Title
Nickel-Catalyzed Amination of Aryl Carbamates and Sulfamates Using an Air-Stable Precatalyst

Author
Hie, Liana

Publication Date
2012

Peer reviewed|Thesis/dissertation

UNIVERSITY OF CALIFORNIA

Los Angeles

Nickel-Catalyzed Amination of Aryl Carbamates and Sulfamates Using an Air-Stable Precatalyst

A thesis submitted in partial satisfaction

of the requirements for the degree Master of Science

in Chemistry

by

Liana Hie

2012

ABSTRACT OF THE THESIS

Nickel-Catalyzed Amination of Aryl Carbamates and Sulfamates

Using an Air-Stable Precatalyst

by

Liana Hie

Master of Science in Chemistry

University of California, Los Angeles, 2012

Professor Neil K. Garg, Chair

This study describes a facile nickel-catalyzed method to achieve the synthetically useful amination of aryl sulfamates and carbamates. This approach uses an air-stable Ni(II) precatalyst, which, when employed with a mild reducing agent, efficiently delivers aminated products in good yields. The scope of the method is broad with respect to both coupling partners. For instance, substrates with electron-donating and electron-withdrawing groups are tolerated, as well as those that possess ortho and para substituents. Furthermore, heteroaryl substrates may also be employed as coupling partners.

The thesis of Liana Hie is approved.

Kendall N. Houk

Yi Tang

Neil K. Garg, Committee Chair

University of California, Los Angeles

2012

Table of Contents

Acknowledgements

It is my pleasure to thank the many people who made this thesis possible.

I would first like to thank Professor Neil K. Garg for his guidance, encouragement and sound advice. Professor Garg's direction was vital to the completion of this thesis. I would also like to thank Professor Houk and Tang for serving on my thesis committee.

My thanks also go to Dr. Tehetena Mesganaw, who, in spite of having practically no spare time, still managed to provide me ample help and advice. I am also exceedingly grateful to Stephen D. Ramgren who has provided invaluable discussion and displayed infinite patience. Noah F. Fine Nathel was extremely helpful in providing constructive feedback for the thesis. Without their assistance and support, this thesis would not have been so facile.

I am thankful to the entire Garg laboratory for enriching my graduate school experience both academically and socially.

Finally, I would like to thank my family and friends for their unconditional love and support.

Introduction

Cross-coupling chemistry has been an area of particular interest in the synthetic community. In 2010, the Nobel Prize in Chemistry was awarded to Heck, Suzuki, and Negishi for their work in palladium-catalyzed cross-coupling chemistry. The methods, which they developed have significantly improved the ease of carbon–carbon (C–C) bond formation. Cross-coupling reactions are not only powerful methods to form C–C bonds, but may also be used to forge C–heteroatom (C–X) bonds. In particular, carbon–nitrogen (C–N) bonds are important because of their abundance in pharmaceutically active compounds. Specifically, aniline derivatives are common in a variety of drugs, as shown in Figure 1.

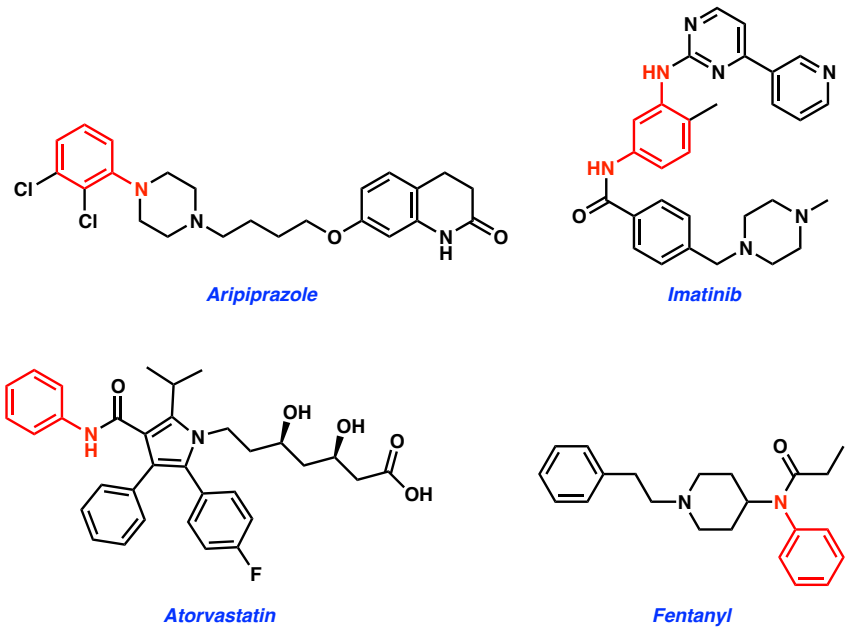


Figure 1. Best-selling drugs that contain the aniline motif.

Before catalytic cross-coupling methods were common, chemists developed a variety of seminal C–N bond-forming reactions. Early work was based on Ullman's *ipso*-substitution of aryl halides, which required a stoichiometric amount of copper and harsh conditions (refer to

Figure 2).[1] Later, aryne chemistry fostered the expansion of the amination of aryl halide. However, this method suffered from functional group incompatibility, poor regioselectivity, and required harsh reaction conditions.[2] Bunnett introduced an aryl amination, which proceeded through an $S_{RN}1$ mechanism.[3] Although this method was the mildest at the time, radical mechanisms were poorly understood and introduced substantial uncertainty.[3]

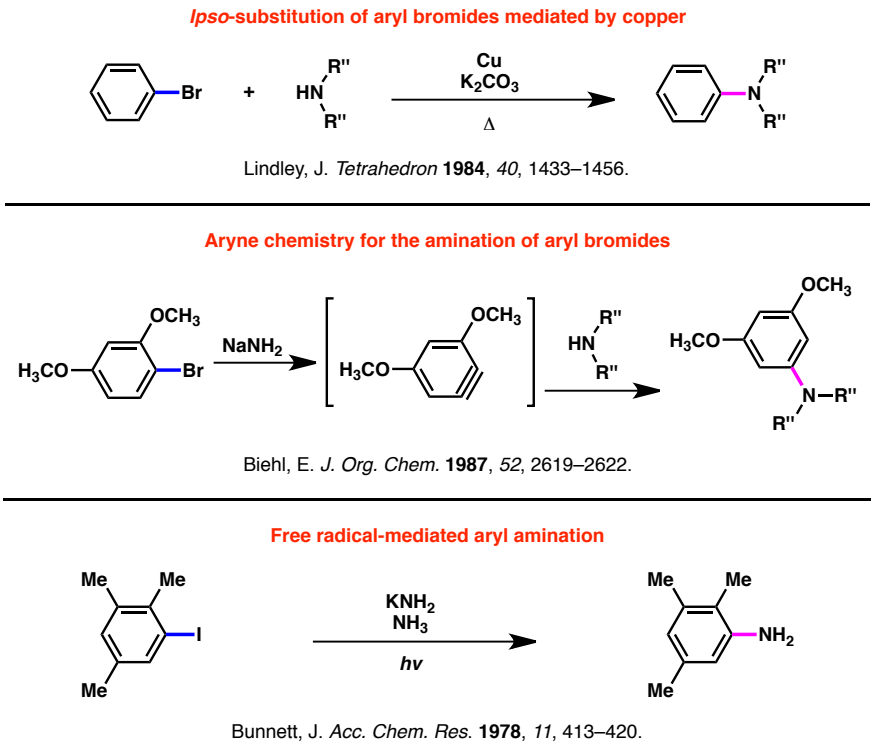
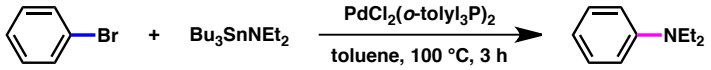


Figure 2. Early methods to achieve aryl amination.

Transition metal-catalyzed cross-coupling reactions are also commonly used methods to form C–N bonds. Migita discovered a major breakthrough in aryl amination with the Pd-catalyzed amination of aryl bromides with *N*,*N*-diethylamino-tributyltin, as shown in Figure 3.[4] This method was the first example of a Pd-catalyzed aryl–amine coupling. Since then, many others have demonstrated the utility of cross-coupling reactions to form C–N bonds.[5,6] Buchwald and Hartwig have independently developed Pd-catalyzed aminations that have become widely

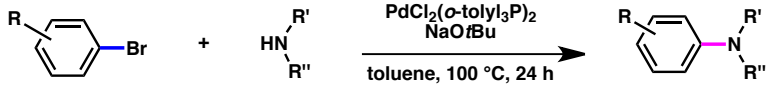
adopted by the synthetic community.[5,6] Copper-mediated aminations of aryl halides and triflates have also been discovered.[7] Pseudohalides, such as mesylates[8] and tosylates[9] undergo amination with primary alkylamines, arylamines, and *N*–imines. Moreover, Buchwald has also developed Ni(0)-catalyzed aminations of aryl halides.[10]

First example of Pd-catalyzed aryl–amine coupling



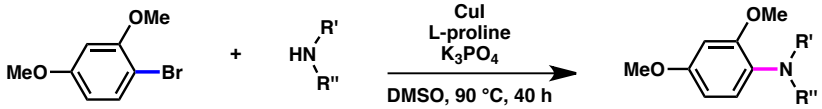
Migita, T. *Chem. Lett.* **1983**, *12*, 927–928.

Amination of aryl bromide under tin-free condition



Buchwald, S. L. *Angew. Chem. Int. Ed.* **2008**, *47*, 6338–6361.

Cu-mediated amination of aryl halide

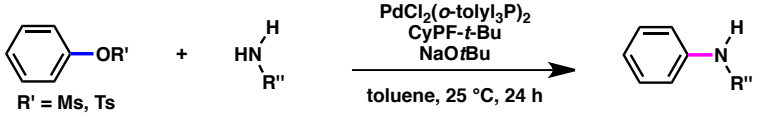


Ma, D. *J. Org. Chem.* **2005**, *70*, 5164–5173.

Cross coupling of acyclic amine with aryl triflate

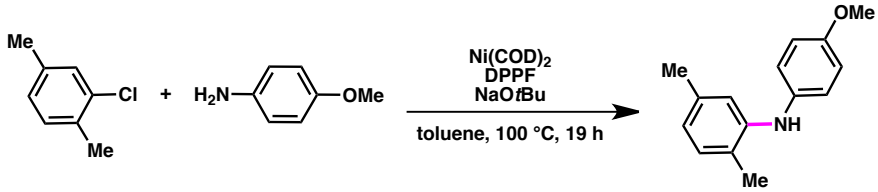
Buchwald, S. L. *J. Org. Chem.* **1997,** *62,* 1264–1267.

Formation of diarylamine using aryl mesylate/tosylate



Hartwig, J. F. *J. Am. Chem. Soc.* **2008**, *130*, 13848–13849.

Nickel-catalyzed amination of aryl halides

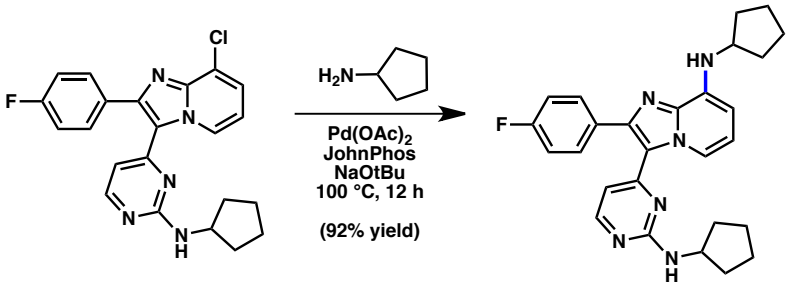


Buchwald, S. L. *J. Am. Chem. Soc.* **1997**, *119*, 6054–6058.

Figure 3. Developments in Pd-, Cu-, and Ni-catalyzed C–N bond formation.

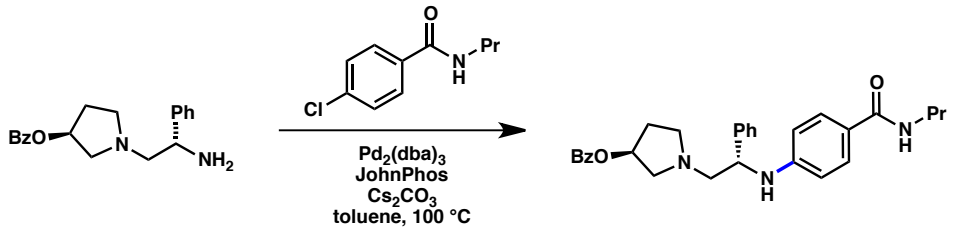
Due to the success of these metal catalyzed C–N bond formations, they have become prevalent in the manufacturing of drugs that contain C–N bond moieties. For example, chemists from GlaxoSmithKline utilized a palladium catalyst for the coupling of cyclopentylamine with an 8-chloroimidazopyridine in the synthesis of imidazo[1,2-*a*]pyridines (Figure 4).[11] This compound has demonstrated potent activity against the herpes virus.[11] Scientists at Pfizer used cross-coupling chemistry to access k-opiod receptor agonist CJ-15,161 drug candidate, which has applications as a potential non-addictive analgesic.[12] The synthesis of estrogen receptor ligands at Merck was also accomplished via the coupling of an aryl triflate with Cbz-protected piperazine without epimerizing the benzylic chiral centers.[13]

GlaxoSmithKline synthesis of an antiherpes agent



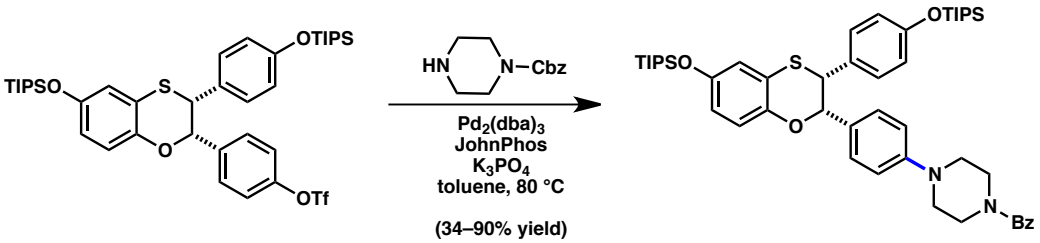
Gudmundsson, K. S.; Johns, B. A. *Org. Lett.* **2003**, *5*, 1369–1372.

Pfizer synthesis of a κ-opiod receptor agonist



Ghosh, A; Sieser, J. E.; Caron, S.; Watson, T. J. N. C*hem. Commun.* **2002**, 1*5,* 1644–1645.

Merck synthesis of estrogen receptor ligands



Tan, Q.; et al. *Bioorg. Med. Chem. Lett.* **2004**, *14*, 3747–3751.

Figure 4. Applications in pharmaceutical synthesis.

Whereas methodologies for cross-coupling aryl halides and pseudohalides have been vastly explored, analogous couplings of less conventional phenol-based derivatives have recently gained popularity.[14] Using nickel, researchers have used esters, ethers, and sulfonates in amination reactions. Chatani has demonstrated that aryl pivalates and aryl methyl ethers are viable substrates (Figure 5).[15,16] Moreover, Yang has developed the Ni-catalyzed amination of

aryl tosylates.[17]

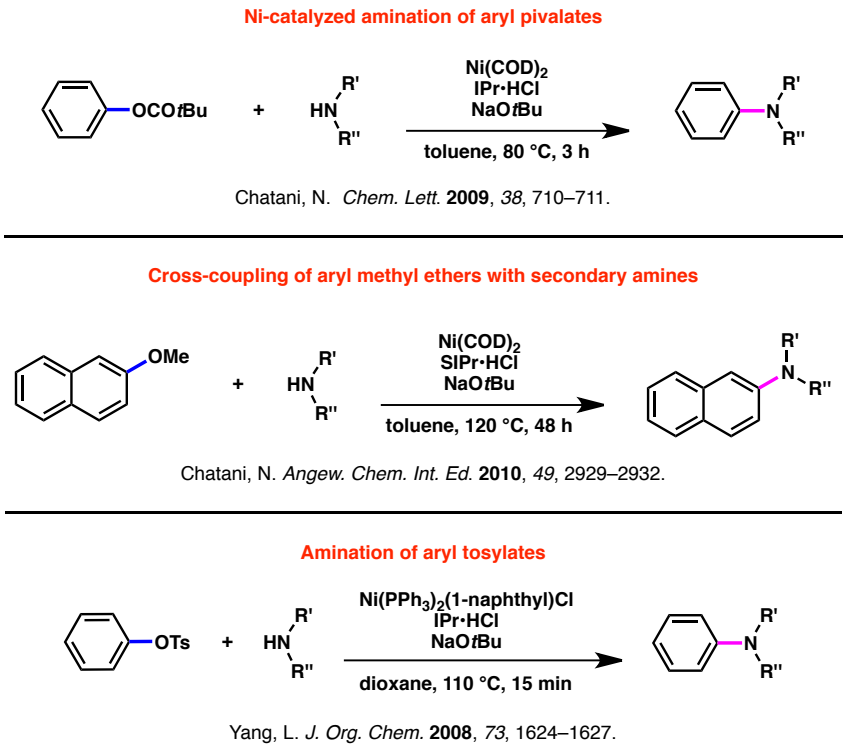


Figure 5. Phenol-based derivatives as alternatives to aryl halides.

Aryl sulfamates and carbamates are also attractive substrates for amination reactions. Aryl sulfamates and carbamates display pronounced stability and, as shown in Figure 6, have the capacity to direct the regioselective installation of functional groups onto an aromatic ring through either directed ortho-metallation[18,19] or electrophilic aromatic substitution processes to access substituted aromatic compounds.[18d] Moreover, they are inexpensive, easy to prepare, and inert toward Pd(0) catalyzed cross-couplings. Although C–C bond forming reactions using aryl sulfamates and carbamates have been most widely studied,[20,21] several reports of carbon–nitrogen (C–N) bond formation are now available.[22]

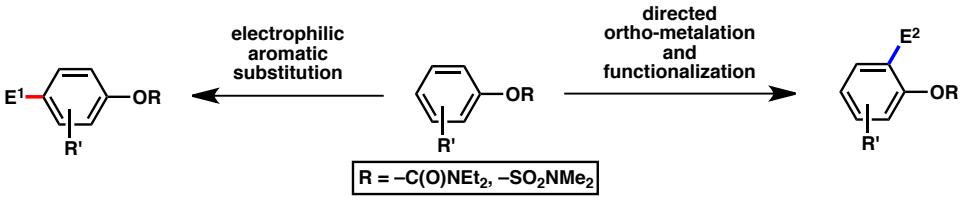


Figure 6. Directing ability of aryl sulfamates and carbamates.

Ni(0)-catalyzed Amination of Aryl Carbamates and Sulfamates

Inspired by the successful amination of other phenol-based electrophiles (i.e. aryl pivalates, aryl tosylates, and aryl methyl ethers), our lab began to develop the Ni(0)-catalyzed amination of aryl sulfamates.[19a] After conducting an extensive survey of reaction parameters, our laboratory found that aminations proceed using NHC ligands, metal *tert*-butoxide bases, and dioxane as solvent (Figure 7). *N*-heterocyclic carbene (NHC) ligands have been shown to be effective for nickel catalyzed aminations of aryl pivalates and aryl methyl ethers.[15,16] For sulfamates and carbamates, SIPr•HCl was found to be most generally useful. Sodium *tert*-butoxide was the optimal base and dioxane proved to be a suitable solvent. The coordinating and polar solvent dioxane was suitable for the Ni(0)-catalyzed amination of aryl sulfamates. The sulfamate amination conditions were also found to be suitable for aryl carbamates.[19b]

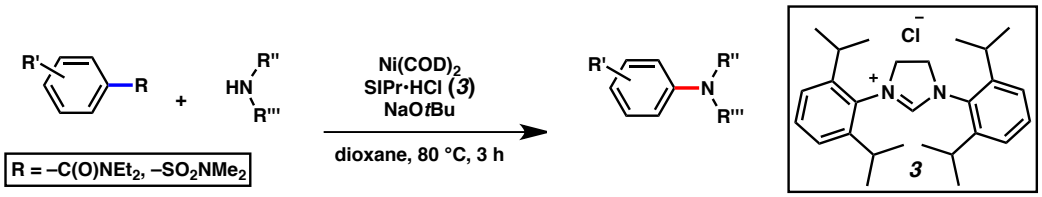


Figure 7. Ni(0)-catalyzed amination of aryl carbamates and sulfamates.

Development of Ni(II) Amination Reaction Conditions

Aminations of aryl sulfamates and carbamates are facile and proceed in synthetically useful conversions. However, the air-sensitivity of the precatalyst (i.e., $Ni(COD)_2$)[23] limits the practical use of these C–N bond forming processes and we sought to develop a modified version with an air stable precatalyst. Ni (II) complexes are known to be more stable to air and water compared to the Ni(0) catalysts and do not require careful handling. To develop amination methodology with a Ni(II) precatalyst, the metal would have to be reduced to an active Ni(0) species in situ.[20a] It should be noted that the reduction of Ni(II) does not proceed as readily as the corresponding reduction of Pd(II).

- **Catalyst Selection**

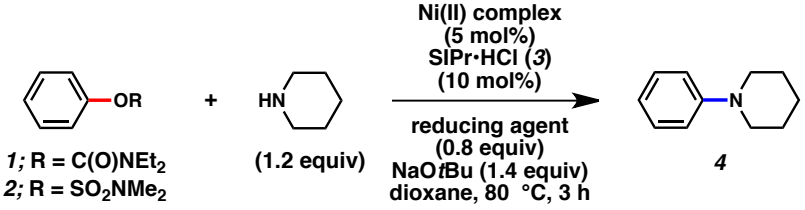
We searched for a Ni(II)-precatalyst that is inexpensive, stable in air, and readily undergoes reduction to Ni(0). We found that $NiCl_2$, $NiCl_2$(DME), and $Ni(acac)_2$ satisfy our criteria. It should be noted that these Ni sources are less expensive than $Ni(COD)_2$. $NiCl_2$(DME) was found to be optimal, as it possesses superior solubility properties in dioxane. However, $Ni(acac)_2$ was also tested.

- **Reducing Agent Screening**

As mentioned above, a key challenge in developing the desired amination reaction using a Ni(II) precatalyst is the reduction of Ni(II) to Ni(0). Although Pd(II) precatalysts readily undergo in situ reduction with amines or phosphines in Pd-catalyzed Buchwald–Hartwig couplings[5,6], the corresponding reduction of Ni(II) is less facile. Aminations that use Ni(II) precatalysts are limited to aryl halides, and typically use harsh reducing agents, such as Zn or hydride sources.[24]

Surveying phenylcarbamate **1** and phenylsulfamate **2** as substrates with a selection of Ni(II) complexes in the presence of the NHC ligand SIPr•HCl (**3**), a variety of reducing agents were screened (Table 1). We started by utilizing Zn, a traditional reducing agent for the reduction of Ni(II).[24g, h] Zn dust proved ineffective (entries 1 and 2) for our system. Another class of traditional reducing agents is hydrides.[24c–k] Our experimental results showed that triethylsilane gave poor results when $Ni(acac)_2$ was applied as the Ni(II) source (entry 3). When the catalyst was switched to $NiCl_2(DME)$, triethylsilane gave modest results (entry 4). This is possibly due to the fact that the Ni (II) sources undergo different modes of reduction. Another hydride source, 1,1,3,3-tetraethyldisiloxane, gave poor results, with $NiCl_2(DME)$ and $Ni(acac)_2$ (entries 5 and 6). Phenylsilane also did not furnish any aminated product (entries 7 and 8). For entries 1–3 and 5–8, the starting material was fully recovered, indicating no reactivity.

Table 1. Optimization using traditional reducing agents.



1; R = $C(O)NEt_2$
2; R = SO_2NMe_2

(1.2 equiv)

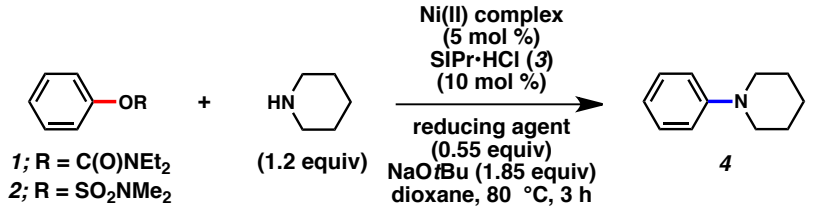
4

entry	substrate	Ni source	reducing agent	yield[a]
1	*1*	$Ni(acac)_2$	Zn dust	0%
2	*1*	$NiCl_2(DME)$	Zn dust	0%
3	*1*	$Ni(acac)_2$	$H–SiEt_3$	0%
4	*1*	$NiCl_2(DME)$	$H–SiEt_3$	51%
5	*1*	$NiCl_2(DME)$	$(H–SiEt_2)_2O$	0%
6	*1*	$Ni(acac)_2$	$(H–SiEt_2)_2O$	0%
7	*1*	$NiCl_2(DME)$	$H–SiH_2Ph$	0%
8	*1*	$Ni(acac)_2$	$H–SiH_2Ph$	0%

[a]Yield determined by ^1H NMR analysis of the crude reaction mixtures using hexamethylbenzene as the internal standard.

Inspired by Suzuki–Miyaura coupling methodologies of sulfamates and carbamates, for which boronic acids serve to reduce Ni(II) to Ni(0) in situ[20a,b,c,e,f] we tested the use of Ph–$B(OH)_2$ in the amination reaction. Gratifyingly, good to excellent yields could be obtained (Table 2, entries 1 and 2). Although these results were promising, we found that the corresponding coupling of sulfamate **2** gave inconsistent results (entry 3). We suspected that the boronic acid consisted of a mixture of the monomer and the corresponding trimer (see Figure 8).

Table 2. Optimization of amination using Ni(II) precatalyst[a]



entry	substrate	Ni source	reducing agent	yield[a]
1	*1*	$Ni(acac)_2$	Ph–$B(OH)_2$	57%
2	*1*	$NiCl_2(DME)$	Ph–$B(OH)_2$	98%
3	*2*	$NiCl_2(DME)$	Ph–$B(OH)_2$	variable

[a] Yield determined by ^1H NMR analysis of the crude reaction mixtures using hexamethylbenzene as the internal standard.

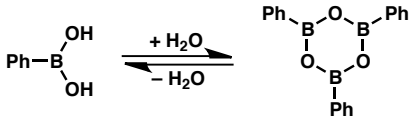


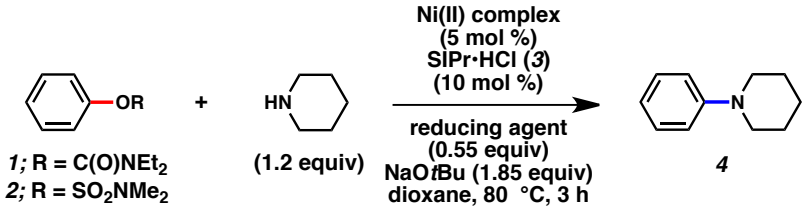
Figure 8. Monomer and trimer of phenyl boronic acid.[25]

Aiming to solve the inconsistency from using the boronic acid, we sought to prepare monomeric boronic acid by synthesizing it freshly. The boronic acid was synthesized by

refluxing a mixture of 2,4,6-triphenylboroxine and Ph–$B(OH)_2$ in water, followed by purification via recrystallization in water. ^{1}H-NMR analysis of the prepared boronic acid showed that it contained 90% monomer and 10% trimer. Applying the self-prepared boronic acid in the Ni(II) amination, the desired product was not observed. We postulated that residual water was present in the boronic acid, which likely impeded the reaction. An anhydrous agent was therefore sought.

Anhydrous reducing agents proved effective as shown in Table 3. KF_3B–Ph showed a promising result (entry 1). When 2,4,6-triphenylboroxine was used as the reducing agent, 58% of aminated product was obtained (entry 2). It was observed that boronic esters could be used in place of Ph–$B(OH)_2$ or the boroxine to give more consistent results and higher yields. By using Ph–B(pin) as the reducing agent with $NiCl_2$(DME) as the precatalyst, a 94% yield of the desired aminated product **4** was obtained (entry 3). These conditions were also found to be useful for the coupling of carbamate **1** (entry 4).

Table 3. Anhydrous reducing agent screening



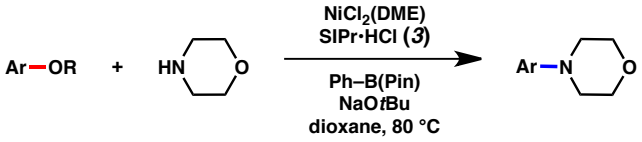
entry	substrate	Ni source	reducing agent	yield[a]
1	*2*	$NiCl_2$(DME)	KF_3BPh	35%
2	*2*	$NiCl_2$(DME)	$(Ph–BO)_3$	58%
3	*2*	$NiCl_2$(DME)	Ph–B(pin)	94%
4	*1*	$NiCl_2$(DME)	Ph–B(pin)	92%

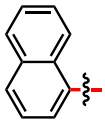
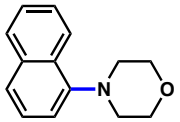
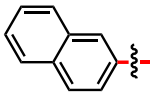
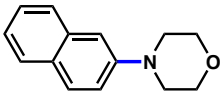
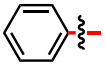
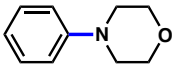
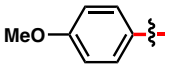
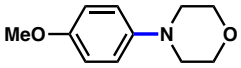
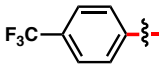
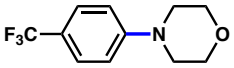
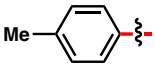
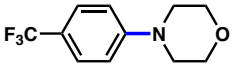
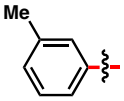
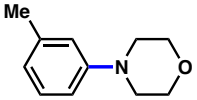
[a]Yield determined by ^{1}H NMR analysis of the crude reaction mixtures using hexamethylbenzene as the internal standard.

Substrate Scope

Having identified optimal reaction conditions,[26] we examined the scope of aryl sulfamates and carbamates using morpholine as the nucleophilic coupling partner (Table 4). Fused arenes were tolerated, as demonstrated by the smooth formation of **5** and **6**. The ability to form **7–11** in good yields exemplified the methodology's tolerance to non-fused arenes with a variety of substituents. This includes *p*-methoxy, -trifluoromethyl, -methyl and *m*-methyl substituents.

Table 4. Amination of aryl sulfamates and carbamates using morpholine

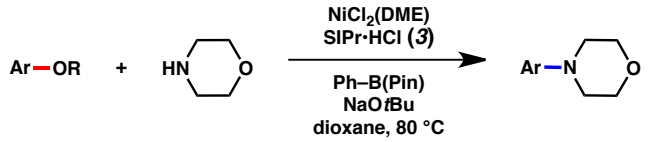


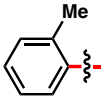
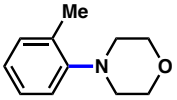
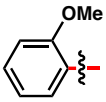
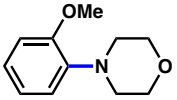
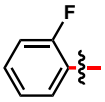
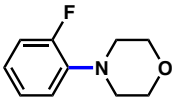
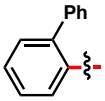
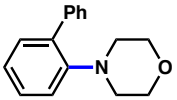
entry	Ar	OR	product	yield
1a		$-OSO_2NMe_2$		89%
1b		$-OCONEt_2$		82%
			5	
2a		$-OSO_2NMe_2$		94%
2b		$-OCONEt_2$		87%
			6	
3a		$-OSO_2NMe_2$		84%
3b		$-OCONEt_2$		85%
			7	
4a		$-OSO_2NMe_2$		67%
4b		$-OCONEt_2$		66%
			8	
5a		$-OSO_2NMe_2$		84%
5b		$-OCONEt_2$		70%
			9	
6a		$-OSO_2NMe_2$		73%
6b		$-OCONEt_2$		72%
			10	
7a		$-OSO_2NMe_2$		79%
7b		$-OCONEt_2$		82%
			11	

Reaction conditions: $NiCl_2$(DME) (5–20 mol %), **3** (10–40 mol %), sulfamate/carbamate substrate (1 equiv), morpholine (1.2–2.4 equiv), Ph–B(pin) (0.15–1.4 equiv), NaO*t*Bu (1.4–3.75 equiv), 3 h. Unless otherwise noted, yields reflect those of isolated product.

The Ni(II) amination conditions tolerate electrophilic substrates that are sterically hindered. *Ortho*-substituted substrates, which are readily accessible by ortho-functionalization of phenyl sulfamates or carbamates, underwent the desired coupling (Table 5). Substrates bearing electron-donating substituents, such as methyl and methoxy, could be aminated in synthetically good yields, as shown by entries 1 and 2, respectively. Electron-poor substituents, such as fluorine, were also tolerated (entry 3). It is worthy to mention that fluorinated compounds are of growing importance, especially in medicine. Studies have shown that fluorine substitution has profound effects on the properties of organic compounds, affecting their absorption, distribution and metabolism.[27] The relatively electron-neutral phenyl substituent imposes a steric blockage, which is seemingly overcome under our reaction conditions (entry 4).

Table 5. Amination of ortho-substituted aryl sulfamates and carbamates using morpholine

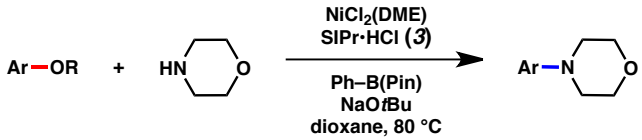


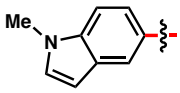
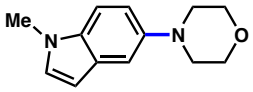
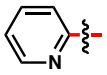
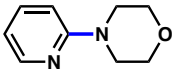
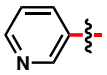
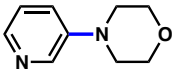
entry	Ar	OR	product	yield[a]
1a		$-OSO_2NMe_2$		67%
1b		$-OCONEt_2$		71%
			12	
2a		$-OSO_2NMe_2$		63%
2b		$-OCONEt_2$		43%
			13	
3a		$-OSO_2NMe_2$		81%
3b		$-OCONEt_2$		50%
			14	
4a		$-OSO_2NMe_2$		53%
4b		$-OCONEt_2$		50%
			15	

Reaction conditions: $NiCl_2$(DME) (5–20 mol %), **3** (10–40 mol %), sulfamate/carbamate substrate (1 equiv), morpholine (1.2–2.4 equiv), Ph–B(pin) (0.15–1.4 equiv), NaO*t*Bu (1.4–3.75 equiv), 3 h. Unless otherwise noted, yields reflect those of isolated product.

Heterocycles were also viable substrates, as shown by Table 6. Indole-containing substrates could be coupled with morpholine to give the aminated products (entry 1). The use of pyridine derivatives gave the aminated products in excellent yields, as seen in entries 2 and 3.

Table 6. Amination of heterocyclic carbamates and sulfamates with morpholine



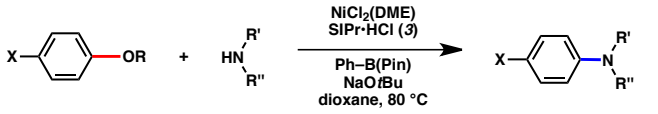
entry	Ar	OR	product	yield[a]
1a		–OSO_2NMe_2		63%
1b		–$OCONEt_2$		40%[b]
			16	
2a		–OSO_2NMe_2		90%
2b		–$OCONEt_2$		80%
			17	
3a		–OSO_2NMe_2		81%
3b		–$OCONEt_2$		82%
			18	

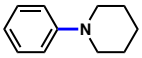
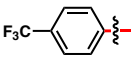
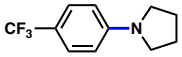
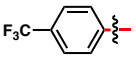
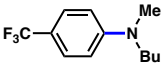
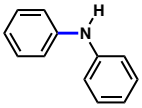
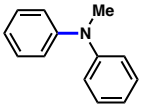
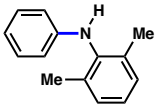
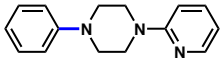
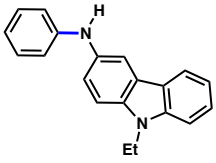
[a] Reaction conditions: $NiCl_2$(DME) (5 mol %), **3** (10 mol %), substrate (1 equiv), morpholine (1.8 equiv), Ph–B(pin) (0.35 equiv), NaO*t*Bu (2.25 equiv), hexamethylbenzene (0.1 equiv), 3 h. [b] Yield determined by ^{1}H NMR analysis with hexamethylbenzene as the internal standard.

Variation of Amine Coupling Partners

The scope with respect to the amine coupling partner is provided in Table 7. In addition to morpholine, the cyclic amines such as piperidine and pyrrolidine, underwent the desired coupling to furnish **4** and **19**, respectively. Acyclic secondary amines and anilines could also be employed (entries 3 and 4). Bulkier secondary anilines were found to be suitable substrates (entries 5 and 6). Amines with appended heterocycles, such as pyridylpiperazine and carbazole, were also tolerated, thus giving rise to **24**–**25** in excellent yields (entries 7 and 8).

Table 7. Amination of various amines and anilines



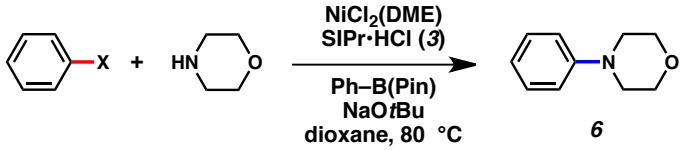
entry	Ar	OR	product	yield
1a		–OSO_2NMe_2	 **4**	91%
1b		–$OCONEt_2$		91%
2a		–OSO_2NMe_2	 **19**	90%
2b		–$OCONEt_2$		86%
3a		–OSO_2NMe_2	 **20**	82%
3b		–$OCONEt_2$		73%
4a		–OSO_2NMe_2	 **21**	63%
4b		–$OCONEt_2$		76%
5a		–OSO_2NMe_2	 **22**	72%
5b		–$OCONEt_2$		75%
6a		–OSO_2NMe_2	 **23**	87%
6b		–$OCONEt_2$		87%
7a		–OSO_2NMe_2	 **24**	96%
7b		–$OCONEt_2$		90%
8a		–OSO_2NMe_2	 **25**	98%
8b		–$OCONEt_2$		81%

Reaction conditions: $NiCl_2$(DME) (5–20 mol %), **3** (10–40 mol %), sulfamate/carbamate substrate (1 equiv), amine (1.2–2.4 equiv), Ph–B(pin) (0.15–1.05 equiv), NaO*t*Bu (1.4–3.75 equiv), 3 h. Unless otherwise noted, yields reflect those of isolated product.

Amination Using Halides and Pseudohalide Electrophiles

Given that most Ni-catalyzed amination reactions employ Ni(0) precatalysts, we desired to test the generality of our reaction conditions on other electrophilic substrate classes. Morpholine was used for our experiments. Amination of the phenyl carbonate is not facile, as shown by the low amination yield of *tert*-butyl phenyl carbonate (Table 8, entry 1). The use of phenyl pivalates and tosylate was more promising (entry 2 and 3). However, phenyl triflate was not a suitable coupling partner, possibly because of its instability to reaction conditions (entry 4). As for the halide-based electrophiles, we observed low yields when using iodobenzene or bromobenzene as substrates (entries 5 and 6). On the other hand, chlorobenzene coupled smoothly under the reaction conditions to furnish the desired aminated product in 98% yield (entry 7).

Table 8. Survey of Halide and Pseudohalide Substrates[a]



entry	X	yield[b]
1	OCO_2tBu	15%
2	OPiv	44%
3	OTs	63%
4	OTf	4%
5	I	25%
6	Br	33%
7	Cl	98%

[a] Conditions: $NiCl_2$(DME) (5 mol %), **3** (10 mol %), substrate (1 equiv), morpholine (1.8 equiv), Ph–B(pin) (0.35 equiv), NaO*t*Bu (2.25 equiv), hexamethylbenzene (0.1 equiv), 3 h. [b] Yield determined by ^{1}H NMR analysis with hexamethylbenzene as the internal standard.

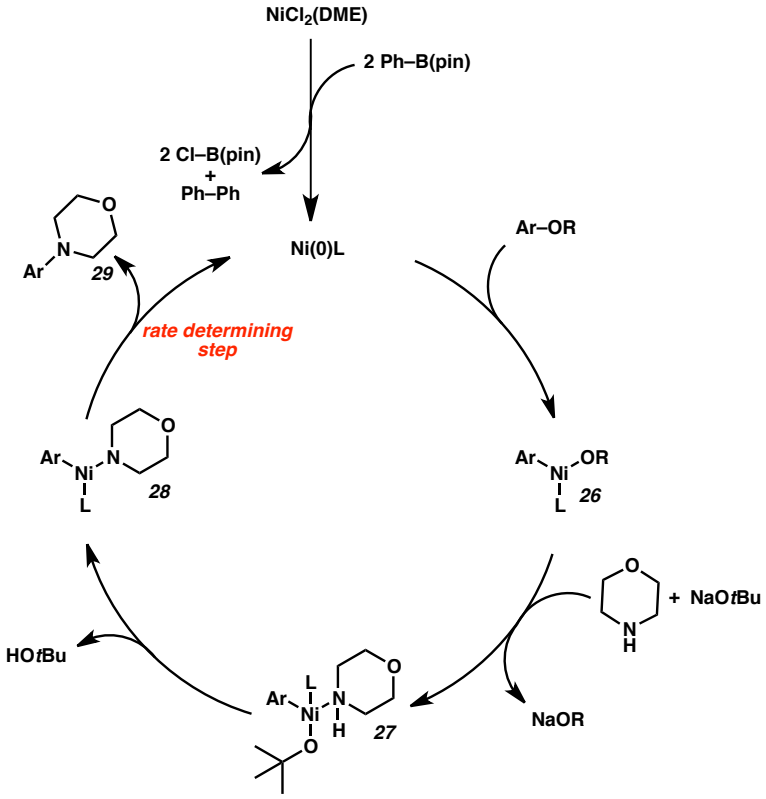
When comparing entries 5, 6, and 7, an interesting trend occurs. Chlorobenzene provided the highest yield while iodobenzene garnered the lowest yield of aminated product. According to the ease of oxidative addition of Ni into aryl halides[28], opposite trend may have been expected. We hypothesized that after oxidative addition occurs, in the case of the iodide and bromide substrates, the catalyst prematurely decomposes. This notion is supported by the observation that unreactive starting material is recovered in the low yielding reactions (entries 5 and 6). In the future work, we hope to circumvent this problem by exploring the use of halide additives.

Mechanism of the Ni(II)-catalyzed Amination of Aryl Carbamates and Sulfamates

Similar to the Ni(0)-catalyzed amination, three fundamental steps are believed to occur in the Ni(II) amination: oxidative addition, nickel–amine binding, and reductive elimination.[22b] However, unlike the Ni(0) catalytic cycle, another essential step is required prior to oxidative addition. The Ni(II) precatalyst has to be reduced to the active catalyst, Ni(0)L. This step likely occurs via two transmetalations of the Ni(II) precatalyst with Ph–Bpin, followed by reductive elimination to form biphenyl. It should be note that the formation of biphenyl is observed in our amination reactions.

Based on computational studies by Hong, Liu and coworkers[22b], the catalytic cycle provided in Scheme 1 is proposed. Following the essential reduction to Ni(0), the electron-rich NHC ligand facilitates the oxidative addition. The oxidative addition leads to a (phenyl)nickel(II) carbamate intermediate **26**. This complex undergoes ligand exchange with morpholine and sodium *tert*-butoxide to liberate carbamate anion and form the intermediate **27**. The internal deprotonation of the amine by the sodium *tert*-butoxide and subsequent dissociation of *tert*-

butanol gives the (phenyl)(amino)nickel(II) complex **28**. Reductive elimination then yields the product **29** and regenerates Ni(0). Preceding studies on the Ni(0) amination of aryl carbamates show that the reductive elimination from **28** to **29** is likely the rate-limiting step in the catalytic cycle.[22b]



Scheme 1. Proposed mechanism for the Ni(II)-catalyzed amination of aryl carbamates and sulfamates.

Conclusions

In summary, we have reported an improved Ni-catalyzed method to achieve the amination of synthetically useful aryl carbamates and sulfamates. Our user-friendy approach employs $NiCl_2$(DME) as a bench-stable Ni(II) precatalyst and Ph–B(pin) as a mild reducing agent. Given the attractive features of aryl sulfamates and carbamates, coupled with the transformation's broad scope, this practical Ni(II)-based methodology is expected to find value in numerous applications that require C–N bond construction.

Supporting Information

Materials and Methods

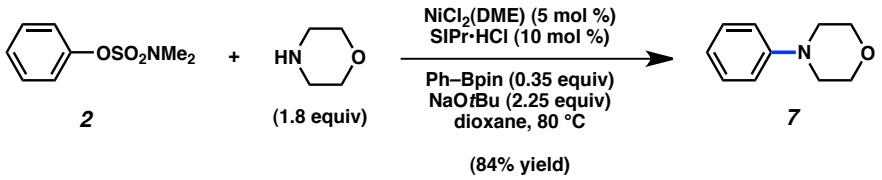
Unless stated otherwise, reactions were conducted in flame-dried glassware under an atmosphere of nitrogen using anhydrous solvents (either freshly distilled or passed through activated alumina columns). Unless otherwise stated, commercially obtained reagents were used as received. Amines were purified by filtration over basic Brockman Grade I 58 Å Al_2O_3 (Activity 1), followed by distillation over calcium hydride, prior to use. $NiCl_2$(DME) was obtained from Strem Chemicals. NaO*t*Bu was obtained from Alfa Aesar. The amines, SIPr•HCl, and Ph–B(pin) were obtained from Sigma Aldrich and Alfa Aesar. Dioxane was purified by distillation over sodium benzophenone ketyl. Reaction temperatures were controlled using an IKAmag temperature modulator, and unless stated otherwise, reactions were performed at room temperature (rt, approximately 23 °C). Thin-layer chromatography (TLC) was conducted with EMD gel 60 F254 pre-coated plates (0.25 mm) and visualized using a combination of UV, anisaldehyde, ceric ammonium molybdate, iodine, vanillin, and potassium permanganate staining. Silicycle Siliaflash P60 (particle size 0.040–0.063 mm) was used for flash column chromatography. ^{1}H NMR spectra were recorded on Bruker spectrometers (at 300, 400, 500, 600 MHz) and are reported relative to deuterated solvent signals. Data for ^{1}H NMR spectra are reported as follows: chemical shift (d ppm), multiplicity, coupling constant (Hz) and integration.

Experimental Procedures

A. Synthesis of Aryl Carbamate and Sulfamate Substrates

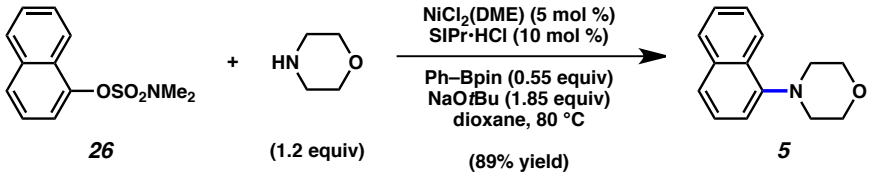
Note: Supporting information for the synthesis of the aryl sulfamates and carbamates shown in Tables 4–7 have previously been reported.[29]

B. Aminations of Aryl Carbamates and Sulfamates

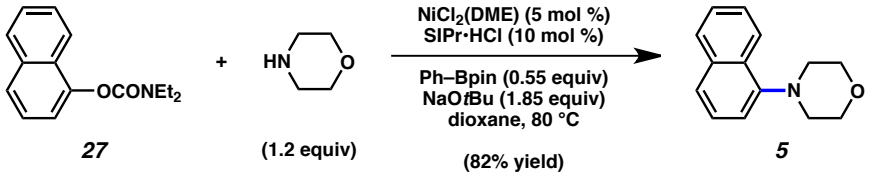


Representative Procedure (coupling of phenylsulfamate 2 is used as an example). 7 (Figure 2). A 4 mL reaction vial was charged with a magnetic stir bar, flame-dried under reduced pressure, and allowed to cool under N_2. The vial was then charged with Ph–B(pin) (35.71 mg, 0.175 mmol, 35 mol%), anhydrous powdered NaO*t*Bu (108.1 mg, 1.125 mmol, 2.25 equiv), $NiCl_2$(DME) (5.5 mg, 0.025 mmol, 5 mol%), and SIPr•HCl (21.3 mg, 0.05 mmol, 10 mol%). Subsequently, dioxane (2.5 ml), phenylsulfamate **2** (100.6 mg, 0.50 mmol, 1.0 equiv), and morpholine (87.1 mL, 0.9 mmol, 1.8 equiv) were added, sequentially. The resulting heterogenous mixture was stirred for 1 min while purging with N_2, and the vial was sealed with a Teflon-lined screw cap. The mixture was stirred at 23 °C for 1 h, and then at 80 °C for 3 h in a preheated aluminum heating block. After cooling the reaction vessel to 23 °C and concentrating the mixture under reduced pressure, the crude residue was purified by flash chromatography (9:1 Hexanes:EtOAc) to yield aminated product **7** (68.3 mg, 84% yield) as a white solid. R_f 0.28 (9:1 Hexanes:EtOAc). Spectral data match those previously reported.[30]

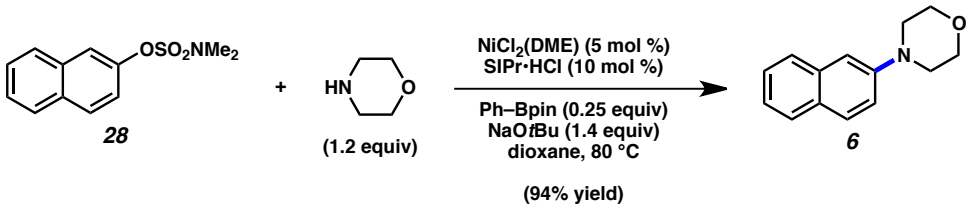
Any modifications of the conditions shown in this representative procedure are specified in the following schemes, which depict all of the results shown in Tables 4–7.



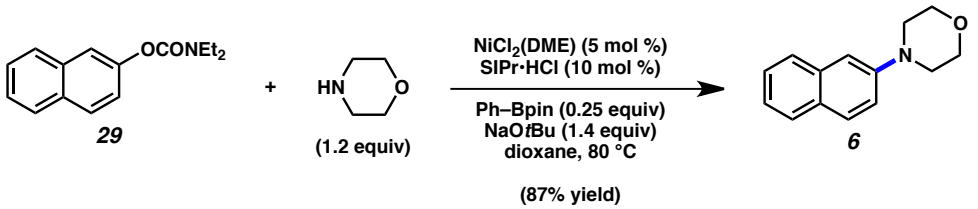
5 **(Figure 2)**. Purification by flash chromatography (9:1 Hexanes:EtOAc) yielded aminated product **5** (89% yield) as a white solid. R_f 0.41 (9:1 Hexanes:EtOAc). Spectral data match those previously reported.[17]



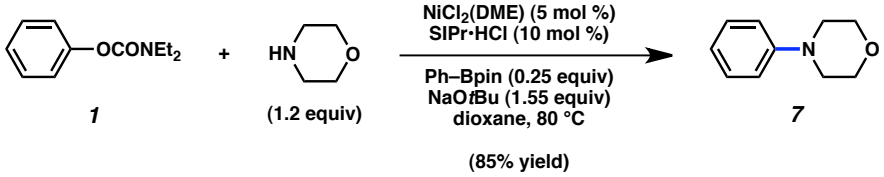
5 **(Figure 2)**. Purification by flash chromatography (9:1 Hexanes:EtOAc) afforded aminated product **5** (82% yield) as a white solid. R_f 0.41 (9:1 Hexanes:EtOAc). Spectral data match those previously reported.[17]



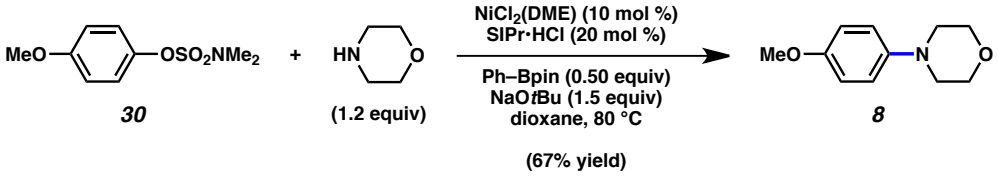
6 **(Figure 2)**. Purification by flash chromatography (9:1 Hexanes:EtOAc) produced aminated product **6** (94% yield) as a white solid. R_f 0.23 (9:1 Hexanes:EtOAc). Spectral data match those previously reported.[17]



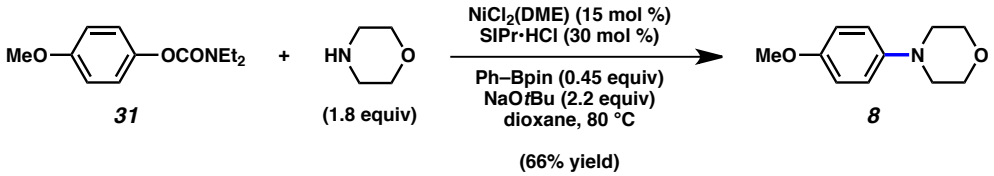
6 (Figure 2). Purification by flash chromatography (9:1 Hexanes:EtOAc) generated aminated product **6** (87% yield) as a white solid. R_f 0.23 (9:1 Hexanes:EtOAc). Spectral data match those previously reported.[14]



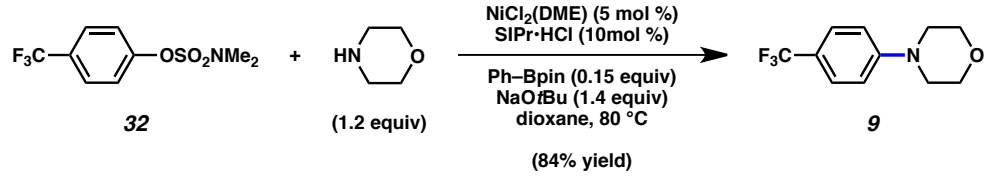
7 (Figure 2). Purification by flash chromatography (9:1 Hexanes:EtOAc) supplied aminated product **7** (85% yield) as a white solid. R_f 0.28 (9:1 Hexanes:EtOAc). Spectral data match those previously reported.[30]



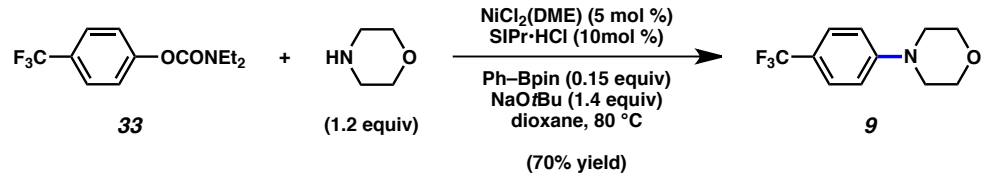
8 (Figure 2). Purification by flash chromatography (10:1:1 Benzene:Et_2O:CH_2Cl_2) afforded aminated product **8** (67% yield) as a white solid. R_f 0.16 (10:1:1 Benzene:Et_2O:CH_2Cl_2). Spectral data match those previously reported.[17]



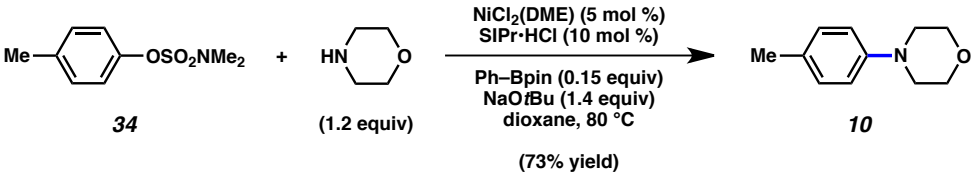
8 (Figure 2). Purification by flash chromatography (10:1:1 Benzene:Et_2O:CH_2Cl_2) afforded aminated product **8** (66% yield) as a white solid. R_f 0.16 (10:1:1 Benzene:Et_2O:CH_2Cl_2). Spectral data match those previously reported.[14]



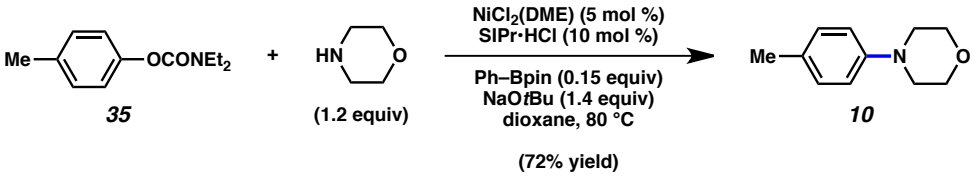
9 (Figure 2). Purification by flash chromatography (30:1 Benzene:Et_2O) generated aminated product **9** (84% yield) as a white solid. R_f 0.38 (30:1 Benzene:Et_2O). Spectral data match those previously reported.[31]



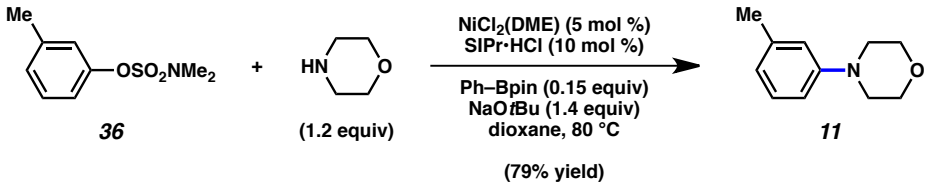
9 (Figure 2). Purification by flash chromatography (30:1 Benzene:Et_2O) produced aminated product **9** (70% yield) as a white solid. R_f 0.38 (30:1 Benzene:Et_2O). Spectral data match those previously reported.[31]



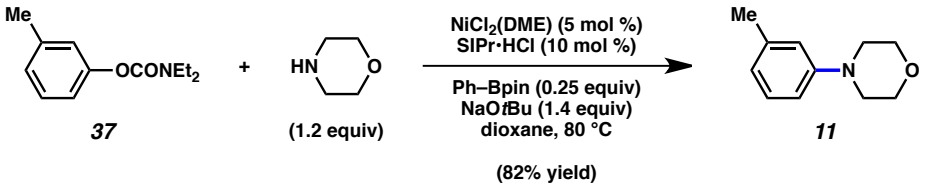
10 (Figure 2). Purification by flash chromatography (19:1 Benzene:Et_2O) afforded aminated product **10** (73% yield) as a white solid. R_f 0.29 (19:1 Benzene:Et_2O). Spectral data match those previously reported.[24e]



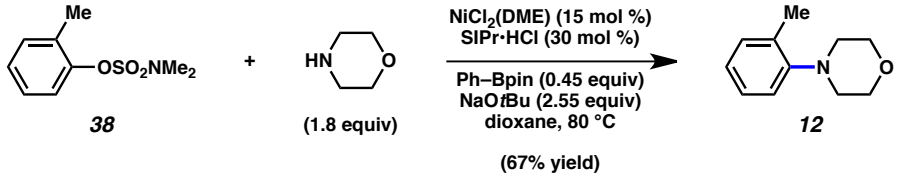
10 (Figure 2). Purification by flash chromatography (19:1 Benzene:Et_2O) yielded aminated product **10** (72% yield) as a white solid. R_f 0.29 (19:1 Benzene:Et_2O). Spectral data match those previously reported.[24e]



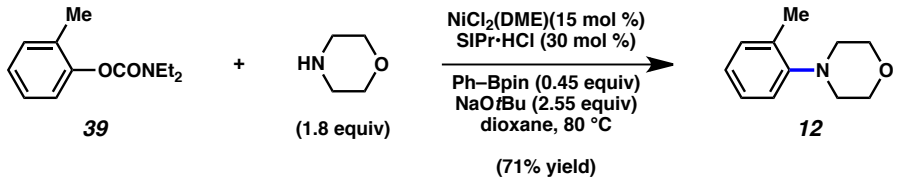
11 (Figure 2). Purification by flash chromatography (19:1 Benzene:Et_2O) generated aminated product **11** (79% yield) as a yellow oil. R_f 0.34 (19:1 Benzene:Et_2O). Spectral data match those previously reported.[24e]



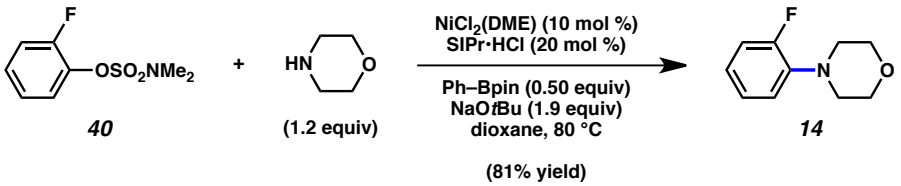
11 (Figure 2). Purification by flash chromatography (19:1 Benzene:Et_2O) afforded aminated product **11** (82% yield) as a yellow oil. R_f 0.34 (19:1 Benzene:Et_2O). Spectral data match those previously reported.[24e]



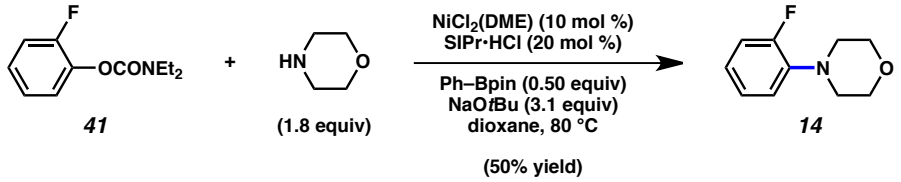
12 (Figure 2). Purification by flash chromatography (20:1 Hexanes:EtOAc) supplied aminated product **12** (71% yield) as a yellow oil. R_f 0.30 (20:1 Hexanes:EtOAc). Spectral data match those previously reported.[24e]



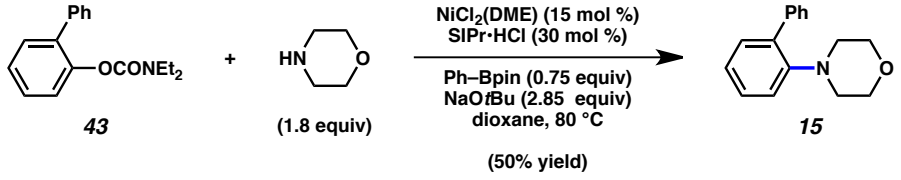
12 (Figure 2). Purification by flash chromatography (20:1 Hexanes:EtOAc) supplied aminated product **12** (71% yield) as a yellow oil. R_f 0.30 (20:1 Hexanes:EtOAc). Spectral data match those previously reported.[24e]



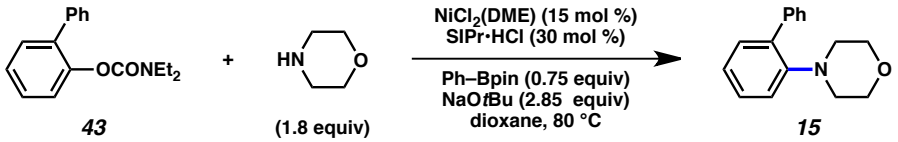
14 (Figure 2). Purification by flash chromatography (60:1:1 Benzene:Et_2O:CH_2Cl_2) afforded aminated product **14** (81% yield) as an off-white solid. R_f 0.45 (60:1:1 Benzene:Et_2O:CH_2Cl_2). Spectral data match those previously reported.[17]



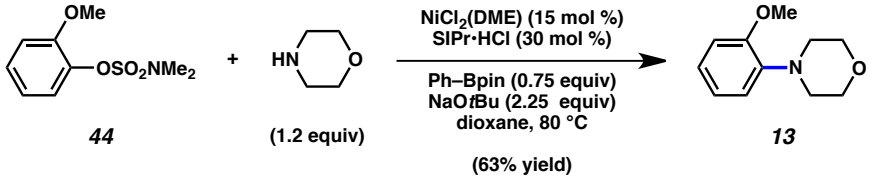
14 (Figure 2). Purification by flash chromatography (60:1:1 Benzene:Et_2O:CH_2Cl_2) supplied aminated product **14** (50% yield) as an off-white solid. R_f 0.45 (60:1:1 Benzene:Et_2O:CH_2Cl_2). Spectral data match those previously reported.[17]



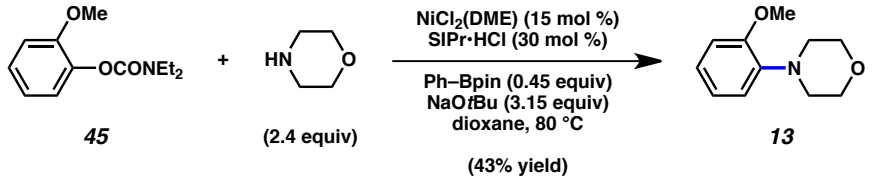
15 (Figure 2). Purification by flash chromatography (100% Benzene) yielded aminated product **15** (53% yield) as a yellow oil. R_f 0.50 (100% Benzene). Spectral data match those previously reported.[32]



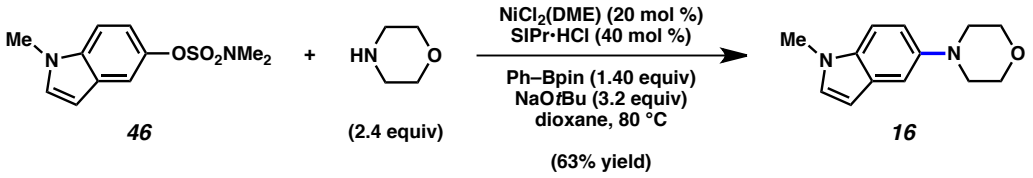
15 (Figure 2). Purification by flash chromatography (100% Benzene) afforded aminated product **15** (50% yield) as a yellow oil. R_f 0.50 (100% Benzene). Spectral data match those previously reported.[32]



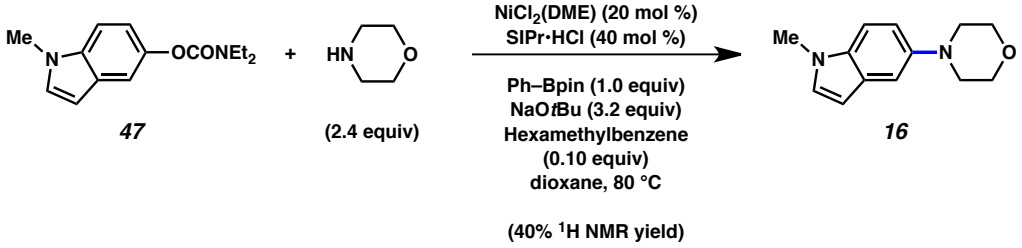
13 (Figure 2). Purification by flash chromatography (20:1 Hexanes:EtOAc) supplied aminated product **13** (63% yield) as a yellow oil. R_f 0.26 (20:1 Hexanes:EtOAc). Spectral data match those previously reported.[32]



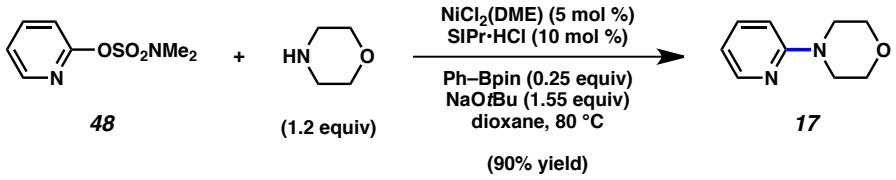
13 (Figure 2). Purification by flash chromatography (9:1 Benzene:Et_2O) generated aminated product **13** (43% yield) as a yellow oil. R_f 0.27 (9:1 Benzene:Et_2O). Spectral data match those previously reported.[32]



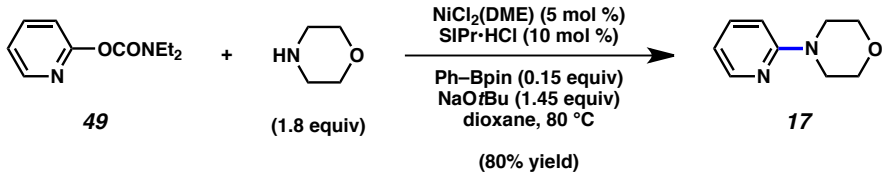
16 (Figure 2). Purification by flash chromatography (6:1:1 Benzene:Et_2O:CH_2Cl_2) yielded aminated product **16** (63% yield) as an off-white solid. R_f 0.36 (6:1:1 Benzene:Et_2O:CH_2Cl_2). Spectral data match those previously reported.[22b]



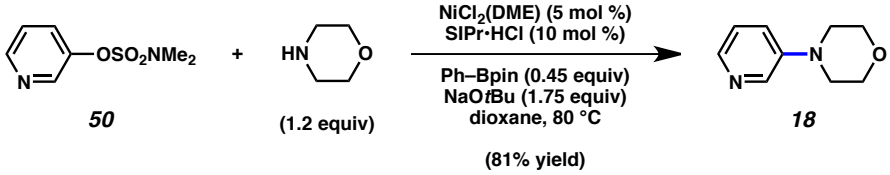
16 (Figure 2). The reaction mixture was filtered over a short plug of silica gel (eluted with EtOAc (10 mL)), then volatiles were removed in in vacuo and evaporated to dryness. The yield was determined by ^{1}H NMR analysis with Hexamethylbenzene as an internal standard.



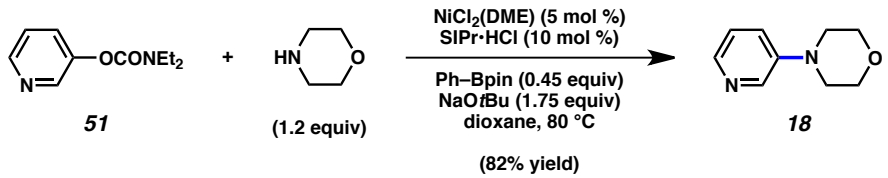
17 (Figure 2). Purification by flash chromatography (2:1 Hexanes:EtOAc) afforded aminated product **17** (90% yield) as a pale yellow oil. R_f 0.23 (2:1 Hexanes:EtOAc. Spectral data match those previously reported.[33]



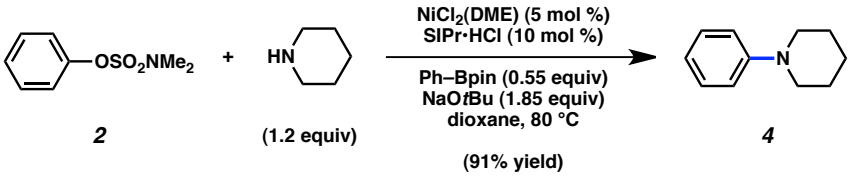
17 (Figure 2). Purification by flash chromatography (2:1 Hexanes:EtOAc) produced aminated product **17** (80% yield) as a pale yellow oil. R_f 0.27 (2:1 Hexanes:EtOAc. Spectral data match those previously reported.[33]



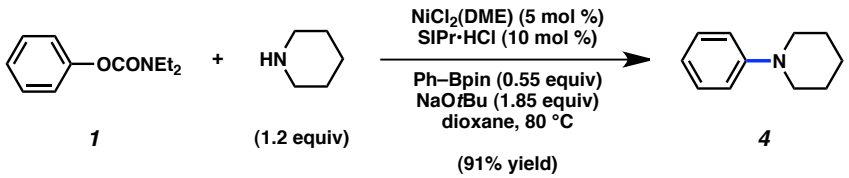
18 (Figure 2). Purification by flash chromatography (100% EtOAc) afforded aminated product **18** (81% yield) as a pale yellow oil. R_f 0.14 (100% EtOAc). Spectral data match those previously reported.[33]



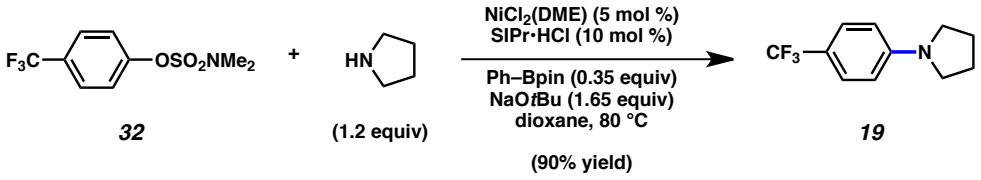
18 (Figure 2). Purification by flash chromatography (100% EtOAc) generated aminated product **18** (82% yield) as a pale yellow oil. R_f 0.14 (100% EtOAc). Spectral data match those previously reported.[33]



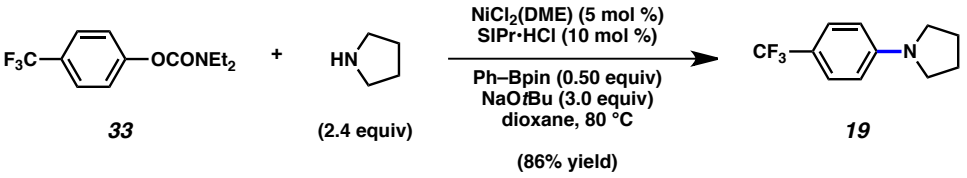
4 (Figure 3). Purification by flash chromatography (50:1 Hexanes:EtOAc) afforded aminated product **4** (91% yield) as a clear oil. R_f 0.39 (50:1 Hexanes:EtOAc). Spectral data match those previously reported.[33]



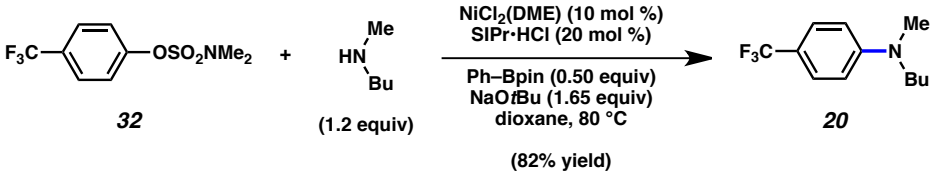
4 (Figure 3). Purification by flash chromatography (50:1 Hexanes:EtOAc) supplied aminated product **4** (91% yield) as a clear oil. R_f 0.39 (50:1 Hexanes:EtOAc). Spectral data match those previously reported.[16]



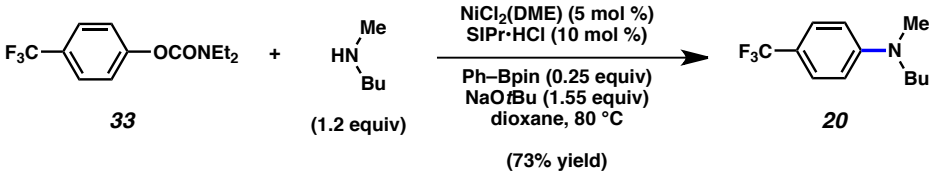
19 (Figure 3). Purification by flash chromatography (50:1 Hexanes:Et_2O) generated aminated product **19** (90% yield) as a white solid. R_f 0.34 (50:1 Hexanes:Et_2O). Spectral data match those previously reported.[16]



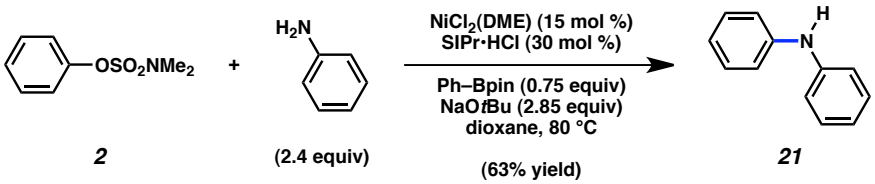
19 (Figure 3). Purification by flash chromatography (50:1 Hexanes:Et_2O) produced aminated product **19** (86% yield) as a white solid. R_f 0.34 (50:1 Hexanes:Et_2O). Spectral data match those previously reported.[16]



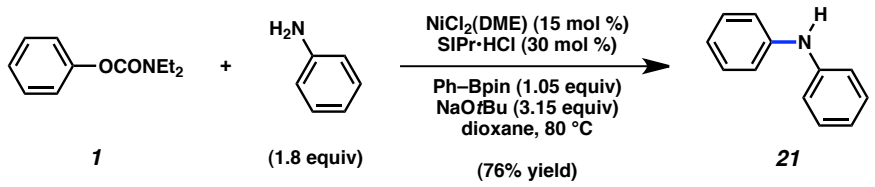
20 (Figure 3). Purification by flash chromatography (90:1 Hexanes:Et_2O) afforded aminated product **20** (82% yield) as a clear oil. R_f 0.37 (90:1 Hexanes:Et_2O). Spectral data match those previously reported.[22b]



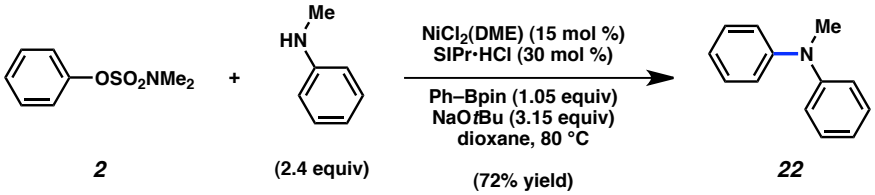
20 (Figure 3). Purification by flash chromatography (90:1 Hexanes:Et_2O) generated aminated product **20** (73% yield) as a clear oil. R_f 0.37 (90:1 Hexanes:Et_2O). Spectral data match those previously reported.[22b]



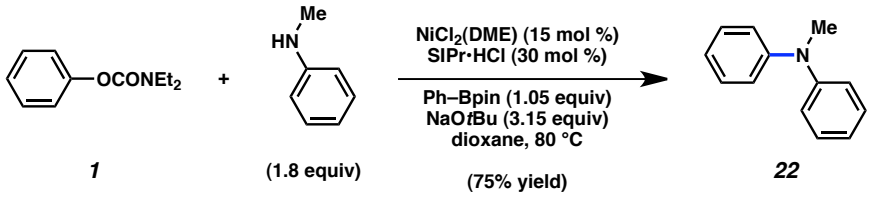
21 (Figure 3). Purification by flash chromatography (4:1 Hexanes:CH_2Cl_2) afforded aminated product **21** (63% yield) as a yellow solid. R_f 0.20 (4:1 Hexanes:CH_2Cl_2). Spectral data match those previously reported.[24e]



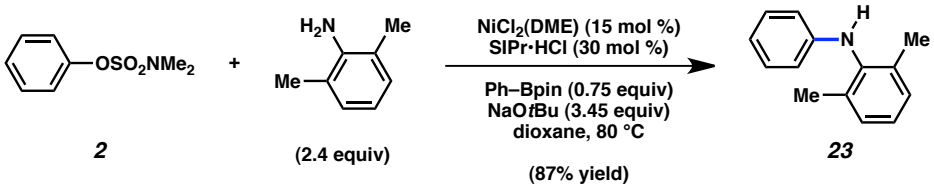
21 (Figure 3). Purification by flash chromatography (4:1 Hexanes:CH_2Cl_2) yielded aminated product **21** (76% yield) as a yellow solid. R_f 0.20 (4:1 Hexanes:CH_2Cl_2). Spectral data match those previously reported.[24e]



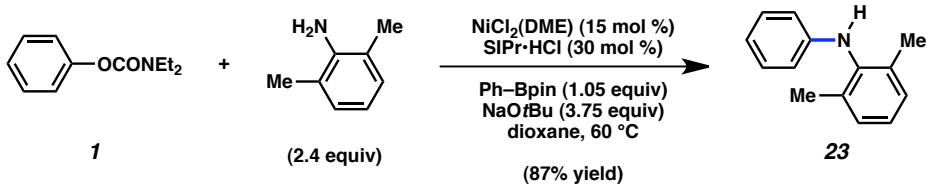
22 (Figure 3). Purification by flash chromatography (100% Hexanes) afforded aminated product **22** (72% yield) as a yellow oil. R_f 0.15 (100% Hexanes). Spectral data match those previously reported.[24e]



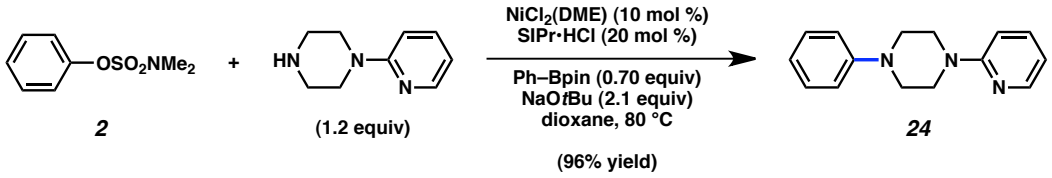
22 (Figure 3). Purification by flash chromatography (100% Hexanes) generated aminated product **22** (75% yield) as a yellow oil. R_f 0.15 (100% Hexanes). Spectral data match those previously reported.[24e]



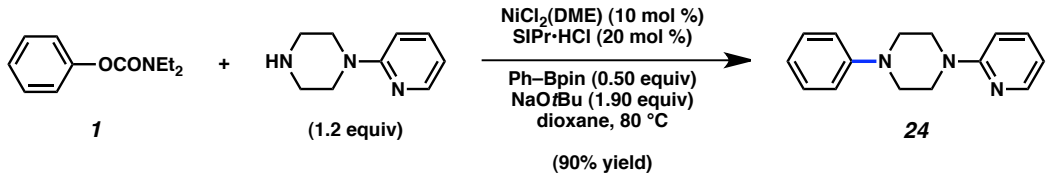
23 (Figure 3). Purification by flash chromatography (20:1 Hexanes:Et_2O) yielded aminated product **23** (87% yield) as a clear oil. R_f 0.45 (40:1 Hexanes:Et_2O). Spectral data match those previously reported.[24e]



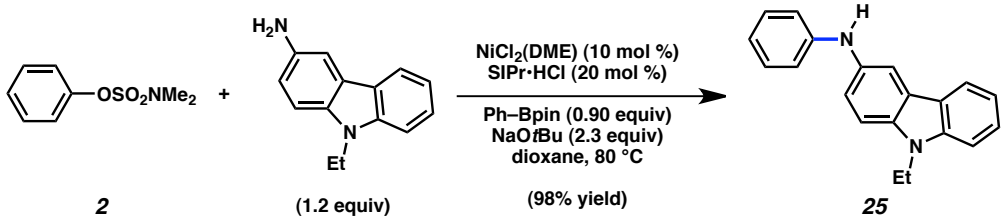
23 (Figure 3). Purification by flash chromatography (20:1 Hexanes:Et_2O) produced aminated product **23** (87% yield) as a clear oil. R_f 0.45 (40:1 Hexanes:Et_2O). Spectral data match those previously reported.[24e]



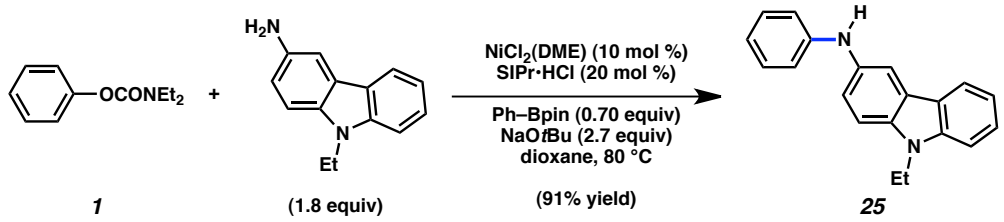
24 (Figure 3). Purification by flash chromatography (8:1 Hexanes:EtOAc) supplied aminated product **24** (96% yield) as a white solid. R_f 0.18 (8:1 Hexanes:EtOAc). Spectral data match those previously reported.[33]



24 (Figure 3). Purification by flash chromatography (8:1 Hexanes:EtOAc) afforded aminated product **24** (90% yield) as a white solid. R_f 0.18 (8:1 Hexanes:EtOAc). Spectral data match those previously reported.[33]



25 (Figure 3). Purification by flash chromatography (300:150:1 Hexanes:CH_2Cl_2:Et_3N) yielded aminated product **25** (98% yield) as a white solid. R_f 0.19 (300:150:1 Hexanes:CH_2Cl_2:Et_3N). Spectral data match those previously reported.[22a]



25 (Figure 3). Purification by flash chromatography (300:150:1 Hexanes:CH_2Cl_2:Et_3N) afforded aminated product **25** (91% yield) as a white solid. R_f 0.19 (300:150:1 Hexanes:CH_2Cl_2:Et_3N). Spectral data match those previously reported.[22a]

Appendix

^{1}H-NMR Spectra

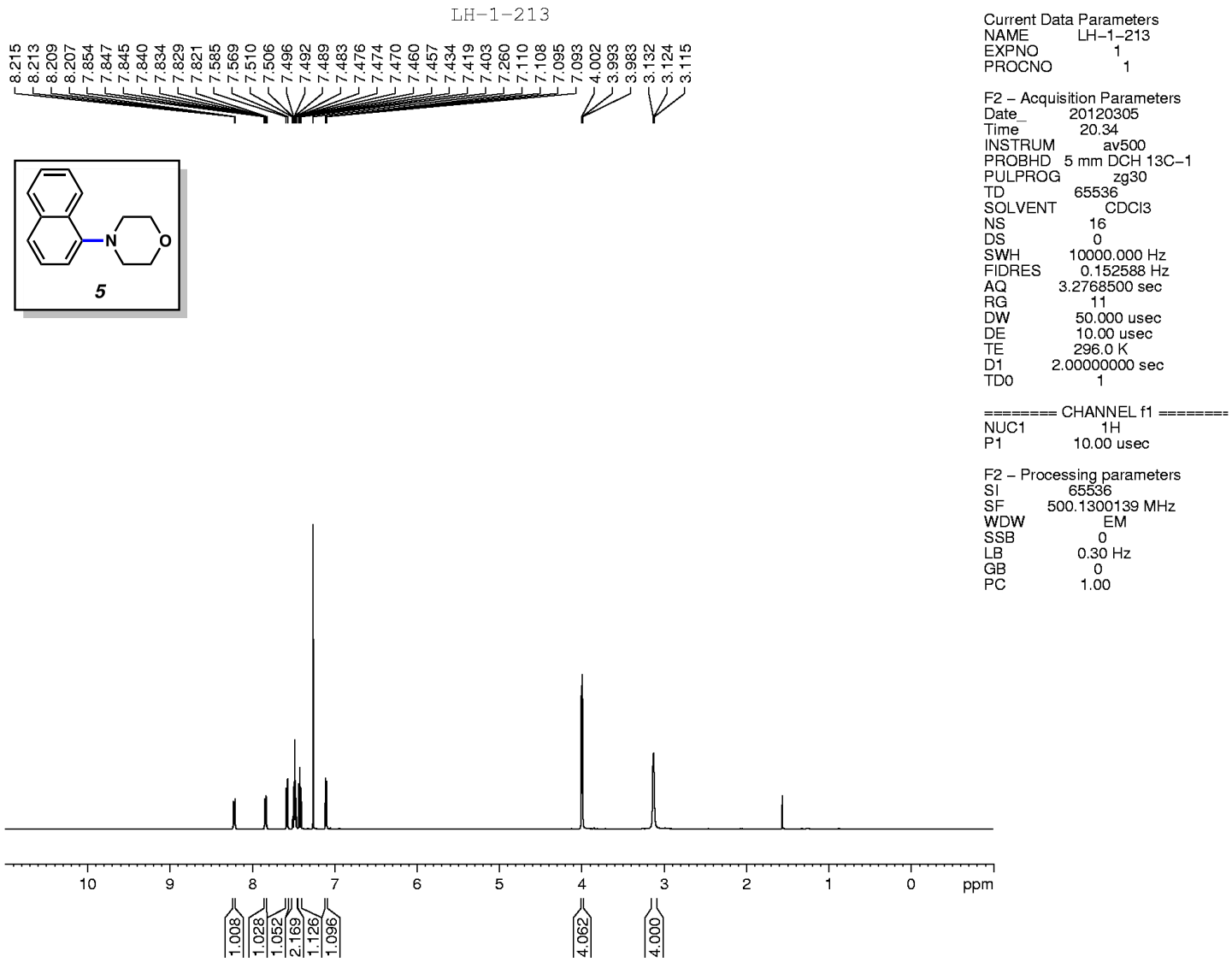


Figure A1.1 ^{1}H NMR (500 MHz, $CDCl_3$) of compound **5**.

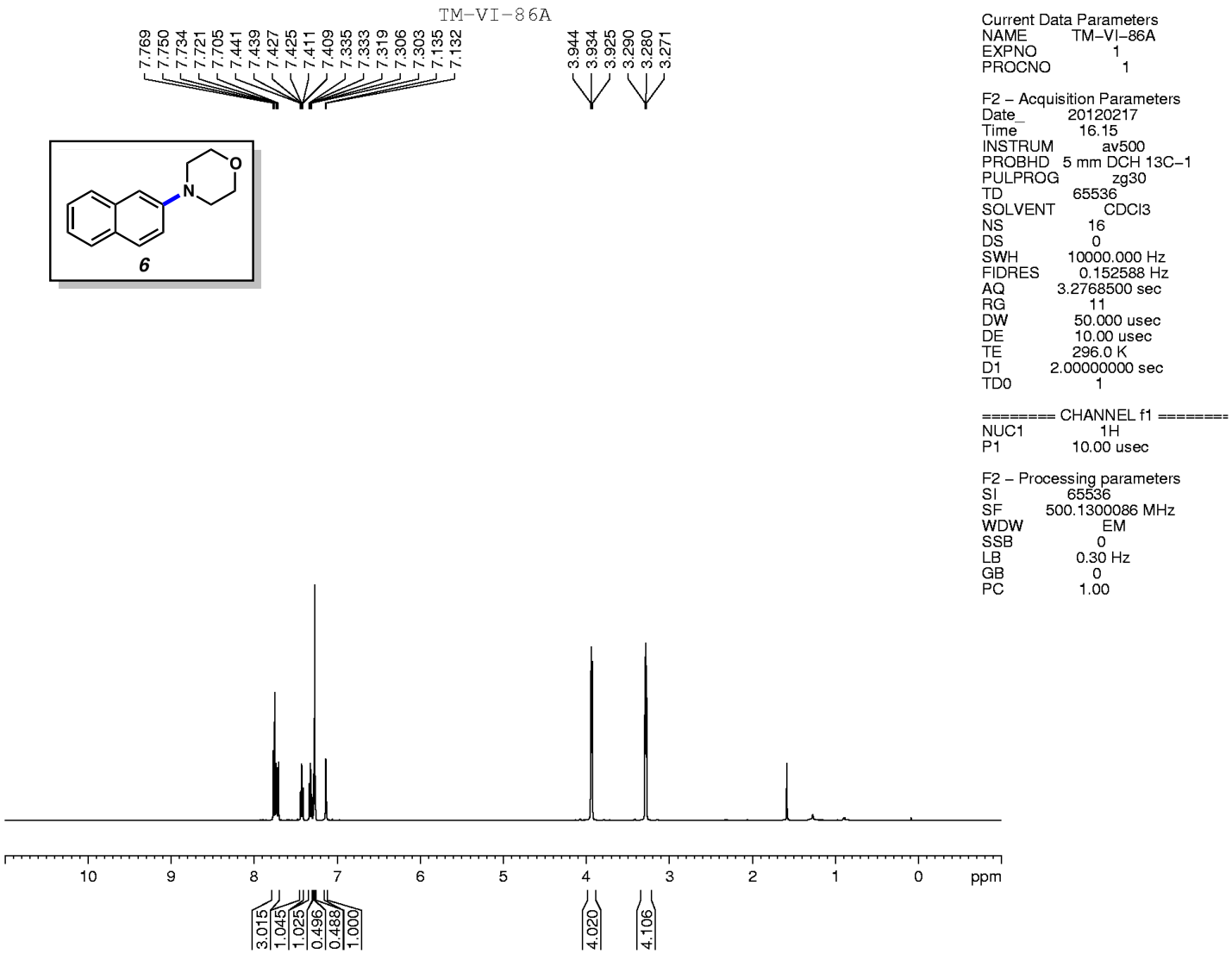


Figure A1.2 ^{1}H NMR (500 MHz, $CDCl_3$) of compound **6**.

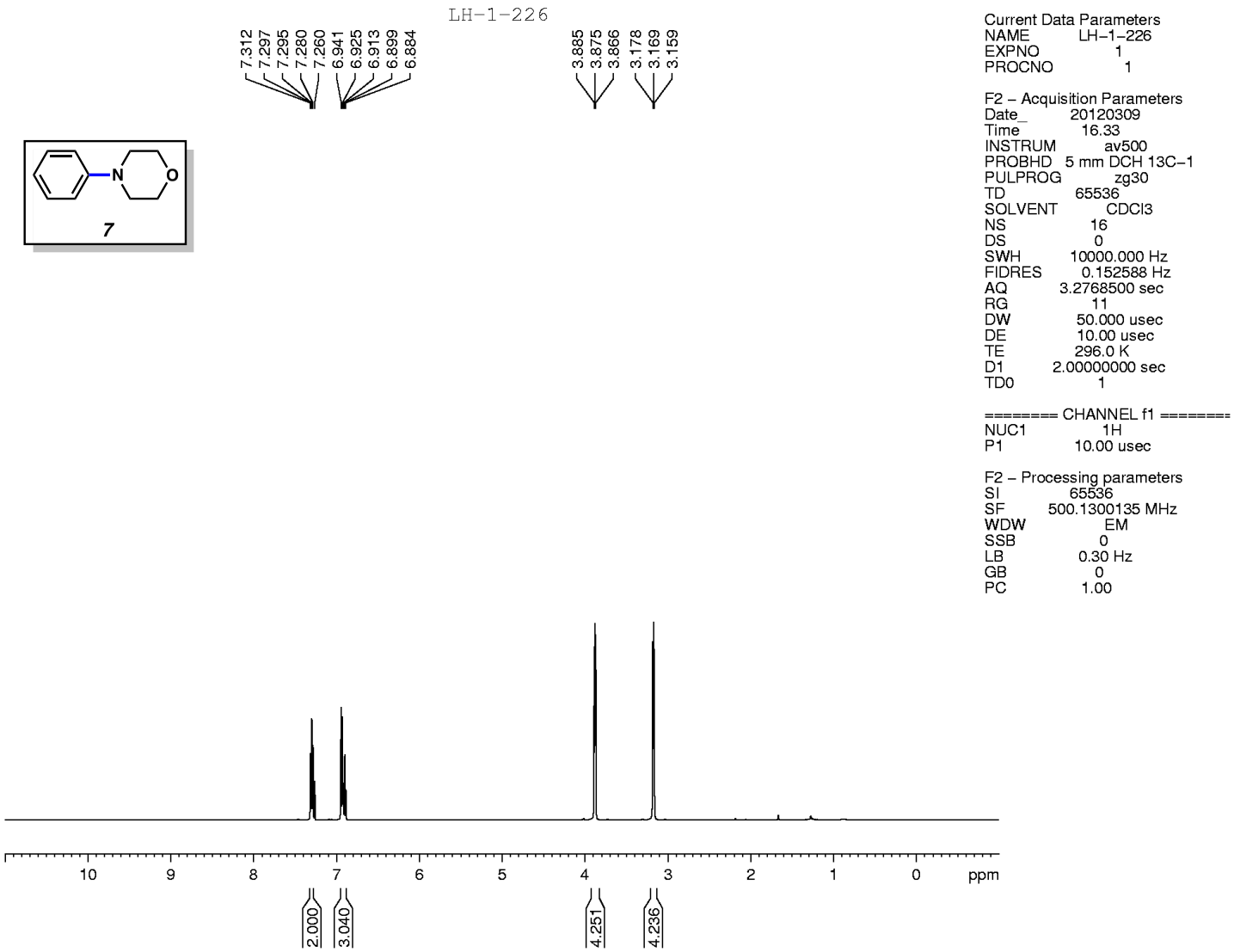


Figure A1.3 ^{1}H NMR (500 MHz, $CDCl_3$) of compound **7**.

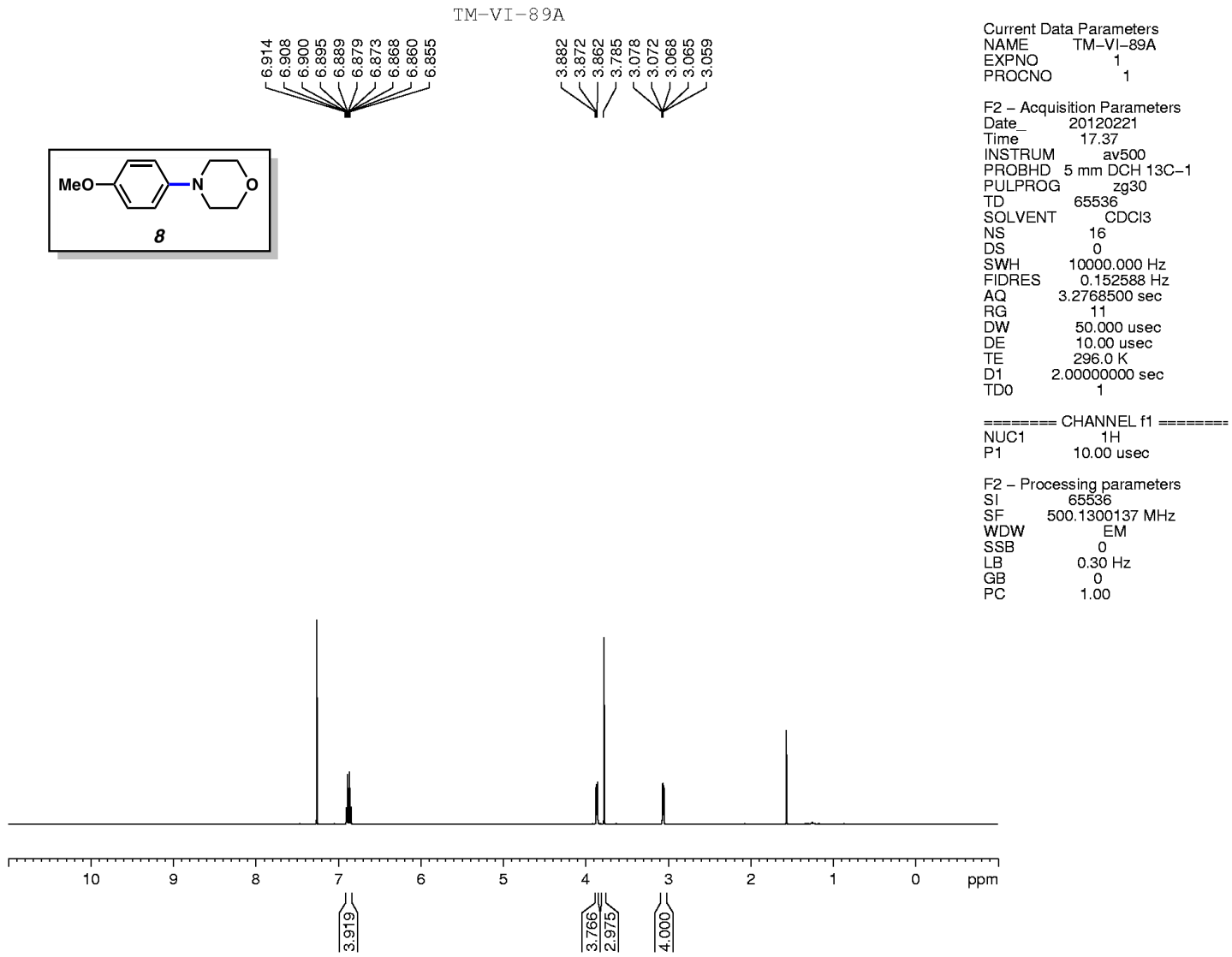


Figure A1.4 ^{1}H NMR (500 MHz, $CDCl_3$) of compound **8**.

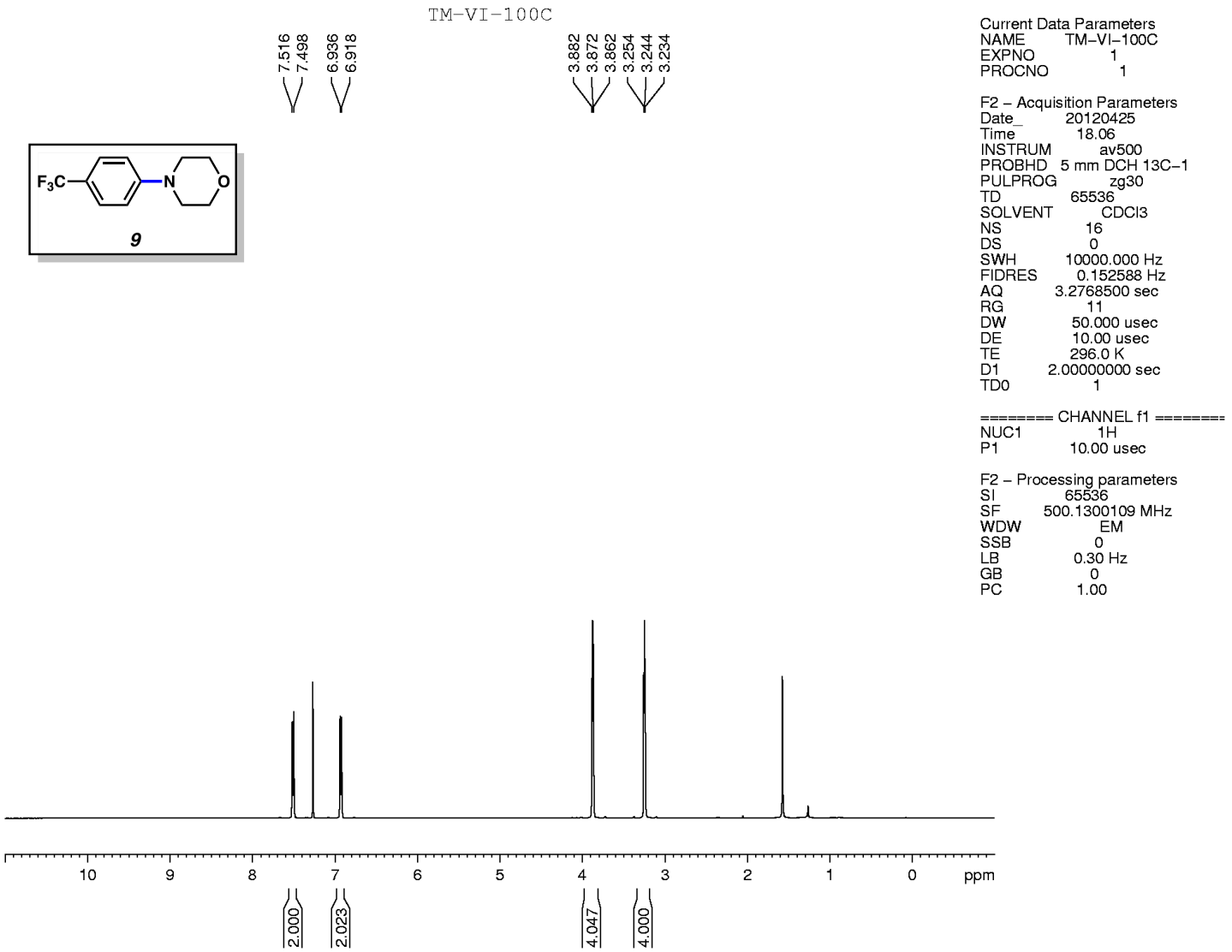


Figure A1.5 ^{1}H NMR (500 MHz, $CDCl_3$) of compound **9**.

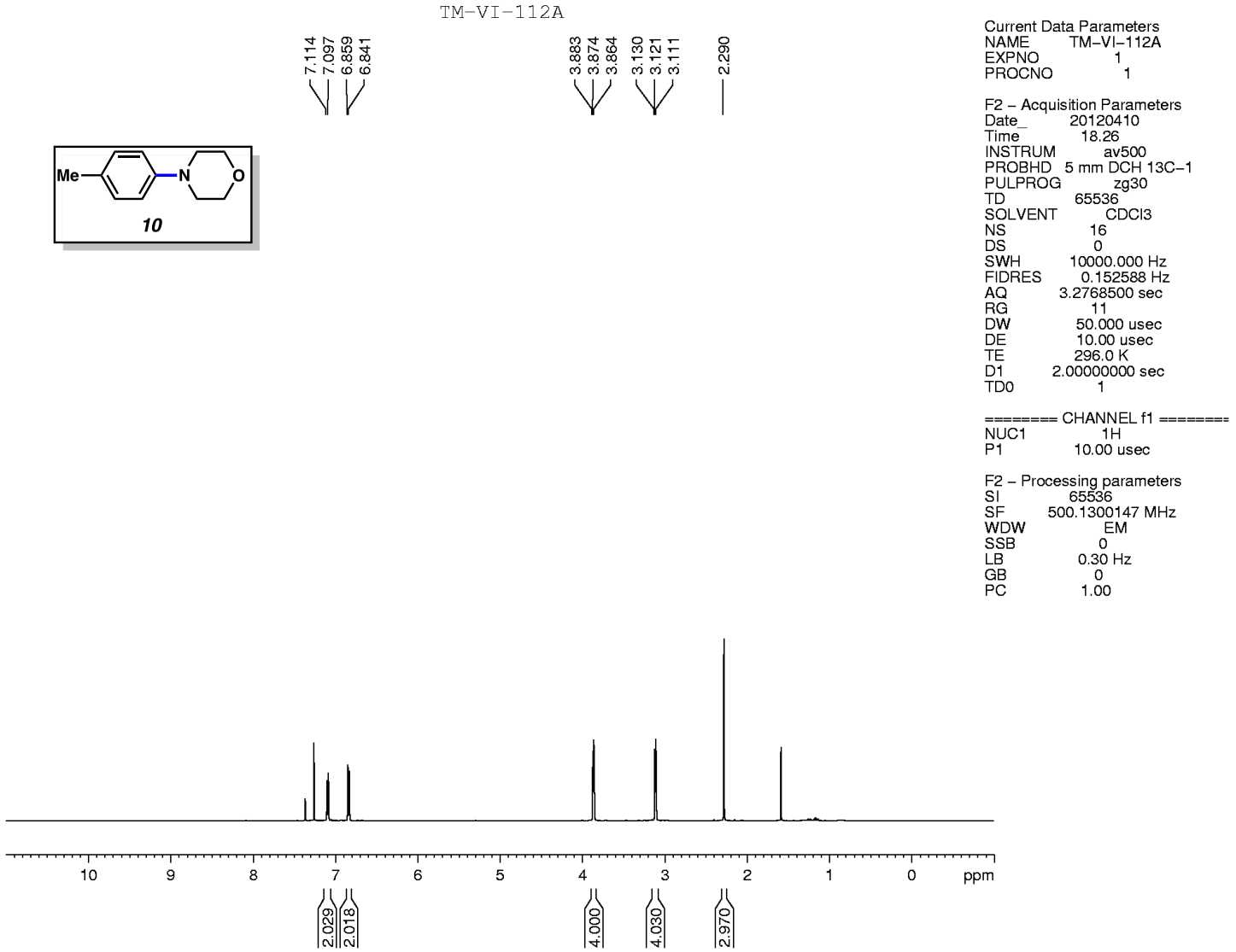


Figure A1.6 ^{1}H NMR (500 MHz, $CDCl_3$) of compound **10**.

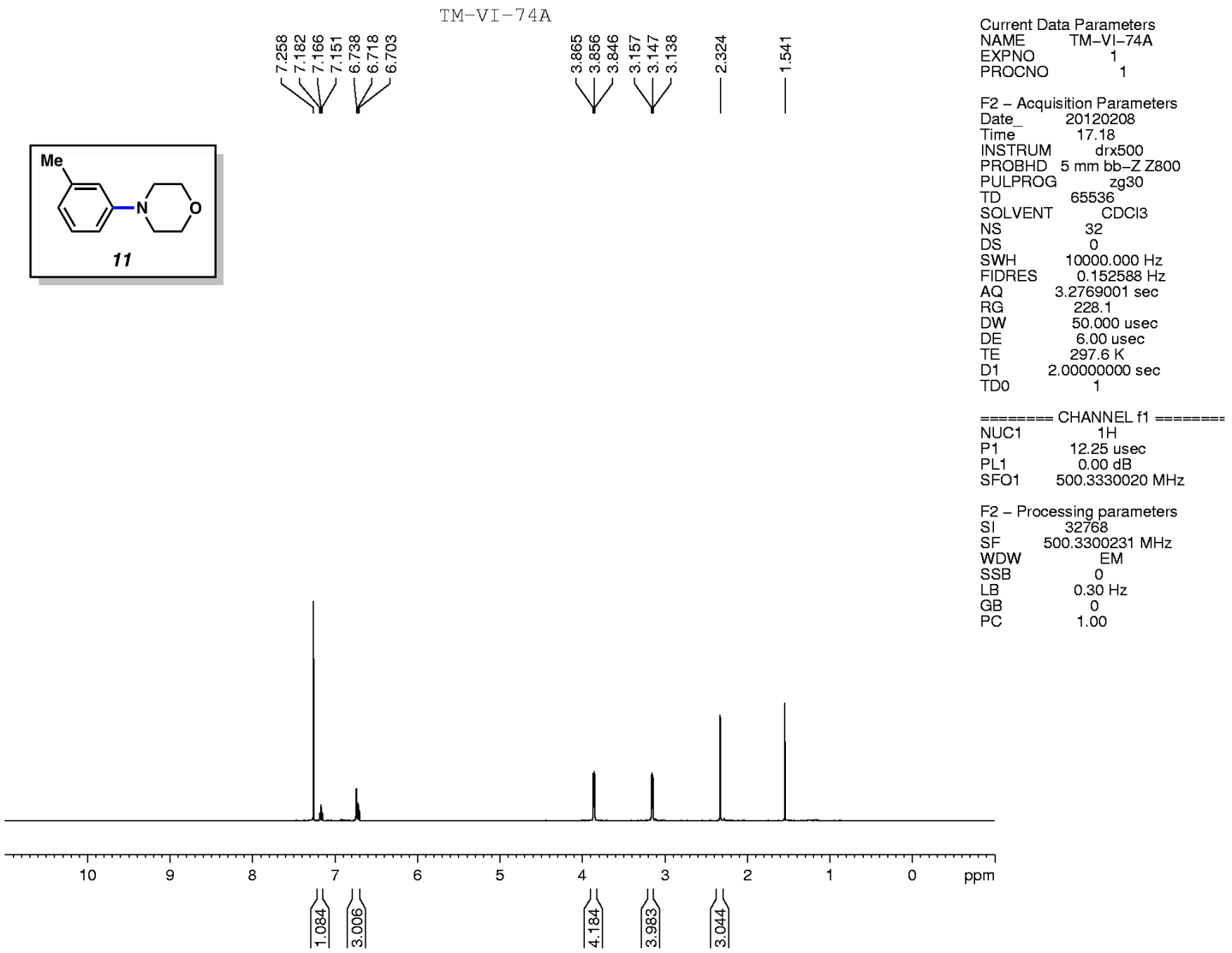


Figure A1.7 ^{1}H NMR (500 MHz, $CDCl_3$) of compound **11**.

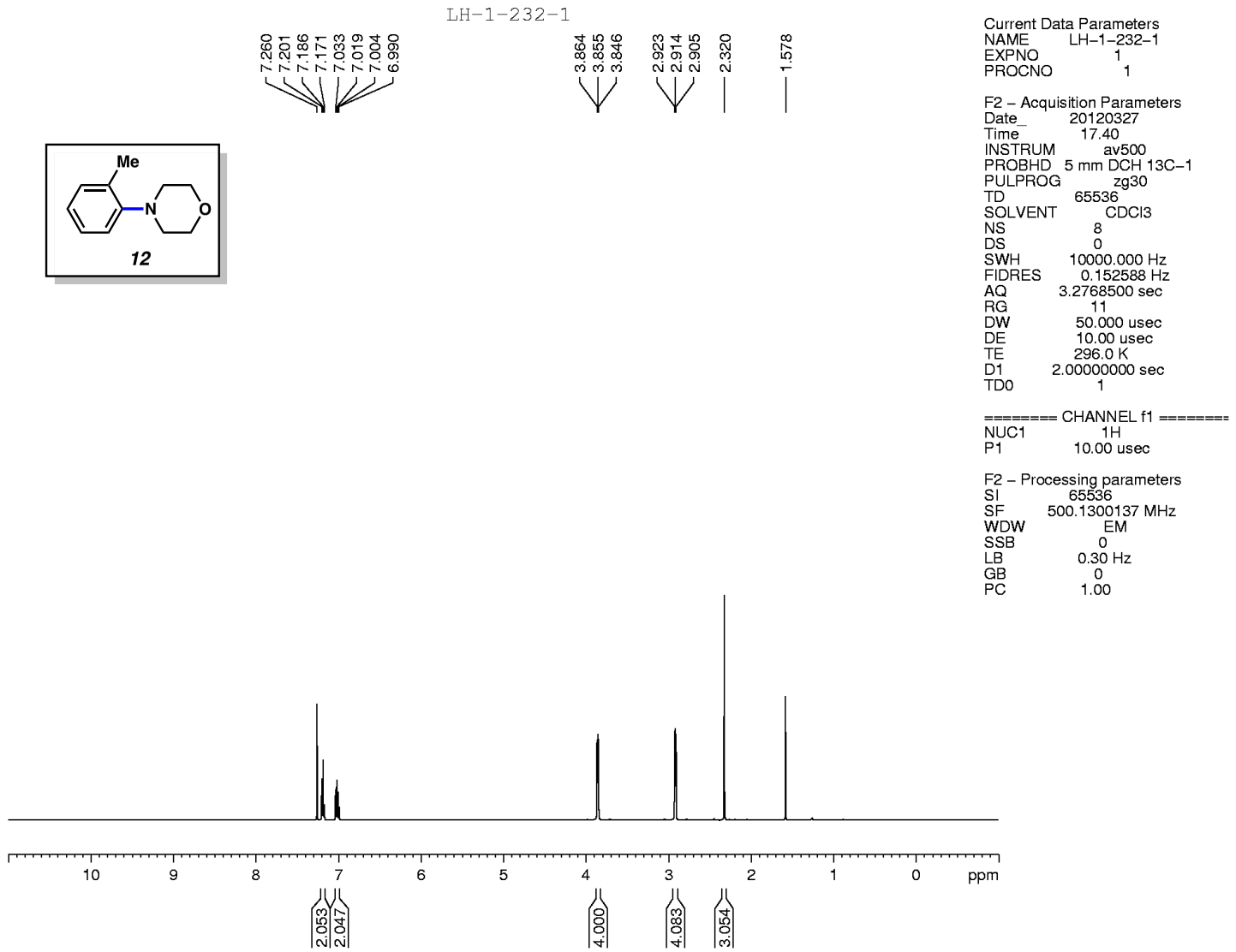


Figure A1.8 ^{1}H NMR (500 MHz, $CDCl_3$) of compound **12**.

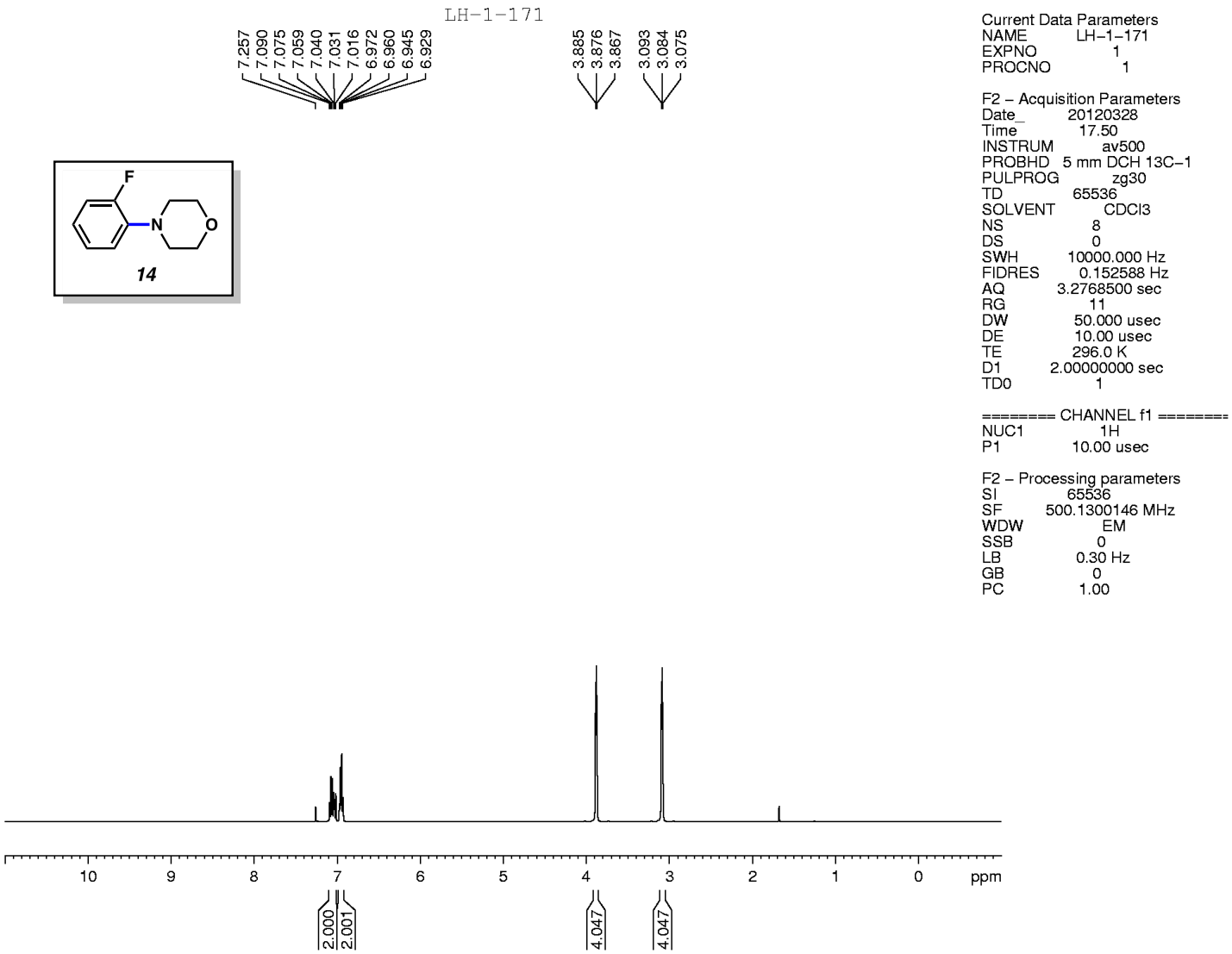


Figure A1.8 ^{1}H NMR (500 MHz, $CDCl_3$) of compound **14**

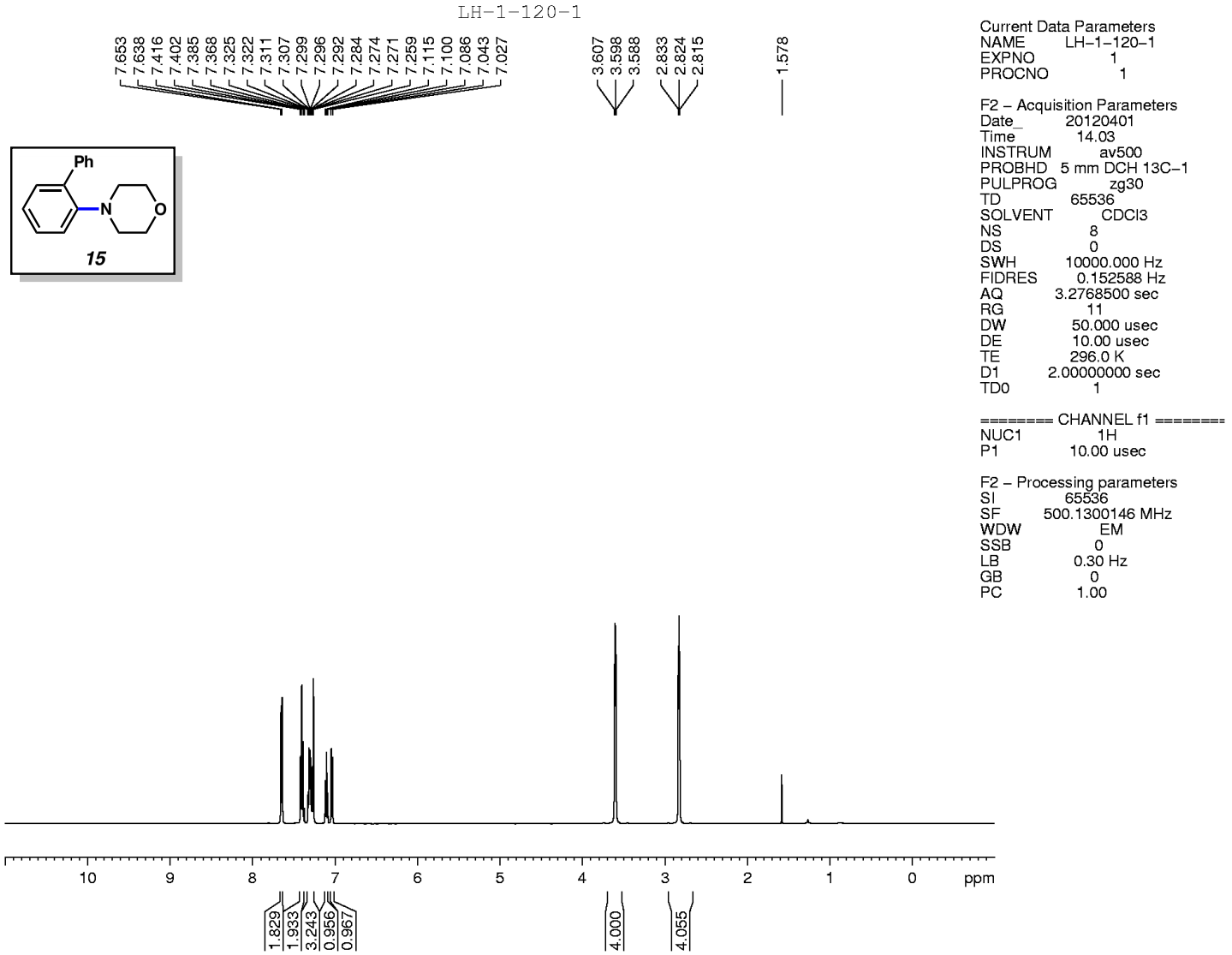


Figure A1.10 ^{1}H NMR (500 MHz, $CDCl_3$) of compound **15**.

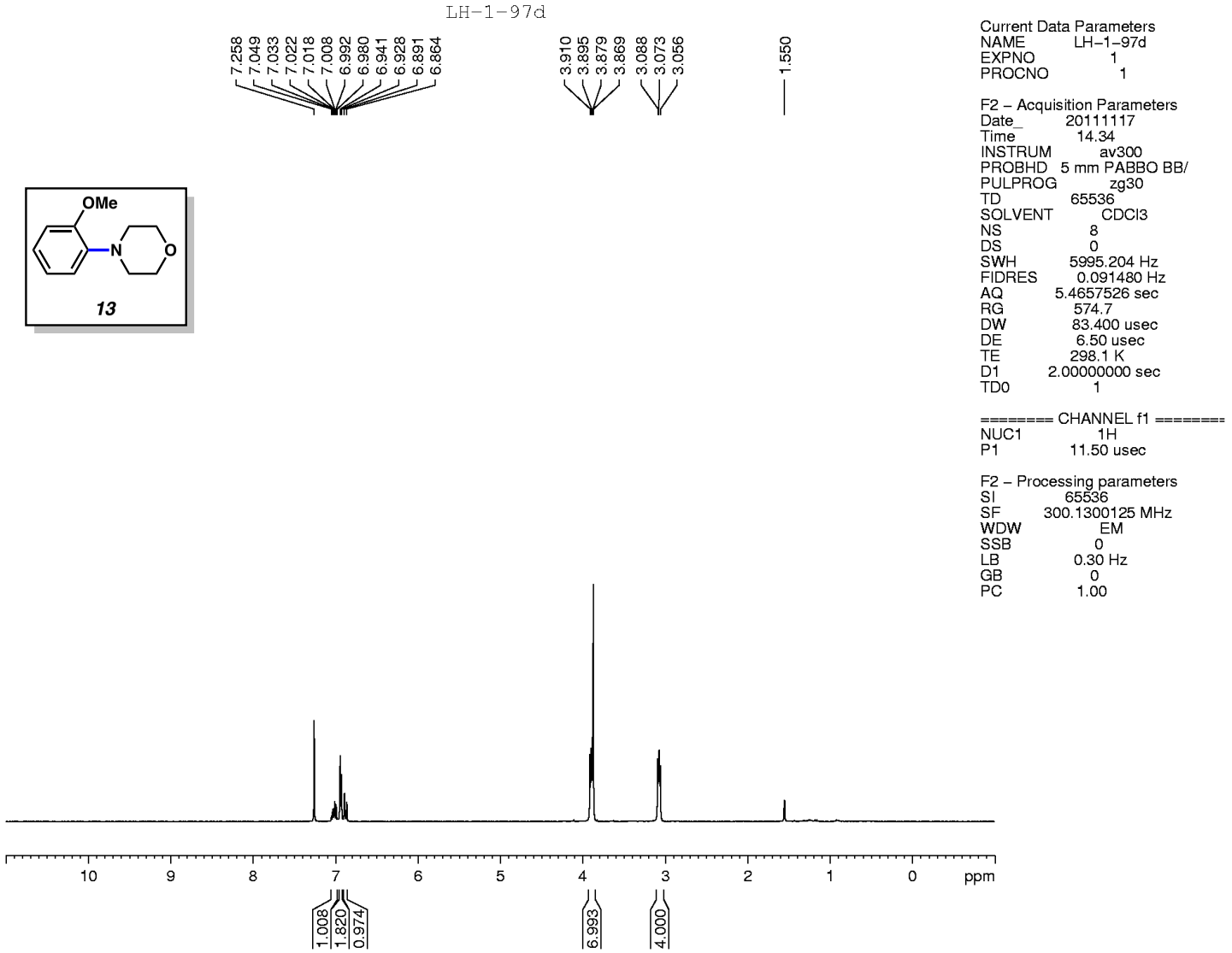


Figure A1.11 ^{1}H NMR (500 MHz, $CDCl_3$) of compound **13.**

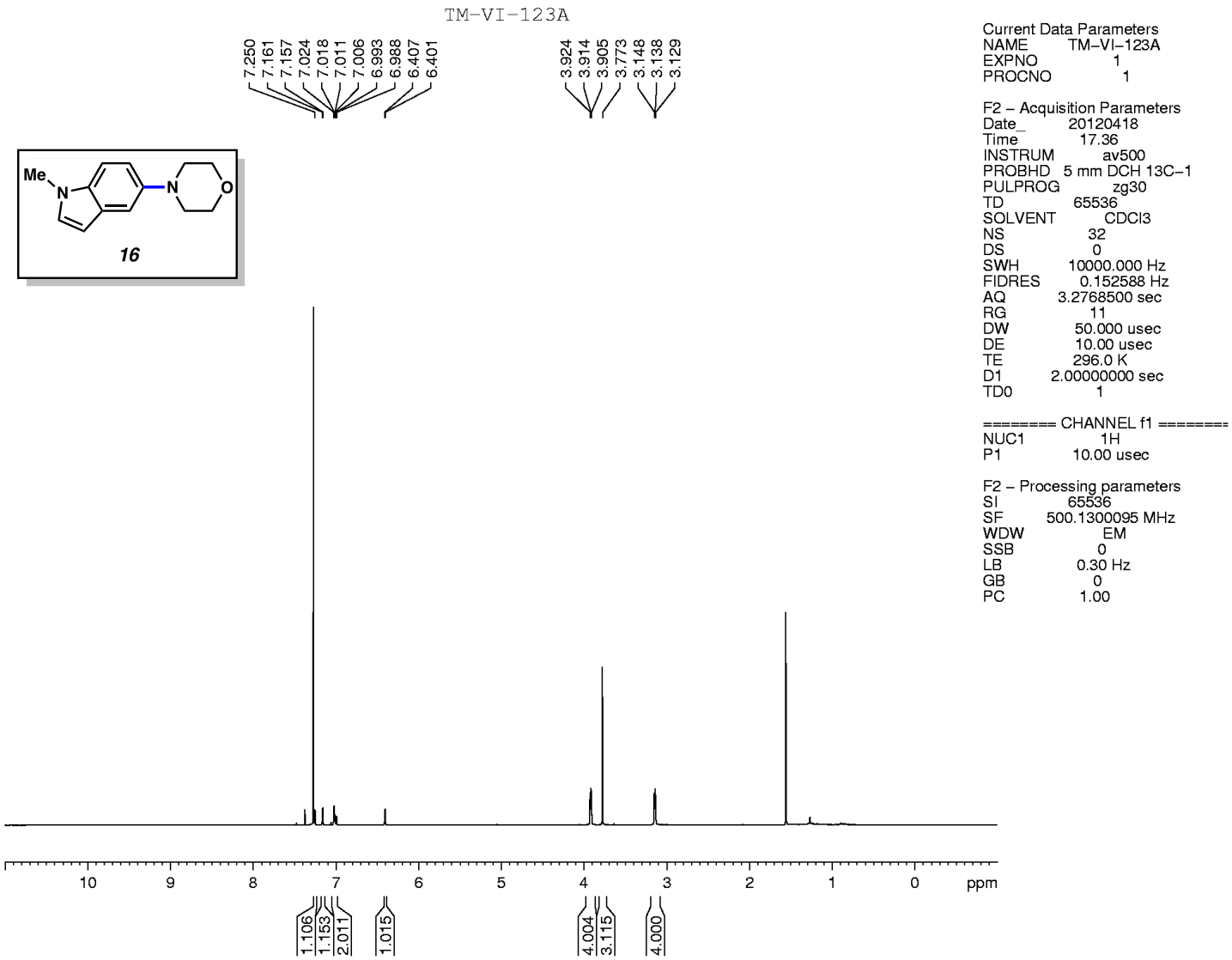


Figure A1.12 ^{1}H NMR (500 MHz, $CDCl_3$) of compound **16**.

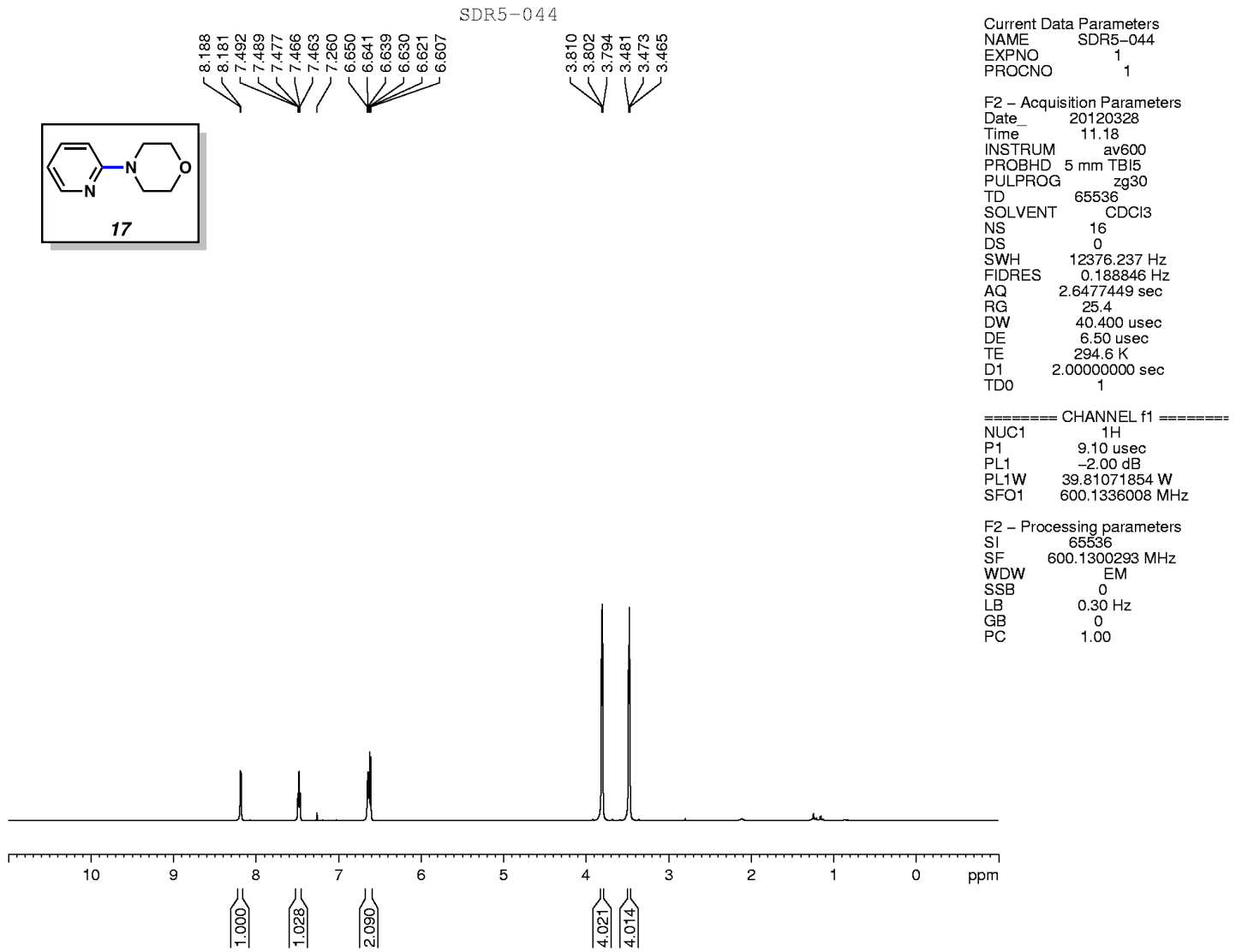


Figure A1.13 ^{1}H NMR (500 MHz, $CDCl_3$) of compound **17**.

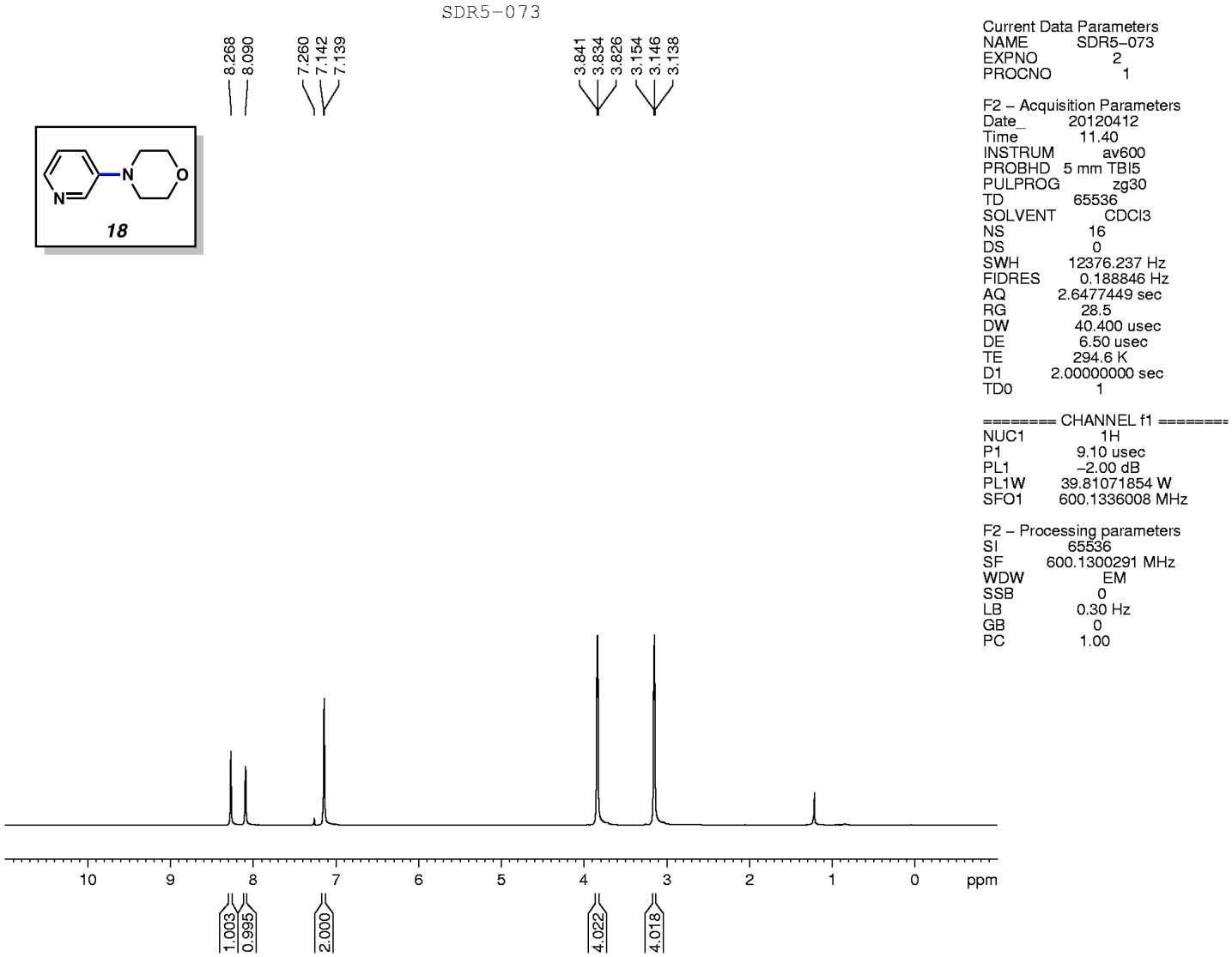


Figure A1.14 ^{1}H NMR (500 MHz, $CDCl_3$) of compound **18**.

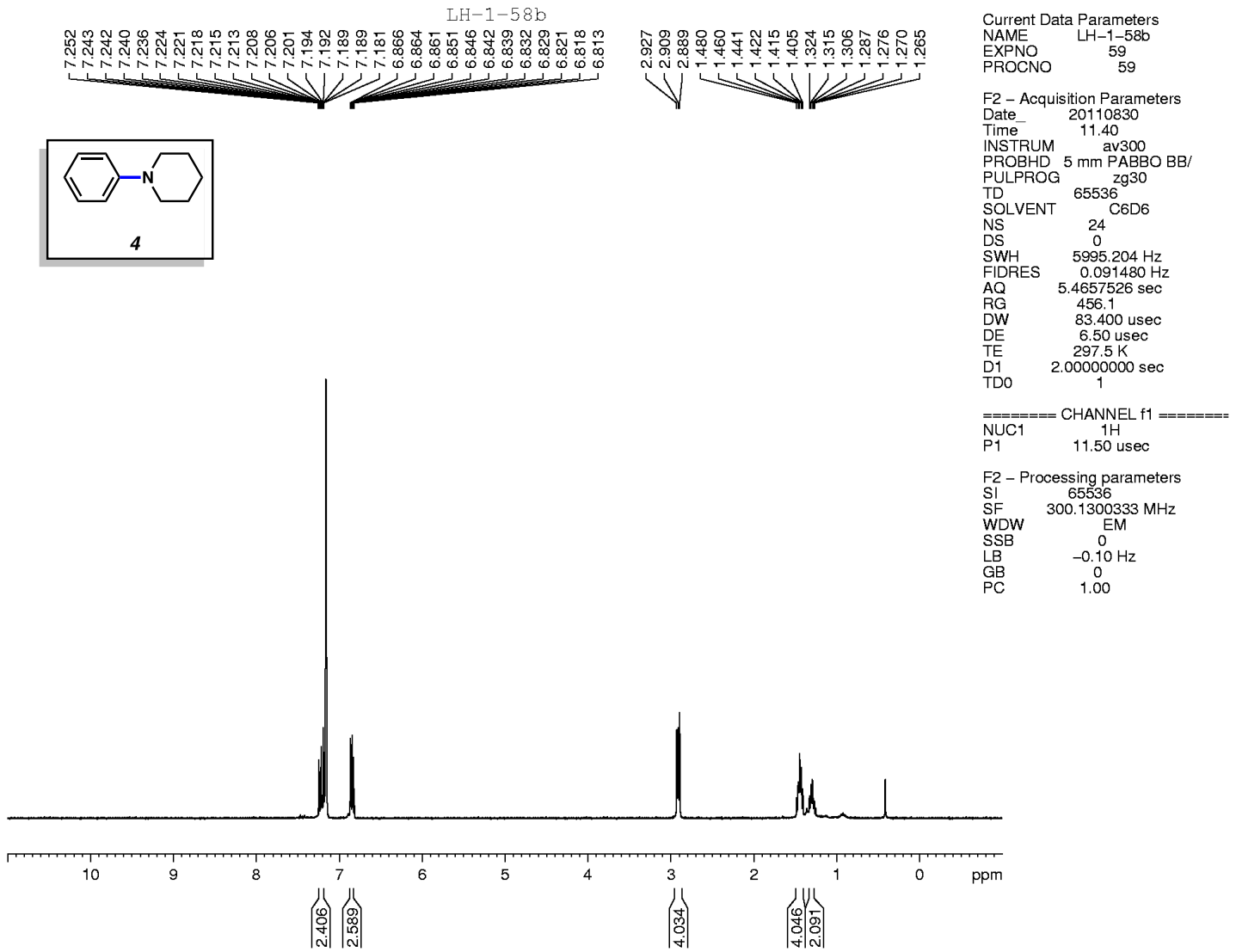


Figure A1.15 ^{1}H NMR (500 MHz, $CDCl_3$) of compound **4**.

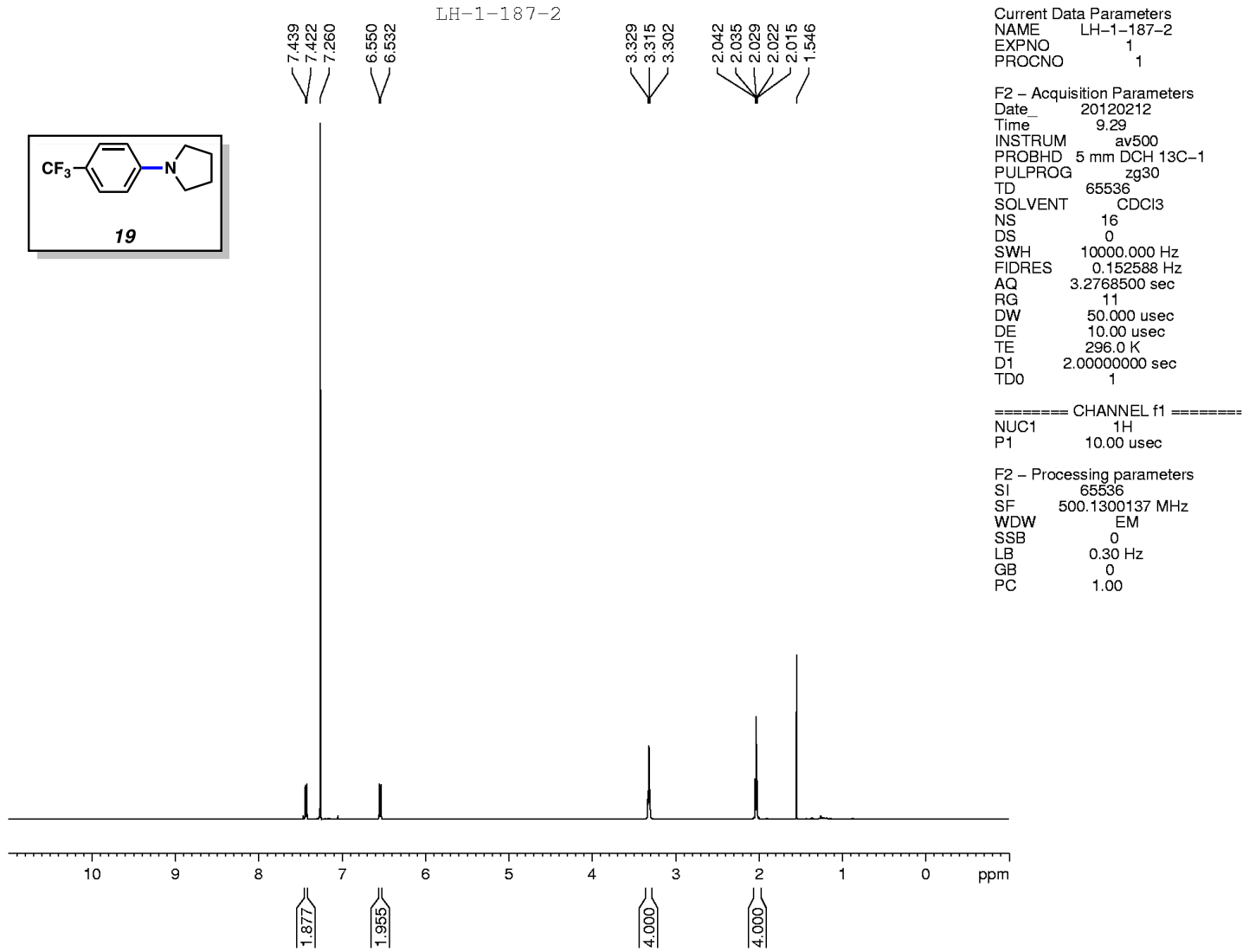


Figure A1.16 ^{1}H NMR (500 MHz, $CDCl_3$) of compound **19**.

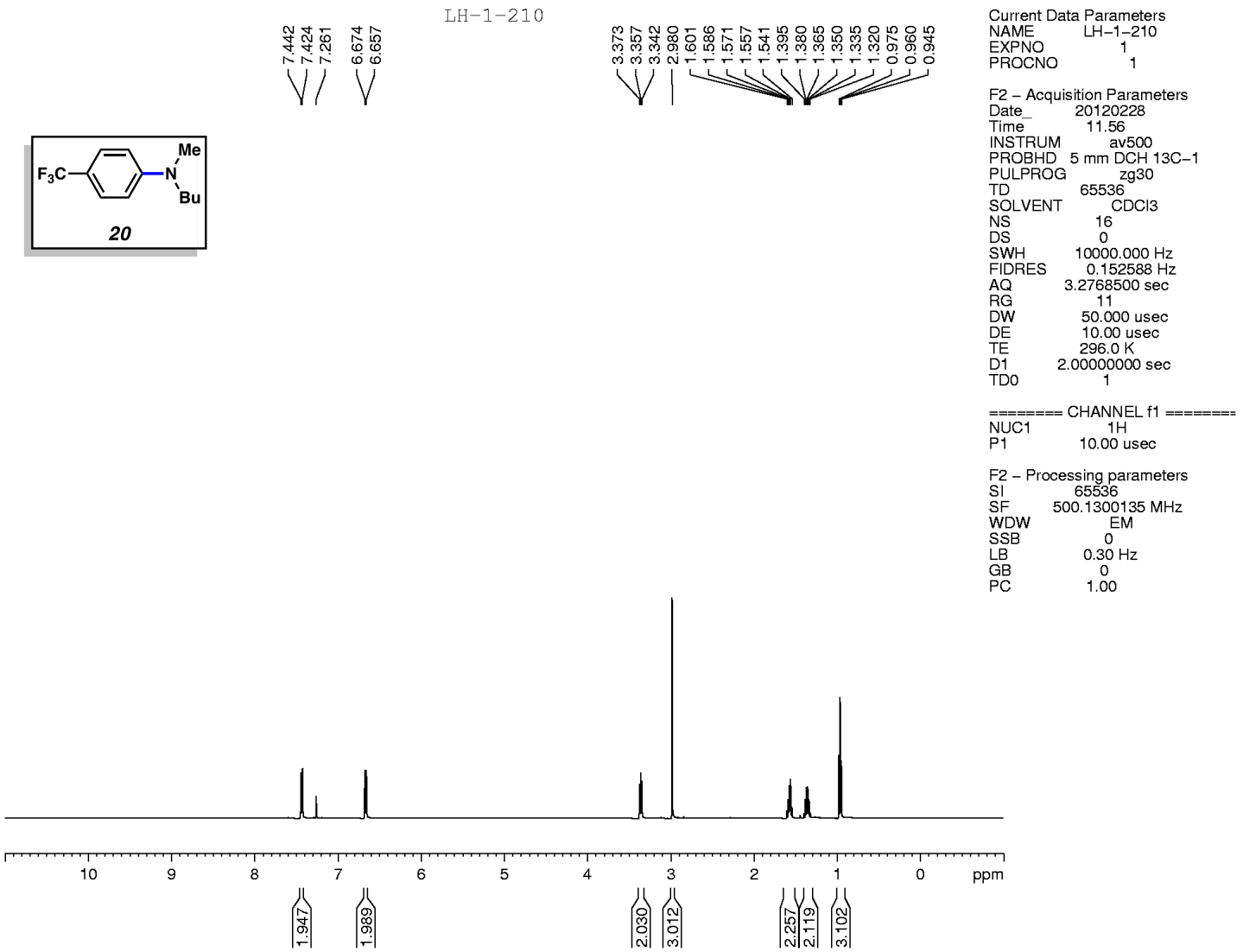


Figure A1.17 ^{1}H NMR (500 MHz, $CDCl_3$) of compound **20**.

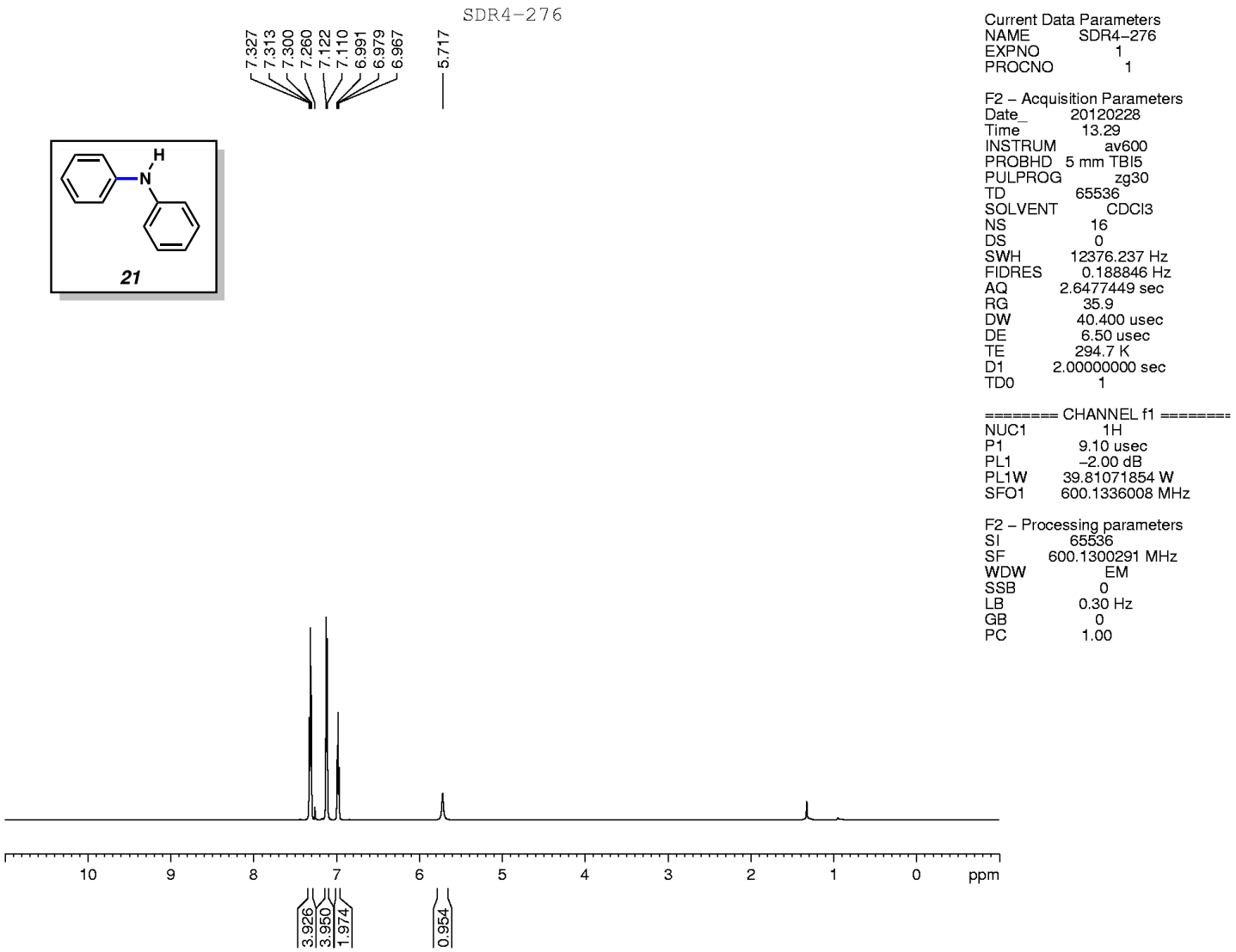


Figure A1.18 ^{1}H NMR (500 MHz, $CDCl_3$) of compound **21**.

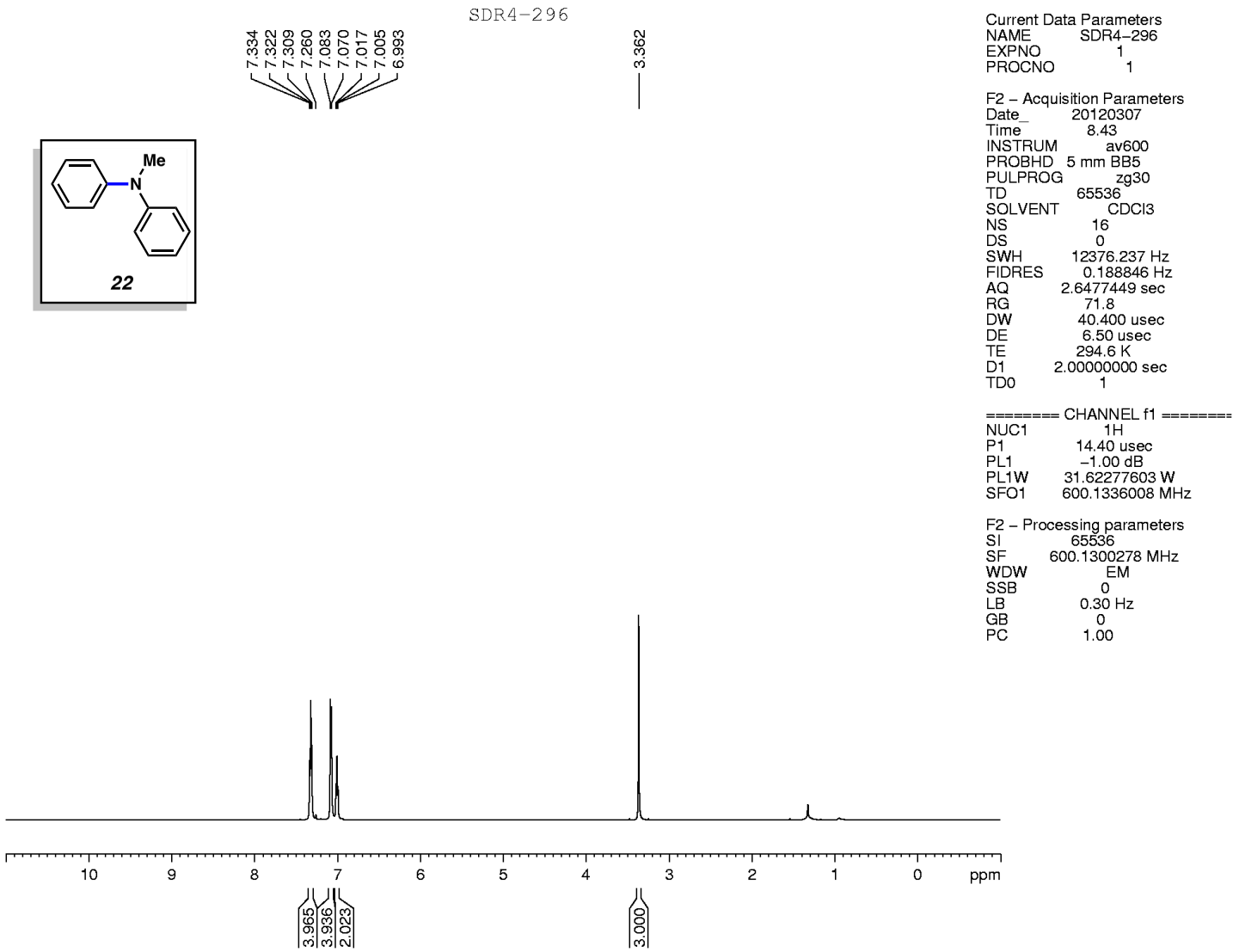


Figure A1.19 ^{1}H NMR (500 MHz, $CDCl_3$) of compound **22**.

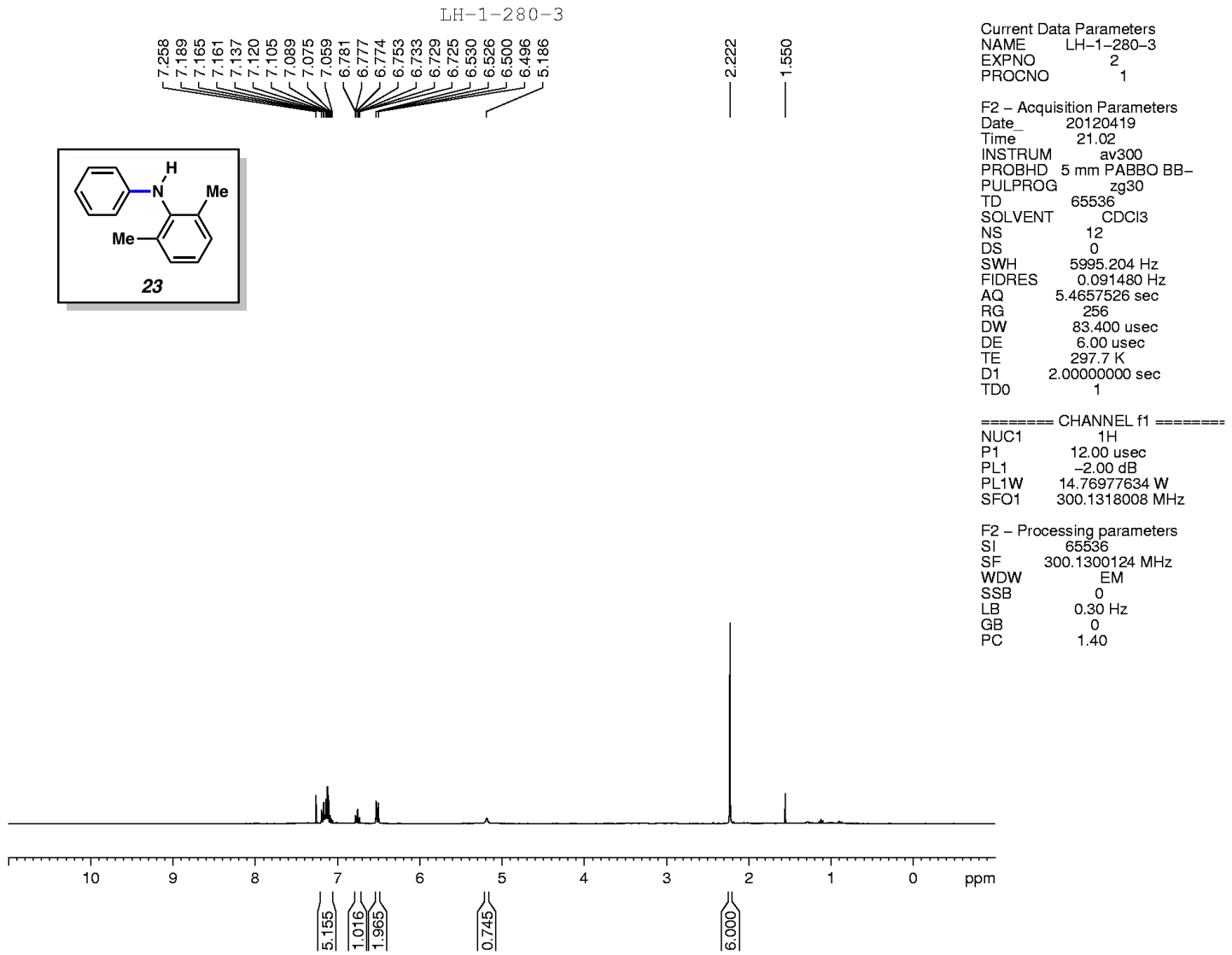


Figure A1.20 ^{1}H NMR (500 MHz, $CDCl_3$) of compound **23**.

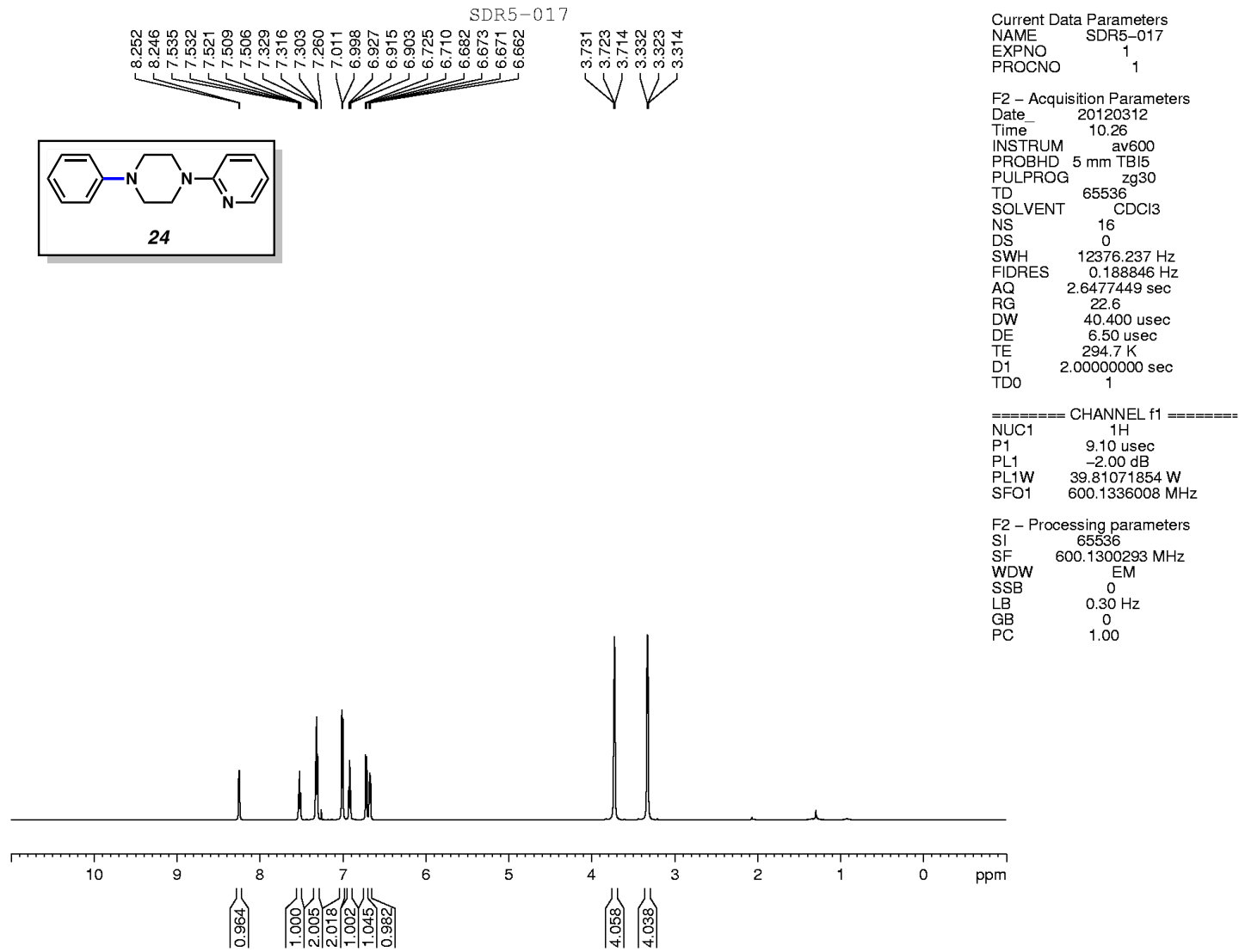


Figure A1.21 ^{1}H NMR (500 MHz, $CDCl_3$) of compound **24**.

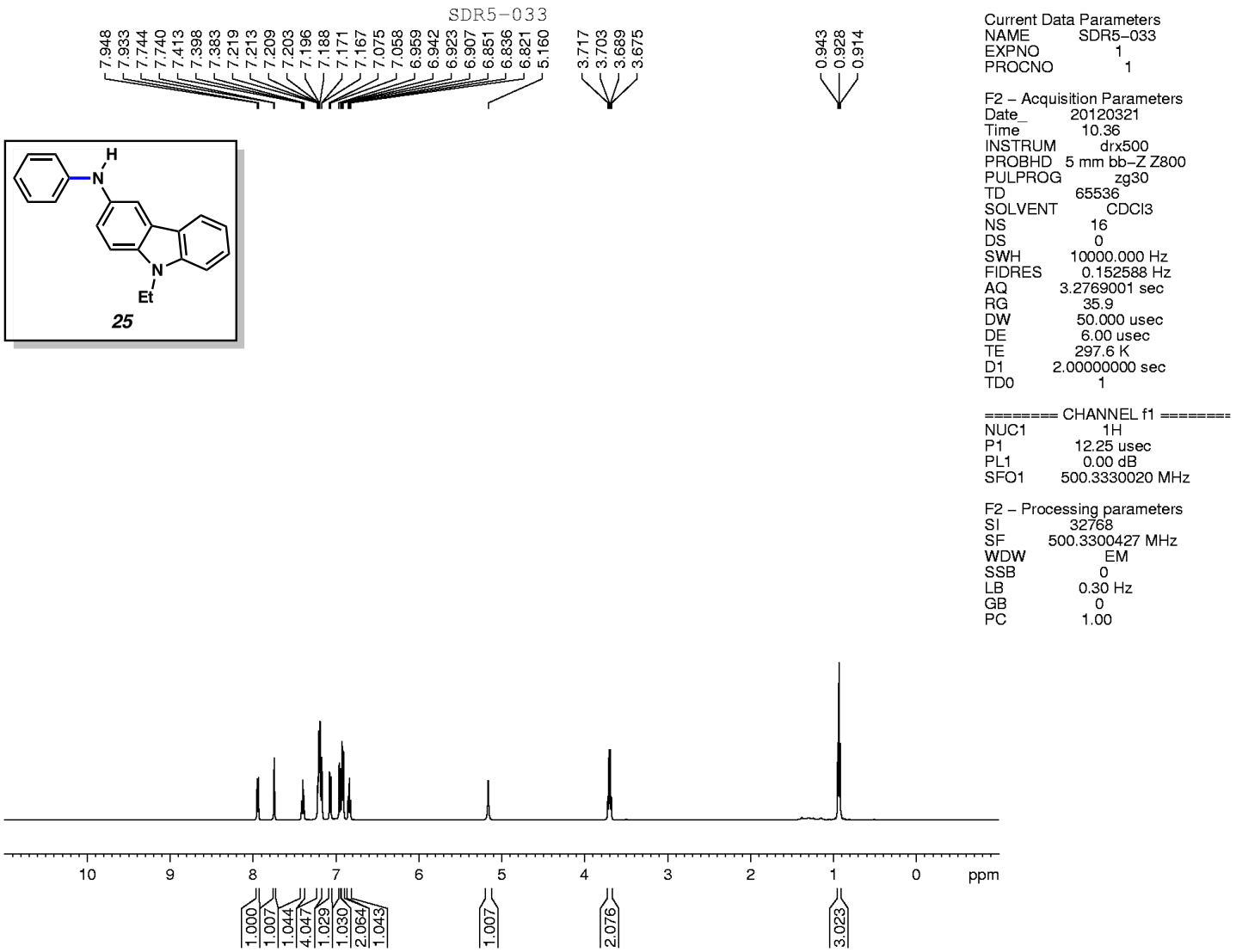


Figure A1.22 ^{1}H NMR (500 MHz, $CDCl_3$) of compound **25**.

References

(1) Lindley, J. *Tetrahedron* **1984**, *40*, 1433–1456.

(2) Biehl, E. *J. Org. Chem.* **1987**, *52*, 2619–2622.

(3) Bunnett, J. *Acc. Chem. Res.* **1978**, *11*, 413–420.

(4) Kosugi, M.; Kameyama, M.; Migita, T. *Chem. Lett.* **1983**, *12*, 927–928.

(5) Surry, D. S.; Buchwald, S. L. *Angew. Chem. Int. Ed.* **2008**, *47*, 6338–6361.

(6) Hartwig, J. F. *Acc. Chem. Res.* **2008**, *41*, 1534–1544.

(7) (a) Wolfe, J. P.; Wagaw, S.; Marcoux, J.-F.; Buchwald, S. L. *Acc. Chem. Res.* **1998**, *31*, 805–818. (b) Hartwig, J. F. *Angew. Chem. Int. Ed.* **1998**, *37*, 2046–2067. (c) Muci, A. R.; Buchwald, S. L. Practical Palladium Catalysts for C–N and C–O Bond Formation. In *Topics in Current Chemistry*; Miyaura, N., Ed.; Springer–Verlag: Berlin, Germany, 2001; Vol. 219, p 131. (d) Kienle, M.; Dubbaka, S.R.; Brade, K.; Knochel, P. *Eur. J. Org. Chem.* **2007**, 4166–4176. (e) Zhang, H.; Cai, Q.; Ma, D. *J. Org. Chem.* **2005**, *70*, 5164–5173. (f) Shafir, A.; Buchwald, S. L. *J. Am. Chem. Soc.* **2006**, *128*, 8742–8743. (g) Altmann, R. A.; Buchwald, S. L. *Org. Lett.* **2007**, *9*, 643–646. (h) Martin, R.; Rodríguez Rivero, M.; Buchwald, S. L. *Angew. Chem. Int. Ed.* **2006**, *45*, 7079–7082. (i) Wolfe, J.; Buchwald, S. L. *J. Org. Chem.* **1997,** *62,* 1264–1267.

(8) (a) Fors, B. P.; Watson, D. A.; Biscoe, M. R.; Buchwald, S. L. *J. Am. Chem. Soc.* **2008**, *130*, 13552–13554. (b) So, C. M.; Zhou, Z.; Lau, C. P.; Kwong, F. Y. *Angew. Chem. Int. Ed.* **2008**, *47*, 6402–6406.

(9) (a) Hamann, B. C.; Hartwig, J. F. *J. Am. Chem. Soc.* **1998**, *120*, 7369–7370. (b) Roy, A. H.; Hartwig, J. F. *J. Am. Chem. Soc.* **2003**, *125*, 8704–8705. (c) Ogata, T.; Hartwig, J. F. *J. Am.*

Chem. *Soc*. **2008**, *130*, 13848–13849. (d) Gao, C.-Y.; Yang, L.-M. *J*. *Org*. *Chem*. **2008**, *73*, 1624–1627.

(10) Wolfe, J. P.; Buchwald, S. L. *J*. *Am*. *Chem*. *Soc*. **1997**, *119*, 6054–6058

(11) Gudmundsson, K. S.; Johns, B. A. *Org*. *Lett*. **2003**, *5*, 1369–1372.

(12) Ghosh, A; Sieser, J. E.; Caron, S.; Watson, T. J. N. *Chem*. *Commun*. **2002**, *15*, 1644–1645.

(13) Tan, Q.; et al. *Bioorg*. *Med*. *Chem*. *Lett*. **2004**, *14*, 3747–3751.

(14) Littke, A. F.; Fu, G. C. *Angew*. *Chem*. *Int*. *Ed*. **2002**, *41*, 4176–4211.

(15) Tobisu, M.; Shimasaki, T.; Chatani, N. *Chem*. *Lett*. **2009**, *38*, 710–711.

(16) Shimasaki, T.; Tobisu, M.; Chatani, N. *Angew*. *Chem*. *Int*. *Ed*. **2010**, *49*, 2929–2932.

(17) Gao, C.; Yang, L. *J*. *Org*. *Chem*. **2008**, *73*, 1624–1627.

(18) (a) Snieckus, V. *Chem. Rev.* **1990**, *90*, 879–933. (b) Hartung, C. G.; Snieckus, V. In *Modern Arene Chemistry;* Astruc, D., Ed.; Wiley–VCH: New York, 2002; p 330–367. (c) Macklin, T.; Snieckus, V. In *Handbook of C–H Transformations*; Dyker, G., Ed.; Wiley–VCH: New York, 2005; p 106–119. (d) Smith, M. B.; March, J. In *March's Advanced Organic Chemistry;* 6th ed.; John Wiley & Sons, Inc.; New Jersey; 2007; p 670. (e) Macklin, T. K.; Snieckus, V. *Org. Lett.* **2005**, *7*, 2519–2522.

(19) Aryl carbamates may also be ortho-functionalized through transition metal-catalyzed processes; see: (a) Bedford, R. B.; Webster, R. L.; Mitchell, C. J. *Org. Biomol. Chem.* **2009**, *7*, 4853–4857. (b) Zhao, X.; Yeung, C. S.; Dong, V. M. *J. Am. Chem. Soc.* **2010**, *132*, 5837–5844. (c) Nishikata, T.; Abela, A. R.; Huang, S.; Lipshutz, B. H. *J. Am. Chem. Soc.* **2010**, *132*, 4978–4979. (d) Yamazaki, K.; Kawamorita, K.; Ohmiya, H.; Sawamura, M. *Org. Lett*. **2010**, *12*, 3978–3981. (e) Feng, C.; Loh, T.-P. *Chem. Commun.* **2011**, *47*, 10458–10460. (f)

Gong, T.-J.; Xiao, B.; Liu, Z.-J.; Wan, J.; Xu, J.; Luo, D.-F.; Fu, Y.; Liu, L. *Org. Lett.* **2011**, *13*, 3235–3237.

(20) For the use of aryl carbamates in C–C bond forming processes, see: (a) Quasdorf, K. W.; Riener, M.; Petrova, K. V.; Garg, N. K. *J. Am. Chem. Soc.* **2009**, *131*, 17748–17749. (b) Finch, A. A.; Blackburn, T.; Snieckus, V. *J. Am. Chem. Soc.* **2009**, *131*, 17750–17752. (c) Xi, L.; Li, B.-J.; Wu, Z.-H.; Lu, X.-Y.; Guan, B.-T.; Wang, B.-Q.; Zhao, K.-Q.; Shi, Z.-J. *Org. Lett.* **2010**, *12*, 884–887. (d) Yoshikai, N.; Matsuda, H.; Nakamura, E. *J. Am. Chem. Soc*. **2009**, *131*, 9590–9599. (e) Quasdorf, K. W.; Antoft-Finch, A.; Liu, P.; Silberstein, A. L.; Komaromi, A.; Blackburn, T.; Ramgren, S. D.; Houk, K. N.; Snieckus, V.; Garg, N. K. *J. Am. Chem. Soc*. **2011**, *133*, 6352–6363. (f) Baghbanzadeh, M.; Pilger, C.; Kappe, C. O. *J. Org. Chem*. **2011**, *76*, 1507–1510. (g) Dallaire, C.; Kolber, I.; Gingras, M. *Org. Synth.* **2002**, *78*, 42. (h) Sengupta, S.; Leite, M.; Raslan, D. S.; Quesnelle, C.; Snieckus, V. *J. Org. Chem.* **1992**, *57*, 4066–4068.

(21) For the use of aryl sulfamates in C–C bond forming processes, see: (a) Civicos, J. F.; Gholinejad, M.; Alonso, D. A.; Najera, C. *Chem. Lett*. **2011**, *40*, 907–909. (b) Shirbin, S. J.; Boughton, B. A.; Zammit, S. C.; Zanatta, S. D.; Marcuccio, S. M.; Hutton, C. A.; Williams, S. J. *Tetrahedron Lett*. **2010**, *51*, 2971–2974. (c) Albaneze-Walker, J.; Raju, R.; Vance, J. A.; Goodman, A. J.; Reeder, M. R.; Liao, J.; Maust, M. T.; Irish, P. A.; Espino, P.; Andrews, D. R. *Org. Lett*. **2009**, *11*, 1463–1466. (d) Ackermann, L.; Barfüsser, S.; Pospech, J. *Org. Lett*. **2010**, *12*, 724–726. (e) Leowanawat, P.; Zhang, N.; Resmerita, A.-M.; Rosen, B. M.; Percec, V. *J. Org. Chem.* **2011**, *76*, 9946–9955. (f) When, P. M.; Du Bois, J. *Org. Lett*. **2005**, *7*, 4685–4688. (g) Chen, G.-J.; Han, F.-S. *Eur*. *J*. *Org*. *Chem*. **2012**, 3575–3579;

(h) Zhang, N.; Hoffman, D. J.; Gutsche, N.; Gupta, J.; Percec, V. *J. Org. Chem.* **2012**, *77*, 5956–5964.

(22) For examples of sulfamate and carbamate amination, see: (a) Ramgren, S. D.; Silberstein, A. L.; Yang, Y.; Garg, N. K. *Angew. Chem. Int. Ed.* **2011**, *50*, 2171–2173. (b) Mesganaw, T.; Silberstein, A. L.; Ramgren, S. D.; Fine Nathel, N. F.; Hong, X.; Liu, P.; Garg, N. K. *Chem. Sci.* **2011**, *2*, 1766–1771. (c) Ackermann, L.; Sandmann, R.; Song, W. *Org. Lett.* **2011**, *13*, 1784–1786.

(23) $Ni(COD)_2$ is commercially available from Strem Chemicals Inc. or Sigma-Aldrich (CAS # 1295-35-8). For more information on this catalyst, see: Wender, P. A.; Smith, T. E.; Zuo, G.; Duong, H. A.; Louie, J. Encyclopedia of Reagents for *Organic Synthesis* **2006**, DOI: 10.1002/ 047084289X.rb118.pub2.

(24) (a) Fan, X.-H.; Li, G.; Yang, L. M. *J. Organomet. Chem.* **2011**, *696*, 2482–2484. (b) Gao, C.-Y.; Cao, X.; Yang, L.-M. *Org. Biomol. Chem.* **2009**, *7*, 3922–3925. (c) Manolikakes, G.; Gavryushin, A.; Knochel, P. *J. Org. Chem.* **2008**, *73*, 1429–1434. (d) Amrani, R. O.; Thomas, A.; Brenner, E.; Schneider, R.; Fort, Y. *Org. Lett.* **2003**, *5*, 2311–2314. (e) Desmarets, C.; Schneider, R.; Fort, Y. *J. Org. Chem.* **2002**, *67*, 3029–3036. (f) Gradel, B.; Brenner, E.; Schneider, R.; Fort, Y. *Tetrahedron Lett.* **2001**, *42*, 5689–5692. (g) Percec, V.; Bae, J-Y.; Hill, D. H. *J. Org. Chem.* **1995**, *60*, 1060–1065. (h) Galland, J.-C.; Savignac, M.; Genet, J.-P. *Tetrahedron Lett.* **1999**, *40*, 2323–2326. (i) Brenner, E.; Fort, Y. *Tetrahedron Lett.* **1998**, *39*, 5359–5362. (j) Brenner, E.; Schneider, R.; Fort, Y. *Tetrahedron* **1999**, *55*, 12829–12842. (k) Desmarets, C.; Schneider, R.; Fort, Y. *Tetrahedron Lett.* **2000**, *41*, 2875–2879. See also reference 15.

(25) Hall, D. G. March, J. *Boronic Acids: Preparation, Applications in Organic Synthesis and Medicine*; Wiley-VCH; Weinheim; 2005; p 394–395.

(26) Although the optimal reaction conditions shown in Table 3 (entries 3 and 4) are generally useful across a range of substrates, further optimization of reaction conditions for individual substrates led to improved yields. The optimized conditions and results are shown in Tables 4–7.

(27) Ismail, F. M. D. *J. Fluorine Chem.* **2002**, *118*, 27–33.

(28) Tsou, T. T.; Kochi, J. K. *J. Am. Chem. Soc.* **1979**, *101*, 6319–6332.

(29) (a) Zhao, Z.; Snieckus, V. *Org. Lett.* **2005**, *7*, 2523–2526. (b) Kamila, S.; Mukherjee, C.; Mondal, S. S.; De, A. *Tetrahedron* **2003**, *59,* 1339–1348. (c) Azzena, U.; Pisano, L.; Pittalis, M. *Appl. Organomet. Chem.* **2008**, *22*, 523–528. See also references 19a, 19d, 20a, 20h.

(30) Barker, T. J.; Jarvo, E. R. *J. Am. Chem. Soc.* **2009**, *131*, 15598–15599.

(31) Guo, D.; Huang, H.; Xu, J.; Jiang, H.; Liu, H. *Org. Lett.* **2008**, *10*, 4513–4516.

(32) Li, J.; Cui, M.; Yu, A.; Wu, Y. *J. Organomet. Chem.* **2007**, *692*, 3732–3742.

(33) Wagaw, S.; Buchwald, S. L. *J. Org. Chem.* **1996**, *61*, 7240–7241.