Selective *N*-monoalkylation of aromatic amines with benzylic alcohols by a hydrogen autotransfer process catalyzed by unmodified magnetite†

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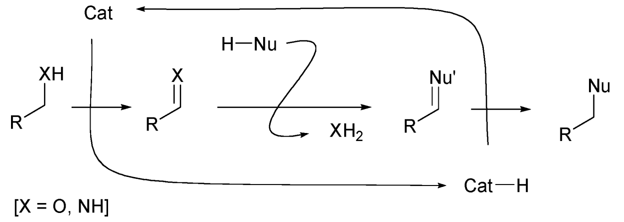
A new catalyst for an old material: magnetite is a good catalyst for the selective *N*-alkylation of aromatic amines using benzylic alcohols as electrophiles. The process could be repeated up to eight times without losing effectiveness. The catalyst recycling is very easy, using a simple magnet. The catalyst is selective and could discriminate between aromatic and aliphatic amines, as well as between benzylic and aliphatic alcohols, as the reactions only take place with aromatic amines and benzylic alcohols.

Introduction

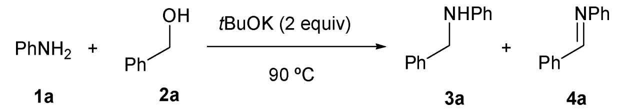
Hydrogen autotransfer,[1] also called borrowing hydrogen, is an old reaction[2] and it is currently of great interest in C–C bond formation processes (Scheme 1).[3] This interest now leans towards the use of amines, and other nitrogenated compounds, as nucleophiles to yield the corresponding *N*-alkylated products. The reason for this change takes root in the great variety of amines present in Nature, as well as their relevant importance in the pharmaceutical and agrochemical industries as usual building blocks. The extremely high advantage of this *N*-alkylation process, compared with classical protocols,[4] is due, on the one hand, to the simplicity of the protocol and, on the other hand, to the avoidance of using either mutagenic alkyl halides, sulfates, *etc.*, or difficult storable carbonyl compounds, as well as to the reduction of wastes. Many different complexes have been proposed as catalysts for this thrifty process, including those derived from nickel,[5] copper,[6] ruthenium,[7] rhodium,[8] palladium,[9] iridium[10] and platinum.[11]



Scheme 1 General scheme for a hydrogen autotransfer process.

Very recently, we have demonstrated the possible usefulness of nano-powder magnetite as catalyst in the four-component aza-Sakuray reaction,[12] which is the first example of using unprotected, naked and commercially available magnetite as a typical soft Lewis acid in organic synthesis.[13] With this study we would like to show that simple magnetite can be used (and re-used) as a typical heterogeneous catalyst in the selective *N*-monoalkylation of aromatic amines.

Table 1 Reaction conditions optimization



Entry	Solvent	**2a** (mol%)	Catalyst (mol%)	t (d)	Yield **3a** (%)[a]	Yield **4a** (%)[b]
1	1,4-dioxane	400	—	10	67	12
2	1,4-dioxane	400	—	7	52	21
3	1,4-dioxane	400	Fe_3O_4 (20)	7	88	<5
4[c]	1,4-dioxane	400	Fe_3O_4 (20)	7	72	13
5	1,4-dioxane	200	Fe_3O_4 (20)	7	80	5
6	1,4-dioxane	400	Fe_3O_4 (40)	7	89	<5
7	1,4-dioxane	400	Fe_3O_4 (1)	8	66	19
8	1,4-dioxane	400	Fe_3O_4 (20)[d]	7	76	8
9	1,4-dioxane	400	Fe_2O_3 (20)	7	62	7
10	1,4-dioxane	400	FeO (20)	7	60	11
11	PhMe	400	Fe_3O_4 (20)	7	65	19

[a] Isolated yields after column chromatography (silica gel: hexane/ethyl acetate. [b] Yields calculated by CG analysis of crude mixture using 1,2,3-trimethylbenzene as standard. [c] Reaction performed using only 1 equivalent of *t*BuOK. [d] Reaction performed using nanopowder (20–30 nm).

Results and discussion

Our starting point is the known surface of the magnetite-Fe_3O_4 (111), which is terminated by a hexagonal oxygen layer covered by one quarter monolayer of iron cations,[14] these metallic centers on the surface are able to act as catalysts. So, the reaction outlined in Table 1 was used as the standard one for optimization of the reaction conditions.

Firstly, we performed the reaction in the absence of any catalyst[15] in order to prove the real effect of catalyst. Thus, the reaction of aniline (**1a**) with an excess of benzylic alcohol (**2a**, 4 equiv) in dioxane, and in the presence of potassium *tert*-butoxide (2 equiv) gave the expected amine **3a** with a modest yield in seven (or even in ten) days, with imine **4a** being detected as the only by-product (entries 1 and 2). The preparation of this product can only be explained by the alcohol undergoing a dehydrogenation process catalyzed by the base,[16] followed by condensation with the amine

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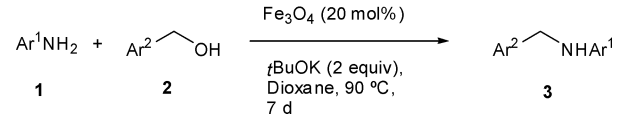
† Electronic supplementary information (ESI) available: TEM images of magnetite after and before being used, as well as ^1H and ^{13}C NMR for compounds **3a–n**. See DOI: 10.1039/b901929d

to give compound **4a**. The final reduction of this compound gave the alkylated amine **3a**, with this process being produced through a Meerwein–Ponndorf–Verley process.[17,18] The same reaction using 20 mol% of commercial powder magnetite[19] (particle size <5 μm) rendered the expected product **3a** with a better yield and in a lower reaction time (compare entries 2 and 3 in Table 1), with the amount of imine **4a** being negligible. This result clearly showed that magnetite catalyzed the hydrogen autotransfer process, this result being in concordance with the fact that glauconite [natural silicate containing Fe(II) and Fe(III)] was able to dehydrogenate different alcohols.[20] Once the catalysis of magnetite was proved, other parameters of the reaction were optimized. Thus, when the amount of base or benzylic alcohol (**2a**) was diminished the results were accountably lower (entries 4 and 5). Although the increase of amount of catalyst did not have any appreciable impact on the chemical yield; its decrease diminished significantly the yield (compare entries 2, 6 and 7). The use of nanoparticles of magnetite did not improve the previous results (compare entries 3 and 8). Other different source of heterogeneous iron, such as iron oxides, gave lower chemical yields (entries 9 and 10). The reaction using a less polar solvent, such as toluene, yielded a moderated result, with the amount of by-product being at a maximum (entry 11).

After completing the optimization study, we faced the problem of the reaction scope (Table 2), and we started by changing the electronic nature of the substituent on benzylic alcohol **2**. The reaction using different 4-substituted benzylic alcohols gave practically the same results (Table 2, entries 1–3), independently of the electron-donor or withdrawing character of the substituent.

However, when different substituted anilines were used as a nucleophile, the best result was obtained with the less nucleophilic one, 3-chloroaniline, whereas the worst results were obtained with the most nucleophilic ones (compare entries 1 and 4–6). The reaction can also be performed using electron-poor heteroaromatic amines. For instance, the reaction with a 2-pyridyl derivative gave a quantitative yield, practically independently of the benzylic alcohol **2** used (entries 7–11). The position of this extra nitrogen atom seems to have no influence on these unbeatable results, as well as the existence of two nitrogen atoms on the six-membered ring of the amine (entries 12 and 13). Finally, it should be pointed out that the reaction can be performed with electron-rich heteroaromatic amines, such as thiazolamine derivatives and the result was appreciably lower (entry 14), as in the case of methoxy substituted anilines.

Table 2 Magnetite catalyzes the *N*-alkylation process



Entry	Ar^1	Ar^2	Product	Yield (%)[a]
1	Ph	Ph	**3a**	88
2	Ph	$4\text{-MeOC}_6\text{H}_4$	**3b**	84
3	Ph	$4\text{-ClC}_6\text{H}_4$	**3c**	83
4	$4\text{-MeOC}_6\text{H}_4$	Ph	**3d**	42
5	$2\text{-MeOC}_6\text{H}_4$	Ph	**3e**	44
6	$3\text{-ClC}_6\text{H}_4$	Ph	**3f**	99
7	2-pyridyl	Ph	**3g**	96
8	2-pyridyl	$4\text{-MeOC}_6\text{H}_4$	**3h**	>99
9	2-pyridyl	$4\text{-MeC}_6\text{H}_4$	**3i**	>99
10	2-pyridyl	$4\text{-ClC}_6\text{H}_4$	**3j**	>99
11	2-pyridyl	$2\text{-MeOC}_6\text{H}_4$	**3k**	>99
12	4-pyridyl	Ph	**3l**	>99
13	2-pyrimidyl	Ph	**3m**	>99
14	5-methylthiazol-2-yl	Ph	**3n**	33

[a] Isolated yields after column chromatography (silica gel: hexane/ethyl acetate).

Once the catalytic activity and scope of the unmodified magnetite was demonstrated, we faced the re-using problem, finding that the chemical yields were constant in a range between 83 and 93%, after 8 cycles of reaction, for the preparation of compound **3a** (Fig. 1), with the magnetite being maintained inside the flask only by the help of a magnet.

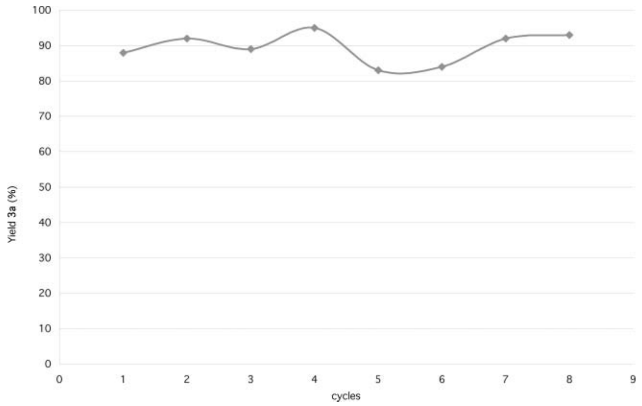


Fig. 1

In order to explore the possible degradation of the naked magnetite on the reaction conditions, the BET surface area was determined at the beginning of the process (being 9.86 m^2/g) and after 8 cycles (being 10.94 m^2/g), with this concordant result showing that there is not any type of significant sinterization process under the assayed reaction conditions. A similar result could be extracted from the observation of TEM microscopy images, which did not show any difference between the unmodified magnetite and the 8-fold reused one (Fig. 2 and ESI†).

To finish the study of magnetite stability, we studied the obtained liquid phase after a one-cycle reaction for the preparation of compound **3a**. The magnetite was isolated by a magnet and washed with toluene; the resulting mixture without filtration was concentrated and re-dissolved in methanol. Flame atomic absorption spectroscopy (FAAS) showed the presence of around 0.0020 mg of iron in the methanolic solution (less than 0.003% of initial iron added). However, if a simple filtration is done before concentration, the FAAS did not show the presence of iron atoms, excluding the presence of homogeneous iron species. Therefore, we believe that the possible degradation of magnetite does not occur, and the FAAS result only showed the capacity of the magnet used to trap the magnetite, keeping free only a very small amount of magnetite.

Finally, we tried to discover the possible selectivity of the process and, for that purpose, we performed different competitive reactions. Thus, the reaction of amine **1e** with two different alcohols **2a** (4 equiv) and **5** (4 equiv) gave the benzylic amine **3g**, as the only compound detected by CG-MS analysis of crude mixture [equation (a) in Scheme 2].

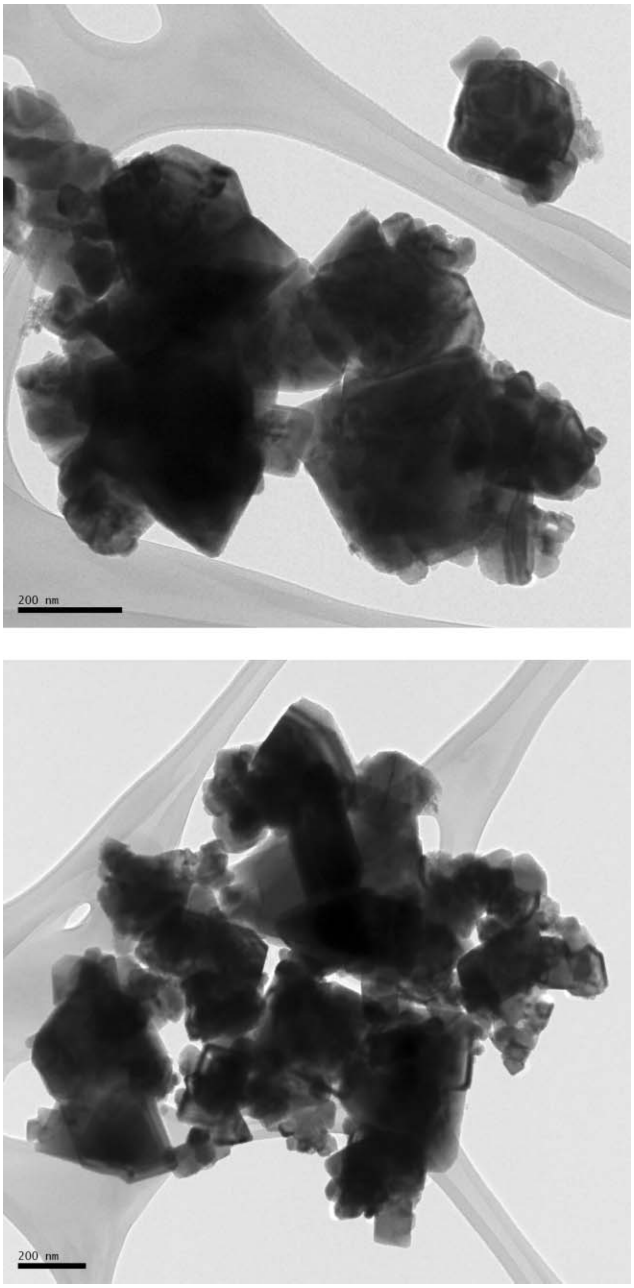
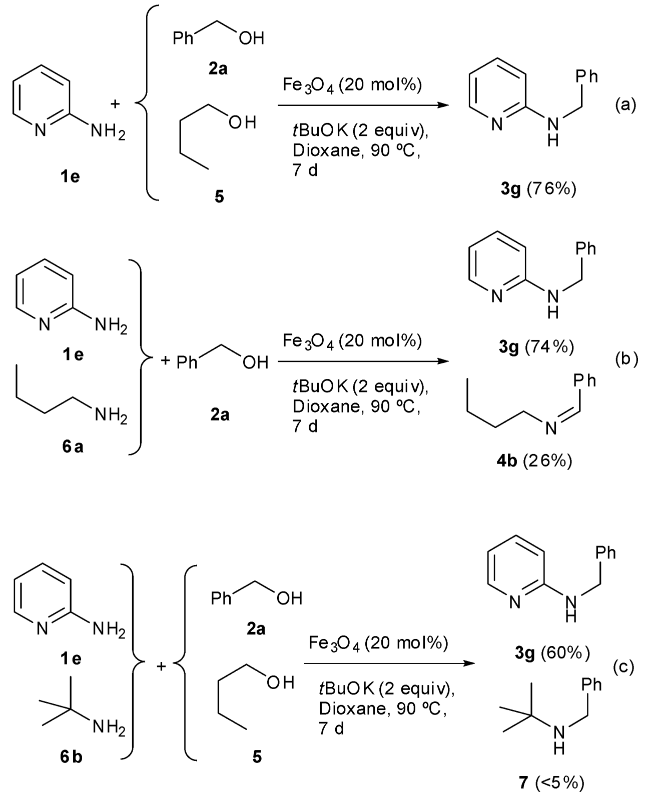


Fig. 2 TEM microscopy images of commercial magnetite (top) and the same magnetite after being used in 8 cycles (bottom).

It should pointed out that the chemical yield is a little bit lower than that presented in entry 7 of Table 2, but this result could be partially explained by the smaller amount of base used with respect to the total amount of alcohol. If the competitive assay is performed between two amines, one aromatic **1e** and another aliphatic **6a**, the only products detected were **3g**, which arose from the coupling of the aromatic amine with the benzylic alcohol, and a small amount of the imine **4b** [equation (b) in Scheme 2]. This result indicates that the reduction process of *N*-alkyl imines does not take place on the magnetite catalyst, at least under these reaction conditions. Finally, the mixture of aromatic and aliphatic amines (**1e** and **6b**) and two alcohols **2a** and **5**, only gave coupling between both aromatic systems, with the by-product being negligible [equation (c) in Scheme 2]. Therefore we might conclude that the process presented here is selective, to a certain level, for the amine as well as for the alcohol partner.



Scheme 2 Competitive experiments.

The last part of this study deals with the study of the possible catalytic cycle and where the catalysis takes place. Firstly, we should mention that the reactions failed in the absence of potassium *tert*-butoxide, therefore we believe that the catalytic cycle starts with the deprotonation of benzylic alcohol. When the reaction was performed under standard conditions but in an open air flask, and after 3 days, the main product detected was the imine **4a**. Whereas 68% yield was obtained in the reaction catalyzed by magnetite, only 35% yield of product **4a** was achieved in the absence of catalyst, showing the effect of the catalyst in the oxidation step, probably rendering initially potassium hydride for the uncatalyzed process and an iron hydride species for the magnetite catalyzed one. Then, we study the final reduction process, and for that purpose the imine **4a** was reacted with an excess of benzyl alcohol (**2a**, 3 equivalents) yielding the expected amine **3a** after two days with yields of 55% for the magnetite catalyzed process and 35% for the uncatalyzed one. The process probably works through a Meerwein–Ponndorf–Verley reaction, since the reaction failed in the absence of benzyl alcohol.[21] Finally, the reduction process was studied by reaction of imine **4a** with NaH (4 equivalents) rendering surprisingly in this case 35% of amine **3a** only when the reaction was performed in the presence of magnetite, with these experiments showing the possible connection between the uncatalyzed cycle with the magnetite catalyzed one. We have proved that magnetite catalyzes the first oxidation step of alcohol to aldehyde rendering either hydrogen or iron hydride species, as well as the second reduction step either by direct addition of hydride or by a Meerwein–Ponndorf–Verley process. It should be pointed out that the condensation process is very fast and does not need any catalysis.[22]

Conclusion

In conclusion, unmodified commercial magnetite has been shown to be an active, stable and highly selective catalyst for the selective monoalkylation of aromatic amines through a hydrogen autotransfer process. Even working with long reaction times, this is the first time that unmodified magnetite has been used as a recyclable catalyst in an alkylation of amines using alcohols as the initial source of electrophiles.

Experimental

General

Melting points were obtained with a Reichert Thermovar apparatus. FT-IR spectra were obtained on a Nicolet Impact 400D spectrophotometer. NMR spectra were recorded on a Bruker AC-300 (300 MHz for ^{1}H and 75 MHz for ^{13}C) using CDCl$_3$ as a solvent and TMS as internal standard; chemical shifts are given in δ (parts per million) and coupling constants (J) in Hertz. Mass spectra (EI) were obtained at 70 eV on a Shimazdu QP-5000 spectrometer, giving fragment ions in m/z with relative intensities (%) in parentheses. The high resolution mass spectroscopy was performed by the corresponding Mass Spectrometry Service at the University of Alicante. The chromatographic analyses (GLC) were determined with a Hewlett Packard HP-5890 instrument equipped with a flame ionization detector and 12 m HP-1 capillary column (0.2 mm diam, 0.33 mm film thickness, OV-1 stationary phase), using nitrogen (2 mL/min) as a carrier gas, $T_{\text{injector}} = 275$ °C, $T_{\text{detector}} = 300$ °C, $T_{\text{column}} = 60$ °C (3 min) and 60–270 °C (15 °C/min), $P = 40$ kPa. Surface areas were determined by the application of the BET equation to the N$_2$ adsorption isotherm at 77K. Adsorption data were obtained from a QUANTACHROME AUTOSORB-6 equipment. TEM images were obtained with a JEOL JEM-2010 Electron Microscope. FAAS analyses were carried out using a Varian SpectrAA 10 plus Atomic Absorption Spectrometer.

Thin layer chromatography (TLC) was carried out on Schleicher & Schuell F1400/LS 254 plates coated with a 0.2 mm layer of silica gel; detection by UV$_{254}$ light, staining with phosphomolybdic acid [25 g phosphomolybdic acid, 10 g Ce(SO$_4$)$_2$·4H$_2$O, 60 ml of concentrated H$_2$SO$_4$ and 940 ml H$_2$O]. Column chromatography was performed using silica gel 60 of 35–70 mesh. All reagents were commercially available (Acros, Aldrich, Strem) and were used as received.

General procedure for the *N*-monoalkylation of amines using alcohols catalyzed by magnetite

To a mixture of Fe$_3$O$_4$ (< 5 μm, 0.093 g) and potassium *tert*-butoxide (0.473 g, 4 mmol) in dry 1,4-dioxane (5 mL) were added the arylamine derivative (**1**, 2.0 mmol) and the corresponding alcohol (**2**, 8 mmol) under an argon atmosphere. The reaction mixture was heated at 90 °C in sealed vessel and stirred for 7 days. Then, the reaction mixture was filtered off through Celite and the solvent was removed under reduced pressure. The resulting residue was purified, if needed, by flash chromatography on silica gel (hexane/ethyl acetate) to give the corresponding product **3**.

Benzyl(phenyl)aniline (3a).[10l] Colourless oil; IR (film, cm^{-1}): 3421, 3071, 1607, 1512, 1323, 1239, 917; ^{1}H NMR δ 4.22 (s, 2H), 4.54 (s, 1H), 6.50–6.55 (m, 2H), 6.65–6.70 (m, 1H), 7.10–7.15 (m, 2H), 7.20–7.30 (m, 5H); ^{13}C NMR δ 48.05, 112.70 (2C), 117.35, 127.05, 127.35 (2C), 128.45 (2C), 129.10 (2C), 139.30, 148.00; MS (EI) m/z 184 (M^{+}+1, 13%), 183 (93), 182 (43), 181 (58), 180 (71), 106 (20), 104 (17), 91 (100), 78 (11), 77 (57), 65 (25), 63 (11), 51 (31); HRMS calcd. for C$_{13}$H$_{13}$N: 183.1048: Found 183.1040.

4-Methoxybenzyl(phenyl)amine (3b).[10j] Pale yellow oil; IR (film, cm^{-1}): 3421, 3054,2837, 1613, 1518, 1307, 1268, 1251; ^{1}H NMR δ 3.50 (s, 1H), 3.68 (s, 3H), 4.15 (s, 2H), 6.50–6.55 (m, 2H), 6.65–6.70 (m, 1H), 6.80–6.85 (m, 2H), 7.10–7.25 (m, 5H); ^{13}C NMR δ 47.40, 54.95, 112.60 (2C), 113.75 (2C), 117.15, 128.30, 128.50 (2C), 129.00 (2C), 131.20, 148.00; MS (EI) m/z 213 (M^{+}, 29%), 211(20), 210 (23), 121 (100), 78 (11), 77 (22); HRMS calcd. for C$_{14}$H$_{15}$NO: 213.1154: Found 213.1158.

4-Chlorobenzyl(phenyl)amine (3c).[10j] Pale yellow oil; IR (film, cm^{-1}) ν 3427, 3060, 1607, 1513, 1429, 1323, 1101; ^{1}H NMR δ 3.80 (.10–7.15 (m, 2H), 7.20–725 (m, 4H); ^{13}C NMR δ 47.35, 112.70 (2C), 117.57, 128.50 (2C), 128.55 (2C), 129.15 (2C), 132.60, 137.90, 147.70; MS (EI) m/z 219 (M^{+}+2, 19%), 218 (14), 217 (73), 216 (35), 215 (47), 214 (50), 182 (11), 127 (34), 125 (100), 106 (10), 104 (12), 89 (23), 77 (51), 75 (11), 65 (10), 63 (12), 51 (24); HRMS calcd. for C$_{13}$H$_{12}$NCl: 217.0658: Found 217.0650.

Benzyl(4-methoxyphenyl)amine (3d).[10l] Brown oil; IR (film, cm^{-1}) 3377, 3026, 1507, 1451, 1239, 1045, 906 cm^{-1}; ^{1}H NMR δ 3.30 (s, 1H), 3.65 (s, 3H), 4.20 (s, 2H), 6.50–6.55 (m, 2H), 6.70–6.75 (m, 2H), 7.20–7.30 (m, 5H); ^{13}C NMR δ 48.95, 55.50, 114.00 (2C), 114.65 (2C), 126.75, 126.95, 127.35 (2C), 128.35 (2C), 142.25, 151.90; MS (EI) m/z 214 (M^{+}+1, 13%), 213 (84), 212 (21), 211 (86), 210 (18), 198 (10), 97 (16), 196 (100), 167 (29), 122 (56), 92 (11), 91 (50), 77 (12), 65 (13), 63 (12); HRMS calcd. for C$_{14}$H$_{15}$NO: 213.1154: Found 213.1157.

Benzyl(2-methoxyphenyl)amine (3e).[10l] Colourless oil; IR (film, cm^{-1}) 3444, 3077, 1607, 1512, 1468, 1423, 1251; ^{1}H NMR δ 3.77 (s, 3H), 4.29 (s, 2H), 4.60 (s, 1H), 6.50–6.55 (m, 1H), 6.60–6.65 (m, 1H), 6.70–6.75 (m, 1H), 6.80–6.85 (m, 1H), 7.20–7.35 (m, 5H); ^{13}C NMR δ 47.85, 55.20, 109.25, 109.95, 116.50, 121.15, 126.95, 127.35 (2C), 128.45 (2C), 138.00, 139.45, 146.65; MS (EI) m/z 214 (M^{+}+1, 15%), 213 (100), 212 (24), 211 (26), 198 (33),196 (12), 180 (12), 167 (11), 120 (21), 104 (11), 94 (13), 92 (19), 91 (84), 77 (17), 65 (29), 63 (10), 51 (13); HRMS calcd. for C$_{14}$H$_{15}$NO: 213.1154: Found 213.1147.

Benzyl(3-chlorophenyl)amine (3f).[10l] Colourless oil; IR (film, cm^{-1}) 3416, 3032, 1596, 1490, 1323 cm^{-1}; ^{1}H NMR δ 4.05 (s, 1H), 4.25 (s, 2H), 6.40–6.45 (m, 1H), 6.55–6.65 (m, 2H), 7.00–7.05 (m, 1H), 7.20–7.35 (m, 5H); ^{13}C NMR δ 48.00, 111.05, 112.40, 117.30, 127.35, 127.40 (2C), 128.65 (2C), 130.15, 134.95, 138.65, 149.15; MS (EI) m/z 219 (M^{+}+2, 15%), 218 (11), 217 (51), 216 (25), 215 (26), 214 (30), 111 (19), 91 (100), 77 (12), 75 (18), 65 (14), 63 (11), 51 (12); HRMS calcd. for C$_{13}$H$_{12}$NCl: 217.0658: Found 217.0653.

Benzyl(2-pyridyl)amine (3g).[10l] Colourless solid; mp 105–107 °C; IR (KBr, cm^{-1}) 3225, 3022, 1604, 1567, 1510, 1448, 1334 cm^{-1};

^{1}H NMR δ 4.40 (s, 2H), 5.25 (s, 1H), 6.29 (d, J = 8.4 Hz, 1H), 6.50–6.55 (m, 1H), 7.20–7.35 (m, 6H), 7.95–8.00 (m, 1H); ^{13}C NMR δ 46.05, 106.50, 112.85, 126.75, 127.15 (2C), 128.45 (2C), 137.45, 138.95, 147.75, 158.50; MS (EI) *m/z* 185 (M^{+}+1, 13%), 184 (100), 183 (52), 182 (10), 181 (21), 107 (17), 106 (69), 91 (36), 79 (47), 78 (29), 77 (11), 65 (17), 52 (13), 51 (19); HRMS calcd. for $C_{12}H_{12}N_2$: 184.1000: Found 184.1002.

4-Methoxybenzyl(2-pyridyl)amine (3h).[101] Colourless solid; mp 85–87 °C; IR (KBr, cm^{-1}) 3438, 3065, 1607, 1513, 1440, 1268, 1251 cm^{-1}; ^{1}H NMR δ 3.75 (s, 3H), 4.40 (s, 2H), 4.50 (s, 1H), 6.50–6.55 (m, 1H), 6.80–6.90 (m, 2H), 7.25 (d, J = 8.6 Hz, 2H), 7.35–7.45 (m, 1H), 7.85–7.90 (m, 1H); ^{13}C NMR δ 45.95, 55.65, 109.70, 113.35, 114.75, 114.85 (2C), 129.60 (2C), 132.85, 138.80, 147.90, 160.25; MS (EI) *m/z* 214 (M^{+}, 51%), 213 (11), 136 (22), 121 (100), 79 (23), 78 (22); HRMS calcd. for $C_{13}H_{14}N_2O$: 214.1106: Found 214.1098.

4-Methylbenzyl(2-pyridyl)amine (3i).[101] White solid; mp 73–75 °C, IR (KBr, cm^{-1}) 3438, 3054, 2976, 1607, 1573, 1507, 1445, 1418, 1273 cm^{-1}; ^{1}H NMR δ 2.30 (s, 3H), 4.40 (s, 2H), 5.36 (s, 1H), 6.30 (d, J = 8.4 Hz, 1H), 6.50–6.55 (m 1H), 7.10 (d, J = 7.9 Hz, 2H), 7.20 (d, J = 7.9 Hz, 2H), 7.30–7.35 (m, 1H), 8.00–8.05 (m, 1H); ^{13}C NMR δ 20.85, 45.85, 106.45, 112.65, 127.15 (2C), 128.90, 129.10 (2C), 135.80, 137.50, 147.60, 158.50; MS (EI) *m/z* 199 (M^{+}, 14%), 198 (100), 197 (46), 196 (13), 195 (26), 183 (16), 120 (79), 105 (57), 103 (10), 91 (14), 79 (65), 78 (29), 77 (17); HRMS calcd. for $C_{13}H_{14}N_2$: 198.1157: Found 198.1152.

4-Chlorobenzyl(2-pyridyl)amine (3j).[101] Colourless solid; mp 98–100 °C; IR (KBr, cm^{-1}) 3444, 3071, 1613, 1568, 1496, 1329, 1268 cm^{-1}; ^{1}H NMR δ 4.40 (s, 2H), 5.35 (s, 1H), 6.30 (d, J = 8.4 Hz, 1H), 6.50–6.55 (m, 1H), 7.20–7.25 (m, 4H), 7.30–7.35 (m, 1H), 8.00–8.05 (m, 1H); ^{13}C NMR δ 45.30, 76.65, 106.65, 113.05, 128.45 (2C), 128.50 (2C), 137.45, 137.70, 147.90, 158.35; MS (EI) *m/z* 220 (M^{+}+1, 25%), 219 (21), 218 (80), 217 (35), 215 (12), 142 (30), 140 (93), 127 (17), 125 (45), 107 (12), 89 (21), 80 (11), 79 (100), 78 (35); HRMS calcd. for $C_{12}H_{11}N_2Cl$: 218.0611: Found 218.0615.

2-Methoxybenzyl(2-pyridyl)amine (3k).[101] Colourless solid; mp 58–60 °C; IR (KBr, cm^{-1}) 3438, 3054, 2843, 1607, 1574, 1496, 1440, 1268, 1240 cm^{-1}; ^{1}H NMR δ 3.75 (s, 3H), 4.45 (d, J = 5.8 Hz, 2H), 5.50 (s, 1H), 6.30 (d, J = 8.4 Hz, 1H), 6.40–6.45 (m, 1H), 6.80–6.85 (m, 2H), 7.15–7.20 (m, 1H), 7.25–7.30 (m, 2H), 8.00–8.05 (m, 1H); ^{13}C NMR δ 41.10, 54.75, 106.30, 109.75, 112.20, 120.05, 126.80, 127.85, 128.20, 136.95, 147.65, 157.00, 158.65; MS (EI) *m/z* 215 (M^{+}+1, 11%), 214 (72), 213 (15), 199 (26), 184 (15), 183 (99), 182 (12), 181 (48), 180 (12), 136 (47), 121 (36), 107 (20), 105 (17), 92 (10), 91 (100), 79 (44), 78 (52), 77 (15), 65 (21), 52 (14), 51 (18); HRMS calcd. for $C_{13}H_{14}N_2O$: 214.1106: Found 214.1099.

Benzyl(4-pyridyl)amine (3l).[23] White solid; mp 88–90 °C; IR (KBr, cm^{-1}) 3465, 3125, 1615, 1522, 1448, 1348, 1228 cm^{-1}; ^{1}H NMR δ 4.30 (d, J = 5.6 Hz, 2H), 5.65 (s, 1H), 6.40 (d, J = 6.4 Hz, 2H), 7.20–7.35 (m, 5H), 8.05 (d, J = 5.4 Hz, 2H); ^{13}C NMR δ 46.40, 107.50, 126.95 (2C), 127.20, 128.50 (2C), 137.90, 149.35, 153.40; MS (EI) *m/z* 185 (M^{+}+1, 10%), 184 (81), 183 (21), 91 (100), 78 (10), 65 (11); HRMS calcd. for $C_{12}H_{12}N_2$: 184.1000: Found 184.1002.

Benzyl(2-pyrimidyl)amine (3m).[24] White solid; mp 74–76 °C; IR (KBr, cm^{-1}) 449, 3104, 1596, 1574, 1518, 1457, 1401, 1362 cm^{-1}; ^{1}H NMR δ 4.61 (d, J = 5.8 Hz, 2H), 6.42 (t, J = 4.8 Hz, 1H), 6.70 (s, 1H), 7.20–7.40 (m, 4H), 8.05 (s, 2H); ^{13}C NMR δ 45.35, 110.35, 127.10 (2C), 127.55, 128.45 (2C), 139.05, 157.85 (2C), 162.20; MS (EI) *m/z* 186 (M^{+}+1, 13%), 185 (100), 184 (71), 108 (13), 106 (54), 91 (30), 80 (19), 79 (20), 77 (11), 64 (14), 53 (11); HRMS calcd. for $C_{11}H_{11}N_3$: 185.0953: Found 185.0962.

Benzyl(5-methyl-1,3-thiazol-2-yl)amine (3n). White solid; mp 89–91 °C; IR (KBr, cm^{-1}) ν 3177, 3127, 2915, 1691, 1579, 1501, 1451, 1345, 1318, 1218, 1173, 1089 cm^{-1}; ^{1}H NMR δ 2.20 (s, 3H), 4.38 (s, 2H), 6.50 (s, 1H), 6.55 (s 1H), 7.25–7.35 (m, 5H); ^{13}C NMR δ 11.85, 49.60, 120.70, 127.40, 127.60 (2C), 128.50 (2C), 135.30, 137.90, 169.00; MS (EI) *m/z* 204 (M^{+}, 58%), 203 (20), 159 (12), 91 (100), 65 (13); HRMS calcd. for $C_{11}H_{12}N_2$: 204.0721: Found 204.0719.

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