

# **CHEMISTRY** A European Journal



### **Accepted Article** Title: Aminomethyl transfer (Mannich) reactions between an Otriethylsilylated hemiaminal and anilines, RnC6H5-nNH2 leading to new diamines, triamines, imines or 1,3,5-triazines dependent upon substituent R Authors: Anwar Jacintomoreno, Hemant K. Sharma, Alejandro Metta-Magaña, and Keith H. Pannell This manuscript has been accepted after peer review and appears as an Accepted Article online prior to editing, proofing, and formal publication of the final Version of Record (VoR). This work is currently citable by using the Digital Object Identifier (DOI) given below. The VoR will be published online in Early View as soon as possible and may be different to this Accepted Article as a result of editing. Readers should obtain the VoR from the journal website shown below when it is published to ensure accuracy of information. The authors are responsible for the content of this Accepted Article. To be cited as: Chem. Eur. J. 10.1002/chem.201901877 Link to VoR: http://dx.doi.org/10.1002/chem.201901877

Supported by ACES



# Aminomethyl transfer (Mannich) reactions between an O-triethylsilylated hemiaminal and anilines, $R_nC_6H_{5-n}NH_2$ leading to new diamines, triamines, imines, or 1,3,5-triazines dependent upon substituent R

Anwar Jacintomoreno, Hemant K. Sharma, Alejandro Metta-Magaña, Keith H. Pannell

### Department of Chemistry, University of Texas at El Paso, El Paso, TX. 79968-0513, USA

Abstract The reactions of the Mannich reagent Et<sub>3</sub>SiOCH<sub>2</sub>NMe<sub>2</sub> (1) with a variety of anilines, mono-substituted R<sub>C6</sub>H<sub>4</sub>NH<sub>2</sub>, R = H, 4-CN, 4-NO<sub>2</sub>, 4-Ph, 4-Me, 4-MeO, 4-Me<sub>2</sub>N; R<sub>2</sub>C<sub>6</sub>H<sub>3</sub>NH<sub>2</sub>; di-substituted R<sub>2</sub> = 3,5-(CH<sub>3</sub>)<sub>2</sub>, 3,5-(CF<sub>3</sub>)<sub>2</sub>; R<sub>3</sub>C<sub>6</sub>H<sub>2</sub>NH<sub>2</sub>; tri-substituted R<sub>3</sub> = 3,5-Me<sub>2</sub>-4-Br; and a "super bulky" aniline (Ar\*NH<sub>2</sub>) [Ar\* = 2,6-bis(diphenylmethyl)-4-*tert*-butylphenyl], led to the immediate formation of a range of products dependent upon the substituent. With electron-withdrawing substituents, previously unknown diamines, RC<sub>6</sub>H<sub>4</sub>NH(CH<sub>2</sub>NMe<sub>2</sub>) [R = CN (**2a**), NO<sub>2</sub> (**2b**)] and R<sub>2</sub>C<sub>6</sub>H<sub>3</sub>NH(CH<sub>2</sub>NMe<sub>2</sub>) [R<sub>2</sub> = 3,5-(CF<sub>3</sub>)<sub>2</sub> (**2c**)] were formed. Further reaction of **2a**, **b**, **c** with **1** yielded the corresponding triamines RC<sub>6</sub>H<sub>4</sub>N(CH<sub>2</sub>NMe<sub>2</sub>)<sub>2</sub> (R = CN (**3a**), NO<sub>2</sub> (**3b**) and R<sub>2</sub>C<sub>6</sub>H<sub>3</sub>N(CH<sub>2</sub>NMe<sub>2</sub>)<sub>2</sub>, R<sub>2</sub> = 3,5-(CF<sub>3</sub>)<sub>2</sub> (**3c**). The new polyamines were characterized by NMR spectroscopy, and for **2a**, **2c**, and **3c**, by single crystal XRD. In the case of electron-donating groups, R = 4-OMe, 4-NMe<sub>2</sub>, 4-Me, 3,5-Me<sub>2</sub>, 3,5-Me<sub>2</sub>-4-Br, and for R = 4-Ph, the reactions with **1** immediately led to the formation of the related 1,3,5-triazines, R = 4-MeO (**5a**), 4-Me<sub>2</sub>N (**5b**), 4-Ph (**5c**), 3,5-Me<sub>2</sub>-4-Br (**5e**), 4-Ph (**5f**), 4-Cl (**5g**). The "super-bulky" aniline rapidly produced a single product, namely the corresponding imine Ar\*N=CH<sub>2</sub> (**4**) which was also characterized by single crystal XRD. Imine **4** is both thermally and oxidatively stable. All reactions are very fast, thus based upon the presence of Si we are tempted to denote the reactions of **1** as examples of *Silick Chemistry*.

#### Introduction

We recently reported that  $Et_3SiOCH_2NMe_2$  (1) is a highly efficient Mannich reagent, with the ability to transform a range of RE-H species, E = O, S, N, P, to the corresponding dimethylamino derivatives, RE-CH<sub>2</sub>NMe<sub>2</sub>, under mild conditions, and generally without the need for either a catalyst or activating co-reagent.<sup>1,2</sup> In each case  $Et_3SiOH$  is formed which is easily removed under vacuum. In the case of the reaction of **1** with aniline the final product obtained was hexahydro-1,3,5-triphenyl-1,3,5-triazine, (PhNCH<sub>2</sub>)<sub>3</sub>. However, *via* NMR spectroscopy we were able to observe the transience of the previously unreported triamine, (Me<sub>2</sub>NCH<sub>2</sub>)<sub>2</sub>NPh and to trap, and characterize, its Mo(CO)<sub>4</sub> derivative. The overall mechanism proposed for the 1,3,5-triazine formation is outlined in Scheme 1.



Scheme 1

We now report the impact upon this chemistry effected by using variously-substituted anilines,  $R_nC_6H_{5-n}NH_2$ , R = H, 4-CN, 4-NO<sub>2</sub>, 4-Me, 4-Ph, 4-MeO, 4-Me<sub>2</sub>N;  $R_2C_6H_3NH_2$ ;  $R_2 = 3,5$ -(CH<sub>3</sub>)<sub>2</sub>, 3,5-(CF<sub>3</sub>)<sub>2</sub>;  $R_3C_6H_2NH_2$ ,  $R_3 = 3,5$ -Me<sub>2</sub>-4-Br; and a "super-bulky" aniline Ar\*NH<sub>2</sub> [Ar\* = 2,6-bis(diphenylmethyl)-4-*tert*-butylphenyl].<sup>3</sup> This group of amines range from significantly electron-rich to electron-poor materials, coupled with a specific sterically demanding material. Overall we observe that electron-withdrawing groups do not go through the complete pathway 1 to 5 and yield only the previously unreported thermally stable diamine (2) and triamine (3) materials. On the other hand, the electron-donating substituents progress directly to the 1,3,5-triazines (5) with little or no observation of the intermediate diamines and triamines. All materials were formed in good yield, have been characterized, and selected unreported diamines, triamines and a triazine have been structurally characterized by single crystal XRD. In the case of the super bulky aniline only a single product was obtained in high yield, the imine Ar\*N=CH<sub>2</sub> (4) which we

also characterized by single crystal XRD, thus completing the characterization of each of the materials **2**, **3**, **4** and **5** suggested in Scheme 1.

#### **Results and Discussion**

Trimethylsiloxymethyl-N,N-dimethylamine, Me<sub>3</sub>SiOCH<sub>2</sub>NMe<sub>2</sub>, was first reported by the Mironov Group in 1981, prepared from the reaction of Me<sub>2</sub>NSiMe<sub>3</sub> and formaldehyde.<sup>4</sup> They further demonstrated that this material reacted with halosilanes, R<sub>3</sub>SiX, to form Me<sub>2</sub>NCH<sub>2</sub>X and the corresponding disiloxane, (Me<sub>3</sub>Si)<sub>2</sub>O. More interestingly, they noted that its reaction with excess silylamine led to the formation of diamines and disiloxane (presumably via condensation of initially formed Me<sub>3</sub>SiOH), eq. 1a. Furthermore, its reaction with a hydroaminosilane, BuNHSiMe<sub>3</sub>, led to a hexahydro-1,3,5-tributyl-1,3,5-triazine, eq. 1b.<sup>5</sup>

 $Me_3SiOCH_2NMe_2 + Me_3SiNMe_2 \rightarrow Me_2NCH_2NMe_2 + Me_3SiOSiMe_3$  (1a)

 $3 \text{ Me}_3\text{SiOCH}_2\text{NMe}_2 + 3 \text{ Me}_3\text{SiNHBu} \rightarrow (\text{BuNCH}_2)_3 + 1.5 \text{ Me}_3\text{SiOSiMe}_3$  (1b)

These results suggested that 1 could be an excellent  $CH_2NMe_2$  transfer agent, Mannich reagent, toward a variety of E-H bonds, E = O, S, N, P and  $C_{sp2}$ . Indeed we have reported such chemistry where 1, which in our hands is preferably synthesized from the Mo-catalyzed reaction of Et<sub>3</sub>SiH and DMF,<sup>6</sup> can react rapidly and efficiently at low temperature, and without catalysts, to perform such transfers. We have used the system with secondary amines to form a series of unusual diamines and reported a single reaction with aniline.<sup>2</sup> The latter reaction resulted in good yields of the hexahydro-1,3,5-triphenyl-1,3,5-triazine, presumably *via* the transformation in Scheme 1. There are many routes in the literature reporting efficient formation of triazines,<sup>7</sup> and such materials and their derivatives have considerable utility as organic synthons and reagents,<sup>8</sup> polymer precursors for resins,<sup>9</sup> and materials with significant biological utility.<sup>10</sup> Of particular interest was a recent article from the IBM Almaden laboratory presenting both experimental and theoretical studies on the formation of hexahydrotriazines.<sup>11</sup> Using a high temperature (185°) reaction between amines, paraformaldehyde and water, the authors clearly noted that depending upon the substituent on the starting amines, either hexahydro-1,3,5-triazines or hemiaminals were produced. In the case of *p*-Me<sub>2</sub>N-aniline a high yield (88%) of the triazine was obtained, whereas for aniline itself and p-NO<sub>2</sub>-aniline only trace amounts of the triazine were noted, 2-3%, whereas 80% of the products were the appropriate hemiaminals. The authors performed some computational studies on the system to model the transformation mechanism and their calculations corroborated triazine vs hemiaminal formation for electron-donating groups, and *vice versa* for the electron-withdrawing groups. A similar behavior was reported by Rivera *et al.* for the formation of triazines *via* reaction of anilines with 1,3,6,8-tetraazatricyclo[4.4.1.1<sup>38</sup>]dodecane.<sup>7d</sup>

Given the very efficient chemistry we have observed for the CH<sub>2</sub>NMe<sub>2</sub> transfer chemistry using **1**, it was of interest to observe the results of the reactions between **1** and substituted anilines to see if they also had a significant product distribution even though the chemistry pathway is very different to the IBM chemistry. Thus, we have reacted **1** with RC<sub>6</sub>H<sub>4</sub>NH<sub>2</sub>, R = H, 4-CN, 4-NO<sub>2</sub>, 4-Ph, 4-Me, 4-MeO, 4-Me<sub>2</sub>N, the bis- and tris-substituted anilines, R<sub>2</sub>C<sub>6</sub>H<sub>3</sub>NH<sub>2</sub>, R<sub>2</sub> = 3,5-CH<sub>3</sub>, 3,5-(CF<sub>3</sub>)<sub>2</sub>, R<sub>3</sub>C<sub>6</sub>H<sub>2</sub>NH<sub>2</sub>, and the "super bulky" aniline (Ar\*NH<sub>2</sub>) [Ar\* = 2,6-bis(diphenylmethyl)-4*tert*-butylphenyl]. It is important to note that all reactions were fast: no heating was needed and no catalytic system was added. In keeping with the theoretical predictions noted above, in the case of the strong-electron-donating substituents R = 4-MeO, 4-Me<sub>2</sub>N, 4-Me, R<sub>2</sub>= 3,5-Me<sub>2</sub> and 3,5-Me<sub>2</sub>-4Accepted Manuscript

Br, the approriate triazines were formed in high yield, eq. 2. The 4-Cl aniline also produced a triazine contrary to expectation.



 $R = 4-MeO~(\textbf{5a});~4-Me_2N~(\textbf{5b});~4-Me~(\textbf{5c});~3,5-Me_2~(\textbf{5d});~3,5-Me_2-4-Br~(\textbf{5e});~4-Ph~(\textbf{5f});~4-Cl~(\textbf{5g})$ 

The structure of a new triazine material, hexahydro-1,3,5-(3,5-dimethyl-4-bromophenyl)-1,3,5-triazine, **5e**, is illustrated in Figure 1, and is the first of this class of material to exhibit a



Figure 1. Structure of 5e (CCDC 1891888)

boat conformation, with two of the substituents in an axial position and one in equatorial. All previously reported 1,3,5-hexahydrotriazine structures exhibited a chair conformation.<sup>12</sup> However, for systems with substituted C atoms, e.g. *trans*-2,4,6-trimethoxy-1,3,5-trinitrotrihydro-1,3,5-triazine a boat conformation was observed, although the *cis* isomer crystallized in a chair conformation.<sup>13</sup>

Diamine and triamine formtion

Using the anilines containing electron-withdrawing groups, R = 4-CN, 4-NO<sub>2</sub>,  $R_2 = 3,5$ -(CF<sub>3</sub>)<sub>2</sub>, we observed no significant hexahydro-1,3,5-triazine formation and only high yields of the corresponding, and unknown, diamines and triamines, eq. 3.



R = 4-CN (2a/3a), 4-NO<sub>2</sub> (2b/3b), 3,5-(CF<sub>3</sub>)<sub>2</sub> (2c/3c)

Since the occurrence of non-symmetrical diamines and triamines is not well-established, we have examined the structural properties of selected compounds using single crystal XRD. The structures of the diamines 4-(CN)C<sub>6</sub>H<sub>4</sub>NH(CH<sub>2</sub>NMe<sub>2</sub>) [**2a**], 3,5-(CF<sub>3</sub>)<sub>2</sub>C<sub>6</sub>H<sub>3</sub>NH(CH<sub>2</sub>NMe<sub>2</sub>) [**2c**], and triamine 3,5-(CF<sub>3</sub>)<sub>2</sub>C<sub>6</sub>H<sub>3</sub>NH(CH<sub>2</sub>NMe<sub>2</sub>) [**3c**] are illustrated in Figure 2.





Figure 2. Structure of **2a** (top left, CCDC 1891885), **2c** (top right, CCDC 1891887), and **3c** (bottom, CCDC 1891886). For **3c** one conformer is shown and disorder is omitted for clarity.

For the diamine 2c we can observe the conjugation of N(1) with the ring as shown by the C-N-C angle of 123.0(4)° and the shorter N-C<sub>aryl</sub> distance of 1.385(5)Å compared to the N-CH<sub>2</sub> bond of 1.438(5)Å. The system is a little out of the plane with respect to the aryl group by 22.5(4)° (C-C-N-C). Nirogen atom N(2) on the other hand is pseudo-tetrahedral with the distances N-C averaging 1.467(9)Å. Compound **2a** has geometrical parameters similar to those of **2c**; however, the dihedral angle (C-C-N-C) is significantly reduced to 5.7(6)° suggesting packing effects.

For the triamine **3c** the N-aryl conjugation is again apparent as shown by the angles C-N-C of  $120.0(5)^{\circ}$ , the C-N distances are also the same within the experimental error. However, the steric congestion is increased, and although this is not reflected in the bond lengths and angles, it does impact the crystal structure by including two conformers in the asymetric unit cell in comparison to only one for **2c**. The CF<sub>3</sub> groups present a disorder that was not observed for **2c** indicating that the packing is more efficient for the latter, a fact corroborated by the calculated density, 1.402 g/cm<sup>3</sup> for **3c** vs 1.549 g/cm<sup>3</sup> for **2c**.

Imine formation

Finally we have been able to observe, isolate and structurally characterize an example the supposed imine intermediates in this chemistry by reacting **1** with a "super bulky" aniline,  $Ar*NH_2$  [Ar\* = 2,6-bis(diphenylmethyl)-4-*tert*-butylphenyl]. The reaction was fast and only a single product was observable under our reaction conditions; i.e. neither diamine nor triamine could be detected as a transient and no triazine product was observed. Clearly the extra bulk of the substituents results in a kinetic stabilization of the imine, an example of such utility of bulky groups across the chemistry of the elements of the Periodic Table.<sup>14</sup> The structure of the imine is presented in Figure 3.



Figure 3. Structure of **4** (CCDC 1891889).

As expected for the imine structure, the C-N methylene bond is significantly shorter than the N-C<sub>aryl</sub> bond, 1.247 Å vs 1.431 Å. Because of the bulky substituents the imine is perpendicular to the aryl plane at 93.6(2)° thereby precluding any conjugation. Interestingly in the crystal structure a H- $\pi$  interaction is observed (3.261 Å) through the CH<sub>2</sub> of the imine, generating a chain on the b axis. The only other such imine structure reported, also with a bulky substituent on nitrogen, CH<sub>2</sub>=NAr (Ar = 2,6-(2,4,6-Me<sub>3</sub>C<sub>6</sub>H<sub>2</sub>)<sub>2</sub>C<sub>6</sub>H<sub>3</sub>), also exhibits a similar NH<sub>2</sub> group Accepted Manuscrip

orthogonal to the aryl group with a similar C-N methylene bond length of 1.247 Å.<sup>15</sup> In both the reported imine and ours, the methylene protons can be noted by <sup>1</sup>H NMR spectroscopy as a pair of doublets, for **4** at 6.12 ( ${}^{1}J_{HH} = 18$  Hz) and 7.13 ppm ( ${}^{1}J_{HH} = 12$  Hz), respectively. Immine **4**, unlike the previously reported example, is a very thermally and oxidatively stable material and its possible chemical reactivity is currently under investigation.

#### Experimental

General reaction of anilines and Et<sub>3</sub>SiOCH<sub>2</sub>NMe<sub>2</sub>: In a typical experiment, a Pyrex NMR tube was charged with 0.200 g, 0.633 mmol of Et<sub>3</sub>SiOCH<sub>2</sub>NMe<sub>2</sub>, 0.316 mmol of NH<sub>2</sub>Ar-substituted material, and 0.500 mL of CDCl<sub>3</sub> or C<sub>6</sub>D<sub>6</sub> under nitrogen gas atmosphere. The contents were degassed *via* three freeze-pump-thaw cycles, and the tube sealed under vacuum. Initial <sup>13</sup>C and <sup>1</sup>H NMR spectra were obtained after thawing of reaction mixture and the reaction was monitored at 25 °C by NMR and evaluated for formation of triazines, mono-substituted diamine, or disubstituted triamines. In the event of formation of a triazine the contents of NMR tube were decanted into a 5 mL round bottom flask, and solvents and volatile byproducts, (Me<sub>2</sub>N)<sub>2</sub>CH<sub>2</sub> and Et<sub>3</sub>SiOH) were removed by vacuum to leave behind pure triazine solids in 45 - 65% yields.

#### Hexahydro-1,3,5-(p-methoxyphenyl)-1,3,5-triazine,<sup>16</sup> from the reaction of 4-

(**methoxy**)**aniline with Et<sub>3</sub>SiOCH<sub>2</sub>NMe<sub>2</sub>:** NMR in CDCl<sub>3</sub>, <sup>13</sup>C: 55.7, 71.3, 114.6, 120.2, 142.8, 154.6. <sup>1</sup>H: 3.77 (s, 9 H, CH<sub>3</sub>), 4.70 (s, 6 H, CH<sub>2</sub>), 6.79 (d, 6 H, CH), 7.05 (d, 6 H, CH). Melting point: Melting point: 128 °C (lit. value 128-130 °C).

Hexahydro-1,3,5-(4-dimethylaminophenyl)-1,3,5-triazine),<sup>17</sup> from the reaction of 4-(dimethylamino)aniline with Et<sub>3</sub>SiOCH<sub>2</sub>NMe<sub>2</sub>: NMR in CDCl<sub>3</sub>, <sup>13</sup>C: 4135, 71.7, 114.4, 120.3, 140.8, 146.3. <sup>1</sup>H: 2.86 (s, 18 H, CH<sub>3</sub>), 4.60 (s, 6 H, CH<sub>2</sub>), 6.72 (d, 6 H, CH), 7.02 (d, 6H, CH). Melting pointMelting point: 154 °C (lit. value 156 °C)

Hexahydro-1,3,5-(4-methylphenyl)-1,3,5-triazine,<sup>17</sup> from the reaction of 4-methyl-aniline with Et<sub>3</sub>SiOCH<sub>2</sub>NMe<sub>2</sub>: NMR in C<sub>6</sub>D<sub>6</sub>, <sup>13</sup>C: 20.6, 69.4, 118.3, 130, 147.2. <sup>1</sup>H: 2.08 s, 4.62 s, 6.88 d. Melting point: Melting point: 125 °C (lit. value 126 °C).

Hexahydro-1,3,5-(3,5-dimethylphenyl)-1,3,5-triazine<sup>17</sup> from the reaction of 3,5-

**dimethylaniline with Et<sub>3</sub>SiOCH<sub>2</sub>NMe<sub>2</sub>:** NMR in C<sub>6</sub>D<sub>6</sub>, <sup>13</sup>C: 21.8, 68.7, 115.9, 122.9, 138.8, 149.4. <sup>1</sup>H: 2.10 (s, 18 H, ), 4.66 (s, 6 H, ), 6.41 (d, 4H, ), 6.56 (d, 6H, ). Melting point: 128 °C (lit. value 128 °C).

Hexahydro-1,3,5-(4-chlorophenyl)-1,3,5-triazine,<sup>17</sup> from the reaction of 4-chloroaniline with Et<sub>3</sub>SiOCH<sub>2</sub>NMe<sub>2</sub>: NMR in CDCl<sub>3</sub>, <sup>13</sup>C: 68.9, 119.18, 126.5, 129.3, 147.2. , <sup>13</sup>C: 68.9, 119.18, 126.5, 129.3, 147.2. <sup>1</sup>H: 4.80 (s, 6H) 6.90 (d, 6H, ), 7.17 (d, 6H, ). Melting point: 148-152 °C (lit. value 154 °C).

**Hexahydro-1,3,5-(4-1,1'-biphenyl)-1,3,5-triazine:**<sup>18</sup> <sup>1</sup>H NMR: δ 4.94 (N-CH<sub>2</sub>), 6.64-6.74, 7.04-7.07, 7.34-7.51 (Ph). <sup>13</sup>C NMR: 68.3(CH<sub>2</sub>), 117.8, 126.6, 127.8, 128.6, 133.8, 140.7, 147.8 (Ph). Anal. Calcd. for C<sub>39</sub>H<sub>33</sub>N<sub>3</sub>: C, 86.15; H, 6.12. Found: C, 84.70; H, 6.63; Melting point: 148-152 °C

Hexahydro-1,3,5-(4-bromo-3,5-dimethylphenyl)-1,3,5-triazine from the reaction of 4bromo-3,5-dimethyl-aniline with Et<sub>3</sub>SiOCH<sub>2</sub>NMe<sub>2</sub>: NMR in CDCl<sub>3</sub>, <sup>13</sup>C: 24.3, 68.7, 117.9, 119.2, 138.9, 147.2. <sup>1</sup>H: 2.33 (s, 18 H, CH<sub>3</sub>), 4.75 (s, 6 H, CH<sub>2</sub>), 6.68 (s, 6 H, CH). <sup>1</sup>H: 2.32 (s, 18 H, CH<sub>3</sub>), 4.74 (s, 6 H, CH<sub>2</sub>), 6.67 (s, 6 H, CH). Melting point: 134°C; HRMS 632.999; calcd. 632.9989.

A typical synthesis of a diamine.

**Reaction of Et<sub>3</sub>SiOCH<sub>2</sub>NMe<sub>2</sub> with 4-cyanoaniline:** A Pyrex NMR tube was charged with 0.17 g, 0.9 mmol of Et<sub>3</sub>SiOCH<sub>2</sub>NMe<sub>2</sub>, 0.106 g, 0.9 mmol, of 4-cyanoaniline in 0.5 mL CDCl<sub>3</sub>. The tube was sealed under vacuum. An immediate reaction occurred and after 10 minutes monitoring by <sup>1</sup>H, <sup>29</sup>Si and <sup>13</sup>C NMR spectroscopy showed the formation of diamine and Et<sub>3</sub>SiOH. The sovent and the triethylsilanol were removed under vacuum and the residue was extracted with 5 mL of hexanes and concentrated. Leaving the solution in the refrigerator overnight resulted in the formation of diamine **2a** as a colourless crystals, 0.12 g (68 %).

Synthesis of triamine: Reaction of Et<sub>3</sub>SiOCH<sub>2</sub>NMe<sub>2</sub> with 4-cyanoaniline (1:2 ratio): In a typical experiment, a 10 mL round bottom flask was charged with 0.24 g (1.27 mmol) of Et<sub>3</sub>SiOCH<sub>2</sub>NMe<sub>2</sub>, 0.301 g (2.54 mmol) of 4-cyanoaniline, in 3 mL of CDCl<sub>3</sub>. The reaction was monitored by <sup>1</sup>H, <sup>29</sup>Si and <sup>13</sup>C NMR spectroscopy, after 10 minutes of the stirring of reaction mixture at room temperature, the <sup>13</sup>C NMR spectra displayed a major resonance at 67.3 ppm due to CH<sub>2</sub> group indicating the formation of diamine **2a**. After 4h of stirring, the resonance at 67.3 ppm due to methylene group of diamine was replaced with a new methylene resonance at 75.3 ppm indicating complete transformation of diamine to triamine **3a**. The solvent and triethylsilanol were removed under vacuum. The residue was extracted with 5 mL of hexanes, concentrated and left in the refrigerator for recrystallization. A white solid triamine, 0.12 g (41%) yield was obtained along with 2-3 % trace impurity of diamine. Recrystallization from hexane/CH<sub>2</sub>Cl<sub>2</sub> produced pure material but upon standing in both the solid state and solution, trace amounts of **2a** would be observable. This process resulted in the C and H analyses for triamines to be poor.

## **Synthesis of triamine: Reaction of Et<sub>3</sub>SiOCH<sub>2</sub>NMe<sub>2</sub> with 4-cyanoaniline diamine (1:1 ratio):** A Pyrex NMR tube was charged with 0.21 g, 1.1 mmol of Et<sub>3</sub>SiOCH<sub>2</sub>NMe<sub>2</sub>, 0.19 g (1.1 mmol) of **2a** in 0.5 mL CDCl<sub>3</sub>. The tube was sealed under vacuum. NMR monitoring after 20 minutes of

11

reaction by <sup>1</sup>H, <sup>29</sup>Si and <sup>13</sup>C NMR spectroscopy exhibited the complete transformation of diamine to triamine. The sovent and the triethylsilanol were removed under vacuum. The residue was extracted with 5 mL of hexanes and recrystallization from hexanes produced triamine, white solid in 80% yield. All diamine and triamine NMR spectra were recorded in CDCl<sub>3</sub>.

Spectral data for {(3,5-trifluorophenyl)aminomethyl}-dimethylamine: <sup>1</sup>H NMR:  $\delta$  2.27 (s, 6H, CH<sub>3</sub>), 3.75 (d, 6 Hz 2H, N-CH<sub>2</sub>), 4.63 (br, 1H, NH), 7.15, 7.04 (3H, Ph). <sup>13</sup>C NMR:  $\delta$  43.3 (N-Me), 67.8 (CH<sub>2</sub>), 110.7 (d, 3.8 Hz), 112.6 (d, 2.8 Hz), 123.5 (q, J = 272.5 Hz).7, 132.0, 132.5 (q, J = 32.6Hz), 148.2 (Ph). Anal. Calcd. for C<sub>11</sub>H<sub>12</sub>F<sub>6</sub>N<sub>2</sub>: C, 46.15; H, 4.23. Found: C, 45.80; H, 4.18.

**Spectral data for 4-cyanophenyl diamine:** <sup>1</sup>H NMR:  $\delta$  1.78 (s, 6H, CH<sub>3</sub>), 3.28 (d, 6 Hz, 2H, N-CH<sub>2</sub>), 4.29 (br, 1H, NH), 6.19, 6.94 (4H, Ph). <sup>13</sup>C NMR:  $\delta$  42.3 (N-Me), 67.3 (CH<sub>2</sub>), 99.4 (CN), 112.9, 114.5, 133.6, 150.9 (Ph). Anal. Calcd. for C<sub>10</sub>H<sub>13</sub>N<sub>3</sub>: C, 68.54; H, 7.48. Found: C, 68.96; H, 6.87.

**Spectral data for 4-nitrophenyl diamine:** <sup>1</sup>H NMR:  $\delta$  2.28 (s, 6H, CH<sub>3</sub>), 3.81 (d, 6 Hz, 2H, N-CH<sub>2</sub>), 5.03 (br, 1H, NH), 8.06, 8.08 (4H, Ph). <sup>13</sup>C NMR:  $\delta$  42.3 (N-Me), 67.3 (CH<sub>2</sub>), 111.9, 126.2, 138.6, 153.0 (Ph). Anal. Calcd. for C<sub>9</sub>H<sub>13</sub>N<sub>3</sub>O<sub>2</sub>: C, 55.37; H, 6.71. Found: C, 54.97; H, 6.54.

**Spectral data for 3,5-trifluorophenyl triamine:** <sup>1</sup>H NMR: δ 2.17 (s, 12H, CH<sub>3</sub>), 3.86 (s, 4H, N-CH<sub>2</sub>), 7.15, 7.00 (3H, Ph). <sup>13</sup>C NMR: δ 42.1 (N-Me), 76.1 (CH<sub>2</sub>), 110.6, 113.8, 123.8 (CF<sub>3</sub>, q, 268.4 Hz), 131.5 (q, J = 32.5 Hz), 148.2 (Ph).

Spectral data for 4-cyanophenyl triamine: <sup>1</sup>H NMR:  $\delta$  1.88 (s, 12H, CH<sub>3</sub>), 3.88 (s, 4H, N-

CH<sub>2</sub>), 6.44, 6.82 (4H, Ph). <sup>13</sup>C NMR: δ 41.7 (N-Me), 75.3 (CH<sub>2</sub>), 100.6 (CN), 114.7, 120.1, 132.7 152.0 (Ph).

**Spectral data for 4-nitrophenyl triamine:** <sup>1</sup>H NMR: δ 2.26 (s, 12H, CH<sub>3</sub>), 3.98 (s, 4H, N-CH<sub>2</sub>), 6.98, 8.14 (4H, Ph). <sup>13</sup>C NMR: δ 42.1 (N-Me), 75.8 (CH<sub>2</sub>), 111.9, 113.1, 125.4, 152.7 (Ph).

#### Synthesis of imine 5, Ar\*N=CH<sub>2</sub>, Ar\* = 2,6-bis(diphenylmethyl)-4-*tert*-butylphenyl.

A 25 mL round bottom flask was charged with 0.480 g (2.54 mmole) of Et<sub>3</sub>SiOCH<sub>2</sub>NMe<sub>2</sub> and 0.612 g (1.27 mmol) of Ar\*NH2 in 13 mL of methylene chloride at room temperature. The reaction was stirred and monitored by <sup>1</sup>H and <sup>13</sup>C NMR spectroscopy. After 15 minutes the reaction was heated to 60°C in an oil bath. After 3 hours the the reaction cooled to room temperature and all volatiles were removed under vacuum. A white solid was obtained and identified by NMR as the imine. Recrystallization from hexane/CH<sub>2</sub>Cl<sub>2</sub> reflux produced pure colorless crystals suitable for SC-XRD, 55% yield.. <sup>13</sup>C NMR (CDCl<sub>3</sub>);  $\delta$  158.63 (N=<u>C</u>H<sub>2</sub>), 148.60, 145.85, 144.20, 131.87, 129.72, 128.25, 126.28, 125.42, 51.94 (Ar<sub>2</sub><u>C</u>), 34.45 (Me<sub>3</sub><u>C</u>), 31.36 (Me). <sup>1</sup>H NMR  $\delta$  7.24, 7.19, 7.13 (d, <sup>1</sup>J<sub>HH</sub> = 18 Hz) 7.07, 7.06, 6.85, 6.12 (d, <sup>1</sup>J<sub>HH</sub> = 18 Hz), 5.44 (CH), 1.08 (Me). Melting Point: 132°C.

#### **AUTHOR INFORMATION**

Corresponding Author

#### kpannell@utep.edu

#### Notes

We declare no competing financial interest.

ACKNOWLEDGEMENTS. We thank the Welch Foundation for support of this research via

Grant # AH-0546. We thank Professor Skye Fortier for a sample of 2,6-bis(diphenylmethyl)-4-

<sup>*t*</sup>butyl-aniline.

#### References

- 1 H. K. Sharma, P. E. Gonzalez, A. L. Craig, S. Chakrabarty, A. J. Metta-Magana, K. H. Pannell, *Chemistry A European Journal* **2016**, *22*, 7363-7366.
- 2 P. E. Gonzalez, H. K. Sharma, S. Chakrabarty, A. J. Metta-Magaña, K. H. Pannell, *Eur. J. Org. Chem.* **2017**, 5610-5616.
- 3 A. K. Maity, S. Fortier, L. Griego, A. J. Metta-Magaña, *Inorg. Chem.*, **2014**, *53*, 8155–8164.
- 4 V. P. Kozyukov, Vik. P. Kozyukov, V. F. Mironov, *Zh. Obshch. Khim.* **1981**, *51*, 2382-2383; ibid **1982**, *52*, 1386-1394
- 5 V. P. Kozyukov, Vik. P. Kozyukov, V. F. Mironov, *Zh. Obshch. Khim.* **1983**, *53*, 119-126
- 6 R. Arias-Ugarte, H. K. Sharma, A. L. C.; Morris, K. H. Pannell, *J. Amer. Chem. Soc.* **2012**, *134*, 848-8512
- (a) A. T. Nielsen, R. L. Atkins, D. W. Moore, R. M. Scott, D. Mallory, J. M. LaBerge, J. Org. Chem., 1973, 38, 3288–3295. (b) K. Singh, K. Ashish, S. Shukla, M. A. Quraishi, J. Materials Environmental Sci. 2011, 2, 403-406. (c) S. D. Pardeshi, P. A. Sathe, B. V. Pawar, K. S. Vadagaonkar, A. C. Chaskar, Eur. J. Org. Chem. 2018, 18, 2098-2102. (d) A. Rivera, L. J. Torres, J. D. Leiton, M. S. Morales-Rios, P. Joseph-Nathan, Synthetic Comm. 2002, 32, 1407-1414.
- 8 (a) P. Liu, G. Xu, J. Sun, Org. Lett. 2017, 19, 1858-1861 (b) D. Ji, J. Sun, Org. Lett.
  2018, 20, 2745-2748. (c) L. K. B. Garve, A. Kreft, P. G. Jones, D. B. Werz, J. Org.
  Chem. 2017, 82, 9235-9242. (d) R. J.Wojtecki, Y. Yuen, T. G. Zimmerman, G. O. Jones,
  H. W. Horn, D. J. Boday, J. L. Hedrick, J. M. Garcia, Analyst, 2015, 140, 5184-5189.
- 9 (a) A. de la Hoz, A. M. Sanchez-Migallon, *Targets in Heterocyclic Systems*, 2016, 20, 139-173. (b) R. Bacaloglu, L. Cotarca, N. Marcu, A. Tarnaveanu, *Materiale Plastice (Bucharest, Romania)*, 1985, 22, 163-167 (c) L. H. Chance, *J. Appl. Poly. Sci.* 1981, 26, 2959-2966.
- 10 (a) J. Fraczyk, B. Kolesinska, M. Swiontek, W. Lipinski, D. Drozdowska, J. Kaminski, Anti-Cancer Agents in Medicinal Chemistry, **2016**, *16*, 1435-1444. (b) R. S Shinde, S. D.

Salunke, J. Chem. and Pharm. Research 2015, 7, 704-714. (c) A. Dandia, A. K. Jain, S. Sharma, Chem. Lett. 2014, 43, 521-523.

- 11 G. O. Jones, J. M. Garcia, H. W. Horn, J. L. Hedrick, Org. Lett. 2014, 16, 5502-5505.
- (a) Davidson, A. J.; Oswald, I. D. H.; Francis, D. J.; Lennie, A. R.; Marshall, W. G.; Millar, D. I. A.; Pulham, C. R.; Warren, J. E.; Cumming, A. S. *CrystEngComm*, 2008, 10, 162-165.
  (b) Jerslev, B.; Brehm, L.; Gabrielsen, M. V. *Acta Chem Scand.* 1977, B31, 875-882.
  (c) Giumanini, A. G.; Verardo, G.; Randaccio, L.; Bresciani-Pahor, N ;Traldi, P. J. Prakt. Chem. 1985, 327, 739-748.
  (d) Brunner, H., Winter, A., Nuber, B. J. Organomet. Chem. 1998, 558, 213-218.
- 13 A. Chafin, L. Merwin, J. Org. Chem. 2000, 65, 4743-4744.
- 14 H. Hisako, H.Tobita, *Coord. Chem. Rev.* 2018, 355, 362-379.
- 15 A. E. Carpenter, A. L. Rheingold, J. S. Figueroa, *Organometallics* **2016**, *35*, 2309-2318.
- 16 M. Shiozaki, Bull. Chem. Soc. Jap. 1987, 60, 645-648.
- 17 A. G. Giumanini, G. Verardo, E. Zangrando, L. Lassiani, *J. Praktische Chemie (Leipzig)* **1987**, *329*, 1087-1103.
- 18 Z. Zeng, H. Jin, X. Song, Q. Wang, M. Rudolph, F. Rominger, A. S. K. Hashmi, *Chem. Commun.* (Cambridge, United Kingdom), **2017**, *53*, 4304-4307.