Efficient, Single-Step Access to Imidazo[1,5-a]pyridine N-Heterocyclic Carbene Precursors

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Supporting Information

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Methods:

Proton and carbon nuclear magnetic resonance (NMR) spectra were recorded on Varian i400 (^{1}H NMR at 400MHz and ^{13}C at 100MHz) and Varian i500 (^{1}H NMR at 300MHz and ^{13}C at 75MHz) spectrometers using solvent resonance as the internal standard (^{1}H NMR: $CDCl_3$ at 7.24 ppm, CD_3OD at 3.31 ppm, CD_3CN at 1.94ppm, and D_2O at 4.79ppm; 13C NMR: $CDCl_3$ at 77.16 ppm, CD_3OD at 49.00 ppm, and CD_3CN at 1.32ppm). ^{1}H NMR data are reported as follows: chemical shift, multiplicity (s = singlet, bs = broad singlet, d = apparent doublet, t = apparent triplet, q = apparent quartet, quint = apparent quintet, and m = multiplet), coupling constants (Hz), and integration. For carbon spectra of compounds containing Boron, q is used to denote any observed 1:1:1:1 quartets. Infrared spectra (IR) were obtained on an Avatar 360-FT IR E.S.P. and recorded in wavenumbers (cm^{-1}). UV-Vis spectra were obtained using a Varian Cary 5000 spectrometer using a 1 cm path length quartz cell. High-resolution mass spectra were obtained using LCT KC366 with electron impact ionization. Optical rotations were obtained at room temperature on a Perkin Elmer 343 polarimeter at 589 nm (sodium D line) using a 10 cm path length and a 1.0 mL volume. Concentrations (c) are given in g/100 mL. Elemental analysis was performed in house on a Thermo FlashEA® 1112 Series CHNO-S elemental analyzer running Eager Xperience® software under PC control. The CHN column consists of a 45cm long (ID = 14 mm, OD = 18 mm) quartz column packed with (from bottom to top) 20 mm of quartz wool, 50 mm silvered cobaltous/cobaltic oxide,10 mm of quartz wool, 100 mm reduced copper,10 mm of quartz wool, 50 mm chromium oxide, and 10 mm quartz wool. Samples were weighed under inert atmosphere into a tin container. Precisely weighed samples were then combusted in a furnace with the introduction of oxygen gas. After combustion, the N2, CO2, and H2O mixture flow on the He carrier gas through a chromatographic column and are analyzed by a thermal conductive detector. The detector generates electrical signals which are processed by the Eager Xperience software to provide

hydrogen, carbon, and nitrogen percentages. The NIST standards D/L-methionine, L-cystine, BBOT, and sulphanilamide were analyzed each time to give a linear regression as a standard for calculation. Chiral high performance liquid chromatography (HPLC) was performed on an Agilent 1090 equipped with a CHIRALPAK IB column from Chiral Technologies Inc. (250mm X 4.6mm, Cellulose tris(3,5-dimethylphenyl carbamate), flow = 0.5 mL/min, detector = UV, 254nm, temperature = 24°C). Analytical thin layer chromatography (TLC) was performed with either Merck alumina oxide 60 F_{254} neutral (type E) or Analtech Silica Gel 0.25 μm silica gel 60 (F_{256}) plates. Visualization was accomplished with UV light (254 nm). Flash chromatography was performed with EcoChrom flash silica gel (60Å) purchased from MP Silitech. Yield refers to isolated yield of analytically pure material unless otherwise noted.

Materials:

Picolinaldehyde was distilled at 82°C/14 torr prior to use. Ethanol was dried over 3Å molecular sieves. Solutions of 3 M HCl in Ethanol were generated through the addition of acetylchloride to dry Ethanol in an ice bath, concentration was confirmed by titration of a known concentration of NaOH using phenalpthalein as an indicator. All other reagents were obtained from commercial sources and used without further purification unless otherwise noted.

General procedure (A) for the preparation of imidazo[1,5-a]pyridine NHCs

To a 0.5 M solution of primary amine (1 equiv) in dry ethanol, formalin (1.5 equiv), 3 M HCl in EtOH (1 equiv) and picolinaldehyde (1 equiv) were added. The reaction was stirred at room temperature for the time given (15 min-4 days) and monitored by analytical TLC for the appearance of a blue fluorescent product spot by UV light. Crude reaction mixtures were then concentrated in vacuo (~15 Torr) and dried under high vacuum at 0.2 Torr (2-12 hours). Chloride

salts were obtained through filtration of precipitate, recrystallization or trituration of the crude solid under conditions given. Hexafluorophosphate salts were obtained by salt metathesis with potassium hexafluorophosphate following the general procedure (shown below). In the case of 2-butyl-6-cyanoimidazo[1,5-a]pyridinium tetraphenylborate (Table 4, entry 2 (6b)), the tetraphenyl borate salt was obtained by salt metathesis using sodium tetraphenyl borate which is outlined in the experimental procedure.

General procedure (B) for the preparation of imidazo[1,5-a]pyridine NHCs

To a 0.5 M solution of primary amine (1 equiv) in dry ethanol at room temperature is added paraformaldehyde (1.5 equiv). The resulting suspension is stirred at room temperature until the solution becomes homogeneous (4.5 h-4 days). (1 equiv) of 3 M HCl in EtOH is then added followed by picolinaldehyde or other 2-acylpyridine (1 equiv). The reaction was stirred at room temperature for the time given (15 min-4 days) and monitored by analytical TLC for the appearance of a blue fluorescent product spot by UV light. Crude reaction mixtures are then concentrated and placed under high vac (0.2 Torr). Chloride salts are obtained through filtration of precipitate, recrystallization or trituration of the crude solid under conditions specific for the given substrate. Hexafluorophosphate salts were obtained by salt metathesis with potassium hexafluorophosphate following the general procedure (shown below).

General procedure (C) for the preparation of bis- and poly-imidazo[1,5-a]pyridine NHCs

To a 0.5 M solution of bis- or poly-primary amine (1 equiv) in dry ethanol, formalin (1.5 n equiv), 3 M HCl in EtOH (n equivs) and picolinaldehyde (n equivs) are added, where n = the number of

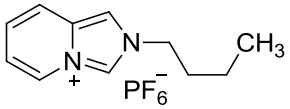
primary amines present in the bis- or poly-amine starting material. The reaction is stirred at room temperature for the time given (4-12 hours) and monitored by analytical TLC for the appearance of a blue fluorescent product spot by UV light. Chloride salts are obtained through filtration of precipitate, recrystallization or trituration of the crude solid under conditions specific for the given substrate. Hexafluorophosphate salts were obtained by salt metathesis with potassium hexafluorophosphate following the general procedure.

General procedure for salt metathesis to access hexafluorophosphate salts

Hexafluorophosphate salts were obtained by dissolving crude solids in a minimal amount of water followed by slow addition of concentrated aqueous KPF_6 (1.1 equiv of KPF_6 per mole of imidazo[1,5-a]pyridinium salt) while stirring. The resulting precipitate is either filtered in the case of a solid or extracted with three portions of ethyl acetate in the event of a semi-solid. Solids collected by precipitation were found to be analytically pure by ^{1}H-NMR. Ethyl acetate layers from extraction procedure were combined, washed once with H_2O, dried over $MgSO_4$, filtered and concentrated. The resulting solids were triturated with diethyl ether, then filtered or decanted to obtain pure material.

Experimental Procedures

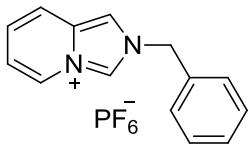
2-Butylimidazo[1,5-a]pyridinium hexafluorophosphate (Table 2, Entry 1)



(Previously reported as the HCl salt.)[1] Following general procedure (A), n-butylamine (0.31 mL, 3.1 mmol), formalin (0.35 mL, 4.7 mmol), 2.94 M HCl in EtOH (1.1 mL, 3.1 mmol) and picolinaldehyde (0.30 mL, 3.1 mmol) were combined in EtOH (5.2 mL) and maintained at rt for 4 hours. Salt metathesis with KPF_6 resulted in a semi-solid which upon extraction with ethyl acetate (3x10mL) and trituration with diethyl ether (6.0 mL) yielded 2-butylimidazo[1,5-a]pyridinium hexafluorophosphate (0.86 g, 2.7 mmol, 86% yield) as a white solid.

^{1}H NMR (400 MHz, CD_3CN): δ 9.03 (s, 1H), 8.28 (d, J = 7.2 Hz, 1H), 7.82 (s, 1H), 7.71 (d, J = 9.4 Hz, 1H), 7.21 (dt, J = 20.9, 10.6 Hz, 1H), 7.10 (t, J = 6.9 Hz, 1H), 4.41 (t, J = 7.3 Hz, 2H), 1.92 (tt, J = 15.0, 7.4 Hz, 2H), 1.46 – 1.26 (m, 2H), 1.03 – 0.86 (t, J = 7.4 Hz, 3H). **^{13}C NMR (101 MHz, CD_3CN):** δ 131.3, 126.3, 125.9, 124.8, 119.1, 118.8, 114.1, 51.6, 33.0, 20.1, 13.7. **HR-MS (ESI):** calcd. For $C_{11}H_{15}N_2$ $[M]^+$ 175.1235, found 175.1237. **UV (MeCN) λ_{max}, nm (ε):** 327 (sh, 471), 312 (sh, 1143), 298 (sh, 1451), 281 (2666), 271 (2594), 261 (sh, 1768), 242 (sh, 734), 233 (sh, 1088), 226 (1206), 204 (12092). **IR (dry film):** 2960, 2880, 1659, 1477, 1381, 1348, 1259, 1157, 838, 791 cm^{-1}.

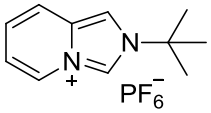
2-Benzylimidazo[1,5-a]pyridinium hexafluorophosphate (Table 2, Entry 2)



(Previously reported as the HCl salt.)[2]Following general procedure (A), benzylamine (0.34 mL, 2.8 mmol), formalin (0.32 mL, 4.2 mmol), 2.94 M HCl in EtOH (0.96 mL, 2.8 mmol) and picolinaldehyde (0.27 mL, 2.8 mmol) were combined in EtOH (4.7 mL) and maintained at rt for 3 hours. Following salt metathesis with KPF_6, 2-benzylimidazo[1,5-a]pyridinium hexafluorophosphate (0.93 g, 2.6 mmol, 93% yield) was obtained as a white solid.

^{1}H NMR (400 MHz, CD_3CN): δ 9.09 (s, 1H), 8.27 (d, J = 7.1 Hz, 1H), 7.81 (s, 1H), 7.68 (d, J = 9.4 Hz, 1H), 7.45 (s, 5H), 7.23 (dd, J = 17.7, 9.8 Hz, 1H), 7.10 (t, J = 6.7 Hz, 1H), 5.60 (s, 2H). **^{13}C NMR (101 MHz, CD_3CN)**: δ 134.5, 131.5, 130.4, 130.3, 129.9, 126.5, 126.1, 124.9, 119.1, 118.9, 114.1, 55.0. **HR-MS (ESI)**: calcd. For $C_{14}H_{13}N_2$ $[M]^+$ 209.1079, found 209.1074. **UV (MeCN) λ_{max}, nm (ε):** 326 (sh, 583), 311 (sh, 1157), 298 (sh, 1437), 283 (2,713), 272 (2755), 262 (1933), 243 (sh, 833), 235 (sh, 1267), 210 (10337). **IR (dry film):** 3154, 2918, 1658, 1588, 1563, 1549, 1456, 1356, 1267, 1157, 1136, 837, 762 cm^{-1}. **Anal. Calcd.** for $C_{14}H_{13}F_6N_2P$: C, 47.47; H, 3.70; N, 7.91. Found: C, 47.45; H, 3.81; N, 7.89.

2-*t*-Butylimidazo[1,5-a]pyridinium hexafluorophosphate (Table 2, Entry 8)

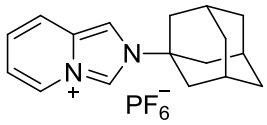


(Known compound, corresponds with previously reported spectra)[2] Following general procedure (B), t-butylamine (0.33 mL, 3.1 mmol) and paraformaldehyde (0.14 mg, 4.7 mmol) were stirred in 6.2 mL of EtOH at room temperature for 2.5 hours at which point the solution became homogeneous. 2.94 M HCl in EtOH (1.1 mL, 3.1 mmol) and picolinaldehyde (0.30 mL, 3.1 mmol) were then added and the reaction was maintained at rt for 4 days. Following salt metathesis with KPF_6, 2-*t*-butylimidazo[1,5-a]pyridinium hexafluorophosphate (0.80 mg, 2.5 mmol, 80% yield) was obtained as a white solid.

^{1}H NMR (400 MHz, CD_3CN): δ 9.13 (s, 1H), 8.24 (dd, J = 7.2, 0.7 Hz, 1H), 7.96 (s, 1H), 7.70 (d, J = 9.4 Hz, 1H), 7.23 (dd, J = 8.9, 6.8 Hz, 1H), 7.10 (t, J = 6.7 Hz, 1H), 1.73 (s, 9H**). ^{13}C NMR (101 MHz, CD_3CN)**: δ 131.4, 126.0, 125.0, 124.8, 119.1, 118.8, 112.0, 62.5, 30.1. HR-MS (ESI): calcd. For $C_{18}H_{14}N_3$ $[M]^+$ 175.1235, found 175.1233. **UV (MeCN) λ_{max}, nm (ε):** 326 (sh, 436), 312 (sh, 906),

299 (sh, 1038), 282 (1793), 270 (1921), 260 (sh, 1267), 242 (sh, 544), 234 (sh, 764), 227 (878), 204 (9861). **IR (dry film):** 2848, 1644, 1557, 1386, 1223, 1195, 1121 cm^{-1}. **Anal. Calcd.** for $C_{11}H_{15}F_6N_2P$: C, 41.26; H, 4.72; N, 8.75. Found: C, 41.01; H, 4.40; N, 8.52.

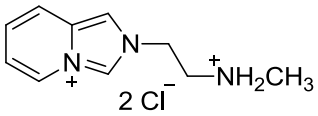
2-Adamantylimidazo[1,5-a]pyridinium hexafluorophosphate (Table 2, Entry 9)



Following general procedure (B), adamantylamine (0.11 g, 0.75 mmol) and paraformaldehyde (34 mg, 1.1 mmol) were stirred in 1.3 mL of EtOH at room temperature for 2.5 hours at which point the solution became homogeneous. 2.95 M HCl in EtOH (0.26 mL, 0.75 mmol) and picolinaldehyde (72 μL, 0.75 mmol) were then added and the reaction was maintained at rt for 4 days. Following salt metathesis with KPF_6, 2-adamantylimidazo[1,5-a]pyridinium hexafluorophosphate (0.22 g, 0.56 mmol, 75% yield) was obtained as a white solid. **Anal. Calcd.** for $C_{17}H_{21}F_6N_2P$: C, 51.26; H, 5.31; N, 7.03. Found: C, 51.46; H, 4.84; N, 7.03.

^{1}H NMR (400 MHz, CD_3CN): δ 9.13 (s, 1H), 8.25 (d, J = 7.1 Hz, 1H), 7.99 (s, 1H), 7.70 (d, J = 9.4 Hz, 1H), 7.22 (dd, J = 9.1, 6.9 Hz, 1H), 7.10 (t, J = 6.9 Hz, 1H), 2.31 (s, 3H), 2.26 (s, 6H), 1.89 – 1.75 (m, 6H). **^{13}C NMR (101 MHz, CD_3CN):** δ 131.1, 125.8, 124.8, 124.4, 119.1, 118.7, 110.9, 62.4, 43.4, 36.0, 30.6. **HR-MS (ESI):** calcd. For $C_{17}H_{21}N_2$ $[M]^+$ 253.1705, found 253.1703. **UV (MeCN) λ_{max}, nm (ε):** 327 (sh, 452), 312 (sh, 1095), 300 (sh, 1254), 281 (2474), 271 (2444), 261 (sh, 1665), 243 (sh, 681), 234 (sh, 1109), 226 (sh, 1470), 209 (10347). **IR (dry film):** 3176, 2918, 2855, 1655, 1548, 1456, 1345, 1151, 1134, 1107, 839, 788 cm^{-1}.

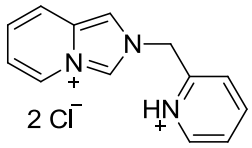
2-(2-(Methylammonio)ethyl)-2H-imidazo[1,5-a]pyridinium dichloride (Table 2, Entry 3)



Following general procedure (B), which was modified by using 2 equiv of HCl (2.94 M in EtOH), *N*-methylethylenediamine (0.41 mL, 4.7 mmol) and paraformaldehyde (0.21 mg, 7.1 mmol) were stirred in 7.8 mL of EtOH at room temperature for 12 hours at which point the solution became homogeneous. 2.95 M HCl in EtOH (3.2 mL, 9.5 mmol) and picolinaldehyde (0.45 mL, 4.7 mmol) were then added and the reaction was maintained at rt for 2 hours. The resulting heterogeneous mixture was then diluted with acetone (3.0 mL), filtered and washed with acetone (3.0 mL), providing 2-(2-(methylammonio)ethyl)-2H-imidazo[1,5-a]pyridinium dichloride (0.90 g, 3.6 mmol, 77% yield) as a tan solid.

^{1}H NMR (400 MHz, CD_3OD): δ 9.81 (s, 1H), 8.57 (d, J = 6.9 Hz, 1H), 8.29 (s, 1H), 7.85 (d, J = 9.3 Hz, 1H), 7.33 (t, J = 7.9 Hz, 1H), 7.22 (t, J = 6.7 Hz, 1H), 5.02 (t, J = 5.4 Hz, 2H), 3.77 (t, J = 5.5 Hz, 2H), 2.80 (s, 3H). **^{13}C NMR (101 MHz, CD_3OD):** δ 132.0, 128.2, 126.4, 125.2, 119.4, 119.3, 114.8, 49.5, 47.9, 34.0. **HR-MS (ESI):** calcd. For $C_{10}H_{14}N_3$ $[M]^+$ 176.1188, found 176.1183. **UV (H_2O) λ_{max}, nm (ε):** 322 (sh, 507), 307 (sh, 1146), 295 (sh, 1386), 281 (2411), 270 (2305), 260 (sh, 1496), 243 (sh, 660), 234 (889), 227 (sh, 974), 206 (8130). **IR (dry film):** 3455, 3398, 3108, 3057, 3011, 2956, 2751, 2676, 2432, 1654, 1558, 1543, 1451, 1384, 1351, 1328, 1241, 1166, 1149, 1128, 1061, 1033, 815, 745, 640 cm^{-1}.

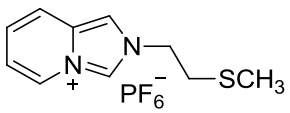
2-(Pyridin-1-ium-2-ylmethyl)-2H-imidazo[1,5-a]pyridinium dichloride (Table 2, Entry 4)



Following general procedure (B), which was modified by using 2 equiv of HCl (2.94 M in EtOH), picolinamine (0.37 mL, 3.5 mmol) and paraformaldehyde (160 mg, 5.3 mmol) were stirred in 5.9 mL of EtOH at room temperature for 12 hours at which point the solution became homogeneous. 2.95 M HCl in EtOH (2.4 mL, 7.1 mmol) and picolinaldehyde (0.34 mL, 3.5 mmol) were then added and the reaction was maintained at rt for 2 hours. The resulting heterogeneous mixture was then filtered and washed with EtOH (1.5 mL), providing 2-(pyridin-1-ium-2-ylmethyl)-2H-imidazo[1,5-a]pyridinium dichloride (0.74 mg, 2.6 mmol, 74% yield) as a light yellow solid.

^{1}H NMR (400 MHz, CD_3OD): δ 9.94 (s, 1H), 8.94 (dd, J = 3.4, 1.8 Hz, 1H), 8.63 (ddd, J = 11.0, 7.8, 3.3 Hz, 2H), 8.34 (s, 1H), 8.14 – 8.06 (m, 2H), 7.86 (d, J = 9.4 Hz, 1H), 7.40 – 7.32 (m, 1H), 7.26 (dd, J = 9.4, 4.4 Hz, 1H), 6.32 (d, J = 2.4 Hz, 2H). **^{13}C NMR (101 MHz, CD_3OD)**: δ 149.8, 148.1, 144.7, 132.3, 128.8, 128.4, 128.0, 126.7, 125.3, 119.6, 119.4, 115.2, 51.8. **HR-MS (ESI):** calcd. For $C_{13}H_{12}N_3$ $[M]^+$ 210.1031, found 210.1022. **UV (H_2O) λ_{max}, nm (ε):** 325 (sh, 365), 309 (sh, 948), 297 (sh, 1164), 282 (2279), 268 (2533), 261 (2501), 253 (sh, 1819), 235 (sh, 1074), 206 (8694). **IR (KBr):** 3111, 3085, 3017, 2563, 2042, 1968, 1638, 1615, 1546, 1473, 1461, 1446, 1333, 1231, 1167, 1148, 1126, 786, 751, 644, 626 cm^{-1}.

2-(2-(Methylthio)ethyl)imidazo[1,5-a]pyridinium hexafluorophosphate (Table 2, Entry 5)

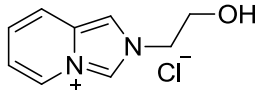


Following general procedure (A), 2-(methylthio)ethanamine[3] (0.14 g, 1.5 mmol), formalin (0.17 mL, 2.2 mmol), 2.94 M HCl in EtOH (0.50 mL, 1.5 mmol) and picolinaldehyde (0.14 mL, 1.5 mmol)

were combined in EtOH (2.5 mL) and maintained at rt for 1 hour. Following salt metathesis with KPF_6, 2-(2-(Methylthio)ethyl)imidazo[1,5-a]pyridinium hexafluorophosphate (0.46 g, 1.4 mmol, 92% yield) was obtained as a white solid.

^{1}H NMR (400 MHz, CD_3CN): δ 9.11 (s, 1H), 8.32 (dd, J = 7.2, 1.0 Hz, 1H), 7.88 (s, 1H), 7.74 (dd, J = 9.4, 0.7 Hz, 1H), 7.25 (ddd, J = 9.4, 6.7, 0.8 Hz, 1H), 7.12 (td, J = 7.1, 1.0 Hz, 1H), 4.62 (t, J = 6.6 Hz, 2H), 3.03 (t, J = 6.6 Hz, 2H), 2.14 (s, 3H). **^{13}C NMR (101 MHz, CD_3CN):** δ 131.1, 126.6, 126.0, 124.7, 119.1, 119.0, 114.3, 50.5, 34.7, 15.2. **HR-MS (ESI):** calcd. For $C_{10}H_{13}N_2S$ $[M]^+$ 193.0799, found 193.0794. **UV (MeCN) λ_{max}, nm (ε):** 325 (sh, 634), 311 (sh, 1347), (298 (sh, 1686), 282 (3253), 272 (3102), 261 (sh, 2183), 242 (sh, 1526), 234 (1743), 227 (1708), 208 (9438). **IR (dry film):** 3166, 2979, 2953, 1659, 1566, 1551, 1457, 1443, 1409, 1345, 1244, 1174, 1154, 1026, 967, 845, 797 cm^{-1}.

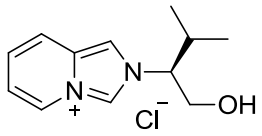
2-(2-Hydroxyethyl)-2H-imidazo[1,5-a]pyridin-4-ium chloride (Table 1, Entries 11 and 12)



Following general procedure (A), ethanolamine (0.15 mL, 2.5 mmol), formalin (0.28 mL, 3.8 mmol), 2.94 M HCl in EtOH (0.86 mL, 2.5 mmol) and picolinaldehyde (0.24 mL, 2.5 mmol) were combined in EtOH (5.0 mL) and maintained at rt for 1.5 hours after which the crude reaction mixture was concentrated and placed under high vac (0.2 Torr) to remove residual water. The crude solid was then dissolved in EtOH (5 mL) and stirred with solid sodium bicarbonate for 10 minutes at room temperature. The reaction mixture was then filtered and concentrated, followed by trituration with acetone (3.0 mL) to provide 2-(2-hydroxyethyl)-2H-imidazo[1,5-a]pyridin-4-ium chloride (0.46 g, 2.3 mmol, 93% yield) as a white solid.

^{1}H NMR (400 MHz, DMSO): δ 9.98 (s, 1H), 8.72 (d, *J* = 7.1 Hz, 1H), 8.32 (s, 1H), 7.85 (d, *J* = 9.3 Hz, 1H), 7.23 (dd, *J* = 9.1, 6.8 Hz, 1H), 7.15 (dd, *J* = 10.0, 3.7 Hz, 1H), 5.60 (s, 1H), 4.64 – 4.52 (m, 2H), 3.87 – 3.77 (m, 2H). **^{13}C NMR (101 MHz, DMSO)**: δ 128.9, 126.8, 124.3, 124.1, 118.1, 117.2, 113.8, 59.6, 52.9. **HR-MS (ESI):** calcd. For $C_9H_{11}N_2O$ $[M]^+$ 163.0871, found 163.0863. **UV (H_2O) λ_{max}, nm (ε):** 324 (sh, 486), 310 (sh, 108), 299 (sh, 1276), 281 (2360), 271 (2294), 259 (sh, 1440), 242 (sh, 661), 233 (sh, 907), 226 (sh, 1000), 207 (9178). **IR (KBr):** 3507, 3417, 3123, 2957, 2931, 1656, 1612, 1544, 1450, 1253, 1150, 1074, 804, 747, 639 cm^{-1}.

(*S*)-2-(1-Hydroxy-3-methylbutan-2-yl)-2H-imidazo[1,5-a]pyridinium chloride (Table 2, Entry 6)

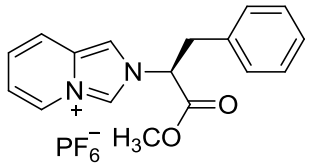


Following general procedure (B), L-valinol (0.21 g, 2.1 mmol) and paraformaldehyde (94 mg, 3.1 mmol) were stirred in 3.5 mL of EtOH at room temperature for 2 hours at which point the solution became homogeneous. 2.95 M HCl in EtOH (0.70 mL, 2.1 mmol) and picolinaldehyde (0.20 mL, 2.1 mmol) were then added and the reaction was maintained at rt for 1 hour. The reaction was then concentrated and the crude solid was recrystallized from acetonitrile and tetrahydrofuran to provide (*S*)-2-(1-hydroxy-3-methylbutan-2-yl)-2H-imidazo[1,5-a]pyridinium chloride (0.43 g, 1.8 mmol, 86% yield) as a white solid.

^{1}H NMR (400 MHz, CD_3OD): δ 9.69 (s, 1H), 8.50 (d, J = 7.1 Hz, 1H), 8.21 (s, 1H), 7.81 (d, J = 9.3 Hz, 1H), 7.30 (t, J = 8.0 Hz, 1H), 7.18 (t, J = 6.9 Hz, 1H), 4.37 (dd, J = 9.4, 6.8 Hz, 1H), 4.07 (dd, J = 11.7, 7.2 Hz, 1H), 4.05 – 3.95 (m, 1H), 2.51 – 2.35 (m, 1H), 1.16 (dd, J = 4.3, 2.3 Hz, 3H), 0.83 (dd, J = 4.3, 2.3 Hz, 3H). **^{13}C NMR (101 MHz, DMSO):** δ 129.0, 126.3, 124.5, 124.3, 118.2, 117.3, 112.8, 69.7, 60.8, 29.1, 19.2, 18.9. **$[\alpha]^{D}_{25}$**= -35.8 (c= 1.06, CH_3CN). HR-MS (ESI): calcd. For $C_{12}H_{17}N_2O$ $[M]^+$

205.1341, found 205.1337. **UV (H_2O) λ_{max}, nm (ε):** 324 (sh, 432), 310 (sh, 945), 298 (sh, 1146), 281 (2200), 271 (2145), 260 (sh, 1399), 242 (sh, 579), 233 (sh, 850), 227 (sh, 969), 208 (6993). **IR (dry film):** 3372, 3128, 3062, 2963, 2941, 2876, 1656, 1544, 1500, 1482, 1468, 1411, 1395, 1376, 1365, 1328, 1260, 1120, 1081, 1042, 798 cm^{-1}.

(*S*)-2-(1-Methoxy-1-oxo-3-phenylpropan-2-yl)-2H-imidazo[1,5-a]pyridinium hexafluorophosphate (Table 2, Entry 7)

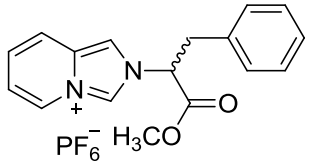


Following general procedure (A), L-phenylalanine methyl ester (0.42 g, 2.3 mmol), formalin (0.26 mL, 3.5 mmol), 2.94 M HCl in EtOH (0.80 mL, 2.3 mmol) and picolinaldehyde (0.22 mL, 2.3 mmol) were combined in EtOH (3.9 mL) and maintained at rt for 4 hours. Salt metathesis with KPF_6 resulted in a semi-solid which was extracted with ethyl acetate (3x10mL). The combined organic layers were then washed with H_2O (2 mL), dried over magnesium sulfate, concentrated and placed under high vac (0.2 Torr) to remove residual water. The resulting oil was triturated with diethyl ether (4.0 mL) to provide (*S*)-2-(1-methoxy-1-oxo-3-phenylpropan-2-yl)-2H-imidazo[1,5-a]pyridinium hexafluorophosphate (0.86 g, 2.0 mmol, 86% yield) as a white solid.

^{1}H NMR (400 MHz, CD_3CN): δ 9.04 (s, 1H), 8.23 (d, J = 7.1 Hz, 1H), 7.87 (s, 1H), 7.69 (d, J = 9.4 Hz, 1H), 7.24 (dd, J = 9.2, 6.8 Hz, 4H), 7.11 (m, 3H), 5.66 (dd, J = 9.6, 5.8 Hz, 1H), 3.80 (s, 3H), 3.68 (dd, J = 14.5, 5.7 Hz, 1H), 3.45 (dd, J = 14.4, 9.6 Hz, 1H). **^{13}C NMR (101 MHz, CD_3CN):** δ 168.6, 135.3, 130.8, 129.9, 129.9, 128.7, 126.6, 126.3, 124.7, 119.4, 119.1, 114.1, 65.1, 54.3, 39.5. **$[\alpha]^D_{25}$**= -39.1 (c= 1.02, MeCN). **HR-MS (ESI):** calcd. For $C_{17}H_{17}N_2O_2$ $[M]^+$ 281.1290, found 281.1295. **UV (MeCN) λ_{max}, nm (ε):** 325 (sh, 447), 310 (sh, 1032), 283 (2325), 273 (2295), 260 (sh, 1496), 236 (sh, 1122),

228 (sh, 1683), 203 (11991**). IR (dry film):** 3110, 2980, 1750 1658, 1551, 1456, 1281, 1230, 1154, 843 cm^{-1}. **Anal. Calcd.** for $C_{17}H_{17}F_6N_2O_2P$: C, 47.90; H, 4.02; N, 6.57. Found: C, 47.77; H, 3.73; N, 6.48.

(*R*,*S*)-2-(1-Methoxy-1-oxo-3-phenylpropan-2-yl)-2H-imidazo[1,5-a]pyridinium hexafluorophosphate

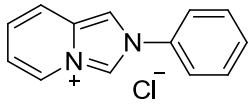


Following general procedure (A), DL-phenylalanine methyl ester (0.42 g, 2.3 mmol), formalin (0.26 mL, 3.5 mmol), 2.94 M HCl in EtOH (0.80 mL, 2.3 mmol) and picolinaldehyde (0.22 mL, 2.3 mmol) were combined in EtOH (3.9 mL) and maintained at rt for 4 hours. Salt metathesis with KPF_6 resulted in a semi-solid which was extracted with ethyl acetate (3x10mL). The combined organic layers were then washed with H_2O (2 mL), dried over magnesium sulfate, concentrated and placed under high vac (0.2 Torr) to remove residual water, providing (*R,S*)-2-(1-methoxy-1-oxo-3-phenylpropan-2-yl)-2H-imidazo[1,5-a]pyridinium hexafluorophosphate (0.86 g, 2.0 mmol, 86% yield) as a tan sticky foam.

^{1}H NMR (400 MHz, CD_3CN): δ 8.92 (d, *J* = 0.7 Hz, 1H), 8.08 (d, *J* = 7.2 Hz, 1H), 7.74 (s, 1H), 7.51 (t, *J* = 12.3 Hz, 1H), 7.14 – 7.02 (m, 4H), 7.02 – 6.88 (m, 3H), 5.53 (dd, *J* = 9.6, 5.8 Hz, 1H), 3.65 (s, 3H), 3.54 (dd, *J* = 14.5, 5.8 Hz, 1H), 3.31 (dd, *J* = 14.4, 9.6 Hz, 1H). **^{13}C NMR (101 MHz, CD_3CN)**: δ 168.7, 135.3, 130.8, 129.9, 129.9, 128.7, 126.6, 126.3, 124.7, 119.4, 119.1, 114.1, 65.2, 54.3, 39.5. **HR-MS (ESI):** calcd. For $C_{17}H_{17}N_2O_2$ $[M]^+$ 281.1290, found 281.1277. **UV (MeCN) λ_{max}, nm (ε):** 325 (sh, 447), 310 (sh, 1032), 283 (2325), 273 (2295), 260 (sh, 1496), 236 (sh, 1122), 228 (sh, 1683), 203 (11991). **IR (dry film):** 3110, 2980, 1750 1658, 1551, 1456, 1281, 1230, 1154, 843 cm^{-1}. **Anal. Calcd.** for

$C_{17}H_{17}F_6N_2O_2P$: C, 47.90; H, 4.02; N, 6.57. Found: C, 47.88; H, 3.94; N, 6.60.

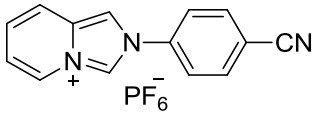
2-Phenylimidazo[1,5-a]pyridinium chloride (Table 2, Entry 10)



(Known compound, corresponds with previously reported spectra,[4] also previously reported as the $HClO_4$[5]) Following general procedure (A), aniline (0.40 mL, 4.3 mmol), formalin (0.49 mL, 6.5 mmol), 2.94 M HCl in EtOH (1.5 mL, 4.3 mmol) and picolinaldehyde (0.41 mL, 4.3 mmol) were combined in EtOH (7.2 mL) and maintained at rt for 15 minutes. The reaction mixture was then concentrated and dried under high vac. The resulting crude oil was the dissolved in hot acetonitrile, filtered hot and recrystallized from acetonitrile and tetrahydrofuran, providing 2-phenylimidazo[1,5-a]pyridinium chloride (0.86 g, 3.7 mmol, 86% yield) as a light orange solid.

^{1}H NMR (400 MHz, CD_3OD): δ 10.13 (s, 1H), 8.60 (d, J = 7.1 Hz, 1H), 8.56 (s, 1H), 7.95 – 7.85 (m, 3H), 7.78 – 7.63 (m, 3H), 7.37 (t, J = 8.0 Hz, 1H), 7.27 (t, J = 6.8 Hz, 1H). **^{13}C NMR (101 MHz, CD_3OD)**: δ 136.7, 132.2, 132.0, 131.7, 126.6, 126.5, 125.2, 124.1, 119.7, 119.5, 113.7. **HR-MS (ESI):** calcd. For $C_{13}H_{11}N_2$ $[M]^+$ 195.0922, found 195.0914. **UV (H_2O) λ_{max}, nm (ε):** 313 (sh, 1204), 285 (sh, 2302), 273 (sh, 2757), 236 (7036). 206 (9815). **IR (dry film):** 1642, 1514, 1504, 1464, 1208, 1086 cm^{-1}.

2-(4-Cyanophenyl)imidazo[1,5-a]pyridinium hexafluorophosphate (Table 2, Entry 11)

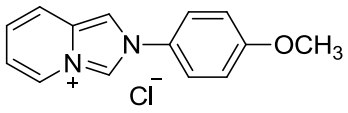


Following general procedure (B), 4-aminobenzonitrile (0.32 g, 2.7 mmol) and paraformaldehyde

(0.12 g, 4.1 mmol) were stirred in EtOH (4.6 mL) for 3.5 hours at rt, at which point the solution became homogeneous. 2.94 M HCl in EtOH (0.93 mL, 2.7 mmol) and picolinaldehyde (0.26 mL, 2.7 mmol) were then added and the reaction was maintained at rt for 12 hours. The resulting heterogeneous mixture was concentrated under a stream of N_2 and the crude solid dissolved in hot H_2O (22 mL), followed by hot filtration, precipitation and salt metathesis with KPF_6. The resulting solid was filtered, washed with water (2.0 mL) and dried under high vac (0.2 Torr) to provide 2-(4-cyanophenyl)imidazo[1,5-a]pyridinium hexafluorophosphate (0.70 g, 1.9 mmol, 70% yield) as a tan solid. It is notable that the chloride salt may be obtained under identical conditions by foregoing concentration and diluting the heterogeneous reaction mixture with Et_2O (5 mL), filtering, rinsing with Et_2O (5 mL) and drying under high vac (0.2 Torr) in a 66% yield

^{1}H NMR (500 MHz, DMSO): δ 10.42 (d, J = 1.6 Hz, 1H), 8.82 (s, 1H), 8.60 (d, J = 7.1 Hz, 1H), 8.27 (d, J = 8.7 Hz, 2H), 8.14 (d, J = 8.7 Hz, 2H), 7.95 (d, J = 9.4 Hz, 1H), 7.37 (dd, J = 9.3, 6.7 Hz, 1H), 7.30 (dd, J = 10.0, 3.7 Hz, 1H). **^{13}C NMR (126 MHz, DMSO)**: δ 138.3, 134.5, 129.9, 126.4, 125.5, 124.2, 123.9, 118.6, 118.4, 117.7, 113.2, 112.2. **HR-MS (ESI):** calcd. For $C_{14}H_{10}N_3$ $[M]^+$ 220.0875, found 220.0875. **UV (MeCN) λ_{max}, nm (ε):** 316 (sh, 1501), 288 (sh, 2989), 276 (sh, 4270), 246 (12888), 205 (14420). IR (KBr): 3157, 3116, 2237, 1659, 1608, 1556, 1519, 1205, 844, 788, 569 cm^{-1}. **Anal. Calcd.** for $C_{14}H_{10}F_6N_3P$: C, 46.04; H, 2.76; N, 11.51. Found: C, 46.32; H, 2.64; N, 11.23.

2-(4-Methoxyphenyl)imidazo[1,5-a]pyridinium chloride (Table 2, Entry 12)

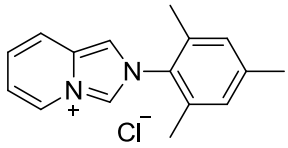


(Known compound, corresponds with previously reported spectra)[4] Following general procedure (A), freshly recrystallized p-anisidine (047 g, 3.8 mmol), formalin (0.43 mL, 5.8 mmol), 2.94 M HCl in EtOH (1.3 mL, 3.8 mmol) and picolinaldehyde (0.37 mL, 3.8 mmol) were combined in EtOH (7.7

mL) and maintained at rt for 12 hours. The resulting heterogeneous mixture was then concentrated under a stream of N_2 and the crude solid was recrystallized from H_2O to provide 2-(4-methoxyphenyl)imidazo[1,5-a]pyridinium chloride (0.92 g, 3.5 mmol, 92% yield) as white needles.

^{1}H NMR (500 MHz, DMSO): 10.77 (d, J = 1.5 Hz, 1H), 8.79 (s, 1H), 8.72 (dd, J = 7.1, 0.9 Hz, 1H), 7.92 – 7.82 (m, 3H), 7.31 (dd, J = 9.3, 6.5 Hz, 1H), 7.24 (td, J = 7.0, 0.9 Hz, 1H), 7.19 (d, J = 9.0 Hz, 2H), 3.84 (s, 3H).**^{13}C NMR (126 MHz, DMSO)**: δ 160.4, 129.6, 128.0, 125.6, 125.1, 124.1, 124.1, 118.2, 117.9, 115.3, 112.1, 55.8. **HR-MS (ESI):** calcd. For $C_{14}H_{13}N_2O$ $[M]^+$ 225.1028, found 225.1031. **UV (H_2O) λ_{max}, nm (ε):** 281 (sh, 3682), 271 (sh, 5461), 261 (6055), 203 (1170). **IR (KBr):** 3059, 2979, 1656, 1546, 1518, 1258, 1186, 1023, 810, 745 cm^{-1}.

2-Mesitylimidazo[1,5-a]pyridinium chloride (Table 2, Entry 13)

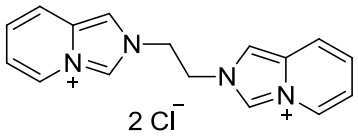


(Previously reported as the HBr and triflic acid salt[6]) Following general procedure (A), 2,4,6-trimethylaniline (0.52 μL, 3.7 mmol), formalin (0.41 mL, 5.5 mmol), 2.94 M HCl in EtOH (1.3 mL, 3.7 mmol) and picolinaldehyde (0.37 mL, 3.8 mmol) were combined in EtOH (7.7 mL) and maintained at rt for 12 hours. The resulting heterogeneous mixture was then filtered and washed with EtOH (3 mL) and diethyl ether (10 mL). The addition of diethyl ether to the filtrate resulted in further precipitate which was collected. The collected solids were combined to provide 2-mesitylimidazo[1,5-a]pyridinium chloride (0.91 g, 3.3 mmol, 91% yield) as a light orange solid.

^{1}H NMR (400 MHz, CD_3OD): δ 9.78 (s, 1H), 8.62 (d, J = 6.9 Hz, 1H), 8.20 (s, 1H), 7.93 (d, J = 9.3 Hz, 1H), 7.41 (t, J = 7.8 Hz, 1H), 7.31 (d, J = 6.5 Hz, 1H), 7.19 (s, 2H), 2.41 (s, 3H), 2.11 (s, 6H). **^{13}C NMR**

(101 MHz, CD_3OD): δ 142.9, 135.6, 132.9, 132.2, 130.7, 128.6, 126.7, 125.5, 119.6, 119.5, 116.2, 21.2, 17.2. **HR-MS (ESI):** calcd. For $C_{16}H_{17}N_2$ $[M]^+$ 237.1392, found 237.1390. **UV (H_2O) λ_{max}, nm (ε):** 323 (sh, 504), 308 (sh, 1157), 295 (sh, 1480), 283 (2750), 272 (2947), 262 (sh, 2347), 246 (sh, 2017), 236 (sh, 2356) 203 (19706). **IR (dry film):** 3049, 2990, 2945, 1648, 1538, 1497, 1492, 1368, 1344, 1213, 1203, 1159, 842, 766, 677 cm^{-1}.

2,2'-(Ethane-1,2-diyl)bis(imidazo[1,5-a]pyridinium) dichloride (Table 3, Entry 2)

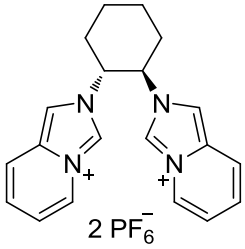


(Known compound[7] also reported as the HBr salt.[8]) Following general procedure (A), ethylenediamine (0.20 mL, 3.0 mmol), formalin (0.70 g, 9.0 mmol), 2.94 M HCl in EtOH (2.0 mL, 6.0 mmol) and picolinaldehyde (0.57 mL, 6.0 mmol) were combined in EtOH (5.0 mL) and maintained at rt for 12 hours. The resulting heterogeneous mixture was then filtered and washed with EtOH (2.0 mL) and diethyl ether (10 mL). The addition of diethyl ether to the filtrate resulted in further precipitate which was collected. The collected solids were combined to provide 2,2'-(ethane-1,2-diyl)bis(imidazo[1,5-a]pyridinium) dichloride (0.99 g, 3.0 mmol, 99% yield) as a cream colored solid. This compound has been previously reported,[7] however the ^{1}H NMR data reported is significantly different from that of our material. We are confident in the identity of this compound, based on similarity to related compounds produced by ourselves as well as other research groups.[8]

^{1}H NMR (400 MHz, DMSO): δ 10.04 (s, 2H), 8.70 (d, J = 7.0 Hz, 2H), 8.38 (s, 2H), 7.85 (d, J = 9.3 Hz, 2H), 7.33 – 7.23 (m, 2H), 7.17 (t, J = 6.6 Hz, 2H), 5.26 (s, 4H). **^{13}C NMR (101 MHz, DMSO):** δ 129.2,

127.3, 124.7, 124.4, 118.3, 117.5, 113.7, 49.7. **HR-MS (ESI):** calcd. For $C_{16}H_{15}Cl_2N_4$ $[M-H]^-$ 333.0679, found 333.0673. **UV (H_2O) λ_{max}, nm (ε):** 321 (sh, 1346), 307 (sh, 2898), 297 (sh, 3452), 282 (6003), 271 (5668), 260 (sh, 3536), 244 (sh, 1518), 234 (sh, 2050), 227 (sh, 2323), 203 (24613). **IR (dry film):** 3119, 3091, 3052, 3008, 1654, 1624, 1546, 1460, 1354, 1149, 1130, 817, 804, 747, 640, 606 cm^{-1}.

2,2'-((*1R,2R*)-Cyclohexane-1,2-diyl)bis(imidazo[1,5-a]pyridinium) bis-hexafluorophosphate (Table 3, Entry 3)



Two procedures were performed to obtain 2,2'-((*1R,2R*)-cyclohexane-1,2-diyl)bis(imidazo[1,5-a]pyridinium) bis-hexafluorophosphate, The first of which produced the material in an 86% yield following a modified general procedure (B), the second of which produced this material in an 80% yield following a modified general procedure (C). The latter procedure was included to demonstrate the ability to use the corresponding HCl salts of amine starting materials. It is noted, however, that HCl salts should not be used with paraformaldehyde (general method (B)) as we have observed that basic amines are necessary for fully solvating paraformaldehyde under our conditions.

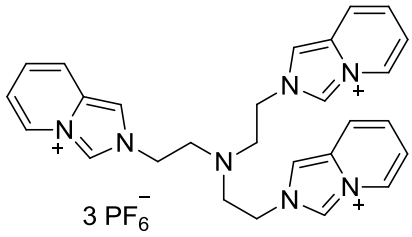
Following general procedure (B), which was modified by the use of 2 equiv of picolinaldehyde, 2 equiv of HCl (1.94 M in EtOH), 3 equiv of paraformaldehyde and 2.2 equiv of KPF_6. (1*R*,2*R*)-cyclohexane-1,2-diaminiium chloride (46 mg, 0.40 mmol) and paraformaldehyde (36 mg, 1.2 mmol) were stirred in 0.80 mL of EtOH at room temperature for 12 hours at which point the

solution became homogeneous. 2.95 M HCl in EtOH (0.27 mL, 0.80 mmol) and picolinaldehyde (76 μL, 0.80 mmol) were then added and the reaction was maintained at rt for 4 hours. Following salt metathesis with KPF_6 2,2'-((*1R,2R*)-cyclohexane-1,2-diyl)bis(imidazo[1,5-a]pyridinium) bis-hexafluorophosphate (0.21 g, 0.34 mmol, 86% yield) was obtained as a tan solid.

Following general procedure (C), which was modified by the use of the bis-HCl salt of (1*R*,2*R*)-cyclohexane-1,2-diamine, (1*R*,2*R*)-cyclohexane-1,2-diaminium chloride (0.15 g, 0.82 mmol), formalin (0.18 mL, 2.5 mmol), and picolinaldehyde (0.16 mL, 1.6 mmol) were combined in EtOH (1.6 mL) and maintained at rt for 6 hours. Following salt metathesis with KPF_6 2, 2'-((*1R,2R*)-cyclohexane-1,2-diyl)bis(imidazo[1,5-a]pyridinium) bis-hexafluorophosphate (0.40 g, 0.66 mmol, 80% yield) was obtained as a tan solid.

^{1}H NMR (400 MHz, CD_3CN): δ 8.93 (s, 2H), 8.15 (d, J = 7.2 Hz, 2H), 7.85 (s, 2H), 7.65 (d, J = 9.4 Hz, 2H), 7.22 (dd, J = 9.3, 6.8 Hz, 2H), 7.07 (t, J = 6.9 Hz, 2H), 5.23 – 4.99 (m, 2H), 2.43 (d, J = 13.8 Hz, 2H), 2.27 – 2.12 (m, 2H), 2.07 (dd, J = 9.2, 4.0 Hz, 2H), 1.80 – 1.63 (m, 2H**). ^{13}C NMR (101 MHz, CD_3CN)**: δ 132.0, 126.6, 125.9, 125.0, 119.3, 119.2, 111.9, 64.8, 33.9, 24.8. $[\alpha]^{D}_{25}$= -64.3 (c= 1.01, MeCN). **HR-MS (ESI):** calcd. for $C_{20}H_{22}F_6N_4P$ $[M+PF_6]^+$ 463.1486, found 463.1476. **UV (MeCN) λ_{max}, nm (ε):** 321 (sh, 940.), 310 (sh, 1708), 297 (sh, 2369), 281 (4130), 273 (4097), 261 (sh, 2801), 235 (sh, 1436), 256 (sh, 1767), 244 (sh, 1153), 208 (14547**). IR (dry film):** 2982, 2087, 1642, 1153 cm^{-1}.

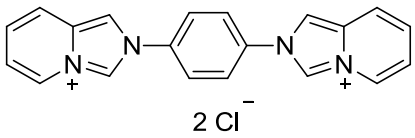
2,2',2''-(Nitrilotris(ethane-2,1-diyl))tris(imidazo[1,5-a]pyridin-2-ium) tris-hexafluorophosphate (Table 3, Entry 4)



Following general procedure (C), *N*,*N*-bis(aminomethyl)methanediamine (0.34 mL, 2.8 mmol), formalin (0.32 mL, 4.2 mmol), were added to EtOH (4.7 mL), followed by the simultaneous addition of 2.94 M HCl in EtOH (0.96 mL, 2.8 mmol) and picolinaldehyde (0.27 mL, 2.8 mmol). The reaction was then maintained at rt for 4 hours. Following salt metathesis with KPF_6, 2,2',2''-(nitrilotris(ethane-2,1-diyl))tris(imidazo[1,5-a]pyridin-2-ium) tris-hexafluorophosphate (0.93 g, 1.1 mmol, 93% yield) was obtained as a white solid.

^{1}H NMR (400 MHz, CD_3CN): δ 9.02 (s, 3H), 8.26 (dd, J = 7.2, 0.9 Hz, 3H), 7.75 (s, 3H), 7.65 (d, J = 9.4 Hz, 3H), 7.22 (ddd, J = 9.4, 6.7, 0.6 Hz, 3H), 7.10 (td, J = 7.1, 1.0 Hz, 3H), 4.46 (t, J = 6.6 Hz, 6H), 3.20 (t, J = 6.6 Hz, 6H). **^{13}C NMR (101 MHz, CD_3CN)**: δ 131.1, 126.5, 126.2, 124.7, 119.1, 119.0, 114.2, 53.4, 48.7. **HR-MS (ESI):** calcd. For $C_{27}H_{30}F_{12}N_7P_2$ $[M+2PF_6]^+$ 742.1846, found 742.1838. **UV (MeCN) λ_{max}, nm (ε):** 326 (sh, 1398), 311 (sh, 3115), 300 (sh, 3,604), 283 (6314), 273 (6285), 262 (sh, 3370), 235 (4252), 228 (sh, 4461), 208 (18162). **IR (dry film):** 3160, 2864, 1658, 1564, 1549, 1456, 1413, 1355, 1250, 1157, 1136, 844, 740 cm^{-1}. **Anal. Calcd.** for $C_{27}H_{30}F_{18}N_7P_3$: C, 36.54; H, 3.41; N, 11.05. Found: C, 36.31; H, 3.44; N, 11.304.

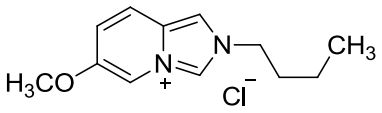
2,2'-(1,4-Phenylene)bis(2H-imidazo[1,5-a]pyridin-4-ium) dichloride (Table 3, Entry 1)



Following general procedure (C), which was modified by running at 0.35 M in EtOH, *p*-phenylenediamine (0.28 g, 2.6 mmol), formalin (0.59 mL, 7.8 mmol), 2.94 M HCl in EtOH (1.8 mL, 5.2 mmol) and picolinaldehyde (0.50 mL, 5.2 mmol) were combined in EtOH (6.0 mL) and maintained at rt for 12 hours. The resulting precipitate was then filtered and washed with EtOH (3.0 mL) and diethyl ether (2 mL) to provide 2,2'-(1,4-phenylene)bis(2H-imidazo[1,5-a]pyridin-4-ium) dichloride (0.81 mg, 2.1 mmol, 81% yield) as a cream colored solid.

^{1}H NMR (400 MHz, DMSO): δ 10.72 (d, *J* = 1.1 Hz, 2H), 8.92 (s, 2H), 8.69 (d, *J* = 7.1 Hz, 2H), 8.33 (s, 4H), 7.97 (d, *J* = 9.2 Hz, 2H), 7.39 (dd, *J* = 8.8, 6.7 Hz, 2H), 7.31 (td, *J* = 7.0, 0.9 Hz, 2H). **^{13}C NMR (126 MHz, DMSO)**: δ 136.2, 129.8, 126.4, 125.5, 124.7, 124.2, 118.5, 118.4, 112.3. **HR-MS (ESI):** calcd. For $C_{20}H_{15}Cl_2N_4$ $[M-H]^-$ 381.0679, found 381.0668. **UV (H_2O) λ_{max}, nm (ε):** 314 (sh, 2392), 288 (sh, 5506), 275 (sh, 8283), 250 (13574), 204 (20312). **IR (KBr):** 3120, 3057, 1631, 1548, 1527, 1384, 1231, 1086, 838, 626 cm^{-1}.

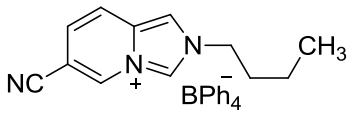
2-Butyl-6-methoxyimidazo[1,5-a]pyridinium chloride (Table 4, entry 1 (7a))



Following general procedure (B), n-butylamine (28. μL, 0.29 mmol) and paraformaldehyde (13 mg, 0.43 mmol) were stirred in EtOH (0.48 mL) at room temperature for 2 hours at which point the solution became homogeneous. 2.95 M HCl in EtOH (88 mL, 0.29 mmol) and picolinaldehyde (39 μL, 0.286 mmol) were then added and the reaction was maintained at rt for 2 hours. The reaction mixture was then concentrated and the crude solid recrystallized from acetone, providing 2-butyl-6-methoxyimidazo[1,5-a]pyridinium chloride (53 mg, 0.22 mmol, 78% yield) as a white crystalline solid.

^{1}H NMR (400 MHz, DMSO): 9.95 (d, J = 1.0 Hz, 1H), 8.53 (d, J = 0.8 Hz, 1H), 8.35 (s, 1H), 7.82 (d, J = 10.0 Hz, 1H), 7.07 (dd, J = 10.0, 2.0 Hz, 1H), 4.51 (t, J = 7.2 Hz, 2H), 3.83 (s, 3H), 1.85 (dd, J = 14.8, 7.4 Hz, 2H), 1.28 (dd, J = 15.0, 7.5 Hz, 2H), 0.90 (t, J = 7.4 Hz, 3H). **^{13}C NMR (101 MHz, DMSO)**: δ 151.3, 126.7, 126.0, 121.4, 118.8, 114.1, 104.7, 56.4, 49.5, 31.8, 18.8, 13.3. **HR-MS (ESI):** calcd. For $C_{12}H_{17}N_2O$ $[M]^+$ 205.1341, found 205.1344. **UV (H_2O) λ_{max}, nm (ε):** 324 (sh, 479), 308 (sh, 980), 287 (1306), 276 (1226), 264 (sh, 875), 249(sh, 2225), 240 (3284), 233 (sh, 3331), 221 (6412). **IR (dry film):** 2981, 1654, 1642, 1460, 1365, 1243, 1152 cm^{-1}.

2-Butyl-6-cyanoimidazo[1,5-a]pyridinium tetraphenylborate (Table 4, entry 2 (7b))

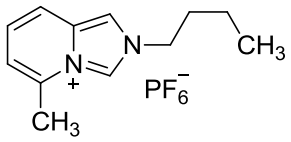


Following general procedure (A), n-butylamine (63 μL, 0.64 mmol), formalin (71 μL, 0.10 mmol), 2.94 M HCl in EtOH (0.22 mL, 4.3 mmol) and 5-cyanopicolinaldehyde (83 mg, 0.64 mmol) were combined in EtOH (1.3 mL) and maintained at rt for 4 days. The reaction mixture was then concentrated and dried under high vac (0.2 Torr). The resulting crude oil was then dissolved in MeOH (1.5 mL) and sodium tetraphenyl borate (0.24 g, 0.70 mmol) in MeOH (1.5 mL) was added dropwise while stirring. The resulting precipitate was filtered and washed with MeOH (1.0 mL) and Et_2O (2.0 mL), providing 2-butyl-6-cyanoimidazo[1,5-a]pyridinium tetraphenylborate (0.14 g, 0.27 mmol, 43% yield) as a tan solid.

^{1}H NMR (400 MHz, DMSO): δ 9.83 (s, 1H), 9.36 (d, *J* = 1.0 Hz, 1H), 8.30 (s, 1H), 7.95 (d, *J* = 9.6 Hz, 1H), 7.40 (dt, *J* = 12.1, 6.0 Hz, 1H), 7.29 – 7.15 (m, 8H), 6.94 (t, *J* = 7.4 Hz, 8H), 6.79 (dd, *J* = 17.4, 10.2 Hz, 4H), 4.48 (t, *J* = 7.1 Hz, 2H), 1.97 – 1.79 (m, 2H), 1.30 (dq, J = 14.8, 7.4 Hz, 2H), 0.92 (t, *J* = 7.4 Hz, 3H). **^{13}C NMR (101 MHz, DMSO)**: δ 163.4 (q, *J* = 50 Hz), 135.5 (q, *J* = 1 Hz), 132.8, 128.8,

128.3, 125.3 (q, *J* = 3 Hz), 123.0, 121.5, 119.6, 115.7, 114.9, 102.6, 50.2, 31.7, 18.7, 13.2. HR-MS (ESI): calcd. For $C_{12}H_{14}N_3$ $[M]^+$ 200.1188, found 200.1179. **UV (MeCN) λ_{max}, nm (ε):** 327 (922), 288 (2397), 277 (3225), 267 (3209), 223 (19129). **IR (KBr):** 3114, 3055, 2875, 2239, 1652, 1580, 1479, 1427, 1311, 1148, 1032, 848, 735, 708 cm^{-1}.

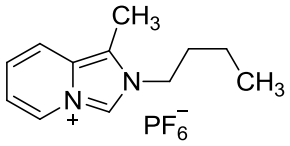
2-Butyl-5-methylimidazo[1,5-a]pyridinium hexafluorophosphate (Table 4, entry 3 (7c))



Following general procedure (A), n-butylamine (89 μL, 0.90 mmol), formalin (0.10 mL, 1.4 mmol), 2.94 M HCl in EtOH (0.30 mL, 0.90 mmol) and 6-methylpicolinaldehyde (0.14 mL, 0.90 mmol) were combined in EtOH (1.5 mL) and maintained at rt for 2.5 hours. Following salt metathesis with KPF_6, 2-butyl-5-methylimidazo[1,5-a]pyridinium hexafluorophosphate (0.27 g, 0.82 mmol, 92% yield) was obtained as a white solid.

^{1}H NMR (400 MHz, CD_3CN): δ 9.00 (s, 1H), 7.88 (d, J = 1.5 Hz, 1H), 7.64 (d, J = 9.4 Hz, 1H), 7.22 (dd, J = 9.3, 6.9 Hz, 1H), 6.96 (d, J = 6.8 Hz, 1H), 4.44 (t, J = 7.3 Hz, 2H), 2.62 (s, 3H), 1.96 (ddd, J = 10.0, 7.5, 5.0 Hz, 2H), 1.47 – 1.25 (m, 2H), 0.96 (t, J = 7.4 Hz, 3H). **^{13}C NMR (101 MHz, CD_3CN)**: δ 134.2, 131.9, 126.5, 124.6, 117.4, 116.7, 114.5, 51.7, 33.0, 20.1, 18.1, 13.7. **HR-MS (ESI):** calcd. For $C_{12}H_{17}N_2$ $[M]^+$ 189.1392, found 189.1398. **UV (MeCN) λ_{max}, nm (ε):** 323 (sh, 963), 309 (sh, 1846), 297 (sh, 1993), 284 (3077), 273 (2787), 263 (sh, 1750), 241 (sh, 720.6), 233 (sh, 1195), 226 (sh, 1416), 208 (11214). **IR (dry film):** 3174, 2957, 2877, 1664, 1564, 1462, 1445, 1393, 1169, 840, 797 cm^{-1}. **Anal. Calcd.** for $C_{12}H_{17}F_6N_2P$: C, 43.12; H, 5.13; N, 8.38. Found: C, 43.04; H, 4.74; N, 8.43.

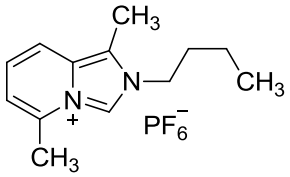
2-Butyl-1-methylimidazo[1,5-a]pyridinium hexafluorophosphate (Table 4, entry 4 (7d)



Following general procedure (B), n-butylamine (0.44 mL, 4.5 mmol) and paraformaldehyde (0.20 g, 6.7 mmol) were stirred in 7.4 mL of EtOH at room temperature for 2 hours at which point the solution became homogeneous. 2.98 M HCl in EtOH (1.5 mL, 4.5 mmol) and 2-acetylpyridine (0.50 mL, 4.5 mmol) were then added and the reaction was maintained at rt for 4.5 hours. Following salt metathesis with KPF_6, 2-butyl-1-methylimidazo[1,5-a]pyridinium hexafluorophosphate (1.4 g, 3.9 mmol, 88% yield) was obtained as a grey solid.

^{1}H NMR (400 MHz, CD_3CN): δ 8.97 (s, 1H), 8.19 (d, J = 7.1 Hz, 1H), 7.66 (d, J = 9.4 Hz, 1H), 7.13 (dd, J = 9.1, 6.8 Hz, 1H), 7.04 (t, J = 6.6 Hz, 1H), 4.33 (t, J = 7.5 Hz, 2H), 2.58 (s, 3H), 1.47 – 1.34 (dq, J = 14.8, 7.4 Hz, 2H),1.92-1.77 (m, 2H) 0.97 (t, J = 7.4 Hz, 3H). **^{13}C NMR (101 MHz, CD_3CN):** δ 128.3, 125.1, 124.4, 124.1, 123.1, 118.8, 118.7, 48.7, 32.4, 20.2, 13.8, 8.6. **HR-MS (ESI):** calcd. For $C_{12}H_{17}N_2$ $[M]^+$ 189.1392, found 189.1386. **UV (MeCN) λ_{max}, nm (ε):** 323 (sh, 1310), 311 (sh, 1438), 287 (2619), 277 (2590), 244 (sh, 725), 235 (sh, 1222), 227 (sh, 1459), 208 (10329). IR: 3159, 2962, 2937, 2878, 1660, 1551, 1475, 1465, 1431, 1338, 1152, 841 (s). **IR (dry film):** 3177, 2965, 2880, 1664, 1652, 1557, 1442, 1359, 839 cm^{-1}. **Anal. Calcd.** for $C_{12}H_{17}F_6N_2P$: C, 43.12; H, 5.13; N, 8.38. Found: C, 42.77; H, 4.77; N, 8.44.

2-Butyl-1,5-dimethylimidazo[1,5-a]pyridinium hexafluorophosphate (Table 4, entry 5 (7e))

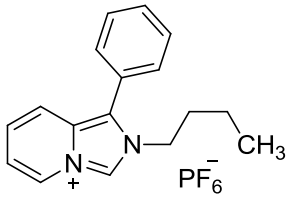


Following general procedure (B), n-butylamine (0.20 mL, 2.1 mmol) and paraformaldehyde (94

mg, 3.1 mmol) were stirred in EtOH (2.8 mL) at room temperature for 2 hours at which point the solution became homogeneous. 2.98 M HCl in EtOH (0.70 mL, 2.1 mmol) and 1-(6-methylpyridin-2-yl)ethanone (0.27 mL, 2.1 mmol) were then added and the reaction was maintained at rt for 5 hours. Following salt metathesis with KPF_6 2-butyl-1,5-dimethylimidazo[1,5-a]pyridinium hexafluorophosphate (0.51 g, 1.5 mmol, 70% yield) was obtained as a tan solid.

^{1}H NMR (400 MHz, CD_3CN): δ 8.91 (s, 1H), 7.60 (d, J = 9.4 Hz, 1H), 7.14 (dd, J = 9.3, 6.9 Hz, 1H), 6.92 (d, J = 6.8 Hz, 1H), 4.36 (t, J = 7.5 Hz, 2H), 2.61 (s, 3H), 2.58 (s, 3H), 1.98 – 1.84 (m, 2 H), 1.53 – 1.33 (dq, J = 14.8, 7.4 Hz, 2H), 0.98 (t, J = 7.4 Hz, 3H). **^{13}C NMR (101 MHz, CD_3CN)**: δ 133.6, 129.0, 125.0, 123.5, 123.2, 117.5, 116.3, 48.9, 32.6, 20.2, 17.9, 13.8, 8.8. **HR-MS (ESI):** calcd. For $C_{13}H_{19}N_2$ $[M]^+$ 203.1548, found 203.1541. **UV (MeCN) λ_{max}, nm (ε):** 337 (sh, 895), 321 (sh, 1837), 310 (sh, 1913), 289 (3095), 278 (2943), 267 (sh, 686), 244 (sh, 670), 235 (sh, 1309), 228 (sh, 1691), 210 (8491). **IR (dry film):** 3177, 2965, 2880, 1664, 1652, 1557, 1442, 1395, 1153, 839, 788, 750 cm^{-1}. **Anal. Calcd.** for $C_{13}H_{19}F_6N_2P$: C, 44.83; H, 5.50; N, 8.04. Found: C, 45.00; H, 5.53; N, 8.24.

2-Butyl-1-phenyl-2H-imidazo[1,5-a]pyridin-4-ium hexafluorophosphate (Table 4, entry 6 (7f))



Following general procedure (A), n-butylamine (0.35 mL, 3.5 mmol), formalin (0.39 mL, 5.2 mmol), 2.94 M HCl in EtOH (1.2 mL, 5.2 mmol) and 2-benzoylpyridine (0.64 g, 3.5 mmol) were combined in EtOH (2.5 mL) and maintained at rt for 12 hours. Following salt metathesis with KPF_6, 2-butyl-1-phenyl-2H-imidazo[1,5-a]pyridin-4-ium hexafluorophosphate (0.91 mg, 2.3 mmol, 91% yield) was obtained as a white solid.

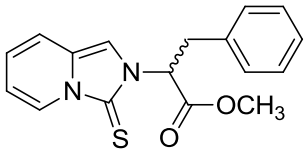
^{1}H NMR (400 MHz, DMSO): δ 9.90 (s, 1H), 8.61 (d, *J* = 6.5 Hz, 1H), 7.67 (s, 5H), 7.59 (d, *J* = 8.8 Hz, 1H), 7.32 – 7.18 (m, 2H), 4.45 (t, *J* = 7.3 Hz, 2H), 1.78 – 1.63 (m, 2H), 1.29 – 1.14 (m, 2H), 0.77 (t, *J* = 7.4 Hz, 3H). **^{13}C NMR (101 MHz, DMSO)**: δ 130.3, 130.3, 129.5, 127.1, 126.5, 125.1, 124.9, 124.2, 123.9, 117.8, 117.4, 47.8, 31.1, 18.7, 13.1. **HR-MS (ESI):** calcd. For $C_{17}H_{19}N_2$ $[M]^+$ 251.1548, found 251.1541. **UV (MeCN) λ_{max}, nm (ε):** 318 (2728), 288 (3559), 277 (3715), 265 (sh, 3206), 225 (sh, 4474), 205 (12338). **IR (dry film):** 3171, 2962, 2936, 2876, 1652, 1551, 1458, 1425, 1339, 1186, 1156, 840, 770, 756 cm^{-1}. **Anal. Calcd.** for $C_{17}H_{19}F_6N_2P$: C, 51.52; H, 4.83; N, 7.07. Found: C, 51.86; H, 4.58; N, 7.03.

Determination of Enantiopurity

In order to determine whether amine chirality is conserved in the course of the reaction (*S*)-2-(1-Methoxy-1-oxo-3-phenylpropan-2-yl)-2H-imidazo[1,5-a]pyridinium hexafluorophosphate and its corresponding racemate were derivitized to their corresponding thioureas for analysis by chiral HPLC. The enantiomeric excess of this compound was determined to be >99%. It was observed that the imidazolium precursor was reasonably base sensitive as enantiopurity was dependent on derivitization reaction conditions with reactions run at room temperature resulting in a partial racemization of the product (86% ee).

Chiral high performance liquid chromatography (HPLC) was performed on an Agilent 1090 equipped with a CHIRALPAK IB column from Chiral Technologies Inc. (250mm X 4.6mm, Cellulose tris(3,5-dimethylphenyl carbamate), flow = 0.5 mL/min, detector = UV, 254nm, temperature = 24°C) with i-PrOH/hexanes (1:1).

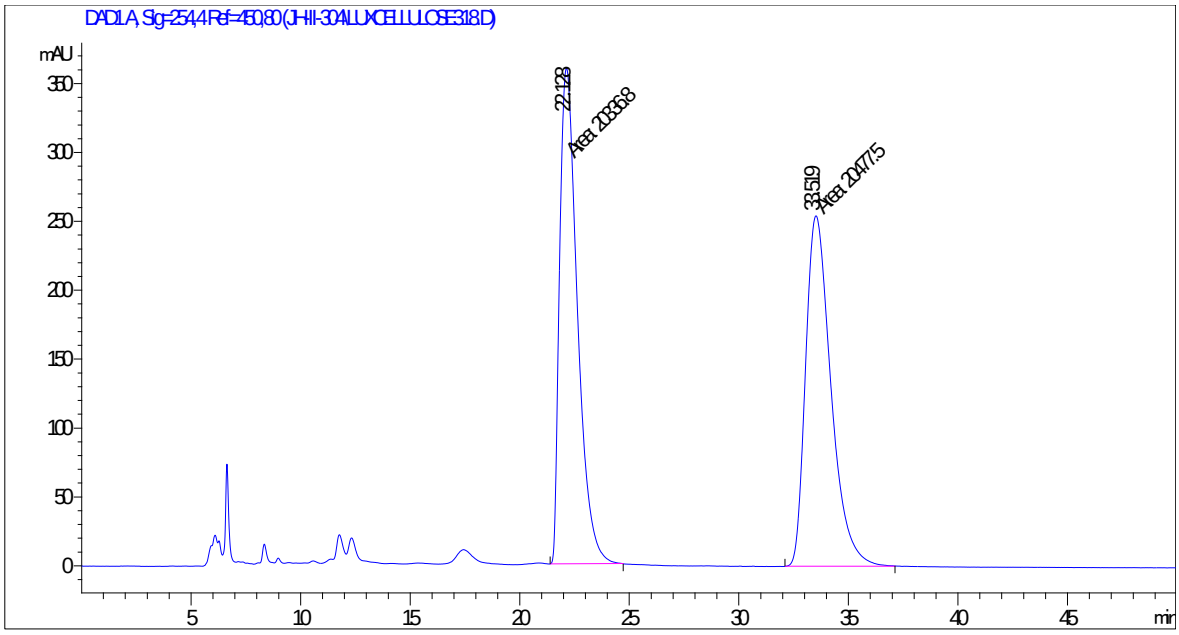
(*R,S*)-Methyl 3-phenyl-2-(3-thioxoimidazo[1,5-a]pyridin-2(3H)-yl)propanoate



(Based on literature procedure[9]) To a mixture of (*R*,*S*)-2-(1-Methoxy-1-oxo-3-phenylpropan-2-yl)-2H-imidazo[1,5-a]pyridinium hexafluorophosphate (57 mg, 0.12 mmol, 1 equiv) and sulfur flakes (12 mg, 0.37 mmol, 3 equiv) in THF (4 mL), NaH (60% in mineral oil, 5 mg, 0.12 mmol, 1 equiv) was added. The resulting mixture was stirred at room temperature for 2.5 hours, at which point of H_2O (3 mL) was added and the mixture was extracted with Et_2O (3x3 mL). The organic layers were combined, washed with H_2O (1.5 mL) and brine (1.5 mL) then dried over Na_2SO_4. The dried EtOAc was then concentrated and purified by column chromatography (SiO_2, ethyl acetate/Hexanes 20:80) to provide (*R,S*)-methyl 3-phenyl-2-(3-thioxoimidazo[1,5-a]pyridin-2(3H)-yl)propanoate (16 mg, 0.052 mmol, 42% yield) as a yellow oil.

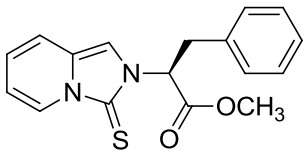
^{1}H NMR (500 MHz, $CDCl_3$): δ 8.23 (d, *J* = 7.4 Hz, 1H), 7.29 – 7.15 (m, 4H), 7.09 (d, *J* = 9.4 Hz, 1H), 7.05 (d, *J* = 5.6 Hz, 1H), 6.71 (dd, *J* = 9.3, 6.4 Hz, 1H), 6.49 (dd, *J* = 10.1, 3.7 Hz, 1H), 6.33 (t, *J* = 7.5 Hz, 1H), 3.73 (s, 3H), 3.50 (dd, *J* = 14.3, 7.1 Hz, 1H), 3.40 (dd, *J* = 14.3, 7.9 Hz, 1H). **^{13}C NMR (126 MHz, $CDCl_3$):** δ 169.9, 154.4, 135.1, 129.3, 128.8, 127.5, 127.3, 125.4, 122.6, 117.6, 112.4, 105.4, 60.0, 52.9, 38.0. **HR-MS (ESI):** calcd. For $C_{17}H_{16}N_2O_2S$ $[M+H]^+$ 313.1011, found 313.1022. **UV (MeCN) λ_{max}, nm (ε):** 387 (3326), 318 (11108), 306 (13481), 249 (sh, 1073), 284 (sh, 9087), 230 (40706). **IR (dry film):** 1741.9, 1643.7, 1408.5, 1351.9, 1331.1, 1213.1, 1163.9, 1073.8 cm^{-1}.

HPLC trace for (*R,S*)-methyl 3-phenyl-2-(3-thioxoimidazo[1,5-a]pyridin-2(3H)-yl)propanoate



#	Time	Area	Height	Width	Area%	Symmetry
1	22.128	20336.8	360.1	0.9413	49.828	0.588
2	33.519	20477.5	254.5	1.3413	50.172	0.665

(*S*)-Methyl 3-phenyl-2-(3-thioxoimidazo[1,5-a]pyridin-2(3H)-yl)propanoate

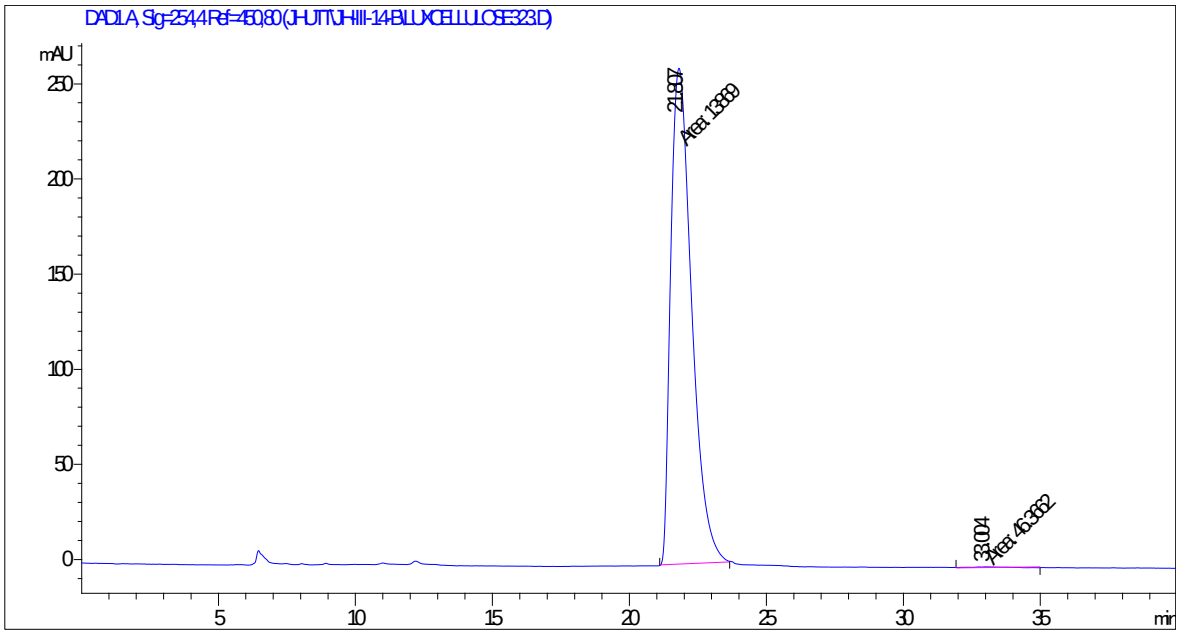


(Based on literature procedure[9]) To a mixture of (*S*)-2-(1-Methoxy-1-oxo-3-phenylpropan-2-yl)-2H-imidazo[1,5-a]pyridinium hexafluorophosphate (0.12 g, 0.28 mmol, 1 equiv) and sulfur flakes (27 mg, 0.84 mmol, 3 equiv) in THF (9.5 mL) was added NaH (60% in mineral oil, 10 mg, 0.25 mmol, 0.9 equiv). The resulting mixture was stirred at 0° C for 1 hour, at which point H_2O (6.0 mL) was added and the mixture was extracted with Et_2O (3x6 mL). The organic layers were combined, washed with H_2O (3 mL) and brine (3 mL) then dried over Na_2SO_4. The dried organic extract were then concentrated and purified by column chromatography (SiO_2, ethyl acetate/Hexanes 20:80) to

provide (*S*)-methyl 3-phenyl-2-(3-thioxoimidazo[1,5-a]pyridin-2(3H)-yl)propanoate (42 mg, 0.14 mmol, 50% yield) as a yellow oil.

^{1}H NMR (500 MHz, $CDCl_3$): δ 8.22 (d, *J* = 7.3 Hz, 1H), 7.28 – 7.13 (m, 4H), 7.08 (d, *J* = 9.4 Hz, 1H), 7.06 (s, 1H), 6.69 (dd, *J* = 8.1, 7.4 Hz, 1H), 6.48 (t, *J* = 6.8 Hz, 1H), 6.32 (t, *J* = 7.4 Hz, 1H), 3.72 (s, 3H), 3.50 (dd, *J* = 14.2, 7.0 Hz, 1H), 3.40 (dd, *J* = 14.1, 8.0 Hz, 1H). **^{13}C NMR (126 MHz, $CDCl_3$)**: δ 169.9, 154.5, 135.1, 129.3, 128.8, 127.4, 127.3, 125.4, 122.5, 117.6, 112.4, 105.4, 60.0, 52.9, 38.0. **HR-MS (ESI):** calcd. For $C_{17}H_{16}N_2O_2S$ $[M+H]^+$ 313.1011, found 313.1001. **UV (MeCN) λ_{max}, nm (ε):** 387 (3326), 318 (11108), 306 (13481), 249 (sh, 1073), 284 (sh, 9087), 230 (40706). **IR (dry film):** 1741.9, 1643.7, 1408.5, 1351.9, 1331.1, 1213.1, 1163.9, 1073.8 cm^{-1}.

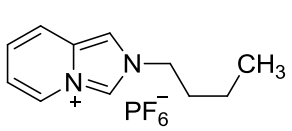
HPLC trace for (*S*)-methyl 3-phenyl-2-(3-thioxoimidazo[1,5-a]pyridin-2(3H)-yl)propanoate



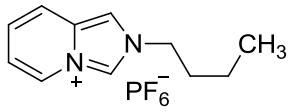
#	Time	Area	Height	Width	Area%	Symmetry
1	21.807	13869	260.7	0.8866	99.667	0.618
2	33.004	46.4	0.54	1.4334	0.333	01.522

^{1}H-NMR (Table 2, Entry 1)

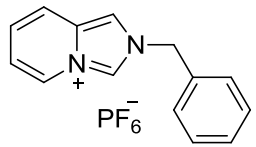
^{1}H and ^{13}C NMR Data of the product

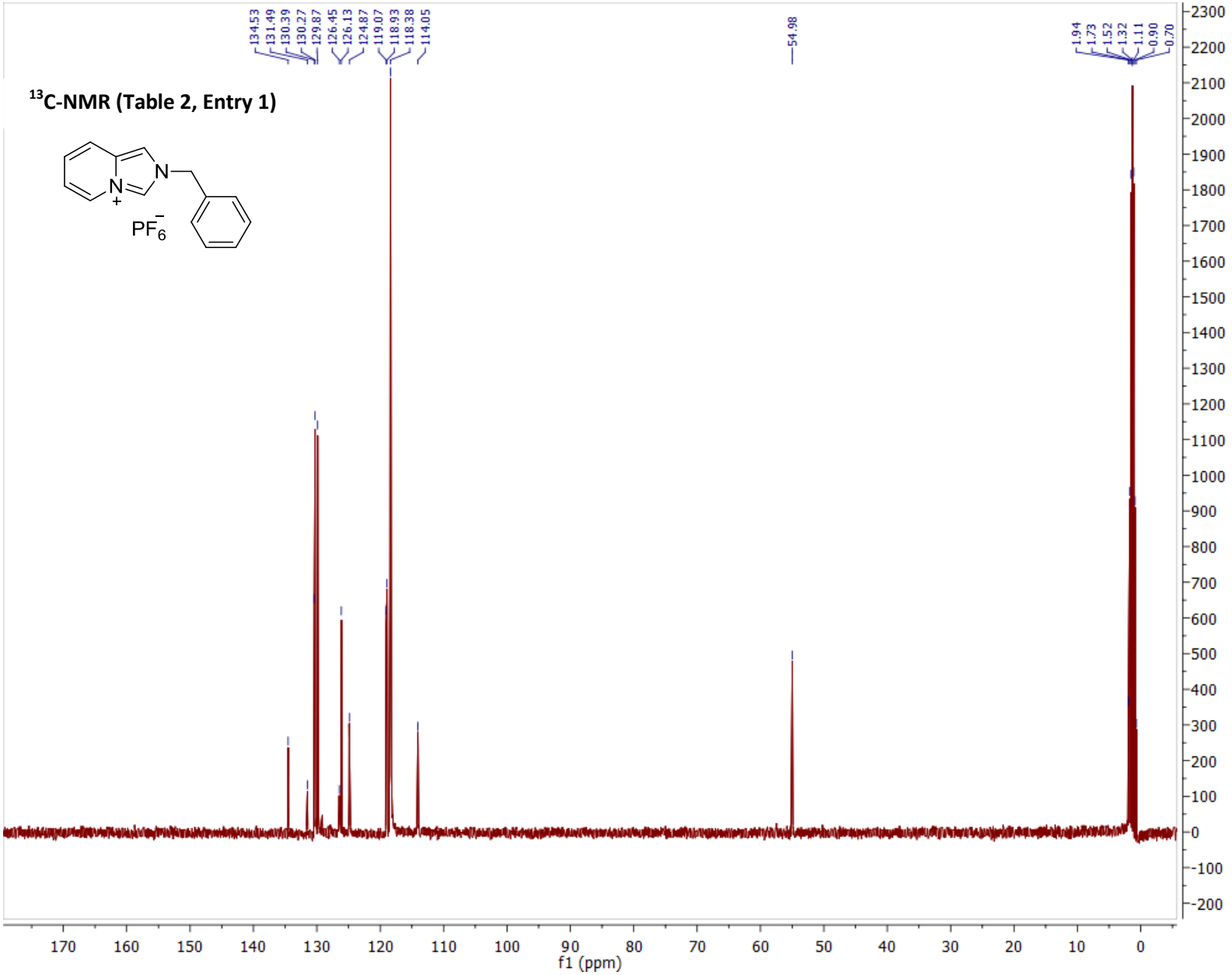


^{13}C-NMR (Table 2, Entry 1)

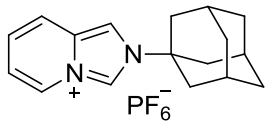


^{1}H-NMR (Table 2, Entry 2)

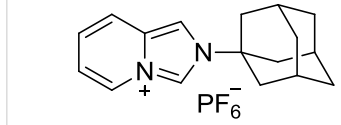



^{13}C-NMR (Table 2, Entry 1)
134.53
131.49
130.39
130.27
129.87
126.45
126.13
124.87
119.07
118.93
118.38
114.05
54.98
1.94
1.73
1.52
1.32
1.11
0.90
0.70
f1 (ppm)

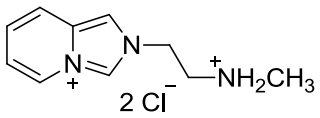
^{1}H-NMR (Table 2, Entry 9)



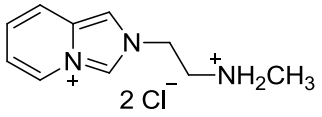
^{13}C-NMR (Table 2, Entry 9)



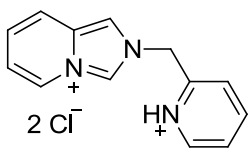
^{1}H-NMR (Table 2, Entry 3)



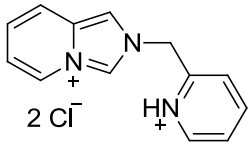
^{13}C-NMR (Table 2, Entry 3)



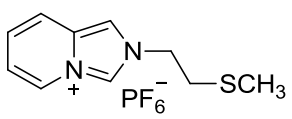
^{1}H-NMR (Table 2, Entry 4)



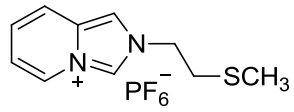
^{13}C-NMR (Table 2, Entry 4)



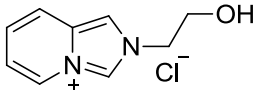
^{1}H-NMR (Table 2, Entry 5)



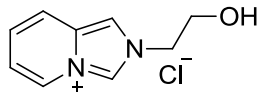
^{13}C-NMR (Table 2, Entry 5)



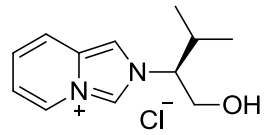
^{1}H-NMR (Table 2, Entries 11 and 12)



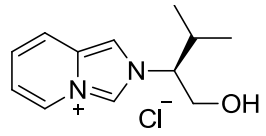
^{13}C-NMR (Table 2, Entries 11 and 12)



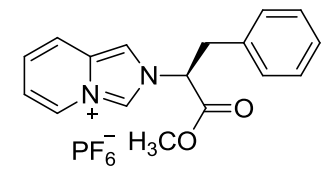
^{1}H-NMR (Table 2, Entry 6)



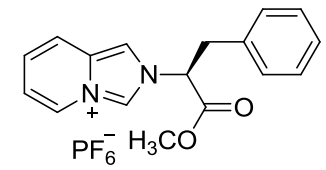
^{13}C-NMR (Table 2, Entry 6)



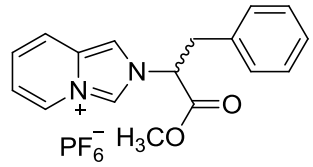
^{1}H-NMR (Table 2, Entry 7)



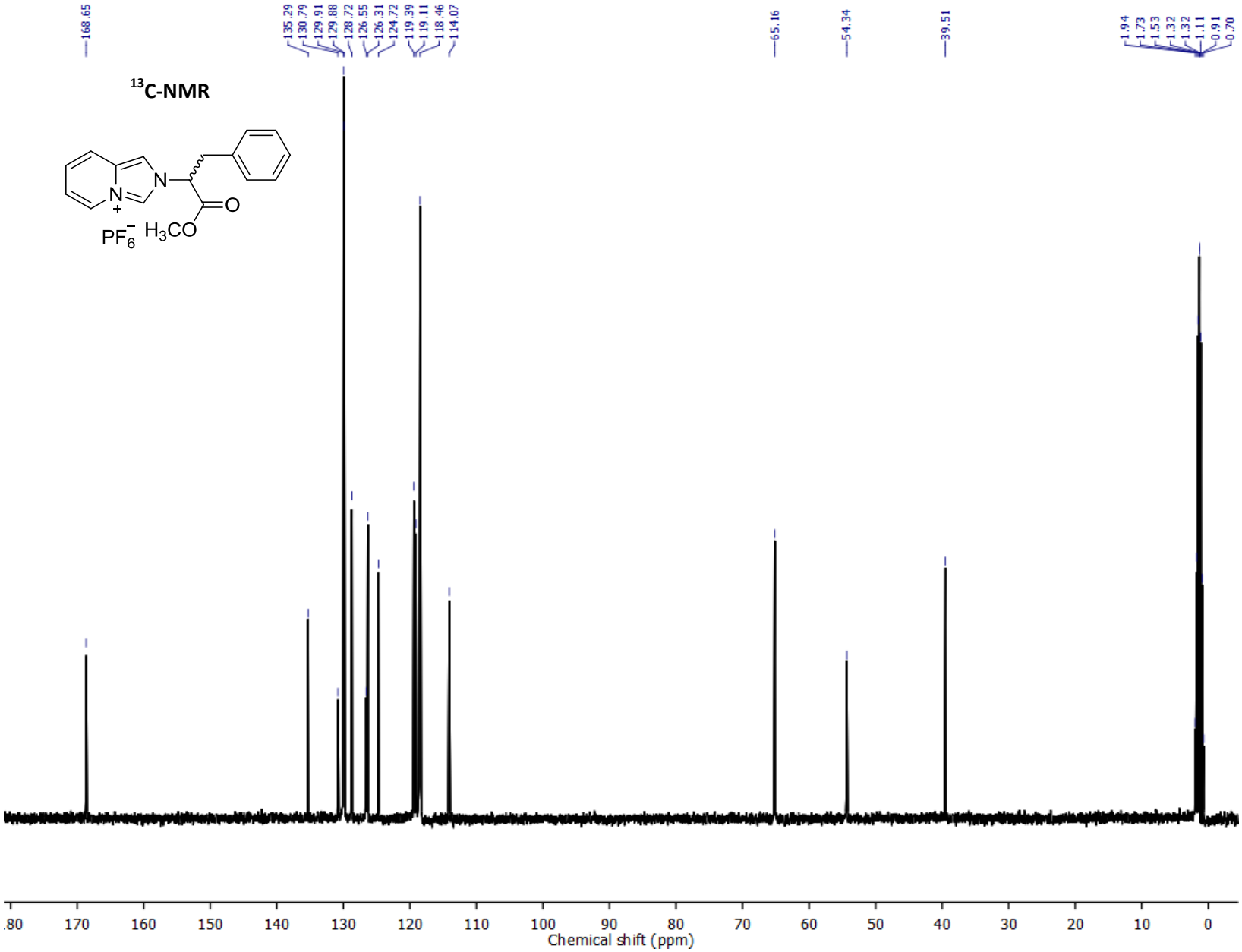
^{13}C-NMR (Table 2, Entry 7)



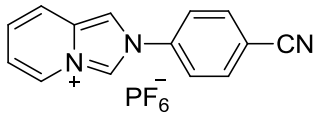
^{1}H-NMR


N
N
+
O
PF_6^-
H_3CO

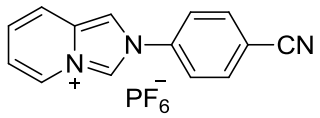
1.00
1.01
0.98
0.98
4.09
1.90
1.04
1.07
3.13
1.15
1.13
0.0
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
Chemical shift (ppm)


168.65
135.29
130.79
129.91
129.88
128.72
126.55
126.31
124.72
119.39
119.11
118.46
114.07
65.16
54.34
39.51
1.94
1.73
1.53
1.32
1.32
1.11
0.91
0.70
13C-NMR
PF6−
H3CO
Chemical shift (ppm)

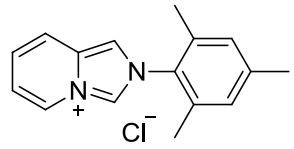
^{1}H-NMR (Table 2, Entry 11)



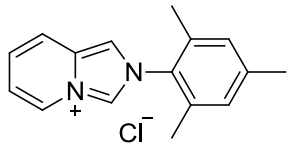
^{13}C-NMR (Table 2, Entry 11)



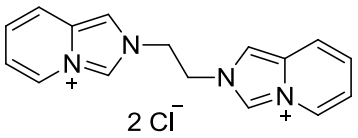
^{1}H-NMR (Table 2, Entry 13)



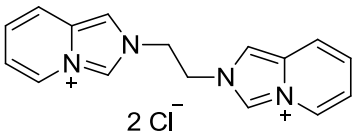
^{13}C-NMR (Table 2, Entry 13)



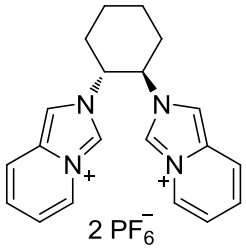
^{1}H-NMR (Table 3, Entry 2)



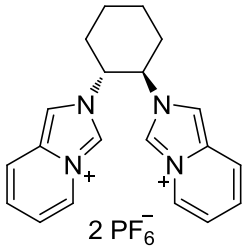
^{13}C-NMR (Table 3, Entry 2)



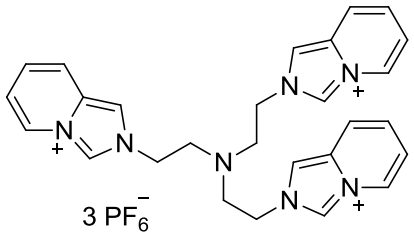
^{1}H-NMR (Table 3, Entry 3)

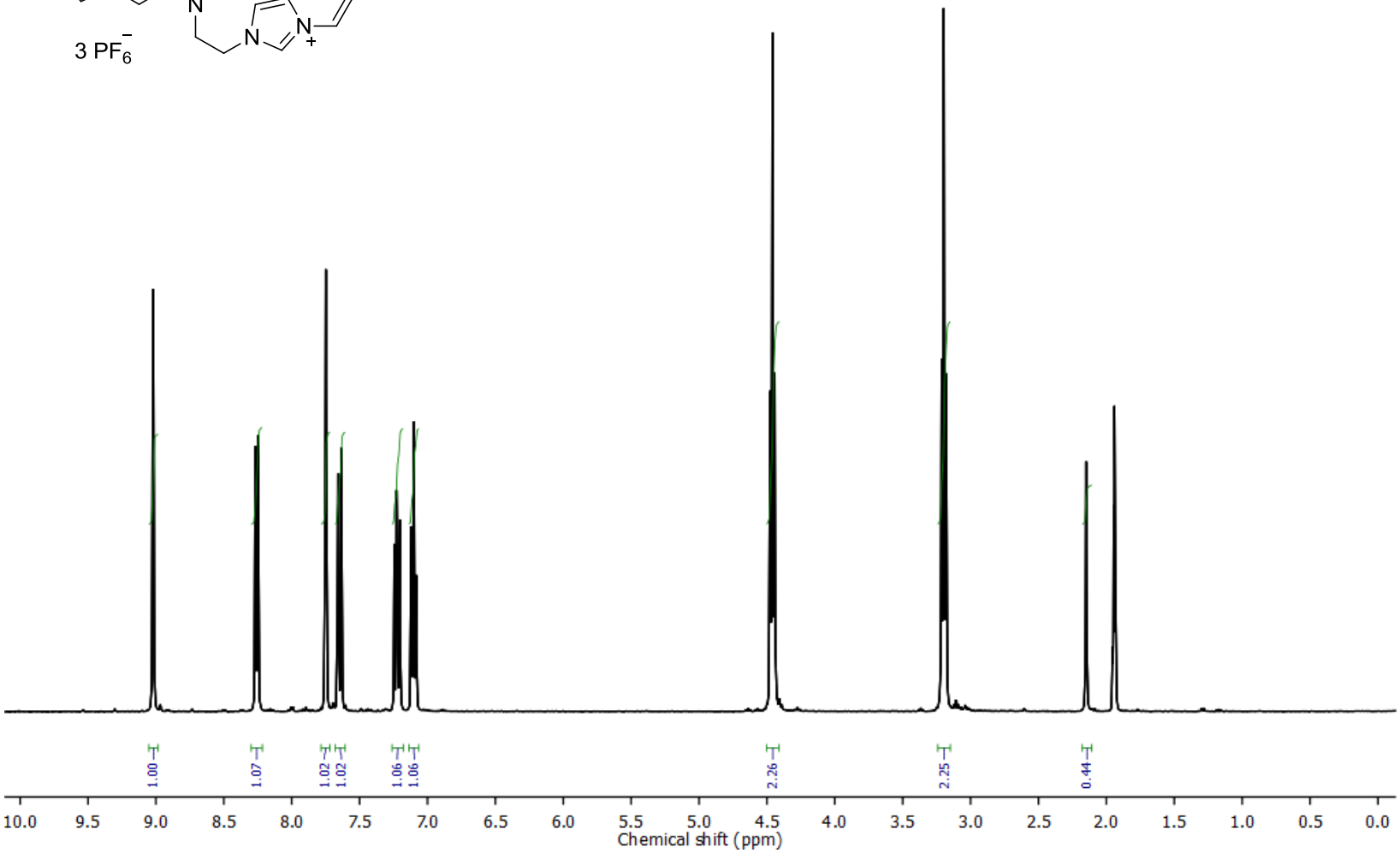


^{13}C-NMR (Table 3, Entry 3)

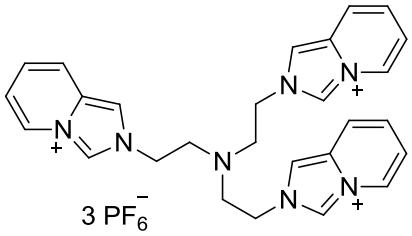


^{1}H-NMR (Table 3, Entry 4)

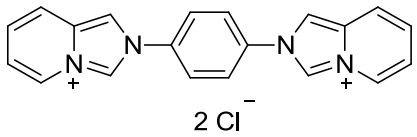




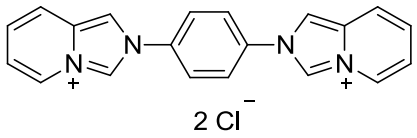
^{13}C-NMR (Table 3, Entry 4)



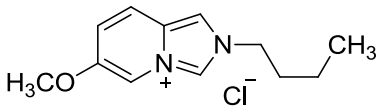
^{13}C-NMR (Table 3, Entry 1)



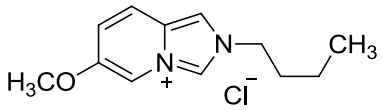
^{13}C-NMR (Table 3, Entry 1)



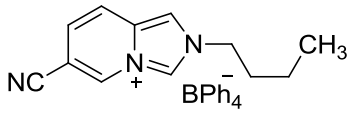
^{1}H-NMR (Table 4, Entry 1, (6a))



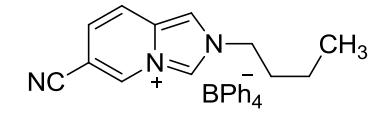
^{13}C-NMR (Table 4, Entry 1, (6a))



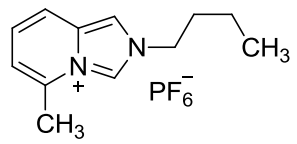
^{1}H-NMR (Table 4, Entry 2, (6b))



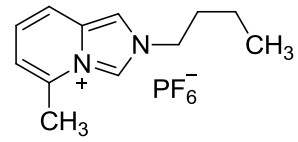
^{13}C-NMR (Table 4, Entry 2, (6b))



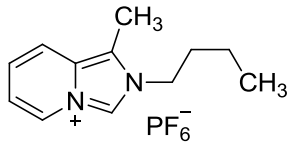
^{1}H-NMR (Table 4, Entry 3, (6c))

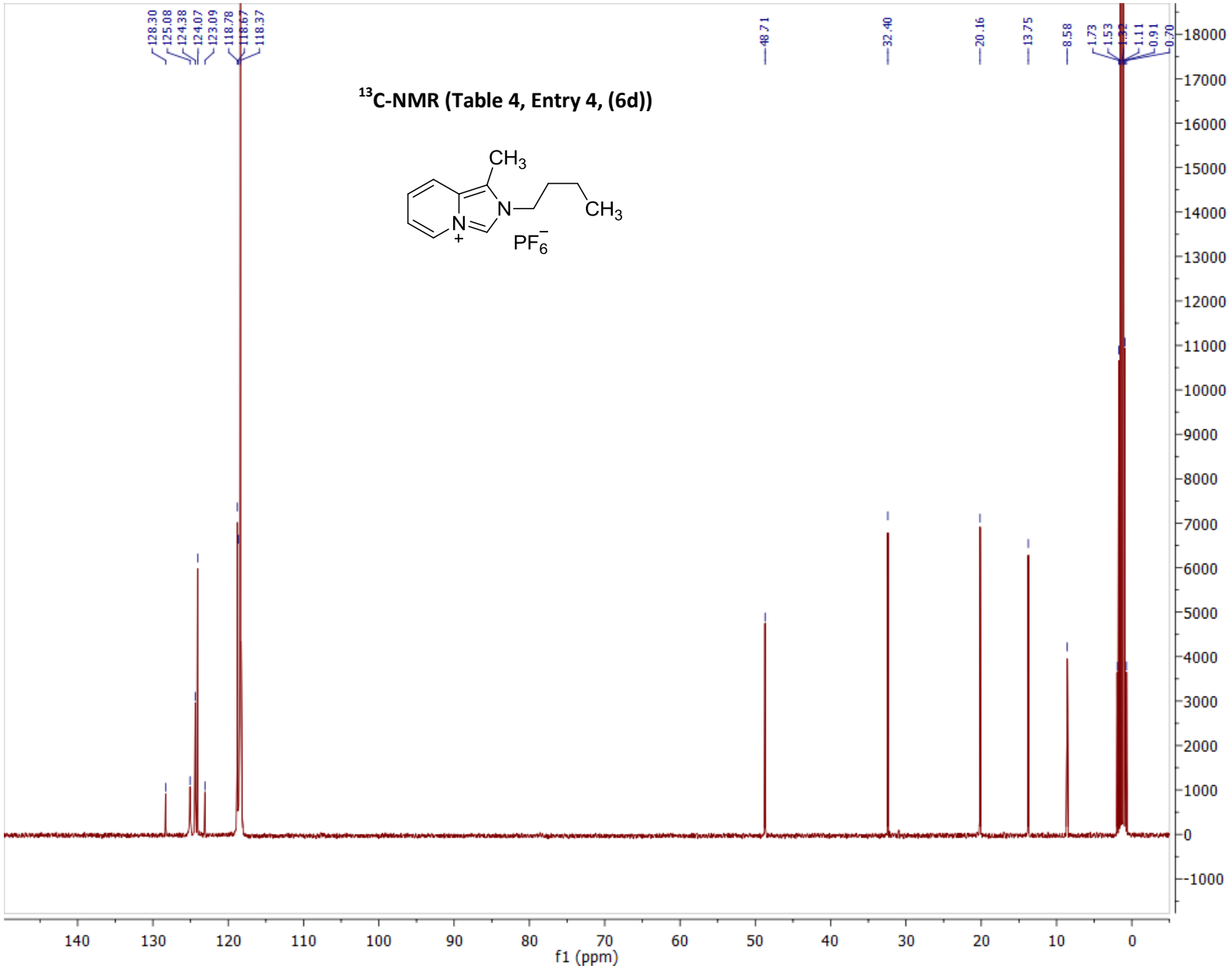


^{13}C-NMR (Table 4, Entry 3, (6c))



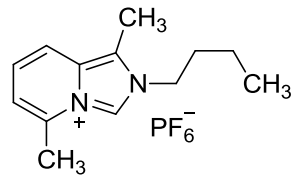
^{1}H-NMR (Table 4, Entry 4, (6d))

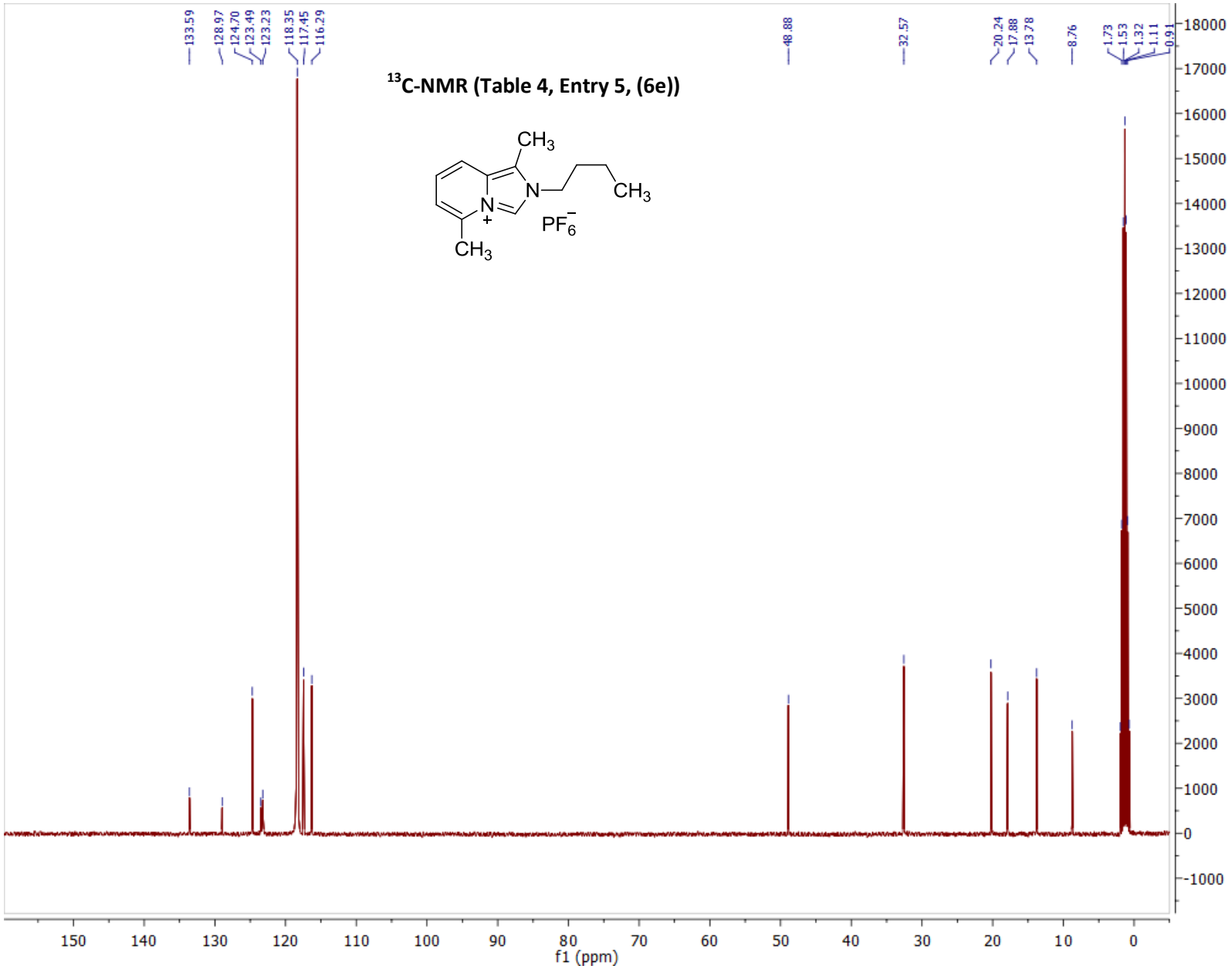




^{13}C-NMR (Table 4, Entry 4, (6d))

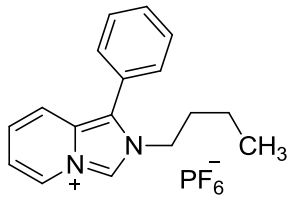
^{1}H-NMR (Table 4, Entry 5, (6e))



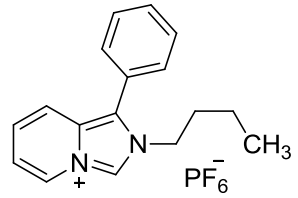


^{13}C-NMR (Table 4, Entry 5, (6e))

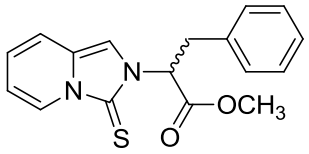
^{1}H-NMR (Table 4, Entry 6, (6f))



^{13}C-NMR (Table 4, Entry 6, (6f))

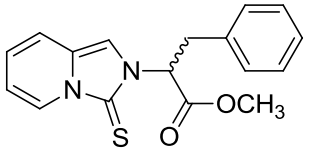


^{1}H-NMR


N
N
S
O
OCH3

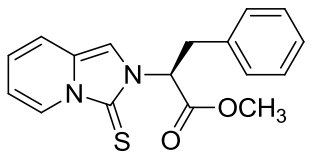
1.00
5.22
2.40
1.06
0.98
1.03
1.04
0.99
3.27
2.41
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
Chemical shift (ppm)

^{13}C-NMR


N
N
S
O
OCH3

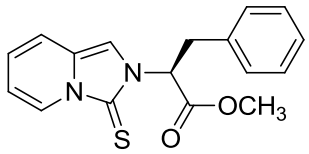
169.92
135.11
129.28
128.80
127.47
127.34
125.41
122.54
117.59
112.44
105.43
77.48
77.16
76.84
60.01
52.91
38.03
230 220 210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -10
Chemical shift (ppm)

^{1}H-NMR


N
N
S
O
OCH3

1.00
3.52
2.31
2.09
1.06
1.07
1.05
3.41
2.50
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
Chemical shift (ppm)

^{13}C-NMR


N
N
S
O
OCH3

169.88
154.47
135.09
129.25
128.77
127.44
127.30
125.36
122.51
117.57
112.41
105.41
77.41
77.16
77.16
76.91
59.98
52.88
37.98
29.82
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
Chemical shift (ppm)

References

1. Pan, H. R.; Wang, X. R.; Yan, C. X.; Sun, Z. X.; Cheng, Y., *Org. Biomol. Chem.* **2011,** *9* (7), 2166-2174.
2. Alcarazo, M.; Roseblade, S. J.; Cowley, A. R.; Fernandez, R.; Brown, J. M.; Lassaletta, J. M., *J. Am. Chem. Soc.* **2005,** *127* (10), 3290-3291.
3. Hinterberger, S.; Hofer, O.; *Tetrahedron* **1994,** *50* (21), 6279-6286.
4. (a) Chien, C. H.; Fujita, S.; Yamoto, S.; Hara, T.; Yamagata, T.; Watanabe, M.; Mashima, K., *Dalton Trans.* **2008,** (7), 916-23; (b) Pan, H.-R.; Li, Y.-J.; Yan, C.-X.; Xing, J.; Cheng, Y., *J. Org. Chem.* **2010,** *75* (19), 6644-6652; (c) Pan, H.-R.; Wang, X.-R.; Yan, C.-X.; Sun, Z.-X.; Cheng, Y., *Org. Biomol. Chem.* **2011,** *9* (7), 2166-2174.
5. Mishra, D.; Naskar, S.; Adhikary, B.; Butcher, R. J.; Chattopadhyay, S. K., *Polyhedron* **2005,** *24* (2), 201-208.
6. Burstein, C.; Lehmann, C. W.; Glorius, F., *Tetrahedron* **2005,** *61* (26), 6207-6217.
7. Ostermeier, M.; Limberg, C.; Ziemer, B.; Karunakaran, V., *Angew. Chem. Int. Ed.* **2007,** *46* (28), 5329-5331.
8. Nonnenmacher, M.; Kunz, D.; Rominger, F.; Oeser, T., *J. Organomet. Chem.* **2007,** *692* (12), 2554-2563.
9. Metallinos, C.; Barrett, F. B.; Wang, Y.; Xu, S. F.; Taylor, N. J., *Tetrahedron* **2006,** *62* (48), 11145-11157.