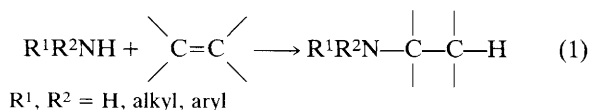# Unexpected Catalytic and Stereoselective Hydroarylation of Norbornene During the Attempted Rhodium-catalysed Hydroamination of Norbornene with Aniline or Diphenylamine

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The reaction of aniline (or diphenylamine) with norbornene in the presence of a catalytic system generated from [{Rh(PEt₃)₂Cl}₂] and PhNHLi (or Ph₂NLi) results in hydroarylation to yield 2-(2-aminophenyl)norbornane [or 2-(2-phenylaminophenyl)norbornane].

The direct addition of an N–H bond of amines across the C=C bond of unactivated alkenes (hydroamination) has attracted a great deal of interest.[1–3] Indeed, a catalytic version of this reaction [eqn. (1)] could be a valuable alternative to the classical industrial synthesis of alkylamines by dehydration of alcohols in the presence of amines. However, efforts to effect this transformation in a general and efficient manner have met with only limited success.[1] Until recently, the basic approaches consisted of either activating the amine *via* alkali metal amido species[4] or activating the alkene by coordination to transition metals.

$$R^1R^2NH + \;\overset{\diagup}{\underset{\diagdown}{C}}{=}\overset{\diagup}{\underset{\diagdown}{C}} \longrightarrow R^1R^2N{-}\overset{|}{\underset{|}{C}}{-}\overset{|}{\underset{|}{C}}{-}H \qquad (1)$$

R¹, R² = H, alkyl, aryl

The first examples of transition metal-catalysed homogeneous hydroamination reactions were reported by Coulson in 1971.[5] They concerned the rhodium- or iridium-catalysed hydroamination of ethylene with secondary amines. This reaction, however, is limited to ethylene, and is strongly dependent upon the pK_a of the amine. An important advance was recently reported by Casalnuovo *et al.* who demonstrated for the first time the hydroamination of an alkene by an iridium-catalysed N–H activation mechanism.[6]

Formation of H–C–C–NR₂ containing molecules can occur by reductive elimination from either an amido(alkyl)metal complex L$_n$M(C–CH)(NR₂) or an aminoalkyl(hydrido)metal L$_m$M(H)(C–C–NR₂) species. In both cases, it would be expected that these intermediate alkylmetal complexes may be generated from L$_n$M(H)(NR₂) derivatives of transition metals able to coordinate alkenes. The crucial step is thus the formation of the metal–nitrogen bond. Casalnuovo *et al.* demonstrated the oxidative addition of aniline with some electron-rich Ir^I complexes and could further design a catalytic system for the addition of aniline to norbornene.[6]

Formation of H–C–C–NR₂ can also conceivably occur by protonolysis of an aminoalkyl derivative L$_n$M(C–C–NR₂) [eqn. (2)].[7] A different catalytic process can thus be expected, which does not involve *per se* an N–H oxidative addition, provided that the transition metal amide L$_n$M–NR₂ could insert the alkene into the metal–nitrogen bond. Amides of the late transition metals are known.[7] To the best of our knowledge, however, the only isolated and well characterized *rhodium* amide is the unstable [Rh(PPh₃)₂N(SiMe₃)₂].[8] We have thus studied the possible hydroamination of alkenes with *in situ* generated amidorhodium species. For comparison,[6] aniline and norbornene were chosen as the test substrates.
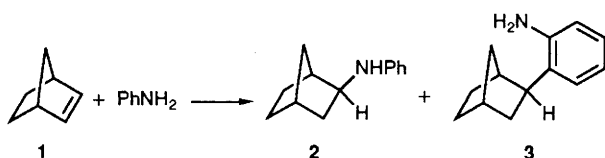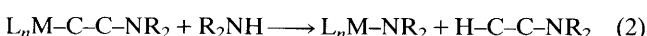
$$L_nM{-}C{-}C{-}NR_2 + R_2NH \longrightarrow L_nM{-}NR_2 + H{-}C{-}C{-}NR_2 \qquad (2)$$

When lithium anilide (2.5 mmol) was added to a solution of [{Rh(PEt₃)₂Cl}₂]† (0.25 mmol) in aniline (15 ml) at −10 °C, a colour change from orange to pale brown was observed. Norbornene **1** (27.5 mmol) was then added at room temperature, and the homogeneous reaction medium heated to 70 °C. Monitoring the reaction by GLC–MS analysis indicated the slow formation of two compounds exhibiting *m/z* 187. After usual workup, these products were separated by liquid chromatography.

The minor product (15% yield based on norbornene) was unambiguously shown to be *exo*-2-(phenylamino)norbornane **2** by comparison (¹H and ¹³C NMR) with authentic samples of the two possible 2-(phenylamino)norbornane isomers.‡ The main product, however, was not the *endo*-isomer but rather the ring-substituted aniline derivative, **3** (30% yield). This was clearly established on the basis of its ¹H NMR spectrum (aromatic proton region) and by comparison of its ¹³C NMR spectrum§ with those of *o*-, *m*- and *p*-toluidine. This compound was definitively characterized as the *exo*-isomer by comparison of its full NMR characteristics with those of an authentic sample prepared by a different reaction, the palladium-catalysed hydroarylation of **1** with 2-iodoaniline according to the procedure reported by Cacchi *et al.*[9]

Under the conditions used, this new reaction (Scheme 1) is slow, but is truly catalytic with respect to both rhodium and lithium. For instance, after 12 days at 70 °C, the overall GLC yield (**2** + **3**) (**2/3** = 0.5) corresponds to 25 cycles/rhodium. This turnover rate is comparable to that reported for the iridium-catalysed hydroamination of **1** with aniline (2–7 cycles
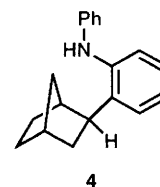
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‡ *exo*-2-(Phenylamino)norbornane was prepared by arynic condensation of *exo*-2-norbornylamine with bromobenzene (P. Caubère and N. Derozier, *Bull. Soc. Chim. Fr.*, 1969, 1737). *endo*-2-(Phenylamino)-norbornane was prepared by reaction of aniline with norcamphor in the presence of K[FcH(CO)₄] (G. P. Boldrini, M. Panunzio and A. Umani-Ronchi, *Synthesis*, 1974, 733).

§ **3**: ¹H NMR (250.133 MHz; C₆D₆), δ (reference δ C₆H₆ = 7.27): 1.1–1.3 (m, 3H), 1.5–1.7 (m, 5H), 2.26 (br s, 1H), 2.4–2.5 (m, 2H), 3.1 (br s, 2H, NH₂), 6.57 (dd, *J* 7.5, 1.2 Hz, 1H); 6.92 (td, *J* 7.5, 1.2 Hz, 1H); 7.16 (td, *J* 7.5, 1.2 Hz, 1H) and 7.21 (br dd, *J* 7.5 Hz 1H); ¹³C{¹H} NMR (62.896 MHz; C₆D₆): δ (reference δ C₆D₆ = 128.4) 30.0, 30.8, 36.8, 37.6, 38.3, 41.1, 42.6, 116.0, 118.0, 125.9, 127.0, 131.6 and 145.1.

Scheme 1 *Reagents*: [{Rh(PEt₃)₂Cl}₂], PhNHLi, PhNH₂

after 3 days in refluxing tetrahydrofuran).[6] Control experiments conducted under the same conditions but omitting either the rhodium precursor or lithium anilide clearly showed that no trace of either compounds **2** or **3** was formed.

When the same reaction was performed with diphenylamine instead of aniline, only one product was formed (GLC–MS: m/z 263) after 8 days at 70 °C. This was isolated (15% yield on the basis of norbornene) and proved also to be a ring-alkylated product **4**, as shown by its NMR characteristics.¶

The formation, in basic media, of the ring-alkylated derivatives **3** and **4** is unexpected. To the best of our knowledge, such a reaction is precedented only by the *ortho*-alkylation of aniline with ethylene in the presence of either granulated aluminium or aluminium anilide under forcing conditions (*e.g.*, 170 bar, 300 °C).[10,11]

The mechanism of this rhodium-catalysed hydroarylation is somewhat obscure but may involve orthometallation of the anilide substituent of a bis(triethylphosphine) rhodium anilido species. Such a process is believed to occur with [Ru-(PMe$_3$)$_4$(D)(NDC$_6$H$_5$)] which, on thermolysis, gives rise to deuterium incorporation on the aryl ring.[12] An orthometallated anilide complex, [Ru(PMe$_3$)$_4$(η^2-NHC$_6$H$_4$)] has recently been reported.[13]

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¶ **4**: ^{1}H NMR (250.133 MHz; CDCl$_3$), δ (reference δ CHCl$_3$ = 7.25): 1.25–1.40 (m, 3H), 1.50–1.75 (m, 4H), 1.8–1.9 (m, 1H), 2.38 (br s, 1H), 2.50 (br s, 1H), 2.79 (dd, J 8.7, 5.5 Hz, 1H), 5.41 (br s, 1H, NH) 6.90 (br t, J 7.4 Hz, 1H), 6.95–7.05 (m, 2H), 7.13 (br t, J 7.5 Hz, 1H) and 7.20–7.35 (m, 5H); ^{13}C{^{1}H} NMR (62.896 MHz; CDCl$_3$), δ (reference δ CHCl$_3$ = 77.0): 29.1, 30.3, 36.4, 36.9, 38.7, 40.8, 42.0, 117.4, 119.5, 120.3, 121.7, 125.8, 126.0, 129.3, 137.4, 140.6 and 144.2.