Selectivity of cyano-Gilman cuprates: synthesis of 10-membered ring cyclophanes

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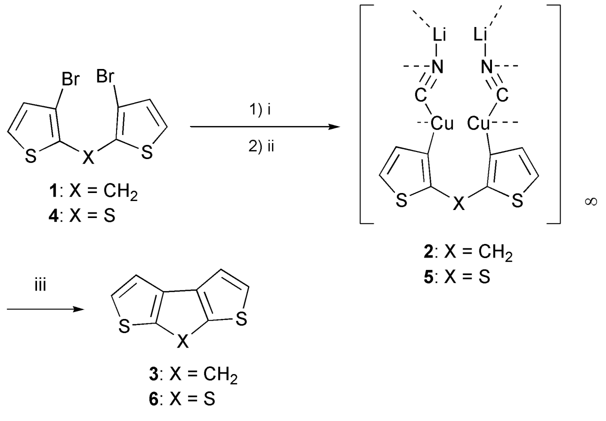
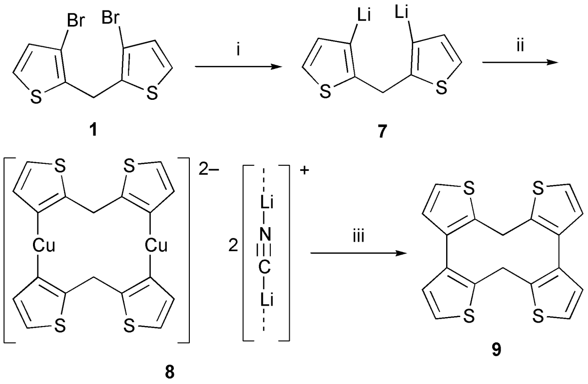
The oxidation of cyano-Gilman cuprates, derived from dibromodithienyl sulfide, dibromodithienyldimethylsilane and dibromodithienylmethane, with molecular oxygen furnishes 10-membered ring cyclophanes selectively and an X-ray analysis of cyclophane 9 reveals that it possesses an *anti* conformation.

Oxidative coupling of Gilman cuprates, prepared from 2 equivalents of an organolithium reagent with 1 equivalent of CuI, was reported to produce bialkyls.[1] Lipshutz *et al.* reported for the first time, the chemistry of lower- and higher-order cyanocuprates and discussed their reactivities in Michael additions and substitution reactions.[2–6] Later, the same group reported the oxidative dimerizations of higher-order cyanocuprates to produce unsymmetrical biaryls.[7] Rajca *et al.* utilized lower-order cyanocuprates for the synthesis of polycyclic aromatics.[8] We recently described the selectivity of lower-order cyanocuprates to produce five-membered rings through intramolecular cyclizations.[9] Here, we report the selectivity of higher-order cyanocuprates or cyano-Gilman cuprates[6] for the formation of 10-membered rings *via* intermolecular cyclization reactions.

The reaction of 3,3′-dibromo-2,2′-dithienylmethane **1**[10,11] with Bu^{n}Li (2 equiv.), followed by treatment with CuCN (2.5 equiv.) produced lower-order cyanocuprates **2**. The oxidation of lower-order cyanocuprates with molecular oxygen produced five-membered ring compound **3**,[9–11] as shown in Scheme 1. Similar reactions were also accessible for compound **6** and its isomer.[9,12] Interestingly, the successive addition of butyllithium and copper(I) cyanide to compounds **1**, **10** and **11**,[9–13] followed by oxidation with molecular oxygen gave 10-membered ring cyclophanes, selectively. Thus the reaction of 3,3′-dibromo-2,2′-dithienylmethane **1** with Bu^{n}Li (2 equiv.) at −78 °C in THF gave a lithio derivative through halogen–lithium exchange, which was treated with CuCN (1 equiv.) to produce cyano-Gilman cuprates **8**. The oxidation of cyano-Gilman cuprates with molecular oxygen afforded 10-membered ring cyclophane **9** in 45% yield. The course of the reaction can be concisely represented as shown in Scheme 2.

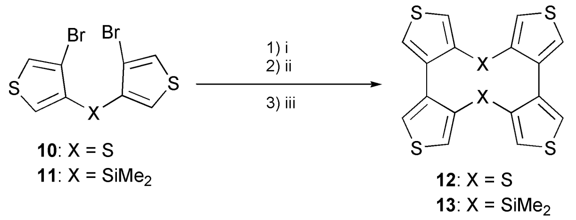


Scheme 1 *Reagents and conditions*: i, Bu^{n}Li (2 equiv.), THF, −78 °C; ii, CuCN (2.5 equiv.), −78 °C to room temp.; iii, O_2, −78 °C to room temp.



Scheme 2 *Reagents and conditions*: i, Bu^{n}Li (2 equiv.), THF, −78 °C; ii, CuCN (1.0 equiv.), −78 °C to room temp.; iii, O_2, −78 °C to room temp.

Similarly, reactions with 4,4′-dibromo-3,3′-dithienyl sulfide **10** and 4,4′-dibromo-3,3′-dithienyldimethylsilane **11** offered the opportunity to obtain cyclophanes **12** and **13**, as shown in Scheme 3. Analogous reactions afforded cyclophanes **12** and **13** in 40 and 42% yields, respectively.



Scheme 3 *Reagents and conditions*: i, Bu^{n}Li (2 equiv.), THF, −78 °C; ii, CuCN (1.0 equiv.), −78 °C to room temp.; iii, O_2, −78 °C to room temp.

The ^{1}H NMR spectrum of **9** shows two doublets for the methylene protons at δ 4.47 and 4.02, which is clearly understood from its X-ray structure (Fig. 1).‡ Owing to the rigidity of the central 10-membered ring, the methylene protons show a coupled AB pattern and thereby appear as doublets.§ The steric repulsion between methylene protons in **9** leads to an *anti* conformation and the dihedral angle between two planes, one defined by the C2–C3 and C2–C6 bonds, and the other defined by the C2–C6 and C6–C7 bonds, is *ca.* 45°. A molecular model of **9** also suggests an *anti* conformation, which forces the bithiophene moieties into a twisted form. This is also the case for **13** with rather bulky $SiMe_2$ bridging moieties. Unlike **9** and **13**, **12** shows a *syn* conformation, owing to the absence of additional atoms on the sulfide bridges. Interestingly, AM 1

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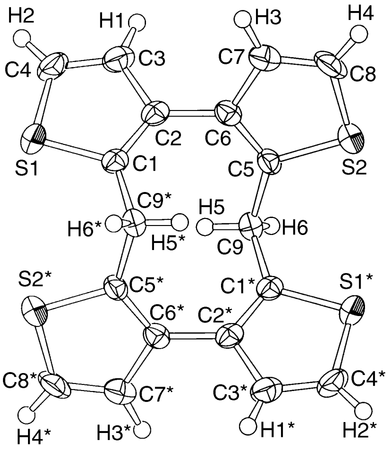

Fig. 1 X-Ray structure of **9**.

calculations on **12** and **13** are consistent with the molecular models.

The absence of π-conjugations in **9** is clearly observed from its UV spectrum. The absorption maximum exhibits a hypsochromic shift in comparison with 3,3′-dithienyl sulfide [**9**: λ_{max} = 245.5 nm (log ε = 4.24); 3,3′-dithienyl sulfide: λ_{max} = 272 nm].[14] A similar hypsochromic shift of the absorption maximum is also observed for **13** [λ_{max} = 243.5 nm (log ε = 4.05)]. Interestingly, the cyclophane **12** exhibits a bathochromic shift [λ_{max} = 289.5 nm (log ε = 4.51)], which indicates extended conjugation and also suggests a *syn* conformation.

Finally, cyclic voltammetry of **12** shows one reversible wave corresponding to radical cation or diradical dication and the half-wave potential ($E_{1/2}$) is 0.1 V (*vs.* Fc/Fc$^+$ in 0.1 M NBu$^n{}_4$ClO$_4$– PhCN).

In conclusion, the oxidation of cyano-Gilman cuprates with molecular oxygen produced 10-membered ring cyclophanes selectively and interesting properties of these cyclophanes have been established.

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Notes and references

‡ *Crystal data* for **9**: $C_{18}H_{12}S_4$, M = 356.53, monoclinic, space group $P2_1/a$ (no. 14), a = 8.731(4), b = 18.134(5), c = 9.953(6) Å, β = 90.57(4)°, V = 1575(1) Å^3, Z = 4, T = 296 K, μ(Mo-Kα) = 5.94 cm^{-1}, 3809 reflections measured, 3609 unique, R_{int} = 0.038, final R_1 = 0.046, wR_2 = 0.046 for 3809 [$I > 3.00\sigma(I)$] observed reflections. CCDC 182/1829.

§ *Selected data*: for **9**: colourless crystals, mp 259–259.6 °C; δ_H(500 MHz, $CDCl_3$) 7.30 (d, 4H, J 5.2 Hz), 6.89 (d, 4H, J 5.2 Hz), 4.47 (d, 2H, J 15.9 Hz), 4.02 (d, 2H, J 15.9 Hz); δ_C(125 MHz, $CDCl_3$) 138.8, 133.4, 129.0, 124.0, 28.0; *m/z* 356 (M$^+$); UV (ethanol) λ_{max} (log ε) 245.5 (4.24); Anal. Calc. for $C_{18}H_{12}S_4$: C, 60.63; H, 3.39. Found: C, 60.24; H, 3.49%. For **12**: colourless crystals, mp 196–196.5 °C; δ_H(400 MHz, $CDCl_3$) 7.36 (d, 4H, J 5.1 Hz), 7.29 (d, 4H, J 5.1 Hz); δ_C(125 MHz, $CDCl_3$) 141.6, 130.9, 125.8, 120.8; *m/z* 392 (M$^+$); UV (ethanol) λ_{max} (log ε) 289.5 (4.51); Anal. Calc. for $C_{16}H_8S_6$: C, 48.98; H, 2.04. Found: C, 49.18; H, 2.19%. For **13**: colourless crystals, mp 204.5–205 °C; δ_H(500 MHz, $CDCl_3$) 7.00 (d, 4H, J 2.7 Hz), 6.99 (d, 4H, J 2.7 Hz), 0.36 (s, 12H); δ_C(125 MHz, $CDCl_3$) 142.5, 140.0, 131.8, 123.6, −2.12; *m/z* 444 (M$^+$); UV (ethanol) λ_{max} (log ε) 243.5 (4.05); Anal. Calc. for $C_{20}H_{20}S_4Si_2$: C, 54.05; H, 4.51. Found: C, 54.30; H, 4.71%.

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