Platinum-Catalyzed Formation of Quinolines from Anilines. Aliphatic α-C−H Activation of Alkylamines and Aromatic *ortho*-C−H Activation of Anilines

Stephane Anguille, Jean-Jacques Brunet,* Ngoc Chau Chu, Ousmane Diallo, Carole Pages, and Sandrine Vincendeau

Laboratoire de Chimie de Coordination du CNRS, Unité No. 8241, Liée par Conventions à l'Université Paul Sabatier et à l'Institut National Polytechnique, 205 Route de Narbonne, 31077 Toulouse Cedex 04, France

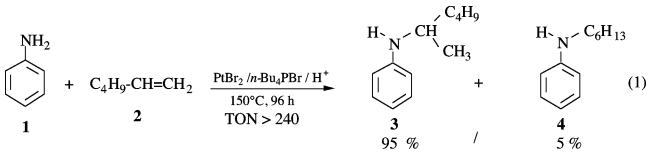
Received September 13, 2005

Platinum(II) bromide catalyzes the reaction of aniline with *n*-Bu_3N to give *N*-butylaniline and 2-propyl-3-ethylquinoline. The formation of the quinoline derivative is strongly favored (TON up to 40) by the presence of both *n*-Bu_4PBr and 1-hexene. The same reaction products are formed by reaction of aniline with either *n*-Bu_2NH or *n*-$BuNH_2$ ($PtBr_2$ catalyst). Under similar experimental conditions, the "$PtBr_2$−*n*-Bu_4PBr−1-hexene" system catalyzes the transformation of *N*-hexylaniline into 2-pentyl-3-butylquinoline (TON up to 42). Similarly, *N*-ethylaniline affords 2-methylquinoline (TON of 22). In both cases, the presence of 1-hexene strongly favors the conversion of the *N*-alkylaniline. On the basis of both complementary experiments and literature data, these unprecendented results are interpreted by an α-C−H activation of *n*-Bu_3N (iminium species as intermediate), leading to *N*-butylaniline (butyl group transfer to aniline). The "$PtBr_2$−n-Bu_4PBr−1-hexene" system also catalyzes an α-C−H activation of the alkyl part of *N*-(*n*-alkyl)anilines to generate the corresponding imines, which dimerize. A heterocyclization then occurs, via a Pt(II)-catalyzed aromatic *ortho*-C−H activation, followed by deamination and dehydrogenation (1-hexene as hydrogen acceptor). Although not completely clear, the role of an alkene (1-hexene or ethylene) is highlighted.

Introduction

During the last forty years, a great deal of effort has been devoted to transition metal-catalyzed reactions and transformations of amines. This interest lies both in potential synthetic applications (hydroamination reactions,[1] synthesis of heterocycles,[2] etc.) and in mechanistic aspects (N−H and C−H activation processes).[3,4]

In recent years, we have been studying platinum(II) catalytic systems for the *intermolecular* hydroamination of nonactivated alkenes.[5−8] We recently reported that a $PtBr_2$−*n*-Bu_4PBr association provides the most efficient catalytic system reported so far for the hydroamination of 1-hexene.[7] The activating role of *n*-Bu_4PBr has been clearly demonstrated. Furthermore, this reaction occurs with an excellent Markovnikov regioselectivity (eq 1).



Complementary investigations into hydroamination with the above catalytic system led us to some unexpected observations concerning the formation of quinoline derivatives. Since different observations seemed to involve common features, we were encouraged to examine more thoroughly the possible reaction mechanism(s). Investigations designed to better understand the origin of quinoline derivatives are described below.

Results and Discussion

Alkyl Group Transfer to Aniline. Heterocyclization to Quinolines. During the study of the reaction of aniline (45 mmol) with 1-hexene (90 mmol) in the presence of $PtBr_2$ (0.13 mmol) and *n*-Bu_4PBr (8.45 mmol) (eq 1 without acid cocatalyst), we first observed that if excess *n*-Bu_3N, **5**, was present in the reaction medium (as a cosolvent, 5 mL), the hydroamination

* To whom correspondence should be addressed. E-mail: brunet@lcc-toulouse.fr.

(1) Brunet, J. J.; Neibecker, D. In *Catalytic Heterofunctionalization*; Togni, A., Grützmacher, H., Eds.; VCH: Weinheim, 2001; pp 91−141. Müller, T. E.; Beller, M. *Chem. Rev.* **1998**, *98*, 675−704. Roundhill, D. M. *Catal. Today* **1997**, *37*, 155−165. Taube, R. In *Applied Homogeneous Catalysis with Organometallic Complexes*; Cornils, B., Herrmann, W., Eds.; VCH: Weinheim, 1996; Vol. 2, pp 507−521.

(2) (a) Hegedus, L. S.; Allen, G. F.; Bozell, J. J.; Waterman, E. L. *J. Am. Chem. Soc.* **1978**, *100*, 5800−5807. (b) Hegedus, L. S. *Angew. Chem., Int. Ed.* **1988**, *27*, 1113−1126. (c) Cho, C. S.; Lim, H. K.; Shim, S. C.; Kim, T. J.; Choi, H. *J. Chem. Commun* **1998**, 995−996. (d) Jacob, J.; Jones, W. *D. J. Org. Chem.* **2003,** *68*, 3563−3568, and references therein. (e) Tsuji, J. *Palladium Reagents and Catalysis*; Wiley: Chichester, 1995.

(3) Shilov, A. E.; Shul'pin, G. B. *Chem. Rev.* **1997**, *97*, 2879−2932. Dyker, G. *Angew. Chem., Int. Ed.* **1999**, *38*, 1698−1712. Jun, C.-H.; Chung, K.-Y.; Hong, J.-B. *Org. Lett.* **2001**, *3*, 785−787.

(4) Casalnuovo, A. L.; Calabrese, J. C.; Milstein, D. *J. Am. Chem. Soc.* **1988**, *110*, 6738−6744.

(5) Brunet, J. J.; Chu, N. C.; Diallo, O.; Mothes, E. *J. Mol. Catal.* **2003**, *198*, 107−110.

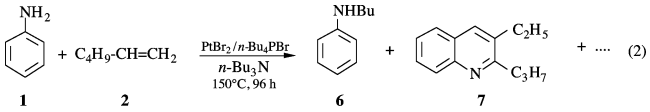
(6) Brunet, J. J.; Cadena, M.; Chu, N. C.; Diallo, O.; Jacob, K.; Mothes, E. *Organometallics* **2004**, *23*, 1264−1268.

(7) Brunet, J. J.; Chu, N. C.; Diallo, O. *Organometallics* **2005**, *24*, 3104−3110.

(8) The hydroamination of ethylene with carboxamides has been reported to be catalyzed by a $[PtCl_2(CH_2{=}CH_2)]_2$−$2PPh_3$ system: Wang, X.; Widenhoefer, R. A. *Organometallics* **2004**, 23 1649−1651.

10.1021/om058047m CCC: $33.50
Publication on Web 05/10/2006

reaction was completely inhibited. Instead, the reaction resulted in an alkyl group transfer, leading to *N*-butylaniline, **6**, and also in a heterocyclization, leading to 2-propyl-3-ethylquinoline, **7** (eq 2). Both compounds have been isolated by chromatography and spectroscopically characterized. Quantification with an external standard (*N*,*N*-dibutylaniline) indicated that both compounds are formed in a catalytic manner with a TON of 5 and 30 for **6** and **7**, respectively. It must also be noted that *n*-Bu_2-NH and *n*-$BuNH_2$ were observed as reaction byproducts (GC-MS analysis) and that the platinum precursor was, at least in part, reduced to platinum metal.



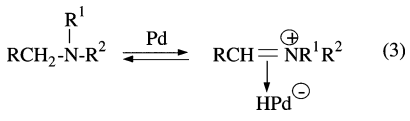
The same reaction products were obtained when the reaction was carried out in the absence of 1-hexene. In the latter case, however, although **6** was formed with a TON of 4, **7** was formed in much lower amounts (TON = 2) than in the presence of 1-hexene. Therefore, 1-hexene appears to play an important role in the rate of formation of **7**.

Finally, the reaction was shown to occur, although with lower yields, in the absence of *n*-Bu_4PBr, therefore ruling out *n*-Bu_4-PBr as the source of the transferred butyl group.

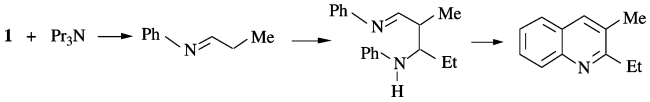
Thus, the platinum(II) system catalyzes both an alkyl group transfer from **5** to aniline to give **6**, and the formation of **7**. The presence of 1-hexene seems important for the formation of the quinoline derivative.

Further studies into the reaction of aniline with *n*-Bu_3N in the presence of $PtBr_2$ (without *n*-Bu_4PBr) as catalyst resulted in the formation of platinum metal (as a coating on the glass) at the end of the reaction. Replacing $PtBr_2$ by commercial platinum black resulted in alkyl group exchange with formation of **6**, *n*-Bu_2NH, and *n*-$BuNH_2$, but no trace of **7** was detected. Similarly, $Pt(PPh_3)_4$ (slowly) catalyzed alkyl transfer but did not promote the heterocyclization. It thus appears that platinum-(0) species are able to promote alkyl group transfer, but that a platinum(II) catalyst is necessary for the heterocyclization to take place. No reaction occurred in the absence of a platinum catalyst.

The reaction of alkylamines using Pd(0) catalysts has been thoroughly studied, especially by Murahashi et al.[9−14] In the case of *tertiary amines*,[11,12] the results of quenching experiments convincingly support the notion that the reaction involves coordination of the transition metal to the nitrogen atom, followed by insertion into an α-C−H bond, leading to an iminium ion coordinated to a hydridopalladate species (eq 3).[12]

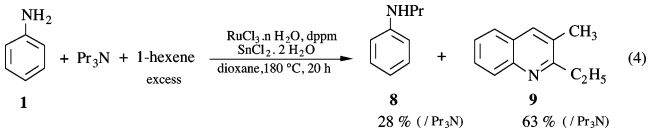


Scheme 1



Subsequent nucleophilic attack occurs on the electrophilic carbon atom of the iminium complex, resulting in the transfer of an alkyl group from the amine to the nucleophile with concomitant liberation of R^1R^2NH. Palladium black, $PdCl_2$, Pd-$(OAc)_2$, and $RuCl_3$ were reported to give similar results.[12]

Reactions similar to that illustated in eq 2 have recently been observed between aniline and trialkylamines under the action of a complex catalytic system ($RuCl_3 \cdot nH_2O$, dppm, $SnCl_2 \cdot 2H_2O$) in the presence of excess 1-hexene (eq 4).[15a] When the above reaction was performed in the absence of 1-hexene, a lower yield was obtained for **9** (48% vs Pr_3N), whereas that of **8** remained unchanged. No mention was made of free dealkylated amines Pr_2NH and $PrNH_2$ being observed.[15a]



The first reaction pathway proposed by Cho et al. involves the intermediate formation of an imine (Scheme 1).[15a] The imine then dimerizes,[16] and as previously proposed by Watanabe et al.,[17] the heteroannulation would occur via aromatic *ortho*-C−H activation by ruthenium, followed by insertion of the C=N bond into the Ru−C bond. The resulting quinoline is thought to form through several classsical processes such as reductive elimination, deamination, and dehydrogenation.[15]

It must be noted, however, that the reaction (eq 4) was carried out in the presence of catalytic amounts of water, introduced with the $RuCl_3 \cdot 3H_2O$ and $SnCl_2 \cdot 2H_2O$. Thus, an alternative *heterocyclization* mechanism deserves consideration, in which water plays a role. Indeed, Kharasch et al. reported that the butylidene aniline dimer reacted simply with aqueous HCl at room temperature, affording 2-propyl-3-ethylquinoline, **7**, in 50% yield.[16]

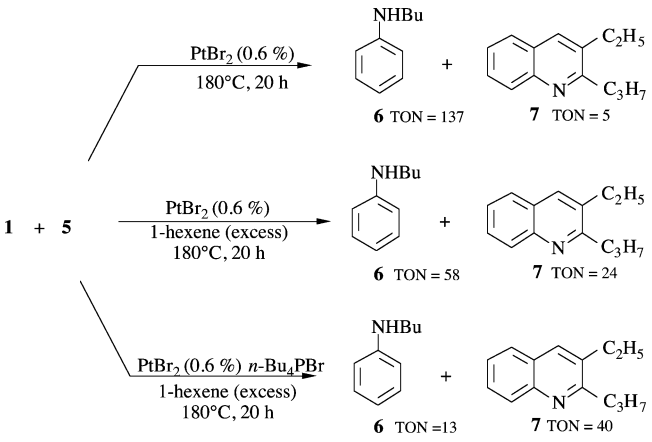
All reactions reported in the present work were conducted with anhydrous $PtBr_2$-based systems under an argon atmosphere. Therefore, the mechanism proposed by Kharasch et al. can be ruled out in our case.

At any rate, we attempted to compare the $PtBr_2$ system with the ruthenium−tin catalyst in the reaction between aniline and *n*-Bu_3N. The reaction between aniline (6 mmol) and *n*-Bu_3N (1 mmol), using 8% of the ruthenium−tin catalyst (in the presence of 10 mmol of 1-hexene) for 20 h at 180 °C has been reported to afford **7** in 51% yield (based on *n*-Bu_3N, i.e., TON = 6.5) (the amount of **6** was not specified).[15a] For comparison (Scheme 2), the reaction of aniline (45 mmol) with *n*-Bu_3N (20 mmol) catalyzed by $PtBr_2$ (0.6%) was also conducted at 180° for 20 h. **6** was produced in 90% yield based on *n*-Bu_3N (TON = 137) and **7** in 7% yield (TON = 5).

When the same reaction was performed in the presence of 1-hexene (90 mmol) (Scheme 2), **6** and **7** were produced with

(9) Yoshimura, N.; Moritani, I.; Shimamura, T.; Murahashi, S.-I. *J. Am. Chem. Soc.* **1973**, *95*, 3038−3039.
(10) Shvo, Y.; Laine, R. M. *J. Chem. Soc., Chem. Commun*. **1980**, 753−754.
(11) Murahashi, S.-I.; Hirano, T.; Yano, T. *J. Am. Chem. Soc.* **1978**, *100*, 348−350.
(12) Murahashi, S.-I.; Yano, T. *J. Chem. Soc., Chem. Commun*. **1979**, 270−271.
(13) Murahashi, S.-I.; Yoshimura, N.; Tsumiyama, T.; Kojima, T. *J. Am. Chem. Soc*. **1983**, *105*, 5002−5011.
(14) Murahashi, S.-I, *Angew. Chem., Int. Ed. Engl*. **1995**, *34*, 2443−2465.
(15) (a) Cho, C. S.; Oh, B. H.; Kim, T.-J.; Shim, S. C. *Chem. Commun*. **2000**, 1885−1888. (b) Cho, C. S.; Kim, J.-S.; Oh, T. J.; Shim, S. C., Yoon, N. S. *Tetrahedron* **2000**, *56*, 7747−7750. (c) Cho, C. S.; Kim, T. K.; Kim, B. T.; Kim, T.-J.; Shim, S. C. *J. Organomet. Chem.* **2002**, *650*, 65−68.
(16) Kharasch, M. S.; Richlin, I.; Mayo, F. R. *J. Am. Chem. Soc*. **1940**, *62*, 494−497.
(17) Watanabe, Y.; Tsuji, Y.; Ohsugi, Y.; Shida, J. *Bull. Chem. Soc. Jpn*. **1983**, *56*, 2452−2457.

Scheme 2



TON = 58 and TON = 24, respectively. Finally, when the reaction was performed in the presence of both 1-hexene and *n*-Bu_4PBr, **6** was formed in lower yield, whereas **7** was formed in 50% yield (vs **5**) (TON = 40). In all reactions depicted in Scheme 2, formation of the dealkylated amines *n*-Bu_2NH and *n*-$BuNH_2$ and reduction of Pt(II) to platinum metal were observed.

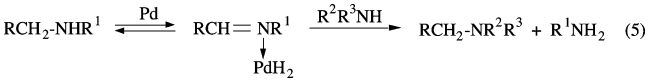
It thus appears that $PtBr_2$ *alone* is a very active catalyst for alkyl group transfer, but much less active than the ruthenium−tin system for the formation of **7**. As noted before, this observation may be tentatively explained by the slow in situ reduction of the Pt(II) catalyst into Pt(0) species, which are inactive for the heterocyclization (vide supra). However, in the presence of 1-hexene and *n*-Bu_4PBr, the $PtBr_2$ catalyst (0.6%) system affords **7** in the same yield (50%) as that obtained with the ruthenium−tin catalyst used in much higher catalyst ratio (8%). The above results also clearly show that, as seen for the ruthenium−tin catalyst, the presence of 1-hexene has a great influence on the formation of **7**. Additionally, for the $PtBr_2$ catalyst, the presence of *n*-Bu_4PBr also promotes the formation of the quinoline derivative. The reason for the last observation is unclear at the present time. However, an intuitive hypothesis would be to consider that *n*-Bu_4PBr inhibits, or at least retards, the reduction of Pt(II) to Pt(0) species.

For reactions conducted with the ruthenium−tin catalyst, Cho et al.[15a] considered that the role of 1-hexene is to act as a hydrogen acceptor, especially in the final step in the formation of **7** (the $PtBr_2$−*n*-Bu_4PBr system has also been shown to catalyze a similar transfer hydrogenation).[7] However, it is clear that 1-hexene also plays another role since in its absence, the yield of **7** was only 6% (Scheme 2), whereas the corresponding tetrahydroquinoline derivative was not detected. It thus appears that 1-hexene is also implicated in the reaction of the platinum complex with *n*-Bu_3N, likely by increasing the reactivity of the platinum center. The effect that an alkene has on the properties of $PtBr_2$ catalytic systems will be discussed later in this paper.

Thus, the reaction described in eq 2 may be explained by a mechanism similar to that proposed by Cho et al.[15] It is also interesting to note that, under identical conditions (presence of 1-hexene), the $PtBr_2$−*n*-Bu_4PBr system is more active than the ruthenium−tin system for the formation of quinoline derivatives.

Another point must be addressed. As mentioned previously, the dealkylated amines *n*-Bu_2NH and *n*-$BuNH_2$ were also formed during the $PtBr_2$-catalyzed *n*-butyl group transfer reaction from *n*-Bu_3N to aniline. This observation led us to briefly examine the reaction of aniline with *n*-Bu_2NH and *n*-$BuNH_2$ in the presence of catalytic amounts of $PtBr_2$ (48 h at 150 °C). In both cases, **6** and **7** were formed, although in lower yields than those obtained in the corresponding reaction betweeen aniline and *n*-Bu_3N. These observations strongly suggest that a common intermediate is involved for the formation of **7**, regardless of the nature of the starting alkylamine. Further investigations (vide infra) indicate the common intermediate to be *N*-butylaniline.

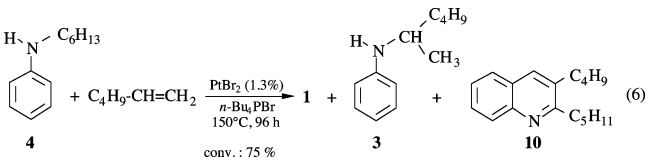
Catalytic alkyl group exchange reactions of *primary and secondary* amines have also been studied by other authors.[11−13,18] These reactions have been found to occur under the action of palladium black, and also $PdCl_2$ and $Pd(OAc)_2$, which are readily reduced to give palladium black under the reaction conditions.[13] As seen for tertiary amines, an α-C−H activation by palladium is believed to occur, generating the corresponding imine coordinated to a transition metal dihydride (eq 5).



Subsequent attack by a different amine (R_2R_3NH) results in the transfer of the RCH_2 group to afford $RCH_2NR_2R_3$ with liberation of R_1NH_2.

The Pt(II)-catalyzed butyl group transfer from either *n*-Bu_2NH or *n*-$BuNH_2$ to aniline can thus be rationalized by a similar mechanism. This is the first report of the formation of quinoline derivatives such as **7** from transition metal-mediated reaction of aniline with a primary (*n*-$BuNH_2$) or secondary amine (*n*-Bu_2NH).

***N*-Alkylanilines: Heterocyclization to Quinolines.** A second intriguing observation was made during complementary experiments aimed at examining the possible in situ isomerization of *N*-hexylaniline into *N*-(2-hexyl)aniline under conditions similar to those shown in eq 1, but without the acid cocatalyst. It was observed that *N*-hexylaniline (14 mmol) (prepared independently), when reacted at 150 °C with $PtBr_2$ (1.3%) and *n*-Bu_4PBr (3 g) in the presence of a large excess of 1-hexene (90 mmol), produced (eq 6) a mixture of aniline (TON = 6), 2-pentyl-3-butylquinoline, **10** (TON = 32), and, unexpectedly, the branched *N*-(2-hexyl)aniline, **3** (TON = 12). The reaction products **3** and **10** were isolated by column chromatography and clearly identified by comparison (GC-MS, ^1H NMR) with authentic samples.[19]



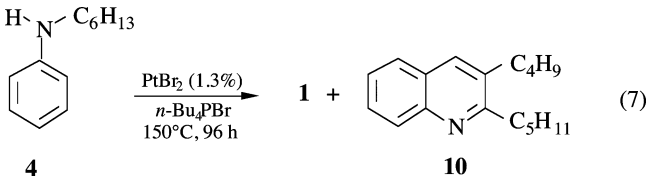
This observation was somewhat troublesome, as it implied that, in the hydroamination of 1-hexene with aniline (eq 1), the Markovnikov hydroamination product **3** could be formed by isomerization of the anti-Markovnikov isomer **4**. We have thus been led to investigate this possibility more thoroughly.

When the reaction shown above was performed in the absence of 1-hexene, a much lower conversion was observed, and **10** (TON = 2) was the only reaction product, together with aniline

(18) The Ru(II)-catalyzed conversion of primary alkylamines (bearing an α-hydrogen atom) to symmetrical secondary amines is believed to involve formation of an imine: Bui-the-Kai; Concilio, C.; Porzi, G. *J. Organomet. Chem.* **1981**, *208*, 249−251.

(19) (a) An authentic sample of **3** has been prepared by adapting the procedure previously reported: Schellenberg, K. A. *J. Org. Chem.* **1963**, *28*, 3259−3260. (b) An authentic sample of **10** has been prepared according to Kharasch et al.[16] and spectroscopically characterized in previous work.[21]

(TON = 3) (eq 7). To the best of our knowledge, this is the first report of such a transformation of a *N*-alkylaniline.



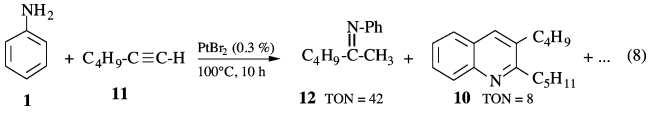
(7)

Comparison of eqs 6 and 7 again highlights the important role of 1-hexene, in the presence of which interaction between the catalyst and **4** and heterocyclization to afford **10** are strongly favored.

Formation of aniline (eqs 6, 7) is convincing evidence supporting the formation of **10** through dimerization of the imine PhN=CH−C_5H_{11} (vide supra). The production of **1**, **3**, and **10** (eq 6) can thus be rationalized as follows: under the action of the platinum catalyst, **4** is transformed into the corresponding imine Ph−N=CH−C_5H_{11}, which dimerizes as previously proposed. After cyclization via aromatic *ortho*-C−H activation (vide supra), **10** is finally formed with liberation of 1 equiv of aniline. The latter is then available for the platinum-catalyzed hydroamination of 1-hexene (95% Markovnikov), leading to **3** according to eq 1. So, the formation of **3** is not due to a direct isomerization of **4**. Another comment may be added. In the direct hydroamination of 1-hexene by aniline catalyzed by the $PtBr_2$−*n*-Bu_4PBr system (eq 1), no traces of **10** have been detected.[6] This may be explained by the high regioselectivity of the hydroamination, leading to **3** (95%) and only small amounts (5%) of **4**. Furthermore, hydroamination reactions were conducted with 0.3% catalyst (as compared to 1.3% for eq 6). It is thus normal that **10** could not be detected in the direct hydroamination reaction (eq 1).

So, the most intriguing observation is the unprecedented platinum-catalyzed, direct transformation of *N-hexyl*aniline into the quinoline **10**.[10−13,18,20] This reaction likely involves the formation of the imine Ph−N=CH−C_5H_{11}, which then evolves as previously proposed by different authors (vide supra), affording the quinoline **10** and aniline.

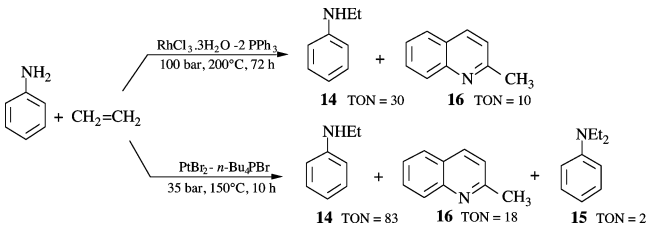
The $PtBr_2$-catalyzed formation of **10** is also seen in the $PtBr_2$-catalyzed hydroamination of 1-hexyne by aniline (eq 8),[21] in which **10** is considered to originate from the anti-Markovnokov hydroamination product, Ph−N=CH−C_5H_{11}.



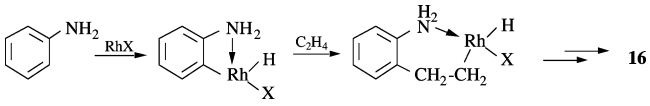
As mentioned previously, the reactions of secondary amines with Pd catalysts have been studied by Murahashi et al.; however reactions involving *N*-alkylanilines gave very low conversions and were not investigated in detail.[9,13] In the case of *N*-ethylaniline, reaction with palladium black (48 h at 150 °C) has been reported to yield *N*,*N*-diethylaniline, with a 5% conversion. No mention was made of the possible formation of 2-methylquinoline.[9]

As discussed above, the $PtBr_2$−*n*-Bu_4PBr system catalyzes the formation of an imine directly from a *N*-alkylaniline, the activity of which is greatly increased in the presence of an alkene. To confirm the above conclusion, *N*-hexylaniline was reacted with the $PtBr_2$−*n*-Bu_4PBr system under *ethylene* pressure (25 bar) for 96 h at 150 °C. A complex reaction mixture resulted, among which we could easily identify *N*-ethylaniline (TON = 3), *N*-ethyl-*N*-hexylaniline (TON = 6), and, *interestingly*, **10** (TON = 7). As expected, the formation of **10** from *N*-ethylaniline is increased by the presence of ethylene (TON = 7 vs TON = 2, eq 7). For this transformation, ethylene appears less efficient than 1-hexene, but it may be considered that although the amount of ethylene used (25 bar = 100 mmol) is near that of 1-hexene (90 mmol), the concentration of the alkene in the condensed phase (at 150 °C) is likely to be less for ethylene (bp = − 104 °C) than for 1-hexene (bp = 63 °C).

Scheme 3



Scheme 4



The above results led us to question a related reaction, namely, the formation of 2-methylquinoline, **16**, during the hydroamination of ethylene by aniline (Scheme 3). This reaction product was first observed by Diamond et al. using $RhCl_3 \cdot 3H_2O$ as catalyst[22] and later by us using the $PtBr_2$−*n*-Bu_4PBr system.[6] Very recently, a similar reaction has also been reported to be catalyzed by a cationic Ru-alkylidene complex.[23]

An elegant mechanistic investigation[22] led Diamond et al. to propose that the formation of **16** involves an aromatic *ortho*-C−H activation of **1** in the first step (Scheme 4).

Diamond et al. also reported that the $RhCl_3$−$2PPh_3$ system does not catalyze the reaction of aniline with 1-butene.[22] In contrast, the $PtBr_2$−*n*-Bu_4PBr system is a very efficient catalyst for the hydroamination of 1-hexene (eq 1).[7] It is thus evident that these two catalytic systems exhibit different properties. In light of the observed formation of the quinoline **10** from *N*-hexylaniline in the platinum system (vide supra, eqs 6, 7), we decided to examine the possible formation of the quinoline **16** from *N*-ethylaniline.

The reaction of *N*-ethylaniline (45 mmol) with catalytic amounts of $PtBr_2$ (0.3%) in *n*-Bu_4PBr (7 g) (150 °C, 96 h) resulted in a low conversion (<10%) affording **1** (TON = 10) and *N*,*N*-diethylaniline, **15** (TON = 6) (Scheme 5). Although some unidentified side-products (<0.5% each) were also formed, quinoline **16** could not be detected. In contrast, when the same reaction was performed in the presence of 1-hexene (90 mmol), a 42% conversion of **14** was observed affording **15** (TON = 3), **16** (TON = 22), and **3** (TON = 3), together with large amounts of aniline (ca. 10 mmol) (Scheme 5).

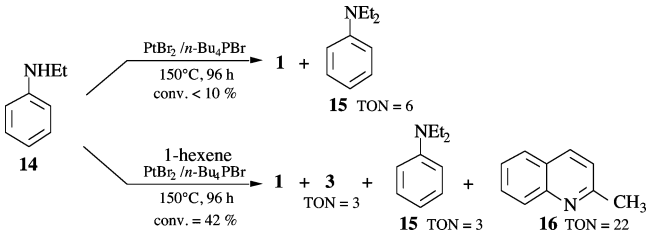
(20) The Ru(II)-catalyzed conversion of *N*-methyl and *N*,*N*-dimethylalkylamines into *N*-methyldialkylamines is believed to involve formation of an imine: Arcelli, A.; Bui-the-Kai; Porzi, G. *J. Organomet. Chem.* **1982**, *231*, C31−C34.

(21) Brunet, J. J.; Chu, N. C.; Diallo, O.; Vincendeau, S. *J. Mol. Catal.* **2005**, *240*, 245−248.

(22) Diamond, S. E.; Szalkiewicz, A.; Mares, F. *J. Am. Chem. Soc.* **1979**, *101*, 490−491. Diamond, S. E.; Szalkiewicz, A.; Mares, F. *Fundam. Res. Homogeneous Catal.* **1979**, *3*, 345−358.

(23) During the preparation of the manuscript, a similar reaction has been reported using the cationic Ru-alkylidene complex $[(PCy_3)_2(CO)Ru{=}CH{-}CH{=}C(CH_3)_2]^+$, BF_4^- as catalyst: Yi, C. S.; Yun, S. Y. *Org. Lett.* **2005**, *7*, 2181−2183.

Scheme 5



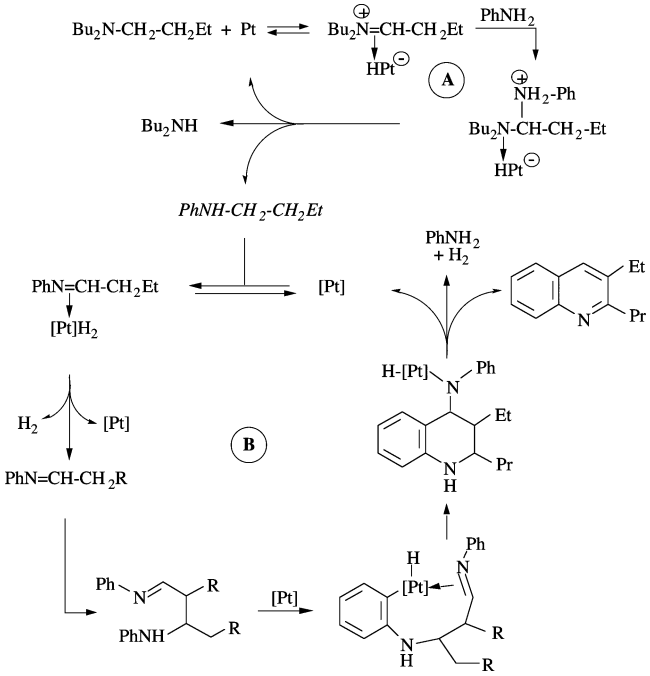
These results clearly show that the conversion of *N*-ethylaniline is promoted by the presence of 1-hexene. More importantly, it is now clear that the presence of pressured ethylene as reagent is not necessary for the formation of **16** to occur. Another argument can be developed. If one considers that for the reaction performed in the presence of 1-hexene (Scheme 5) the conversion (42%) of *N*-ethylaniline affords aniline and ethylene (whatever the mechanism), the total amount of ethylene liberated would reach 18 mmol. Taking into account the volume of the autoclave, this would correspond to a less than 5 bar of ethylene pressure. The reaction of aniline (18 mmol) with ethylene (5 bar at RT) for 96 h at 150 °C in the presence of the $PtBr_2-n$-Bu_4PBr system (0.7% Pt/aniline) yields **14** and **16** with TON = 25 and 4, repectively. Thus, even with a doubled catalyst loading (0.7%), the yield of **16** is much lower than that obtained directly from *N*-ethylaniline in the presence of 1-hexene (Scheme 5). This result is a good argument to suggest that **16** is formed via the imine $PhN{=}CH-CH_3$ and rules out the formation of **16** (Scheme 3, $PtBr_2-n$-Bu_4PBr catalyst) via the aromatic *ortho*-C−H activation mechanism proposed by Diamond et al. (Scheme 4).

These results are in agreement with the outcome of the reaction between *N*-hexylaniline and $PtBr_2-n$-Bu_4PBr (vide supra): the presence of an alkene promotes a higher conversion of *N*-alkylanilines. A possible hypothesis is that, in the presence of an alkene, the platinum complex evolves from $[PtBr_4]^{2-}$ (or $[LPtBr_3]^-$) to more active species such as $[PtBr_3(\text{alkene})]^-$ (or $[LPtBr_2(\text{alkene})]$).[7] In its active form, the platinum complex catalyzes the transformation of *N*-alkylanilines. It is tempting to speculate that in both cases (*N*-hexyl- and *N*-ethylanilines) the formation of the quinoline derivatives has the same origin: α-C−H activation of the *N*-alkylaniline and formation of an imine.

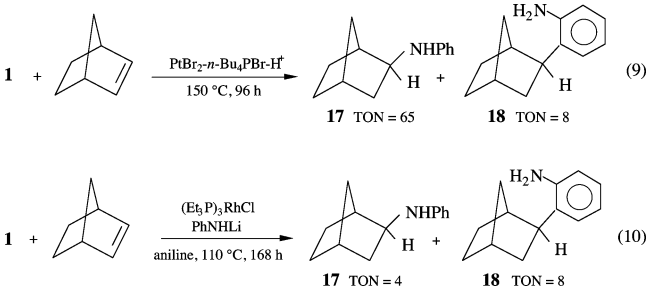
In conclusion, the $PtBr_2$-catalyzed reactions studied in this work may be rationalized by Scheme 6 (exemplified for n-Bu_3N).

Two catalytic cycles seem to be involved. The first one (cycle A) corresponds to the transfer of an alkyl group from n-Bu_3N to aniline, catalyzed by either Pt(II) or Pt(0) (referred to as "Pt") to afford *N*-butylaniline. This process originates from an α-C−H activation of n-Bu_3N. The second cycle (cycle B) describes the formation of the quinoline derivative by reaction of *N*-butylaniline with Pt(II) species, noted "[Pt]". The first step of cycle B, evidenced for the first time, is a platinum(II)-catalyzed α-C−H activation of *N*-butylaniline, generating the corresponding imine. Both the above α-C−H activation processes are favored by the presence of an alkene, which increases the activity of the catalyst (likely as hydrogen acceptor for cycle B). The imine dimerizes, spontaneously or under Pt(II) catalysis (?), and a heterocyclization takes place in which a platinum-(II)-catalyzed aromatic *ortho*-C−H activation seems to be involved. The quinoline derivative is finally formed through deamination of a benzylic carbon atom, followed by dehydrogenation (alkene as hydrogen acceptor).

Scheme 6



Nevertheless, the aromatic *ortho*-C−H activation of aniline proposed by Diamond et al. (Scheme 4) seems to fit with the *ortho*-alkylation of aniline with norbornene observed in two instances: 2-(2-norbornyl)aniline **18** was formed during the hydroamination of norbornene catalyzed by the $PtBr_2-n$-Bu_4-PBr system (eq 9)[5] but also when catalyzed by $(Et_3P)_3RhCl$/PhNHLi in THF (eq 10).[24] In the latter case, **18** was in fact the major reaction product.[25]



Such an aromatic α-C−H activation of aniline is also believed to be involved during the iridium(I)-catalyzed *ortho*-alkylation of phenol with norbornene.[26] A few other examples of *ortho*-C−H activation of aniline derivatives have been reported.[27,28]

Experimental Section

Methods and Materials. Tetra(*n*-butyl)phosphonium bromide (Janssen), *N*,*N*-dibutylaniline, *N*-butylaniline, tributylamine, and 2-methylquinoline (Acros), *N*-ethylaniline and hexylamine (Aldrich), 1-hexene (Fluka), platinum bromide, platinum black, Pt-

(24) Brunet; J. J.; Neibecker, D.; Philippot, K. *J. Chem. Soc., Chem. Commun*. **1992**, 1215−1216. Brunet, J. J.; Commenges, G.; Neibecker, D.; Philippot, K. *J. Organomet. Chem.* **1994**, *469*, 221−228.

(25) A similar reaction has been reported to be catalyzed by a cationic alkyl tantalum imido complex: Anderson, L. L.; Arnold, J.; Bergman, R. G. *Org. Lett*. **2004**, *6*, 2519−2522.

(26) Porta, R.; Togni, A. *Chem. Commun*. **2003**, 760−761.

(27) Uchimaru, Y. *Chem. Commun*. **1999**, 1133−1134.

(28) Yadav, J. S.; Reddy, B. V. S.; Rao, K. V.; Raj, K. S.; Prasad, A. R.; Kumar, S. K.; Kunwar, A. C.; Jayaprakash, P.; Jagannath, B. *Angew. Chem., Int. Ed*. **2003**, *42*, 5198−5201.

$(PPh_3)_4$, $[PtCl_2(C_2H_4)_2]_2$, and $RhCl_3 \cdot 3H_2O$ (Strem) were used as received. Aniline (Fluka or Acros) was distilled before use. *N*-Hexylaniline was prepared according to Buchwald et al.[29] Ethylene (N 45) was purchased from L'Air Liquide. All catalytic experiments were carried out under argon using vacuum line techniques.

Instrumentation. GC analyses were performed on a Hewlett-Packard HP 4890 (FID) chromatograph (HP 3395 integrator) equipped with a 30 m HP1 capillary column and GC-MS analyses on a Hewlett-Packard HP 6890 apparatus equipped with a HP 5973 M ion detector. NMR analyses were performed on Brüker AM 250 or Avance 500 apparatus. Catalytic experiments were conducted in a 100 mL stainless steel autoclave with a glass liner and a magnetic stirring bar.

Reactions. The typical procedure is exemplified in Scheme 2. An autoclave was charged with $PtBr_2$ (46.2 mg, 0.13 mmol) and *n*-Bu_4PBr (3 g), closed, and submitted to argon-vacuum cycles. Degassed aniline (4.1 mL, 45 mmol), *n*-Bu_3N (5 mL, 20 mmol), and 1-hexene (11.5 mL, 90 mmol) were then introduced into the autoclave via syringe. The temperature was adjusted to 180 °C. After 20 h, the autoclave was allowed to cool to room temperature. The reaction mixture was dropped into 50 mL of diethyl ether, stirred, and then filtered. The solid phase was extracted again with diethyl ether (2 × 50 mL). The external standard (*N*,*N*-dibutylaniline) was added to the combined ethereal phases and the solution analyzed by GC and GC-MS. For a run carried out according to the last reaction of Scheme 2, the external standard was omitted. After evaporation of the solvents, column chromatography (hexane/diethyl ether: 98/2) afforded pure **7** (satisfactory elemental analysis).

^{1}H NMR ($CDCl_3$, 200 MHz): δ (ppm) ($CHCl_3$ at 7.25) 8.01 (d, 1H), 7.86 (s, 1H), 7.72 (d, 1H), 7.60 (t, 1H), 7.40 (t, 1H), 2.95 (t, 2H), 2.84 (q, 2H), 1.73−1.92 (m, 2H), 1.38 (t, 3H), 1.06 (t, 3H). This spectrum is identical to that reported in the literature.[2d] GC-MS (EI, 70 eV) *m*/*z*: 199, 184, 171, 157, 143, 128.

Acknowledgment. The authors wish to thank the Centre National de la Recherche Scientifique and the Université Paul Sabatier for financial support. Thanks are also due to R. Poli and M. Rodriguez for helpful discussions. The English language has been checked and improved by J. Houghton (York University, UK), who is gratefully acknowledged for her kindness.

OM058047M

(29) Kwong, F. Y.; Klapars, A.; Buchwald, S. L. *Org. Lett.* **2002**, *4*, 581−584.