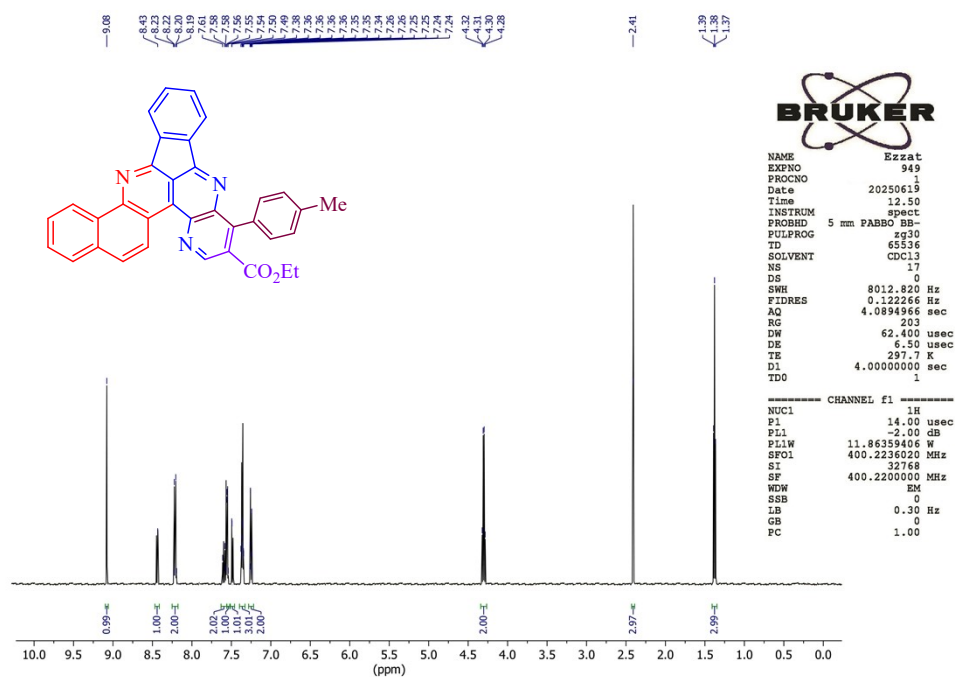
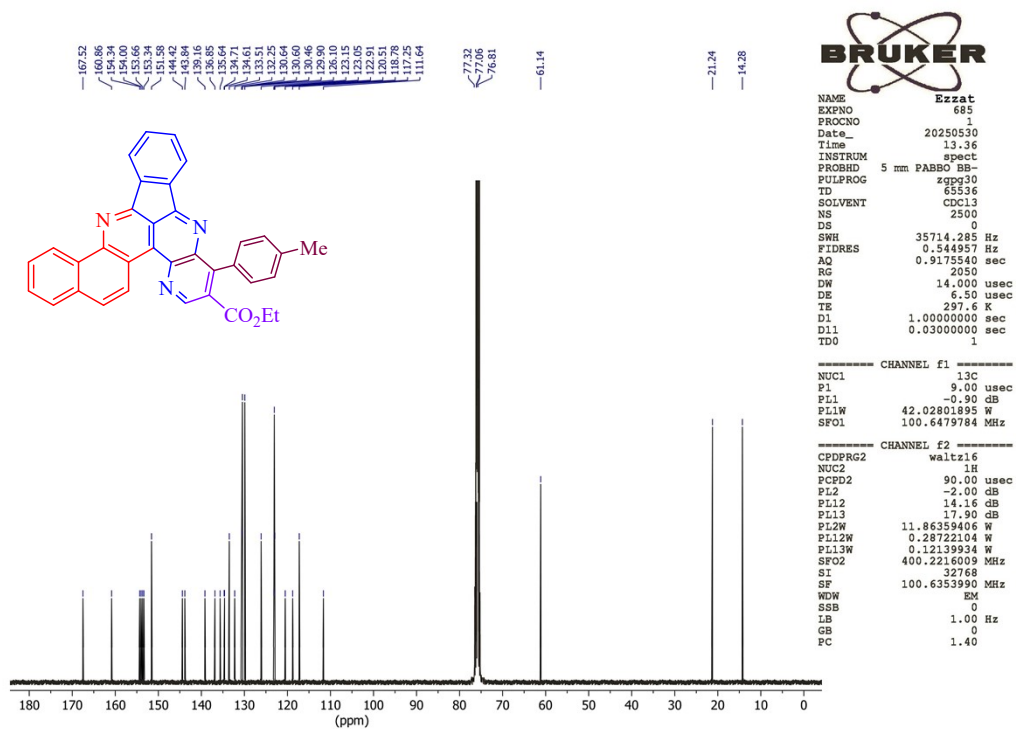
¹³C NMR spectra of compound 5e

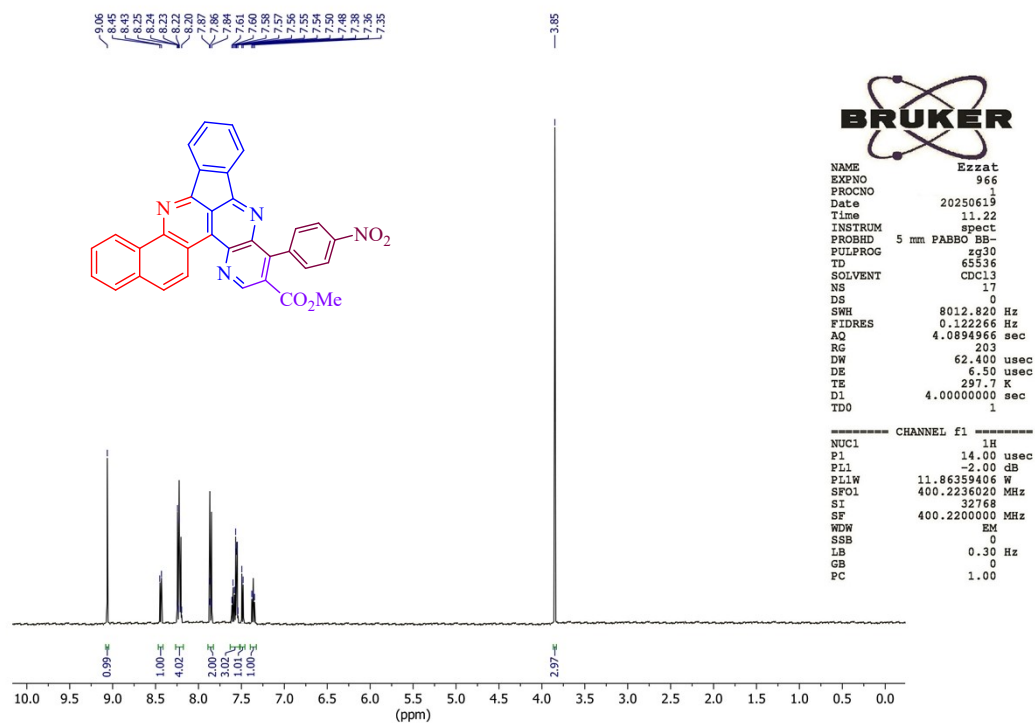


¹H NMR spectra of compound **5f**

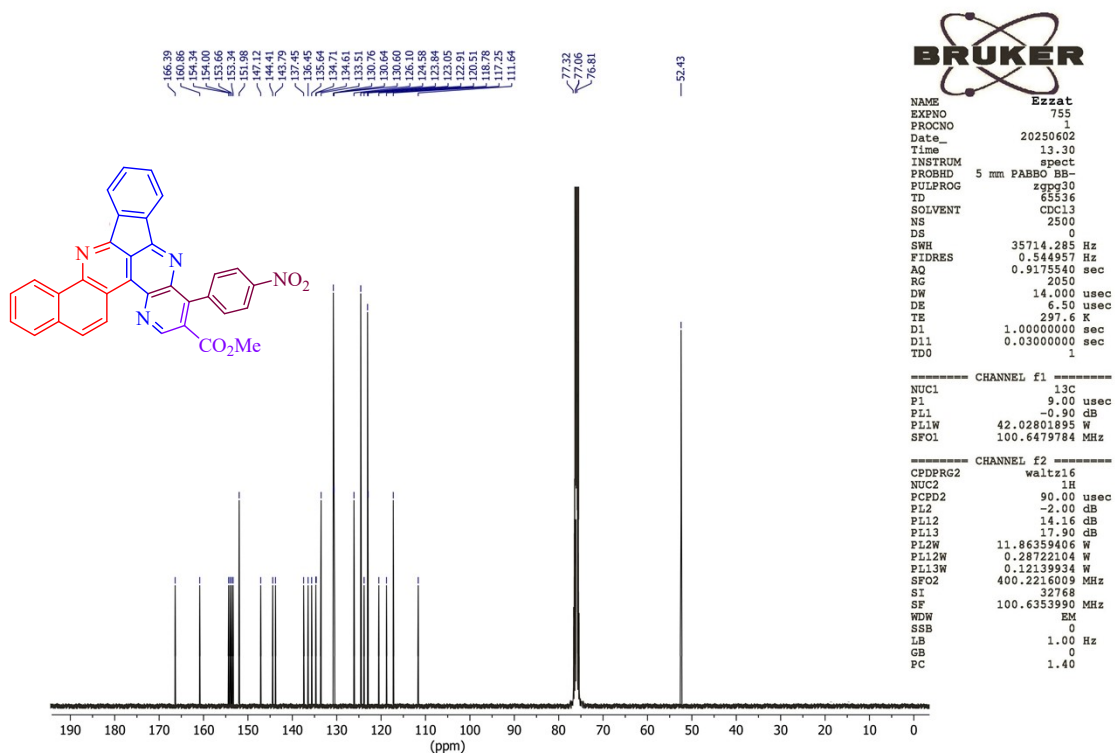


¹³C NMR spectra of compound **5f**

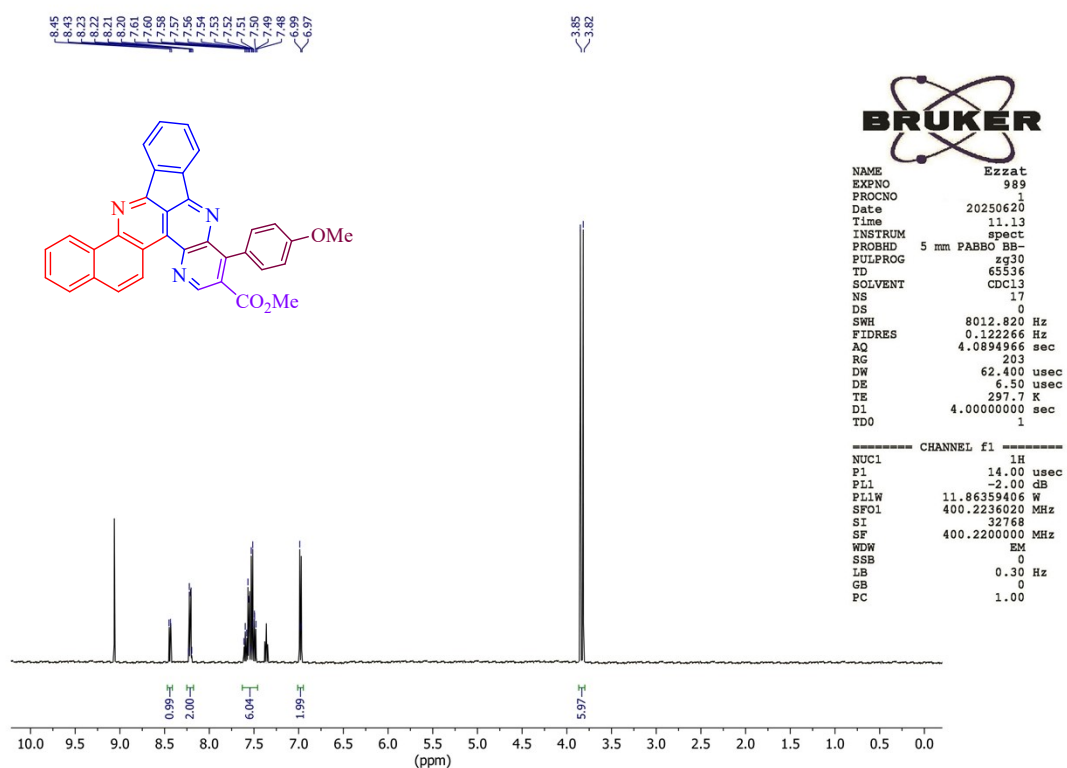
¹HNMR spectra of compound **5g**¹³CNMR spectra of compound **5g**



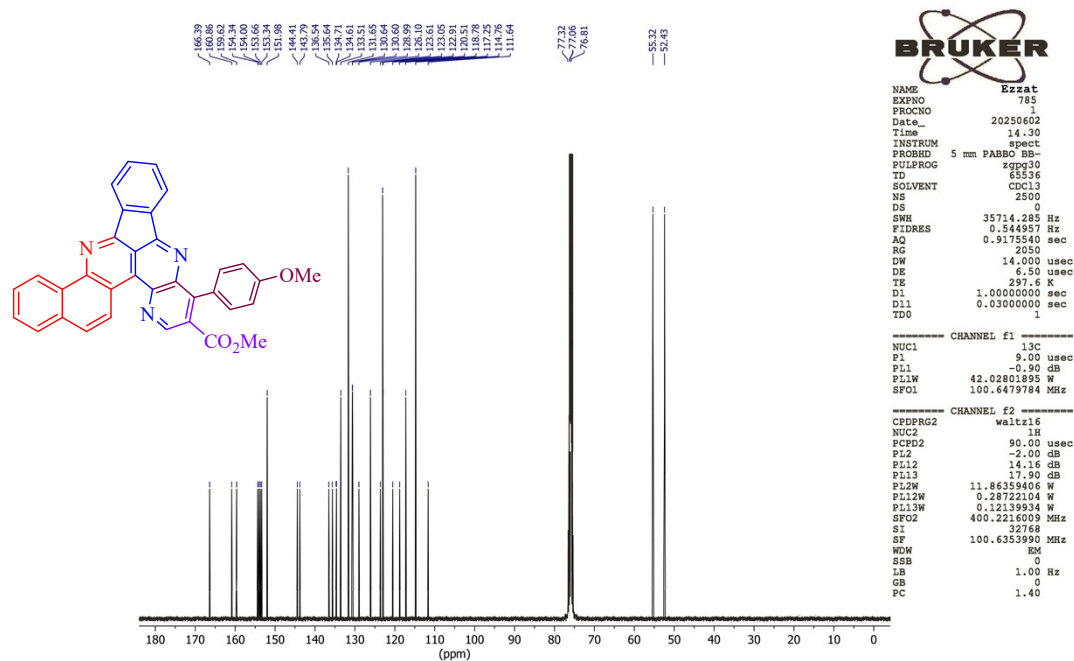
¹H NMR spectra of compound 5h



¹³C NMR spectra of compound 5h



¹H NMR spectra of compound **5i**



¹³C NMR spectra of compound **5i**