Novel Heteroatom-Substituted Trityl Radical Analogues: Preparation and Properties of Diaryl(benzotriazol-2-yl)methyl Radical Dimers‡

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Since Gomberg's discovery of the triphenylmethyl radical at the beginning of this century,[1a−c] a wealth of information has been amassed on the structure and stability of these types of hydrocarbon radicals.[2a−d] It is now widely accepted that triphenylmethyl radicals are in equilibrium with their dimers[3a,b] which possess a cyclohexadiene structure **1** as shown in Figure 1.

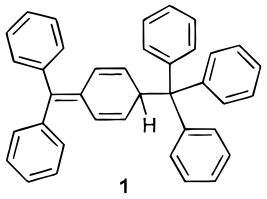
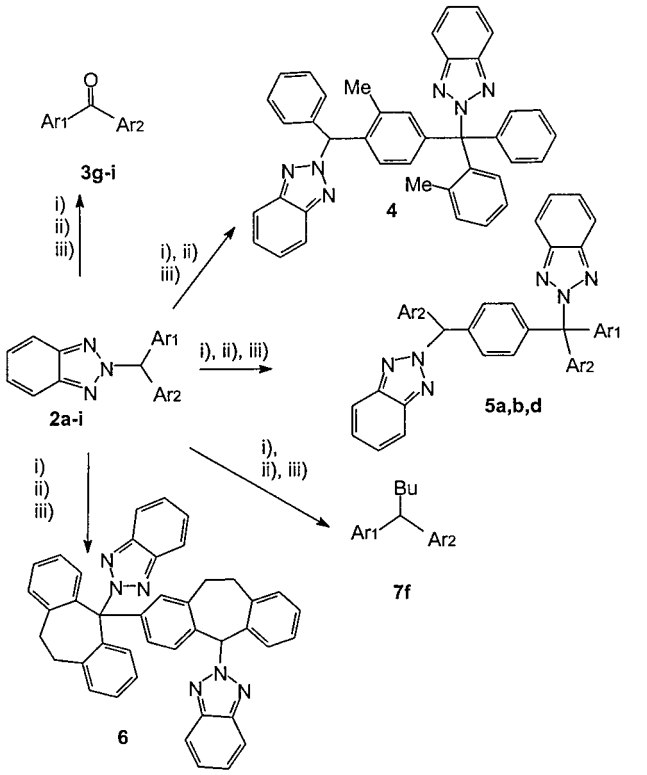


Figure 1.

However, heteroarylmethyl radicals have received little attention.[4a,b] Furthermore, to the best of our knowledge, no account of a hydrocarbon radical of this type with the central carbon atom directly attached to a heteroatom had been published until our recent report[5] which described diaryl(benzotriazol-1-yl)methyl radicals and their conversion into dimers accompanied with phenanthridines resulting from the opening of the five-membered ring of the benzotriazol-1-yl moiety. In our endeavor to eliminate the alternative ring-opening pathway previously observed,[5] we investigated the behavior of diaryl(benzotriazol-2-yl)methyl radicals, believed to be more stable due to the structure of the benzotriazol-2-yl moiety.[6] We now report the results of these studies.

Preparation of Diaryl(benzotriazol-2-yl)methyl Radicals and Dimerization. The diaryl(benzotriazol-2-yl)methanes **2a**−**i** were obtained as previously reported.[7] The corresponding radicals were obtained from diaryl(benzotriazol-2-yl)methanes **2a**−**i** according to the protocol previously described for diaryl(benzotriazol-1-yl)methanes.[5] In line with our previous results, application of this treatment to substrates **2a**−**e** led to the dimers **4**, **5a, 5b, 5d**, and **6** in fair-to-good yields (Tables 1 and 2). All of these dimers were formed from α,*para*-dimerization, and as before,[5] no α,α- or α,*ortho*-dimerization products were observed. In the case of substrate **2c** in which Ar^1 and Ar^2 were different and each had its *para*-position unsubstituted, the dimerization process intriguingly took place regioselectively at the 4-position of the 2-methylphenyl group, giving rise to dimer **4**.

Scheme 1



i) *n*-BuLi (1.1 equiv), THF/-78 °C. ii) I_2 (1 equiv), -78 °C. iii) H_2O, -78 °C

2, 3, 5, 7	Ar^1	Ar^2
a	Ph	Ph
b	Ph	*p*-MePh
c	Ph	*o*-MePh
d	Ph	*p*-ClPh
e	dibenzosuberanyl	dibenzosuberanyl
f	*p*-dimethylaminophenyl	*p*-dimethylaminophenyl
g	*p*-MePh	*p*-MePh
h	*p*-ClPh	*p*-ClPh
i	*p*-fluorophenyl	*p*-fluorophenyl

Dimerizations occurred when one *para*-position was substituted, as illustrated by the formation of dimers **5b** and **5d**. When the respective *para*-positions of each aryl group were substituted (substrates **2f**−**i**), no α,α- or α,*ortho*-dimerization occurred. Compound **2f** gave 1,1-

‡ The products formed by the combination of these radicals and those described in the present paper are described as "dimers" because they are formed by dimerization and they are similar in structure to dimers formed from trityl radicals. However, we emphasize that we have no evidence that such dimerization are reversible.

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Table 1. NMR Data of Dimers 4, 5a, 5b, 5d, and 6

		^{13}C NMR					
				benzotriazol-2-yl			
compd	^{1}H NMR	T[a]	Q[b]	C-3a	C-4	C-5	others
5a	7.83−7.88 (m, 4H), 7.27−7.40 (m, 16H), 7.19−7.22 (m, 4H), 7.12−7.16 (m, 4H)	73.6	83.9	144.3, 143.5	118.7, 118.3	126.5, 126.4	142.6, 142.3, 137.9, 137.8, 130.7, 130.3, 128.7, 128.6, 128.5, 128.0, 127.6, 127.4
5b	7.83−7.88 (m, 4H), 7.25−7.38 (m, 12H), 7.02−7.21 (m, 10H), 2.33 (s. 3H), 2.32 (s, 3H)	73.5	83.8	144.3, 143.5	118.7, 118.3	126.3, 126.4	142.7, 142.5, 139.3, 138.4, 138.0, 137.8, 134.8, 130.6, 130.3, 130.2, 129.3, 128.7, 128.3, 127.9, 127.6, 127.2, 21.1, 21.0
4	7.84−7.89 (m, 4H), 7.55 (s, 1H), 7.04−7.38 (m, 20H), 6.75−6.78 (m, 1H), 2.25 (s, 3H), 1.44 (d, 3H, J = 2.5 Hz)	70.6	83.8	144.3, 143.6	118.7, 118.4	126.3, 126.4	142.8, 142.7, 141.3, 139.5, 137.6, 136.6, 136.2, 132.1, 130.7, 130.6, 130.3, 130.2, 129.7, 128.7, 128.6, 128.5, 128.0, 127.7, 127.4, 127.3, 125.6, 21.5, 19.4
5d	7.80−7.86 (m, 4H), 7.23−7.36 (m, 15H), 7.06−7.18 (m, 8H)	72.9	83.3	144.4, 143.5	118.6, 118.3	126.6, 126.6	142.5, 141.9, 140.7, 137.8, 136.2, 134.6, 134.2, 131.9, 130.6, 130.1, 130.0, 128.9, 128.2, 127.8, 127.4
6	7.85−7.88 (m, 2H), 7.80−7.83 (m, 2H), 7.52 (d, 1H, J = 7.0 Hz), 7.44 (d, 1H, J = 8.1 Hz), 7.14−7.38 (m, 12H), 6.97−7.04 (m, 2H), 6.94 (s, 1H), 6.82 (d, 1 H, J = 8.0 Hz), 6.71 (s, 1H), 6.14 (t, 2H, J = 8.4 Hz), 2.65−3.25 (m, 8H)	76.1	84.7	144.0, 143.8	118.8, 118.3	126.5, 126.2	143.4, 141.0, 140.9, 140.7, 140.5, 139.9, 134.9, 134.3, 132.7, 131.6, 131.3, 130.9, 130.8, 130.7, 130.6, 129.4, 128.6, 128.2, 125.5, 34.3, 34.2, 32.6, 32.0

[a] Tertiary carbon. [b] Quaternary carbon.

Table 2. Preparation of Dimers 4, 5a, 5b, 5d, and 6

compd	mol formula	yield (%)	mp (°C)	CHN anal. found (calcd)	HRMS M$^+$ found (calcd)
4	$C_{40}H_{32}N_6$	52	120−123		596.268 (596.269)
5a	$C_{38}H_{28}N_6$	75	115−118	C: 80.52 (80.26) H: 5.00 (4.96) N: 14.56 (14.78)	
5b	$C_{40}H_{32}N_6$	82	116−119	C: 80.12 (80.51) H: 5.60 (5.41) N: 13.60 (14.08)	596.257 (596.269)
5d	$C_{38}H_{26}Cl_2N_6$	80	118−120	C: 71.60 (71.47) H: 4.30 (4.26) N: 12.62 (13.16)	636.169 (636.160)
6	$C_{42}H_{32}N_6$	55	192−195		620.258 (620.269)

di(4-dimethylaminophenyl)pentane (**7f**) by displacement of the benzotriazolyl group (benzotriazole was also isolated), assisted by the presence of the strongly electron-donating dimethylamino groups. The corresponding diaryl ketones **3g**−**i** (in yields of 80−85%) probably resulted from the oxidation of radical intermediates. It is evident that substitution at one *para*-position does not prevent the α,*para*-dimerization process, whereas substitution at both *para*-positions prohibits it. Our findings are in agreement with previous reports.[3b,5]

Proof of Structure of Dimers 4, 5a, 5b, 5d, and 6. Products **4**, **5a, 5b, 5d**, and **6** were analyzed and characterized by NMR (Table 1) and CHN analysis or HRMS (Table 2). The NMR spectra clearly reveal that the two different benzotriazol-2-yl groups are nonequivalent. Thus, every dimer gives two sets of benzotriazol-2-yl signals in its ^{13}C NMR spectrum (Table 1). This is illustrated with dimer **5a** (Figure 2), for which all the assignments were confirmed by 2D, APT spectra, and NOE experiments.

The NMR data recorded for dimers **4**, **5a, 5b, 5d**, and **6** differ from those reported for a trityl dimer exhibiting a cyclohexadiene structure[8] and confirm the structure of the given dimers. This structure, shown in Figure 2 for dimer **5a**, is similar to the one observed and previously reported for dimers obtained from diaryl(benzotriazol-1-yl)methyl radicals.[5]

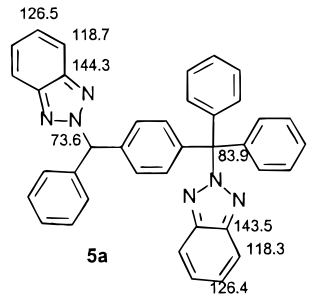

Figure 2.

In the MS spectra of dimers **4**, **5a, 5b, 5d**, and **6**, the molecular ion and molecular fragments were observed and the base peak was found at M$^+$ − 118, accounting for the easy loss of a benzotriazolyl group to relieve steric strain as previously observed.[5]

The reaction mechanism for the formation of the dimers **4**, **5a, 5b, 5d**, and **6** is similar to the one previously reported for diaryl(benzotriazol-1-yl) methanes,[5] with the exception that no phenanthridine products due to the ring opening of the benzotriazolyl moiety were detected. In the present report, dimers were obtained in high yields, probably due to the greater stability of the benzotriazol-2-yl structure, which is less inclined to ring opening than the isomeric benzotriazol-1-yl structure. For instance, compounds **2a** and **2b** produced dimers in high yields (75% and 82%, respec-

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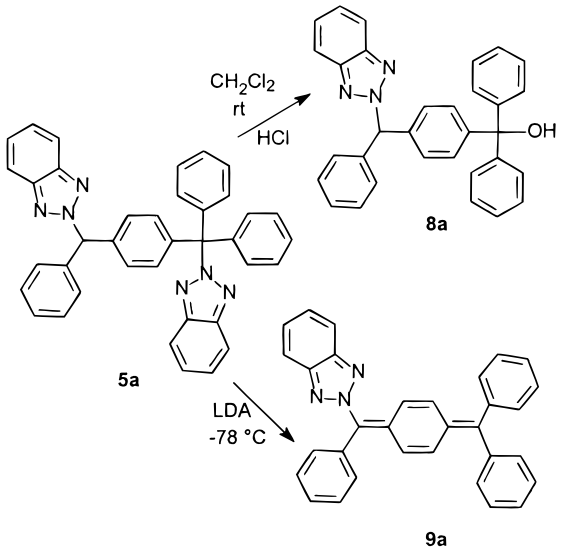
Scheme 2



tively), whereas their counterparts containing a benzotriazol-1-yl group gave dimers in lower yields (44% and 59%, respectively).

Reactivity of the Dimers 4, 5a, 5b, 5d, and 6. Treatment of dimer **5a** with hydrochloric acid in methylene chloride at room temperature for 4 h gave the hydroxyl derivative **8a** in which one benzotriazol-2-yl group was lost (Scheme 2), as evidenced by ^{1}H NMR. The integration of the low field signal (7.82−7.86 ppm) revealed two protons instead of the four in the case of **5a**, and a new single signal appeared at 3.14 ppm, accounting for the hydroxyl group. The ^{13}C NMR spectrum of **8a** also confirmed that there was only one benzotriazol-2-yl group present.

Upon treatment with LDA at −78 °C, substrate **5a** gave product **9a** (98%) after losing one of the benzotriazol-2-yl groups (Scheme 2). Compound **9a** is red due to the highly conjugated system. The ^{1}H NMR and ^{13}C NMR spectra of **9a** suggest that the structure of **9a** possesses a cyclohexadiene structure analogous to that previously encountered with the trityl radical dimer.[3b] Compound **9a** was also obtained by heating dimer **5a** with methanolic sodium hydroxide at 60 °C for 12 h or by reacting it with MeMgBr. Similar results were obtained when diaryl(benzotriazol-1-yl)methanes were subjected to similar treatments.[5]

Crossover Reaction. As is well documented, the dimers of trityl radicals undergo reversible dissociation to the corresponding radicals in solution.[3b] To investigate possible dissociation in solution, we carried out a crossover experiment in which dimers **5a** and **5b** were mixed and dissolved in THF. After 10 h of stirring at room temperature, no new dimers were observed (monitored by TLC). Further stirring for an additional 10 h under reflux led to the recovery of starting materials **5a** and **5b** with no new dimers generated. This experiment confirms that dimers **4**, **5a, 5b, 5d**, and **6** have a different structure from that of the trityl radical dimer. The same observations (no new dimer generated) were made when a similar crossover experiment was carried out with diaryl(benzotriazol-1-yl)methanes.[5]

In conclusion, the dimers **4**, **5a, 5b, 5d**, and **6** of diaryl(benzotriazol-2-yl)methyl radicals were readily obtained using the procedure described for the generation of diaryl(benzotriazol-1-yl)methyl radicals. Owing to the more stable nature of the benzotriazol-2-yl (i.e., less susceptible to ring opening than the benzotriazol-1-yl moiety), dimers were obtained in fair-to-good yields without any other side product. The dimeric structure was proven to be different from that of trityl radical dimers (by NMR). Further heteroaryl substituted trityl radicals have been prepared and studied and are the subject of a future paper.

Experimental Section

Preparation of Dimers 4, 5a, 5b, 5d, and 6 (General Procedure). To a solution of diaryl(benzotriazol-2-yl)methane (2 mmol) in dried THF (20 mL) was added *n*-BuLi (1.1 mL, 2 M solution in hexane, 2.2 mmol) at −78 °C under nitrogen. The reaction mixture was stirred at −78 °C for 10 min, and iodine (254 mg, 1 mmol) solution in THF (5 mL) was added. After 20 min of stirring at −78 °C, water (5 mL) was added to quench the reaction. The mixture was allowed to warm to room temperature, washed with sodium bisulfate solution (2 × 20 mL), and extracted with ethyl acetate (3 × 20 mL). The combined organic extracts were dried over $MgSO_4$. After removal of the solvent under vacuum, the residue was purified by column chromatography (see Tables 1 and 2).

Preparation of 4-Diphenylhydroxymethyl-α-[phenyl-(benzotriazol-2-yl)] Toluene (8a). A mixture of dimer **6a** (0.564 g, 1 mmol), methylene chloride (10 mL), and concentrated hydrochloric acid (2 mL) was stirred at room temperature for 4 h. The mixture was neutralized by an aqueous solution of NaOH (2 N, 2 × 10 mL), washed with water, extracted with ethyl acetate (3 × 10 mL), and dried over $MgSO_4$. After removal of the solvent under vacuum, the residue was purified by column chromatography to give **8a** (0.420 g, 90%): mp 87−89 °C; ^{1}H NMR ($CDCl_3$) δ 7.82−7.86 (m, 2H), 7.20−7.35 (m, 22H), 3.14 (s, 1H); ^{13}C NMR δ 147.0, 146.6, 144.2, 137.9, 137.1, 128.6, 128.4, 128.3, 128.2, 127.9, 127.8, 127.2, 126.4, 118.3, 81.7, 73.7. Anal. Calcd for $C_{32}H_{25}N_3O$: C, 82.20; H, 5.39; N, 8.99. Found: C, 81.83; H, 5.58; N, 8.62.

Preparation of 1-Diphenylmethylene-4-[phenyl(benzotriazol-2-yl)methylene]-2,5-cyclohexadiene (9a). To a solution of **5a** (0.564 g, 1 mmol) in dried THF (30 mL) was added LDA (0.72 mL, 1.5 M in hexane, 1.1 mmol) at −78 °C under nitrogen. The reaction mixture was stirred for 10 min and turned red. After the mixture warmed to 0 °C, water (2 mL) was added to quench the reaction. The reaction mixture was extracted with ethyl acetate (2 × 20 mL). The combined organic extracts were dried over $MgSO_4$, and the solvent was removed under vacuum to give product **9a** as a red solid in a yield of 98% (0.440 g): mp 120−122 °C; ^{1}H NMR δ 6.42 (dd, 1H, J = 10.1, 1.4 Hz), 6.79 (dd, 1H, J = 10.0, 1.3 Hz), 6.85 (d, 1H, J = 1.3 Hz), 6.87 (d, 1H, J = 1.8 Hz), 7.10−7.31 (m, 17H), 7.79−7.82 (m, 2H); ^{13}C NMR δ 145.0, 144.6, 141.3, 141.2, 135.7, 132.9, 131.9, 131.4, 131.3, 131.2, 129.8, 128.9, 128.5, 128.1, 128.0, 127.0, 125.8, 125.0, 118.2. Anal. Calcd for $C_{32}H_{23}N_3$: C, 85.50; H, 5.16; N, 9.35. Found: C, 85.24; H, 5.49; N, 9.55.

Supporting Information Available: ^{1}H NMR spectra of starting materials **2** and 2D NMR spectra of **5b** (6 pages). This material is contained in libraries on microfiche, immediately follows this article in the microfilm version of the journal, and can be ordered from the ACS; see any current masthead page for ordering information.

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