One-Pot Synthesis of Unsymmetrical Triarylamines from Aniline Precursors

Michele C. Harris and Stephen L. Buchwald*

Department of Chemistry, Massachusetts Institute of Technology, Cambridge, Massachusetts 02139

sbuchwal@mit.edu

Received May 2, 2000

The "one-pot" synthesis of triarylamines from an aniline and two different aryl halides is described. A catalytic system composed of $Pd_2(dba)_3$/P(*t*-Bu)$_2$-*o*-biphenyl (**1**) is used to prepare a variety of triarylamines in a single flask by the coupling of an aniline with an aryl bromide and aryl chloride. The synthesis of triarylamines containing a heterocyclic aryl group is also described by employing a one-flask, two-step method. These methods can be used to synthesize both discrete triarylamines and a triarylamine library.

Introduction and Background

Triarylamines are important structural elements of many organic materials, including dendrimers and polymers. They are of interest due to their electronic properties, particularly their ability to act as efficient hole conductors.[1,2] For example, TPD (Figure 1) and structurally related compounds are well-known for their use in electroluminescent devices[3] and light-emitting diodes.[4] The triarylamine moiety is also a component of nonlinear optical chromophores,[5] Xerox photoreceptors,[6] and holographic materials.[7]

One of the most widely used methods for the synthesis of triarylamines is the Ullmann condensation, in which a diarylamine is condensed with an aryl halide in the presence of base and a copper catalyst.[8] Traditionally, this method has been plagued by the requirement to use a stoichiometric amount of copper and harsh reaction conditions while providing variable yields. Improved reaction conditions have been developed which address some of these issues. For example, it has been found that the use of crown ethers as phase-transfer catalyst allow for the use of milder reaction conditions.[9] Recently, 1,10-phenanthroline has been employed to ligate the copper, enabling the use of lower temperatures and shorter reaction times.[10] These catalytic systems also facilitate the double coupling of an aniline with 2 equiv of an aryl halide to form a symmetrical triarylamine, a process which is difficult under traditional Ullmann conditions.

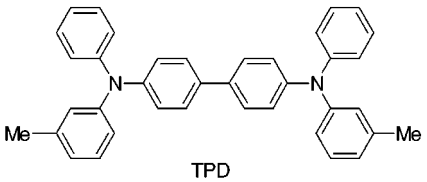


Figure 1.

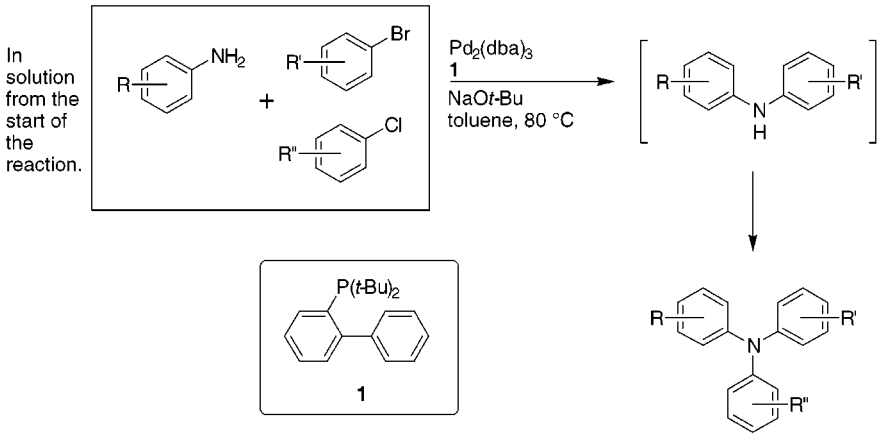
The palladium-catalyzed amination of aryl halides and sulfonates has been the focus of intensive research in recent years.[11−14] The use of a Pd/P(*t*-Bu)$_3$ catalyst system was first reported by Koie and a modified system was used by Hartwig to efficiently couple diarylamines with aryl halides to make both discrete[13,15,16] and polymeric triarylamines.[17] Hartwig also reported the use of a Pd/DPPF catalyst system to synthesize triarylamine-based dendrimers[18] and polymers.[19] The Pd/DPPF catalyst system was also employed by Marder to prepare unsymmetrical triarylamines in "one-pot" by the sequential coupling of an aniline with two different aryl bromides.[20] While this "one-pot" method is noteworthy, it requires the addition of more catalyst and base when the second aryl bromide is added. Also, in the case where the second aryl bromide is electron-rich, a lower yield is obtained and a longer reaction time is required.

Recently, we have found that Pd/P(*t*-Bu)$_2$-*o*-biphenyl is an efficient catalyst system for the coupling of a wide range of amines with aryl bromides, chlorides, and triflates.[21] Since the coupling of both anilines and dia-

(1) Sakanoue, K.; Motoda, M.; Sugimoto, M.; Sakaki, S. *J. Phys. Chem. A* **1999**, *103*, 5551.
(2) Adachi, C.; Tokito, S.; Tsutsui, T.; Saito, S. *Jpn. J. Appl. Phys.* **1988**, *27*, L269.
(3) Takada, N.; Saito, S. In *Macromolecules in Science and Engineering*; Tanabe, Y., Ed.; Springer Series in Materials Science 35; Springer: New York, 1999; p 345.
(4) Thelakkat, M.; Hagen, J.; Haarer, D.; Schmidt, H.-W. *Synth. Met.* **1999**, *102*, 1125.
(5) Thayumanavan, S.; Mendez, J.; Marder, S. R. *J. Org. Chem.* **1999**, *64*, 4289.
(6) Law, K.-Y. *Chem. Rev.* **1993**, *93*, 449.
(7) Schloter, S.; Schreiber, A.; Grasruck, M.; Leopold, A.; Kol'chenko, M.; Pan, J.; Hohle, C.; Strohriegl, P.; Zilker, S. J.; Haarer, D. *Appl. Phys. B* **1999**, *68*, 899.
(8) Paine, A. J. *J. Am. Chem. Soc.* **1987**, *109*, 1496.
(9) Gauthier, S.; Fréchet, J. M. J. *Synthesis* **1987**, 383.
(10) Goodbrand, H. B.; Hu, N.-X. *J. Org. Chem.* **1999**, *64*, 670.
(11) a) Wolfe, J. P.; Buchwald, S. L. *Angew. Chem., Int. Ed.* **1999**, *38*, 2413. (b) Wolfe, J. P.; Tomori, H.; Sadighi, J. P.; Yin, J.; Buchwald, S. L. *J. Org. Chem.* **2000**, *65*, 1158.
(12) Yang, B. H.; Buchwald, S. L. *J. Organomet. Chem.* **1999**, *576*, 125.
(13) Hartwig, J. F.; Kawatsura, M.; Hauck, S. I.; Shaughnessy, K. H.; Alcazar-Roman, L. M. *J. Org. Chem.* **1999**, *64*, 5575.
(14) Hartwig, J. F. *Angew. Chem., Int. Ed.* **1998**, *37*, 2047.
(15) Yamamoto, T.; Nishiyama, M.; Koie, Y. *Tetrahedron Lett.* **1998**, *39*, 2367.
(16) Watanabe, M.; Nishiyama, M.; Yamamoto, T.; Koie, Y. *Spec. Chem.* **1998**, *18*, 445.
(17) Goodson, F. E.; Hauck, S. I.; Hartwig, J. F. *J. Am. Chem. Soc.* **1999**, *121*, 7527.
(18) Louie, J.; Hartwig, J. F. *J. Am. Chem. Soc.* **1997**, *119*, 11695.
(19) Goodson, F. E.; Hartwig, J. F. *Macromolecules* **1998**, *31*, 1700.
(20) Thayumanavan, S.; Barlow, S.; Marder, S. R. *Chem. Mater.* **1997**, *9*, 3231.

10.1021/jo000674s CCC: $19.00
Published on Web 07/15/2000

Scheme 1



rylamines with aryl halides was efficient with this new catalyst system, we sought to develop a simple, general, and efficient method for the synthesis of unsymmetrical triarylamines from aniline precursors.

Results and Discussion

Simple Triarylamines. Initially, we attempted to prepare triarylamines by the coupling of an aniline with two different aryl chlorides. While we could follow a two-step, "one-pot" procedure similar to that developed by Marder, we decided to explore a simpler route to these compounds. Our goal was to develop a protocol in which all components could be in the reaction solution from the onset of the procedure. Hence, we devised a method in which an aniline is coupled sequentially with an aryl bromide and an aryl chloride in the same flask (Scheme 1).

The rate of oxidative addition of an aryl bromide to a Pd(0) complex is faster than the oxidative addition of the corresponding aryl chloride.[22] Thus, we expected that the aniline would selectively react with the aryl bromide in the presence of the aryl chloride. However, we were unsure as to whether the aryl bromide would selectively react with the aniline or both the aniline and the in situ-generated diarylamine. Therefore, we conducted an experiment in which an aniline, a diarylamine, and an aryl bromide were mixed in a 1:1:1 ratio, and a palladium-catalyzed coupling was carried out. We observed that the aryl bromide combined selectively with the aniline with no evidence of triarylamine formation. In subsequent experiments, we have observed that anilines react with high selectivity with the aryl bromides relative to the aryl chlorides. The crude reaction mixtures, however, contain a small amount of undesired triarylamines, resulting from the double arylation of an aryl halide. These impurities could be removed by flash chromatography to give products of high purity.

A variety of triarylamines have been synthesized by this method (Table 1). For example, very electron-rich triarylamines have been prepared in good yield (Table 1, entries 2 and 3). We have further demonstrated the efficiency of this reaction by the double arylation of 1,3-phenylenediamine with 2 equiv of 1-bromo-4-*tert*-butylbenzene and 4-chlorotoluene in 95% yield (Table 1, entry 6).

This method is relatively general with respect to substrate scope, but is not without its limitations. First, the triarylamine can only have one *ortho*-substituent. We have observed that reactions in which the *ortho*-substituent is introduced from either the aniline or aryl bromide are faster than reactions in which an *ortho*-substituted aryl chloride is used. Another limitation is the inability to couple diarylamines with aryl halides containing base-sensitive functional groups utilizing weak bases, such as K_3PO_4 and Cs_2CO_3. We are currently attempting to overcome this limitation.

Although the rate of oxidative addition of an aryl bromide to a Pd(0) complex is faster than that of the corresponding aryl chloride, in some cases the reaction of the aryl chloride can be competitive with the reaction of the aryl bromide. For example, at 80 °C the coupling of 2,4-dimethylaniline (Table 1, entry 4) with 4-bromoanisole (an electron-rich aryl bromide) and 3-chlorotoluene leads to the formation of 10% (as determined by GC analysis) of the undesired triarylamine products. However, this can be overcome by decreasing the reaction temperature to 60 °C. Upon complete consumption of the aryl bromide, the temperature is raised to 80 °C for the coupling of the aryl chloride with the diarylamine.

Heteroaromatic Triarylamines. Triarylamines containing a heterocyclic moiety have also been synthesized (Table 2), although a modification of the procedure is necessary. We observed that reactions of an aniline with an aryl bromide in the presence of a heterocyclic aryl halide were sluggish and not selective for one diarylamine. Therefore, it was necessary to employ a "one-pot", two-step method wherein the heterocyclic aryl halide is added after complete consumption of the first aryl bromide (Scheme 2). A higher quantity of catalyst is also necessary to ensure complete conversion to product.

In the coupling of 2-chloropyridine (Table 2, Entry 3), the Pd/**2** catalyst system (Figure 2) was determined to be superior to the Pd/**1** catalyst system. It should be noted that while reactions with 2-chloropyridine are successful, reactions with the less-activated 3-bromopyridine only proceeded to 75% conversion even when using 5 mol % catalyst.

Triarylamine Library. The use of combinatorial methods in the pharmaceutical industry[23,24] has increased

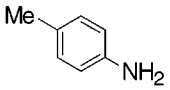
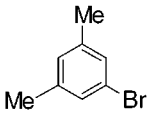
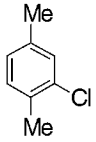
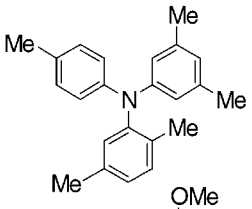
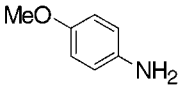
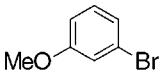
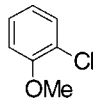
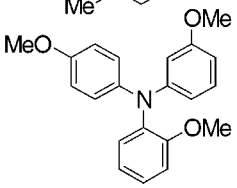
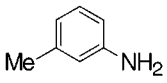
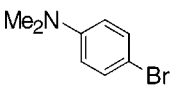
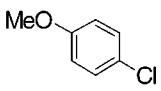
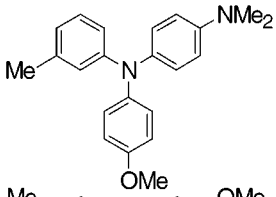
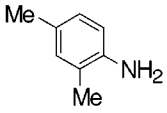
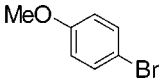
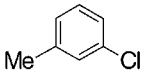
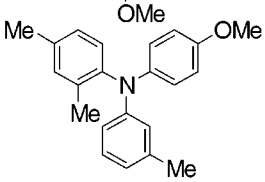
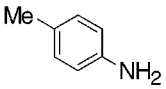
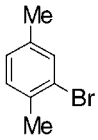
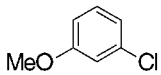
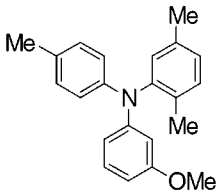
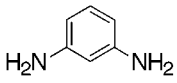
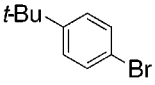
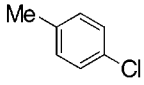
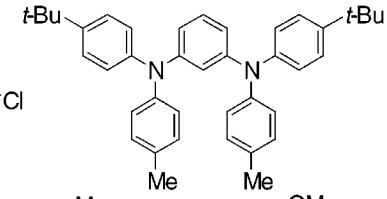
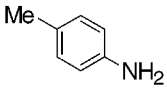
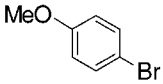
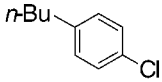
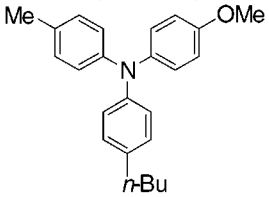
(21) Wolfe, J. P.; Buchwald, S. L. *Angew. Chem., Int. Ed.* **1999**, *38*, 2413.

(22) Tsuji, J. *Palladium Reagents and Catalysis*; John Wiley and Sons: Chichester, 1995.

(23) Mayer, T. U.; Kapoor, T. M.; Haggarty, S. J.; King, R. W.; Schreiber, S. L.; Mitchison, T. J. *Science* **1999**, *286*, 971.

(24) Martin, E. J.; Critchlow, R. E. *J. Comb. Chem.* **1999**, *1*, 32.

Table 1. "One-Pot" Synthesis of Triarylamines[a]

Entry	Amine	ArBr	ArCl	Product	Yield(%)[b]
1					84
2					74
3					91
4					82[c]
5					90
6					95
7					85

[a] Reaction conditions: 1.0 mmol of aniline, 1.0 mmol of aryl bromide, 1.05 mmol of aryl chloride, 2.1 mmol of NaO*t*-Bu, 0.5−1.5 mol % $Pd_2(dba)_3$, 2−6 mol % **1**, toluene (4 mL/mmol aniline), 80 °C. [b] Yields represent isolated yields of compounds estimated to be ≥95% pure as judged by ^{1}H NMR, GC analysis, and combustion analysis (average of two runs). [c] A temperature gradient of 60−80 °C was employed.

dramatically in recent years. Combinatorial methods for the rapid synthesis of compounds has also been utilized in materials science.[25]

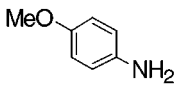
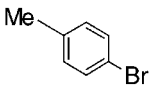
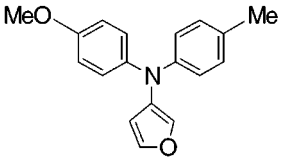
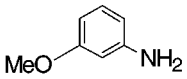
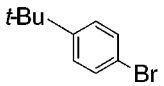
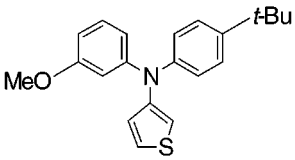
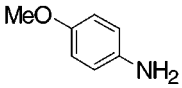
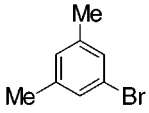
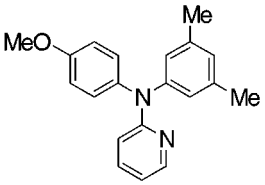
The wide substrate scope and simple reaction conditions of our catalytic protocol makes it amenable to combinatorial synthesis. To demonstrate the utility of our catalyst system in this regard, three anilines, three aryl bromides, and three aryl chlorides were combined in a single flask and coupled to give a mixture of 27 products with a 96% total mass recovery (Scheme 3);[26] the size of the "library" was limited so that we could readily determine whether each of the expected components was present in the reaction mixture.

The substrates were chosen so that each of the expected triarylamine products had a unique molecular weight, in order that they could be identified by GC/MS (Figure 3).[27] Each signal could be assigned to a unique

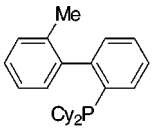
(25) Jandeleit, B.; Schaefer, D. J.; Powers, T. S.; Turner, H. W.; Weinberg, W. H. *Angew. Chem., Int. Ed.* **1999**, *38*, 2494.

(26) Compounds were detected in 1−11% (uncorrected) relative to the total peak integration. Peaks corresponding to other triarylamine products were detected in <1% (total) relative to the total peak integration. We recognize that our sample may include additional compounds which did not separate under any of the conditions examined.

Table 2. Sequential "One-Pot" Synthesis of Heterocyclic Triarylamines[a]

Entry	Amine	ArBr	ArX	Product	Yield(%)[b]
1					89
2					92
3					94[c]

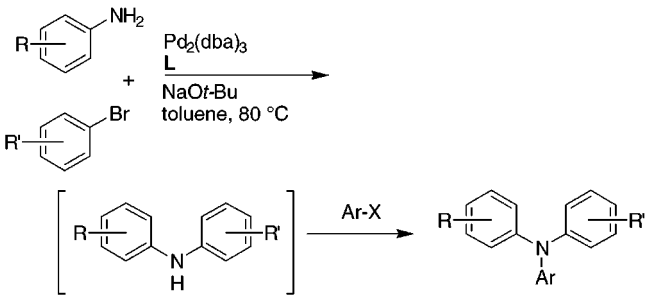
[a] Reaction conditions: 1.0 mmol of aniline, 1.0 mmol of aryl bromide, 2.0 mmol of heterocyclic aryl halide, 2.4−2.8 mmol of NaO*t*-Bu, 1.5−2.5 mol % $Pd_2(dba)_3$, 6−10 mol % **1**, toluene (2 mL/mmol aniline), 80 °C. [b] Yields represent isolated yields of compounds estimated to be ≥95% pure as judged by ^{1}H NMR, GC analysis, and combustion analysis (average of two runs). [c] Ligand **2** is used in place of ligand **1**.



2

Figure 2.

Scheme 2



triarylamine based on its mass spectrum. To confirm our assignments, triarylamines corresponding to numbers 8, 12, 18, 20, and 21 were independently prepared and analyzed using the same GC methods as for the mixture; retention times and mass spectra of the individual compounds confirmed the previous assignments.

Conclusion

In conclusion, we have developed a method to prepare a variety of unsymmetrical triarylamines in a single flask procedure by coupling an aniline with an aryl bromide and an aryl chloride. This method is versatile in that it can accommodate electron-rich systems, *ortho*-substituted aryl halides, and multiple couplings. A modification of this method was developed to prepare triarylamines containing a heterocyclic moiety, such as furan, thiophene, and pyridine. We have also utilized this method to synthesize a small solution triarylamine library of 27 triarylamines.

Experimental Section

General. All reactions were performed under an argon atmosphere in oven-dried glassware and assembled without the aid of a glovebox. Elemental analyses were performed by Atlantic Microlab, Norcross, GA. Toluene was distilled under nitrogen from molten sodium. Substrates were purchased from Aldrich Chemical Co., with the exception of *p*-anisidine, 1-*n*-butyl-4-chlorotoluene, 3-chlorotoluene, and 3-chloroanisole which were purchased from Lancaster and 4-bromoanisole, which was purchased from Alfa-Aesar. Sodium *tert*-butoxide was purchased from Aldrich Chemical Co. and stored in a Vacuum Atmospheres glovebox under nitrogen. Small amounts were removed from the glovebox as needed, stored in a desiccator for up to one week, and weighed in the air. Tris(dibenzylideneacetone)dipalladium(0) was purchased from Strem Chemical Co. All chemicals were used as supplied. Preparative flash chromatography was performed on ICN Flash Silica gel (230−400 mesh). The yields in Table 1 refer to isolated yields (average of two runs) of compounds estimated to be ≥95% pure as determined by ^{1}H NMR, GC analysis, and combustion analysis. The procedures described in the Experimental Section are representative; thus, the yields may differ from those given in Tables 1 and 2.

2-(Di-*tert*-butylphosphino)-*o*-biphenyl (1). Prepared according to the literature procedure.[28]

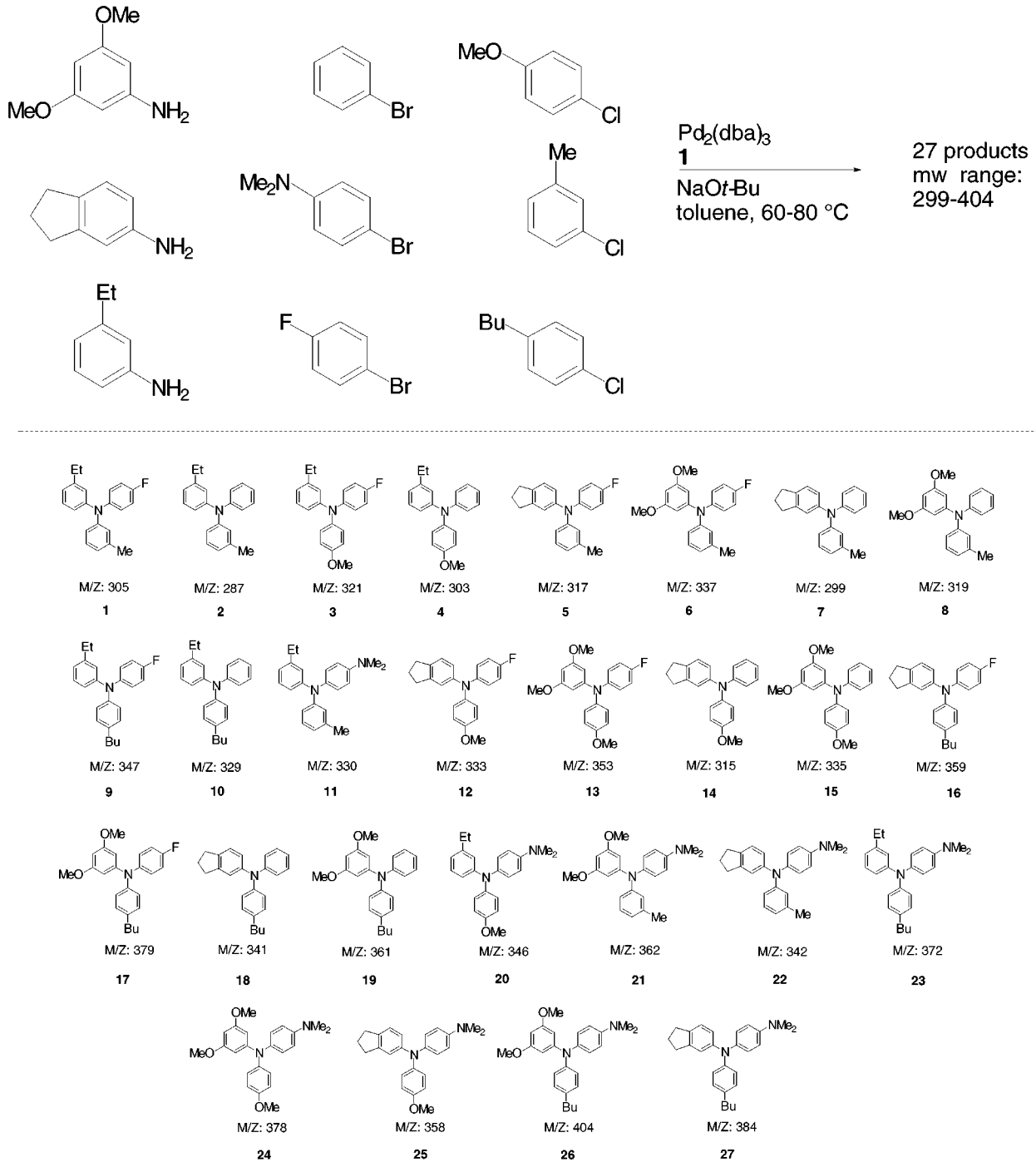
2-(Dicyclohexylphosphino)-2′-methylbiphenyl (2). Prepared according to the literature procedure.[28]

General Procedure for the One-Pot Synthesis of Triarylamines (A). A Schlenk tube was charged with $Pd_2(dba)_3$ (4.6 mg, 0.005 mmol, 1 mol % Pd), P(*t*-Bu)$_2$-*o*-biphenyl (6.0 mg, 0.02 mmol, 2 mol %), and sodium *tert*-butoxide (202 mg, 2.1 mmol). The flask was evacuated, backfilled with argon, and fitted with a rubber septum. Amine (1.0 mmol), aryl bromide (1.0 mmol), aryl chloride (1.05 mmol), and toluene (4 mL) were

(27) To accomplish this, several different sets of acquisition parameters were necessary.

(28) Wolfe, J. P.; Singer, R. A.; Yang, B. H.; Buchwald, S. L. *J. Am. Chem. Soc.* **1999**, *121*, 9550.

Scheme 3



each added via syringe (amines or aryl halides which were solids at room temperature were added prior to the evacuation/backfill cycle). The flask was sealed with a Teflon screwcap, and the reaction mixture was heated to 80 °C with stirring until the intermediate diarylamine had been consumed, as judged by GC analysis. The reaction mixture was then cooled to room temperature, taken up in diethyl ether, washed with brine, dried with $MgSO_4$, and concentrated in vacuo. The product was purified by flash chromatography on silica gel using a mixture of hexanes and ethyl acetate and/or toluene as the eluent.

General Procedure for the "One-Pot", Two-Step Synthesis of Heterocyclic Triarylamines (B). A Schlenk tube was charged with $Pd_2(dba)_3$ (23.0 mg, 0.025 mmol, 5 mol % Pd), P(*t*-Bu)$_2$-*o*-biphenyl (30.0 mg, 0.10 mmol, 10 mol %), and sodium *tert*-butoxide (270 mg, 2.8 mmol). The flask was evacuated, backfilled with argon, and fitted with a rubber septum. Amine (1.0 mmol), aryl bromide (1.0 mmol), and toluene (2 mL) were each added via syringe (amines or aryl bromides which were solids at room temperature were added prior to the evacuation/backfill cycle). The flask was sealed with a Teflon screwcap, and the reaction mixture was heated to 80 °C with stirring until the starting materials had been consumed, as judged by GC analysis. While maintaining the reaction mixture at 80 °C, the Teflon screwcap was replaced with a rubber septum, and the reaction mixture was purged with argon for 2 min. The heterocyclic aryl halide (2.0 mmol) was added to the Schlenk tube via syringe [caution: appropriate care should be exercised], and the reaction vessel was purged with argon for an additional 2 min and then resealed. When the intermediate diarylamine had been consumed (as judged by GC analysis), the reaction mixture was cooled to room temperature, taken up in diethyl ether, washed with brine, dried with $MgSO_4$, and concentrated in vacuo. The

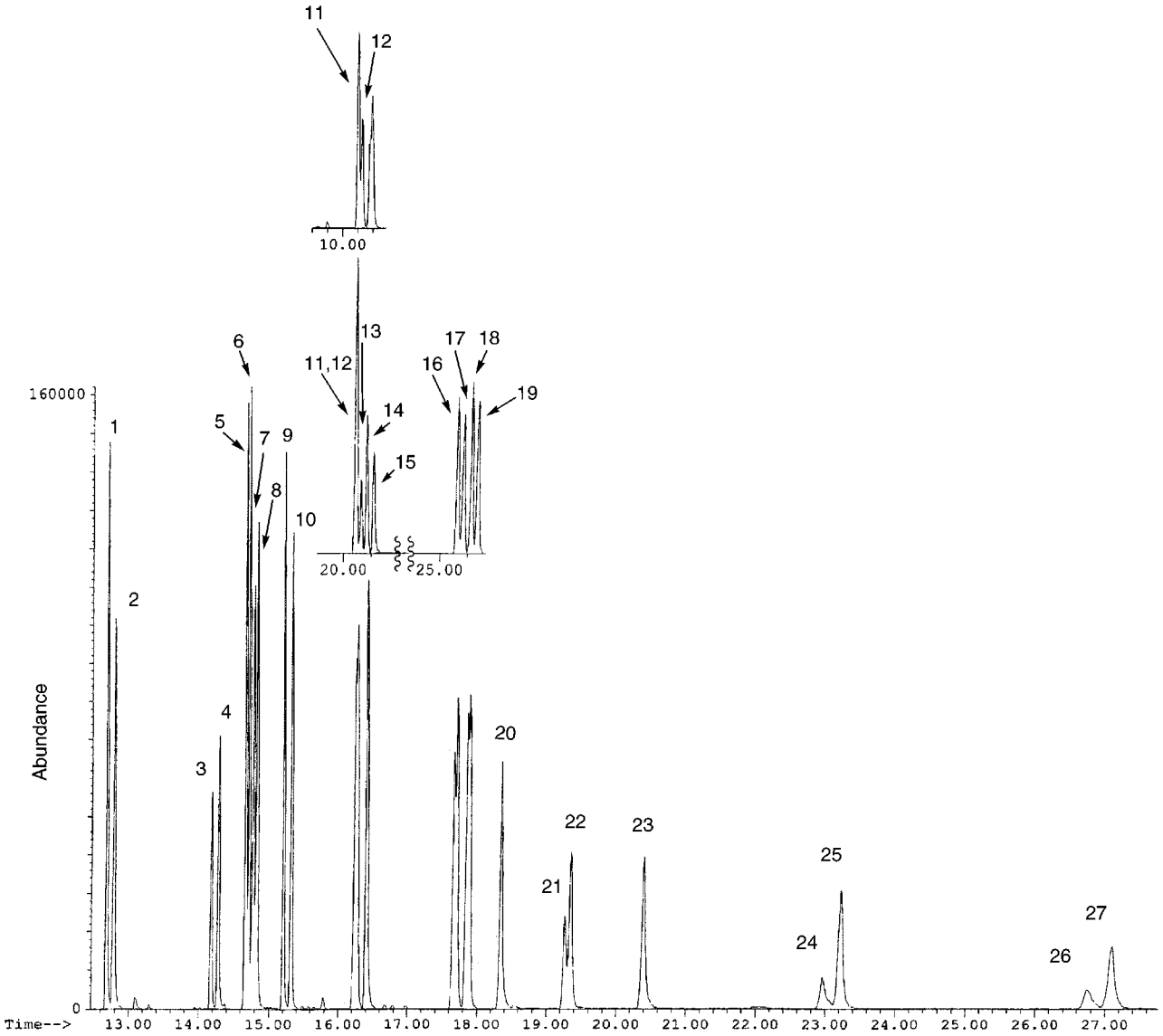


Figure 3. GC/MS of the library prepared according to Scheme 3. The numbers refer to compounds shown in Scheme 3.

product was purified by flash chromatography using a mixture of hexanes and ethyl acetate and/or toluene as eluent.

***N*-(2,5-Dimethylphenyl)-*N*-(3,5-dimethylphenyl)-*N*-(4-methylphenyl)amine (Table 1, Entry 1).** General procedure A was followed to afford the title product as a colorless oil (0.274 g, 87%). ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.11−7.08 (m, 2H), 7.01−6.99 (m, 2H), 6.95−6.91 (m, 2H), 6.87−6.84 (m, 2H), 6.53 (s, 2H), 2.28 (s, 3H), 2.25 (s, 3H), 2.18 (s, 6H), 1.97 (s, 3H); ^{13}C (125 MHz, $CDCl_3$) δ 148.0, 145.6, 145.3, 138.6, 137.0, 133.3, 131.4, 130.8, 130.1, 129.7, 126.7, 122.9, 122.3, 118.9, 21.6, 21.0, 20.9, 18.4. Anal. Calcd for $C_{23}H_{25}N$: C, 87.57; H, 7.99. Found: C, 87.36; H, 7.95.

***N*-(2-Methoxyphenyl)-*N*-(3-methoxyphenyl)-*N*-(4-methoxyphenyl)amine (Table 1, Entry 2).** General procedure A was followed with the following adjustments of 1.5 mol % $Pd_2(dba)_3$, 6 mol % **1**, and 2.8 mmol sodium *tert*-butoxide, to afford the title product as a yellow oil (0.254 g, 76%). ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.17−7.14 (m, 2H), 7.10−7.00 (m, 3H), 6.95−6.92 (m, 2H), 6.81−6.78 (m, 2H), 6.38−6.34 (m, 3H), 3.77 (s, 3H), 3.68 (s, 3H), 3.66 (s, 3H); ^{13}C (125 MHz, $CDCl_3$) δ 160.3, 156.0, 155.8, 150.1, 140.4, 135.6, 130.0, 129.4, 126.7, 126.3, 121.6, 114.4, 113.2, 111.3, 104.7, 104.6, 56.0, 55.6, 55.3. Anal. Calcd for $C_{21}H_{21}NO_3$: C, 75.20; H, 6.31. Found: C, 75.10; H, 6.38.

***N*-(4-Dimethylaminophenyl)-*N*-(4-methoxyphenyl)-*N*-(3-methylphenyl)amine (Table 1, Entry 3).** General procedure A was followed with the following adjustments of 1.5 mol % $Pd_2(dba)_3$, 6 mol % **1**, and 2.8 mmol sodium *tert*-butoxide, to afford the title product as a yellow solid (0.289 g, 87%, mp 80−81 °C). ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.05−6.98 (m, 5H), 6.80−6.83 (m, 7H), 3.78 (s, 3H), 2.92 (s, 6H), 2.21 (s, 3H); ^{13}C (125 MHz, $CDCl_3$) δ 155.4, 149.1, 147.4, 141.6, 138.7, 137.9, 128.8, 127.0, 126.2, 121.0, 117.7, 114.6, 113.7, 55.6, 41.1, 21.7. Anal. Calcd for $C_{22}H_{24}NO_2$: C, 79.48; H, 7.28. Found: C, 79.27; H, 7.28.

***N*-(2,4-Dimethylphenyl)-*N*-(3-methylphenyl)-*N*-(4-methoxyphenyl)amine (Table 1, Entry 4).** General procedure A was followed, except the reaction was initially heated to 60 °C until the aryl bromide had been consumed (as judged by GC analysis) and then heated to 80 °C until the intermediate diarylamine had been consumed (as judged by GC analysis). The product was isolated as a pale yellow oil (0.269 g, 85%). ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.02−6.95 (m, 6H), 6.79−6.76 (m, 2H), 6.64−6.62 (m, 3H), 3.77 (s, 3H), 2.32 (s, 3H), 2.21 (s, 3H), 2.00 (s, 3H); ^{13}C (125 MHz, $CDCl_3$) δ 154.9, 148.5, 143.2, 140.9, 138.7, 136.0, 135.3, 132.8, 129.2, 128.8, 128.0, 124.8, 120.9, 120.0, 116.7, 114.5, 55.6, 21.8, 21.2, 18.8. Anal. Calcd for $C_{22}H_{23}NO$: C, 83.24; H, 7.30. Found: C, 83.18; H, 7.37.

***N*-(2,5-Dimethylphenyl)-*N*-(4-methylphenyl)-*N*-(3-methoxyphenyl)amine (Table 1, Entry 5).** General procedure A was followed to afford the title product as a pale yellow oil (0.295 g, 92%). ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.10−7.08 (m,

2H), 7.06−7.00 (m, 2H), 6.95−6.89 (m, 4H), 6.48−6.40 (m, 3H), 3.69 (s, 3H), 2.28 (s, 3H), 2.24 (s, 3H), 1.98 (s, 3H); ^{13}C (125 MHz, $CDCl_3$) δ 160.4, 149.2, 145.1, 144.7, 137.0, 133.3, 131.5, 131.4, 130.1, 129.7, 129.6, 126.9, 122.7, 113.2, 106.5, 105.5, 55.3, 21.1, 20.9, 18.3. Anal. Calcd for $C_{22}H_{23}NO$: C, 83.24; H, 7.30. Found: C, 82.99; H, 7.39.

***N,N′*-(4-*tert*-Butylphenyl)-*N,N′*-(4-methylphenyl)-1,3-phenylenediamine (Table 1, Entry 6).** General procedure A was followed with the following adjustments of 1.5 mol % $Pd_2(dba)_3$, 6 mol % **1**, and 2.8 mmol sodium *tert*-butoxide, to afford the title product as a white solid (0.522 g, 95%, mp 158−160 °C). ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.19−7.16 (m, 4H), 7.03−6.94 (m, 13H), 6.81−6.78 (m, 1H), 6.57−6.54 (m, 2H), 2.27 (s, 6H), 1.27 (s, 18H); ^{13}C (125 MHz, $CDCl_3$) δ 148.8, 145.3, 145.2, 145.1, 132.3, 129.9, 129.5, 125.9, 124.8, 123.4, 118.2, 117.0, 34.3, 31.6, 21.0. Anal. Calcd for $C_{40}H_{44}N_2$: C, 86.91; H, 8.02. Found: C, 86.76; H, 8.17.

***N*-(4-*n*-Butylphenyl)-*N*-(4-methylphenyl)-*N*-(4-methoxyphenyl)amine (Table 1, Entry 7).** General procedure A was followed to afford the title product as a pale yellow oil (0.278 g, 83%). ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.04−6.99 (m, 6H), 6.94−6.90 (m, 2H), 6.81−6.78 (m, 4H), 3.78 (s, 3H), 2.53 (t, J = 7.8 Hz, 2H), 2.28 (s, 3H), 1.59−1.54 (m, 2H), 1.39−1.32 (m, 2H), 0.92 (t, J = 7.4 Hz, 3H); ^{13}C (125 MHz, $CDCl_3$) δ 155.8, 146.1, 146.0, 141.8, 136.4, 131.4, 129.8, 129.1, 126.7, 123.3, 122.9, 114.7, 55.6, 35.1, 33.9, 22.6, 20.9, 14.2. Anal. Calcd for $C_{24}H_{27}NO$: C, 83.44; H, 7.88. Found: C, 83.50; H, 7.92.

3-[*N*-(4-Methylphenyl)-*N*-(4-methoxyphenyl)amino]furan (Table 2, Entry 1). General procedure B was followed to afford the title product as a pale yellow oil (0.248 g, 89%). ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.30−7.29 (m, 1H), 7.12−7.11 (m, 1H), 7.08−7.00 (m, 4H), 6.94−6.91 (m, 2H), 6.82−6.79 (m, 2H), 6.27−6.26 (m, 1H), 3.78 (s, 3H), 2.28 (s, 3H); ^{13}C (125 MHz, $CDCl_3$) δ 155.9, 145.7, 142.5, 140.9, 135.6, 133.7, 131.2, 129.8, 125.6, 121.3, 114.7, 108.3, 55.6, 20.8. Anal. Calcd for $C_{18}H_{17}NO_2$: C, 77.40; H, 6.13. Found: C, 77.25; H, 6.23.

3-[*N*-(4-*tert*-butylphenyl)-*N*-(3-methoxyphenyl)amino]thiophene (Table 2, Entry 2). General procedure B was followed to afford the title product as a yellow oil (0.304 g, 90%). ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.26−7.18 (m, 4H), 7.13−7.08 (m, 1H), 7.04−6.99 (m, 2H), 6.88−6.86 (m, 1H), 6.66−6.60 (m, 2H), 6.52−6.49 (m, 1H), 3.71 (s, 3H), 1.30 (s, 9H); ^{13}C (125 MHz, $CDCl_3$) δ 160.5, 149.4, 146.6, 146.1, 145.0, 129.8, 126.2, 125.2, 124.9, 123.5, 115.0, 113.0, 108.4, 107.2, 55.4, 34.4, 31.6. Anal. Calcd for $C_{21}H_{23}NOS$: C, 74.74; H, 6.87. Found: C, 74.94; H, 7.00.

2-[*N*-(3,5-dimethylphenyl)-*N*-(4-methoxyphenyl)amino]pyridine (Table 2, Entry 3). General procedure B was followed with the following adjustments of 1.5 mol % $Pd_2(dba)_3$, 6 mol % **2**, and 2.4 mmol of sodium *tert*-butoxide, to afford the title product as a yellow solid (0.276 g, 81%, mp 95−97 °C). ^{1}H NMR (300 MHz, $CDCl_3$) δ 8.19−8.17 (m, 1H), 7.40−7.35 (m, 1H), 7.15−7.09 (m, 2H), 6.89−6.84 (m, 2H), 6.79 (s, 2H), 6.75 (s, 1H), 6.71−6.63 (m, 2H), 3.79 (s, 3H), 2.24 (s, 6H); ^{13}C (125 MHz, $CDCl_3$) δ 159.2, 156.9, 148.0, 145.9, 139.0, 137.3, 128.3, 126.6, 124.0, 115.1, 114.9, 112.8, 55.6, 21.6. Anal. Calcd for $C_{20}H_{20}N_2O$: C, 78.92; H, 6.62. Found: C, 78.84; H, 6.69.

Triarylamine Library. A Schlenk tube was charged with $Pd_2(dba)_3$ (21.0 mg, 0.022 mmol, 3 mol % Pd), P(*t*-Bu)$_2$-*o*-biphenyl (27.0 mg, 0.90 mmol, 6 mol %), 4-aminoveratrole (76 mg, 0.5 mmol), 4-bromo-*N*,*N*-dimethylaniline (100 mg, 0.5 mmol), and sodium *tert*-butoxide (302 mg, 3.15 mmol). The flask was evacuated, backfilled with argon, and fitted with a rubber septum. 5-Aminoindan (68 μL, 0.5 mmol), 3-ethylaniline (62 μL, 0.5 mmol), bromobenzene (53 μL, 0.5 mmol), 1-bromo-4-fluorobenzene (55 μL, 0.5 mmol), 4-chloroanisole (65 μL, 0.53 mmol), 3-chlorotoluene (63 μL, 0.53 mmol), 4-*n*-butylchlorobenzene (90 μL, 0.53 mmol), and toluene (1 mL) were each added via syringe. The flask was sealed with a Teflon screwcap, and the reaction mixture was heated to 60 °C with stirring for 2 h and 15 min and then 80 °C until the intermediate diarylamines had been consumed, as judged by GC analysis. The reaction mixture was then cooled to room temperature, taken up in diethyl ether, washed with brine, dried with $MgSO_4$, filtered through a mixture of Celite/silica gel, and concentrated. This mixture was analyzed by GC/MS.

Acknowledgment. We are grateful to the National Institutes of Health (GM58160) and the National Cancer Institute (Training Grant NCI CI T32CA09112) for financial support. We also thank Pfizer, Merck, and Novartis for additional unrestricted support. We thank Dr. Robert Singer for helpful discussions, and Dr. Joseph Sadighi and Dr. Joseph Fox for the preparation of ligands **1** and **2**, respectively.

JO000674S