

Supporting Information for:

'Highly active iridium(I) complexes for catalytic hydrogen isotope exchange'

Jack A. Brown, Stephanie Irvine, Alan R. Kennedy, William J. Kerr,* Shalini Andersson
and Göran N. Nilsson

General Procedure for Synthesis of Complexes 5a-5e:

A flame dried and nitrogen cooled Schlenk tube was charged with **3** and dry benzene (10 mL). The solution was treated with freshly prepared 1M sodium ethoxide solution and stirred for 10 minutes. After this time, **4a** or **4b** was added and the mixture stirred for 5 h at r.t. The solvent was removed under high vacuum and the residue triturated with dry ether prior to filtration through celite under N₂. After solvent exchange to dry THF (15 mL), AgPF₆ was added and the resultant slurry stirred for 30 minutes at r.t. After filtration through celite under N₂, the solution was treated with phosphine and the resultant ruby red solution was stirred for 2 h. Purification by recrystallization from DCM/Et₂O yielded the desired complex.

Following the general procedure, data are reported as: (a) amount of **3**, (b) volume of sodium ethoxide, (c) amount of imidazolium salt, (d) amount of AgPF₆, (e) amount of phosphine, and (f) product yield.

Complex 5a:

(a) 0.2 g, 0.298 mmol, (b) 0.6 mL, 0.595 mmol, (c) **4a**, 0.203 g, 0.595 mmol, (d) 0.150 g, 0.595 mmol, (e) triphenylphosphine, 0.156 g, 0.595 mmol, and (f) 0.375 g, 62%.

$\nu_{\max}(\text{CH}_2\text{Cl}_2)/\text{cm}^{-1}$ 3050, 2981, 2305, 1608 and 1480; $\delta_{\text{H}}(400 \text{ MHz}; \text{CDCl}_3)$: 7.47-7.41 (5 H, m, CH), 7.33-7.28 (6 H, m, CH), 7.15-7.08 (6 H, m, CH), 6.99 (2 H, s, CH), 6.65 (2 H, s, CH), 4.41-4.33 (2 H, m, CH), 3.38-3.25 (2 H, m, CH), 2.36 (6 H, s, CH₃), 2.12 (6 H, s, CH₃), 1.77 (6 H, s, CH₃), 1.71-1.50 (6 H, m, CH₂) and 1.29-1.25 (2 H, m, CH₂); $\delta_{\text{C}}(100 \text{ MHz}; \text{CDCl}_3)$: 177.0, 139.9, 136.0, 135.9, 135.4, 135.0, 131.5, 131.0, 130.5, 129.9, 128.8, 127.1, 80.7, 80.6, 78.1, 32.1, 30.4, 21.4, 21.1 and 19.2; $\delta_{\text{P}}(162 \text{ MHz}; \text{CDCl}_3)$: 17.1 (PPh₃) and -143.5 (PF₆); m/z (ESI) 867.3407 (Calc. for C₄₇H₅₁¹⁹³IrN₂P [M-PF₆]⁺: 867.3414). Also see the associated CIF file for single crystal diffraction data.

Complex 5b:

(a) 0.2 g, 0.298 mmol, (b) 0.6 mL, 0.595 mmol, (c) **4a**, 0.203 g, 0.595 mmol, (d) 0.150 g, 0.595 mmol, (e) tribenzylphosphine, 0.181 g, 0.595 mmol, and (f) 0.373 g, 59%.

(Found: C, 56.7; H, 5.3; N, 2.7. Calc. for $C_{50}H_{57}F_6IrN_2P_2$: C, 57.0; H, 5.45; N, 2.7%); $\nu_{max}(CH_2Cl_2)/cm^{-1}$ 3045, 2989, 2303, 1603 and 1495; $\delta_H(400\text{ MHz}; [D_6]acetone)$: 7.79 (2 H, s, olefinic CH), 7.40 (2 H, s, ArH), 7.34 (2 H, s, ArH), 7.30-7.26 (9 H, m, ArH), 6.98-6.96 (6 H, m, ArH), 4.72-4.70 (2 H, m, COD CH), 3.43-3.38 (2 H, m, COD CH), 3.02 (6 H, d, $^2J_{PH}$ 8.8, PCH_2Ar), 2.57 (6 H, s, $ArCH_3$), 2.51 (6 H, s, $ArCH_3$), 2.47 (6 H, s, $ArCH_3$), 1.80-1.77 (2 H, m, COD CH_2), 1.58-1.49 (4 H, m, COD CH_2) and 1.37-1.31 (2 H, m, COD CH_2); $\delta_C(100\text{ MHz}; [D_6]acetone)$: 176.5, 141.1, 137.4, 137.0, 136.2, 134.3, 134.3, 131.0, 130.9, 130.7, 129.5, 127.9, 127.7, 87.2, 75.8, 32.3, 31.0, 30.7, 21.1, 20.6 and 19.9; $\delta_P(162\text{ MHz}; [D_6]acetone)$: -6.3 (PBn_3) and -143.5 (PF_6); m/z (ESI) 907.3852 (Calc. for $C_{50}H_{57}^{191}IrN_2P [M-PF_6]^+$: 907.3860). Also see the associated CIF file for single crystal diffraction data.

Complex 5c:

(a) 0.2 g, 0.298 mmol, (b) 0.6 mL, 0.595 mmol, (c) **4a**, 0.203 g, 0.595 mmol, (d) 0.150 g, 0.595 mmol, (e) dimethylphenylphosphine, 0.085 mL, 0.595 mmol, and (f) 0.371 g, 71%.

(Found: C, 50.0; H, 5.3; N, 3.0. Calc. for $C_{37}H_{47}F_6IrN_2P_2$: C, 50.05; H, 5.3; N, 3.15%); $\nu_{max}(CH_2Cl_2)/cm^{-1}$ 3045, 2985, 2302, 1606 and 1484; $\delta_H(400\text{ MHz}; CDCl_3)$: 7.41-7.36 (4 H, m, ArH), 7.30-7.28 (3 H, m, ArH and olefinic CH), 7.06 (2 H, s, ArH), 6.92 (2 H, s, ArH), 4.30-4.28 (2 H, m, COD CH), 3.48-3.45 (2 H, m, COD CH), 2.39 (6 H, s, $ArCH_3$), 2.21 (6 H, s, $ArCH_3$), 2.15, (6 H, s, $ArCH_3$), 1.78-1.56 (8 H, m, COD CH_2) and 1.50 (6 H, d, $^2J_{PH}$ 8.4, CH_3); $\delta_C(100\text{ MHz}; CDCl_3)$: 177.3, 140.1, 135.7, 134.8, 132.0, 130.9, 130.2, 129.9, 128.9, 126.0, 83.5, 83.3, 77.4, 76.1, 31.6, 30.6, 21.1, 20.4, 19.3, 16.6 and 16.3; $\delta_P(162\text{ MHz}; CDCl_3)$: -13.3 (PMe_2Ph) and -143.5 (PF_6); m/z (ESI) 743.3107 (Calc. for $C_{37}H_{47}^{193}IrN_2P [M-PF_6]^+$: 743.3101). Also see the associated CIF file for single crystal diffraction data.

Complex 5d:

(a) 0.100, 0.149 mmol, (b) 0.3 mL, 0.298 mmol, (c) **4b**, 0.100 g, 0.298 mmol, (d) 0.076 g, 0.298 mmol, (e) tributylphosphine, 0.040 mL, 0.298 mmol, and (f) 0.080 g, 30%.

δ_{H} (400 MHz; CDCl_3): 6.98 (2 H, s, ArH), 6.93 (2 H, s, ArH), 4.32-4.23 (2 H, m, olefinic CH), 4.11-4.00 (4 H, m, alkyl CH_2), 3.69-3.60 (2 H, m, olefinic CH), 2.45 (6 H, s, ArCH_3), 2.40 (6 H, s, ArCH_3), 2.32 (6 H, s, ArCH_3), 1.69-1.55 (10 H, m, overlapping $\text{P}(\text{nBu})_3$ CH_2 and COD CH_2), 1.49-1.40 (4 H, m, COD CH_2), 1.36-1.29 (6 H, m, $\text{P}(\text{nBu})_3$ CH_2), 1.21-1.12 (6 H, m, $\text{P}(\text{nBu})_3$ CH_2) and 0.89 (9 H, t, J 7.25, $\text{P}(\text{nBu})_3$ CH_3); δ_{C} (100 MHz; CDCl_3): 205.1, 139.1, 136.6, 136.2, 135.7, 130.1, 130.0, 80.2, 80.1, 75.3, 53.3, 31.7, 30.9, 27.0, 24.8, 24.7, 24.5, 21.1, 20.3, 19.5 and 14.0; δ_{P} (162 MHz; CDCl_3): -2.6 [$\text{P}(\text{nBu})_3$] and -143.6 (PF_6); m/z (ESI) 809.4505 (Calc. for $\text{C}_{41}\text{H}_{65}^{193}\text{IrN}_2\text{P} [\text{M-PF}_6]^+$: 809.4509).

Complex 5e:

(a) 0.100, 0.149 mmol, (b) 0.3 mL, 0.298 mmol, (c) **4b**, 0.100 g, 0.298 mmol, (d) 0.076 g, 0.298 mmol, (e) triphenylphosphine, 0.078 mg, 0.298 mmol, and (f) 0.080 g, 31%.

$\nu_{\text{max}}(\text{CH}_2\text{Cl}_2)/\text{cm}^{-1}$ 1480, 1607, 2306, 2981 and 3065; δ_{H} (400 MHz; CDCl_3): 7.50-7.30 (15 H, m, ArH), 7.00 (2 H, s, ArH), 6.59 (2 H, s, ArH), 4.60-4.50 (2 H, m, olefinic CH), 4.37-4.19 (4 H, m, alkyl CH_2), 2.31-2.22 (2 H, m, olefinic CH), 2.48 (6 H, s, ArCH_3), 2.32 (6 H, s, ArCH_3), 1.78 (6 H, s, ArCH_3), 1.69-1.50 (4 H, m, COD CH_2), 1.50-1.35 (3 H, m, COD CH_2) and 1.15-1.25 (1 H, m, COD CH_2); δ_{C} (100 MHz; CDCl_3): 204.1, 138.8, 137.5, 136.4, 135.6, 135.1, 131.5, 130.6, 130.0, 128.8, 128.7, 78.8, 67.9, 53.5, 32.0, 30.1, 25.8, 21.4, 21.0 and 19.6; δ_{P} (162 MHz; CDCl_3): 16.4 (PPh_3) and -143.5 (PF_6); m/z (ESI) 869.3568 (Calc. for $\text{C}_{47}\text{H}_{53}^{193}\text{IrN}_2\text{P} [\text{M-PF}_6]^+$: 869.3570).

Standard Hydrogen Isotope Exchange Procedure:

A flame dried and nitrogen cooled 250 mL 3-neck round bottomed flask, equipped with two stopcock valves and a suba seal, was charged with the iridium complex (5 mol%) and dry DCM (2.5 ml), followed by the substrate (0.215 mmol). The suba seal was replaced by a greased glass stopper and the reaction vessel was cooled to -78°C in a dry ice/acetone bath, prior to being purged twice with nitrogen. The flask was then evacuated and filled with deuterium gas *via* balloon. The flask was removed from the slurry and allowed to warm to room temperature. (NOTE: the glass stopper must be physically restrained as the reaction mixture warms to room temperature). The reaction mixture was then allowed to stir vigorously at room temperature for the allotted reaction time. The level of isotope incorporation into the substrate was determined by ¹H NMR analysis of the reaction products. As such, the residual proton signal from the site of incorporation was compared against that of a site where incorporation was not expected or occurred.

Spectral details for substrates in labelling studies:

*Acetophenone, 6a:*¹

δ_{H} (400 MHz; CDCl₃): 7.95 (2 H, d, *J* 8.0, ArCH), 7.54 (1 H, t, *J* 8.0, ArCH), 7.44 (2 H, t, *J* 8.0, ArCH) and 2.58 (3 H, s, CH₃).

Incorporation expected at δ_{H} 7.95.

Determined against integral at δ_{H} 2.58.

*Benzophenone, 6b:*²

δ_{H} (400 MHz; CDCl₃): 7.81 (4 H, d, *J* 8.0, ArCH), 7.59 (2 H, t, *J* 8.0, ArCH) and 7.49 (4 H, t, *J* 7.9, ArCH).

Incorporation expected at δ_{H} 7.81.

Determined against integral at δ_{H} 7.59.

*Benzamide, 6c:*³

δ_{H} (400 MHz; [D₆]acetone): 7.92 (2 H, d, *J* 7.5, ArCH), 7.49 (1 H, t, *J* 7.5, ArCH) and 7.41 (2 H, t, *J* 7.5, ArCH).

Incorporation expected at δ_{H} 7.92.

Determined against integral at δ_{H} 7.49.

*N,N-Diethyltoluamide, 6d:*⁴

mp 43-44°C; ν_{max} (CH₂Cl₂)/cm⁻¹ 3042, 2976, 2935, 2880, 1910, 1612, 1516 and 1459;
 δ_{H} (400 MHz; [D₆]acetone): 7.27-7.22 (4H, m, ArCH), 3.38 (4 H, br s, NCH₂CH₃), 2.35 (3H, s, ArCH₃) and 1.13 (6 H, s, NCH₂CH₃).

Incorporation expected at δ_{H} 7.27-7.22.

Determined against integral at δ_{H} 2.35.

*2-Phenylpyridine, 6e:*⁵

δ_{H} (400 MHz; CDCl₃): 8.71 (1 H, d, *J* 4.7, ArCH), 8.00 (2 H, d, *J* 7.1, ArCH), 7.79-7.73 (2 H, m, ArCH), 7.52-7.41 (3 H, m, ArCH) and 7.26-7.23 (1 H, m, ArCH).

Incorporation expected at δ_{H} 8.00.

Determined against integral at δ_{H} 7.79-7.73.

*N-Phenylpyrazole, 6f:*⁶

δ_{H} (400 MHz; CDCl₃): 7.93 (1 H, d, *J* 7.5, ArCH), 7.74-7.66 (3 H, m, ArCH), 7.46 (2 H, t, *J* 7.4, ArCH), 7.29 (1 H, t, *J* 7.4, ArCH) and 6.46 (1 H, t, *J* 2.0, ArCH).

Incorporation expected at δ_{H} 7.74-7.66.

Determined against integral at δ_{H} 6.46.

*Nitrobenzene, 6g:*⁷

δ_{H} (400 MHz; CDCl₃): 8.25 (2 H, dd, *J* 7.7, ⁴*J* 1.1, ArCH), 7.71 (1 H, tt, *J* 7.4, ⁴*J* 1.1, ArCH) and 7.56 (2 H, t, *J* 7.4, ArCH).

Incorporation expected at δ_{H} 8.25.

Determined against integral at δ_{H} 7.71.

Supplementary Material (ESI) for Chemical Communications
This journal is (c) The Royal Society of Chemistry 2007

Acetanilide, 6h:⁸

δ_{H} (400 MHz; CDCl_3): 7.54 (1 H, s, NH), 7.50 (2 H, d, J 7.4, ArCH), 7.31 (2 H, t, J 7.4, ArCH), 7.10 (1 H, t, J 7.4, ArCH) and 2.17 (3 H, s, CH_3).

Incorporation expected at δ_{H} 7.50.

Determined against integral at δ_{H} 2.17.

N-(2-Nitrophenyl)benzamide, 6i:⁹

mp 91-92°C; $\nu_{\text{max}}(\text{CH}_2\text{Cl}_2)/\text{cm}^{-1}$ 3364, 3048, 2989, 1689, 1605, 1587 and 1498; δ_{H} (400 MHz; CDCl_3): 11.39 (1H, s, NH) 9.06 (1 H, dd, J 8.5, 4J 1.2, ArCH), 8.33 (1 H, dd, J 8.5, 4J 1.5, ArCH), 8.05 (2 H, d, J 8.5, ArCH), 7.76 (1 H, td, J 8.6, 4J 1.5, ArCH), 7.68-7.64 (1 H, m, ArCH), 7.61-7.57 (2 H, m, ArCH) and 7.27 (1 H, td, J 8.5, 4J 1.3 Hz, ArCH).

Incorporation expected at δ_{H} 9.06, 8.33 and 8.05.

Determined against integral at δ_{H} 7.76.

Benzanilide, 6j:¹⁰

δ_{H} (400 MHz; $[\text{D}_6]\text{acetone}$): 9.49 (1 H, s, NH), 7.99 (2 H, dd, J 7.0, 4J 1.2, ArCH), 7.85 (2 H, d, J 7.5, ArCH), 7.59-7.48 (3 H, m, ArCH), 7.35 (2 H, m, ArCH) and 7.11 (1 H, tt, J 7.4, 4J 1.1, ArCH).

Incorporation expected at δ_{H} 7.99 and 7.85.

Determined against integral at δ_{H} 7.11.

References:

- [1] Z. Liu, Z.-C. Chen and Q.-G. Zheng, *Org. Lett.*, 2003, **5**, 3321.
- [2] J. P. Hwang, G. K. S. Prakash and G. A. Olah, *Tetrahedron*, 2000, **56**, 7199.
- [3] N. V. Kaminskaia and N. M. Kostic, *J. Chem. Soc., Dalton Trans.*, 1996, 3677.
- [4] E. T. McCabe, W. F. Barthel, S. I. Gertler and S. A. Hall, *J. Org. Chem.*, 1954, **19**, 493.
- [5] Q. Dai, W. Gao, D. Lui, L. M. Kapes and X. Zhang, *J. Org. Chem.*, 2006, **71**, 3928.
- [6] L. Xu, D. Zhu, F. Wu, R. Wang and B. Wan, *Tetrahedron*, 2005, **61**, 6553.
- [7] S. Suresh, R. Joseph, B. Jayachandran, A. V. Pol, M. P. Vinod, A. Sudalai, H. R. Sonawane and T. Ravindranathan, *Tetrahedron*, 1995, **51**, 11305.
- [8] Y. Furuya, K. Ishihara and H. Yamamoto, *J. Am. Chem. Soc.*, 2005, **127**, 11240.
- [9] J. A. Murphy, F. Rasheed, S. Gastaldi, T. Ravishanker and N. Lewis, *J. Chem. Soc., Perkin Trans. 1*, 1997, 1549.
- [10] T. Yuzuri, H. Suezawa and M. Hirota, *Bull. Chem. Soc. Jpn.*, 1994, **67**, 1664.