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Apparent Alkyl Transfer and Phenazine Formation via an Aryne Intermediate

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ABSTRACT: Treatment of chlorotriaryl derivatives **3a** and **3d** or fluorotriaryl derivatives **3b** and **3e** with potassium diisopropylamide afforded alkyl-shifted phenazine derivatives **5a/5b**, rather than the expected 9-membered triaza *orthocyclophane* **2a**. The phenazine derivatives were isolated in 78-98% yield depending on the halogen and alkyl group present. In the absence of the halogen (chloro or fluoro), the apparent alkyl shift proceeds more slowly and cannot proceed via the intermediacy of the aryne intermediate. Mechanistic possibilities include intramolecular nucleophilic attack on an aryne intermediate leading to a zwitterionic intermediate and alkyl transfer via either a 5-endo-tet process, or via a Smiles rearrangement.

INTRODUCTION

Cyclotrimeratrylene (CTV, **1**), a [1.1.1]orthocyclophane, is an archetypal cyclophane scaffold that is commonly employed in supramolecular chemistry.¹⁻⁴ As part of our research program directed toward the synthesis and application of apex-modified CTV derivatives⁵⁻⁷ with unique material properties and applications involving host-guest

chemistry⁸ we recently reported the synthesis of the new triaza orthocyclophane **2a**⁹ (Figure 1) which was alkylated to give the N,N',N''-trimethyl derivative **2b**. Following a 6-step linear sequence to obtain the precursor **3a** (Scheme 1), two mechanistically different approaches were examined in order to obtain the final desired triazacyclophane **2a** (Scheme 1). The first method employed a Buchwald-Hartwig N-arylation,¹⁰⁻¹³ which was ultimately successful in the macrocyclization of **3a** to azacyclophane **2a**.⁹ In parallel, we had also envisioned that the use of benzyne (aryne) intermediate **4a** should be a viable synthetic route to the triazacyclophane skeleton, which led to the observation of an unexpected alkyl transfer and phenazine formation with interesting mechanistic implications that we describe herein.

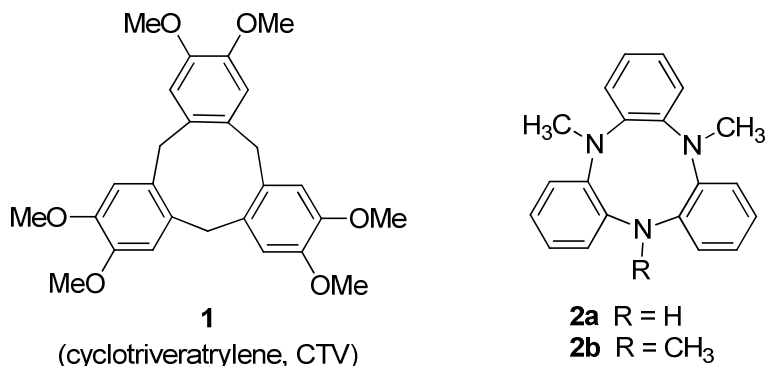


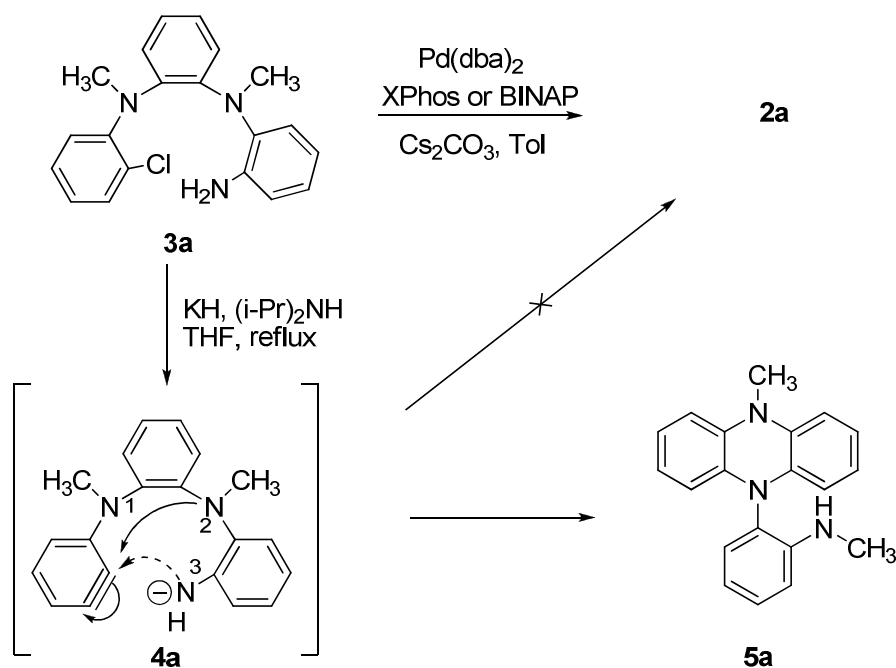
Figure 1: Structures of CTV and 1,4,7-triazacyclononatriene derivatives

Ring closures via aryne intermediates were first introduced independently by Bunnett¹⁴ and Huisgen.¹⁵ Since then, aryne intermediates have been used extensively in organic synthesis¹⁶ and in the synthesis of natural products.¹⁷ Barluenga *et al.* exploited the use of benzyne-tethered vinyl or aryl lithium compounds to obtain indole and benzo-fused

heterocyclic derivatives.¹⁸ The reactivity of aryne intermediates toward nucleophilic attack is attributed to the low energy LUMO, which is a consequence of the “bending” of the triple bond within the ring; decreasing the energy gap between the LUMO of the aryne and the HOMO of the attacking nucleophile enables reaction between the two partners.¹⁹ For generating benzyne intermediates, a well-established method involves treating an aryl halide with a strong base, especially alkali metal aryls/alkyls or amides in ether solvents or liquid ammonia. Limitations arising from these reactions are due to the tendency for the solvent or the base itself to react with the benzyne intermediate, or from reduction of the benzyne via hydride transfer from the alpha-carbon of an amide base such as lithium diisopropylamide (LDA).¹⁹

RESULTS AND DISCUSSION

When we treated intermediate **3a** with potassium diisopropylamide (KDA) in THF under reflux in order to form benzyne intermediate **4a**, a curious methyl shift was observed accompanied by the production of an unexpected phenazine derivative **5a**, rather than the desired triaza orthocyclophane derivative **2a** (Scheme 1). Reactions that were attempted with lithium diisopropylamide (LDA) were more sluggish and were not as clean. We had expected that the most nucleophilic anilide nitrogen (N³) would react rather than the neutral, more sterically encumbered, and presumably less nucleophilic tertiary nitrogen (N²).



Scheme 1: Cyclization of **3a** via Buchwald-Hartwig yielding orthocyclophane **2a** and benzyne route affording phenazine **5a**

Although the high-resolution molecular ion observed at 301.1562 was consistent with the expected molecular formula for orthocyclophane **2a**, the isomeric structure **5a** was suggested by analysis of the spectral data and was ultimately confirmed by single crystal X-ray analysis of its tosylate and hydrochloride salts (Figures 2 and S1). Both salts independently afforded X-ray quality crystals from diethyl ether.

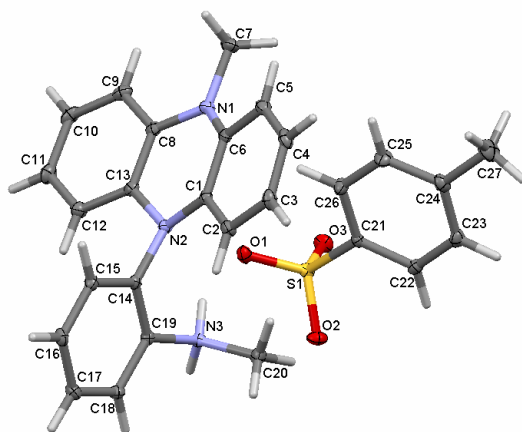
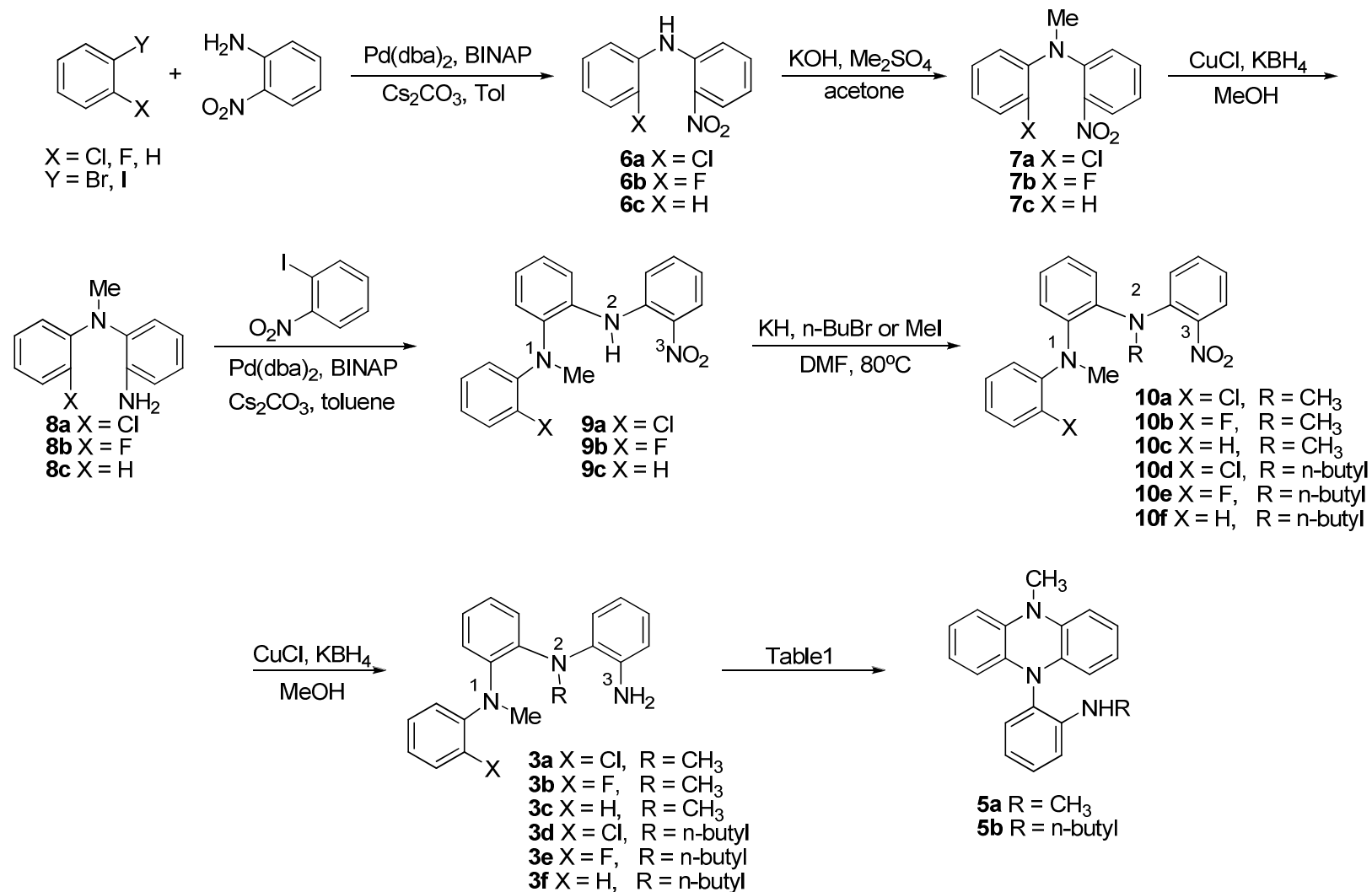


Figure 2: X-Ray crystal structure of the methyl-shifted phenazine **5a** as the tosylate salt. Thermal ellipsoid probability level at 50%.

The phenazine by-product was surprising since molecular models had predicted an ideal overlap of the N³ anionic anilide lone pair with the in-plane orbital on the proximal alkyne carbon of the benzyne, and we conjectured that the entropic cost of forming the 9-membered ring would not be prohibitive due to the conformational constraints provided by the three intervening aryl rings. Yet 6-membered ring formation with alkyl shift proceeds exceptionally efficiently, with only the phenazine derivative as the major product formed and isolated (92% yield).

We assumed that intramolecular or intermolecular methyl transfer from N² to N³ was faster than the closure of the 9-membered ring, and might be faster than formation of the benzyne. Thus, we sought to slow down the alkyl transfer. Since S_N2 displacement of a primary center is ~ 50× slower than of a methyl center,²⁰ we replaced the N²-methyl by an *n*-butyl group. Scheme 2 describes the preparation of the requisite *n*-butyl derivative

3d wherein X = Cl. Adapted from our earlier report⁵, intermediate **9a** was alkylated with *n*-butyl bromide to afford N-methyl-N¹-butyl derivative **10d**, which was reduced according to the general method of Sanz²¹ to afford **3d**. Ultimately, we also wanted to speed up the formation of the aryne intermediate by utilizing the fluoride substrates (**3b** and **3e**), which commenced via a Buchwald-Hartwig reaction on 2-fluoro-iodobenzene (X = F, Y = I) to give the diarylamine **6b** after purification by column chromatography. Methylation of N¹ was accomplished with KOH and Me₂SO₄ in refluxing acetone²² or with sodium hydride followed by methyl iodide to give 2-fluoro-2'-nitrodiphenylamine **7b**. This was followed by reduction of the nitro group to give aniline **8b** employing the general method of Sanz²¹ using CuCl and KBH₄ in dry MeOH. Pd-catalyzed N-arylation of **8b** with *o*-iodonitrobenzene produced the triaryl derivative **9b** in 55% isolated yield after purification. Methylation of N² proceeded with KH and MeI in warm DMF, and reduction of the nitro group was once again accomplished using CuCl and KBH₄ to give compounds **10b** and **3b** respectively. Finally, nor-halo substrates **3c** and **3f** (X = H; R = CH₃ or *n*-butyl, respectively) were prepared by Buchwald-Hartwig N-arylation of 2-nitroaniline with bromobenzene to afford **6c**²³ which was alkylated to give **7c**.²⁴ Reduction of nitroaniline **7c** gave **8c**, which underwent N-arylation to afford phenylene diamine derivative **9c**. Alkylation with either methyl iodide or *n*-bromobutane gave **10c** and **10f**, respectively, followed by reduction to give **3c** and **3f**, respectively.

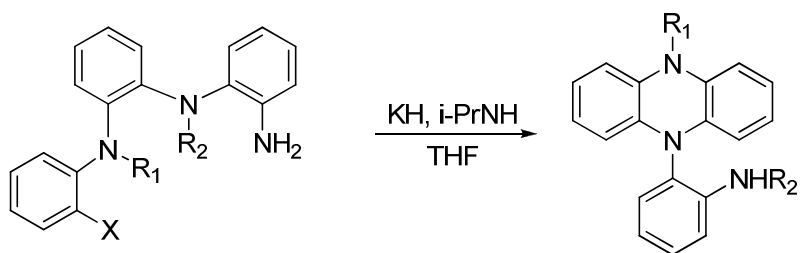


Scheme 2: Synthesis of triaryl derivatives **3a-f** and formation of alkyl-shifted phenazine derivatives **5a** and **5b**.

As noted above, treatment of starting material **3a** with KDA in THF under reflux afforded phenazine derivative **5a** which had suffered the apparent methyl shift. Table 1 outlines the different reaction conditions and substrates explored. The order in which the alkyl shift is occurring appears to be dependent upon several factors including the halogen leaving group as well as the alkyl group substituent on the internal nitrogen (N²). When the reaction of chloro-N,N'-dimethyl aniline **3a** was carried out at -78°C (entry 1) no reaction occurred, as confirmed by 96% recovery of **3a** even though benzyne formation has been observed at this temperature in some cases. However, when the reaction mixture was heated to reflux (66°C), phenazine **5a** was isolated in 92% yield having suffered the apparent methyl shift (entry 2). In an attempt to slow the rate of the S_N2 reaction, in consideration of the possibility that demethylation *preceded* the formation of the benzyne intermediate and that prior alkyl transfer from N² to N³ was essential for phenazine formation, the incorporation of a more sterically hindered blocking group was employed. Initial attempts to install an isopropyl substituent led to elimination, though these efforts were not exhaustive, so an *n*-butyl group on the internal nitrogen (N²) was employed since S_N2 displacement of a primary center is ~ 50× slower than of a methyl center.²⁰ The reaction with the N²-butyl derivative **3d** was conducted under the same conditions (KDA, THF, reflux, entry 4) and remarkably, no reaction occurred, including no alkyl shift, hence aryne formation must have preceded the alkyl shift and is required for the alkyl shift to occur for this particular substrate. Alternatively, this suggests the unexpected possibility that the benzyne formation itself may be

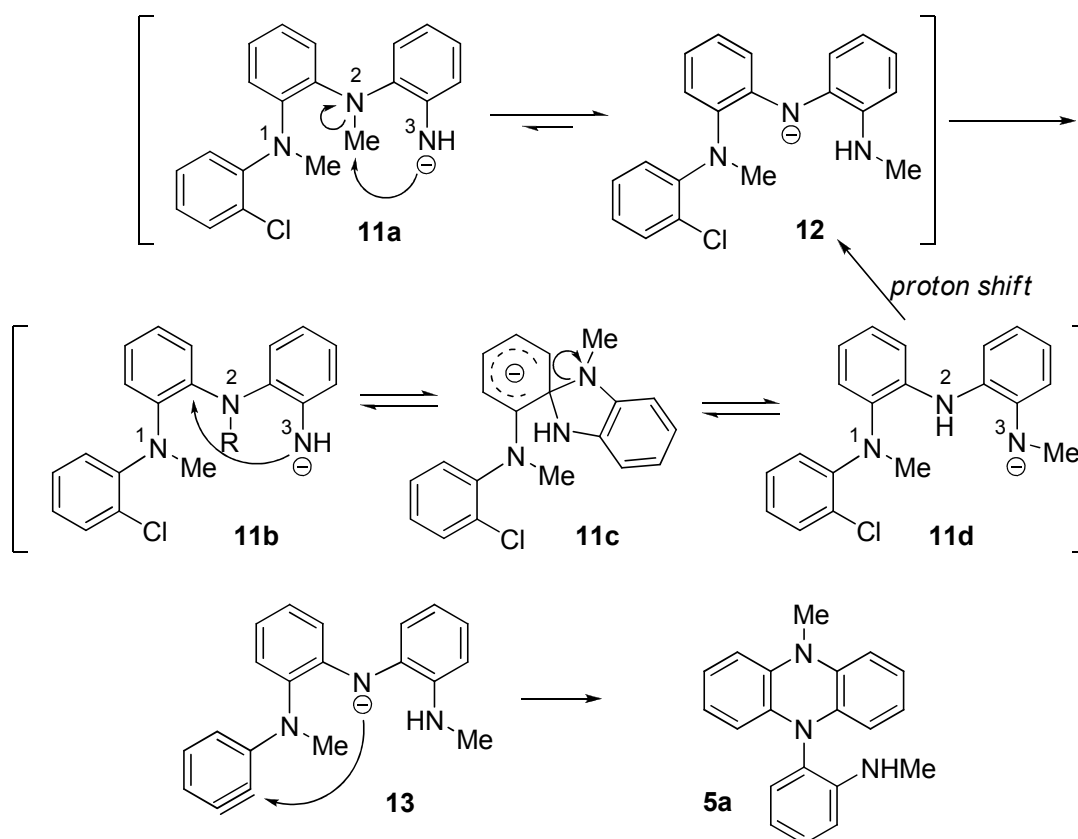
dependent upon prior alkyl shift since the N,N'-dimethyl derivative *did* afford the methyl-shifted phenazine under the same conditions (entry 2). When the reaction was conducted in a sealed vessel at 95°C (entry 5) alkyl transfer of the butyl group was seen with concomitant formation of the phenazine derivative **5b**. The higher temperature required for the butyl shift is consistent with the rate difference for primary alkyl versus methyl substrates in an S_N2-type reaction.

Table 1: Phenazine formation via benzyne intermediates



Entry	S.M.	X	R ₁	R ₂	Temp (°C)	Product
1	3a	Cl	CH ₃	CH ₃	-78	no reaction
2	3a	Cl	CH ₃	CH ₃	66	5a
3	3b	F	CH ₃	CH ₃	66	5a
4	3d	Cl	CH ₃	<i>n</i> -butyl	66	no reaction
5	3d	Cl	CH ₃	<i>n</i> -butyl	95	5b
6	3e	F	CH ₃	<i>n</i> -butyl	66	5b

We considered that the rate of dealkylation in the case of $R^2 = CH_3$ may be faster than the rate of the benzyne formation (Scheme 2). The deprotonated terminal aniline nitrogen (N^3 , structure **11**) should be more basic as well as more nucleophilic than the N^2 -dealkylated anilide **12**. Therefore, if a dynamic equilibrium exists wherein the alkyl substituent can shuttle back and forth between N^2 and N^3 (anilides **11** and **12**, Scheme 3), then the equilibrium should shift toward having the anionic charge on N^2 where it enjoys greater stabilization via resonance. This, however, begs the question of why N^1 is not dealkylated as well. The isolated phenazine always bears a methyl on N^1 and is not observed as a mixture of N^1-CH_3 and N^1-H derivatives. However, only N^2 is appropriately spaced to attack the benzyne, and dealkylation of N^1 would be very unlikely after the phenazine formation since the *N*-methyl bond is orthogonal to the π system. The direct transfer of the methyl from N^2 to N^3 (**11a** to **12**) requires an *a priori* forbidden²⁵ but occasionally observed²⁶ 5-*endo-tet* mechanism. The transition state for the 5-*endo-tet* in this case, however, is essentially an S_N2 reaction from the same face as the leaving group. Alternatively, a Smiles²⁷ rearrangement (**11b-d**) may occur which would *appear* to proceed via an alkyl shift while actually exchanging N^2 and N^3 along with their respective substituents. The Smiles rearrangement often proceeds with anion-stabilizing groups on the aromatic ring that is attacked, and typically with an exchange of heteroatoms, for example an N-nucleophile replacing an O-leaving group.



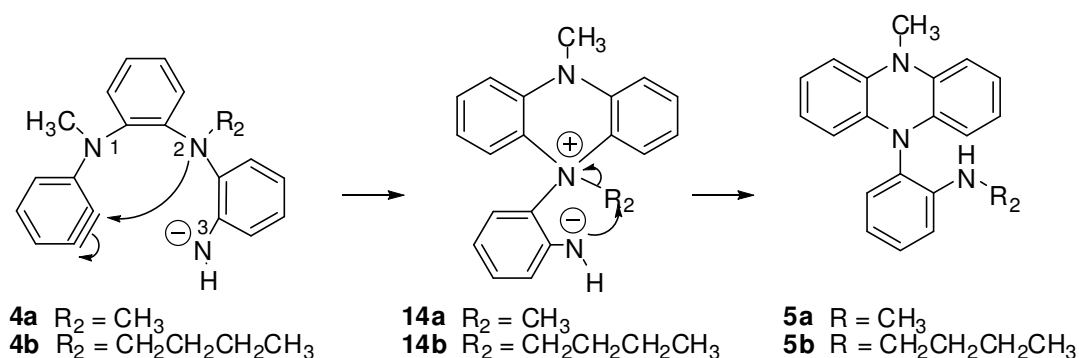
Scheme 3: Possible mechanism of alkyl shift prior to phenazine formation

Encouraged by the lack of alkyl shift with $R^2 = \text{butyl}$ in our quest for a benzyne approach to the 1,4,7-triazacyclononatriene, we reasoned that if the benzyne could be formed under milder conditions, then N^2 would remain blocked and potentially circumvent 6-membered ring formation. We therefore decided to change the halogen from chlorine to fluorine to enhance the rate of formation of the aryne as it can stabilize the incipient negative charge on the adjacent carbon.^{28, 29} Substitution of the chlorine atom with a fluorine atom was accomplished as outlined in Scheme 2, adapted from our earlier

reported procedure⁹ as described above. Treatment of fluoro aniline substrate **3b** with KDA in refluxing THF afforded a 98% yield of phenazine **5a** (Table 1, entry 3).

The formation of phenazine derivative **5a** employing fluorine as the halogen led us to combine strategies and introduce the *n*-butyl substituent on N² as was done for substrate **3d**. When aniline **3e** containing the fluorine and the *n*-butyl group was subjected to KDA in refluxing THF (Table 1, entry 6), the alkyl transfer was once again observed giving rise to phenazine **5b** in 98% isolated yield, and suggests that the formation of the benzyne intermediate *precedes* that of the alkyl transfer. The possible change in the reaction sequence and the isolation of phenazine **5b** suggests the unusual zwitterion **14a/b** as an intermediary (Scheme 4). The zwitterion could be formed from the neutral, tertiary aniline attacking the benzyne intermediate, followed by either an intramolecular alkyl transfer again via a 5-endo-tet mechanism, or via intermolecular S_N2 dealkylation. Formation of zwitterions **14a/b** requires attack by a less nucleophilic neutral aniline in the presence of a more nucleophilic anilide, yet the formation of a zwitterion from attack by a neutral nucleophile on an aryne is not without precedent. Kunai and co-workers³⁰ reported nucleophilic attack on an aryne by an imidazole forming a zwitterion which was neutralized by abstraction of a proton, consistent with our proposed intermediates **14a** and **14b**. Since the internal nitrogen N² has no proton to abstract, dealkylation is required to lead to the neutral phenazine derivative. We believe that the alkyl transfer is intramolecular, although labeling experiments would be required to confirm this in the present case. Reactant concentrations were kept intentionally rather low to encourage intramolecular macrocycle formation and to discourage intermolecular processes; the

dimethyl chloro-aniline **3a** concentration was 0.05M and the methyl butyl chloro-aniline **3d** concentration was at 0.03M, whereas KDA concentrations were kept at 0.17M and 0.16M in these two reactions respectively (initial concentrations of DIPA in the presence of excess KH). Phenazines **5a** and **5b** were isolated in high yield in both cases, and we did not isolate any phenazine where the N²-alkyl group was lost rather than transferred, as would be expected if a slower intermolecular process were competing with dealkylation by KDA in solution. Alternatively, a Smiles rearrangement could precede or even follow aryne formation.

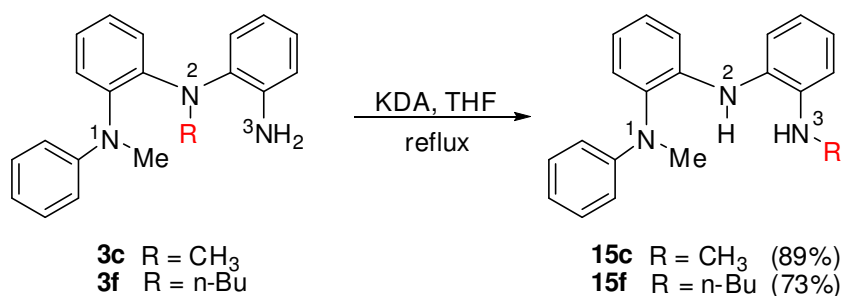


Scheme 4: Alkyl shift and rearrangement via proposed zwitterionic intermediate **14**

In order to determine if alkyl transfer is dependent on prior benzyne formation, substrates lacking a halogen leaving group were subjected to the identical conditions which were employed for benzyne formation. Nor-halo derivatives **3c** and **3f** were synthesized as outlined in Scheme 2 bearing methyl and *n*-butyl groups on N², respectively. When compound **3c** was treated with KDA in refluxing THF, one methyl substituent was cleanly transferred from N² to the terminal (N³) aniline nitrogen affording **15c** in 89%

yield (Scheme 5), demonstrating that dealkylation can occur independently of benzyne formation by the action of the nucleophilic terminal anilide (N^3). When anilide **3f** bearing N^1 -methyl and N^2 -butyl groups but no halogen was subjected to KDA in THF at reflux, the major product isolated in 73% yield was the N^3 -butyl derivative **15f**, with the methyl group remaining on the N^1 position. This result is surprising since the angle of attack by the N^3 -anilide nitrogen is not ideal for an S_N2 reaction for the proximal N^2 -methyl (5-endo-trig). This experiment employing aryl substrates lacking a halogen that are unable to form an aryne demonstrates that the alkyl shift can occur without benzyne formation. Furthermore, the N^2 -methyl or N^2 -*n*-butyl are the groups transferred, as evidenced by upfield ^{13}C shifts of the migrating carbon, and by comparison with calculated ^{13}C spectra utilizing *ab initio* density functional (DFT) calculation of equilibrium geometry with RB3LYP/6-31G* level of theory (Supplementary Schemes S1 and S2).

We believe that the alkyl transfer from N^2 to N^3 in the conversion of **3c/f** to **15c/f** is intramolecular. In the case of the nor-halo substrate **3c**, intermolecular alkyl transfer is very unlikely because a single product is formed in which only one alkyl group is transferred. If the transfer were intermolecular, a mixture of products where either the N^1 -methyl or the N^2 -methyl were transferred would have been expected, as the two methyl groups of **3c** should have comparable reactivity toward S_N2 displacement given the similar diphenylamine leaving groups. Products from outright loss of alkyl groups from dealkylation by KDA were not isolated.



Scheme 5: Alkyl transfer without benzyne formation

CONCLUSIONS

It was originally hoped that a benzyne intermediate would provide an efficient route to the targeted 1,4,7-triazacyclononatriene **2a**. Models suggested that overlap of the N³ anilide with the in-plane benzyne orbital would be ideal for the final cyclization step of the linear synthesis. However, when NMR spectra from the benzyne cyclization reactions commencing with halo derivatives **3** were compared with those of the purified N,N'-dimethyl-1,4,7-triazacyclononatriene orthocyclophane molecule isolated from Buchwald-Hartwig N-arylation conditions, there was no trace of the 9-membered cyclophane detected in the crude mixtures by ¹H NMR, whereas the apparent alkyl-shifted phenazine derivatives **5a/b** were formed very efficiently, in 78-98% depending on the halogen and alkyl group present. This conversion is dependent upon two factors: the halogen present and the alkyl group employed as the substituent on the internal nitrogen. The evidence provided by these studies suggests the possibility of a neutral N² aniline nucleophile attacking the proximal carbon of the aryne affording a zwitterionic intermediate (**14a/b**) followed by an alkyl shift from N² to N³ to afford a phenazine derivative. We envisioned that this may occur via a rare 5-endo-tet pathway, although a

classic Smiles rearrangement may be more likely since theoretical studies do not support a frontside attack, which would be required in a genuine 5-endo-tet process. Specifically, Hase³¹ has performed an ab initio (HF/3-21+G^{*}) trajectory study of the S_N2 reaction of Cl⁻ + CH₃Cl at a reagent relative translational energy of 100 kcal/mol and observed the expected backside attack but no frontside attack, and suggested that extensive electrophile vibrational energy would be required for frontside attack. Furthermore, reported 5-endo-tet processes²⁶ are ambiguously categorized since they involve 3-membered ring (generally epoxide) openings under acidic conditions with significant carbocation character, and hence are more appropriately categorized as (allowed) 5-exo-trig reactions. Indeed, Baldwin noted that three-membered ring openings lie between tetrahedral and trigonal systems.²⁵ It may be noted that some confusion arises upon categorization of the cyclizations of a 3,4-epoxy butan-1-ol system to form a tetrahydrofuran, which is an “endo” cyclization (per Baldwin) but could be considered either an allowed 5-exo-tet or a disfavored 6-endo-tet (counting the oxygen atom of the epoxide as part of the larger ring). As noted, a genuine 5-endo-tet pathway would involve attack by a nucleophile at the same face as the leaving group, in opposition to the classic S_N2 trajectory of 180°, thus it is unlikely that the intramolecular alkyl transfer occurs as depicted in Scheme 3, and more likely is the result of a Smiles rearrangement, although the intermediacy of the zwitterionic intermediate (**14a/14b**) remains an intriguing possibility. Labeling experiments would be required to definitely differentiate between these possibilities. Further experiments are underway to study this unusual and theoretically interesting alkyl transfer in more detail.

EXPERIMENTAL SECTION

General Experimental Methods

All solvents were distilled prior to use. All reagents were used without further purification unless otherwise noted. All Pd-catalyzed and Cu-catalyzed reactions were conducted under an inert atmosphere of argon, and all other reactions were conducted under a nitrogen atmosphere. Silica gel 60A, 40–75 μm (200 \times 400 mesh) was used for column chromatography. Aluminum-backed silica gel 200 μm plates were used for TLC. ^1H NMR spectra were obtained utilizing a 300 MHz spectrometer with trimethylsilane (TMS) as the internal standard. ^{13}C NMR spectra were obtained using a 75 MHz spectrometer. A 300 watt microwave reactor with pressure and temperature sensors was used for all microwave (MW) reactions. Infrared (IR) spectra were determined as a solution in CHCl_3 . HRMS spectra were measured on a TOF instrument by electrospray ionization (ESI). Single crystal X-ray diffraction data were collected on a charge-coupled-device (CCD) diffractometer with a liquid nitrogen vapor cooling device. Data were collected at 100 K with graphite monochromatized $\text{MoK}\alpha$ X-ray radiation ($\lambda = 0.71073 \text{ \AA}$). Collected and reduced data were corrected for absorption using multi-scan methods. The structure was solved by direct methods and refined by full matrix least squares against F^2 with all reflections. Non hydrogen atoms were refined anisotropically. C-H hydrogen atom positions were idealized. Additional details of the structure determinations for the tosylate and hydrochloride salts of **5a** can be found in the supporting information and the supplementary cif files.

***N*-Methyl-2-(10-methylphenazin-5(10*H*)-yl)aniline (2a)**

Similar to the procedure employed by Panagopoulos *et al.*⁹ but under optimized thermal conditions, a 125 mL pressure flask was charged with XPhos (426 mg, 0.89 mmol) and Pd(dba)₂ (255 mg, 0.443 mmol) and a solution of compound **3a** (712 mg, 2.11 mmol) in 42 mL anhydrous 1,4-dioxane was added. The resulting solution was stirred at room temperature for 15 minutes as argon was passed over the top of the solution. Then cesium carbonate (1.38 g, 4.23 mmol) was added as a solid and the resulting suspension purged with argon for 30 minutes. The flask was then sealed and heated in a 140°C oil bath for 16 hours. The reaction mixture was cooled to room temperature and filtered through a pad of Celite and the filter cake washed with 1:1 methanol/CH₂Cl₂. The filtrate was concentrated to dryness leaving a brown solid which was dissolved in ethyl acetate and the solution passed through a plug of silica gel eluting with 2:1 pet ether /CH₂Cl₂. The filtrate was concentrated to dryness leaving a tan powder that was dissolved in CH₂Cl₂. The CH₂Cl₂ solution was purified by flash chromatography eluting with a gradient from 10% CH₂Cl₂ /pet ether to 33% CH₂Cl₂ /pet ether to give **2a** (375 mg, 59% yield) as a tan powder, mp 228-230°C.

***N*¹-(2-Aminophenyl)-*N*²-(2-fluorophenyl)-*N*¹,*N*²-dimethylbenzene-1,2-diamine (**3b**)**

CuCl (137 mg, 1.38 mmol) was added to a stirring solution of the nitroaryl derivative **10b** (164 mg, 0.46 mmol) in dry MeOH (5 mL) at rt. KBH₄ (248 mg, 4.60 mmol) was then added in portions.¹³ The reaction effervesced and a black precipitate formed upon each addition. Once all the KBH₄ was added, the reaction continued to stir at rt until the

solution became clear in color (2-4 h). The reaction was quenched with H₂O and extracted with 3 x 10 mL 90/10 EA/MC. The organic layers were combined and dried over Na₂SO₄. The solvent was removed under vacuum to give the aniline **3b** as a light brown oil (144 g, 98% yield). ¹H NMR (300 MHz, CDCl₃) δ 7.12 (2H, m), 7.00 (2H, m), 6.92 (3H, m), 6.78 (2H, m), 6.65 (2H, m), 6.56 (1H, dd, J = 9.2, 1.5 Hz), 3.17 (2H, bs), 3.08 (3H, s), 2.97 (3H, s); ¹³C NMR (75 MHz, CDCl₃) δ 154.1 (d, J = 270 Hz), 145.2, 141.7, 140.8, 137.4, 137.1, 127.0, 125.6, 124.9, 124.0, 123.5, 122.6, 120.1, 119.9, 119.3, 118.7, 116.4, 116.1, 39.8, 38.4; IR (CDCl₃) 3435 (NH₂), 3346 (NH₂), 1612 (C=C), 1501 (NO₂) cm⁻¹; HRMS MH⁺ calcd for C₂₀H₂₁N₃F 322.1719 found 322.1728.

***N*¹-(2-Aminophenyl)-*N*¹,*N*²-dimethyl-*N*²-phenylbenzene-1,2-diamine (**3c**)**

CuCl (0.297 g, 3 mmol) was added to a stirring solution of the nor-halo dimethyl derivative **10c** (0.212 g, 1.00 mmol) in a 1:1 mixture of dry MeOH and MC (20 mL) at rt. KBH₄ (0.540 g, 8.0 mmol) was then added in portions.²¹ The reaction effervesced and a black ppt formed upon each addition. Once all the KBH₄ was added, the reaction continued to stir at rt until the solution became clear in color and TLC showed consumption of **10c** (2-4 h). The reaction was quenched with H₂O and extracted with 3 x 10 mL 90/10 EA/MC. The organic layers were combined and dried over Na₂SO₄. The solvent was removed under vacuum to give the N,N'-dimethyl diphenylamine derivative **3c** as a light brown oil (0.163 g, 96% yield). ¹H NMR (500 MHz, CDCl₃) δ 7.27 (1H, td, J = 6.3, 2.3 Hz), 7.21 (1H, d, J = 4.8 Hz), 7.10 (2H, td, J = 7.0, 1.0 Hz), 7.05-7.04 (2H, m), 6.87 (1H, td, J = 7.5, 1.0 Hz), 6.66 (1H, td, J = 7.5, 1.2 Hz), 6.61-6.58 (3H, m), 6.31

(2H, dd, $J = 8.5, 1.0$ Hz), 2.99 (2H, br s), 2.97 (3H, s), 2.50 (3H, s). ^{13}C NMR (125 MHz, CDCl_3) δ 147.8, 147.3, 142.8, 138.7, 138.3, 129.9, 128.6, 126.8, 125.3, 123.9, 122.6, 118.8, 118.6, 116.2, 116.1, 112.3, 38.4, 37.9. HRMS MH^+ Calc for $\text{C}_{20}\text{H}_{22}\text{N}_3$ 304.1808, found 304.1808.

***N*¹-(2-Aminophenyl)-*N*¹-butyl-*N*²-(2-chlorophenyl)-*N*²-methylbenzene-1,2-diamine
(3d)**

Following the general procedure of Sanz,²¹ CuCl (0.060 g, 0.060 mmol) was added to a stirring solution of compound **10d** (0.079 g, 0.2 mmol) in MeOH (2.0 mL) at rt, then KBH_4 (0.108 g, 2.0 mmol) was added in portions. The reaction stirred at rt until the solution became clear (2-4 h). The reaction was then quenched with H_2O and extracted 3 \times 15 mL 90/10 EA/DCM. The organic layers were combined and dried over Na_2SO_4 and the solvent was removed to give the desired aniline **3d** as a brown oil (0.063 g, 82%). ^1H NMR (300 MHz, CDCl_3) δ 7.29 (1H, dd, $J = 7.8, 1.5$ Hz), 7.15-7.00 (4H, m), 6.95-6.84 (5H, m), 6.73-6.62 (2H, m), 3.46 (5H, m), 3.20 (3H, s), 1.42-1.32 (2H, m), 1.25-1.16 (2H, m), 0.82 (3H, t, $J = 7.2$ Hz); ^{13}C NMR (75 MHz, CDCl_3) δ 147.2, 143.3, 143.2, 142.4, 135.8, 131.2, 127.4, 127.3, 125.3, 124.8, 124.5, 123.7, 123.0, 118.4, 116.4, 50.6, 40.3, 30.2, 20.5, 14.1; IR (CDCl_3) 3436 (NH_2), 3375 (NH_2), 2956 (C-H), 2929 (C-H), 2869 (C-H), 1491 (C=C) cm^{-1} ; HRMS MH^+ calcd for $\text{C}_{23}\text{H}_{27}\text{N}_3\text{Cl}$ 380.1888, found 380.1892.

***N*¹-(2-Aminophenyl)-*N*¹-butyl-*N*²-(2-fluorophenyl)-*N*²-methylbenzene-1,2-diamine
(3e)**

CuCl (47 mg, 0.48 mmol) was added to a stirring solution of nitroaryl derivative **10e** (63 mg, 0.17 mmol) in dry MeOH (2 mL) at rt. KBH₄ (86 mg, 1.6 mmol) was then added in portions.²¹ The reaction effervesced and a black ppt formed upon each addition. Once all the KBH₄ was added, the reaction continued to stir at rt until the solution became clear in color (2-4 h). The reaction was quenched with H₂O and extracted with 3 x 10 mL 90/10 EA/MC. The organic layers were combined and dried over Na₂SO₄. The solvent was removed under vacuum to give the aniline derivative **3e** as a light brown oil (60 mg, 100% yield). ¹H NMR (300 MHz, CDCl₃) δ 7.18-6.99 (5H, m), 6.95-6.86 (2H, m), 6.78-6.71 (2H, m), 6.66-6.60 (2H, m), 6.50 (1H, ddd, J = 9.6, 8.2, 1.8 Hz), 3.38 (2H, t, J = 7.8 Hz), 3.20 (2H, bs), 2.90 (3H, s), 1.51-1.41 (2H, m), 1.32-1.20 (2H, m), 0.86 (3H, t, J = 7.3 Hz); ¹H NMR (CDCl₃, 125 MHz) δ 154.2 (d, J = 274 Hz), 145.9, 142.6, 142.1, 137.3, 128.0, 125.8, 125.1, 124.7, 124.2, 121.4, 121.3, 121.0, 119.8, 119.8, 119.4, 118.7, 116.5, 116.3, 50.9, 40.4, 30.0, 20.6, 14.2 ppm; HRMS MH⁺ calcd for C₂₃H₂₇N₃F 364.2184, found 364.2175.

***N*¹-(2-Aminophenyl)-*N*¹-butyl-*N*²-methyl-*N*²-phenylbenzene-1,2-diamine (3f)**

Compound **10f** (633 mg, 1.69 mmol) was dissolved in 17 mL dry methanol and the solution stirred at RT. According to the general method of Sanz,²¹ to that solution was added CuCl (508 mg, 5.13 mmol) in one portion and stirring was continued for 10 min before KBH₄ (738 mg, 13.7 mmol) was added portion-wise maintaining the reaction temperature below 30°C. The reaction mixture was stirred at ambient temperature under

nitrogen atmosphere for 2.5 h. The reaction was then quenched via the addition of water and then was extracted 3× with ethyl acetate. The organic extracts were combined, dried over MgSO₄, filtered and the filtrate concentrated to dryness leaving a brown gum that was purified by flash chromatography eluting with an eluent comprised of 3% ether, 5% methylene chloride and 92% petroleum ether to give triaryl derivative **3f** (202 mg, 25% yield, 2 steps) as a brown oil. ¹H NMR (500 MHz, CDCl₃) δ 7.29-7.26 (1H, m), 7.13 (1H, d, J=8.0 Hz), 7.08 (1H, t, J=11.0 Hz), 7.05-7.01 (2H, m), 6.86-6.83 (1H, m), 6.66 (1H, t, J=7.0 Hz), 6.60-6.54 (2H, m), 6.32 (1H, s), 6.30 (1H, s), 3.27 (2H, t, J=8.0 Hz), 2.99 (2H, bs), 2.46 (3H, s), 1.61-1.55 (4H, m), 1.30 (2H, q, J=7.5 Hz), 0.99 (3H, t, J=7.5 Hz). ¹³C NMR (125 MHz, CDCl₃) δ 147.3, 146.2, 143.1, 139.8, 138.3, 130.3, 128.5, 126.5, 125.0, 124.7, 122.7, 119.7, 118.5, 116.2, 116.0, 112.4, 50.6, 37.9, 29.8, 20.4, 14.0. HRMS MH⁺ Calc for C₂₃H₂₈N₃ 346.2278, found 346.2279.

***N*-Methyl-2-(10-methylphenazin-5(10*H*)-yl)aniline (5a)**

In an oven-dried round-bottom flask, KH (0.543 g, 4.06 mmol) was washed with dry pet ether (3 x 5 mL) under N₂ at rt, and 1 mL of THF was added to the KH and stirred at rt for 5 min. Diisopropylamine (0.15 mL, 1.0 mmol) was then added to the KH and the mixture stirred at rt for 5 min. Compound **3a** (0.098 g, 0.29 mmol) in THF (5 mL) was added dropwise by syringe to the KDA in THF (1 mL). The mixture was heated to reflux for 1-2 hr until TLC showed complete consumption of **3a**. The reaction mixture was quenched with 15 mL of H₂O and extracted 3 × 20 mL Et₂O. The organic layers were combined and dried over MgSO₄ and the solvent was removed in vacuo to yield

phenazine **5a** as a colorless solid (80 mg, 92%): mp 202-204 °C; ¹H NMR (300MHz, CDCl₃) δ 7.33 (1H, ddd, J = 9.2, 7.8, 1.5 Hz), 7.16 (1H, dd, J = 8.1, 1.5 Hz), 6.82 (2H, t, J = 15.7, 7.8 Hz), 6.63 (2H, ddd, J = 9.1, 7.7, 1.4 Hz), 6.41 (2H, ddd, J = 8.7, 7.8, 1.2 Hz), δ 6.34 (2H, dd, J = 7.7, 1.1 Hz), δ 5.82 (2H, dd, J = 7.8, 1.2 Hz), δ 4.45 (1H, bs), 3.01 (3H, s), 2.79 (3H, bs); ¹³C NMR (75 MHz, CDCl₃) δ 146.9, 136.9, 131.1, 129.6, 129.2, 125.5, 121.7, 120.7, 117.5, 111.8, 111.2, 110.9, 30.2, 29.7; HRMS M⁺ calcd for C₂₀H₂₀N₃ 301.1573, found 301.1562. The desired product was then dissolved in 2-3 mL of Et₂O and 1 equivalent of p-toluenesulfonic acid was added to form the tosylate salt as clear crystals suitable for X-ray crystallography. Similarly, addition of HCl/ether to **5a** in Et₂O afforded the hydrochloride salt as clear crystals suitable for X-ray crystallography.

***N*-Butyl-2-(10-methylphenazin-5(10*H*)-yl)aniline (5b)**

In a round bottom flask, 2 mL of THF and DIPA (0.11 mL, 0.80 mmol) were added to KH (0.300 g, 2.24 mmol) at rt. The mixture was stirred for 10 min and aniline **3e** (58 mg, 0.16 mmol) in 3 mL of THF was added dropwise via syringe. The reaction mixture was heated to reflux for 2 h. The reaction mixture was cooled to rt and quenched with H₂O. The product was extracted with 3 × 20 mL of 90/10 EA/MC. The organic layers were combined and dried over Na₂SO₄, the solvent was removed under reduced pressure to give the phenazine derivative **5b** as a green oil (0.048 g, 87% yield). ¹H NMR (500MHz, CDCl₃) δ 7.3 (1H, ddd, J = 8.5, 7.3, 2.3), 7.16, (1H, dd, J = 7.7, 1.4), 6.83-6.75 (2H, m), 6.62 (2H, t, J = 7.7), 6.41 (1H, t, 7.7), 6.34 (1H, d, J = 7.8), 5.81 (2H, dd, J = 7.8, 1.2), 4.37 (1H, bs), 3.12 (2H, t, J = 7.1), 3.02 (3H, s), 1.55-1.43 (2H, m), 1.36-1.21 (2H, m),

0.85 (3H, t, J = 7.3); ^{13}C NMR (125 MHz, CDCl_3) δ 137.2, 131.5, 129.7, 121.9, 121.1, 117.7, 112.2, 112.0, 111.1, 43.3, 31.6, 29.9, 20.3, 14.0 (all aromatic carbons peaks are broadened due to hindered rotation except for 129.7, while the aliphatic carbon resonances are sharp); IR (CDCl_3) 3415 (NH), 2965 (C-H), 2962 (C-H), 2870 (C-H), 1607 (C=C), 1508 (C=C), 1482 (C=C) cm^{-1} ; HRMS M^+ calcd for $\text{C}_{23}\text{H}_{26}\text{N}_3$ 343.2043, found 343.2046.

(2'-Fluorophenyl)-(2-nitrophenyl)-amine (6b)

(2'-Fluorophenyl)-(2-nitrophenyl)-amine **6b** was synthesized according to the general procedures outlined by Tietze *et al.*²³ A pressure tube was charged with o-nitroaniline (0.690 g, 5.00 mmol), o-fluoroiodobenzene (0.70 mL, 6 mmol), $\text{Pd}(\text{dba})_2$ (0.144 g, 5%), BINAP (0.233 g, 7.5%), Cs_2CO_3 (3.26 g, 10 mmol) and toluene (10 mL). The mixture was purged with argon for 10 min at rt and the pressure tube was sealed. The reaction was placed in an oil bath. The temperature was brought to 120°C and the reaction stirred for 24 h. TLC showed complete consumption of o-nitroaniline and the reaction mixture was filtered through a pad of SiO_2 using 10/90 DCM/EA as the eluent. The solvent was removed under reduced pressure and product was purified by column chromatography using 1/99 $\text{Et}_2\text{O}/\text{PE}$ as the eluent to afford the final product **6b** as orange crystals (0.915 g, 78% yield): mp 79-80°C; ^1H NMR (300 MHz, CDCl_3) δ 9.31 (1H, br s), 8.24 (1H, dd, J = 8.7, 1.5 Hz), 7.44-7.37 (2H, m), 7.24-7.18 (3H, m), 7.08 (1H, dt, J = 2.9, 1.5, 1.4 Hz), 6.83 (1H, ddd, J = 7.2, 7.0, 1.2 Hz). ^{13}C NMR (75 MHz, CDCl_3) δ 156.6 (d, J = 248 Hz), 142.2, 139.4, 135.7, 130.1, 126.8, 125.9, 124.7, 118.1, 116.8, 116.7, 116.0; IR (CDCl_3)

3345 (NH), 1609 (C=C), 1577 (C=C), 1509 (NO₂) cm⁻¹; HRMS (M+H)⁺ calcd for C₁₂H₁₀N₂O₂F 233.0721, found 233.0727.

2-Nitro-N-phenylaniline (6c)

2-Nitro-N-phenylaniline **6c** was synthesized according to the general procedures outlined by Tietze *et al.*²³ A pressure tube was charged with o-nitroaniline (1.38 g, 10 mmol), bromobenzene (1.2 mL, 10 mmol), Pd(dba)₂ (0.288 g, 5%), BINAP (0.466 g, 7.5%), Cs₂CO₃ (6.52 g, 20 mmol) and toluene (20 mL). The mixture was purged with argon for 10 min at rt and the pressure tube was sealed. The reaction was placed in an oil bath. The temperature was brought to 120°C and the reaction stirred for 48 h. TLC showed complete consumption of o-nitroaniline and the reaction mixture was filtered through a pad of silica gel using 5/5/90 EA/MC/PE as the eluent. The filtrate was dried over Na₂SO₄ and the solvent removed under reduced pressure to give the desired 2-nitro-N-phenylaniline **6c** as an orange solid without further purification (2.08 g, 98% yield). ¹H NMR (300 MHz, CDCl₃) δ 9.48 (1H, bs), 8.19 (1H, dd, J=8.7, 1.8 Hz), 7.43 (1H, d, J=1.8 Hz), 7.41-7.32 (2H, m), 7.28-7.23 (4H, m), 6.76 (1H, dd, J=1.8, 1.2 Hz). ¹³C NMR (75 MHz, CDCl₃) δ 142.9, 138.6, 135.5, 133.0, 129.6, 126.5, 125.5, 124.2, 117.4, 115.9.

2-Fluoro-N-methyl-N-(2-nitrophenyl)aniline (7b)

To a solution of aniline **6b** (0.122 g, 0.525 mmol) in acetone (2 mL) at rt was added freshly crushed KOH (0.130 g, 2.31 mmol). The reaction was heated to reflux and

Me₂SO₄ (0.23 mL, 2.42 mmol) was added dropwise via syringe. The mixture was allowed to reflux for 1 h. The reaction was cooled to rt and 1 mL of 10 M NaOH was added to the solution. After 1 h the mixture was quenched with 2 mL H₂O and extracted with 3 × 10 mL of 90/10 EA/MC. The organic layers were combined and dried over MgSO₄. The solvent was removed under reduced pressure and the mixture was placed in an 80°C oil bath under vacuum to remove excess Me₂SO₄ providing fluoro nitrobenzene derivative **7b** as a brown oil (0.122 g, 95% yield). ¹H NMR (300 MHz, CDCl₃) δ 7.73 (1H, dd, J = 7.8, 1.7 Hz), 7.5 (1H, ddd, J = 8.2, 7.4, 1.7 Hz), 7.24 (1H, dd, J = 8.4, 1.2 Hz), 7.09-6.94 (5H, m), 3.33 (3H, s); ¹³C NMR (75 MHz, CDCl₃) δ 155.6 (d, J = 255 Hz), 142.5, 138.9, 136.9, 126.9, 125.7, 125.4, 122.6, 120.8, 119.3, 117.2, 116.5, 41.1; IR (CDCl₃) 1522 (NO₂), 1501 (NO₂) cm⁻¹; HRMS (M+H)⁺ calcd for C₁₃H₁₁N₂O₂F 247.0877, found 247.0871.

***N*-Methyl-2-nitro-*N*-phenylaniline (7c)**

To a solution of aniline **6c** (0.182 g, 1.0 mmol) in DMF (5 mL) at rt was added freshly crushed KOH (0.252 g, 4.5 mmol). After 10 min, MeI (0.20 mL, 3 mmol) was added to the stirring mixture dropwise via syringe. Stirring was continued at rt until TLC showed consumption of the aniline starting material. The reaction was then quenched with 25 mL deionized H₂O and extracted with 3 × 30 mL of EA. The organic layers were combined and dried over MgSO₄. The solvent was removed under reduced pressure and no further purification was needed to obtain the nor-halo *N*-methyl derivative **7c**²⁴ as a brown oil. (0.194 g, 100% yield). ¹H NMR (300 MHz, CDCl₃) δ 7.83 (1H, dd, J = 8.1, 1.5 Hz), 7.57

(1H,dt, J=8.6, 1.8 Hz), 7.35 (1H, dd, J=8.1, 1.5 Hz), 7.27 (2H, dt, J=15.4, 1.5 Hz), 7.21 (2H, dt, J=8.1, 1.5 Hz), 6.83 (1H, dt, J=7.2, 1.2 Hz), 6.72 (1H, dt, J=7.2, 1.2 Hz), 3.31 (3H, s). ¹³C NMR (75 MHz, CDCl₃) δ 147.8, 146.3, 142.2, 133.8, 129.2, 129.1, 125.6, 125.0, 119.9, 115.6, 40.2.

***N*¹-(2-Fluorophenyl)-*N*¹-methylbenzene-1,2-diamine (8b)**

CuCl (0.150 g, 1.50 mmol) was added to a stirring solution of fluoro nitrobenzene derivative **7b** (0.122 g, 0.5 mmol) in dry MeOH (5.0 mL) at rt. KBH₄ (0.270 g, 5.0 mmol) was then added in portions.²¹ The reaction effervesced and a black precipitate formed upon each addition. Once all the KBH₄ was added, the reaction continued to stir at rt until the solution became clear in color (2-4 h). The reaction was quenched with H₂O and extracted with 3 x 10 mL 90/10 EA/MC. The organic layers were combined and dried over Na₂SO₄. The solvent was removed under vacuum to give the desired fluoro aniline **8b** as a light brown oil (0.096 g, 89% yield). ¹H NMR (300 MHz, CDCl₃) δ 7.06-6.85 (6H, m), 6.76 (1H,dd, J = 7.8, 1.2 Hz), 6.70 (1H, ddd, J = 8.8, 7.7, 1.4 Hz), 3.91 (2H, bs), 3.15 (3H, s); ¹³C NMR (75 MHz, CDCl₃) δ 154.9 (d, J = 240 Hz), 142.1, 138.6, 136.8, 126.1, 124.5 (d, J = 37 Hz), 121.7, 119.6, 118.8, 116.4, 116.1, 115.8, 34.0; IR (CDCl₃) 3452 (NH₂), 3351 (NH₂), 1608 (C=C), 1500 (C=C) cm⁻¹; HRMS MH⁺ calcd for C₁₃H₁₄N₂F 217.1136, found 217.1133.

***N*¹-Methyl-*N*¹-phenylbenzene-1,2-diamine (8c)**

CuCl (0.297 g, 3 mmol) was added to a stirring solution of the nor-halo N-methyl derivative **7c** (0.208 g, 1.00 mmol) in dry MeOH (10 mL) at rt. KBH₄ (0.540 g, 8.0 mmol) was then added in portions.²¹ The reaction effervesced and a black precipitate formed upon each addition. Once all the KBH₄ was added, stirring was continued at rt until the solution became clear in color and TLC showed consumption of **7c** (2-4 h). The reaction was quenched with H₂O and extracted with 3 x 10 mL 90/10 EA/MC. The organic layers were combined and dried over Na₂SO₄. The solvent was removed under vacuum to give the N-methyl diphenylamine derivative **8c**²⁴ as a light brown oil (0.163 g, 96% yield). ¹H NMR (300 MHz, CDCl₃) δ 7.19 (2H, dt, J=5.4, 1.8 Hz), 7.07 (1H, dt, J=7.8, 1.5 Hz), 7.03 (1H, dd, J=7.8, 1.5 Hz), 6.80-6.72 (3H, m), 6.66 (1H, s), 6.63 (1H, s), 3.77 (2H, bs), 3.19 (3H,s).

***N*¹-(2-Fluorophenyl)-*N*¹-methyl-*N*²-(2-nitrophenyl)benzene-1,2-diamine (**9b**)**

The fluoroaniline derivative **8b** (0.096 g, 0.44 mmol), o-iodonitrobenzene (0.132 g, 0.53 mmol), Pd(dba)₂ (0.013 g, 5% mol), BINAP (0.021 g, 7.5% mol), Cs₂CO₃ (0.215 g, 0.66 mmol) and 2 mL of toluene were placed in a pressure tube. The mixture was purged with argon at rt for 15 min. The pressure tube was then sealed and placed in a pre-heated oil bath at 130°C for 24 h. When TLC showed consumption of **8b**, the reaction mixture was filtered through a pad of SiO₂ eluting with 90/10 EA/MC. The solvent was removed under reduced pressure and the resulting product was purified by column chromatography eluting with 1/99 Et₂O/pet ether to afford the N,N'-diaryl

phenylenediamine derivative **9b** as a red oil (0.082 g, 55% yield). ^1H NMR (300 MHz, CDCl_3) δ 9.12 (1H, bs), 8.05 (1H, dd, $J = 8.5, 1.7$ Hz), 7.34-7.05 (6H, m), 6.86-6.83 (4H, m), 6.69 (1H, ddd, $J = 8.5, 7.1, 1.4$ Hz), 3.21 (3H, s); ^{13}C NMR (75 MHz, CDCl_3) δ 156.3 (d, $J = 240$ Hz), 144.4, 142.3, 137.8, 135.1, 133.4, 132.5, 126.4, 125.7, 124.2, 123.7, 123.5, 122.7, 122.4, 117.1, 116.4, 116.1, 115.8, 40.6; IR (CDCl_3) 3343 (NH), 1615 (C=C), 1593 (C=C), 1573 (C=C), 1501 (NO_2) cm^{-1} ; HRMS MH^+ calcd for $\text{C}_{19}\text{H}_{17}\text{N}_3\text{O}_2\text{F}$ 338.1299, found 338.1306.

***N*¹-Methyl-*N*²-(2-nitrophenyl)-*N*¹-phenylbenzene-1,2-diamine (**9c**)**

Nor-halo aniline derivative **8c** (0.163 g, 2.5 mmol), o-iodonitrobenzene (0.249 g, 2.50 mmol), $\text{Pd}(\text{dba})_2$ (0.072 g, 5% mol), BINAP (0.112 g, 7.5% mol), Cs_2CO_3 (0.900 g, 2.75 mmol) and 5 mL of toluene were placed in a pressure tube. The mixture was purged with argon at rt for 15 min. The pressure tube was then sealed and placed in a pre-heated oil bath at 120°C for 36 h. When TLC showed consumption of **8c**, the reaction mixture was filtered through a pad of silica gel eluting with 90/10 EA/MC. The solvent was removed under reduced pressure and the resulting product was purified by column chromatography eluting with 10/90 EA/pet ether to afford the desired dimethyl derivative **9c** as a yellow gum (0.163 g, 70% yield). ^1H NMR (300 MHz, CDCl_3) δ 9.24 (1H, s), 8.08 (1H, dd, $J = 9.9, 1.8$ Hz), 7.47-7.43 (1H, m), 7.34-7.20 (5H, m), 7.11 (2H, dt, $J = 6.4, 1.0$ Hz), 6.74 (2H, ddd, $J = 7.5, 7.9, 1.2$ Hz), 6.65 (1H, d, $J = 1.0$ Hz), 6.62 (1H, d, $J = 1.0$ Hz), 3.23 (3H, s). ^{13}C NMR (75 MHz, CDCl_3) δ 148.6, 142.1, 141.8, 135.6, 135.12,

133.9, 129.0, 127.8, 126.6, 126.0, 125.9, 123.7, 119.1, 117.7, 116.1, 115.1, 39.6. HRMS MH⁺ Calc for C₁₉H₁₈N₃O₂ 320.1394, found 320.1394.

***N*¹-(2-Fluorophenyl)-*N*¹,*N*²-dimethyl-*N*²-(2-nitrophenyl)benzene-1,2-diamine (10b)**

A solution of fluoro nitroaryl derivative **9b** (0.082 g, 0.24 mmol) in 2 mL of DMF was added to KH (0.100 g, 0.72 mmol, freshly washed with pet ether). Upon addition, the solution changed color from orange to deep purple. The mixture was stirred at rt for 10 min, then methyl iodide (1.0 mL, 1.2 mmol) was added dropwise via syringe. Stirring was continued until the solution became bright yellow in color (2 h). The reaction was then quenched with H₂O and extracted with 3 × 10 mL 90/10 EA/CH₂Cl₂. The organic layers were combined and washed with 3 × 20 mL H₂O, then brine. The organic layer was dried over Na₂SO₄, and the solvent was removed under reduced pressure to give the desired *N*¹,*N*²-dimethyl derivative **10b** as a yellow solid (0.082 g, 97% yield). ¹H NMR (500 MHz, CDCl₃) δ 7.62 (1H, dd, J = 8.2, 1.7 Hz), 7.34 (1H, ddd, J = 8.8, 7.4, 1.9 Hz), 7.1-6.75 (10H, m), 3.22 (3H, s), 3.14 (3H, s); ¹³C NMR (125 MHz, CDCl₃) δ 155.1 (d, J = 148 Hz), 143.0, 143.8, 140.9, 137.6, 132.9, 132.6 (d, J = 25 Hz), 125.9, 125.8, 125.6, 125.1, 125.0, 124.4 (d, J = 2 Hz), 122.1 (d, J = 5 Hz), 121.7, 121.5 (d, J = 2 Hz), 120.0, 116.5 (d, J = 12 Hz), 40.1, 39.2; IR (CDCl₃) 1606 (C=C), 1591 (C=C), 1568 (C=C), 1522 (NO₂), 1500 (NO₂) cm⁻¹; HRMS (M+H)⁺ calcd for C₂₀H₁₉N₃O₂F 352.1456, found 352.1463.

***N*¹,*N*²-Dimethyl-*N*¹-(2-nitrophenyl)-*N*²-phenylbenzene-1,2-diamine (10c)**

To a solution of aniline **9c** (0.163 g, 2.0 mmol) in DMF (10 mL) at rt was added freshly crushed KOH (0.504 g, 9 mmol). After 10 min, MeI (0.40 mL, 6 mmol) was added to the stirring mixture dropwise via syringe. Stirring was continued at rt until TLC showed consumption of the aniline starting material. The reaction was then quenched with 25 mL deionized water and extracted with 3 x 30 mL of EA. The organic layers were combined and dried over MgSO₄. The solvent was removed under reduced pressure to provide the nor-halo N,N'-dimethyl derivative **10c** as a brown oil. (0.170 g, 100% yield). ¹H NMR (300 MHz, CDCl₃) δ 7.59 (1H, dd, J=8.2, 1.6 Hz), 7.29-7.15 (3H, m), 7.11-7.04 (4H, m), 6.92 (1H, dt, J=7.2, 1.2 Hz), 6.76 (1H, dd, J=8.2, 1.2 Hz), 6.72 (1H, dt, J=13.5, 1.2 Hz), 6.34 (1H, d, J=3.2 Hz), 6.31 (1H, d, J=1.9 Hz), 3.27 (3H, s), 2.82 (3H,s). ¹³C NMR (75 MHz, CDCl₃) δ 147.8, 144.1, 143.5, 142.9, 140.1, 132.8, 129.0, 128.4, 126.5, 125.3, 124.7, 124.4, 123.6, 121.5, 117.5, 113.9, 41.2, 38.1. HRMS MH⁺ calc for C₂₀H₂₀N₃O₂ 334.1550, found 334.1547.

***N*¹-Butyl-*N*²-(2-chlorophenyl)-*N*²-methyl-*N*¹-(2-nitrophenyl)benzene-1,2-diamine (10d)**

A solution of chloro *N*¹-methyl aniline derivative **9a**⁹ (0.100 g, 0.28 mmol) in 2 mL of DMF was added to KH (0.112 g, 0.830 mmol). Upon addition, the solution went from orange to deep purple. The mixture was stirred at rt for 10 min. *n*-Butyl bromide (0.30 mL, 2.8 mmol) was added dropwise via syringe. The reaction was warmed to 80°C and stirred until the solution returned to an orange color (3 h). The reaction was then

quenched with H₂O and extracted with 3 × 15 mL EA. The organic layers were combined and washed with 3 × 25 mL H₂O, brine, then again with H₂O to remove excess DMF. The organic layer was then dried over MgSO₄, and the solvent was removed under reduced pressure. The crude product was purified by column chromatography using a gradient of EA/pet ether as the eluent to give the desired product **10d** as a red oil (0.065 g, 56%). ¹H NMR (300 MHz, CDCl₃) δ 7.57 (1H, dd, J = 8.0, 1.7 Hz), 7.40 (1H, ddd, J = 8.7, 7.2, 1.6 Hz), 7.24 (1H, dd, J = 15.4, 1.4 Hz), 7.21 (1H, dd, J = 14.8, 1.7 Hz), 7.06 (1H, dd, J = 8.1, 1.5 Hz), 7.02-6.87 (6H, m), 6.76 (1H, dd, J = 8.2, 1.7 Hz), 3.77 (2H, t, J = 8.1 Hz), 3.31 (3H, s), 1.6 (2H, m), 1.29 (2H, m), 0.90 (3H, t, J = 7.4, 7.1 Hz); ¹³C NMR (75 MHz, CDCl₃) δ 146.7, 132.8, 132.3, 131.0, 130.1, 128.4, 128.3, 127.8, 127.5, 126.3, 125.9, 125.8, 124.1, 124.0, 123.7, 120.7, 120.6, 119.1, 49.8, 38.6, 29.0, 20.1, 14.0 IR (CDCl₃) 2958 (C-H), 2929 (C-H), 2871 (C-H), 2817 (C-H), 1524 (NO₂) cm⁻¹; HRMS MH⁺ calcd for C₂₃H₂₅N₃O₂Cl 410.1630, found 410.1640.

***N*¹-Butyl-*N*²-(2-fluorophenyl)-*N*²-methyl-*N*¹-(2-nitrophenyl)benzene-1,2-diamine (10e)**

A solution of the fluoro nitroaryl derivative **9b** (0.102 g, 0.300 mmol) in 2 mL of DMF was added to KH (0.121 g, 0.910 mmol). Upon addition, the solution went from orange to deep purple. The mixture was stirred at rt for 10 min. *n*-Butyl bromide (0.32 mL, 3.0 mmol) was added dropwise via syringe. The reaction was heated to 80°C and stirred until the solution returned to an orange color 3 h. The reaction was then quenched with H₂O and extracted with 3 × 15 mL DCM. The organic layers were combined and washed with

3 × 25 mL H₂O, with brine and then with H₂O again to remove excess DMF. The organic layer was then dried over MgSO₄, and the solvent was removed under reduced pressure. The crude product was purified by column chromatography using a gradient of EA/PE as the eluent to produce the N¹-methyl-N²-butyl derivative **10e** as a red oil (0.063 g, 53%).
¹H NMR (300 MHz, CDCl₃) δ 7.57 (1H, dd, J = 8.1, 1.5 Hz), 7.34 (1H, ddd, J = 8.7, 7.3, 1.7 Hz), 7.11-6.77 (9H, m), 3.59 (2H, t, J = 15.9, 8.0 Hz), 3.06 (3H, s), 1.65-1.54 (2H, m), 1.30 (2H, s, J = 7.3 Hz), 0.88 (3H, t, J = 7.3 Hz); ¹³C NMR (75 MHz, CDCl₃) δ 154.4 (d, J = 255 Hz), 141.8, 141.0, 137.5, 132.6, 132.3, 132.0, 130.1, 129.3 (d, J = 30 Hz), 128.3, 127.8, 125.8, 125.6, 125.1, 124.1, 122.6, 121.3, 120.8, 120.3, 116.3 (d, J = 22 Hz), 52.5, 39.2, 29.7, 20.3, 13.9; HRMS MH⁺ calcd for C₂₃H₂₅N₃O₂F 394.1925, found 394.1939.

***N*¹-Butyl-*N*²-methyl-*N*¹-(2-nitrophenyl)-*N*²-phenylbenzene-1,2-diamine (10f)**

Nitro triaryl compound **9c** (735 mg, 2.30 mmol) was placed in a round bottom flask and 12 mL anhydrous DMF was added. To that solution was added powdered KOH (593 mg, 10.6 mmol) and the reaction mixture stirred 10 min at RT. Then, *n*-butyl bromide (3.21 g, 23.4 mmol) was added neat and the reaction mixture was heated in an 80°C oil bath for 3h. The reaction mixture was then cooled to RT and diluted with 20 mL water and extracted 3× with diethyl ether. The organic extracts were combined, dried over MgSO₄, filtered and the filtrate concentrated to dryness to give the *N*-butyl derivative **10f** as a brown oil that was carried on directly without further purification.

***N*¹-Methyl-*N*²-(2-(methylamino)phenyl)-*N*¹-phenylbenzene-1,2-diamine (15c)**

A round bottom flask was charged with 30% KH (187 mg, 1.4 mmol) and the solid was washed under nitrogen atmosphere with 3 × 5 mL portions of petroleum ether. The solid was then suspended in 1 mL anhydrous THF and stirred at RT while diisopropylamine (50.0 μL, 0.356 mmol) was added. Stirring at ambient temperature was continued for 10 min before *N,N'*-dimethyl triaryl derivative **3c** (30 mg, 0.10 mmol) was added as a solution in 1ml THF. The reaction mixture was then heated and maintained at reflux for 2 h and then cooled to RT. The reaction mixture was diluted with water and extracted 2× with ethyl acetate. The organic extracts were combined, dried over MgSO₄, filtered and the filtrate concentrated to dryness. The residue was dissolved in petroleum ether and purified by passing the solution through silica gel eluting with petroleum ether and then with 2% dichloromethane, 10% ether, 88% petroleum ether. The purified material was concentrated to dryness to give the product **15c** as a clear gum (26.8 mg, 89%). ¹H NMR (500 MHz, CDCl₃) δ 7.23 (2H, t, J = 7.5 Hz), 7.13-7.07 (4H, m), 6.80 (2H, t, J = 7.5 Hz), 6.80 (2H, t, J = 7.5 Hz), 6.71 (2H, t, J = 4 Hz), 6.65 (3H, t, J = 3.0 Hz), 5.51 (1H,s), 4.06 (1H, bs), 3.29 (3H, s), 2.76 (3H, s). ¹³C NMR (125 MHz, CDCl₃) δ 149.3, 146.0, 143.3, 135.0, 129.4, 128.0, 127.6, 127.4, 126.8, 125.9, 119.5, 118.4, 117.0, 114.1, 114.0, 110.5, 39.4, 30.7. HRMS MH⁺ Calc for C₂₀H₂₂N₃ 304.1802, found 304.1802.

***N*¹-(2-(Butylamino)phenyl)-*N*²-methyl-*N*²-phenylbenzene-1,2-diamine (15f)**

A round bottom flask was charged with 30% KH (374 mg, 2.80 mmol) and the solid was washed with 3 portions of petroleum ether under nitrogen atmosphere. The solid was then suspended in 1 mL anhydrous THF and to that suspension was added distilled diisopropylamine (100 μ L, 0.714 mmol). Stirring at ambient temperature was continued for 10 min before a solution of triaryl aniline **3f** (69 mg, 0.2 mmol) in 3mL THF was added. The reaction mixture was then heated and maintained at reflux for 2h before cooling to RT. The reaction mixture was diluted with water and extracted 2X ethyl acetate. The organic extracts were combined, dried over MgSO₄, filtered and the filtrate concentrated to dryness. The residue was purified using flash chromatography eluting with 1% dichloromethane, 5% ether, 94% petroleum ether to give the product **15f** as a pale yellow gum (50.3 mg, 73%). ¹H NMR (500 MHz, CDCl₃) δ 7.22 (1H, d, J = 1.0 Hz), 7.21 (1H, d, J = 1.0 Hz), 7.12-7.07 (4H, m), 6.79 (2H, dt, J = 7.0, 1.0 Hz), 6.72-6.64 (5H, m), 5.54 (1H, bs), 3.99 (1H, bs), 3.30 (3H, s), 3.04 (2H, t, J = 7.0 Hz), 1.46 (2H, q, J = 7.5 Hz), 1.28 (2H, dq, J = 7.5, 1.0 Hz), 0.90 (3H, t, J = 7.5 Hz). ¹³C NMR (125 MHz, CDCl₃) δ 144.9, 143.1, 134.6, 129.2, 127.7, 127.4, 127.0, 126.5, 125.8, 119.1, 118.1, 116.6, 113.7, 113.7, 110.7, 43.4, 39.1, 31.6, 20.3, 13.9. HRMS MH⁺ calc for C₂₃H₂₈N₃ 346.2278, found 346.2276.

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Supporting Information Available: Includes copies of spectral data (^1H NMR, ^{13}C NMR, IR and HRMS), details of X-ray crystal structure determination, coordinates, and files for the tosylate and chloride salts of compound **5a** (in CIF format). Ortep style representation for the chloride salt of compound **5a**. This material is available free of charge via the Internet at <http://pubs.acs.org>.

References

- (1) Collet, A. *Tetrahedron* **1987**, *43*, 5725-5759.
- (2) Hardie, M. J. *Chem. Soc. Rev.* **2010**, *39*, 516-527.
- (3) Hardie, M. J. In *Cyclotrimeratrylene and cryptophanes*. Section Title: Physical Organic Chemistry; 2012; Vol. 3, pp 895-916.
- (4) Brotin, T.; Dutasta, J. *Chem. Rev.* **2009**, *109*, 88-130.
- (5) Lutz Jr., M. R.; French, D. C.; Rehage, P.; Becker, D. P. *Tetrahedron Letters* **2007**, *48*, 6368-6371.
- (6) Lutz, M. R., Jr.; Zeller, M.; Becker, D. P. *Tetrahedron Lett.* **2008**, *49*, 5003-5005.
- (7) Zeller, M.; Lutz, M. R., Jr.; Becker, D. P. *Acta Crystallogr., Sect. B: Struct. Sci.* **2009**, *B65*, 223-229, S223/1-S223/10.
- (8) Osner, Z. R.; Nyamjav, D.; Holz, R. C.; Becker, D. P. *Nanotechnology* **2011**, *22*, 275611/1-275611/6, S275611/1-S275611/3.
- (9) Panagopoulos, A. M.; Zeller, M.; Becker, D. P. *J. Org. Chem.* **2010**, *75*, 7887-7892.
- (10) Hartwig, J. F. *Acc. Chem. Res.* **1998**, *31*, 852-860.

- (11) Wolfe, J. P.; Wagaw, S.; Marcoux, J.; Buchwald, S. L. *Acc. Chem. Res.* **1998**, *31*, 805-818.
- (12) Hartwig, J. F.; Kawatsura, M.; Hauck, S. I.; Shaughnessy, K. H.; Alcazar-Roman, L. *M. J. Org. Chem.* **1999**, *64*, 5575-5580.
- (13) Muci, A. R.; Buchwald, S. L. *Top. Curr. Chem.* **2002**, *219*, 131-209.
- (14) Bunnett, J. F.; Hrutfiord, B. F. *J. Am. Chem. Soc.* **1961**, *83*, 1691-1697.
- (15) Huisgen, R.; Sauer, J. *Angew. Chem.* **1960**, *72*, 91-108.
- (16) Sanz, R. *Org. Prep. Proced. Int.* **2008**, *40*, 215-291.
- (17) Tadross, P. M.; Stoltz, B. M. *Chem. Rev.* **2012**, *112*, 3550-3577.
- (18) Barluenga, J.; Fananas, F. J.; Sanz, R.; Fernandez, Y. *Chem. --Eur. J.* **2002**, *8*, 2034-2046.
- (19) Kessar, S. V. In *Comprehensive Organic Synthesis*; Trost, B. M., Fleming, I., Eds.; 1991; Vol. 4, pp 483-515.
- (20) DePuy, C. H.; Gronert, S.; Mullin, A.; Bierbaum, V. M. *J. Am. Chem. Soc.* **1990**, *112*, 8650-8655.
- (21) Sanz, R.; Fernandez, Y.; Castroviejo, M. P.; Perez, A.; Fananas, F. J. *J. Org. Chem.* **2006**, *71*, 6291-6294.
- (22) Wilshire, J. F. K. *Aust. J. Chem.* **1988**, *41*, 995-1001.
- (23) Tietze, M.; Iglesias, A.; Merisor, E.; Conrad, J.; Klaiber, I.; Beifuss, U. *Org. Lett.* **2005**, *7*, 1549-1552.
- (24) Moore, G. G. I.; Harrington, J. K.; Swingle, K. F. *J. Med. Chem.* **1975**, *18*, 386-391.
- (25) Baldwin, J. E. *J. Chem. Soc., Chem. Commun.* **1976**, 734-736.
- (26) Prange, T.; Rodriguez, M. S.; Suarez, E. *J. Org. Chem.* **2003**, *68*, 4422-4431.

- (27) Truce, W. E.; Kreider, E. M.; Brand, W. W. *Org. React.* **1970**, *18*, 99-215.
- (28) Rao, U. N.; Maguire, J.; Biehl, E. *ARKIVOC (Gainesville, FL, U. S.)* **2004**, 88-100.
- (29) Takagishi, S.; Schlosser, M. *Synlett* **1991**, 119-121.
- (30) Yoshida, H.; Sugiura, S.; Kunai, A. *Org. Lett.* **2002**, *4*, 2767-2769.
- (31) Li, G.; Hase, W. L. *J. Am. Chem. Soc.* **1999**, *121*, 7124-7129.

TOC Graphic

