JOC Article

Triphenylphosphine-Mediated Reductive Cyclization of 2-Nitrobiphenyls: A Practical and Convenient Synthesis of Carbazoles

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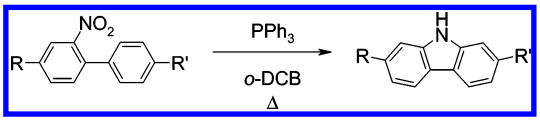

The synthesis of a series of substituted carbazoles from the corresponding 2-nitrobiphenyl derivatives using a novel modification of the Cadogan reaction is described. Cyclization of the 2-nitrobiphenyls was achieved via reductive deoxygenation of the nitro groups using a slight excess of triphenylphosphine in a suitable solvent. We have observed a temperature dependence on the extent of conversion under these conditions, with higher boiling solvents affording higher yields across a range of substrates. The new reaction conditions are very straightforward and convenient to execute, tolerate a broad range of functional groups, and yield carbazole products in the absence of unwanted side products.

Introduction

By virtue of their widespread occurrence in both important natural products[1] (e.g., alkaloids) and unnatural synthetic materials,[2] carbazoles have received considerable attention in the literature, particularly in terms of their synthetic methodology. In synthetic materials, carbazoles are an important building block for both small-molecule and polymeric−optoelectronic materials because of their desirable electronic and charge-transport properties, as well as their high thermal stability. The ability to tune the carbazole's properties and incorporate them into more complex molecular structures requires either the chemical functionalization of the parent carbazole nucleus or its construction from simple, readily available synthons.

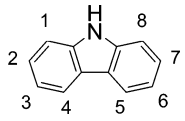

FIGURE 1. Structure of carbazole ring system.

Owing to its highly electron-rich nature, the carbazole skeleton (Figure 1) is a modest nucleophile that can be readily derivatized with a wide variety of electrophiles (tertiary alkyl, acyl, nitro, halogen, etc.).[3] While commonly employed, such methods are limited in the position(s) on the ring system to which electrophiles can be introduced. The most reactive positions for electrophilic substitution are the 3 and 6 position, "para" to the nitrogen atom, and to a lesser extent, the 1 and 8 positions, which often require more forcing reaction conditions. When functionalization of the 2, 4, 5, or 7 ring positions is desired, or when mono and/or unsymmetrical substitution patterns are needed, and/or when functional groups not readily introduced by electrophilic substitution are desired, alternate syntheses are required. Fortunately several methods exist for the synthesis of

(1) For some recent examples of carbazole-containing natural products, see: (a) Wang, Y.-S.; He, H.-P.; Shen, Y.-M.; Hong, X.; Hao, X.-J. *J. Nat. Prod.* **2003**, *66*, 416. (b) Ito, C.; Katsuno, S.; Itoigawa, M.; Ruangungsi, N.; Mukainaka, T.; Okuda, M.; Kitigawa, Y.; Tokuda, H.; Nishino, H.; Furukawa, H. *J. Nat. Prod.* **2000**, *63*, 125. (c) Chakravarty, A. K.; Sarkar, T.; Masuda, K.; Shiojima, K. *Phytochemistry* **1999**, *50*, 1263. (d) Wu, T.-S.; Huang, S.-C.; Wu, P.-L. *Chem. Pharm. Bull.* **1998**, *46*, 1459. (e) Ito, C.; Katsuno, S.; Ohta, H.; Omura, M.; Kajura, I.; Furukawa, H. *Chem. Pharm. Bull.* **1997**, *45*, 48.

(2) For some recent references on carbazoles in materials, see: (a) Ferreira, I. C. F. R.; Queiroz, M.-J. R. P. *J. Heterocycl. Chem.* **2001**, *38*, 749. (b) Morin, J.-F.; Leclerc, M. *Macromolecules* **2001**, *34*, 4680. (c) Bouchard, J.; Wakim, S.; Leclerc, M. *J. Org. Chem.* **2004**, *69*, 5705. (d) Li, H.; Zhang, Y.; Hu, Y.; Ma, D.; Wang, L.; Jing, Z.; Wang, F. *Macromol. Chem. Phys.* **2004**, *205*, 247. (e) Kimoto, A.; Cho, J.-S.; Miguchi, M.; Yamamoto, K. *Macromolecules* **2004**, *37*, 5531. (f) Iraqi, A.; Wataru, I. *Chem. Mater.* **2004**, *16*, 442.

(3) (a) Neugebauer, F. A.; Fischer, H. *Chem. Ber.* **1972**, *105*, 2686. (b) Moskalev, N. V. *Khim. Geterotsikl. Soedin.* **1990**, *2*, 187. (c) Zhu, Z.; Moore, J. S. *J. Org. Chem.* **2000**, *65*, 116. (d) Zhu, Z.; Moore, J. S. *Macromolecules* **2000**, *33*, 801. (e) Joule, J. A. In *Advances in Heterocyclic Chemistry*; Katritsky, A. R., Ed.; Academic: Orlando, 1984; Vol. 35, p 129.

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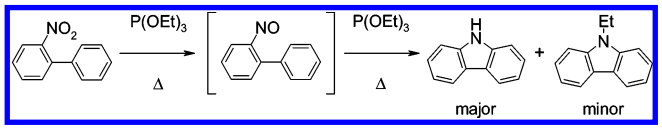


FIGURE 2. Cadogan synthesis of carbazoles.

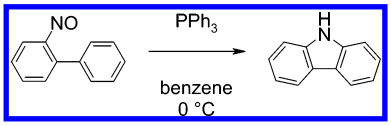


FIGURE 3. Reductive cyclization of 2-nitroso biphenyl derivatives affords carbazoles.

carbazoles, often bearing functionality, by either ring contraction or cyclization of suitable precursors.[4,5]

One of the most common methods for carbazole synthesis involves the reductive cyclization of 2-nitrobiphenyl derivatives in the presence of suitable organophosphorus reagents.[6] This method is commonly referred to as the Cadogan cyclization (Figure 2) and has a number of advantages over the electrophilic syntheses described above, which include increased substrate scope and functional group tolerance, and more precise regiocontrol of functional group placement within the product (determined by relative position in the biphenyl starting material). The reaction is commonly conducted using an excess of triethyl phosphite, as both the reductant and reaction solvent, at reflux (156 °C). While generally successful, this procedure exhibits considerable substrate dependence, both in terms of the reaction time and product distribution. We and others have found that the desired carbazole is often contaminated by the *N*-ethyl derivative, which results from alkyl transfer to the product either directly from solvent or, more likely, from the triethyl phosphate byproduct of the reaction.[7] This problematic side reaction is particularly prevalent when either long reaction times or substrates bearing electron-donating substituents are involved. Furthermore, the undesired alkylated impurity is usually quite difficult to remove, requiring careful, tedious chromatographic purification, which complicates the large-scale syntheses required for industrial applications.

To circumvent the problem of unwanted alkylation (i.e., product destruction) by the reagent or byproduct, we decided to explore the use of alternative reducing agents for this transformation. Triphenylphosphine is a convenient substitute because it is an easily handled, inexpensive, and stable solid. Moreover, the use of PPh_3 offered the possibility to remove the byproduct, triphenylphosphine oxide, by a number of convenient methods including precipitation, or simple chromatography, thus simplifying purification.

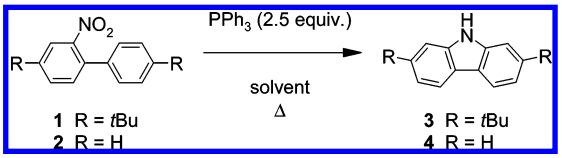
(4) For an overview of the common methods used to prepare carbazoles see: (a) Kuroki, M.; Tsunashima, Y. *J. Heterocycl. Chem.* **1981**, *18*, 709. (b) Joule, J. A. In *Advances in Heterocyclic Chemistry*; Katritzky, A. R., Ed.; Academic: Orlando, 1984; Vol. 35, p 83.

(5) Smitrovich, J. H.; Davies, I. W. *Org. Lett.* **2004**, *6*, 533.

(6) (a) Cadogan, J. I. G. *Quart. Rev.* **1962**, *16*, 208. (b) Cadogan, J. I. G.; Cameron-Wood, M. *Proc. Chem. Soc.* **1962**, 361. (c) Cadogan, J. I. G.; Cameron-Wood, M.; Mackie, R. K.; Searle, R. J. G. *J. Chem. Soc.* **1965**, 4831. (d) Cadogan, J. I. G. *Synthesis* **1969**, 11. (e) Cadogan, J. I. G. In *Organophosphorus Reagents in Organic Synthesis*; Cadogan, J. I. G., Ed.; Academic: London, 1979; Chapter 6.

(7) (a) Puskas, I.; Fields, E. K. J. *Org. Chem.* **1968**, *33*, 4237. (b) Tsunashima, Y.; Kuroki, M. *J. Heterocycl. Chem.* **1981**, *18*, 315.

TABLE 1. Reaction Optimization of PPh_3-Mediated Reductive Cyclization of 2-Nitrobiphenyls: Solvent Effects



R =	solvent	*T* (°C)	dielectric constant[c]	dipole moment (D)[c]	time (h)	% yield[a]
t-Bu	PhMe	110	2.38	0.36	39	low[b]
t-Bu	PhCl	132	5.62	1.69	39	low[b]
t-Bu	*o*-DCB	180	9.93	2.50	16	83
H	DMF	152	36.7		27	60
H	DMAc	165	37.8	3.81	21	91
H	o-DCB	180	9.93	2.50	21	91

[a] Yield of isolated product. [b] Mostly starting materials by TLC at the indicated time. Additional PPh_3 (1 equiv) added after 18 h. [c] Gordon, A. J.; Ford, R. A. *The Chemist's Companion*; Wiley: New York, 1972; p 3.

To the best of our knowledge, only a single example exists in the literature describing the use of PPh_3 as a reductant in carbazole synthesis from nitrobiphenyls.[6c] In this report, Cadogan and co-workers describe a single experiment in which 2-nitrobiphenyl is reductively cyclized to carbazole with molten PPh_3 in a sealed tube, with only modest yield (43%). Surprisingly, no further examples of this or related procedures can be found, and little description beyond the synthetic procedure was given in the original account. While from an industrial chemistry perspective, solventless processes are potentially attractive, this particular procedure was not because of low yields and the necessity to eliminate excess reagent and byproducts. In a related report, Cadogan and co-workers describe the reductive cyclization of 2-nitrosobiphenyl compounds to carbazoles using PPh_3 in benzene as solvent at low temperatures (Figure 3).[8] Although this method is unattractive because of the difficulties involved in preparing and manipulating sensitive nitroso compounds, it is significant because such compounds are probable intermediates in the reduction of the analogous nitro materials. In addition, and perhaps more importantly, it demonstrates that solvent does not adversely affect the cyclization reaction.

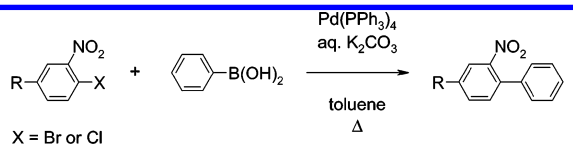
Results and Discussion

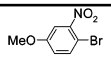
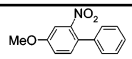
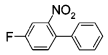
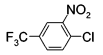
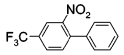
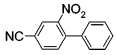
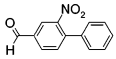
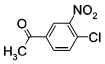
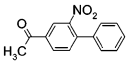
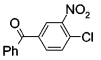
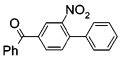
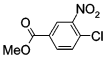
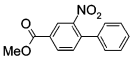
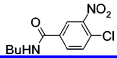
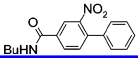
We describe our efforts to use PPh_3 to affect the reductive cyclization of 2-nitrobiphenyls to the corresponding carbazoles. 4,4′-Di-*tert*-butyl-2-nitrobiphenyl **1** and 2-nitrobiphenyl **2** were used as the starting materials to help us identify suitable solvents and establish reaction conditions.

The reaction setup was simple. Initially, **1** and 2.5 equivalents of PPh_3 were taken up in toluene, chlorobenzene, and *o*-dichlorobenzene (*o*-DCB), and refluxed for 39 h or until completion (Table 1). These solvents were selected because of their similar polarity, high solvent power, high boiling points, and availability. Interestingly, the extent of the reaction paralleled with temperature. After 16 h, the reaction conducted in *o*-DCB appeared

(8) Bunyan, P. J.; Cadogan, J. I. G. *J. Chem. Soc.* **1963**, 42.

TABLE 2. 2-Nitrobiphenyls Prepared by Suzuki–Miyaura Cross-Coupling

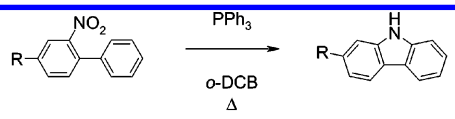


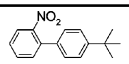
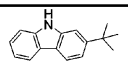
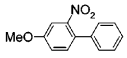
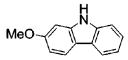
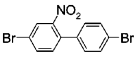
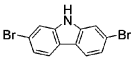
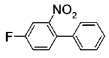
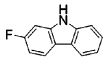
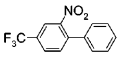
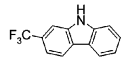
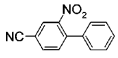
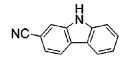
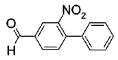
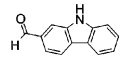
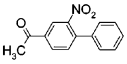
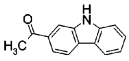
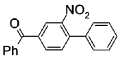
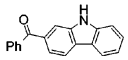
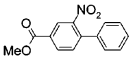
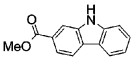
Entry	Aryl halide	Nitrobiphenyl	Rxn Time (h)	% Yield
7			18	99
8			42	55
9			4	91
10			19	92
11			21	87
12			18	95
13			22	97
14			3	86
15			23	98

complete, while the others were not. Removal of the solvent, followed by simple column chromatography afforded the desired product **3** in 83% yield, without any unwanted *N*-alkylcarbazole byproducts. Unfortunately, in the case of the toluene and chlorobenzene reactions, the addition of another equivalent of PPh_3 (after 18 h), along with prolonged reaction times (up to 39 h), did little to promote the conversion. Thus, the reaction performed in *o*-DCB gave the highest yields in the shortest reaction time, with the smallest excess of PPh_3, presumably as a result of the higher reaction temperature. In all cases, conversion was clean—only PPh_3, the starting material and product, and PPh_3O were ever present. The primary byproduct, 2 equivalents of PPh_3O, could be readily removed by either chromatography or precipitation from hexane.

Subsequently, we probed the effects of strongly polar solvents by conducting the reductive cyclization of 2-nitrobiphenyl to carbazole in refluxing DMF and DMAc, with an identical reaction in *o*-DCB as a control. As in the previous reactions, temperature appeared to be the most important parameter because DMF and DMAc are nearly identical in terms of their dielectric constant and polarity. The reaction in DMF (at 152 °C) proceeded to only a moderate degree of conversion (60%), and even after 27 h, a significant amount of 2-nitrobiphenyl remained. Conversely, the reaction in DMAc (165 °C) proceeded to very high conversion, with complete consumption of starting material within 21 h. The control reaction, conducted in *o*-DCB, gave identical results to that done in DMAc, suggesting that solvent polarity is not a determining factor in the outcome of the reaction.

TABLE 3. Reductive Cyclization of Nitrobiphenyls to Carbazoles



Entry	Nitrobiphenyl	Carbazole	Rxn Time (h)	% Yield	% Yield (lit.)
19			21	67	65[c]
20			7	91	22[d]
21			5	75	56[e]
22			3.5	91	54[f]
23			6	85	45[g]
24			5	75	49[h]
25			4	78	34[i]
26			6.5	81	82[j]
27			8[a]	99	85[k]
28			7[a]	90	53[l] 62–83[m]
29			7[a]	high[b]	NA
30			8	0	40[n]
31			17	0	NA

[a] Reaction was run overnight, although it appeared essentially complete at the time indicated. [b] TLC showed only the product, PPh_3O, and a small excess of PPh_3. This product could not be separated from the PPh_3O. [c] Tashiro, M.; Yamato, T. *Synthesis* **1979**, 48. [d] Smitrovich, J. H.; Davies, I. W. *Org. Lett.* **2004**, *6*, 533. [e] Dierschke, F.; Grimsdale, A. C.; Mullen, K. *Synthesis* **2003**, 2470. [f] Allen, F. C.; Suschitzky, H. *J. Chem. Soc.* **1953**, 3845. [g] Forbes, E. J.; Wragg, R. T. *Tetrahedron* **1960**, *8*, 79. [h] Mayor, C.; Wentrup, C. *J. Am. Chem. Soc.* **1975**, *97*, 7467. [i]Carter, P. H.; Plant, S. G. P.; Tomilinson, M. *J. Chem. Soc.* **1957**, 2210. [j] Kyziol, J. B.; Lyzniak, A. *Tetrahedron* **1980**, *36*, 3017. [k] Ghosh, S.; Datta, D. B.; Datta, I.; Das, T. K. *Tetrahedron* **1989**, *45*, 3775. [l] Diaz, J. L.; Dobarro, A.; Villacamp, B.; Velasco, D. *Chem. Mater.* **2001**, *13*, 2528. [m] Holzabfel, C. E.; Dwyer, C. *Heterocycles* **1998**, *48*, 1513. [n] Benzies, D. W. M.; Fresneda, P. M.; Jones, R. A.; McNab, H. *J. Chem. Soc., Perkin Trans. 1* **1986**, 1651.

Ultimately, we settled on the use of *o*-DCB because of its comparatively short reaction times and its widespread availability and use in our laboratory. Thus, with the general experimental conditions established, we set out to elaborate the substrate scope and functional group tolerance of our new method.

We first prepared a wide variety of 2-nitrobiphenyls that possessed a range of common functionalities via

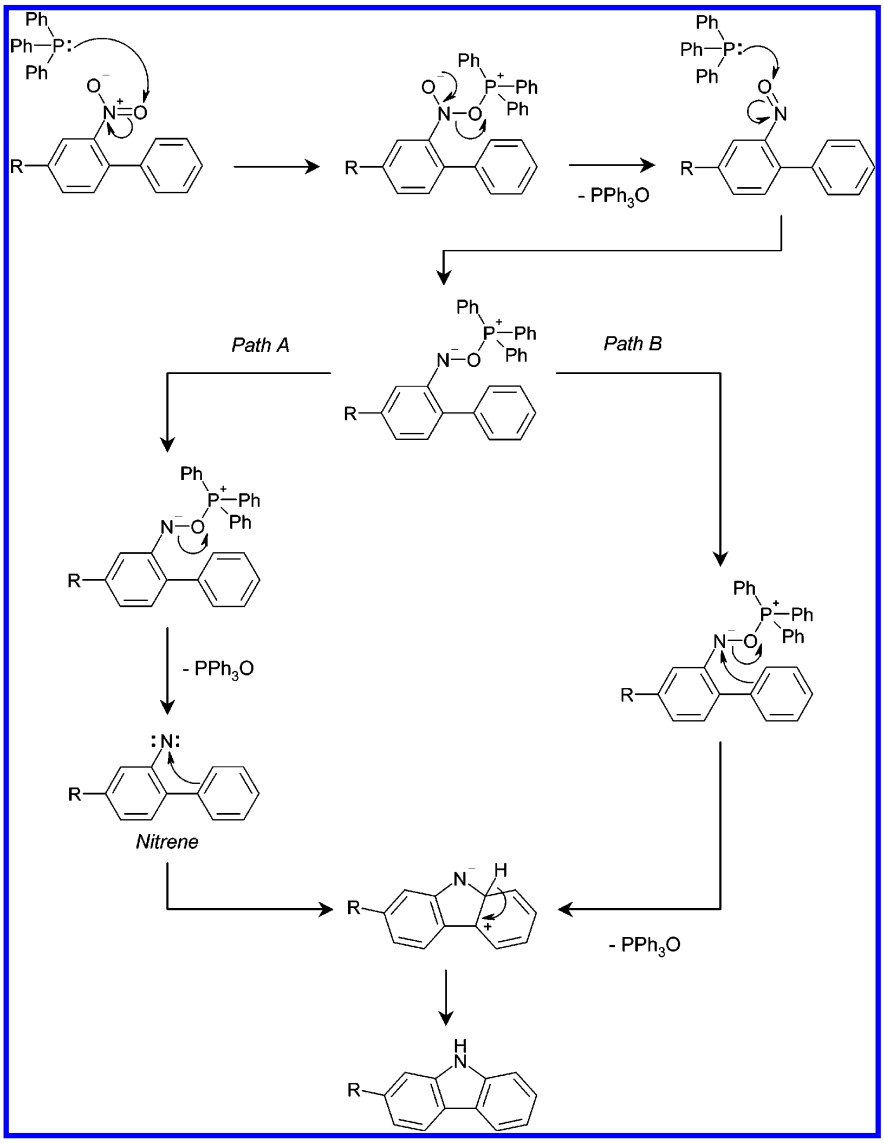


FIGURE 4. Proposed reaction mechanism for reductive cyclization.[6c,10]

Suzuki−Miyaura cross-coupling between phenyl boronic acid, and the appropriately substituted 2-halonitrobenzene (Table 2).[9] The cross-couplings were conducted under standard conditions [Pd(PPh$_3$)$_4$, aqueous carbonate base] and proceeded in excellent to quantitative yields, in most cases, for the arylbromides and electron-deficient aryl chlorides employed. Only in the case of the fluorinated nitrobiphenyl **8** was the isolated yield low, which was mainly due to difficulties in separating the product from unidentified impurities. Once in hand, these intermediates were subjected to reductive cyclization under our previously optimized conditions—reflux in *o*-DCB in the presence of 2.5 equivalents of PPh$_3$ until complete consumption of the starting material. The results are summarized in Table 3.

As seen in Table 3, the reaction tolerates a wide array of functional groups, encompassing alkyls, ethers, carbonyls (including aldehydes and enolizable ketones), nitriles, halogens, carboxylic esters, and amides. In general, reaction times are short, with most reactions complete within 7−8 h. Even those reactions that were allowed to proceed overnight were essentially complete within approximately 7 h. Moreover, we observed slight rate acceleration for the reductive cyclization of substrates bearing electron-withdrawing substituents (**21**−**29**). We speculate that this rate enhancement likely results from the increased efficacy of reductive deoxygenation (via nucleophilic attack by PPh$_3$) of the nitro groups, which is likely to be the rate-limiting step, preceding the cyclization in the proposed reaction mechanism (Figure 4).[6c,10]

In addition, good to excellent isolated yields are consistently observed for this reductive cyclization across the range of substrates examined, nearly all of which compare favorably to corresponding literature values. It is important to note that the literature yields cited in Table 3 generally pertain to substituted carbazoles formed by cyclization or condensation/oxidation reactions

(9) Miyaura, N.; Yanagi, T.; Suzuki, A. *Synth. Commun.* **1981**, *11*, 513. (b) Miyaura, N.; Suzuki, A. *Chem. Rev.* **1995**, *95*, 2457.

(10) (a) Smolinsky, G.; Feuer, B. I. *J. Org. Chem.* **1966**, *31*, 3882. (b) Brooke, P. K.; Herbert, R. B.; Holliman, F. G. *Tetrahedron Lett.* **1973**, *10*, 761. (c) Sundberg, R. J. *J. Org. Chem.* **1965**, *30*, 3604.

on suitably derivatized precursors, rather than simple functional group transformations (e.g., ester hydrolysis) on substituted carbazoles.

At present, the only functional groups that appear to be incompatible with this method are those with free, acidic protons, such as phenols and carboxylic acids, **30** and **31**, respectively. Unfortunately, we do not currently understand the origin of this incompatibility. However, this limitation is not severe because the desired phenols and carboxylic acids can generally be obtained from the corresponding alkyl aryl ethers and carboxylic esters, respectively, following reductive cyclization.

In general, purification of the carbazoles is readily achieved by column chromatography in which the only byproduct of the reaction, triphenylphosphine oxide, is easily separated from the relatively nonpolar product. When carbazoles possessing highly polar functionality are formed, separation of the PPh_3O from the product can be very difficult. Such was the case with the primary amide **29** that formed in apparently high yield (conversion estimated to be >90% by TLC) but could not be isolated apart from the PPh_3O, despite repeated chromatography. In this, the only case of difficulty encountered in purification, we suspect strong hydrogen bonding between the product and PPh_3O resulted in coelution, despite good apparent thin-layer chromatographic resolution.

Summary and Conclusions

In conclusion, we have refined and expanded upon the early single experiment reported by Cadogan and coworkers demonstrating that PPh_3 can be used to reductively cyclize 2-nitrobiphenyls to carbazoles. We have established that the reaction can be efficiently conducted in solvent and that the reaction temperature, rather than the solvent polarity, is the crucial factor governing the extent of reaction. As such, high-boiling *o*-DCB was found to afford the highest yields in the shortest reaction times for a number of substrates. Moreover, these conditions avoid the formation of troublesome *N*-alkylated byproducts that often form when the trialkyl phosphite procedure is used. Thus, purification is simplified to either precipitation of the PPh_3O from the product using hexanes, simple chromatography, or in some cases, a combination of the two.

Furthermore, we examined a series of substituted 2-nitrobiphenyl derivatives to elucidate the scope and functional-group tolerance of our new experimental conditions. The breadth of substrates amenable to reductive cyclization using PPh_3 at elevated temperatures is substantial and includes reactants possessing halogens, alkyl groups, ethers, carbonyls, and several carboxylic acid derivatives. The desired carbazole products are formed cleanly and in good yields. Reaction times are generally short, and the reaction seems to proceed more rapidly with electron-deficient substrates. Only in the case of the most polar products, and where strong hydrogen bonding is possible, is separation of PPh_3O difficult. Although the reason is unclear, the only substrates not tolerated by this reaction are those bearing acidic hydrogens, such as phenols and carboxylic acids.

This chemistry has allowed us to prepare a series of highly pure carbazoles with a spectrum of optical and electronic properties, as well as functional handles. Their complete characterization is ongoing in our laboratories. In addition, we are currently incorporating these new building blocks into novel conjugated and nonconjugated polymeric systems with the goal of exploiting their localized structural diversity to achieve the maximum diversity of properties with fewest structural perturbations to the overall system. We expect to report on these results soon.

Experimental Section

4,4′-Di-*tert*-butyl-2-nitrobiphenyl (1). A suspension of 4,4′-di-*tert*-butylbiphenyl (5.00 g, 18.77 mmol) in Ac_2O (100 mL) was immersed in a room-temperature water bath. A mixture of HOAc (5 mL) and fuming HNO_3 (3 mL) was added rapidly, dropwise via pipet. TLC indicated that the reaction was complete within 30 min. The mixture was poured into H_2O (1 L), stirred only for a few minutes, and extracted with CH_2Cl_2 (100 mL, then 2 × 75 mL). The combined organic layers were washed with 1 N NaOH (2 × 100 mL) and brine, dried over $MgSO_4$, and concentrated; a large volume remained (probably Ac_2O that had not hydrolyzed). The solution was then taken up in H_2O (400 mL), treated with NaOH (approximately 7−10 g), and stirred for approximately 1 h during which time a yellow precipitate developed. The mixture was extracted with Et_2O (3 × 100 mL), and the combined layers washed with saturated $NaHCO_3$ (75 mL) and brine, dried over $MgSO_4$, and concentrated to a yellow solid. Chromatography (80:20 P950 Ligroin:CH_2Cl_2) gave the desired product as a pale yellow solid (4.67 g, 80% yield): mp 113−116 °C; ^{1}H NMR ($CDCl_3$) δ 1.36 (S, 9H), 1.39 (s, 9H), 7.26 (ABq, 2H), 7.38 (d, J = 8.1 Hz, 1H), 7.43 (ABq, 2H), 7.62 (dd, J = 1.9 Hz, 8.1 Hz, 1H), 7.81 (d, J = 1.9 Hz, 1H); ^{13}C NMR ($CDCl_3$) δ 31.3, 31.6, 34.9, 35.1, 121.1, 126.8, 127.8, 129.5, 131.8, 133.5 134.5, 149.5, 151.2, 152.0; MS (HR EI) *m/z* calcd for $[M]^+$ 311.1885, found 311.1891. Anal. Calcd for $C_{20}H_{25}NO_2$: C, 77.14; H, 8.09; N, 4.50. Found: C, 77.24; H, 7.83, N, 4.51.

4-Benzoyl-2-nitrobiphenyl (13).: 4-Chloro-3-nitrobenzophenone (2.00 g, 7.64 mmol), phenylboronic acid (1.03 g, 8.41 mmol), and K_2CO_3 (8 mL of 2 M aqueous solution, 15.29 mmol) were taken up in toluene (11 mL) and sparged with N_2 for 5 min. At that time, $Pd(PPh_3)_4$ (0.09 g, 0.08 mmol) was added, and N_2 sparging continued for an additional 5 min before the reaction was fitted with a condenser and immersed in an oil bath at 110 °C. After 17 h, the reaction was cooled, diluted with Et_2O (150 mL), and filtered. The filtrate was washed with H_2O (2 × 50 mL) and brine, dried over $MgSO_4$, and concentrated in vacuo. Chromatography (gradient of 40:60 to 0:100 P950 ligroin/CH_2Cl_2) gave the product as a pale yellow solid (2.25 g, 97% yield): mp 115−118 °C; ^{1}H NMR ($CDCl_3$) δ 7.37 (dd, J = 2.2 Hz, 6.0 Hz, 2H), 7.43−7.50 (m, 3H), 7.50−7.70 (m, 4H), 7.82−7.89 (m, 2H), 8.06 (dd, J = 1.9 Hz, 8.1 Hz, 1H), 8.26 (d, J = 1.8 Hz, 1H); ^{13}C NMR ($CDCl_3$) δ 125.7, 128.0, 128.9, 129.1, 130.2, 132.4, 133.3, 133.5, 136.6, 136.6, 137.7, 140.0, 149.4, 194.1; MS (HR EI) *m/z* calcd for $[M]^+$ 303.0895, found 303.0898. Anal. Calcd for $C_{19}H_{13}NO_3$: C, 75.54; H, 4.32; N, 4.62. Found: C, 75.14; H, 4.21; N, 4.58.

***N*-Butyl-2-nitrobiphenyl-4-carboxamide (15).** *N*-butyl-4-chloro-3-nitrobiphenyl carboxamide (1.50 g, 5.84 mmol), phenylboronic acid (0.78 g, 6.43 mmol), and K_2CO_3 (6 mL of 2 M aqueous solution, 11.69 mmol) were taken up in toluene (7.6 mL) and sparged with N_2 for 5 min. At that time, $Pd(PPh_3)_4$ (0.07 g, 0.06 mmol) was added, and N_2 sparging continued for an additional 5 min before the reaction was fitted with a condenser and immersed in an oil bath at 110 °C. After 20 h the reaction was cooled, diluted with Et_2O (150 mL), and filtered. The filtrate was washed with H_2O (2 × 50 mL) and brine, dried over $MgSO_4$, and concentrated in vacuo. Chromatography (gradient of 0:100 to 5:95 Et_2O:CH_2Cl_2) gave the product as a yellow powder (1.71 g, 98% yield): mp 91−94 °C;

^{1}H NMR ($CDCl_3$) δ 0.99 (t, J = 7.1 Hz, 3H), 1.44 (sextet, J = 7.9 Hz, 2H), 1.65 (quintet, J = 2.6 Hz, 2H), 3.51 (q, J = 5.9 Hz, 2H), 6.21 (bs, 1H), 7.30 (dd, J = 3.5,Hz, 7.3 Hz, 2H), 7.41−7.47 (m, 3H), 7.54 (d, J = 8.1 Hz, 1H), 8.03 (dd, J = 1.8 Hz, 8.1 Hz, 1H), 8.21 (d, J = 1.6 Hz, 1H); ^{13}C NMR ($CDCl_3$) δ 14.0, 20.4, 31.6, 40.4, 122.8, 128.0, 128.9, 129.9, 130.9, 132.6, 135.1, 136.7, 139.1, 149.3, 165.1; MS (HR EI) *m/z* calcd for $[M]^+$ 298.1317, found 298.1314. Anal. Calcd for $C_{17}H_{18}N_2O_3$: C, 68.44; H, 6.08; N, 9.39. Found: C, 68.89; H, 5.99; N, 9.44.

4′-*tert*-Butyl-2-nitrobiphenyl (17). A mixture of 2-bromonitrobenzene (2.50 g, 12.38 mmol), 4-*tert*-butylphenylboronic acid (2.42 g, 13.61 mmol). and K_2CO_3 (13 mL of 2 M aqueous solution) was taken up in toluene (20 mL) and sparged with bubbling N_2 for approximately 5 min before $Pd(PPh_3)_4$ (0.21 g, 0.19 mmol) was added. After sparging for an additional 10 min, the orange reaction was refluxed with vigorous stirring for 17 h. The reaction was filtered through filter paper and washed with Et_2O (250 mL). The organic phase was washed with H_2O (3 × 50 mL) and brine, dried over $MgSO_4$, and concentrated to a dark-colored oil. Chromatography (75:25 P950 ligroin/CH_2Cl_2) gave the product as a viscous yellow oil (3.05 g, 97% yield): ^{1}H NMR ($CDCl_3$) δ 1.37 (s, 9H), 7.27 (ABq, 2H), 7.43−7.50 (m, 4H), 7.58−7.63 (m, 1H), 7.81−7.85 (m, 1H);. ^{13}C NMR ($CDCl_3$) δ 31.6, 34.9, 124.2, 125.9, 127.8, 128.1, 132.2, 132.4, 134.5, 136.4, 149.7, 151.5; MS (HR EI) *m/z* calcd for $[M]^+$ 255.1259, found 255.1255. Anal. Calcd for $C_{16}H_{17}NO_2$: C, 75.27; H, 6.71; N, 5.49. Found: C, 75.26; H, 6.82; N, 5.63.

2,7-Di-*tert*-butylcarbazole (3). A solution of 4,4′-di-*tert*-butyl-2-nitrobiphenyl (1.00 g, 3.21 mmol) and PPh_3 (2.11 g, 8.04 mmol) in *o*-DCB (6.5 mL) was heated to reflux with vigorous stirring. After 16 h, the solvent was stripped under high vacuum and the resulting dark orange semisolid slurried in P950 ligroin (15 mL) to precipitate the PPh_3O, which was removed by filtration. Chromatography of the filtrate (100:0, then 75:25 P950 ligroin/CH_2Cl_2) gave the product as a white solid (0.75 g, 83% yield): ^{1}H NMR (DMSO-d_6) δ 1.37 (s, 18H), 7.20 (dd, J = 8.3 Hz, 1.6 Hz, 2H), 7.40 (d, J = 1.1 Hz, 2H), 7.92 (d, J = 8.3 Hz, 2H), 10.93 (s, 1H). Spectroscopic data and analytical characterization are consistent with the literature.[11]

Carbazole (4). A solution of 2-nitrobiphenyl (1.19 g, 5.98 mmol) and PPh_3 (3.92 g, 14.85 mmol) in *o*-DCB (12 mL) was heated to reflux with vigorous stirring for 21 h, during which time the color changed from yellow to brown. At that time, the reaction was cooled to room temperature and concentrated under high vacuum. Chromatography of the yellow residue (75:25 P950/CH_2Cl_2) gave the product as a flaky, lustrous solid (0.91 g, 91% yield): ^{1}H NMR ($CDCl_3$) δ 7.19−7.27 (m, 2H), 7.39−7.46 (m, 4H), 8.08 (d, J = 7.8 Hz, 2H). Spectroscopic data and analytical characterization are consistent with a commercially available sample.

Acknowledgment. We thank Dr. Thomas Jackson for the high-resolution mass spectrometry (HRMS) data.

Supporting Information Available: Experimental procedures and spectroscopic data for compounds **5**−**12**, **14**, **16**, and **18**−**29**. Complete characterization data is provided for all new compounds. This material is available free of charge via the Internet at http://pubs.acs.org.

JO0503299

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