A Convenient Rhodium-Catalyzed Intermolecular Hydroamination Procedure for Terminal Alkynes

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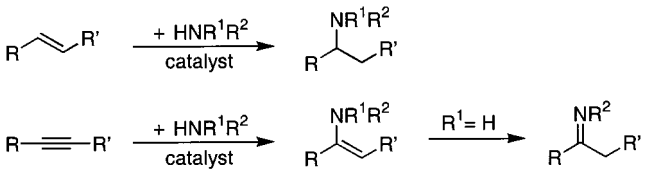
The first rhodium-catalyzed intermolecular hydroamination of alkynes is presented. Terminal alkynes react efficiently with anilines in the presence of cationic rhodium(I) catalysts under very mild reaction conditions (e.g., base and acid free at room temperature) to yield up to 99% of the corresponding imines. An easy one-pot protocol for the synthesis of secondary amines was developed by combining this alkyne amination reaction with in situ addition of organolithium reagents.

New C−N bond forming reactions are of considerable interest in both synthetic organic and industrial chemistry due to the importance of amines and their derivatives in almost all areas of chemistry. The most atom economic process for the synthesis of amines is the hydroamination reaction, in which the C−N bond is formed directly by the addition of NH_3, a primary, or secondary amine to a multiple bond, without generating any waste products.[1] The catalytic hydroamination of C−C double bonds (Scheme 1) has been investigated only rarely.[2] Hence, a generally applicable procedure has yet to be reported. In particular the efficient hydroamination of aliphatic alkenes is not yet possible and remains one of the most important challenges for catalysis research.

In contrast to alkenes, alkynes are better π-donors and have a sterically less hindered, cylindrical π-system as well as more nucleophilic sp-hybridized C-atoms.[3] Thus alkynes are in general more reactive in amination reactions, which is illustrated by the more exothermic (∼70 kJ/mol) addition of NH_3 to acetylene compared to the equivalent reaction with ethylene.[4] Even though the hydroamination of alkynes is thermodynamically more favorable, a high activation barrier nevertheless exists. Catalytic procedures are indispensable in overcoming these activation barriers.[1]

Scheme 1. Hydroamination of Alkenes and Alkynes



A variety of catalysts have successfully been employed in catalytic cyclization of aminoalkynes to give nitrogen-containing heterocycles.[1,5] Intermolecular amination reactions with alkynes are, however, much more difficult, and only a few examples have been reported. Furthermore these reactions are generally limited to specific substrates. Pioneering work was done by J. Barluenga et al. who employed mercury and thallium salts for the Markovnikov hydroamination of alkynes with anilines.[6] Only moderate yields of the imine or enamine products were obtained using 2−5 mol % of the toxic metal catalysts. Later on, the intermolecular hydroamination of alkynes was also realized with catalysts of the alkali metals (Cs),[7] early transition metals (Zr),[8] lanthanides

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(Nd),[9] and actinides (U, Th).[10] The applicability and efficiency of these various types of catalysts are still limited, due to sensitivity to air, humidity, and functional groups.

Two recent publications describe distinct improvement in the hydroamination of alkynes. Y. Wakatsuki et al. introduced a $Ru_3(CO)_{12}$/acid catalyst system permitting predominantly the high-yielding conversion of anilines with terminal phenyl acetylenes to give the corresponding branched imines.[11,12] However, only one example is given for the hydroamination of aliphatic 1-octyne with aniline which gives the corresponding product in 63% yield. Advantageously, the reactions can be run under an air atmosphere and often without a solvent.

An alternative method employing titanocene catalysts was developed by S. Doye et al.[13] The best results were obtained with aromatic, disubstituted alkynes, which can be aminated with a series of aryl and alkylamines to yield the corresponding products with high regioselectivity. It is noteworthy that both the Doye and Wakatsuki groups employed reaction temperatures of about 100 °C, and nonactivated aliphatic alkynes have only given low to moderate yields so far.

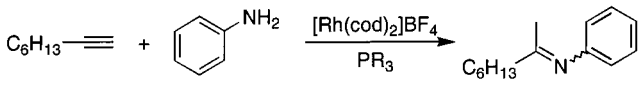
Results and Discussion

To improve and extend our previously reported rhodium-catalyzed amination reactions,[14] we became interested in the amination of aliphatic alkynes. We describe herein an efficient and mild conversion of aliphatic alkynes with anilines by means of a commercially available rhodium catalyst.

The initial experiments for the hydroamination of alkynes were performed under our previously described standard reaction conditions. 1-Octyne **1a** was reacted with aniline **2a** in the presence of 2.5 mol % $Rh(cod)_2BF_4$/2 PPh_3 in THF in a pressure tube at 100 °C giving *N*-(2-octylidene)aniline **3a** regioselectively in 26% yield (Table 1, entry 1) via hydroamination of the alkyne followed by tautomerization of the resultant enamine to the more stable imine. Oligomerization and polymerization of the alkyne are observed as side reactions.

Other rhodium complexes ([Rh(cod)Cl]$_2$, [Rh(cod)(acac)], $[Rh(PPh_3)_3Cl]$, $RhCl_3 \cdot xH_2O$) also in combination with phosphine ligands show no hydroamination reactivity at all. Hence, the cationic character of the catalyst seemed to be a necessary requirement for a successful reaction. We assume that the alkyne is activated by the cationic metal center to rate-determining nucleophilic attack of the amine, in agreement with kinetic measurements which reveal that the initial reaction rate is first order in catalyst and amine concentration and zero order in alkyne concentration. However, an amine activation pathway cannot be excluded. The addition of a phosphine is essential, since without phosphine the product is only formed in very low yields (<5%). A screening of several phosphine ligands showed that the best results were obtained in the presence of 3 equiv (refers to rhodium) of the basic tricyclohexylphosphine (PCy_3) (Table 1, entry 2). PPh_3, P(*o*-tolyl)$_3$, and P(*n*-Bu)$_3$ were also active as ligands but proved to be less suitable than PCy_3. In the presence of chelating phosphines, however, no reaction was observed.

Table 1. Rhodium-Catalyzed Hydroamination of 1-Octyne with Aniline[a]



1a **2a** **3a**

entry	temp [°C]	1-octyne/ aniline ratio	mol % cat.	catalyst system	yield of **3a** [%]
1[b]	100	4:1	2.5	$[Rh(cod)_2]BF_4/2PPh_3$	26
2	50	2:1	1.5	$[Rh(cod)_2]BF_4/3PCy_3$	>99
3	r.t.	2:1	1.0	$[Rh(cod)_2]BF_4/3PCy_3$	63
4	r.t.	2:1	1.5	$[Rh(cod)_2]BF_4/3PCy_3$	79
5	r.t.	2:1	2.0	$[Rh(cod)_2]BF_4/3PCy_3$	>99
6	r.t.	4:1	1.5	$[Rh(cod)_2]BF_4/3PCy_3$	77
7	r.t.	1.2:1	1.5	$[Rh(cod)_2]BF_4/3PCy_3$	67
8	r.t.	1:2	1.5	$[Rh(cod)_2]BF_4/3PCy_3$	70
9	r.t.	1:4	1.5	$[Rh(cod)_2]BF_4/3PCy_3$	91
10	0	2:1	1.5	$[Rh(cod)_2]BF_4/3PCy_3$	46
11[c]	0	2:1	1.5	$[Rh(cod)_2]BF_4/3PCy_3$	73

[a] 20 h reaction time in toluene. Yields and mol % catalyst refer to the limiting reagent. Yields were determined by GC analysis with an internal standard (hexadecane). [b]Reaction in an ACE pressure tube with THF as the solvent. [c]44 h reaction time.

Toluene, THF, and dioxane used as solvents showed similar results in the reaction. In CH_2Cl_2 the reaction proceeds initially very rapidly, but soon stops probably due to acid impurities inhibiting the cationic catalyst. Strongly coordinating solvents such as acetonitrile or DMSO are unsuitable. A variation of the reaction temperature revealed that the reaction runs smoothly at room temperature (Table 1, entries 3−9). Hence, in the presence of 2 mol % of Rh catalyst and 6 mol % of PCy_3, the desired product *N*-(2-octylidene)aniline **3a** is obtained in 99% yield. Even at 0 °C, high yields of the imine product can be obtained; however, the reaction is somewhat slower (Table 1, entries 10, 11). An important advantage of using lower reaction temperatures is that only small amounts of alkyne oligomers are produced. At higher reaction temperatures (e.g., 50 °C, Table 1, entry 2) quantitative yield is obtained after 20 h using 1.5 mol % rhodium catalyst. With respect to the alkyne/amine ratio, the yields are increased by using an excess of either amine or alkyne.

The present scope and limitations of the new rhodium-catalyzed hydroamination of alkynes are shown in Table 2. 1-Octyne and 1-hexyne react well (Table 2, entries 1−7), while in the case of phenylacetylene rapid oligomerization occurs, thus leading to lower product yields

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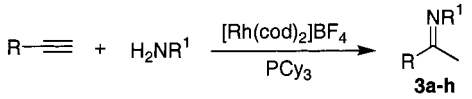
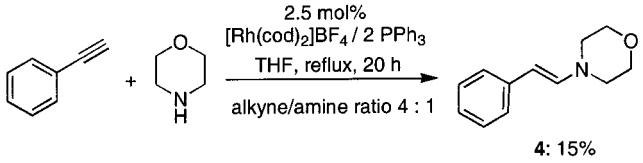
Table 2. Rhodium-Catalyzed Hydroamination of 1-Alkynes with Anilines[a]



entry	alkyne R	aniline R^1	mol % catalyst	yield [%]
1	*n*-hexyl	C_6H_5	1.5	79 (**3a**)
2	*n*-butyl	C_6H_5	1.5	83 (**3b**)
3[b]	*n*-butyl	2-Me-C_6H_4	1.5	55 (**3c**)
4	*n*-hexyl	4-Me-C_6H_4	1.5	73 (**3d**)
5	*n*-hexyl	4-MeO-C_6H_4	1.5	63 (**3e**)
6	*n*-hexyl	3-F-C_6H_4	1.5	80 (**3f**)
7	*n*-hexyl	4-Cl-C_6H_4	1.0	>99 (**3g**)
8	Ph	C_6H_5	2.5	10[c] (**3h**)

[a] 20 h reaction time at room temperature in toluene with $[Rh(cod)_2]BF_4$/3 PCy_3 as the catalytic system, alkyne/amine ratio 2:1. Yields and mol % catalyst refer to the aniline. Yields were determined by GC analysis with an internal standard (hexadecane). [b]44 h reaction time. [c]Conversion of aniline; product identified by GC/MS analysis.

Scheme 2. Reaction of Phenylacetylene and Morpholine



4: 15%

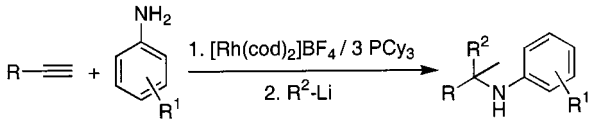
(Table 2, entry 8). Using anilines as the amine component of the reaction furnishes the products in good to very good yield. Substituents at the aniline core are tolerated with respect to both electronic as well as steric properties, whereby electron-withdrawing substituents react faster, electron-donating slower. Higher yields and faster reactions can be achieved either using reaction temperatures of about 50 °C or higher catalyst amounts. In a kinetic experiment the reaction of 1-octyne with 4-chloroaniline in the presence of 5.5 mol % $[Rh(cod)_2]BF_4$/3PCy_3 gave the corresponding imine in 59% yield after only 20 min. TON's of up to 100 in 20 h and TOF's of up to 35 mol/(mol·h) (initial rate to an extend of 50% yield) were reached at room temperature.

The products of the conversion of 1-octyne with *N*-methylaniline or with aliphatic or alicyclic amines were only formed in low yields (identified by GC/MS analysis). Interestingly, under our previously reported reaction conditions,[14] the conversion of phenylacetylene with morpholine furnished the anti-Markovnikov hydroamination product **4** in 15% yield (nonoptimized) (Scheme 2).

Since we had a convenient procedure for the ambient amination of aliphatic alkynes in hand, we were interested in the further functionalization of the imine products. Advantageously, compared to the general preparation of imines via amination of carbonyl compounds the hydroamination of alkynes does not produce any water as byproduct. Hence, we envisaged a one-pot protocol for the synthesis of branched amines directly from alkynes by in situ addition of organometallic compounds.

Unfortunately, enolizable ketimines are known to show poor reactivity toward nucleophilic 1,2-addition, mainly due to enolization on addition of organometallic reagents.[15] Thus only poor yields of amines are obtained in these reactions. Nevertheless, by simply adding alkyl and phenyllithium reagents as nucleophiles to our reaction mixtures, the corresponding secondary amines were obtained in reasonable yields (not optimized). The results of this convenient one-pot protocol are summarized in Table 3. It is clear that this procedure can be easily extended to other nucleophilic alkyl and aryl reagents, making amines with a number of different substitution patterns accessible.

Table 3. One-Pot Protocol for the Synthesis of Secondary Amines by Nucleophilic Addition of Organolithium Compounds[a]



5a-e

R= C_4H_9, C_6H_{13}
R^1= H, 4-Cl
R^2= Me, Bu, Ph

entry	alkyne R	aniline R^1	R^2-Li (equiv)	overall yield [%]
1	*n*-hexyl	H	MeLi (1.1)	45 (**5a**)
2	*n*-hexyl	H	*n*-BuLi (1.1)	60 (**5b**)
3	*n*-hexyl	H	PhLi (2.2)	42 (**5c**)
4	*n*-hexyl	Cl	*n*-BuLi (1.1)	55 (**5d**)
5	*n*-butyl	H	*n*-BuLi (1.1)	56 (**5e**)

[a] Step 1: 1.5 mol % $[Rh(cod)_2]BF_4$/3 PCy_3, 20 h, room temperature, toluene, alkyne/aniline ratio 2:1. Step 2: 0.5 h at −70 °C, then 2 h at room temperature. Yields were determined by GC analysis with an internal standard (hexadecane) and refer to the aniline.

In conclusion we have established that the cationic rhodium catalyst system $[Rh(cod)_2]BF_4/PR_3$ is active and practical for the intermolecular hydroamination of 1-alkynes with anilines under mild reaction conditions. For the first time, efficient catalytic hydroamination of alkynes is possible at room temperature. This methodology constitutes an easy route to the corresponding imines in high yields, which can subsequently be used in situ for the preparation of secondary amines by addition of nucleophiles. Apart from the $Ru_3(CO)_{12}$-catalyzed method, it is the only intermolecular amination reaction of alkynes using late transition metals. Clearly the substrate scope of the procedure has still to be improved, but compared to previously reported methods, our catalytic system has also some advantages (weakly oxophilic, nontoxic, easy to handle).

Experimental Section

Chemicals were obtained from Aldrich, Fluka, Acros, and Strem and unless otherwise noted were used without further purification. Liquid amines were distilled from CaH_2. Alkynes were degassed, flushed with argon, and stored over molecular sieves (4 Å). Absolute solvents were purchased from Fluka. All operations were carried out under an argon atmosphere.

The $[Rh(cod)_2]BF_4$ catalyst was synthesized according to a literature procedure.[16]

General Procedure for the Conversion of Alkynes with Amines. The alkyne was added slowly using a syringe to a solution or suspension of the $[Rh(cod)_2]BF_4/PR_3$ catalyst

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and the amine (5.0 mmol) in toluene (10 mL) under argon at room temperature. The mixture was stirred at the given temperature for the specified time. Isolation of the product was done by fractional distillation in vacuo. The products were stored under argon at −20 °C. The purity of the products (>99.5%) was verified by GC analysis. The imine products were isolated as a mixture of the *E*- and *Z*-isomers; thus, some NMR resonances were present as two signals (indicated below by "+"), representing both isomers.

***N*-(2-Octylidene)aniline (3a).** According to the general procedure, aniline (0.46 mL, 5.0 mmol) and 1-octyne (1.48 mL, 10.0 mmol) were reacted in the presence of 1.5 mol % $[Rh(cod)_2]BF_4$ (30.5 mg, 0.075 mmol) and 4.5 mol % PCy_3 (63.1 mg, 0.225 mmol) at room temperature for 20 h. Fractional distillation afforded **3a** as a colorless oil. Yield: 79% (GC); bp 65−66 °C/0.1 mbar. ^{1}H NMR ($CDCl_3$, 400 MHz) δ: 7.27 (m, 2H), 7.01 (m, 1H), 6.67 (m, 2H), 2.39 + 2.10 (m, 2H), 2.14 + 1.76 (s, 3H), 1.66 + 1.42 (m, 2H), 1.41−1.15 (m, 6H), 0.91 + 0.83 (t, J = 7.1 Hz, 3H). ^{13}C NMR ($CDCl_3$, 100 MHz) δ: 172.7 + 172.2, 151.6 + 151.1, 128.8 + 128.7, 122.9 + 122.8, 119.5, 41.7 + 34.1, 31.7 + 31.4, 29.1 + 29.0, 26.8 + 26.3, 25.9 + 19.4, 22.6 + 22.4, 14.1 + 14.0. GC/MS (EI, 70 eV) *m*/*z*: 203 (M^+), 188 ($M^+ - CH_3$), 174 ($M^+ - CH_2CH_3$), 160 ($M^+ - (CH_2)_2CH_3$), 146 ($M^+ - (CH_2)_3CH_3$), 132 ($M^+ - (CH_2)_4CH_3$), 118 ($M^+ - (CH_2)_5CH_3$), 92, 77.

***N*-(2-Hexylidene)aniline (3b).** According to the general procedure, aniline (0.46 mL, 5.0 mmol) and 1-hexyne (1.15 mL, 10.0 mmol) were reacted in the presence of 1.5 mol % $[Rh(cod)_2]BF_4$ (30.5 mg, 0.075 mmol) and 4.5 mol % PCy_3 (63.1 mg, 0.225 mmol) at room temperature for 20 h. Fractional distillation afforded **3b** as a colorless oil. Yield: 83% (GC); bp 52 °C/0.2 mbar. ^{1}H NMR (CD_2Cl_2, 400 MHz) δ: 7.28 (m, 2H), 7.02 (m, 1H), 6.66 (m, 2H), 2.39 + 2.11 (m, 2H), 2.12 + 1.75 (s, 3H), 1.65 + 1.46 (m, 2H), 1.43 + 1.20 (sext, J = 7.3 Hz, 2H), 0.97 + 0.81 (t, J = 7.3 Hz, 3H). ^{13}C NMR (CD_2Cl_2, 100 MHz) δ: 172.1 + 171.6, 152.0 + 151.5, 128.8 + 128.7, 122.6 + 122.5, 119.3, 41.2 + 33.7, 29.0 + 28.3, 25.5 + 19.1, 22.6 + 22.4, 13.8 + 13.5. GC/MS (EI, 70 eV) *m*/*z*: 175 (M^+), 160 ($M^+ - CH_3$), 146 ($M^+ - CH_2CH_3$), 133, 132 ($M^+ - (CH_2)_2CH_3$), 118 ($M^+ - (CH_2)_3CH_3$), 92, 77.

***N*-(2-Hexylidene)-2-methylaniline (3c).** According to the general procedure, *o*-toluidine (0.54 mL, 5.0 mmol) and 1-hexyne (1.15 mL, 10.0 mmol) were reacted in the presence of 1.5 mol % $[Rh(cod)_2]BF_4$ (30.5 mg, 0.075 mmol) and 4.5 mol % PCy_3 (63.1 mg, 0.225 mmol) at room temperature for 44 h. Fractional distillation afforded **3c** as a colorless oil. Yield: 55% (GC); bp 43 °C/0.1 mbar. ^{1}H NMR (CD_2Cl_2, 400 MHz) δ: 7.18−7.06 (m, 2H), 6.93 (m, 1H), 6.52 (m, 1H), 2.42 + 2.03 (m, 2H), 2.15 + 1.68 (s, 3H), 2.01 (s, 3H), 1.67 + 1.46 (m, 2H), 1.44 + 1.19 (m, 2H), 0.98 + 0.80 (t, J = 7.3 Hz, 3H). ^{13}C NMR (CD_2Cl_2, 100 MHz) δ: 171.7 + 171.3, 150.7 + 150.1, 130.2 + 130.1, 127.0, 126.3 + 126.2, 122.7, 118.7 + 118.5, 41.0 + 34.0, 28.8 + 28.6, 25.3 + 19.4, 22.8 + 22.6, 17.5 + 17.4, 13.9 + 13.6. GC/MS (EI, 70 eV) *m*/*z*: 189 (M^+), 174 ($M^+ - CH_3$), 160 ($M^+ - CH_2CH_3$), 147, 146 ($M^+ - (CH_2)_2CH_3$), 132 ($M^+ - (CH_2)_3CH_3$), 91, 65.

***N*-(2-Octylidene)-4-methylaniline (3d).** According to the general procedure, *p*-toluidine (536 mg, 5.0 mmol) and 1-octyne (1.48 mL, 10.0 mmol) were reacted in the presence of 1.5 mol % $[Rh(cod)_2]BF_4$ (30.5 mg, 0.075 mmol) and 4.5 mol % PCy_3 (63.1 mg, 0.225 mmol) at room temperature for 20 h. Fractional distillation afforded **3d** as a colorless oil. Yield: 73% (GC); bp 74−75 °C/0.1 mbar. ^{1}H NMR (CD_2Cl_2, 400 MHz) δ: 7.08 (m, 2H), 6.94 (m, 2H), 2.36 + 2.09 (m, 2H), 2.30 (s, 3H), 2.10 + 1.73 (s, 3H), 1.64 + 1.46 (m, 2H), 1.43−1.14 (m, 6H), 0.91 + 0.84 (t, J = 7.1 Hz, 3H). ^{13}C NMR (CD_2Cl_2, 100 MHz) δ: 172.2 + 171.6, 149.4 + 148.9, 132.0 + 131.9, 129.3 + 129.2, 119.2, 41.6 + 33.8, 31.7 + 31.4, 29.1 + 29.0, 26.8 + 26.2, 25.6 + 19.0, 22.6 + 22.4, 20.4, 13.8 + 13.7. GC/MS (EI, 70 eV) *m*/*z*: 217 (M^+), 202 ($M^+ - CH_3$), 188 ($M^+ - CH_2CH_3$), 174 ($M^+ - (CH_2)_2CH_3$), 160 ($M^+ - (CH_2)_3CH_3$), 147, 146 ($M^+ - (CH_2)_4CH_3$), 132 ($M^+ - (CH_2)_5CH_3$), 106, 91, 65.

***N*-(2-Octylidene)-4-methoxyaniline (3e).** According to the general procedure, *p*-anisidine (616 mg, 5.0 mmol) and 1-octyne (1.48 mL, 10.0 mmol) were reacted in the presence of 1.5 mol % $[Rh(cod)_2]BF_4$ (30.5 mg, 0.075 mmol) and 4.5 mol % PCy_3 (63.1 mg, 0.225 mmol) at room temperature for 20 h. Fractional distillation afforded **3e** as a colorless oil. Yield: 63% (GC); bp 109−113 °C/0.1−0.2 mbar. ^{1}H NMR (CD_2Cl_2, 400 MHz) δ: 6.83 (m, 2H), 6.59 (m, 2H), 3.77 (s, 3H), 2.37 + 2.12 (m, 2H), 2.10 + 1.75 (s, 3H), 1.65 + 1.47 (m, 2H), 1.42−1.14 (m, 6H), 0.91 + 0.85 (t, J = 7.0 Hz, 3H). ^{13}C NMR (CD_2Cl_2, 100 MHz) δ: 173.0 + 172.3, 156.0 + 155.9, 145.5 + 145.1, 120.8 + 120.7, 114.4 + 114.4, 55.7, 42.0 + 34.1, 32.1 + 31.8, 29.6 + 29.4, 27.2 + 26.6, 26.0 + 19.4, 23.0 + 22.8, 14.2 + 14.1. GC/MS (EI, 70 eV) *m*/*z*: 233 (M^+), 218 ($M^+ - CH_3$), 204 ($M^+ - CH_2CH_3$), 190 ($M^+ - (CH_2)_2CH_3$), 176 ($M^+ - (CH_2)_3CH_3$), 163, 162 ($M^+ - (CH_2)_4CH_3$), 148 ($M^+ - (CH_2)_5CH_3$), 122, 107, 92, 77.

***N*-(2-Octylidene)-3-fluoroaniline (3f).** According to the general procedure, 3-fluoroaniline (0.48 mL, 5.0 mmol) and 1-octyne (1.48 mL, 10.0 mmol) were reacted in the presence of 1.5 mol % $[Rh(cod)_2]BF_4$ (30.5 mg, 0.075 mmol) and 4.5 mol % PCy_3 (63.1 mg, 0.225 mmol) at room temperature for 20 h. Fractional distillation afforded **3f** as a colorless oil. Yield: 80% (GC); bp 83 °C/0.2 mbar. ^{1}H NMR (CD_2Cl_2, 400 MHz) δ: 7.24 (m, 1H), 6.72 (m, 1H), 6.44 (m, 1H), 6.39 (m, 1H), 2.38 + 2.11 (m, 2H), 2.11 + 1.76 (s, 3H), 1.65 + 1.47 (m, 2H), 1.43−1.08 (m, 6H), 0.91 + 0.84 (t, J = 7.1 Hz, 3H). ^{13}C NMR (CD_2Cl_2, 100 MHz) δ: 173.2 + 172.7, 163.3 + 163.2 (d, J = 245 Hz), 153.9 + 153.4 (d, J = 9 Hz), 130.1 + 130.0 (d, J = 10 Hz), 115.1 + 115.0, 109.1 + 109.0 (d, J = 21 Hz), 106.4 + 106.3 (d, J = 21 Hz), 41.4 + 34.2, 31.7 + 31.3, 29.1 + 28.9, 26.7 + 26.0, 25.5 + 19.3, 22.6 + 22.4, 13.8 + 13.7. GC/MS (EI, 70 eV) *m*/*z*: 221 (M^+), 206 ($M^+ - CH_3$), 192 ($M^+ - CH_2CH_3$), 178 ($M^+ - (CH_2)_2CH_3$), 164 ($M^+ - (CH_2)_3CH_3$), 151, 150 ($M^+ - (CH_2)_4CH_3$), 136 ($M^+ - (CH_2)_5CH_3$), 110, 95, 75.

***N*-(2-Octylidene)-4-chloroaniline (3 g).** According to the general procedure, 4-chloroaniline (638 mg, 5.0 mmol) and 1-octyne (1.48 mL, 10.0 mmol) were reacted in the presence of 1.0 mol % $[Rh(cod)_2]BF_4$ (20.3 mg, 0.05 mmol) and 3.0 mol % PCy_3 (42.1 mg, 0.15 mmol) at room temperature for 20 h. Fractional distillation afforded **3g** as a colorless oil. Yield: 99% (GC); bp 110−113 °C/0.1−0.2 mbar. ^{1}H NMR (CD_2Cl_2, 400 MHz) δ: 7.24 (m, 2H), 6.60 (m, 2H), 2.37 + 2.09 (m, 2H), 2.10 + 1.74 (s, 3H), 1.64 + 1.45 (m, 2H), 1.43−1.13 (m, 6H), 0.90 + 0.84 (t, J = 7.1 Hz, 3H). ^{13}C NMR (CD_2Cl_2, 100 MHz) δ: 173.4 + 172.8, 150.8 + 150.2, 128.9 + 128.8, 127.8 + 127.8, 120.9, 41.6 + 34.2, 31.8 + 31.5, 29.2 + 29.1, 26.9 + 26.2, 25.7 + 19.3, 22.7 + 22.5, 13.9 + 13.8. GC/MS (EI, 70 eV) *m*/*z*: 239, 237 (M^+), 224, 222 ($M^+ - CH_3$), 210, 208 ($M^+ - CH_2CH_3$), 196, 194 ($M^+ - (CH_2)_2CH_3$), 182, 180 ($M^+ - (CH_2)_3CH_3$), 169, 168, 167, 166 ($M^+ - (CH_2)_4CH_3$), 154, 152 ($M^+ - (CH_2)_5CH_3$), 126, 111, 91, 75.

***(E)*-*N*-(2-Phenylethenyl)morpholine (4).** According to the general procedure, morpholine (0.44 mL, 5.0 mmol) and phenylacetylene (2.20 mL, 20.0 mmol) were reacted in the presence of 2.5 mol % $[Rh(cod)_2]BF_4$ (50.8 mg, 0.125 mmol) and 5.0 mol % PPh_3 (65.6 mg, 0.250 mmol) in 10 mL of THF under reflux for 20 h. Fractional distillation afforded **4** as a pale yellow oil, that crystallizes under cooling. Yield: 15% (GC). ^{1}H NMR ($CDCl_3$, 360 MHz) δ: 7.27 (m, 2H), 7.24 (m, 2H), 7.10 (m, 1H), 6.53 (d, J = 14.0 Hz, 1H), 5.36 (d, J = 14.0 Hz, 1H), 3.68 (t, J = 4.7 Hz, 4H), 2.95 (t, J = 4.7 Hz, 4H). ^{13}C NMR ($CDCl_3$, 91 MHz) δ: 139.8, 138.6, 128.5, 124.4, 124.2, 101.5, 66.5, 49.1. GC/MS (EI, 70 eV) *m*/*z*: 189 (M^+), 158 ($M^+ - OCH_3$), 130 ($C_6H_5C_2H_2NCH^+$), 104 ($C_6H_5C_2H_3^+$), 91 ($C_6H_5CH_2^+$), 77 ($C_6H_5^+$).

In Situ Conversion of the Built Imines with Organolithium Compounds. A solution of the organolithium compound (1.1 or 2.2 equiv based to the amine) was added slowly by a syringe at −70 °C to the reaction mixture of the conversion of the alkyne and the aniline. The solution was stirred for 30 min at −70 °C, allowed to warm to room temperature for 2 h, diluted with dichloromethane, and quenched with methanol. The mixture was washed with water and dried over $MgSO_4$. After removal of the solvents in vacuo, the product was isolated by column chromatography.

***N*-2-(2-Methyloctyl)aniline (5a).** A solution of methyllithium (1.6 M in diethyl ether, 3.44 mL, 5.5 mmol) was added to the reaction mixture as described for compound **3a**. The

residue was purified by column chromatography (*n*-hexane/ethyl acetate = 30:1) to afford **5a** as a pale yellow oil. Yield: 45% (GC). ^{1}H NMR ($CDCl_3$, 400 MHz) δ: 7.12 (m, 2H), 6.74−6.68 (m, 3H), 2.98 (br s, 1H), 1.59 (m, 2H), 1.36−1.18 (m, 14H), 0.86 (t, J = 6.9 Hz, 3H). ^{13}C NMR ($CDCl_3$, 100 MHz) δ: 146.9, 128.9, 117.8, 116.8, 53.7, 41.9, 31.8, 29.8, 28.3, 24.0, 22.6, 14.1. GC/MS (EI, 70 eV) *m*/*z*: 219 (M^+), 204 ($M^+ - CH_3$), 134 ($M^+ - (CH_2)_5CH_3$), 93 (H_2NPh^+). Anal. Calcd for $C_{15}H_{25}N$: C, 82.13; H, 11.49; N, 6.39. Found: C, 81.99; H, 11.43; N, 6.32.

***N*-5-(5-Methylundecanyl)aniline (5b).** A solution of *n*-butyllithium (1.6 M in hexane, 3.44 mL, 5.5 mmol) was added to the reaction mixture as described for compound **3a**. The residue was purified by column chromatography (*n*-hexane/ethyl acetate = 50:1) to afford **5b** as a pale yellow oil. Yield: 60% (GC). ^{1}H NMR ($CDCl_3$, 400 MHz) δ: 7.10 (m, 2H), 6.68 (m, 3H), 3.25 (br s, 1H), 1.58 (m, 4H), 1.34−1.18 (m, 15H), 0.86 (m, 6H). ^{13}C NMR ($CDCl_3$, 100 MHz) δ: 147.0, 128.9, 117.4, 116.2, 56.0, 39.8, 39.5, 31.8, 29.8, 26.1, 25.9, 23.6, 23.2, 22.6, 14.1, 14.1. GC/MS (EI, 70 eV) *m*/*z*: 261 (M^+), 246 ($M^+ - CH_3$), 204 ($M^+ - (CH_2)_3CH_3$), 176 ($M^+ - (CH_2)_5CH_3$), 93 (H_2NPh^+). Anal. Calcd for $C_{18}H_{31}N$: C, 82.69; H, 11.95; N, 5.36. Found: C, 82.62; H, 12.00; N, 5.23.

***N*-2-(2-Phenyloctyl)aniline (5c).** A solution of phenyllithium (1.8 M in cyclohexane/ether (70/30), 6.11 mL, 11.0 mmol) was added to the reaction mixture as described for compound **3a**. The residue was purified by column chromatography (*n*-hexane/ethyl acetate = 70:1) to afford **5c** as a pale yellow oil. Yield: 42% (GC). ^{1}H NMR ($CDCl_3$, 400 MHz) δ: 7.47 (m, 2H), 7.33 (m, 2H), 7.23 (m, 1H), 6.99 (m, 2H), 6.60 (m, 1H), 6.33 (m, 2H), 4.01 (br s, 1H), 1.83 (m, 2H), 1.65 (s, 3H), 1.35−1.16 (m, 8H), 0.85 (t, J = 6.9 Hz, 3H). ^{13}C NMR ($CDCl_3$, 100 MHz) δ: 146.7, 146.1, 128.6, 128.3, 126.2, 126.2, 116.9, 115.2, 58.3, 44.6, 31.7, 29.6, 25.6, 23.6, 22.6, 14.0. GC/MS (EI, 70 eV) *m*/*z*: 281 (M^+), 266 ($M^+ - CH_3$), 196 ($M^+ - (CH_2)_5CH_3$), 131, 118, 105, 93, 77. Anal. Calcd for $C_{20}H_{27}N$: C, 85.35; H, 9.67; N, 4.98. Found: C, 85.24; H, 9.70; N, 4.91.

***N*-5-(5-Methylundecanyl)-4-chloroaniline (5d).** A solution of *n*-butyllithium (1.6 M in hexane, 3.44 mL, 5.5 mmol) was added to the reaction mixture as described for compound **3g**. The residue was purified by column chromatography (*n*-hexane/ethyl acetate = 50:1) to afford **5d** as a pale yellow oil. Yield: 55% (GC). ^{1}H NMR ($CDCl_3$, 400 MHz) δ: 7.04 (d, J = 8.9 Hz, 2H), 6.57 (d, J = 8.9 Hz, 2H), 3.17 (br s, 1H), 1.64−1.46 (m, 4H), 1.32−1.20 (m, 12H), 1.19 (s, 3H), 0.85 (m, 6H). ^{13}C NMR ($CDCl_3$, 100 MHz) δ: 145.6, 128.8, 122.0, 117.0, 56.2, 39.7, 39.4, 31.8, 29.8, 26.0, 25.8, 23.5, 23.2, 22.6, 14.1, 14.1. GC/MS (EI, 70 eV) *m*/*z*: 297, 295 (M^+), 282, 280 ($M^+ - CH_3$), 240, 238 ($M^+ - (CH_2)_3CH_3$), 212, 210 ($M^+ - (CH_2)_5CH_3$), 127 ($H_2NC_6H_4Cl^+$). Anal. Calcd for $C_{18}H_{30}ClN$: C, 73.07; H, 10.22; N, 4.73. Found: C, 73.34; H, 10.40; N, 4.67.

***N*-5-(5-Methylnonyl)aniline (5e).** A solution of *n*-butyllithium (1.6 M in hexane, 3.44 mL, 5.5 mmol) was added to the reaction mixture as described for compound **3b**. The residue was purified by column chromatography (*n*-hexane/ethyl acetate = 40:1) to afford **5e** as a pale yellow oil. Yield: 56% (GC). ^{1}H NMR ($CDCl_3$, 400 MHz) δ: 7.11 (m, 2H), 6.68 (m, 3H), 3.38 (br s, 1H), 1.58 (m, 4H), 1.33−1.23 (m, 8H), 1.22 (s, 3H), 0.87 (t, J = 7.0 Hz, 6H). ^{13}C NMR ($CDCl_3$, 100 MHz) δ: 147.0, 128.9, 117.4, 116.2, 56.0, 39.5, 26.1, 25.9, 23.2, 14.1. GC/MS (EI, 70 eV) *m*/*z*: 233 (M^+), 218 ($M^+ - CH_3$), 176 ($M^+ - (CH_2)_3CH_3$), 132, 120, 93 (H_2NPh^+). Anal. Calcd for $C_{16}H_{27}N$: C, 82.34; H, 11.66; N, 6.00. Found: C, 82.42; H, 11.60; N, 5.89.

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