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Heterogeneous Catalytic Reductive Amination of Carbonyl Compounds with Ni-Al Alloy in Water as Solvent and Hydrogen Source

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Abstract The heterogeneous catalytic reductive amination of carbonyl compounds has been achieved by reactions of ammonium hydroxide and various amines with ketones and aldehydes. The process is based on the application of Raney type Ni-Al alloy in an aqueous medium. The reaction of the carbonyl compounds with the amine provided the corresponding Schiff bases that immediately underwent a reduction to provide primary and secondary amines as products. The controlled reaction of the Al content of the alloy with the solvent water generates hydrogen, and the in situ formed Raney Ni® serves as a hydrogenation catalyst. The method is a simple and efficient way of preparing a broad variety of primary and secondary amines.

Key words reduction, amination, aluminum, catalysis, hydrogenation

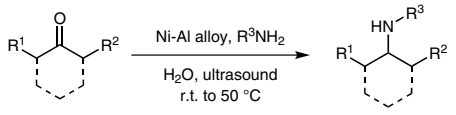
Reductive amination is a well-known process for the preparation of primary and secondary amines.[1] Due to the extended use of amines, a broad array of reductive amination methods was described.[2] However, most of the classic methods do not conform to the increasing environmental regulations, resulting in an ever growing demand for green chemical transformations. Therefore, the focus of contemporary synthesis design for the development of reductive aminations is the application of safe and convenient reagents and environmentally benign solvents.[3]

Nickel-catalyzed hydrogenations were developed and introduced to mainstream organic synthesis by Paul Sabatier over a century ago.[4] Since then heterogeneous catalytic hydrogenation[5] has become one of the most commonly applied procedures in the preparation of organic compounds. The use of heterogeneous catalytic hydrogenation overcomes many environmental issues caused by the use of complex hydrides as reducing reagents. Catalytic hydrogenation[5] is widely considered an environmentally benign process. Both the heterogeneous and homogeneous alternatives are popular in industry.[6] While the explosive character of hydrogen gas is well known, less attention is paid to how hydrogen is produced. Currently, the majority of hydrogen gas is produced by steam reforming involving the transformation of methane and water into hydrogen gas and carbon dioxide.[7] This process requires the presence of a metal catalyst and high temperatures (700–1000 °C) while producing a significant amount of CO_2, a common greenhouse gas. Therefore, the current method of hydrogen production cannot be considered environmentally friendly and should be factored in when considering the environmental impact of a process.

Expanding our interest in developing new environmentally benign synthetic methodologies,[8] we recently explored the application of the aqueous Ni-Al alloy hydrogenation system in the reduction of carbonyl compounds.[9] Using water as a possible solvent or reagent in organic synthesis has generated extended interest over the years.[10] In an earlier application, the selective hydrogenation of imines in water have been successfully achieved by cyclodextrin-stabilized Pd nanoparticles.[11] The use of Ni-Al and other metal-Al alloys (Co, Cu, Fe) has been pioneered by Tashiro et al. for the reduction of a variety of organic compounds.[12,13] Our group recently described the use of Ni-Al alloy in water for the selective reduction of N-heterocycles.[14] The chemicals required by these processes are considered to be safe. Neither the metal catalysts nor the Al powder are considered dangerous or particularly toxic. They are easy to work with under regular conditions and do not require any special handling. Water, used as a solvent as well as a hydrogen source, is the most environmentally benign solvent. As discussed above, catalytic hydrogenation requires high pressure H_2; using Al-H_2O for hydrogen generation does not. The Al-H_2O system is chemically neutral to the environment: the produced $Al(OH)_3$ can be recycled through the regular industrial Al production. Thus, the overall environ-

mental impact of the proposed process is reduced to net energy consumption and no harmful by-products are formed. In general, we believe that the storage and generation of hydrogen from water is a safer and greener process than the current hydrogen generation-catalytic hydrogenation setup.

Continuing our efforts to explore the use of this hydrogenation system in green transformations, herein we describe the selective reductive amination of aldehydes and ketones with NH_4OH, benzylamines, and anilines under aqueous conditions using nickel-aluminum alloy (Scheme 1). The reactions are carried out under mild and environmentally benign conditions providing the amines in good to excellent yields. The product primary amines are important building blocks while the secondary benzylated benzylamines and anilines are biologically active compounds of pharmaceutical importance.[15,16]



Scheme 1 Selective reductive amination of ketones and aldehydes by Ni-Al alloy in water

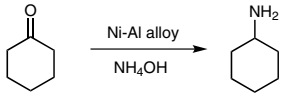
The selective reductive amination of carbonyl compounds commonly requires ammonia and hydrogen gases as well as acid and metal hydrogenation catalysts, usually in organic solvents and high pressure reaction vessels.[2]

In the present work, we explored the use of Ni-Al alloy in water or aqueous ammonium hydroxide, which would eliminate the use of organic solvent during the reaction step, using water as a medium as well as a hydrogen source at room temperature, thus also eliminating the need for a high pressure system. First, the effect of the reaction conditions on the yield and selectivity was assessed using the reductive amination of cyclohexanone with NH_4OH as a test reaction (Table 1).

Based on our earlier work on the application of Ni-Al alloy in reductive processes,[9,14] we had attempted to test general conditions including a broad variety of parameters, such as temperature, reaction time, and activation method. The data in Table 1 reveal some major characteristics of the reduction. While the aluminum content of the Ni-Al alloy reacts at ambient temperature, it shows a significant lag-phase and provides near complete conversion only after 20 hours (Table 1, entries 1–3). While the increase in temperature had a positive effect on the reaction rates, a longer reaction time did not provide significant further improvements (entries 3, 4).

Ultrasonic activation appeared to be an effective method for the activation of the Ni-Al alloy via a proposed surface cleaning effect of ultrasonic waves[17] providing good yields and excellent selectivities in our previous work.[14] Thus, the reaction was carried out by ultrasonic activation

Table 1 Optimizing the Conditions for the Reductive Amination of Cyclohexanone by Ni-Al/NH_4OH System[a]



Entry	Presonication (h)[b]	Sonication (h)[c]	Temp (°C)	Time (h)[d]	Yield (%)[e]
1	–	–	25	20	93
2	–	–	25	2	22[f]
3	–	–	50	20	92
4	–	–	50	2	90
5	0.5	–	25	20	93
6	0.5	–	25	1.5	31[f]
7	1	–	25	20	94
8	1	–	25	1	15
9	–	0.5	25	–[g]	24[f]
10	–	1	25	–[g]	38
11	–	2	25	–[g]	94

[a] Reactions were carried out with 200 mg Ni-Al, 3 mL 28–30% NH_4OH, and 0.34 mmol cyclohexanone.
[b] In certain cases, the alloy was presonicated in the solvent only.
[c] The reaction was carried out with continuous ultrasound exposure with cyclohexanone in the mixture.
[d] Time the reaction was allowed to proceed after sonication.
[e] GC yields.
[f] Approximately 30% of *N*-(cyclohexylidene)cyclohexylamine was also formed.
[g] No extra time was allowed without sonication.

in different manners. First, a simple pretreatment by ultrasound was applied to the catalyst and the substrate was only added after the presonication was completed. The presonication appeared only to slightly increase the product yields (Table 1, entries 5–8) compared to the nonsonicated examples (entries 1–4). However, the presonication did not result in an improvement towards high yields in short reaction times. Therefore, it was decided to carry out the reaction under continuous ultrasonic irradiation with the substrate present (entries 9–11). The yields showed improvement and it was observed that 2-hour-long ultrasonic activated reaction produced the best results (94%, entry 11). While the yield was not higher than that of the 1-hour presonication (entry 7) the same yield was obtained in a much shorter reaction time (2 h vs 21 h).

The beneficial effects of ultrasound can be explained by the formation of a clean, oxide-free aluminum surface that is of utmost importance in hydrogen generation. As an Al_2O_3 layer is thought to cover the aluminum surface of the alloy, its removal produces a fresh Al surface that can readily react with water used as a solvent to yield hydrogen gas. In addition, the rapid dissolution of the aluminum results in the timely formation of a Raney-type Ni catalyst that economically uses the hydrogen gas generated. The surface

cleaning effect is also applicable for the remaining Raney-Ni catalyst, most likely by the reduction or removal of Ni oxide species, which, in our experience, improves reaction rates.[18] It is worth mentioning that after the aluminum content reacted, the only by-product of the reaction is the Raney Ni particles deposited on the surface of the aluminum oxide, essentially an alumina-supported Ni catalyst, that can be used for other purposes.

Based on the optimization efforts, it appears that a 2-hour continuous ultrasonic irradiation with the substrate present, represents the optimum conditions for the reaction; providing the product in high yields and exclusive selectivity in a reasonably short (2 h) reaction time. As our goal was to extend the scope of the method to a broad variety of substrates, we have selected several carbonyl compounds to be submitted to these conditions using NH_4OH as an amination reagent. The reactions were all carried out at ambient temperature with 2-hour continuous ultrasonic irradiation. The results are summarized in Table 2.

The data show that the reductive amination of carbonyl compounds with ammonium hydroxide occurs with high to excellent yields. Aliphatic ketones were transformed to primary amines in excellent yields (Table 2, entries 1–7). In the case of 2-methylcyclohexanone, the two diastereomeric products were obtained in a ratio of 1.7:1 (entry 5). The reaction can be performed with additional heteroatoms in the cyclic structure (entries 6 and 7). Substituting a CH_2 group with an oxygen atom did not significantly affect the yield of the amination reaction. The catalytic system even tolerates the presence of sulfur, a common poison for hydrogenation catalysts. With a sulfur atom present in the cyclohexanone ring a conversion of 65% was achieved. The product of reductive amination is obtained in 19% yield, together with 46% of the condensation product of the formed amine with the unreacted ketone.

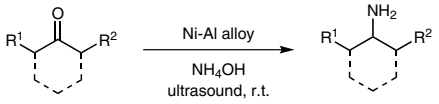
Aromatic ketones such as acetophenone only provide the desired amines in low yields, accompanied by the corresponding alcohol as the major product. In this case, the C=O reduction occurs faster than the imine formation, yielding the alcohol as the major product. When 4-nitroacetophenone is used, the reduction of the nitro group and the formation of an aniline is observed as the main product, reductive amination only generated its product to a minor extent. When 1,3-diketo compounds were subjected to the reaction conditions, one of the keto groups underwent amination but no reduction was observed. This can be explained by the higher stability these structures enjoy due to the possibility of imine-enamine tautomerism. The reaction can also be extended to aldehydes. The transformation of benzaldehyde gave benzylamine in excellent yield (Table 2, entry 8).

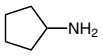
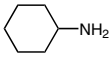
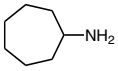
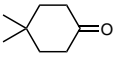
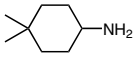
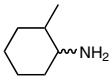
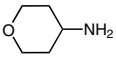
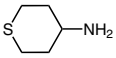
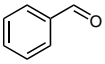
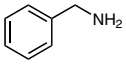
After having successfully applied the optimum reaction conditions for the reductive amination of ketones with NH_4OH, efforts were made to further extend the scope of this method. When different substituted benzaldehydes are submitted to reductive amination with benzylamines as a partner, the corresponding secondary amines can be obtained. These molecules represent interesting substructures of bioactive compounds.[15] From a more methodological point of view this reaction can also be considered as an easy transformation of carbonyl groups into benzyl-protected amines in one step. The data obtained for these transformations are summarized in Table 3.

It was found that for these reactions a presonication of the Ni-Al alloy for 90 minutes, followed by addition of the reaction partners and subsequent stirring at 50 °C provides the best performance. Prolonged sonication in the presence of the reaction partners leads to the debenzylation of the product secondary amines.[19]

As shown in Table 3, a variety of substituted benzaldehydes readily undergo reductive amination with substituted benzylamines to the corresponding secondary amines in

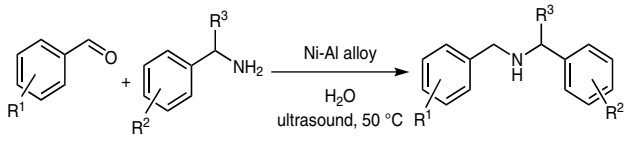
Table 2 Synthesis of Primary Amines via Reductive Amination of Ketones with NH_4OH[a]



Entry	Carbonyl compound	Product	Yield (%)[b]
1			77
2			94
3			88
4			83[c]
5			96[d]
6			90
7			65[e]
8			92

[a] Reactions were carried out with 200 mg Ni-Al, 3 mL 28–30% NH_4OH, and 0.34 mmol carbonyl compound at r.t. with 2-hour continuous sonication.
[b] GC yields.
[c] Reaction time: 2.5 h.
[d] Obtained as a 1.7:1 mixture of diastereomers.
[e] The product was obtained as a mixture of tetrahydro-2*H*-thiopyran-4-amine (30%) and *N*-(tetrahydro-2*H*-thiopyran-4-yl)tetrahydro-4*H*-thiopyran-4-imine (70%).

Table 3 Reductive Amination of Benzaldehydes with Benzylamines Using the Ni-Al/H_2O System[a]



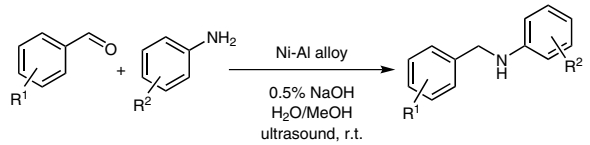
Entry	R^1	R^2	R^3	Yield (%)[b]
1	H	H	H	88
2	H	H	Me	94
3	H	4-Me	H	86
4	4-Me	4-Me	H	72
5	4-F	H	H	100
6	4-F	H	Me	81
7	4-F	2-OMe	H	72
8	2-OBn	H	H	91
9	2-OBn	4-Me	H	91
10	2-OBn	H	Me	76
11	4-NMe_2	H	H	58
12	4-NMe_2	H	Me	84
13	3,4-(OCH_2CH_2O)	H	Me	78
14	1-naphthyl	H	H	70
15	2-naphthyl	H	Me	67
16	1-naphthyl	2-OMe	H	64

[a] Reactions were carried out by presonicating 200 mg Ni-Al for 90 min in 3 mL H_2O, then 0.34 mmol aldehyde and 0.34 mmol amine were added and the mixture was stirred at 50 °C for 18 h without ultrasound.
[b] GC yields.

good to excellent yields. The reaction tolerates both electron-donating and -withdrawing substituents on both aromatic rings and in different substitution patterns. When the reaction is performed with halogen-substituted benzaldehydes certain limitations apply. While the reductive amination occurs with F-, Cl-, and Br-substituted materials, only the fluoride-substituted products appear stable under the reaction conditions. Chloro- and bromo-substituted compounds undergo dehalogenation when treated with Ni-Al alloy.[13] The reaction can also be performed with sterically demanding reactants (Table 3, entries 8–10 and 14–16). Debenzylation of the OBn group does not occur under the conditions used (entries 8–10).

After having successfully implemented the reductive amination with benzylamines, it was decided to further extend the scope of the reaction to the reductive amination of benzaldehydes with aromatic amines, such as anilines. While the reactions with benzylamines and ammonia proceed easily, anilines are less reactive, probably due to their decreased nucleophilicity and solubility in water. In addition, the product Schiff base required harsher conditions to undergo hydrogenation. Therefore, the benzaldehyde and aniline were premixed in MeOH when the Schiff base formation occurred. After the formation of the intermediate, we decided to use a dilute base solution to enhance the rate of the Al dissolution in order to provide more vigorous conditions for the hydrogen evolution and hydrogenation. Careful investigation revealed that the best results can be obtained when the Ni-Al alloy is presonicated for 1 hour in 1% aqueous NaOH solution. Then the solutions are combined (0.5% overall NaOH conc.) and stirred for 18 hours at room temperature. An increase in temperature or sonication of the reaction mixture in the presence of the starting materials leads to the formation of undesired debenzylated products. The results obtained are tabulated in Table 4.

Table 4 Reductive Amination of Benzaldehydes with Anilines Using the Ni-Al/H_2O System[a]



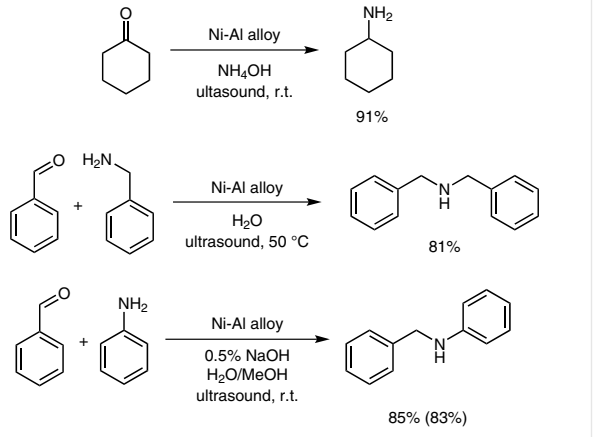
Entry	R^1	R^2	Yield (%)[b]
1	H	H	92
2	H	4-F	64
3	4-F	H	98
4	4-Cl	H	79 (15)[c]
5	H	4-Cl	11 (13)[c]
6	H	4-Cl	53 (17)[c,d]
7	4-Cl	4-Cl	97 (3)[c]
8	4-NMe_2	H	36
9	H	4-CF_3	72
10	4-CF_3	H	93
11	3-CF_3	H	58
12	2-Me	H	92
13	3-Me	H	94
14	4-Me	H	98
15	H	4-Me	91

[a] Reactions were carried out with 200 mg Ni-Al, presonicated for 1 h in 1 mL 1% NaOH; 0.5 mmol benzaldehyde and 0.5 mmol aniline were mixed in 1 mL MeOH, then the Ni-Al mixture was added and stirred for 18 h at r.t.
[b] GC yields.
[c] Yield in parentheses corresponds to the dechlorinated compound.
[d] Reaction time: 36 h; 200 mg Al added after 18 h.

As shown in Table 4, a large variety of substrates undergo reductive amination under the experimental conditions. Both electron-withdrawing and -donating substituents are tolerated. In the case of halogen substituents some interesting observations can be made. It is not surprising after the results of the benzylamine reactions (Table 3) that fluorine substituted compounds gave better results than the chlorine substituted ones. Again, Cl-substituted product can un-

dergo dehalogenation after a prolonged reaction time. In terms of the position of the substituent, it seems as if a substituent on the benzaldehyde moiety gives higher yields compared to the same substituent on the aniline reaction partner (Table 4, compare entries 2 vs 3, 4 vs 5, 10 vs 9, and 14 vs 15). The effect is more pronounced with electron-withdrawing substituents such as F and Cl than with the electron-donating methyl substituent. In the case of 4-chloroaniline, only 11% of the desired product was obtained. This yield could be increased to 53% by the addition of extra aluminum after an 18-hour reaction time and prolonged stirring (entries 5 and 6). It can be deduced that the presence of an electron-withdrawing group on the benzaldehyde moiety activates the carbonyl group while an electron-withdrawing group on the aniline deactivates the nucleophilic nitrogen and thus hinders the reaction. Interestingly, when a 4-Cl substituent is placed on both the benzaldehyde and the aniline the product is obtained in an excellent yield of 97% (entry 7). It can be explained by the activating effect on the 4-chlorobenzaldehyde that enhances the reaction rates and overcomes the inhibiting effect on the 4-chloroaniline. The position of an electron-withdrawing substituent on the aromatic ring matters in terms of the yield obtained. In the case of a CF_3 as substituent, the 4-CF_3 substituted compound gives a significantly higher yield than with 3-CF_3 substituted one (entries 10 and 11). This appears less important for electron-donating substituents. In the case of methyl-substituted benzaldehydes there was no significant difference between the reactivity of *ortho*-, *meta*-, and *para*-substituted aldehydes.

In order to verify the practicality of the method presented, the reactions were carried out on a larger scale. Sample reactions from all three types were run at a 5 mmol scale (10-fold increase, Scheme 2).



Scheme 2 Scale-up of reductive amination reactions. Reactions were carried out on a 5 mmol scale using the corresponding conditions (see Tables 2–4). Yield in parentheses corresponds to isolated yield.

As shown in Scheme 2 only a slight decrease in yield is obtained when the reactions were performed on a larger scale as compared to the above smaller scale reactions. In addition, using the formation of *N*-benzylaniline, it was shown that the isolated yield is nearly identical to the yield determined by gas chromatography.

Based on the results presented above, it is expected that the process would readily occur with other carbonyl compounds or amines. As the reactivity of those compounds generally surpasses that of the above used substrates; it is reasonable to suggest that the method is broadly applicable for open chain ketones or aldehydes and aliphatic amines as well.

In summary, we have demonstrated that Ni-Al alloy can be effectively and selectively applied in water for the reductive amination of carbonyl compounds. The reaction tolerates a variety of functional groups and is a green and easy to perform alternative to classic reductive amination methods. Major advantages of the described method are as follows: (i) the reaction can be performed in water; (ii) no harmful by-products are formed. The obtained alumina-supported Ni catalyst can be directly used in other reactions, or upon the dissolution of the $Al(OH)_3$ by the addition of a base the Ni-powder can be easily separated from the alumina by filtration and reused, while the $Al(OH)_3$ is nontoxic and can be converted to Al electrochemically; (iii) the reaction does not require the use of hydrogen and ammonia gas and no high pressure reaction vessels are needed; (iv) the use of complex hydrides commonly applied for reductive aminations is not necessary; and (v) reductive aminations with benzylamines and anilines can be performed as one-pot reactions, as the isolation of the imine intermediate is not necessary.

All amines and carbonyl compounds were purchased from Aldrich and used without any purification. $CDCl_3$ used as a solvent (99.8%) for NMR studies was an Aldrich product. EtOAc used for product isolation in the NH_4OH reactions (minimum purity of 99.5%) was a Fisher product.

The ^1H and ^{13}C spectra were obtained on a 300 MHz Varian Gemini NMR spectrometer and a 400 MHz Agilent DD2 spectrometer in $CDCl_3$ with either using the signal of TMS or the residual solvent signal as standards.

The mass spectrometric identification of the products was carried out by an Agilent 6850 gas chromatograph 5973 mass spectrometer system (70 eV electron impact ionization) using a 30 m long DB-5 type column (J & W Scientific).

Reductive Amination of Ketones in NH_4OH; Cyclohexylamine; Typical Procedure

Ni-Al alloy (200 mg) and cyclohexanone (35 µL, 0.34 mmol) were suspended in 28–30% NH_4OH (3 mL) and sonicated (Branson 1510MTH ultrasonic bath) for 2 h. After the completion of the reaction, the excess alloy and solid by-products were removed by filtration. The fil-

trate was extracted with EtOAc (2 × 2 mL). The organic extracts were combined and dried over anhyd Na_2SO_4. The solvent was removed in vacuo and the crude product was purified by flash chromatography.

All products obtained are known in the literature and the spectral data obtained were in agreement with literature data or those of authentic, commercially available compounds.[20]

Reductive Amination of Benzaldehydes with Benzylamines; *N*-Benzyl-1-phenylmethanamine; Typical Procedure

Ni-Al alloy (200 mg) was suspended in deionized H_2O (3 mL) and sonicated (Branson 1510MTH ultrasonic bath) for 90 min. Benzaldehyde (35 µL, 0.34 mmol) and benzylamine (37 µL, 0.34 mmol) were added and the reaction mixture was stirred at 50 °C for 18 h. After the completion of the reaction, the excess alloy and solid by-products were removed by filtration. The filtrate was extracted with EtOAc (2 × 2 mL). The organic extracts were combined and dried over anhyd Na_2SO_4. The solvent was removed in vacuo and the crude product was purified by flash chromatography.

The spectral characterization of new compounds (listed below) can be found in the Supporting Information. The spectral data of known products were in agreement with literature data.[21]

***N*-(4-Fluorobenzyl)-1-(2-methoxyphenyl)methanamine**

Yield: 88 mg (72%); yellow oil.

^{1}H NMR (300 MHz, $CDCl_3$): δ = 7.48–7.16 (m, 4 H), 7.12–6.74 (m, 4 H), 3.83 (s, 3 H), 3.79 (s, 2 H), 3.74 (s, 2 H), 1.89 (br s, 1 H).

^{13}C NMR (75 MHz, $CDCl_3$): δ = 163.4, 157.7, 136.2, 129.9, 129.7, 129.6, 128.3, 128.1, 120.3, 115.2, 114.9, 110.2, 55.2, 52.2, 48.7.

^{19}F NMR (282 MHz, $CDCl_3$): δ = –60.79.

MS [$C_{15}H_{16}FNO$ (245)]: *m*/*z* (%) = 245 (M^+, 22), 244 (51), 136 (30), 124 (51), 121 (45), 109 (100), 91 (46).

***N*-Benzyl-1-(2-phenoxyphenyl)methanamine**

Yield: 138 mg (91%); yellow oil.

^{1}H NMR (300 MHz, $CDCl_3$): δ = 7.39–7.34 (m, 4 H), 7.29–7.21 (m, 8 H), 6.97–6.92 (m, 2 H), 5.08 (s, 2 H), 3.86 (s, 2 H), 3.76 (s, 2 H), 2.04 (br s, 1 H).

^{13}C NMR (75 MHz, $CDCl_3$): δ = 156.8, 140.3, 137.0, 130.1, 128.6, 128.3, 128.23,128.19, 127.9, 127.3, 126.8, 120.7, 111.6, 69.9, 53.1, 49.0.

MS [$C_{21}H_{21}NO$ (303)]: *m*/*z* (%) = 303 (M^+, 11), 281 (25), 226 (18), 196 (36), 195 (26), 91 (100).

***N*-(4-Methylbenzyl)-1-(2-phenoxyphenyl)methanamine**

Yield: 144 mg (91%); pale yellow oil.

^{1}H NMR (300 MHz, $CDCl_3$): δ = 7.41–7.16 (m, 9 H), 7.11–7.08 (m, 2 H), 6.97–6.92 (m, 2 H), 5.08 (br s, 2 H), 3.86 (s, 2 H), 3.73 (s, 2 H), 2.33 (s, 3 H), 1.94 (br s, 1 H).

^{13}C NMR (75 MHz, $CDCl_3$): δ = 156.8, 137.4, 137.0, 136.3, 130.1, 129.0, 128.7, 128.6, 128.1 (2C), 127.9, 127.2, 120.7, 111.6, 69.8, 52.8, 48.9, 21.1.

MS [$C_{22}H_{23}NO$ (317)]: *m*/*z* (%) = 317 (M^+, 15), 224 (16), 210 (16), 196 (38), 120 (48), 106 (16), 105 (71), 91 (100).

***N*-(2-Phenoxybenzyl)-1-phenylethan-1-amine**

Yield: 121 mg (76%); yellow oil.

^{1}H NMR (300 MHz, $CDCl_3$): δ = 7.40–7.34 (m, 4 H), 7.29–7.16 (m, 8 H), 6.95–6.89 (m, 2 H), 5.08 (br s, 1 H), 5.07 (br s, 1 H), 3.76 (A part of AB system, d, *J* = 13.1 Hz, 1 H), 3.74 (q, *J* = 6.6 Hz, 1 H), 3.58 (B part of AB system, d, *J* = 13.1 Hz, 1 H), 1.98 (br s, 1 H), 1.30 (d, *J* = 6.6 Hz, 3 H).

^{13}C NMR (75 MHz, $CDCl_3$): δ = 156.9, 145.6, 137.0, 130.3, 128.6, 128.3, 128.2, 127.9, 127.4, 126.8 (2C), 126.8, 120.7, 111.5, 69.9, 57.3, 47.7, 24.5.

MS [$C_{22}H_{23}NO$ (317)]: *m*/*z* (%) = 317 (M^+, 10), 302 (32), 197 (30), 196 (17), 91 (100).

***N*-{(2,3-Dihydrobenzo[*b*][1,4]dioxin-6-yl)methyl}-1-phenylethan-1-amine**

Yield: 105 mg (78%); yellow oil.

^{1}H NMR (300 MHz, $CDCl_3$) δ = 7.35–7.23 (m, 5 H), 6.81–6.71 (m, 3 H), 4.23 (s, 4 H), 3.79 (q, *J* = 6.6 Hz, 1 H), 3.54 (A part of AB system, d, *J* = 13.0 Hz, 1 H), 3.47 (B part of AB system, d, *J* = 13.0 Hz, 1 H) 1.63 (br s, 1 H), 1.35 (d, *J* = 6.6 Hz, 3 H).

^{13}C NMR (75 MHz, $CDCl_3$): δ = 145.5, 143.3, 142.3, 134.0, 128.4,126.9, 126.7, 121.1, 117.0,116.9, 64.32, 64.29, 57.3, 51.0, 24.5.

MS [$C_{17}H_{19}NO_2$ (269)]: *m*/*z* (%) = 269 (M^+, 2), 254 (18), 164 (10), 150 (20), 149 (100), 120 (18).

***N*-(2-Methoxybenzyl)-1-(naphthalen-2-yl)methanamine**

Yield: 89 mg (64%); yellow oil.

^{1}H NMR (300 MHz, $CDCl_3$): δ = 7.99–7.69 (m, 4 H), 7.58–7.39 (m, 3 H), 7.32–7.20 (m, 2 H), 7.06–6.80 (m, 2 H), 3.95 (s, 2 H), 3.85 (s, 2 H), 3.83 (s, 3 H), 1.98 (br s, 1 H).

^{13}C NMR (75 MHz, $CDCl_3$): δ = 157.7, 138.0, 133.4, 132.6, 130.0, 128.2 (2 C), 127.9, 127.7, 127.6, 126.7, 126.4, 125.9, 125.4, 120.3, 110.2, 55.2, 53.1, 48.8.

MS [$C_{19}H_{19}NO$ (277)]: *m*/*z* (%) = 277 (M^+, 28), 156 (26), 136 (100), 121 (40), 91 (38).

Reductive Amination of Benzaldehydes with Anilines; *N*-Benzylaniline; Typical Procedure

Ni-Al alloy (200 mg) was suspended in 1% aq NaOH (1 mL) and sonicated (Branson 1510MTH ultrasonic bath) for 1 h. Benzaldehyde (51 µL, 0.5 mmol) and aniline (46 µL, 0.5 mmol) were mixed in MeOH (1 mL) and stirred for 1 h. Then, the Ni-Al suspension and the imine solution were mixed and stirred at r.t. for 18 h. After the completion of the reaction, the excess alloy and solid by-products were removed by filtration. The filtrate was extracted with EtOAc (2 × 2 mL). The organic extracts were combined and dried over anhyd Na_2SO_4. The solvent was removed in vacuo and the crude product was purified by flash chromatography.

All products obtained are known in the literature and the spectral data obtained were in agreement with literature data.[22]

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Supporting Information

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