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IRIDIUM CATALYZED ENANTIOSELECTIVE HYDROGENATION OF *N*-IMINOPYRIDINIUM YLIDES: MECHANISTIC INSIGHTS

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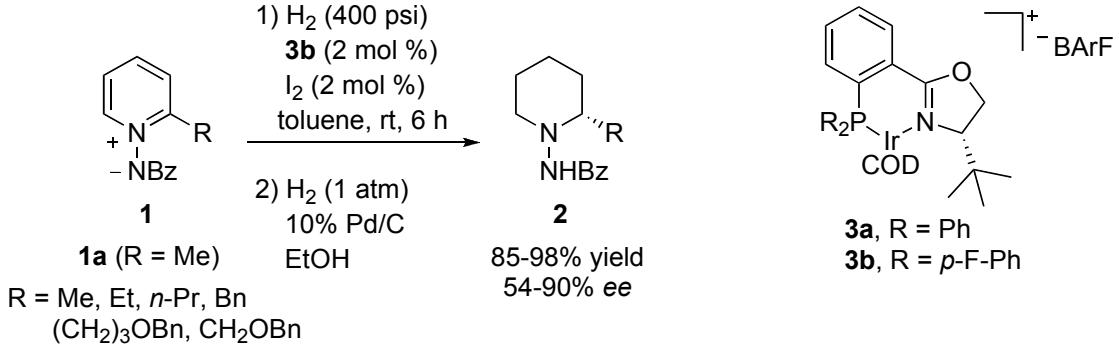
Dedicated to *Prof. Dr. Ryoji Noyori* on the occasion of his 70th birthday.

Abstract – Mechanistic insights of the efficient iridium catalyzed asymmetric hydrogenation of *N*-iminopyridinium ylides are reported. Using NMR and mass spectrometry, the nature of the pre-catalyst and role of iodine was studied. The effect of solvent as well as an extensive ligand screening is presented. Deuteration experiments also show that C-H(D) insertion pathways occur in competition with the hydrogenation process.

INTRODUCTION

Polysubstituted piperidines are ubiquitous structural units, found in a variety of natural compounds possessing diverse biological activities.[1] Moreover, they have received growing interest from the pharmaceutical domain. Tremendous efforts have been devised to access this useful synthetic moiety.[2] Our group has been active in the development of asymmetric methodologies of additions of nucleophiles to pyridinium salts and ylides to access dihydro- and tetrahydropyridines, unsaturated derivatives of the corresponding piperidines.[3] Polysubstituted pyridines are either readily available commercially or can be easily prepared using recent cross-coupling chemistry.[4] In view of this, asymmetric hydrogenation of this class of compounds represents an attractive strategy to access enantioenriched substituted piperidines. Glorius *et al.* were recently successful in developing a diastereoselective method,[5] but an enantioselective version remained a longstanding challenge.[6] Activation of the pyridine should permit hydrogenation to occur under mild conditions. We envisioned that *N*-iminopyridinium ylides could bind

the catalyst and facilitate the hydrogenation process due to their exceptional directing nature. We recently reported the efficient iridium catalyzed asymmetric hydrogenation of 2-substituted *N*-iminopyridinium ylides using chiral phosphinooxazolines.[7] The method tolerates a variety of substituents at the 2-position of the pyridinium ring and affords the piperidine derivatives in excellent yields and fair to excellent enantioselectivities (**Scheme 1**). The products obtained can be easily enriched to afford enantiopure compounds through recrystallization. The ylides used in the methodology are easily accessed in excellent yields by a one-pot direct *N*-amination/benzoylation procedure.[8]



Scheme 1. Outline of the iridium catalyzed asymmetric hydrogenation of *N*-benzoyliminopyridinium ylides.

In our continuing efforts to enhance the enantioselectivities and scope of our methodology, we report herein our findings concerning the optimization of the reaction conditions and catalyst, as well as insights concerning the nature of the catalyst and the actual hydrogenation process.

RESULTS AND DISCUSSION

Role of iodine and catalyst nature

A key requirement in our reaction conditions is the presence of an equimolar quantity of iodine with respect to the iridium(I) catalyst. Optimization of the reaction conditions revealed that an excess of iodine is detrimental to the enantioselectivities whereas a substoichiometric quantity led to a loss of reactivity. This requirement is in contrast with the conditions developed by Zhou *et al*. for the iridium catalyzed enantioselective hydrogenation of quinoline,[9] where an excess of iodine is used in order to get optimal results. Moreover, the initial iridium(I) catalyst must be let to react for at least 5 hours with the iodine in order to obtain the optimal yields and enantioselectivities. This led to suppose that the role of iodine was to oxidize the initial iridium(I) complex to an iridium(III) pre-catalyst. Catalyst **3a** was let to react with a stoichiometric quantity of iodine in C_6D_6 and the reaction was followed by ^{31}P NMR. Within 5 minutes, the signal of complex **3a** (17.6 ppm) completely disappears to afford a complex mixture of signals which proportions vary during the course of 5 hours. Afterward the signals observed do not vary even after 2 weeks. The ^{31}P NMR spectrum of the resulting species is shown in **Figure 1**.

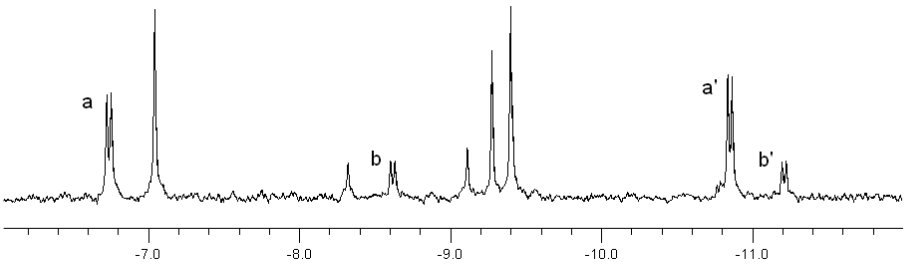
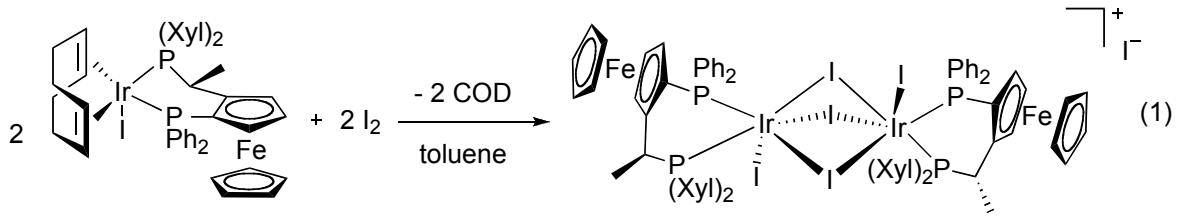


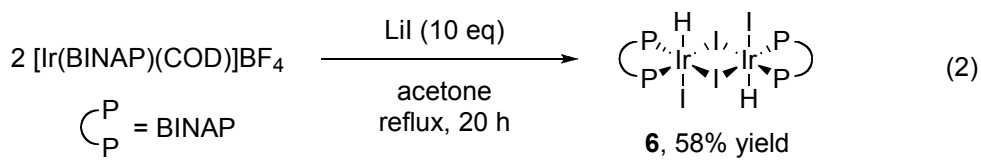
Figure 1. ^{31}P NMR of the species observed after reaction of complex **3b** with iodine.

It is possible to obtain numerous information from the data. In particular, the two pairs of doublets, shown as **a,a'** (2 doublets at -6.7 et -10.8 ppm, $J_{P\text{-}P}$ = 3.5 Hz) and **b,b'** (2 doublets at -8.6 and -11.2 ppm, $J_{P\text{-}P}$ = 3.6 Hz), can be attributed to dimeric iridium(III) species, as shown by the phosphorus-phosphorus coupling. A similar iridium(III) dimer (**5**) has already been reported by Dorta *et al.*[10] for the asymmetric hydrogenation of imines, applied to the industrial synthesis of Metolachlor, an herbicide.[11] This dimer was obtained from the non-cationic iridium(I) complex **4** by treatment with a stoichiometric quantity of iodine (Eq 1). They confirmed the nature of the dimer through X-ray diffraction analysis and ^{31}P NMR.



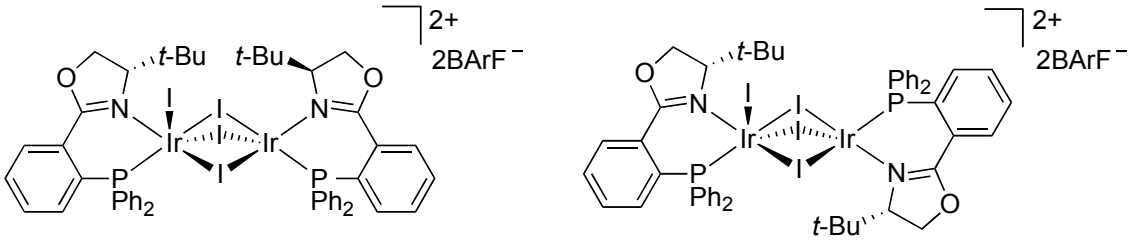
4 **5**

Osborn *et al.* have synthesized other iridium(III) dimers bearing similarities to **5** and used them in the asymmetric hydrogenation of imines (Eq 2).[12] We synthesized **6** according to the literature procedure and evaluated it in the hydrogenation of ylide **1a** and obtained similar reactivity and enantioselectivity when compared to reaction conditions using Ir(BINAP)(COD)Cl and iodine.



6, 58% yield

Due to the cationic nature of **3a**, it is conceivable that treatment of the former with iodine results in the formation of the two dimers **7a** and **7b** (**Figure 2**), explaining the doublet pairs in ^{31}P NMR. The NMR study also shows that the **b,b'** dimer forms initially, but slowly equilibrates to dimer **a,a'**. It is also conceivable that the other signals observed by ^{31}P NMR are other dimeric forms with smaller or non-existent phosphorus-phosphorus coupling constants.



7a **7b**

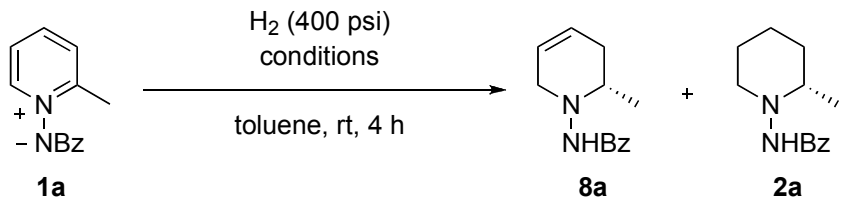
Figure 2. Proposed dimers formed by the reaction of complex **3a** and iodine.

Solutions of complex **3a** and iodine that reacted between 12 hours and 2 weeks were tested for the hydrogenation of **1a** and were found to yield identical results, thus giving evidence that no decomposition occurs following the reaction of the iridium complex with iodine. A solution was also heated at 40 °C for 26 hours with no sign of decomposition by ^{31}P NMR. It is interesting to note however that at this temperature a broad signal is observed at 17.8 ppm which indicates the presence of **3a** and thus possible reversibility between the iridium(III) species and complex **3a**. A mass spectrometry analysis was done on complex **3a** as well as a solution of complex **3a** and iodine reacted for 2 weeks. Using APCI mass spectrometry, it is possible to observe the mass of the cationic portion of complex **3a**, including the COD ligand (*m*/*z* = 688). After reaction with the iodine, the mass of diiodo iridium(III) species with no COD ligand is observed (*m*/*z* = 834), in accord with dimer **5** reported by Dorta (Eq 1). The mass observed gives further evidence of the presence of dicationic dimers in solution.

To evaluate the stability of the species formed by the reaction with iodine, the reacted solution of complex **3a** with iodine was eluted on a silica gel filled column (100% dichloromethane). As with complex **3a**, the iridium(III) species elutes with the front of the eluent. The ^{31}P NMR spectrum of the purified species is practically identical to **Figure 1**.

These experiments were also done using complex **3b** and showed the same behavior. The purified species obtained with **3b** were used for the hydrogenation of ylide **1a** and afforded almost identical yield and enantioselectivity as the unpurified solution (**Table 1**, entries 1 and 2). Following hydrogenation, the crude reaction mixture was eluted with 100% dichloromethane and iridium species could be recovered. Mass spectrometry showed the presence of diiodo iridium(III) species. However, ^{31}P NMR showed none of the signals found in the initial pre-catalytic solution. Analysis by ^{19}F NMR showed that 46% of the BArF counterion was recovered. The recovered species were used in the hydrogenation conditions of ylide **1a** and the results were inferior to the original catalytic solution (**Table 1**, entry 3).

Table 1. Hydrogenation of ylide **1a** using different catalytic species.



1a **8a** **2a**

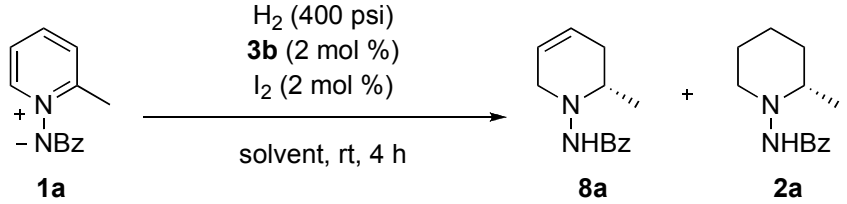
Entry	Conditions[a]	Conv. (%)[b]	Ratio (**8a**:**2a**)[b]	Yield (%)[c]	*ee* **2a** (%)[d]
1	A	>98	13:87	>98	90
2	B	>98	12:88	94	89
3	C	93	8:92	52	50

[a] Condition A: A solution of **3b** (2 mol %) and I_2 (2 mol %) that reacted for 2 weeks; B: Solution from condition A purified on a silica gel filled column (100% CH_2Cl_2); C: Recovered species from the front of eluent by silica gel chromatography (100% CH_2Cl_2) after hydrogenation under conditions B; [b] Conversions and ratios determined by ^{1}H NMR; [c] Combined yield of **8a** and **2a** determined by ^{1}H NMR with an internal standard; [d] Enantiomeric excess determined by HPLC after hydrogenation of **8a** in **2a**.

Solvent Effect

The effect of the solvent on the hydrogenation outcome was investigated in order to determine the tolerance of the reaction conditions. The results of the effect of the reaction solvent on the hydrogenation of ylide **1a** using catalyst **3b** are summarized in **Table 2**.

Table 2. Solvent effect on the hydrogenation of ylide **1a** with complex **3b**.



1a **8a** **2a**

Entry	Solvent	Conv. (%)[a]	Ratio (**8a**:**2a**)[a]	Yield (%)[b]	*ee* **2a** (%)[c]
1	toluene	>98	13:87	>98	90
2	benzene	>98	16:84	>98	87
3	PhEt	>98	11:89	96	81
4	PhCl	>98	20:80	95	85
5	$PhCF_3$	>98	14:86	96	81
6	CH_2Cl_2	94	19:81	94	65
7	1,2-DCE	>98	14:86	95	57
8	Et_2O	18	-	<2	-
9	THF	20	-	<2	-
10	EtOAc	>98	13:87	90	68
11	*i*-PrOH	84	16:84	68	70

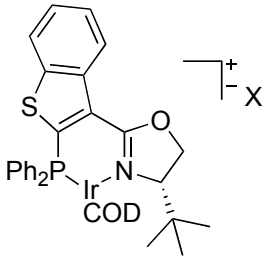
[a] Conversions and ratios determined by ^{1}H NMR; [b] Combined yield of **8a** and **2a** determined by ^{1}H NMR with an internal standard; [c] Enantiomeric excess determined by HPLC after hydrogenation of **8a** in **2a**.

The results clearly show that toluene and benzene are the solvents of choice for the hydrogenation. However, the use of modified aromatic containing solvents to tune their solubility properties and polarity

(entries 3 to 5) only results in small deterioration in yields and enantioselectivities. It is noteworthy that common halogenated solvents (entries 6 and 7) leave the reactivity mostly unaffected, but produce a clear decrease of the enantioselectivity. This is in contrast with the hydrogenation methodologies described by Pfaltz *et al*., where dichloromethane is usually the solvent of choice for the hydrogenation of unfunctionalized alkenes.[13] Strongly coordinating solvents (entries 8 and 9) deactivate the catalyst and mostly no reactivity is observed with them. However, it is important to note that ethyl acetate and even a protic solvent, isopropanol, were found to be compatible with the methodology, although they proved to be detrimental to the yield and enantioselectivities.

Ligand Optimization

A thorough screening of numerous ligands with different general structures was reported in our initial communication. Through this optimization, we found that phosphinooxazoline (PHOX) ligands, developed by Pfaltz *et al*.,[14] led to the best chiral induction. We have thus decided to investigate other P,N ligands with similar chiral environments in order to find possible enantioselectivity enhancement. The iridium complexes illustrated were synthesized according to literature procedures and were tested under the optimal hydrogenation conditions found with complex **3b**. The results obtained with these catalysts are reported in **Table 3**.



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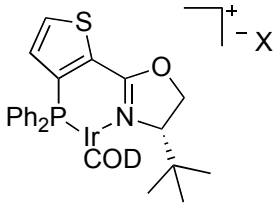

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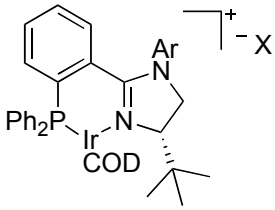
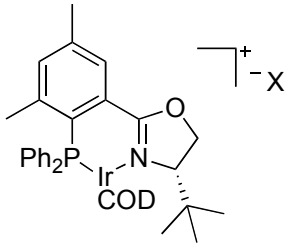


Ar = Ph, **11**
p-MeOPh, **12**



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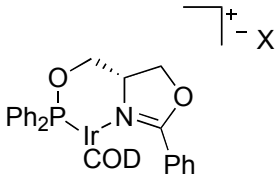

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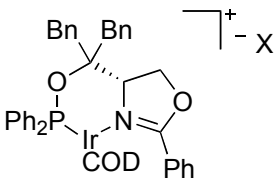

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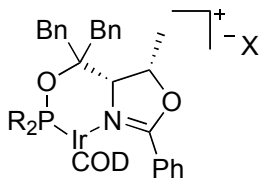
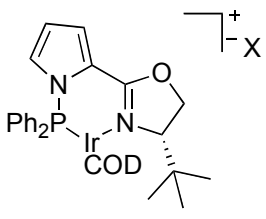


R = Ph, **16**
c-Hex, **17**



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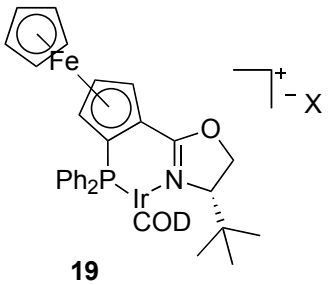

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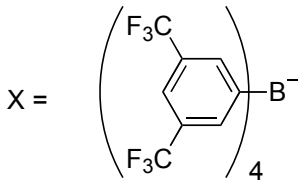
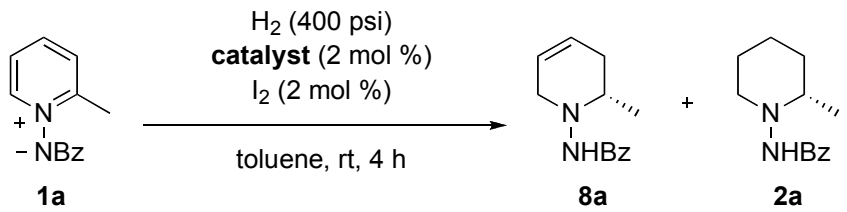


BArF

Table 3. Screening of different iridium catalysts for the hydrogenation of ylide **1a**.



1a **8a** **2a**

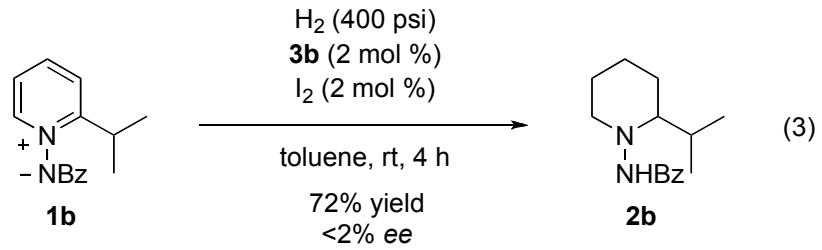
Entry	Catalyst	Conv. (%)[a]	Ratio (**8a**:**2a**)[a]	Yield (%)[b]	*ee* **2a** (%)[c]
1	**3b**	>98	13:87	>98	90
2	**3a**	>98	11:89	92	87
3	**9**	>98	12:88	89	87
4	**10**	>98	12:88	60	24
5	**11**	>98	15:85	85	85
6	**12**	>98	21:79	87	85
7	**13**	>98	25:75	41	31
8	**14**	24	8:92	5	10
9	**15**	>98	7:93	70	63
10	**16**	>98	7:93	43	52
11	**17**	>98	10:90	13	43
12	**18**	>98	20:80	73	26
13	**19**	>98	<5:95	63	75

[a] Conversions and ratios determined by ^{1}H NMR; [b] Combined yield of **8a** and **2a** determined by ^{1}H NMR with an internal standard; [c] Enantiomeric excess determined by HPLC after hydrogenation of **8a** in **2a**.

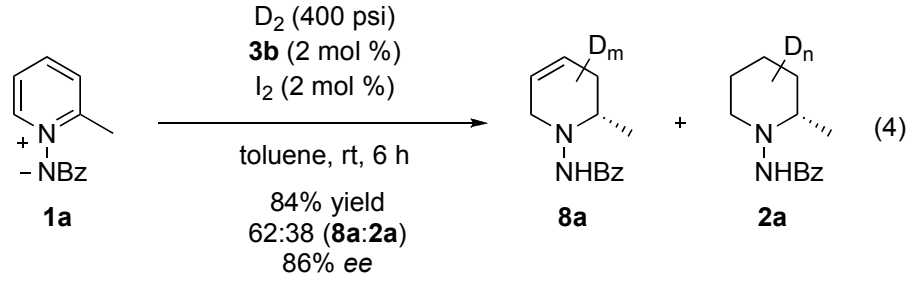
As reported in our initial communication, complex **3b**, bearing the more electron deficient bis(*p*-fluorophenyl)phosphino group, was found to yield similar enantioselectivities but enhanced reactivity compared to complex **3a**, derived from the classical *t*-butyl substituted PHOX ligand reported by Pfaltz. Complex **9**, derived from the benzothiophene based PHOX ligand reported by Cozzi *et al.*,[15] shows virtually identical catalytic activity of **3a**. In contrast, it is interesting to note that **10**, derived from the thiophene based ligand, is drastically inferior to **3a**. Complexes **11** and **12**, derived from phosphinoimidazolines (PHIM) developed by Pfaltz *et al.*,[16] lead to hydrogenation results almost identical to complex **3a**. The rotational liberty of the phosphine group seems important as catalyst **13** efficiency is clearly inferior in terms of activity and chiral induction compared to **3a**.[17] We investigated phosphinite based P,N ligands developed by Pfaltz *et al.* as they have exhibited excellent potential in iridium catalyzed hydrogenation of unfunctionalized alkenes.[18] Complex **14** shows very low catalytic activity, probably due to its degradation. More sterically hindered phosphite based ligands (complexes **15**, **16** and **17**) lead to an increase in term of yields, but with yet inferior enantioselectivities. In a similar fashion, catalyst **18**, derived from the PyrPHOX ligand developed by Cozzi *et al.*,[19] does not achieve the catalytic activity of **3a**. Finally, the use of a chiral planar PHOX ligand (complex **19**),[20] does not improve reactivity or enantioselectivity. From these results, complex **3b** remains the optimal catalyst for the hydrogenation reaction.

Deuteration Experiments

During the investigation of the scope of the methodology, it was found that the hydrogenation of the 2-*i*-propyl-*N*-benzoyliminopyridinium ylide (**1b**) leads to an acceptable yield of the desired hydrogenated product, but in a racemic form (Eq 3). In order to understand this result and determine if the lack of selectivity was caused by an alternative hydrogenation pathway, deuteration experiments were done.



The deuteration of the 2-methyl-*N*-benzoyliminopyridinium ylide (**1a**) was initially done as a control experiment. Interestingly, the yield and tetrahydropyridine quantity observed indicates a slower reaction under deuterium atmosphere. This can be explained by the stronger D-D bond, resulting in a more difficult oxidative insertion of the catalyst into the latter, slowing down the overall deuteration process. Alternatively, iridium catalysts have been reported to become deactivated through the formation of inactive hydrogen bridged iridium trimers.[21] Stronger Ir-D bonds could favor the formation of these trimers and accelerate the catalyst deactivation process.



The ^{1}H NMR analysis of the products obtained shows a very complex process. Whereas the expected deuteration process should result in a precise isotopic distribution on the piperidine ring, an important migration of the hydrogen and deuterium atoms is observed (**Figure 3**). This indicates that competing C-H(D) insertion processes occur concurrently to the hydrogenation processes. In both the tetrahydropyridine (**8a**) and piperidine (**2a**) derivatives, the chiral center at the 2 position of the ring shows a higher than expected (44% and 36% respectively) content of hydrogen. Almost no insertion of deuterium is observed on the 2-methyl substituent. Most surprisingly, a fair amount of deuterium is found at the 4 position of the tetrahydropyridine (**8a**), clearly indicating a C-H insertion mechanism. The overall hydrogen content of both products is the expected 7 hydrogens. This seems to indicate that in the hydrogenation and C-H(D) insertion process, there is no reductive elimination of H-D from the catalyst. Finally, no deuteration is observed on the phenyl ring of the benzoyl group on the exocyclic nitrogen.

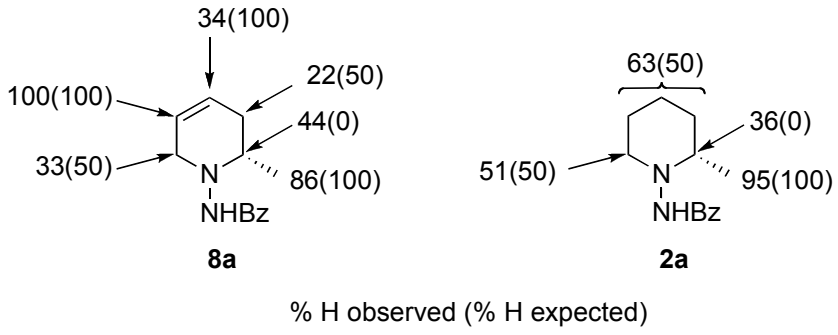
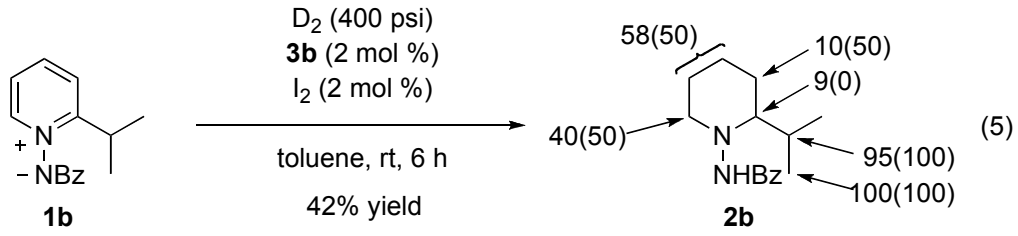


Figure 3. Isotopic distribution on the deuteration products of ylide **1a** and catalyst **3b**.

The deuteration of 2-*i*-propyl-*N*-benzoyliminopyridinium ylide (**1b**) was then done (Eq 5). Similarly to **1a**, the deuteration of the ylide results in a much lower yield compared to the hydrogenation reaction. The ^{1}H NMR shows the same type of complex H/D distribution as for the deuteration of **1a**. The hydrogen content of the chiral center at the 2-position is much lower than what is observed for the deuteration of **1a**, it can be explained by a minimization of the C-H(D) insertion process at this position caused by the larger isopropyl group. A slight trace of deuteration is observed on the tertiary carbon of the isopropyl group. These results indicate that the lack of enantioselectivity is not due to the migration of one of the intracyclic double bonds in the isopropyl group. The lack of selectivity appears to originate from low enantiodifferentiation in the hydrogenation step of the prochiral unsaturated intermediate.



This competing C-H(D) insertion mechanism is surprising but not unique. Other cationic iridium(III) complexes have been shown to be very active towards C-H insertions and used for the deuteration of compounds.[22,23] Burgess *et al*. have shown various levels of isotopic insertion in deuteration experiments of polysubstituted styrenes catalyzed by cationic iridium(I) catalysts.[24] They explained these results by double bond migration involving C-H insertion leading to the formation of π-allyl complexes. A similar type of double bond migration has been observed in the hydrogenation/deuteration of pinene derivatives using Crabtree catalyst.[25]

CONCLUSION

The iridium catalyzed asymmetric hydrogenation of *N*-benzoyliminopyridinium ylides is a milestone in the field of stereoselective synthesis of chiral piperidines. An investigation of the reaction conditions and the catalyst nature has shown that beside the complexity of the catalytic species involved, they are quite

robust and can tolerate purification under air and be active even in protic solvents. Deuteration experiments have shown that despite the efficiency of the methodology and the high yields observed, a complex combination of hydrogenation and C-H insertion processes occur concurrently. These surprising findings might open the way to new methodologies to further functionalize the piperidine ring in a stereoselective fashion.

EXPERIMENTAL

Melting points were obtained on a Buchi melting point apparatus and are uncorrected. Infrared spectra were taken on a Perkin Elmer Spectrum One FTIR and are reported in reciprocal centimeters (cm^{-1}). Nuclear magnetic resonance spectra (^{1}H, ^{13}C, ^{19}F, ^{31}P, DEPT 135, COSY, HMQC, NOESY) were recorded either on a Bruker AV 300, AMX 300, AV 400, ARX 400, or DMX 600 spectrometer. Chemical shifts for ^{1}H NMR spectra are recorded in parts per million from tetramethylsilane with the solvent resonance as the internal standard (chloroform, δ 7.27 ppm). Chemical shifts for ^{13}C NMR spectra are recorded in parts per million from tetramethylsilane using the central peak of deuterochloroform (77.23 ppm) as the internal standard. All spectra were obtained with complete proton decoupling. High resolution mass spectra were performed by the Centre régional de spectroscopie de masse de l'Université de Montréal. Combustion analyses were performed by the Laboratoire d'analyse élémentaire de l'Université de Montréal. Analytical High Performance Liquid Chromatography was performed either on an Agilent 1100 Series LC system equipped with a electrospray (ES) or APCI mass detector with simultaneous diode array UV detection. Data are reported as follows: (column type, eluent, flow rate: retention time (t_r)).

Preparation of a stock solution of the catalyst. In a flame dried round bottom flask under argon was added complex **3b** (64 mg, 0.040 mmol) and toluene (15 mL) at rt. Iodine (15 mg, 0.061 mmol) in toluene (5 mL) was added to the flask and was stirred to 8 h in darkness under argon. The solvent and excess iodine was removed under reduced pressure and the catalyst dried under vacuum. The residue was redissolved in toluene (20 mL) under argon and used as a 2.0 mM catalyst stock solution.

General hydrogenation procedure: *N*-[(2*S*)-2-methylpiperidinyl]benzamide (2a). In a flame dried 10 mL test tube under argon is added **1a** (42 mg, 0.20 mmol) and 2 mL of the catalyst stock solution (0.0040 mmol, 2 mol %). The reaction is stirred under argon until **1a** is dissolved. The test tube is inserted in a high pressure hydrogenation vessel and purged three times with 100 psi of hydrogen. A pressure of 400 psi of hydrogen is applied, the vessel is sealed and the reaction is stirred at rt for 6 h. The pressure is released and the reaction is poured directly on a pad of silica gel (6(h) x 1(w) cm), washed with 10 mL of

CH_2Cl_2 and the product is recovered using 20 mL of 50% EtOAc/CH_2Cl_2. The solvent is removed under reduced pressure affording the crude mixture of **2a** and **8a** (87:13, 42 mg, 98% yield). The residue is dissolved in a round bottom flask with 2 mL of MeOH and 10% Pd/C (2 mg, 1 mol %) is added. The flask is purged three times by cycle of vacuum/hydrogen and the reaction is stirred under 1 atmosphere of hydrogen at rt for 1 h. The solvent is removed under reduced pressure, the residue dissolved in 50% EtOAc/CH_2Cl_2 and filtered on a short silica gel pad (2(h) x 1(w) cm). The solvent is removed under reduced pressure affording the desired product **2a** as a white solid (42 mg, 98% yield, 90% ee): enantiomeric excess was determined by HPLC analysis (Chiralpak AD-H+AS, 70:30 hexanes:*i*-PrOH, 0.7 mL/min: (*R*)-**2a** t_r = 13.3 min, (*S*)-**2a** t_r = 21.6 min); R_f = 0.29 (50% EtOAc/Hex); mp 158 °C; $[\alpha]_D$ +34.0 (c 2.2, CH_2Cl_2); ^{1}H NMR (300 MHz, $CDCl_3$) * denotes minor conformers δ 7.83* (d, *J* = 7.1 Hz), 7.72 (d, *J* = 6.9 Hz, 2H), 7.47 (t, *J* = 7.4 Hz, 1H), 7.39 (t, *J* = 6.9 Hz, 2H), 6.63 (s(br), 1H), 6.23* (s(br)), 3.26-3.14 (m, 1H), 2.67-2.52 (m, 2H), 1.87-1.58 (m, 4H), 1.58-1.36 (m, 1H), 1.35-1.16 (m, 1H), 1.14 (d, *J* = 6.2 Hz, 3H), 0.94* (d, *J* = 6.2 Hz); ^{13}C NMR (75 MHz, $CDCl_3$) * denotes minor conformers δ 166.2, 134.3, 131.6, 130.8*, 129.4*, 128.7, 127.6*, 127.1, 60.8, 57.5, 33.7, 25.7, 24.1, 20.0; IR (neat) 3189, 3031, 2926, 1641, 1557, 1307, 692 cm^{-1}; LRMS (APCI, Pos) calcd for $C_{13}H_{18}N_2O$ $[M+H]^+$: 219.1 *m/z*, observed: 219.1 *m/z*. Rapid recrystallization in boiling ethyl acetate afforded **2a** (84% yield, 97% ee).

***N*-[2-*i*-propylpiperidinyl]benzamide (2b)**. White solid; R_f 0.54 (50%EtOAc/CH_2Cl_2); mp 174-177 °C; ^{1}H NMR (300 MHz, $CDCl_3$) * denotes minor conformers δ 7.84* (d, *J* = 7.3 Hz), 7.73 (d, *J* = 7.2 Hz, 2H), 7.49 (t, *J* = 7.1 Hz, 1H), 7.41 (t, *J* = 7.3 Hz, 2H), 6.67 (s(br), 1H), 6.11* (s(br)), 5.82-6.78 (m, 1H), 3.41-3.40* (m), 3.30 (m, 1H), 2.75-2.57 (m, 1H), 2.51-2.36 (m, 1H), 2.19-2.05 (m, 1H), 1.85-1.70 (m, 2H), 1.69-1.61 (m, 2H), 1.48-1.35 (m, 1H), 1.32-1.19 (m, 1H), 0.94 (d, *J* = 6.2 Hz, 3H), 0.89 (d, *J* = 6.2 Hz, 3H), 0.77* (d), 0.27* (d); ^{13}C NMR (100 MHz, $CDCl_3$) δ 165.9, 134.4, 131.6, 128.8, 127.2, 69.8, 58.3, 28.5, 25.4, 24.2, 23.9, 19.8, 16.2; IR (pure) 3223, 2938, 2825, 1643, 1535, 1303, 915, 799, 641, 616 cm^{-1}; LRMS (APCI, pos) calcd for $C_{15}H_{22}N_2O$ $[M + H]^+$: 247.2 *m/z*, observed: 247.2 *m/z*.

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