Asymmetric Catalytic Hydroamination of Activated Olefins in Ionic Liquids

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The addition of a series of both aliphatic and aromatic amines to electron-poor olefins was investigated using $[\mathrm{Ni}(\textit{Pigiphos})(\mathrm{THF})]^{2+}$ as catalyst (with different counterions) in various ionic liquids based on imidazolium- and picolinium-salt derivatives. The catalysts gave rise to selectivities comparable to those obtained when the reaction was conducted in neat organic solvents (ee up to 66%), but significant higher activities, with a total turnover number (TON) of up to 300.

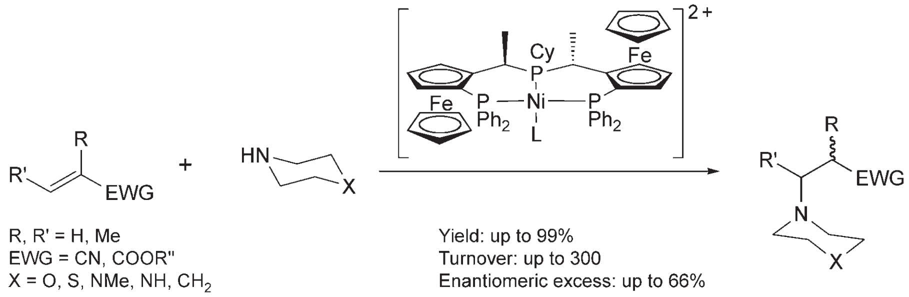
Introduction. – The use of ionic liquids [1] [2] in catalysis has grown recently [3] [4], mainly in the context of exploiting solvent properties for the optimization and/or recycling of catalysts [5]. For example, ionic liquids with non-coordinating anions dissolve cationic transition-metal complexes and can have a positive effect on both the activity and enantioselectivity of catalytic reactions [3] [6]. These effects may result from stabilization of polar complexes or transition states [7]. Additionally, the *Lewis* acidity of such solvents might activate the catalyst [8], or the ionic liquids can react to form carbene-like ligands [9]. The most important feature of ionic liquids, however, is related to the possibility of catalyst recycling to improve the total turnover number (TON). Catalyst recycling is especially important in slow catalysis, and it is in this area where the use of ionic liquids has been most significant [10] [11].

There are only few examples of the addition of amines to olefins in ionic liquids. *Brunet* and co-workers [12] have shown that molten salts can increase rates and TON values in $\mathrm{Rh^{III}}$-catalyzed (hydroamination of norbornene with anilines) and $\mathrm{Pt^{II}}$-catalyzed reactions (reaction of aniline with ethylene or hexene), giving rise to TON values of up to 250. Moreover, *Müller* and co-workers [13] described the intramolecular reaction of hex-6-yne-1-amine catalyzed by *Lewis* acids; conversion and selectivity are improved when the reaction is carried out in ionic liquids. Also, $\mathrm{Zn^{II}}$ catalysts have been used in biphasic systems for *i*) the intermolecular addition of aniline derivatives to cyclohexadiene and *ii*) for the hydroamination of phenylacetylene with different primary amines, with respective turnover frequencies (TOFs) of 1.8 $\mathrm{h^{-1}}$ and 25 $\mathrm{h^{-1}}$ [14]. Recently, the use of *Lewis* and/or *Brønsted* acids for the hydroamination/hydroarylation of olefins in ionic liquids has been reported, with a positive solvent effect on the activity [15].

So far, there have been no examples of chiral Pd [16], Ir [17] [18], lanthanide [19], or Zr [20] complexes catalyzing the asymmetric additions of amines to olefins [21] in ionic liquids. Herein, we, thus, report the first asymmetric hydroamination of activated olefins catalyzed by Ni^{II} complexes in various ionic liquids [22].

Recently, we illustrated that complexes of Ni^{II} with tridentate phosphorous (PPP) ligands such as *Pigiphos* catalyze the addition of aliphatic and aromatic amines to activated (*i.e.*, electron-poor) olefins, as shown in the *Scheme* below [22] [23]. The good productivity of the catalyst (up to quantitative yields, TON values up to 71 at room temperature), the modest activity (TOF up to $2.5\ h^{-1}$), and the low-to-moderate enantioselectivity (enantiomeric excess (ee) up to 69% for the addition of morpholine to methacrylonitrile) motivated us to improve this system. The tuning of the ferrocenyl tridentate ligand of *Pigiphos* and the possible transformation of the catalysis products to β-amino acids have recently been reported [22]. Because the active Ni^{II} complexes may be cationic species [24], the next step was to perform the reaction in ionic liquids.

Scheme. *Hydroamination of Olefins Catalyzed by [Ni(*Pigiphos*)(L)]*$^{2+}$ (L = THF)



Results and Discussion. – To better understand the effectiveness of the reported cationic Ni complexes, different salts containing more- or less-coordinating anions were added to a model catalytic system: the Ni^{II}-catalyzed hydroamination of morpholine with methacrylonitrile (=2-methylprop-2-enenitrile). Dicationic Ni^{II} complexes were previously reported to be highly active in such reactions [23]. Thus, cation–anion interactions may have important effects on the catalytic activity. The effect of different tested salts on the above hydroamination reaction (*Scheme*) are illustrated in *Fig. 1*. As can be seen, addition of the non-coordinating anions BF_4^- or PF_6^- led to almost unaltered selectivities and activities, giving rise to isolated yields of *ca.* 80%. However, when halide salts were added, both lower enantioselectivities ($Cl > Br > I$) and moderate activities ($I > Cl > Br$) were observed. These results indicate that *in situ* formed $[Ni(PPP)(halide)]^+$ complexes are less-active catalysts. The addition of a 'naked' fluoride (F^-) [17] even caused complete deactivation of the catalytic system, probably by forming $[Ni(PPP)F]^+$. Nitrate (NO_3^-) and acetate (AcO^-) gave similar results as with halides, leading to decreased activities and selectivities.

Having noted significant counterion effects on the enantioselectivity of the $[Ni($*Pigiphos*$)(THF)]^{2+}$-catalyzed hydroamination, with ClO_4^- being better than BF_4^- or PF_6^- (*Fig. 1*), we next attempted to improve the catalytic system by using 3-alkyl-1-methyl-1*H*-imidazolium ($RMIM^+$)- and 1-alkylpicolinium ($RPIC^+$)-based ionic liquids as solvents (*Fig. 2*). We anticipated that the hydroamination catalysis would benefit

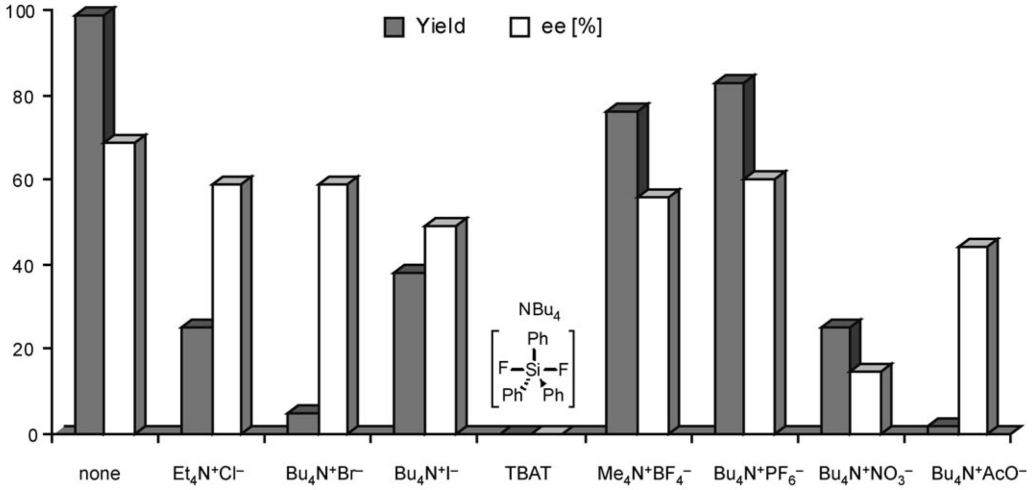


Fig. 1. *Effect of the addition of salt* (5 mol-%) *on the hydroamination reaction between morpholine and methacrylonitrile catalyzed by [Ni(*Pigiphos*)(THF)]$(ClO_4)_2$ in THF solution*

from such a more-polar reaction medium. As catalyst for the hydroamination of morpholine with methacrylonitrile, $[Ni($*Pigiphos*$)(THF)]^{2+}(ClO_4^-)_2$ was used in different ionic liquids. Thereby, it was necessary to use THF or acetone as co-solvent, which, however, were evaporated after complete dissolution of the Ni^{II} salts. Some preliminary results of this reaction are summarized in *Table 1*.

The use of ionic liquids as solvent, either in a one-phase or two-phase-system¹), gave results comparable to those obtained when working in neat THF or acetone, but with much higher activities (TON values of up to 300; *Table 1*, *Entry 6*). Thus, the catalyst loading was reduced to 0.1 mol-%, and the reaction still gave 30% yield and 48% ee. However, the enantioselectivities in ionic liquids *vs.* classical organic solvents were comparable (up to 66%) for reaction times of 24 h at room temperature using 5 mol-% of catalyst. Catalysis in ionic liquids was less sensitive to air (O_2; *Entry 8*) and

$X^- = BF_4^-, PF_6^-, CF_3SO_3^-, (CN)_2N^-$

EMIM R = ethyl
BMIM R = butyl
HMIM R = hexyl

BPIC R = butyl
OPIC R = octyl

Fig. 2. *Imidazole- and picoline-derived ionic liquids used in this study*

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¹) Single phase: ionic liquid as solvent for all components. Binary system: catalyst dissolved in ionic liquid, substrates dissolved in organic solvent (*e.g.*, hexane or Et_2O) immiscible with ionic liquid.

Table 1. *Hydroamination of Methacrylonitrile with Morpholine.* All reactions were performed for 24 h at r.t. in BMIM · BF_4/THF 2 : 1 under inert conditions (unless noted otherwise); the catalyst, [Ni(*Pigiphos*)(THF)]$(ClO_4)_2$, was generated *in situ*. For abbreviations of ionic liquids, see *Fig. 2*.

Entry	mol-% catalyst	Recycling	TON[a])	Yield [%][b])	ee [%][c])
1	5	none	19.2	96	62
2	5[d])	none	20	> 95[e])	64
3	5	from *1*	20	> 95[e])	59
4	1	none	95	> 95[e])	61
5	1	from *4*	72	72	51
6	0.1	none	300	30	48
7	5[f])	none	18	90	57
8	5[g])	none	20	> 95[e])	59

[a]) Total turnover number. [b]) Isolated yield after flash chromatography. [c]) Enantiomeric excess, determined by chiral GC on a *β-dex* column; abs. configuration of the major products: (*R*) [24]. [d]) Reaction performed with a different commercial sample of BMIM · BF_4. [e]) Determined by NMR after extraction with Et_2O/hexane 1 : 5 and solvent evaporation. [f]) Reaction performed in ionic liquid/hexane binary phase. [g]) Reaction performed under aerobic conditions.

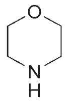
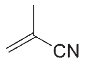
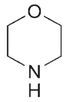
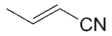
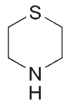
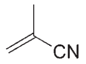
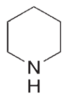
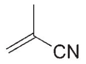
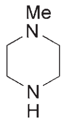
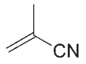
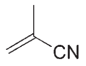
moisture (H_2O), allowing the use of non-distilled reagents. These might be due to stabilization of the cationic species in the ionic liquid. Also, the reaction was fully reproducible when using different commercial samples of the same ionic liquid (*Entries 1* and *2*) [25]. Activity and enantioselectivity were similar when the catalytic reaction was carried out in a binary system of hexane/ionic liquid (*Entry 7*), but greatly facilitated the extraction of the organic compounds. On the other hand, the positive environmental effect of the absence of solvents with low vapor pressure was missing.

Next, the catalytic hydroaminations of methacrylonitrile or crotonitrile with morpholine, thiomorpholine, piperidine, 1-methylpiperazine, dibenzylamine, and aniline, respectively, were examined using different imidazolium salts as solvents. The results are collected in *Table 2*. As can be seen, addition of morpholine to methacrylonitrile always gave the best results in terms of activity and enantioselectivity (*Table 2*, *Entry 1*). As expected, the counterion, X^-, of the ionic liquid has a significant effect, in particular on enantioselectivity. However, when ionic salts with dicyanoamide, $[N(CN)_2]^-$, as anion were used, the reaction did not proceed (*Entries 2*, *7*, and *10*). Although ionic liquids with this specific counterion are less viscous, both the catalyst and the substrates were found to be only poorly soluble. This likely explains our recovery of the starting materials.

The hexyl-substituted imidazolium ($HMIM^+$) ionic liquids gave rise to comparable activities but lower asymmetric induction in the addition of morpholine (*Table 2*, *Entries 5*, *13*, and *16*). When thiomorpholine was used, both lower conversion and lower selectivity were observed (44% yield, 53% ee).

The ethyl ($EMIM^+$)-substituted ionic liquids gave rise to an improvement in enantioselectivity for the hydroamination of methacrylonitrile with thiomorpholine. Thus, when $EMIM^+ \cdot CF_3SO_3^-$ was used as solvent, the ee was 66%, while it was 61% in THF (*Table 2*, *Entry 12*). Aliphatic amines such as dibenzylamine (Bn_2NH) reacted in excellent yield to the corresponding addition product (*Entry 18*). The addition of

Table 2. *Catalytic Hydroamination of Olefins with Different Amines in Various Imidazolium-Based Ionic Liquids.* All reactions were performed in ionic-liquid/THF 2 : 1 at r.t. under inert conditions, with *in situ* generated [Ni(*Pigiphos*)(THF)]$(ClO_4)_2$ (5 mol-%) as catalyst.

Entry	Amine	Olefin	Ionic liquid[a])	TON	TOF [h^{-1}][b])	Yield [%][c])	ee [%][d])
1			BMIM · CF_3SO_3	20	0.83	> 95[e])	57
2			BMIM · $(CN)_2N$	0	–	0	–
3			EMIM · BF_4	19	0.79	95	63
4			EMIM · CF_3SO_3	19	0.79	95	61
5			HMIM · PF_6	20	0.83	> 95[e])	46
6			BMIM · CF_3SO_3	20	0.83	> 95[e])	16
7			BMIM · $(CN)_2N$	0	–	0	–
8			EMIM · BF_4	20	0.83	> 95[e])	14
9			BMIM · CF_3SO_3	10.4	0.43	52	30
10			BMIM · $(CN)_2N$	0	–	0	–
11			EMIM · BF_4	20	0.83	> 95[e])	61
12			EMIM · CF_3SO_3	20	0.83	> 95[e])	66
13			HMIM · PF_6	8.8	0.37	44	53
14			BMIM · BF_4	20	0.83	> 95[e])	65
15			EMIM · BF_4	19	0.79	95	44
16			HMIM · PF_6	20	0.83	> 95[e])	42
17			EMIM · BF_4	19	0.79	95	55
18	Bn_2NH		HMIM · PF_6	19	0.79	95	0

[a]) For abbreviations, see *Fig. 2.* [b]) Total turnover frequency. [c]) Yield of isolated material after flash chromatography. [d]) Determined by chiral GC on a *β-dex* column; abs. configuration of major products: (*R*) [24]. [e]) Yield determined by NMR after extraction with Et_2O/hexane 1 : 5 and evaporation of the solvent.

aniline to either crotonitrile or methacrylonitrile did not proceed at all, except when performed in $EMIM^+ \cdot CF_3SO_3^-$ (10% yield, 8% ee; data not shown). Probably, the lower nucleophilicity of the aromatic amines and the poor solubility of the substrates in the chosen ionic liquids are responsible for these results.

Next, the hydroamination reaction of a wide range of substrates were tested with picolinium ($RPIC^+$) derivatives, and the results are shown in *Table 3*. The corresponding tetrafluoroborate, hexafluorophosphate, and dicyanoamide salts have the advantage of not being soluble in Et_2O, THF, and AcOEt, which greatly facilitates the extraction of organic substrates [1] [3] [10].

As can be seen from *Table 3*, the catalytic properties of $[Ni($*Pigiphos*$)(THF)]^{2+}$ in the presence of picolinium ionic-liquids were similar or better than those in imidazolium salts, and the binary system was viable also with these solvents. For example, reaction of morpholine with methacrylonitrile in the octyl-substituted ionic liquid ($OPIC^+ \cdot BF_4^-$), proceeded under complete conversion, affording 53% ee after 24 h at room temperature, both in single or binary phases; *Table 3*, *Entries 1* and *2*). The reaction of aniline and methacrylonitrile in a solvent mixture of $OPIC^+ \cdot BF_4^-$/hexane gave rise to a good yield (71%), but a low enantioselectivity (23% ee; *Entry 22*), with similar results (*Entry 24*) for the addition of aniline to crotonitrile (65% yield, 14% ee). On the other hand, the enantioselectivities were in general lower than for the catalysis in THF under the same conditions. Only in the case of thiomorpholine/methacrylonitrile was the enantioselectivity similar in ionic liquid compared to THF (59% ee; *Entry 13*). In the case of various aniline derivatives, the reaction performed in $OPIC^+ \cdot BF_4^-$ gave similar results as in THF (*Entries 25–30*) [23][24].

In *Fig. 3*, the results of the Ni^{II}-catalyzed addition of morpholine to methacrylonitrile in various ionic liquids are summarized.

As shown in *Tables 4–6*, an additional benefit of the use of ionic liquids is that the catalyst/ionic-liquid mixture can be readily recycled. After the original catalysis (24 h at room temperature), the catalyst/ionic-liquid mixture was extracted repeatedly with hexane/Et_2O 1:1 (5–10 ×). The washed ionic liquid, containing the dicationic Ni–*Pigiphos* catalyst, was re-used by addition of an immiscible organic solvent (Et_2O or hexane) containing the organic hydroamination substrates. The resulting binary-phase was stirred at room temperature for another 24 h, and worked up analogously.

However, the good productivity of the recycled catalyst (TON up to 116 after 6 cycles) in the hydroamination in $OPIC^+ \cdot BF_4^-$ solution was not accompanied by constant enantioselectivity. Unexpectedly, for the addition of morpholine or thiomor-

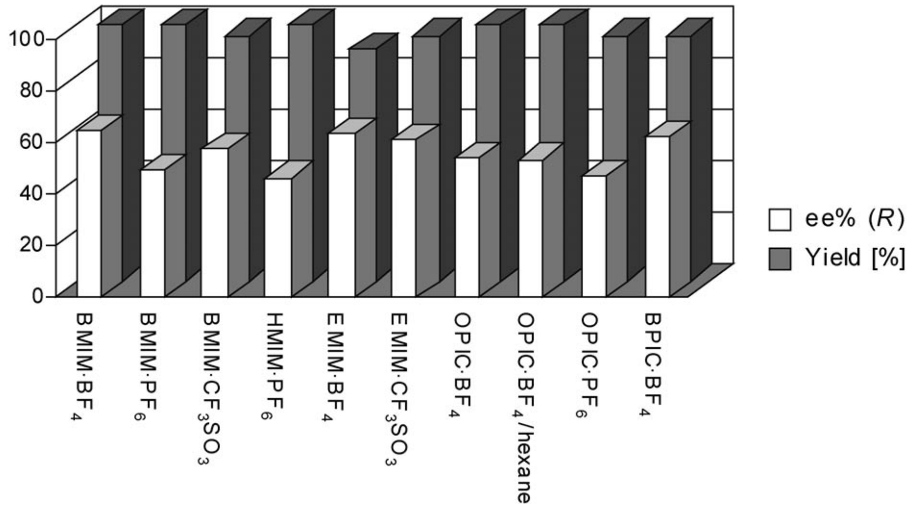
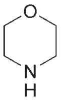
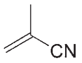
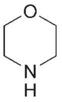
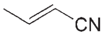
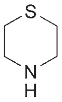
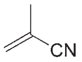
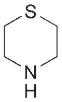
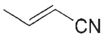
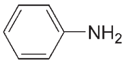
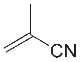
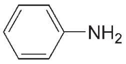
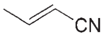
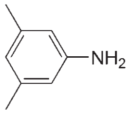
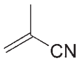
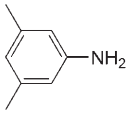
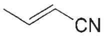
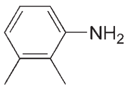
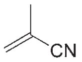
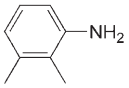
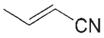


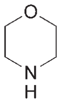
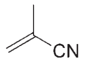
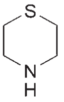
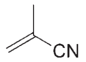
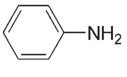
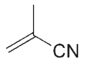
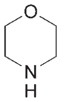
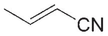
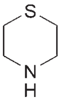
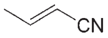
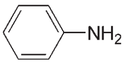
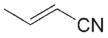
Fig. 3. *Yield and enantiomeric excess* (ee) *of the hydroamination of methacrylonitrile with morpholine catalyzed by* $[Ni($Pigiphos$)(THF)](ClO_4)_2$ *in various ionic liquids*

Table 3. *Catalytic Hydroamination of Olefins with Different Amines in Various Picolinium-Based Ionic Liquids.* Reactions were performed either in pure ionic-liquid (*neat*) or in ionic liquid/hexane 2 : 1 (*binary*) for 24 h at r.t. under inert conditions, with *in situ* generated $[Ni(\mathit{Pigiphos})(THF)](ClO_4)_2$ (5 mol-%) as catalyst.

Entry	Amine	Olefin	Ionic liquid	System	Yield [%][a])	ee [%][b])
1			$OPIC \cdot BF_4$	neat	99	53
2			$OPIC \cdot BF_4$	binary	99	53
3			$OPIC \cdot PF_4$	binary	> 95[c])	46
4			$OPIC \cdot (CN)_2N$	binary	25	35
5			$BPIC \cdot BF_4$	binary	> 95[c])	62
6			$BPIC \cdot (CN)_2N$	binary	5	0
7			$OPIC \cdot BF_4$	neat	99	10
8			$OPIC \cdot BF_4$	binary	99	4
9			$OPIC \cdot PF_6$	binary	> 95[c])	18
10			$OPIC \cdot (CN)_2N$	binary	0	–
11			$BPIC \cdot BF_4$	binary	> 95[c])	6
12			$BPIC \cdot (CN)_2N$	binary	0	–
13			$OPIC \cdot BF_4$	neat	99	59
14			$OPIC \cdot BF_4$	binary	99	57
15			$OPIC \cdot PF_4$	binary	30	30
16			$OPIC \cdot (CN)_2N$	binary	0	–
17			$BPIC \cdot BF_4$	binary	50	50
18			$BPIC \cdot (CN)_2N$	binary	5	30
19			$OPIC \cdot BF_4$	neat	62	5
20			$OPIC \cdot BF_4$	binary	50	14
21			$OPIC \cdot BF_4$	neat	17	10
22			$OPIC \cdot BF_4$	binary	71	23
23			$OPIC \cdot BF_4$	neat	26	0
24			$OPIC \cdot BF_4$	binary	65	14
25			$OPIC \cdot BF_4$	neat	8	19
26			$OPIC \cdot BF_4$	binary	14	18
27			$OPIC \cdot BF_4$	neat	9	0
28			$OPIC \cdot BF_4$	binary	13	0
29			$OPIC \cdot BF_4$	binary	4	9
30			$OPIC \cdot BF_4$	binary	5	0

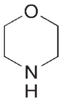
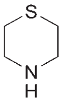
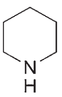
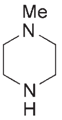
[a]) Isolated yield after flash chromatography. [b]) Enantiomeric excess, determined by chiral GC or HPLC. [c]) Determined by NMR after extraction with Et_2O/hexane 1 : 5 and evaporation of the solvent.

Table 4. *Activity of Recycled Catalyst in the Hydroamination of Olefins in Picolinium-Based Ionic Liquid*. Reactions were performed in OPIC$\cdot$BF$_4$/hexane 1 : 1 for 24 h at r.t. under inert conditions, with *in situ* generated [Ni(*Pigiphos*)(THF)](ClO$_4$)$_2$ as catalyst. The catalyst was recycled by extractive removal (hexane/Et$_2$O 1 : 1) of the organic products.

Entry	Amine	Olefin	*n*[a])	TON (cycles)[b])	Yield [%][c])	ee [%][d])
1			0	20	99	53
			1[e])	40 (2)	99	10.1
			2	59 (3)	95	6.3
			3[f])	78 (4)	95	6.2
			4	97 (5)	95	6.2
			5	116 (6)	95	0
			6[g])	–	82	50
2			0	20	99	59
			1[e])	32 (2)	61	2.1
			2	51 (3)	95	4.6
			3[f])	70 (4)	95	0
			4	89 (5)	95	0
			5	108 (6)	95	0
3			0	14	71	13.5
			1[e])	22 (2)	40	24.1
			2	30 (3)	40	23.8
			3[f])	34 (4)	20	24.3
			4	38 (5)	18	24.3
			5	40 (6)	8	23.6
4			0	20	99	4.2
			1[e])	39 (2)	95	7.1
			2	59 (3)	99	8.4
			3[f])	78 (4)	95	3.6
			4	97 (5)	95	3.8
			5	116 (6)	95	2.6
5			0	12	62	10.1
			1[e])	18 (2)	28	8.7
			2	33 (3)	75	8.9
			3[f])	43 (4)	50	10
			4	53 (5)	50	9.7
			5	72 (6)	95	8.5
6			0	13	65	16.9
			1[e])	32 (2)	95	16.9
			2	52 (3)	99	15.1
			3[f])	54 (4)	8	14.7
			4	56 (5)	9	14.1
			5	58 (6)	10	14.9

[a]) Recycling number; $n = 0$ means that the catalyst was freshly prepared and not used before. [b]) Total turnover number (TON) and number of cycles (in parenthesis). [c]) Isolated yield after extraction. [d]) Enantiomeric excess, determined by chiral GC or HPLC. [e]) Catalyst was exposed to air for 3 d before being re-used. [f]) Re-used after 3 d. [g]) Catalyst from *Entry 6*.

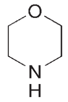
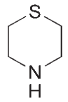
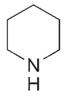
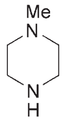
Table 5. *Activity of Recycled Catalyst in the Hydroamination of Methacrylonitrile.* Reactions were performed in $BMIM \cdot BF_4$/hexane 1 : 1 for 24 h at r.t. under inert conditions, with *in situ* generated $[Ni($*Pigiphos*$)(THF)](ClO_4)_2$ as catalyst. The catalyst was recycled by extractive removal (hexane/Et_2O 5 : 1) of the organic products.

Entry	Amine	*n*[a])	TON (cycles)[b])	Yield [%][c])	ee [%][d])
1		0	20	> 99[e])	52.7
		1	40 (2)	> 99[e])	53.5
		2	60 (3)	> 99[e])	53.4
		3	72 (4)	58	51.1
		4	81 (5)	47	51.6
		5	87 (6)	32	48.2
2		0	20	> 99[e])	53.8
		1	36 (2)	80	52.4
		2	48 (3)	60	54.0
		3	57 (4)	45	54.1
		4	65 (5)	38	53.2
		5	71 (6)	30	53.3
3		0	20	> 99[e])	65.5
		1	40 (2)	> 99[e])	64.3
		2	54 (3)	71	57.9
		3	59 (4)	27	36.8
		4	65 (5)	27	12.1
		5	67 (6)	12	1.0
4		0	20	> 99[e])	54.5
		1	39 (2)	94	54.9
		2	51 (3)	61	50.2
		3	56 (4)	25	44.5
		4	58 (5)	11	36.7
		5	59 (6)	5	27.0

[a]) Recycling number. [b]) Total turnover number (TON) and number of cycles (in parenthesis). [c]) Isolated yield after extraction. [d]) Enantiomeric excess, determined by chiral GC or HPLC. [e]) No traces of starting material detected by GC/MS or GC/HPLC analysis.

pholine to methacrylonitrile (*Table 4*, *Entries 1* and *2*), the enantioselectivity strongly decreased after each recycling, the products being racemic after six cycles. In contrast, for the reaction between methacrylonitrile and aniline, or between crotonitrile and morpholine, thiomorpholine, or aniline, the enantiomeric excess remained constant (*Table 4*, *Entries 3–6*). It is important to note that the less-nucleophilic aniline reacted more efficiently (TON up to 58 after six cycles; *Entry 6*). A catalyst mixture that had been recycled six times in the reaction of aniline and crotonitrile was then used for the addition of morpholine to methacrylonitrile. Surprisingly, after 24 h at room temperature, the corresponding hydroamination product, 2-methyl-3-morpholin-4-ylpropanenitrile, was formed with moderate enantioselectivity (50% ee) in 82% yield. This result is similar to the hydroamination results with the non-recycled catalyst. Thus, it appears that aniline does not deactivate the Ni^{II} catalyst to the same degree as morpholine does.

Table 6. *Activity of Recycled Catalyst in the Hydroamination of Crotonitrile.* Reactions were performed in BMIM·BF$_4$/hexane 1:1 for 24 h at r.t. under inert conditions, with *in situ* generated [Ni(*Pigiphos*)(THF)](ClO$_4$)$_2$ as catalyst. The catalyst was recycled by extractive removal (hexane/Et$_2$O 5:1) of the organic products.

Entry	Amine	*n*[a])	TON (cycles)[b])	Yield [%][c])	ee [%][d])
1		0	20	99[e])	6.0
		1	40 (2)	99[e])	1.8
		2	60 (3)	99[e])	5.9
		3	78 (4)	90	6.9
		4	94 (5)	81	8.0
		5	107 (6)	67	7.0
2		0	20	99[e])	8.5
		1	30 (2)	50	8.2
		2	38 (3)	40	4.4
		3	43 (4)	25	3.2
		4	49 (5)	32	3.1
		5	53 (6)	20	2.1
3		0	20	99[e])	7.3
		1	40 (2)	99[e])	6.4
		2	60 (3)	99[e])	–
		3	80 (4)	99[e])	5.4
		4	100 (5)	99[e])	7.4
		5	114 (6)	72	2.4
4		0	20	99[e])	14
		1	40 (2)	99[e])	–
		2	60 (3)	99[e])	13.3
		3	80 (4)	99[e])	12.1
		4	92 (5)	60	3.7
		5	104 (6)	60	1.5

[a]) Recycling number. [b]) Total turnover number (TON) and number of cycles (in parenthesis). [c]) Isolated yield after extraction. [d]) Enantiomeric excess, determined by chiral GC or HPLC. [e]) No traces of starting material detected by GC/MS or GC/HPLC analysis.

However, at present, it is difficult to identify the specific factors responsible for the loss of enantioselectivity upon catalyst recycling.

The recycling procedure was next tried with the imidazolium salts, namely with BMIM$^+$·BF$_4^-$, as shown in *Tables 5* and *6*. The hydroamination with methacrylonitrile did not give very high yields. After recycling, the activity decreased, with a total TON of 87 after six cycles (*Table 5*, *Entry 1*). Nevertheless, the enantioselectivities remained constant for the first three cycles, and were comparable to those of the non-recycled catalysts. The [Ni(*Pigiphos*)(THF)](ClO$_4$)$_2$ complex in BMIM$^+$·BF$_4^-$ did not catalyze the addition of aniline to methacrylonitrile. Only traces of the products were detected by GC/MS analysis.

The addition of amines to crotonitrile was more productive, with TON values of up to 114. The results were comparable to those obtained with the recycled catalyst in the picolinium salts (*Table 6*). No significant changes were detected for the rather low enantioselectivities, and even after five cycles, the asymmetric induction remained in the same range. Once again, the Ni^{II} complexes in imidazolium-based ionic liquids did not catalyze the addition of aniline to an electron-poor olefin.

Conclusions. – [Ni(*Pigiphos*)(THF)]$^{2+}$ complexes catalyze the hydroamination of aliphatic amines with methacrylonitrile or crotonitrile in different ionic liquids, with typically higher catalytic activities than in regular organic solvents. Unfortunately, the enantioselectivity of the reaction in ionic liquids could not be improved. Ionic liquids seem to stabilize the cationic Ni^{II} complexes, allowing to carry out the reaction without particular protection from O_2 and H_2O, and to re-use the catalyst/solvent mixture. The recycling process permits, in fact, an improvement of the total turnover number of the hydroamination reactions.

Experimental Part

General. All reactions with air- or moisture-sensitive materials were carried out under Ar gas using standard *Schlenk* techniques, or in a glove box under N_2 atmosphere. Hydroamination reactions performed with the help of a parallel synthesizer were conducted with a thermostated *Argonaut Quest-210* system (*Artisan Scientific*) using 20 vials (1–10, Part A; 11–20, Part B), 5 or 10 ml, with vertical stirring. HPLC Analyses were performed on a *Agilent Series-1100* and *HP-1050* using *Chiralcel OD-H* (4.6 × 250 mm; 5 μm), *Chiralcel OJ* (4.6 × 250 mm; 10 μm), or *Chiralcel OB-H* (4.6 × 250 mm; 5 μm) columns and a DAD-type UV detector, eluting with hexane/i-PrOH. GC Analyses were performed on a *Fisons Instruments GC-8000* or a *ThermoQuest Trace GC-2000* instrument with FID detector and one of the following columns: *α-dex 120* (30 m × 0.25 mm × 0.25 μm), *β-dex 120* (30 m × 0.25 mm × 0.25 μm), or *γ-dex 120* (30 m × 0.25 mm × 0.25 μm). Routine $^{31}P\{^1H\}$-, $^{13}C\{^1H\}$-, and ^1H-NMR spectra were recorded on *Bruker Avance-200* (^{13}C: 50.32, ^1H: 200.13 MHz), *Bruker Avance-250* (^{31}P: 101.26, ^{13}C: 62.90, ^1H: 250.13 MHz), *Bruker Avance-300* (^{31}P: 121.49, ^{19}F: 282.40, ^{13}C: 75.47, ^1H: 300.13 MHz), or *Bruker Avance-DPX500* [^{31}P: 202.46, ^{13}C: 125.75, ^1H: 500.23 MHz) spectrometers at r.t. Chemical shifts δ in ppm rel. to Me_4Si, referenced to solvent signals for ^1H- and $^{13}C\{^1H\}$-NMR, or relative to an external reference for $^{19}F\{^1H\}$- ($CFCl_3$: $\delta = 0.0$ ppm), and $^{31}P\{^1H\}$-NMR (85% H_3PO_4: $\delta = 0.0$ ppm), coupling constants *J* in Hz. EI-, FAB-, and MALDI-MS experiments were performed by the MS service of the 'Laboratorium für Organische Chemie', ETH Zurich; in *m*/*z* (rel. %). GC/MS Analyses were performed on a *Thermo Finnigan TraceMS* system in the EI mode, with a *Zebron ZB-5* (30 m × 0.25 mm × 0.25 μm) column.

*Bis{(1*R*)-1-[(*S*)-2-(Diphenylphosphino)ferrocenyl]ethyl}cyclohexylphosphine* (*Pigiphos*). (*S*)-2-Diphenylphosphino-1-[(1*R*)-1-(dimethylamino)ethyl]ferrocene (7 g, 15.9 mmol) was dissolved at 40° in degassed AcOH (30 ml), containing TFA (1.2 ml, 15.9 mmol). Then, cyclohexylphosphane (H_2PCy; 1.05 ml, 7.9 mmol) was added, and the mixture was stirred at 80° for 4 h. The solvent was removed under reduced pressure at 60°, and AcOEt was added. The resulting precipitate was filtered and washed with hexane/AcOEt 1:1, yielding the pure product. The solvent of the mother liquor was removed under reduced pressure, and the residue was further purified by flash chromatography (FC) (hexane/AcOEt 3:1) and recrystallization (hexane, −20°). Total yield: 6.101 g (85.2%). Microscopic orange crystals. ^1H-NMR (250 MHz, CD_2Cl_2)[2]): 0.70–1.70 (*m*, 11 H, Cy); 1.59 (*dd*, *J* = 6.5, *Me*CH); 1.65 (*dd*, *J* = 7.5, *Me*CH); 2.77–2.91 (*m*, MeC*H*); 3.08–3.22 (*m*, MeC*H*); 3.80 (*s*, 5 H of cp′), 3.84 (*s*, 5 H of cp′); 3.90 (*s*, 1 H of cp); 3.97–4.02 (*m*, 2 H of cp); 4.04–4.12 (*m*, 1 H of cp); 4.22–4.27 (*m*, 2 H of cp); 7.20 (*d*, *J* = 3.5, 5 H of Ph); 7.25–7.29 (*m*, 5 H of Ph); 7.37–7.46 (*m*, 6 H of Ph)); 7.50–7.75 (*m*, 4 H of Ph). $^{31}P\{^1H\}$-NMR

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[2]) Cy = cyclohexyl; cp = cyclopentadienyl.

(101 MHz, $CDCl_3$): -25.15 (*d*, $J = 11.8$, $P_A Ph_2$); -25.07 (*d*, $J = 28.9$, $P_B Ph_2$); 18.04 (*dd*, $J = 11.1$, 29.7, P_{Cy}). Anal. calc. for $C_{54}H_{55}Fe_2P_3$ (908.64): C 71.38, H 6.10, P 10.23; found: C 71.42, H 6.30, P 10.26.

General Procedure for Pigiphos-*Catalyzed Hydroamination in THF.* In a *Teflon*-valve flask (*Young*), $Ni(ClO_4)_2 \cdot 6\,H_2O$ (0.02 – 0.1 mmol; 5 mol-%), *Pigiphos* (0.02 – 0.1 mmol; 5 mol-%), and the chosen salt were dissolved in THF (3 ml). The resulting red-purple soln. was stirred at r.t. for 20 – 30 min. Then, the olefin (0.4 – 2.0 mmol) was added, and the soln. was stirred for an additional 10 – 30 min. Finally, the amine (0.2 – 1.0 mmol) was added, and the mixture was stirred overnight at r.t. After 24 h, hexane was added to precipitate the catalyst, and the product was purified by FC.

General Procedure for Pigiphos-*Catalyzed Hydroamination in Ionic Liquids.* In a *Schlenk* flask, $Ni(ClO_4)_2 \cdot 6\,H_2O$ (0.02 – 0.1 mmol; 5 mol-%) and *Pigiphos* (0.02 – 0.1 mmol; 5 mol-%) were suspended in ionic liquid (2 ml), and some THF or acetone (2 – 4 ml) was added to completely dissolve the materials. The mixture was stirred at r.t. for 15 min, and the org. solvent was removed under reduced pressure. To the resulting red-purple soln., the olefin (0.4 – 2.0 mmol) was added, and the mixture was stirred for an additional 10 – 30 min. Then, the amine (0.2 – 1.0 mmol) was added, and the soln. was stirred overnight at r.t. After 24 h, the org. substrates were extracted with hexane/Et_2O 5 : 1 (5 – 10 ×), and the products were purified by FC.

General Procedure for Hydroamination Catalysis in a Parallel Synthesizer. In a *Schlenk* flask, $Ni(ClO_4)_2 \cdot 6\,H_2O$ (0.1 – 0.5 mmol; 5 mol-%) and either *Pigiphos* or the corresponding isolated complex $[Ni(PPP)(THF)](ClO_4)_2)$ (0.1 – 0.5 mmol; 5 mol-%) were dissolved in ionic liquid (20 ml) and THF (5 ml). The soln. was stirred at r.t. for 15 min, and the org. solvent was removed under reduced pressure. Then, an aliquot (2 ml) of this standard soln. was added *via* syringe to each of the ten vials of a *Quest-210* manual synthesizer. To the resulting red-purple soln., the olefin (0.2 – 1.0 mmol) was added, and the mixture was stirred for an additional 10 – 30 min. Finally, the amine (0.1 – 0.5 mmol) was added, and the soln. was stirred overnight at r.t. After 24 h, the mixture was poured into a vial, hexane was added, and the products were purified by FC.

2-Methyl-3-(morpholin-4-yl)propanenitrile. Purified by FC (hexane/AcOEt/Et_3N 47.5 : 47.5 : 5.0). GC (*β-dex*; 90°, isothermal): t_R 168.5 (*R*), 174.3 (*S*). ^1H-NMR (250 MHz, $CDCl_3$): 1.31 (*d*, $J = 7.0$, *Me*CH); 2.38 (*dd*, $J = 12.5$, 12.5, 1 H of CH_2); 2.48 (*dd*, $J = 4.75$, $(CH_2)_2N$); 2.6 (*dd*, $J = 12.5$, 12.5, 1 H of CH_2); 2.62 – 2.95 (*m*, MeC*H*); 3.67 (*t*, $J = 4.75$, $(CH_2)_2O$). ^{13}C\{DEPT\}-NMR (62.9 MHz, $CDCl_3$): 15.74 (Me); 23.98 (*C*HCN); 53.68 ($(CH_2)_2N$); 61.41 (*C*H_2CH); 66.73 ($(CH_2)_2O$). GC/MS (120°, isothermal; t_R 6.15): 154.1 (0.5, M^+), 100.0 (100, $[M - MeCHCN]^+$). Anal. calc. for $C_8H_{14}N_2O$ (154.21): C 62.31, H 9.15, N 18.17; found: C 62.49, H 9.15, N 18.36.

3-(Morpholin-4-yl)butanenitrile. Purified by FC (hexane/AcOEt/Et_3N 47.5 : 47.5 : 5.0). GC (*β-dex*; 100°, isothermal): t_R 95.9, 97.1. ^1H-NMR (250 MHz, $CDCl_3$): 1.15 (*d*, $J = 6.5$, *Me*CH); 2.38 (*dd*, $J = 7$, 13, 1 H of CH_2); 2.47 (*t*, $J = 4$, $(CH_2)_2N$); 2.48 (*dd*, $J = 6$, 13, 1 H of CH_2); 2.68 – 2.92 (*m*, MeC*H*); 3.65 (*t*, $J =$ 5, $(CH_2)_2O$). $^{13}C\{^1H\}$-NMR (50 MHz, $CDCl_3$): 15.23 (Me); 21.29 (*C*H_2CN); 48.83 ($(CH_2)_2N$); 56.31 (CHN); 67.05 ($(CH_2)_2O$); 118.58 (CN). GC/MS (120°, isothermal; t_R 8.14): 154.1 (1, M^+), 139.0 (5, $[M - Me]^+$), 114 (100, $[M - CH_2CN]^+$). Anal. calc. for $C_8H_{14}N_2O$ (154.1): C 62.31, H 9.15; found: C 62.42, H 9.27.

2-Methyl-3-(thiomorpholin-4-yl)propanenitrile. Purified by FC (hexane/AcOEt/Et_3N 47.5 : 47.5 : 5.0). HPLC (*OJ*; hexane/i-PrOH 95 : 5, 0.5 ml/min, 25°, detection at 230 nm): t_R 26.0, 28.4. ^1H-NMR (250 MHz, $CDCl_3$): 0.79 (*d*, $J = 7.0$, *Me*CH); 1.78 (*dd*, $J = 8.0$, 10, 1 H of CH_2); 2.06 (*dd*, $J = 8.0$, 11, 1 H of CH_2); 2.33 (*t*, $J = 5.0$, $(CH_2)_2N$); 2.38 (*t*, $J = 5.0$, $(CH_2)_2S$); 2.70 – 2.95 (*m*, MeC*H*). ^{13}C\{DEPT\}-NMR (75 MHz, $CDCl_3$): 15.95 (Me); 24.51 (*C*HCN); 27.96 ($(CH_2)_2N$); 55.26 ($(CH_2)_2S$); 61.73 (*C*H_2CH). GC/MS (120°, isothermal; t_R 13.21): 170.0 (0.5, M^+), 116.0 (100, $[M - MeCHCN]^+$). Anal. calc. for $C_8H_{14}N_2O$ (170.28): C 56.43, H 8.29; found: C 56.78, H 8.14.

3-(Thiomorpholin-4-yl)butanenitrile. Purified by FC (hexane/AcOEt/Et_3N 47.5 : 47.5 : 5.0). HPLC (*OJ*; hexane/i-PrOH 95 : 5, 0.5 ml/min, 25°, detection at 210 nm): t_R 35.45, 38.46. ^1H-NMR (300 MHz, CD_2Cl_2): 1.16 (*d*, $J = 7.0$, *Me*CH); 2.35 (*dd*, $J = 7$, 12, 1 H of CH_2); 2.52 (*dd*, $J = 7$, 16, 1 H of CH_2); 2.61 – 2.72 (*m*, $(CH_2)_2N$)); 2.75 – 2.90 (*m*, $(CH_2)_2S$); 2.95 – 3.10 (*m*, C*H*CH_2). ^{13}C\{DEPT\}-NMR (62.9 MHz, $CDCl_3$): 15.07 (Me); 21.09 (*C*H_2CN); 28.32 ($(CH_2)_2N$); 50.79 ($(CH_2)_2S$); 57.75 (CHN). GC/MS (120°, isothermal; t_R 8.14): 154.1 (1, M^+), 139.0 (5, $[M - Me]^+$), 114 (100, $[M - CH_2CN]^+$). Anal. calc. for $C_8H_{14}N_2S$ (170.28): C 56.43, H 8.29, N 16.45; found: C 56.61, H 8.35, N 16.60.

2-Methyl-3-(piperidin-1-yl)propanenitrile. Purified by FC (hexane/AcOEt/Et$_3$N 47.5:47.5:5.0). GC (*α-dex*; 52°, isothermal): t_R 447.9, 453.2. ^{1}H-NMR (250 MHz, CDCl$_3$): 1.29 (*d*, J = 8.0, *Me*CH); 1.30–1.50 (*m*, CH$_2$); 1.55–1.65 (*m*, 2 CH$_2$); 2.33 (*dd*, J = 7.0, 1 H of CH$_2$); 2.43 (*q*, J = 7.0, (CH$_2$)$_2$N); 2.57 (*dd*, J = 8.0, 1 H of CH$_2$); 2.70–2.92 (*m*, MeC*H*). ^{13}C{DEPT}-NMR (62.9 MHz, CDCl$_3$): 13.33 (CH$_2$), 19.41 (Me); 29.70 (*C*HCN); 36.42 ((CH$_2$)$_2$); 69.95 ((CH$_2$)$_2$N); 70.22 (*C*H$_2$CH). GC/MS (120°, isothermal; t_R 5.32): 152 (0.5, M^+), 98.0 (100, [M – MeCHCN]$^+$).

2-Methyl-3-(4-methylpiperazin-1-yl)propanenitrile. Purified by FC (hexane/AcOEt/Et$_3$N 47.5:47.5:5.0). GC (*α-dex*; 80°, isothermal): t_R 230.8, 234.9. ^{1}H-NMR (250 MHz, CDCl$_3$): 1.30 (*d*, J = 7.0, *Me*CH); 2.28 (*s*, MeN); 2.41 (*dd*, J = 6.2, 12.5, CH$_2$); 2.47 (br. *s*, (CH$_2$)$_2$N); 2.55 (br. *s*, (C*H$_2$*)$_2$NMe); 2.62 (*dd*, J = 8.0, 12.5, 1 H of CH$_2$); 2.65–2.75 (*m*, MeC*H*). ^{13}C{DEPT}-NMR (75 MHz, CDCl$_3$): 16.02 (Me); 24.45 (*C*HCN); 45.60 (MeN); 52.71 ((CH$_2$)$_2$N); 54.78 ((CH$_2$)$_2$N); 60.80 (*C*H$_2$CH). GC/MS (120°, isothermal; t_R 11.37): 167.1 (16, M^+), 113.1 (67.2, [M – MeCHCN]$^+$), 70.0 (100, [M – CH$_2$CH(Me)CN]$^+$). Anal. calc. for $C_8H_{14}N_2O$ (167.25): C 64.63, H 10.24; found: C 64.01; H 9.24.

2-Methyl-3-(phenylamino)propanenitrile. Purified by FC (hexane/AcOEt/Et$_3$N 47.5:47.5:5.0). HPLC (*OD-H*; hexane/i-PrOH 98:2, 1.0 ml/min, 25°, detection at 254 nm): t_R 38.09, 39.53. ^{1}H-NMR (300 MHz, CD$_2$Cl$_2$): 1.37 (*d*, J = 8.0, *Me*CH); 2.90–3.05 (*m*, MeC*H*); 3.39 (*dd*, J = 6.0, 8.0, 2 CH$_2$); 4.11 (br. *s*, NH); 6.65 (*d*, J = 9, 2 *o*-H of Ph); 6.75 (*dd*, J = 8, 9, 1 *m*-H of Ph); 7.20 (*dd*, J = 8, 9, 2 *p*-H of Ph). ^{13}C{DEPT}-NMR (75.47 MHz, CDCl$_3$): 15.42 (Me); 25.99 (*C*HCN); 46.99 (CH$_2$NH); 113.04 (CH of Ph); 118.45 (CH of Ph), 129.53 (CH of Ph). GC/MS (120°, isothermal; t_R 18.95): 160.0 (12.5, M^+), 106.0 (100, [M – MeCHCN]$^+$). Anal. calc. for $C_{10}H_{12}N_2$ (160.22): C 74.97, H 7.55, N 17.48; found: C 75.19; H 7.50; N 17.31.

3-[(2,3-Dimethylphenyl)amino]-2-methylpropanenitrile. Purified by FC (hexane/AcOEt/Et$_3$N 47.5:47.5:5.0). HPLC (*OD-H*; hexane/i-PrOH 98:2, 1.0 ml/min, 25°, detection at 254 nm): t_R 50.64, 54.35. ^{1}H-NMR (300 MHz, CD$_2$Cl$_2$): 1.37 (*d*, J = 7.0, *Me*CH); 2.09 (*d*, J = 6.0, Me); 2.28 (*d*, J = 7.0, Me); 2.95–3.07 (*m*, MeC*H*); 3.36–3.48 (*m*, C*H$_2$*NH); 3.95 (br. *s*, NH); 6.40–6.70 (*m*, 2 arom. H); 6.89 (*dd*, J = 4, 7, 1 arom. H). ^{13}C{DEPT}-NMR (75 MHz, CDCl$_3$): 12.50 (Me); 15.45 (Me); 20.74 (Me); 25.88 (*C*HCN); 42.25 (CH$_2$NH); 107.87 (arom. CH); 120.41 (arom. CH); 126.23 (arom. CH). GC/MS (120°, isothermal; t_R 39.38): 188.1 (14.4, M^+), 134.0 (100, [M – MeCHCN]$^+$). Anal. calc. for $C_{12}H_{16}N_2$ (188.27): C 76.56, H 8.57, N 14.88; found: C 76.71, H 8.53, N 14.76. HPLC (*OD-H*; hexane/i-PrOH 98:2, 1.0 ml/min, 25°, detection at 254 nm): t_R 50.64, 54.35.

3-[(3,5-Dimethylphenyl)amino]-2-methylpropanenitrile. Purified by FC (hexane/AcOEt/Et$_3$N 47.5:47.5:5.0). HPLC (*OD-H*; hexane/i-PrOH 98:2, 1.0 ml/min, 25°, detection at 254 nm): t_R 20.79, 23.71. ^{1}H-NMR (300 MHz, CD$_2$Cl$_2$): 1.35 (*d*, J = 8.0, *Me*CH); 2.24 (*s*, 2 Me); 2.90–3.02 (*m*, MeC*H*); 3.21–3.44 (*m*, C*H$_2$*NH); 4.0 (br. *s*, NH); 6.28 (*s*, 2 arom. H); 6.43 (*s*, 1 arom. H). ^{13}C{DEPT}-NMR (62.90 MHz, CDCl$_3$): 15.18 (Me); 21.1 (2 Me); 25.9 (*C*HCN); 46.9 (CH$_2$NH); 110.8 (arom. CH); 120.1 (arom. CH). GC/MS (120°, isothermal; t_R 47.56): 188.1 (13.8, M^+), 134.0 (100, [M – MeCHCN]$^+$). Anal. calc. for $C_{12}H_{16}N_2$ (188.27): C 76.56, H 8.57, N 14.88; found: C 76.74, H 8.69, N 14.76.

3-(Phenylamino)butanenitrile. Purified by FC (hexane/AcOEt/Et$_3$N 47.5:47.5:5.0). GC (*α-dex*; 120°, isothermal): t_R 116.2 (*S*), 118.5 (*R*). HPLC (*OD-H*; hexane/i-PrOH 98:2, 1.0 ml/min, 25°, detection at 254 nm): t_R 49.8 (*S*), 52.6 (*R*). ^{1}H-NMR (250 MHz, C$_6$D$_6$): 0.91 (*d*, J = 6.0, *Me*CH); 1.77 (*ddd*, J = 5.0, 13.0, 30, CH$_2$); 3.19 (br. *s*, NH); 3.23 (br. *s*, MeC*H*); 6.31 (*d*, J = 8, 2 arom. H); 6.79 (*dd*, J = 7, 8, 1 arom. H); 7.20 (*dd*, J = 8, 2 arom. H). ^{13}C{DEPT}-NMR (75 MHz, CDCl$_3$): 20.42 (Me); 24.35 (*C*H$_2$CN); 45.43 (CHNH); 113.56 (arom. CH); 118.57 (arom. CH); 129.60 (arom. CH). GC/MS (120°, isothermal; t_R 17.24): 160.0 (15, M^+), 120.0 (100, [M – CH$_2$CN]$^+$). Anal. calc. for $C_{10}H_{12}N_2$ (160.22): C 74.97, H 7.55, N 17.48; found: C 75.22, H 7.68, N 17.21.

3-[(2,3-Dimethylphenyl)amino]butanenitrile. Purified by FC (hexane/*t*-BuOMe/Et$_3$N 47.5:47.5:5.0). GC (*α-dex*; 120°, isothermal): t_R 206.7, 207.1. ^{1}H-NMR (300 MHz, CD$_2$Cl$_2$): 0.98 (*d*, J = 6.0, *Me*CH); 1.66 (*dd*, J = 3.0, 16.0, 1 H of CH$_2$); 1.82 (*s*, Me); 1.94 (*dd*, J = 6.0, 17.0, 1 H of CH$_2$); 2.18 (*s*, Me); 3.24 (br. *s*, NH); 3.14–3.36 (*m*, MeC*H*); 6.43 (*d*, J = 9.0, 1 arom. H); 6.75 (*dd*, J = 8, 1 arom. H); 7.01–7.16 (*m*, 1 arom. H). ^{13}C{DEPT}-NMR (62.9 MHz, CDCl$_3$): 12.59 (Me); 20.65, 20.85 (2 Me); 24.38 (*C*H$_2$CN); 45.44 (CHNH); 108.81 (arom. CH); 120.43 (arom. CH); 126.34 (arom. CH). GC/MS (120°, isothermal; t_R 44.23): 188.1 (19.9, M^+), 148.0 (100, [M – CH$_2$CN]$^+$). Anal. calc. for $C_{12}H_{16}N_2$ (188.27): C 76.56; H 8.57; N 14.88; found: C 76.81; H 8.33, N 14.63.

3-[(3,5-Dimethylphenyl)amino]butanenitrile. Purified by FC (hexane/*t*-BuOMe/Et_3N 47.5 : 47.5 : 5.0). HPLC (*OD-H*; hexane/i-PrOH 98 : 2, 1.0 ml/min, 25°, detection at 254 nm): t_R 18.9, 22.5. ^{1}H-NMR (250 MHz, C_6D_6): 0.94 (*d*, $J = 7.0$, *Me*CH); 1.68 (*dd*, $J = 4.0$, 15.0, 1 H of CH_2); 1.89 (*dd*, $J = 5.0$, 14.0, 1 H of CH_2); 2.25 (*s*, 2 Me); 3.09 (br. *s*, NH); 3.11 – 3.31 (*m*, MeC*H*); 6.02 (*s*, 2 arom. H); 6.50 (*s*, arom. H). ^{13}C{DEPT}-NMR (62.9 MHz, $CDCl_3$): 20.45 (Me); 21.55 (2 Me); 24.38 (CH_2CN); 45.44 (CHN); 111.57 (arom. CH); 120.53 (arom. CH). GC/MS (120°, isothermal; t_R 42.26): 188.1 (17.8, M^+), 148.1 (100, $[M - CH_2CN]^+$). Anal. calc. for $C_{12}H_{16}N_2$ (188.27): C 76.56, H 8.57, N 14.88; found: C 76.63, H 8.41, N 14.69.

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