Unexpected Lewis Acid-Mediated Dimerization of 1,3-Diarylpropargylic Alcohols

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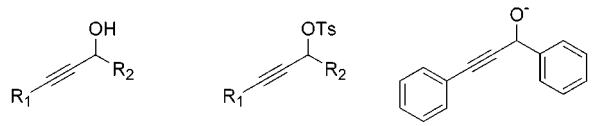
Propargylic alcohols **1** are useful intermediates for the synthesis of a variety of organic compounds of diverse complexity.[1,2] One of the trivial applications involves the corresponding tosylates **2**, which can undergo a variety of displacement reactions to give the allene or alkyne derivatives.[3−5] Dimerization of substituted allenes via different kinds of mechanisms may occur. To illustrate this, [2 + 2] cycloaddition leading to cyclobutane derivatives is well documented.[6] Alternatively, an allyl cationic intermediate may be formed by the electrophilic addition of an allene at the C_2 position.[7] Accordingly, electrophilic addition or substitution with another molecule of allene or alkyne may take place leading to the corresponding dimeric products. In this paper, we report two unexpected dimerization reactions of 1,3-diarylpropargylic alcohol **1** promoted by Lewis acids.

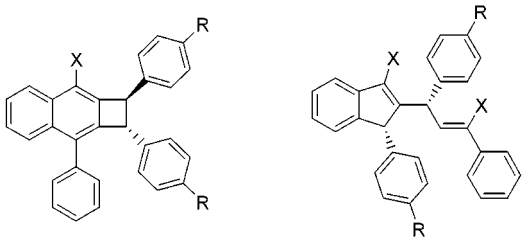
In the beginning of this research, phenylacetylene anion was treated with one equiv of benzaldehyde in THF at −78 °C to give alkoxide **3**. Without any further quenching procedure, 1 equiv of TsCl was then added, and the mixture was stirred at room temperature for 12 h to give **4** in 38% yield. The structure of **4** was unambiguously proved by X-ray crystallography.



1a $R^1 = R^2 = Ph$ **2** **3**

1b $R^1 = Ph$, $R^2 = 4\text{-}MeC_6H_4$

When **1a** was allowed to react with BBr_3 in CH_2Cl_2 at room temperature, in addition to the expected bromonaphthocyclobutene derivative **5** (20%), dimeric indene **6** was also obtained in 36% yield. Again, the structure of **6** was determined by X-ray crystallography. The reaction of **1a** with PBr_3 behaved similarly. Treatment of **1a** with $SOCl_2$ in CH_2Cl_2 at room temperature for 12 h afforded **7** in 48% yield. Interestingly, direct reaction of **1a** with TsCl yielded **7** (24%), no **4** being detected at all.



4 X = Cl, R = H
5 X = Br, R = H
8 X = Br, R = Me

6 X = Br, R = H
7 X = Cl, R = H
9 X = Br, R = Me

To have a better understanding of the mechanism for these transformations, we have investigated the reaction of alcohol **1b** with BBr_3 in CH_2Cl_2. Naphthocyclobutene derivative **8** was obtained in 20% yield. The X-ray structure for **8** is shown in the Supporting Information. The NMR spectrum of the crude mixture of this reaction indicated the presence of an indene product **9** (**8**/**9** = 1/1).[8] Unfortunately, attempts to obtain pure **9** from the mixture were unsuccessful. It is noteworthy that the tolyl substituents occurred exclusively at the cyclobutene ring in **8**. This implies that dimerization reaction may occur regioselectively. It is known that 1,2-bisallenylbenzene can undergo intramolecular cyclization giving naphthcyclobutene derivative under various conditions.[9] Accordingly, a similar pathway may occur to yield **4** or **8**. A plausible mechanism for the formation of **8** is proposed (Scheme 1). Lewis acid-catalyzed heterolytic cleavage of the carbon−oxygen bond in **1** may generate carbocation

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(8) The ^1H NMR spectrum of this crude mixture exhibited signals at δ 4.47 (s) and 5.11 (d, J = 9.6 Hz) attributed to the absorptions of the nonaromatic protons other than the methyl groups for **9**.

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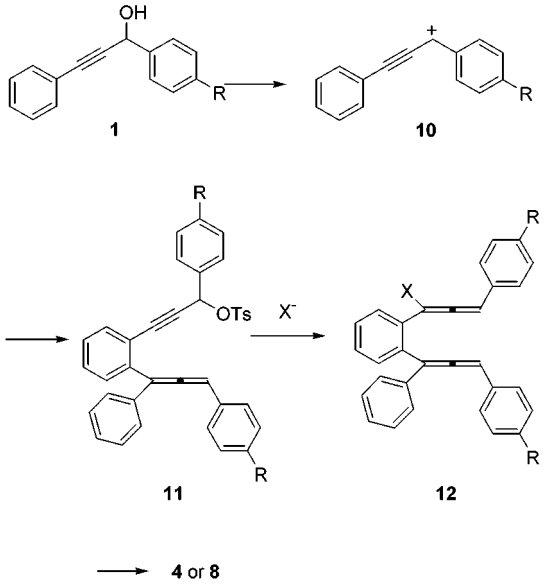
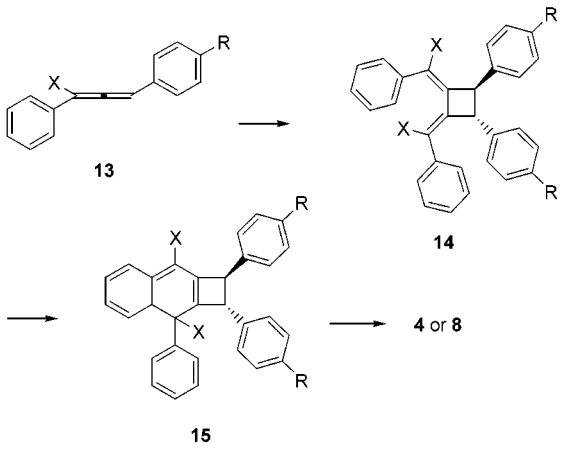
Scheme 1



Scheme 2



10. Friedel−Crafts reaction of **10** with **2** ($R^1 = R^2 =$ Ph) at the ortho position may produce **11** which may undergo displacement reaction with the halide ion to yield **12** Electrocyclization of **12** to yield **4** or **8**. One drawback of this route may arise from the regioselectivity of the Friedel−Crafts reaction of **2**. Alternatively, [2 + 2] cycloaddition of haloallene **13**,[10] formed by displacement reaction of **2**,[4] may occur to give cyclobutane intermediate **14**, which may undergo electrocyclization via **15** followed by elimination of HX to yield **4** or **8** (Scheme 2).

Protonation of **13** may generate the allyl cation **16**, which can undergo electrophilic addition to another molecule of **13** leading to the corresponding carbocation **17**. Nazarov cyclization of **17** may yield indene **6** or **7** (Scheme 3). The presence of a proton source is crucial for the formation of indene product. As described earlier, no indene product was obtained when the propargylic alkoxide **3** formed in situ was directly treated with TsCl. Since the reaction medium is lack of proton source, the corresponding allyl cation **16**, which could not be formed under these conditions, will be unavailable for further reactions.

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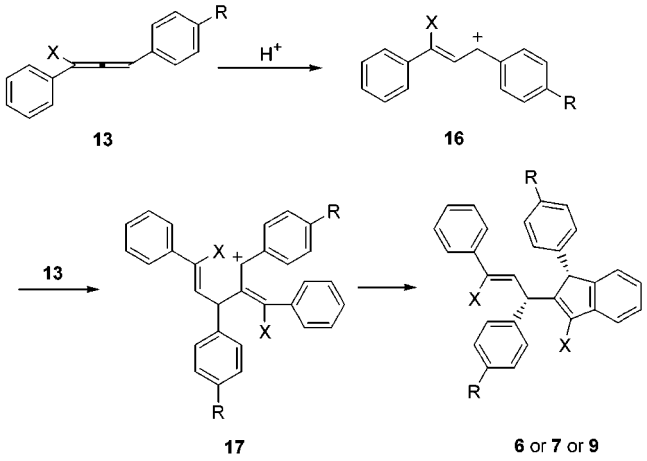
Scheme 3



Experimental Section

3-Chloro-*trans*-1,2-diphenyl-1,2-dihydrocyclobuta[*b*]naphthalene (4). To a THF solution (10 mL) of phenylacetylene (1.1 mL, 10 mmol) was added ^{n}BuLi (1.6 M in hexane, 6.3 mL, 10 mmol) at −78 °C. The mixture was stirred at −78 °C for 1 h. Benzaldehyde (1.1 mL, 10 mmol) was introduced at −78 °C, and the mixture was stirred for 30 min. TsCl (1.9 g, 10 mmol) in THF (5 mL) was then added, and the mixture was stirred for 30 min at −78 °C, warmed to room temperature, and further stirred for 12 h. The mixture was poured into water (50 mL) and extracted with ether (2 × 50 mL). The combined organic layers were dried ($MgSO_4$) and evaporated in vacuo to give a brown liquid that was chromatographed on silica gel (CH_2Cl_2/hexane = 1/5) to yield **4** as a white solid (795 mg, 38%): mp 132−133 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 4.56 (d, J = 3.2 Hz, 1 H), 4.72 (d, J = 3.2 Hz, 1 H), 7.04−7.06 (m, 2 H), 7.13−7.19 (m, 3 H), 7.21−7.37 (m, 10 H), 7.47 (ddd, J = 8.4, 6.8, 1.2 Hz, 1 H), 7.60 (ddd, J = 8.4, 6.8, 1.2 Hz, 1 H), 7.96 (dd, J = 8.4, 1.2 Hz, 1 H), 8.39 (dd, J = 8.4, 1.2 Hz, 1 H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 57.0, 58.0, 124.1, 124.2 125.9, 126.0, 126.4, 126.7, 127.0, 127.09, 127.10, 127.4, 128.2, 128.4, 128.7, 130.0, 132.0, 133.6, 134.1, 135.7, 140.2, 140.4, 140.9, 142.6; MS *m*/*z* (rel intensity) 418, 416. Anal. Calcd for $C_{30}H_{21}Cl$: C, 86.42; H, 5.08. Found: C, 86.44; H, 4.92.

3-Bromo-*trans*-1,2-diphenyl-1,2-dihydrocyclobuta[*b*]-naphthalene (5) and 3-Bromo-2-(2-bromo-1,2-diphenylvinyl)-1-phenyl-1*H*-indene (6). A CH_2Cl_2 solution (10 mL) of **1a** (2.09 g, 10 mmol) and BBr_3 (0.32 mL, 3.4 mmol) was stirred at −78 °C for 30 min, warmed to room temperature, and stirred for an additional 12 h. The reaction mixture was filtered through silica gel. The filtrate was evaporated in vacuo, and the residue was chromatographed on silica gel (CH_2Cl_2/hexane = 1/4) to give **5** (460 mg, 20%)and **6** (983 mg, 36%) obtained as a white solid. **5:** mp 147−148 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 4.55 (d, J = 3.2 Hz, 1 H), 4.65 (d, J = 3.2 Hz, 1 H), 7.03−7.06 (m, 2 H), 7.12−7.19 (m, 3 H), 7.21−7.37 (m, 10 H), 7.50 (ddd, J = 8.4, 6.8, 1.2 Hz, 1 H), 7.63 (ddd, J = 8.4, 6.8, 1.2 Hz, 1 H), 7.93 (dd, J = 8.4, 1.2 Hz, 1 H), 8.34 (dd, J = 8.4, 1.2 Hz, 1 H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 57.8, 58.0, 115.0, 126.0, 126.3, 126.4, 126.5, 126.7, 127.0, 127.1, 127.2, 127.4, 128.2, 128.3, 128.7, 130.0, 133.0, 134.1, 134.2, 135.6, 139.8, 140.9, 143.0, 143.6; MS *m*/*z* 462, 460. Anal. Calcd for $C_{30}H_{21}Br$: C, 78.09; H, 4.59. Found: C, 77.45; H, 4.98.

6: mp 147−148 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 4.47 (s, 1 H), 5.11 (d, J = 9.6 Hz, 1 H), 6.89 (d, J = 9.6 Hz, 1 H), 6.91−6.94 (m, 2 H), 7.05 (br d, J = 7.6 Hz, 1 H), 7.14−7.20 (m, 9 H), 7.28−7.36 (m, 4 H), 7.46 (dt, J = 7.6, 0.8 Hz, 1 H), 7.53−7.55 (m, 2 H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 48.9, 58.5, 120.1, 123.6, 126.2, 126.6, 126.7, 127.2, 127.3, 127.6, 127.7, 127.9, 128.3, 128.5, 128.6, 128.8, 129.0, 131.0, 137.6, 139.7, 140.7, 143.0, 146.3, 148.4; MS *m*/*z* 544, 542, 540. Anal. Calcd for $C_{30}H_{22}Br_2$: C, 66.44; H, 4.09. Found: C, 65.89; H, 4.01.

3-Chloro-2-(2-chloro-1,2-diphenylvinyl)-1-phenyl-1*H*-indene (7). A solution of **1a** (2.09 g, 10 mmol) and $SOCl_2$ (0.4 mL, 5.5 mmol) in CH_2Cl_2 (10 mL) was stirred for 12 h. After filtration through silica gel, the filtrate was evaporated in vacuo and the

residue was chromatographed on silica gel (CH_2Cl_2/hexane = 1/4) to give **7** as a white solid (387 mg, 17%): mp 131 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 4.47 (s, 1 H), 5.08 (d, J = 9.2 Hz, 1 H), 6.80 (d, J = 9.2 Hz, 1 H), 6.93−6.96 (m, 2 H), 7.06 (br d, J = 7.6, Hz, 1 H), 7.14−7.22 (m, 9 H), 7.29−7.35 (m, 4 H), 7.46 (dt, J = 7.6, 0.8 Hz, 1 H), 7.55−7.57 (m, 2 H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 45.3, 57.3, 118.9, 123.8, 126.5, 126.6, 126.7, 127.2, 127.3, 127.4, 127.9, 128.3, 128.□□, 128.64, 128.8, 128.9, 133.1, 137.8, 137.9, 141.2, 141.8, 145.3, 146.1; MS *m*/*z* 456, 454, 452; Anal. Calcd. for $C_{30}H_{22}Cl_2$: C, 79.47; H, 4.89. Found: C, 79.17; H, 5.35.

3-Bromo-*trans*-1,2-di(4-tolyl)-1,2-dihydrocyclobuta[*b*]-naphthalene (8). A mixture of **1b** (2.22 g, 10 mmol) and BBr_3 (0.32 mL, 3.4 mmol) in CH_2Cl_2 (10 mL) was stirred at room temperature for 12 h. After filtration through silica gel, the filtrate was evaporated in vacuo to give the residue containing both **8** and **9** (ratio = 1:1). The residue was chromatographed on silica gel (CH_2Cl_2/hexane = 1/4) to afford **8** as a white solid (479 mg, 20%): mp 142−143 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 2.25 (s, 3 H), 2.34 (s, 3 H), 4.48 (d, J = 3.2 Hz, 1 H), 4.56 (d, J = 3.2 Hz, 1 H), 6.93 (AB q, J = 8.4 Hz, 4 H), 7.17 (AB q, J = 8.0 Hz, 4 H), 7.21−7.30 (m, 5 H), 7.46 (ddd, J = 8.4, 6.8, 1.2 Hz, 1 H), 7.59 (ddd, J = 8.4, 6.8, 1.2 Hz, 1 H), 7.92 (dd, J = 8.4, 1.2 Hz, 1 H), 8.32 (dd, J = 8.4, 1.2 Hz, 1 H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 21.1, 21.2, 57.6, 58.0, 115.0, 125.9, 126.2, 126.4, 126.5, 126.9, 127.1, 127.4, 128.2, 129.0, 129.3, 130.0, 132.9, 134.0, 134.1, 135.7, 136.2, 136.5, 136.9, 138.0, 143.2, 143.9; MS *m*/*z* 490, 488; Anal. Calcd for $C_{32}H_{25}Br$: C, 78.53; H, 5.15. Found: C, 78.48; H, 4.87. Attmepts to obtain pure **9** were unseccessful.

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Supporting Information Available: X-ray structures of **4**, **6**, and **8**. This material is available free of charge via the Internet at http://pubs.acs.org.

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