Strong-Base-Induced Intramolecular Cycloaddition of Homophthalic Anhydrides: An Efficient Synthesis of Polycyclic *peri*-Hydroxy Aromatic Compounds

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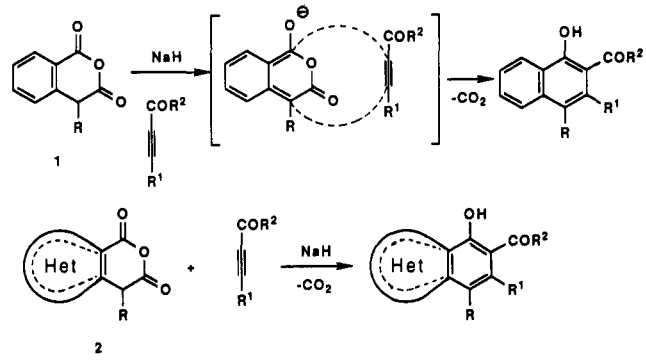
A strong-base-induced intramolecular cycloaddition reaction of homophthalic anhydrides has been examined as a method for preparing nonlinear polycyclic *peri*-hydroxy aromatic compounds.

Considerable effort has been devoted to the synthesis of biologically important linear polycyclic *peri*-hydroxy aromatic compounds,[1] which include anthracyclines,[2] nogalamycin,[3] olivomycin,[4] bostrycin,[5] granaticin,[6] and other polycyclic antibiotics. In an effort to develop a new, efficient synthetic method for the preparation of these compounds, we have reported the strong-base-induced cycloaddition of homophthalic anhydrides (**1**) and their heteroanalogues (**2**), which gives various types of polycyclic *peri*-hydroxy aromatics[7] and heteroaromatics,[8] regioselectively (Scheme I). Although the intermolecular cycloaddition reaction of these anhydrides was successfully applied to the synthesis of linear polycyclic *peri*-hydroxy aromatics, anthracycline antibiotics,[9] heteroanthracyclines,[10] SS-228R,[11] and others,[12] the intramolecular cycloaddition has never been reported. We now report here the first examples[13] of intramolecular cycloadditions of homophthalic anhydrides leading to nonlinear polycyclic *peri*-hydroxy aromatics.

Scheme I



Results and Discussion

The substrates for the intramolecular cycloaddition are 4-substituted homophthalic anhydrides (**18a–e**) and their heteroanalogues (**20a,b**) bearing an alkyl chain with a terminal triple bond. These compounds were prepared from the alkylation of the C-2′ position of homophthalic diesters (**14a,b**) and their heteroanalogues (**15a,b**) with alkyl iodides (**8a,b**, **11**, and **13**) bearing triple bonds followed by hydrolysis of the diesters and subsequent dehydration. The alkyl iodides (**8a,b**, **11**, and **13**) were prepared from the known alcohols,[14] 5-hexyn-1-ol (**3a**) and 4-pentyn-1-ol (**3b**), in the following three routes: (i) **3a,b** → **4a,b** → **5a,b** → **6a,b** → **7a,b** → **8a,b**; (ii) **3a** → **9** → **10** → **11**; and (iii) **3b** → **12** → **13** (Scheme II). Homophthalic diesters (**14a,b**) were treated with **8a,b**, **11**, **13**, and 6-iodo-1-hexyne to give the 2′-alkylated diesters (**16a–g**). Mild hydrolysis of the diesters, **16a**, **16b**, **16e**, **16f**, and **16g** gave

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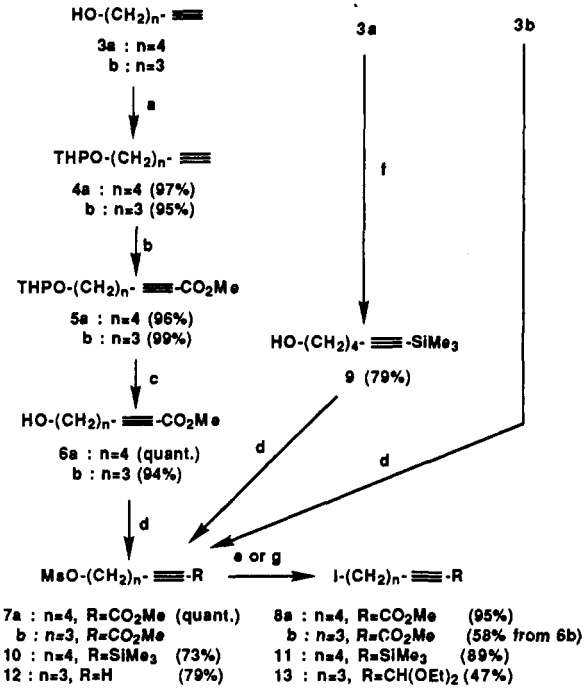
0022-3263/91/1956-0119$02.50/0

Scheme II. Synthesis of Alkyl Iodides (8a,b, 11, 13) Bearing a Terminal Triple Bond[a]



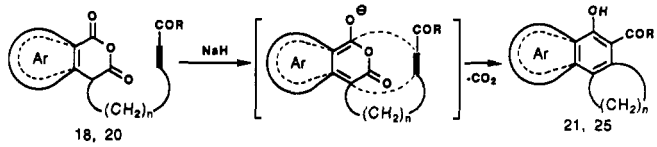
[a] (a) 3,4-Dihydro-2*H*-pyran, *p*-TsOH, CH_2Cl_2. (b) *n*-BuLi, $ClCO_2Me$, THF. (c) *p*-TsOH, MeOH. (d) MsCl, pyridine, CH_2Cl_2. (e) NaI, acetone. (f) (1) *n*-BuLi, TMSCl, THF; (2) AcOH, MeOH. (g) (1) NaI, acetone; (2) $CH(OEt)_3$, ZnI_2.

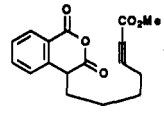
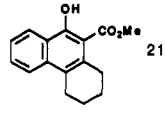
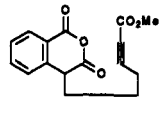
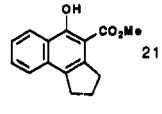
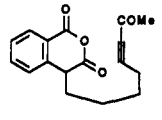
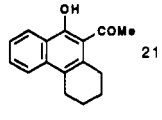
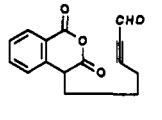
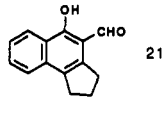
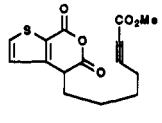
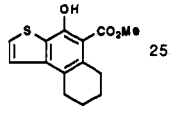
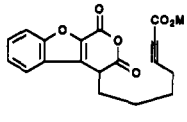
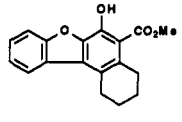
the diacids (**17a–e**), which were dehydrated with (trimethylsilyl)ethoxyacetylene[15] to give the corresponding anhydrides (**18a–e**), respectively. Heterohomophthalic diesters (**15a,b**) were similarly converted to the anhydrides (**20a,b**) via the 2′-alkylated diesters (**19a,b**) (Scheme III). The details of the preparation of **18a–e** and **20a,b** from **3a,b** are given in the Experimental Section.

Although the anhydride (**18a**) bearing an alkyl chain with a terminal carbomethoxyethynyl group refused to cyclize under various thermal conditions, it underwent a strong-base-induced intramolecular cycloaddition, followed by extrusion of carbon dioxide to give the tetrahydrophenanthrene (**21a**). Thus, treatment of **18a** with NaH in anhydrous tetrahydrofuran (THF) at room temperature for 1 h under nitrogen gave **21a** in 54% yield. The anhydride (**18b**) bearing a shorter alkyl chain with a terminal triple bond was treated with NaH under the same conditions to give the dihydrobenzindene (**21b**) in only 24% yield after stirring for 14 h. The anhydrides (**18c,d**) bearing an alkyl chain with other activated terminal triple bonds such as acetylethynyl and formylethynyl groups also underwent facile intramolecular cycloaddition to give the corresponding intramolecular cycloaddition products, tetrahydrophenanthrene (**21c**) and dihydrobenzindene (**21d**), respectively. The formation of 5-membered rings (runs 2 and 4) is less favorable than that of 6-membered rings (runs 1 and 3) in the present cycloaddition reaction (Table I).

The formation of **21d** from **18d** is quite interesting, since the strong-base-induced intermolecular cycloaddition of homophthalic anhydride (**22**) with the formylacetylene (**23**) involved the carbonyl part of **23** exclusively, to give the dihydroisocoumarin derivative (**24**) in 62% yield. In the case of intramolecular reaction, the cycloaddition occurred selectively to the acetylene part, probably because of the inner strain which would have been associated with producing a 7-membered acetylene ring (Scheme IV). The anhydride (**18e**) bearing an alkyl chain with an unactivated triple bond failed to undergo intramolecular cycloaddition.

Table I. Intramolecular Cycloaddition of 4-Substituted Homophthalic Anhydrides (18a–d) and Their Hetero Analogues (20a,b)



run	starting anhydrides	reaction condition	products	yield (%)
1	 18a	r.t. 1h	 21a	54
2	 18b	r.t. 14h	 21b	24
3	 18c	r.t. 12h	 21c	64
4	 18d	r.t. 15h	 21d	36
5	 20a	r.t. 2h	 25a	67[a]
6	 20b	r.t. 15h	 25b	41

[a] Overall yield from the dicarboxylic acid.

The generality of the present intramolecular cycloaddition reaction was ascertained in the heteroanalogues of **18a**. Treatment of the thiophene and benzofuran analogues (**20a** and **20b**) with NaH in anhydrous THF at room temperature gave the corresponding cycloaddition products (**25a** and **25b**, respectively) in moderate yields (Table I).

The present methodology opens a potentially straightforward approach to nonlinearly condensed polycyclic aromatic compounds such as resistomycin,[16] heliomycin,[17] urdamycin,[18] and actinoplanone.[19]

Experimental Section

All boiling and melting points are uncorrected. Infrared (IR) absorption spectra were recorded on a JASCO HPIR-102 spectrophotometer with $CHCl_3$ as a solvent. Proton nuclear magnetic resonance (^1H NMR) spectra were measured on Hitachi R-600 (60 MHz), R-22 (90 MHz), and JEOL JNM-GX500 (500 MHz)

(15) (a) Kita, Y.; Akai, S.; Yoshigi, M.; Nakajima, Y.; Yasuda, H.; Tamura, Y. *Tetrahedron Lett.* **1984**, *25*, 6027. (b) Kita, Y.; Akai, S.; Ajimura, N.; Yoshigi, M.; Tsugoshi, T.; Yasuda, H.; Tamura, Y. *J. Org. Chem.* **1986**, *51*, 4150. (c) Kita, Y.; Akai, S.; Yamamoto, M.; Taniguchi, M.; Tamura, Y. *Synthesis* **1989**, 334.

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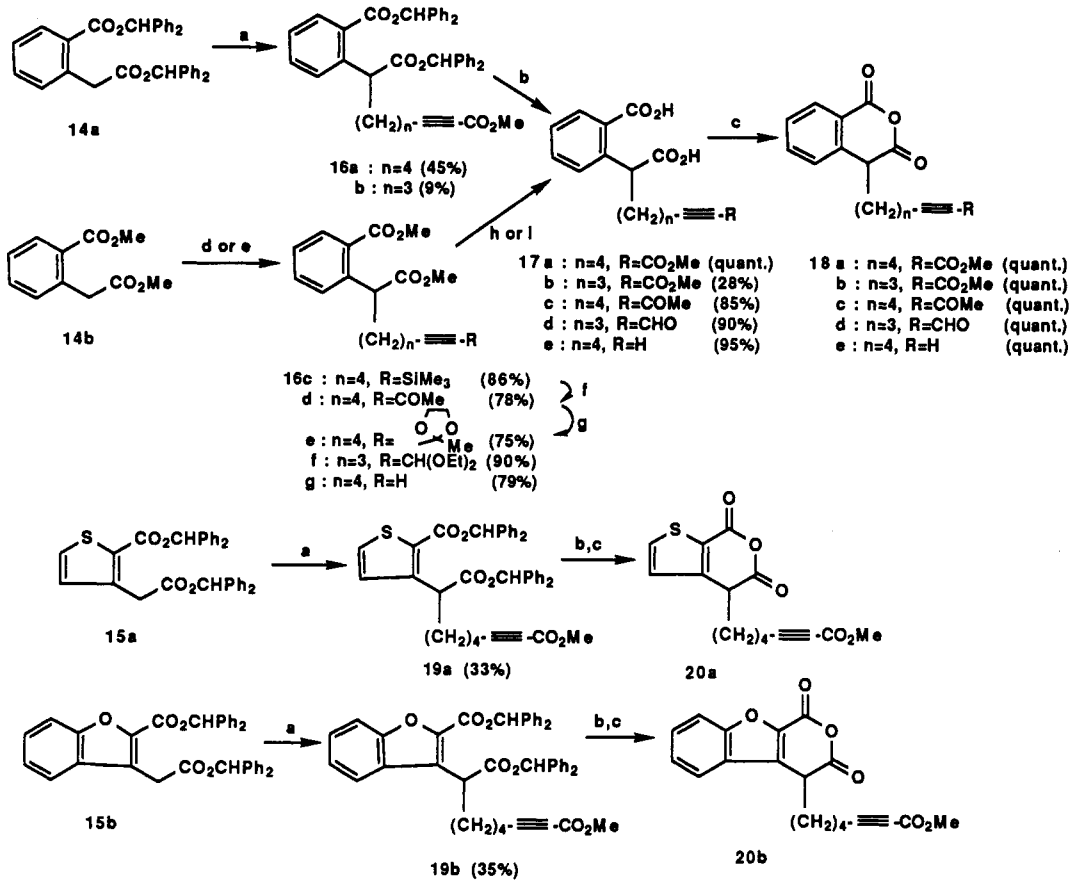
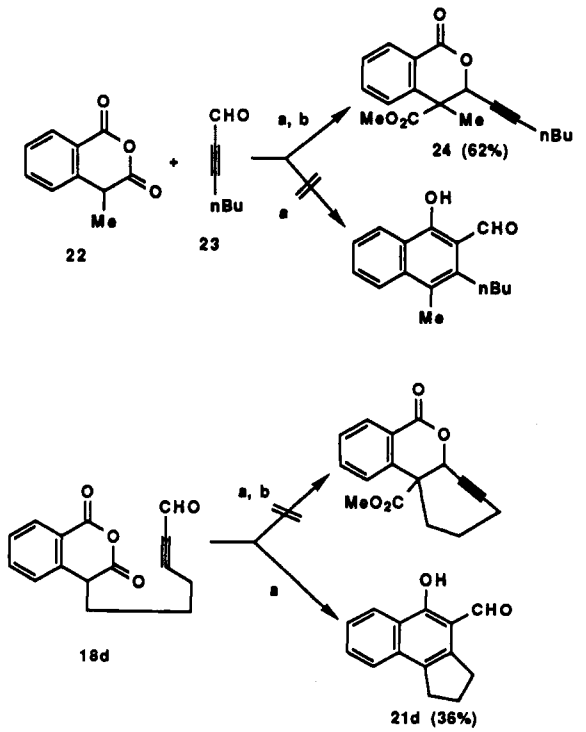
Scheme III. Synthesis of 4-Substituted Homophthalic Anhydrides (18a–e) and Their Hetero Analogues (20a,b)[a]



[a] (a) LDA, HMPA, 8, THF. (b) BF_3-Et_2O, AcOH. (c) (Trimethylsilyl)ethoxyacetylene, CH_2Cl_2. (d) LDA, HMPA, 11, THF. (e) LDA, HMPA, 13, THF. (f) Acetyl chloride, $AlCl_3$, CH_2Cl_2. (g) $(CH_2OH)_2$, *p*-TsOH, benzene. (h) (1) KOH, MeOH, H_2O; (2) H^+. (i) (1) KOH, MeOH, H_2O; (2) CF_3CO_2H, $CHCl_3$, H_2O.

Scheme IV[a]



[a] (a) NaH, THF. (b) CH_2N_2, Et_2O.

spectrometers with $CDCl_3$ as a solvent unless otherwise noted with tetramethylsilane as an internal standard. Mass spectra (MS) and high-resolution MS were obtained by ESCO EMD-05A and JEOL JMS-D300 mass spectrometers. E. Merck silica gel 60 (70–230-mesh ASTM) for column chromatography and E. Merck precoated TLC plates, silica gel F_{254} for preparative thin-layer chromatography (prep TLC) were used. Organic layers were dried with anhydrous $MgSO_4$. Tetrahydrofuran (THF) was distilled from the sodium benzophenone dianion under nitrogen.

5-Hexyn-1-ol (3a). This was prepared from 2-(chloromethyl)-tetrahydrofuran (2.00 g, 14.9 mmol) by the reported method.[14] The crude product was distilled under reduced pressure to give the pure product (1.15 g, 79%) as a colorless oil: bp 86–87 °C (15 mmHg) (lit.[14] bp 75 °C (16 mmHg)); IR 3300, 2950 cm^{-1}; ^1H NMR δ 1.46–1.80 (m, 4 H, $CH_2 \times 2$), 1.80 (br s, 1 H, OH), 1.96 (t, 1 H, J = 3 Hz, C≡CH), 2.10–2.34 (m, 2 H, C≡CCH_2), 3.59–3.77 (m, 2 H, OCH_2).

4-Pentyn-1-ol (3b). This was prepared from 2-(chloromethyl)tetrahydrofuran (10.0 g, 83.0 mmol) by the same procedure as described for the prepration of **3a**. Distillation under reduced pressure gave **3b** (5.1 g, 73%) as a colorless oil: bp 47–53 °C (8–10 mmHg) (lit.[14] bp 64–65 °C (16 mmHg)); IR 3650, 3320, 2950, 2120 cm^{-1}; ^1H NMR δ 1.77 (quint, 2 H, J = 8 Hz, CH_2), 1.97 (t, 1 H, J = 3.2 Hz, C≡CH), 2.31 (td, 2 H, J = 8, 3.2 Hz, C≡CCH_2), 3.73 (t, 2 H, J = 8 Hz, OCH_2).

1-(Tetrahydropyranyloxy)-5-hexyne (4a). To a mixture of **3a** (1.15 g, 11.7 mmol), 3,4-dihydro-2*H*-pyran (1.29 mL, 14.2 mmol), and dry CH_2Cl_2 (14 mL) was added *p*-TsOH (5 mg), and the mixture was stirred at room temperature for 3 h. After addition of saturated aqueous $NaHCO_3$, the organic layer was separated. The aqueous layer was extracted with CH_2Cl_2. The combined organic layers were dried and concentrated under reduced pressure. The crude product was purified by column chromatography on silica gel (hexane–AcOEt, 20:1) to give **4a** (2.08 g, 97%) as a colorless oil: bp 91–94 °C (10 mmHg) (lit.[20] bp 60–65

(20) Tufariello, J. J.; Trybulski, E. J. *J. Org. Chem.* **1974**, *39*, 3378.

°C (0.2 mmHg)); IR 3320, 2950, 1140, 1120, 1075, 1030 cm^{-1}; ^1H NMR δ 1.39–1.89 (m, 10 H, CH_2 × 3 and CH_2 × 2), 1.93 (t, 1 H, J = 3 Hz, C≡CH), 2.12–2.37 (m, 2 H, C≡CCH_2), 3.27–3.68 (m, 2 H, OCH_2), 3.70–4.04 (m, 2 H, OCH_2), 4.51–4.68 (m, 1 H, OCHO); MS m/e 181 (M^+ - H). Anal. Calcd for $C_{11}H_{18}O_2$: C, 72.49; H, 9.95. Found: C, 72.33; H, 10.05.

1-(Tetrahydropyranyloxy)-4-pentyne (4b). This was prepared from **3b** (2.00 g, 23.8 mmol), 3,4-dihydro-2*H*-pyran (26.2 mL, 28.8 mmol), and *p*-TsOH (10.2 mg) by the same procedure described for the preparation of **4a**. Purification by column chromatography on silica gel (hexane–AcOEt, 20:1) gave **4b** (3.9 g, 95%) as a colorless oil: bp 40–41 °C (0.3 mmHg) [lit.[21] bp 75–100 °C (0.08 mmHg) (Kugelrohr apparatus)]; IR 3330, 2970, 2150 cm^{-1}; ^1H NMR δ 1.33–1.91 (m, 8 H, CH_2 × 3 and CH_2), 1.92 (t, 1 H, J = 2 Hz, C≡CH), 2.29 (td, 2 H, J = 6.4, 2 Hz, C≡CCH_2), 3.35–3.60 (m, 2 H, OCH_2), 3.70–3.98 (m, 2 H, OCH_2), 4.57 (s, 1 H, OCHO).

Methyl 7-(Tetrahydropyranyloxy)-2-heptynoate (5a). To a dry THF (2 mL) solution of **4a** (182 mg, 1.00 mmol) was added *n*-BuLi (1.6 N in hexane, 0.625 mL, 1.00 mmol) dropwise at −78 °C under nitrogen. After 1 h, methyl chloroformate (0.232 mL, 3.00 mmol) was added dropwise to the solution at the same temperature. The reaction mixture was stirred at room temperature for 1 h, quenched with brine, and extracted with CH_2Cl_2. The extract was dried and concentrated under reduced pressure. The residue was purified by column chromatography on silica gel (hexane–AcOEt, 10:1) to give **5a** (230 mg, 96%) as a colorless oil: bp 148–152 °C (0.4 mmHg); IR 2950, 2240, 1710, 1260 cm^{-1}; ^1H NMR δ 1.37–1.96 (m, 10 H, CH_2 × 3 and CH_2 × 2), 2.24–2.54 (m, 2 H, C≡CCH_2), 3.20–4.01 (m, 4 H, OCH_2 × 2), 3.74 (s, 3 H, OCH_3), 4.48–4.66 (m, 1 H, OCHO); MS m/e 240 (M^+). Anal. Calcd for $C_{13}H_{20}O_4$: C, 64.98; H, 8.39. Found: C, 64.78; H, 8.50.

Methyl 6-(Tetrahydropyranyloxy)-2-hexynoate (5b). This was prepared from **4b** (4.64 g, 27.6 mmol) and methyl chloroformate (6.10 mL, 78.9 mmol) by the same procedure described for the preparation of **5a**. Purification by column chromatography on silica gel (hexane–AcOEt, 10:1) gave **5b** (6.15 g, 99%) as a colorless oil: bp 115–135 °C (0.8–1.0 mmHg) [lit.[21] bp 110–140 °C (0.08 mmHg) (Kugelrohr appratus)]; IR 2950, 2250, 1710 cm^{-1}; ^1H NMR δ 1.39–1.76 (m, 6 H, CH_2 × 3), 1.88 (quint, 2 H, J = 7 Hz, CH_2), 2.50 (t, 2 H, J = 7 Hz, C≡CCH_2), 3.37–3.60 (m, 2 H, OCH_2), 3.71–4.04 (m, 2 H, OCH_2), 3.78 (s, 3 H, OCH_3), 4.58 (s, 1 H, OCHO).

Methyl 7-Hydroxy-2-heptynoate (6a). A mixture of **5a** (84.8 mg, 0.353 mmol), *p*-TsOH (2.5 mg), and MeOH (1.8 mL) was stirred at room temperature overnight. To the reaction mixture were added AcOEt and brine. The aqueous layer was extracted with AcOEt. The combined extracts were dried and concentrated under reduced pressure. The residue was purified by column chromatography on silica gel (AcOEt) to give **6a** (56.0 mg, quant) as a colorless oil: bp 120–122 °C (0.5 mmHg) (lit.[20] 90–95 °C (0.15 mmHg)); IR 2950, 2250, 1710, 1265 cm^{-1}; ^1H NMR δ 1.58–1.82 (m, 4 H, CH_2 × 2), 2.12 (br s, 1 H, OH), 2.27–2.51 (m, 2 H, C≡CCH_2), 3.58–3.84 (m, 2 H, OCH_2), 3.77 (s, 3 H, OCH_3); MS m/e 156 (M^+). Anal. Calcd for $C_8H_{12}O_3$: C, 61.52; H, 7.74. Found: C, 61.53; H, 7.96.

Methyl 6-Hydroxy-2-hexynoate (6b). This was prepared from **5b** (358 mg, 1.58 mmol) by the same procedure described for the preparation of **6a**. Purification by column chromatography on silica gel (AcOEt) gave **6b** (210 mg, 94%) as a colorless oil: bp 118–124 °C (0.3 mmHg) [lit.[21] bp 115–130 °C (0.08 mmHg) (Kugelrohr apparatus)]; IR 3630, 2950, 2250, 1715 cm^{-1}; ^1H NMR δ 1.81 (quint, 2 H, J = 7 Hz, CH_2), 2.47 (t, 2 H, J = 7 Hz, C≡CCH_2), 3.64–3.86 (m, 2 H, OCH_2), 3.74 (s, 3 H, OCH_3); MS m/e 142 (M^+). Anal. Calcd for $C_7H_{10}O_3$: C, 59.14; H, 7.09. Found: C, 59.24; H, 7.30.

Methyl 7-(Mesyloxy)-2-heptynoate (7a). To a solution of **6a** (46 mg, 0.30 mmol) and Et_3N (0.060 mL, 0.45 mmol) in CCl_4 (2 mL) was added methanesulfonyl chloride (0.030 mL, 0.36 mmol) dropwise at 0 °C. The reaction mixture was stirred at room temperature for 9 h and quenched with MeOH. $CHCl_3$ and brine were added to the mixture. The aqueous layer was extracted with $CHCl_3$. The combined $CHCl_3$ layers were dried and concentrated under reduced pressure. The crude product was purified by column chromatography on silica gel (AcOEt) to give **7a** (71.6 mg, quant) as a colorless oil: bp 155 °C (0.25 mmHg) (bath temperature); IR 3050, 2240, 1710, 1265, 1175 cm^{-1}; ^1H NMR δ 1.57–2.10 (m, 4 H, CH_2 × 2), 2.42 (t, 2 H, J = 6.3 Hz, C≡CH_2), 3.00 (s, 3 H, SO_2CH_3), 3.77 (s, 3 H, OCH_3), 4.27 (t, 2 H, J = 6.3 Hz, OCH_2); exact mass calcd for $C_8H_{11}O_4S$ (M^+ - OMe) 203.0376, found 203.0346. Anal. Calcd for $C_9H_{14}O_5S$: C, 46.15; H, 6.02. Found: C, 45.65; H, 5.96.

Methyl 6-(Mesyloxy)-2-hexynoate (7b). This was prepared from **6b** (154 mg, 1.08 mmol), methanesulfonyl chloride (0.10 mL, 1.3 mmol), and Et_3N (0.22 mL, 1.6 mmol) by the same procedure described for the preparation of **7a**. The crude product was purified by short column chromatography on silica gel (AcOEt) to give **7b** (204 mg, quant) as a pale yellow oil, which was used for the next reaction without distillation because of its unstability: IR 3030, 2950, 2250, 1715, 1360, 1175 cm^{-1}; ^1H NMR δ 2.01 (quint, 2 H, J = 7 Hz, CH_2), 2.52 (t, 2 H, J = 7 Hz, C≡CCH_2), 3.03 (s, 3 H, SO_2CH_3), 3.74 (s, 3 H, OCH_3), 4.31 (t, 2 H, J = 7 Hz, OCH_2); exact mass calcd for $C_7H_9O_4S$ (M^+ - OMe) 189.0220, found 189.0215.

Methyl 7-Iodo-2-heptynoate (8a). A mixture of **7a** (114 mg, 0.487 mmol) and NaI (183 mg, 1.22 mmol) in acetone (10 mL) was stirred at room temperature for 92 h. After removal of the solvent, the residue was diluted with CH_2Cl_2, washed with aqueous $Na_2S_2O_3$, dried, and concentrated under reduced pressure. The crude product was purified by column chromatography on silica gel (hexane–AcOEt, 10:1) to give **8a** (122.4 mg, 95%) as a colorless oil: bp 120–122 °C (0.2 mmHg) (bath temperature); IR 2950, 2240, 1710, 1435, 1265, 1080 cm^{-1}; ^1H NMR δ 1.49–2.16 (m, 4 H, CH_2 × 2), 2.48 (t, 2 H, J = 6.3 Hz, C≡CCH_2), 3.20 (t, 2 H, J = 6.3 Hz, ICH_2), 3.76 (s, 3 H, OCH_3); MS m/e 266 (M^+). Anal. Calcd for $C_8H_{11}O_2I$: C, 36.11; H, 4.17; I, 47.69. Found: C, 36.03; H, 4.05; I, 47.73.

Methyl 6-Iodo-2-hexynoate (8b). This was prepared from crude **7b** (204 mg, 0.927 mmol) and NaI (347 mg, 2.31 mmol) by the same procedure described for the preparation of **8a**. Purification by column chromatography on silica gel (hexane–AcOEt, 10:1) gave **8b** (157.4 mg, 58% from **6b**) as a colorless oil: bp 125–132 °C (0.5 mmHg); IR 2950, 2250, 1710 cm^{-1}; ^1H NMR δ 2.04 (quint, 2 H, J = 7 Hz, CH_2), 2.48 (t, 2 H, J = 7 Hz, C≡CCH_2), 3.27 (t, 2 H, J = 7 Hz, ICH_2), 3.74 (s, 3 H, OCH_3); exact mass calcd for $C_7H_9O_2I$ 251.9647, found 251.9662.

6-(Trimethylsilyl)-5-hexyn-1-ol (9). To a THF (2 mL) solution of **3a** (59.0 mg, 0.602 mmol) was added *n*-BuLi (1.6 N in hexane, 0.820 mL, 1.32 mmol) dropwise at −78 °C under nitrogen; the reaction mixture was then stirred for 30 min under the same conditions. Trimethylsilyl chloride (0.170 mL, 1.32 mmol) was added to the solution at the same temperature. The mixture was stirred at −78 °C for 1 h and at room temperature for 1.5 h, quenched with saturated aqueous NH_4Cl, and extracted with $CHCl_3$. The extract was dried and concentrated under reduced pressure to give the C,O-ditrimethylsilylated compound (38.1 mg, 0.157 mmol), which was treated with acetic acid (0.2 mL) in MeOH (4 mL) at room temperature for 2 h.[22] The reaction mixture was partitioned between saturated aqueous $NaHCO_3$ and CH_2Cl_2. The organic layer was dried and concentrated under reduced pressure to give crude **9**, which was purified by column chromatography on silica gel (hexane–AcOEt, 2:1) to give pure **9** (21.2 mg, 79%) as a colorless oil: bp 85–86 °C (0.5 mmHg); IR 2960, 2180, 1250 cm^{-1}; ^1H NMR δ 0.13 (s, 9 H, $Si(CH_3)_3$), 1.51–1.77 (m, 4 H, CH_2 × 2), 2.24 (t, 2 H, J = 6 Hz, C≡CCH_2), 3.66 (t, 2 H, J = 6 Hz, OCH_2); MS m/e 170 (M^+). Anal. Calcd for $C_9H_{18}OSi$: C, 63.47; H, 10.65. Found: C, 63.45; H, 10.57.

6-(Trimethylsilyl)-5-hexynyl Methanesulfonate (10). This was prepared from **9** (5.2 mg, 0.031 mmol) and methanesulfonyl chloride (0.0050 mL, 0.065 mmol) by the same procedure described for the preparation of **7a**. Purification by column chromatography on silica gel (hexane–AcOEt, 2:1) gave **10** (5.5 mg, 73%) as a colorless oil: bp 116–117 °C (0.4 mmHg); IR 2960, 2180, 1360, 1175 cm^{-1}; ^1H NMR δ 0.13 (s, 9 H, $Si(CH_3)_3$), 1.44–2.07 (m, 4 H, CH_2 × 2), 2.27 (t, 2 H, J = 6 Hz, C≡CCH_2), 2.98 (s, 3 H, SO_2CH_3),

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4.26 (t, 2 H, J = 6 Hz, OCH_2); MS m/e 248 (M^+). Anal. Calcd for $C_{10}H_{20}O_3SSi$: C, 48.35; H, 8.11. Found: C, 48.16; H, 8.28.

6-Iodo-1-(trimethylsilyl)-1-hexyne (11). This was prepared from **10** (792 mg, 3.19 mmol) and NaI (1.20 g, 8.00 mmol) by the same procedure described for the preparation of **8a**. Purification by column chromatography on silica gel (hexane–AcOEt, 5:1) gave **11** (796 mg, 89%) as a colorless oil: bp 91–93 °C (0.3 mmHg) (bath temperature); IR 2960, 2180, 1250 cm^{-1}; ^1H NMR δ 0.14 (s, 9 H, $Si(CH_3)_3$), 1.52–2.14 (m, 4 H, CH_2 × 2), 2.26 (t, 2 H, J = 6 Hz, $C{\equiv}CCH_2$), 3.21 (t, 2 H, J = 6 Hz, ICH_2); MS m/e 280 (M^+). Anal. Calcd for $C_9H_{17}SiI$: C, 38.58; H, 6.11. Found: C, 38.86; H, 6.02.

4-Pentynyl Methanesulfonate (12). This was prepared from **3b** (1.00 g, 11.9 mmol) and methanesulfonyl chloride (0.921 mL, 11.9 mmol) by the same procedure described for the preparation of **7a**. Purification by short column chromatography on silica gel (hexane–AcOEt, 2:1) gave **12** (1.53 g, 79%) as a colorless oil: bp 85–90 °C (0.45 mmHg) (bath temperature); IR 3320, 3030, 1365, 1175 cm^{-1}; ^1H NMR δ 1.80–2.45 (m, 4 H, CH_2 × 2), 2.02 (t, 1 H, J = 2 Hz, C≡CH), 3.02 (s, 3 H, SO_2CH_3), 4.36 (t, 2 H, J = 6 Hz, OCH_2); exact mass calcd for C_5H_7O ($M^+ - SO_2CH_3$) 83.0495, found 83.0490.

1,1-Diethoxy-6-iodo-2-hexyne (13). The methanesulfonate (**12**, 870 mg, 5.37 mmol) was treated with NaI (2.01 g, 13.4 mmol) by the same procedure described for the preparation of **8a,b** to give the 6-iodo compound (830 mg, 4.28 mmol), which was reacted with ethyl orthoformate (1.42 mL, 8.56 mmol) in the presence of zinc iodide (50 mg) under reflux for 12 h.[23] The reaction mixture was quenched with brine and extracted with CH_2Cl_2. The extract was dried and concentrated under reduced pressure to give a residue, which was purified by column chromatography on silica gel (hexane–AcOEt, 5:1) to give **13** (740 mg, 47% overall) as a pale yellow oil: bp 105–115 °C (0.5–0.6 mmHg) (bath temperature); IR 2980, 2240, 1150, 1080, 1045 cm^{-1}; ^1H NMR δ 1.19 (t, 6 H, J = 7 Hz, CH_2CH_3 × 2), 1.79–2.42 (m, 4 H, CH_2 × 2), 3.22 (t, 2 H, J = 7 Hz, ICH_2), 3.61 (q, 4 H, J = 7 Hz, CH_2CH_3 × 2), 5.18 (s, 1 H, OCHO); exact mass calcd for $C_{10}H_{17}O_2I$ 296.0270, found 296.0248.

Bis(diphenylmethyl) Homophthalate (14a). Diphenyldiazomethane, obtained from benzophenone hydrazone (2.2 g, 11 mmol) and HgO (2.4 g, 11 mmol) by the reported method,[24] was added dropwise to a mixture of homophthalic acid (500 mg, 2.78 mmol) in CH_2Cl_2 (7.5 mL) and MeOH (2.5 mL) at 0 °C. The reaction mixture was stirred at room temperature for 2 h. The excess diphenyldiazomethane was trapped with acetic acid. The reaction mixture was diluted with Et_2O, washed with brine, dried, and concentrated under reduced pressure. The residue was purified by column chromatography on silica gel (hexane–AcOEt, 5:1) to give **14a** (1.48 g, quant) as colorless crystals: mp 79–80 °C (hexane–AcOEt); IR 1710, 1255 cm^{-1}; ^1H NMR δ 4.12 (s, 2 H, $COCH_2$), 6.72 (s, 1 H, $CHPh_2$), 6.90 (s, 1 H, $CHPh_2$), 6.94–8.21 (m, 24 H, ArH × 24). Anal. Calcd for $C_{35}H_{28}O_4$: C, 82.01; H, 5.66. Found: C, 81.84; H, 5.45.

Bis(diphenylmethyl) 2′-(6-(Methoxycarbonyl)-5-hexynyl)homophthalate (16a). To a solution of lithium diisopropylamide (LDA) in THF (2 mL), obtained from dry diisopropylamine (0.040 mL, 0.29 mmol) and n-BuLi (1.6 N in hexane, 0.19 mL, 0.29 mmol), was added dropwise a solution of bis(diphenylmethyl)ester **14a** (128 mg, 0.250 mmol) in THF (2 mL) at −78 °C under nitrogen; the mixture was then stirred for 30 min. A solution of the iodide (**8a**, 70 mg, 0.26 mmol) and hexamethylphosphoric triamide (HMPA, 0.05 mL) in THF (2 mL) was added to the mixture. The mixture was stirred at the same temperature for 2 h and at room temperature for 1 h, quenched with saturated aqueous NH_4Cl, extracted with CH_2Cl_2, washed with brine, dried, and concentrated under reduced pressure to give a residue. Purification by column chromatography on silica gel (hexane–AcOEt, 5:1) gave **16a** (73 mg, 45%) as a viscous oil: IR 2250, 1720, 1715, 1260 cm^{-1}; ^1H NMR δ 1.02–1.47 (m, 4 H, CH_2 × 2), 1.47–1.62 (m, 2 H, $CHCH_2$), 1.93–2.24 (m, 2 H, $C{\equiv}CCH_2$), 3.70 (s, 3 H, OCH_3), 4.78 (t, 1 H, J = 7.5 Hz, CHCO), 6.74 (s, 1 H, $CHPh_2$), 7.07 (s, 1 H, $CHPh_2$), 6.81–8.04 (m, 24 H, ArH × 24); exact mass calcd for $C_{43}H_{38}O_6$ 650.2665, found 650.2665.

Bis(diphenylmethyl) 2′-(5-(Methoxycarbonyl)-4-pentynyl)homophthalate (16b). This was prepared from **14a** (586 mg, 1.14 mmol) and iodide **8b** (313 mg, 1.24 mmol) by the same procedure described for the preparation of **16a**. Purification by prep TLC (hexane–AcOEt, 5:1) gave **16b** (65.9 mg, 9%) as a viscous oil: IR 2950, 2230, 1720, 1710 cm^{-1}; ^1H NMR δ 1.39–1.60 (m, 4 H, CH_2 × 2), 2.18 (t, 2 H, J = 7 Hz, $C{\equiv}CCH_2$), 3.71 (s, 3 H, OCH_3), 4.81 (t, 1 H, J = 7 Hz, CHCO), 6.77 (s, 1 H, $CHPh_2$), 7.10 (s, 1 H, $CHPh_2$), 6.91–7.53 (m, 23 H, ArH × 23), 7.96–8.09 (m, 1 H, ArH); exact mass calcd for $C_{29}H_{25}O_6$ ($M^+ - CHPh_2$) 469.1648, found 469.1621.

2′-(6-(Methoxycarbonyl)-5-hexynyl)homophthalic Acid (17a). Bis(diphenylmethyl) ester **16a** (41.3 mg, 0.0635 mmol) was treated with $BF_3{\cdot}Et_2O$ (0.20 mL, 1.6 mmol) in acetic acid (0.20 mL) at 0 °C for 1 h under nitrogen.[25] The reaction mixture was quenched with saturated aqueous NaOAc, extracted with Et_2O, dried, and concentrated under reduced pressure. The crude product was recrystallized from hexane–CH_2Cl_2 to give **17a** (22 mg, quant) as colorless crystals: mp 115–116 °C (hexane–CH_2Cl_2); IR 2950, 2250, 1710, 1270 cm^{-1}; ^1H NMR δ 1.30–1.68 (m, 4 H, CH_2 × 2), 2.14–2.40 (m, 4 H, CH_2 × 2), 3.72 (s, 3 H, OCH_3), 4.50 (t, 1 H, J = 7.5 Hz, CHCO), 7.27–7.46 (m, 3 H, ArH × 3), 7.90–8.07 (m, 1 H, ArH); exact mass calcd for $C_{17}H_{18}O_6$ 318.1103, found 318.1103.

2′-(5-(Methoxycarbonyl)-4-pentynyl)homophthalic Acid (17b). This was prepared from **16b** (39.1 mg, 0.0615 mmol) by the same procedure described for the preparation of **17a**. The same workup as described above gave **17b** (5.4 mg, 28%) as a colorless syrup: IR 2950, 2240, 1710, 1700 cm^{-1}; ^1H NMR δ 1.45–1.73 (m, 4 H, CH_2 × 2), 2.00–2.51 (m, 2 H, CH_2), 3.76 (s, 3 H, OCH_3), 4.36–4.44 (m, 1 H, CHCO), 6.98–7.78 (m, 3 H, ArH × 3), 7.93–8.20 (m, 1 H, ArH); exact mass calcd for $C_{15}H_{14}O_3$ ($M^+ - H_2O - CO_2$) 242.0942, found 242.0942.

4-(6-(Methoxycarbonyl)-5-hexynyl)homophthalic Anhydride (18a). Dicarboxylic acid **17a** (81.0 mg, 0.255 mmol) was treated with (trimethylsilyl)ethoxyacetylene (47.0 mg, 0.311 mmol) in dry CH_2Cl_2 (3 mL) at room temperature for 5 h. The reaction mixture was concentrated under reduced pressure to give **18a** (quant), which was used for the next reaction without further purification: IR 3020, 2950, 2850, 2225, 1795, 1705, 1600 cm^{-1}; ^1H NMR δ 1.20–2.42 (m, 8 H, CH_2 × 4), 3.73 (s, 3 H, OCH_3), 4.00 (t, 1 H, J = 6 Hz, CHCO), 7.15–7.71 (m, 3 H, ArH × 3), 8.18 (dd, 1 H, J = 8, 2 Hz, ArH).

4-(5-(Methoxycarbonyl)-4-pentynyl)homophthalic Anhydride (18b). This was prepared from **17b** (23.9 mg, 0.0786 mmol) by the same procedure described for the preparation of **18a** (23.2 mg, quant), which was used for the next reaction without further purification: IR 2950, 2230, 1785, 1750, 1710 cm^{-1}; ^1H NMR δ 1.51–2.44 (m, 6 H, CH_2 × 3), 3.79 (s, 3 H, OCH_3), 4.38–4.44 (m, 1 H, CHCO), 7.04–7.78 (m, 4 H, ArH × 4).

Dimethyl 2′-(6-(Trimethylsilyl)-5-hexynyl)homophthalate (16c). This was prepared from **14b** (372 mg, 1.79 mmol) and **11** (507 mg, 1.81 mmol) by the same procedure described for the preparation of **16a**. Purification by column chromatography on silica gel (hexane–AcOEt, 5:1) gave **16c** (550 mg, 86%) as a colorless oil: bp 140–145 °C (0.4 mmHg) (bath temperature); IR 2950, 2170, 1720 cm^{-1}; ^1H NMR δ 0.11 (s, 9 H, $Si(CH_3)_3$), 1.22–2.11 (m, 6 H, CH_2 × 3), 2.24 (t, 2 H, J = 6 Hz, $C{\equiv}CCH_2$), 3.70 (s, 3 H, OCH_3), 3.96 (s, 3 H, OCH_3), 4.69 (t, 1 H, J = 8 Hz, CHCO), 7.30–7.66 (m, 3 H, ArH × 3), 7.92–8.09 (m, 1 H, ArH); exact mass calcd for $C_{20}H_{28}O_4Si$ 360.1757, found 360.1764. Anal. Calcd for $C_{20}H_{28}O_4Si$: C, 66.63; H, 7.83. Found: C, 66.14; H, 7.70.

Dimethyl 2′-(7-Oxo-5-octynyl)homophthalate (16d). To a solution of **16c** (511 mg, 1.42 mmol) and acetyl chloride (0.110 mL, 1.56 mmol) in CH_2Cl_2 (10 mL) was added powdered anhydrous $AlCl_3$ (817 mg, 6.13 mmol) at 0 °C.[26] The mixture was stirred at 0 °C for 20 min, quenched with H_2O, extracted with CH_2Cl_2, dried, and concentrated under reduced pressure. The residue was purified by column chromatography on silica gel (hexane–AcOEt, 3:1) to give **16d** (363 mg, 78%) as a colorless oil:

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bp 165–170 °C (0.55 mmHg) (bath temperature); IR 2960, 2220, 1720, 1670 cm^{-1}; ^1H NMR δ 1.09–2.21 (m, 6 H, $CH_2 \times 3$), 2.27 (s, 3 H, $COCH_3$), 2.33 (t, 2 H, J = 6 Hz, $C{\equiv}CCH_2$), 3.64 (s, 3 H, OCH_3), 3.90 (s, 3 H, OCH_3), 4.64 (t, 1 H, J = 7 Hz, CHCO), 7.16–7.52 (m, 3 H, ArH × 3), 7.82–7.96 (m, 1 H, ArH); exact mass calcd for $C_{17}H_{19}O_3$ 271.1335 ($M^+ - CO_2Me$), found 271.1345. Anal. Calcd for $C_{19}H_{22}O_5$: C, 69.07; H, 6.71. Found: C, 68.61; H, 6.62.

Dimethyl 2′-(7,7-(Ethylenedioxy)-5-octynyl)homophthalate (16e). A solution of **16d** (212 mg, 0.643 mmol), ethylene glycol (0.430 mL, 7.71 mmol), and *p*-TsOH (54 mg) in benzene (15 mL) was refluxed for 20 min under azeotropic conditions. The reaction mixture was allowed to cool to room temperature, and then saturated aqueous $NaHCO_3$ was added; the mixture was extracted with CH_2Cl_2; the extracts were dried and concentrated under reduced pressure. The residue was purified by column chromatography on silica gel (hexane–AcOEt, 5:1) to give a colorless oil (180 mg, 75%): IR 2950, 1720 cm^{-1}; ^1H NMR δ 1.25–1.60 (m, 4 H, $CH_2 \times 2$), 1.64 (s, 3 H, CCH_3), 1.74–1.84 (m, 1 H, $CHCH_2 \times {}^1/_2$), 2.08–2.17 (m, 1 H, $CHCH_2 \times {}^1/_2$), 2.17 (t, 2 H, J = 7 Hz, $C{\equiv}CCH_2$), 3.64 (s, 3 H, OCH_3), 3.90 (s, 3 H, OCH_3), 3.92–4.05 (m, 4 H, $OCH_2 \times 2$), 4.62 (t, 1 H, J = 7 Hz, CHCO), 7.31 (td, 1 H, J = 8, 1.2 Hz, 4-CH), 7.43 (dd, 1 H, J = 8, 1.2 Hz, 6-CH), 7.48 (td, 1 H, J = 8, 1.2 Hz, 5-CH), 7.88 (dd, 1 H, J = 8, 1.2 Hz, 3-CH); exact mass calcd for $C_{21}H_{26}O_6$ 374.1730, found 374.1731. Anal. Calcd for $C_{21}H_{26}O_6$: C, 67.36; H, 7.00. Found: C, 67.02; H, 6.95.

2′-(7-Oxo-5-octynyl)homophthalic Acid (17c). A solution of **16e** (144 mg, 0.385 mmol) and KOH (84.0 mg, 1.49 mmol) in MeOH (2.8 mL) and H_2O (1.0 mL) was refluxed for 4 h. The solvent was concentrated under reduced pressure, and then the residue was diluted with brine and washed with Et_2O. The aqueous layer was acidifed (pH = 3) with 10 % HCl and extracted with Et_2O; the extracts were dried and concentrated under reduced pressure. Recrystallization of the crude product gave pure **17c** as colorless crystals (98.7 mg, 85%): mp 155–157 °C (hexane–CH_2Cl_2); IR 2940, 2200, 1700, 1665 cm^{-1}; ^1H NMR δ 1.24–1.68 (m, 6 H, $CH_2 \times 3$), 2.26 (s, 3 H, $COCH_3$), 2.32 (t, 2 H, J = 6 Hz, $C{\equiv}CCH_2$), 4.61 (t, 1 H, J = 7.6 Hz, CHCO), 7.28–7.58 (m, 3 H, ArH × 3), 7.93–8.09 (m, 1 H, ArH); exact mass calcd for $C_{17}H_{18}O_5$ 302.1152, found 302.1135.

4-(7-Oxo-5-octynyl)homophthalic Anhydride (18c). This was prepared from **17c** (45.5 mg, 0.151 mmol) by the same procedure described for the preparation of **18a** (42.8 mg, quant), which was used for the next reaction without further purification: IR 2950, 2220, 1800, 1755, 1670 cm^{-1}; ^1H NMR δ 1.33–1.70 (m, 6 H, $CH_2 \times 3$), 2.28 (s, 3 H, $COCH_3$), 2.33 (t, 2 H, J = 8 Hz, $C{\equiv}CCH_2$), 4.02 (t, 1 H, J = 6 Hz, CHCO), 7.26–8.22 (m, 4 H, ArH × 4).

Dimethyl 2′-(6,6-Diethoxy-4-hexynyl)homophthalate (16f). This was prepared from **14b** (393 mg, 1.89 mmol) and **13** (560 mg, 1.89 mmol) by the same procedure described for the preparation of **16a**. **16f** (642 mg, 90%) was obtained as a viscous oil: IR 2250, 1725, 1600 cm^{-1}; ^1H NMR δ 1.20 (t, 6 H, J = 7.2 Hz, $CH_2CH_3 \times 2$), 1.38–2.33 (m, 6 H, $CH_2 \times 3$), 3.62 (s, 3 H, OCH_3), 3.63 (q, 4 H, J = 7.2 Hz, $CH_2CH_3 \times 2$), 3.90 (s, 3 H, OCH_3), 4.62 (t, 1 H, J = 7 Hz, CHCO), 5.21 (s, 1 H, OCHO), 7.17–7.48 (m, 3 H, ArH × 3), 7.87 (d, 1 H, J = 7 Hz, ArH); MS m/e 376 (M^+). Anal. Calcd for $C_{21}H_{28}O_6$: C, 67.00; H, 7.50. Found: C, 66.78; H, 7.59.

2′-(5-Formyl-4-pentynyl)homophthalic Acid (17d). A solution of **16f** (53.2 mg, 0.141 mmol) and KOH (69.0 mg, 1.23 mmol) in MeOH (0.9 mL) and H_2O (1.5 mL) was refluxed for 3 h. The solvent was concentrated under reduced pressure, and then the residue was diluted with brine and washed with Et_2O. The aqueous layer was acidified (pH = 3) with 10% HCl and extracted with Et_2O; the extract was dried and concentrated under reduced pressure to give 2′-(6,6-diethoxy-4-hexynyl)homophthalic acid (49.1 mg, quant). The crude diethoxy acid (150 mg, 0.431 mmol) was deacetalized with 50% CF_3CO_2H (1.6 mL) in $CHCl_3$ (3 mL) at 0 °C for 2 h. The reaction mixture was diluted with brine and extracted with Et_2O; the extract was dried and concentrated under reduced pressure to give **17d** (122 mg, 90%) as a colorless syrup: IR 2210, 1705, 1665 cm^{-1}; ^1H NMR δ 1.46–2.52 (m, 6 H, $CH_2 \times 3$), 4.72 (t, 1 H, J = 7 Hz, CHCO), 7.25–7.66 (m, 3 H, ArH × 3), 8.03 (dd, 1 H, J = 7, 1 Hz, ArH), 9.18 (s, 1 H, CHO), 9.68 (s, 2 H, OH × 2); exact mass calcd for $C_{15}H_{14}O_5$ 274.0840, found 274.0835.

4-(5-Formyl-4-pentynyl)homophthalic Anhydride (18d). This was prepared from **17d** (29.0 mg, 0.106 mmol) by the same procedure described for the preparation of **18a** (27.0 mg, quant.), and was used for the next reaction without further purification: IR 2170, 1790, 1750, 1690 cm^{-1}.

Dimethyl 2′-(5-Hexynyl)homophthalate (16g). This was prepared from **14b** (176 mg, 0.846 mmol) and 6-iodo-1-hexyne[27] (176 mg, 0.846 mmol) by the same procedure described for the preparation of **14a**. Purification by column chromatography on silica gel (benzene–Et_2O, 30:1) gave **16g** (192 mg, 79%) as a viscous oil: IR 3300, 2950, 2100, 1720, 1600, 1575 cm^{-1}; ^1H NMR δ 1.20–2.40 (m, 9 H, $CH_2 \times 4$ and $C{\equiv}CH$), 3.63 (s, 3 H, OCH_3), 3.89 (s, 3 H, OCH_3), 4.62 (t, 1 H, J = 5 Hz, COCH), 7.10–7.60 (m, 3 H, ArH × 3), 7.88 (dd, 1 H, J = 8, 2 H, ArH); MS m/e 288 (M^+). Anal. Calcd for $C_{17}H_{20}O_4$: C, 70.81; H, 6.99. Found: C, 70.80; H, 7.16.

2′-(5-Hexynyl)homophthalic Acid (17e). The mixture of **16g** (192 mg, 0.667 mmol), KOH (300 mg, 5.36 mmol), H_2O (5 mL), and MeOH (5 mL) was refluxed for 3 h. The reaction mixture was concentrated under reduced pressure, diluted with H_2O, acidified (pH = 1) with concentrated HCl, and extracted with Et_2O. The organic layer was dried and concentrated under reduced pressure to give **17e** (165 mg, 95%), which was used for the next reaction without further purification: ^1H NMR (CD_3COCD_3) δ 1.30–2.50 (m, 9 H, $CH_2 \times 4$ and $C{\equiv}CH$), 4.87 (t, 1 H, J = 7 Hz, COCH), 7.29–7.76 (m, 3 H, ArH × 3), 8.10 (d, 1 H, J = 8 Hz, ArH).

4-(5-Hexynyl)homophthalic Anhydride (18e). This was prepared from **17e** (52 mg, 0.20 mmol) by the same procedure described for the preparation of **18a–d** (48 mg, quant), which was used for the next reaction without further purification: IR 3300, 1800, 1760, 1605 cm^{-1}; ^1H NMR δ 1.30–2.35 (m, 9 H, $CH_2 \times 4$ and $C{\equiv}CH$), 4.02 (t, 1 H, J = 6 Hz, COCH), 7.15–7.85 (m, 3 H, ArH × 3), 8.00–8.25 (m, 1 H, ArH).

Diphenylmethyl (2-((Diphenylmethoxy)carbonyl)-thiophene-3-yl)acetate (15a). This was prepared from (2-carboxythiophene-3-yl)acetic acid[28] (186 mg, 1.00 mmol) by the same procedure described for the preparation of **14a**. Purification by column chromatography on silica gel (hexane–AcOEt, 10:1) gave **15a** (535.6 mg, quant) as colorless crystals: mp 90.5–92 °C (hexane–AcOEt); IR 3025, 1740, 1710 cm^{-1}; ^1H NMR δ 4.20 (s, 2 H, CH_2CO), 6.80 (s, 1 H, $CHPh_2$), 6.96 (s, 1 H, $CHPh_2$), 6.98 (d, 1 H, J = 5 Hz, 4-CH), 7.40 (d, 1 H, J = 5 Hz, 5-CH), 7.13–7.36 (m, 20 H, ArH × 20); MS m/e 351 ($M^+ - CHPh_2$). Anal. Calcd for $C_{33}H_{26}O_4S$: C, 76.43; H, 5.05. Found: C, 76.16; H, 5.15.

Diphenylmethyl (2-((Diphenylmethoxy)carbonyl)benzo-[*b*]furan-3-yl)acetate (15b). This was prepared from (2-carboxybenzo[*b*]furan-3-yl)acetic acid[29] (569 mg, 2.59 mmol) by the same procedure described for the preparation of **14a**. Purification by column chromatography on silica gel (hexane–AcOEt, 10:1) gave **15b** (1.27 g, 89%) as colorless crystals: mp 127–128 °C (hexane–CH_2Cl_2); IR 3000, 1740, 1720 cm^{-1}; ^1H NMR δ 4.30 (s, 2 H, CH_2CO), 6.85 (s, 1 H, $CHPh_2$), 7.14 (s, 1 H, $CHPh_2$), 7.20–7.47 (m, 24 H, ArH × 24); MS m/e 552 (M^+). Anal. Calcd for $C_{37}H_{28}O_5$: C, 80.42; H, 5.11. Found: C, 80.32; H, 4.98.

Diphenylmethyl 2-(6-(Methoxycarbonyl)-5-hexynyl)-2-(2-((diphenylmethoxy)carbonyl)thiophene-3-yl)acetate (19a). This was prepared from **15a** (170 mg, 0.328 mmol) by the same procedure described for the preparation of **16a**. Purification by column chromatography on silica gel (hexane–AcOEt, 5:1) gave **19a** (71 mg, 33%) as a viscous oil: IR 2240, 1710 cm^{-1}; ^1H NMR δ 1.13–2.04 (m, 6 H, $CH_2 \times 3$), 2.14 (t, 2 H, J = 6 Hz, $C{\equiv}CCH_2$), 3.71 (s, 3 H, OCH_3), 5.01 (t, 1 H, J = 7 Hz, CHCO), 6.78 (s, 1 H, $CHPh_2$), 7.06 (d, 1 H, J = 5 Hz, 4-CH), 7.11 (s, 1 H, $CHPh_2$), 7.37 (d, 1 H, J = 5 Hz, 5-CH), 6.97–7.47 (m, 20 H, ArH × 20); exact mass calcd for $C_{28}H_{25}O_6S$ ($M^+ - CHPh_2$) 489.1372, found 489.1378.

Diphenylmethyl 2-(6-(Methoxycarbonyl)-5-hexynyl)-2-(2-((diphenylmethoxy)carbonyl)benzo[*b*]furan-3-yl)acetate (19b). This was prepared from **15b** (312 mg, 0.565 mmol) by the same procedure described for the preparation of **16a**. Purification by column chromatography on silica gel (hexane–AcOEt, 5:1) gave

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19b (137 mg, 35%) as a viscous oil: IR 3050, 2250, 1715 cm^{-1}; ^1H NMR δ 1.20–1.60 (m, 6 H, $CH_2 \times 3$), 2.05–2.10 (m, 2 H, $C{\equiv}CCH_2$), 3.71 (s, 3 H, OCH_3), 5.01 (dd, 1 H, J = 9, 6 Hz, CHCO), 6.82 (s, 1 H, $CHPh_2$), 6.91–7.58 (m, 25 H, $CHPh_2$ and ArH × 24); exact mass calcd for $C_{45}H_{38}O_7$ (M^+), 690.2617, found 690.2683, and calcd for $C_{32}H_{27}O_7$ ($M^+ - CHPh_2$) 523.1757, found 523.1785.

General Procedure for Strong-Base-Induced Intramolecular Cycloaddition Reactions of Homophthalic Anhydrides (18a–e) and Their Hetero Analogues (20a,b). To a suspension of NaH (60% in mineral oil, 1.3 mmol) in anhydrous THF (16 mL), the solution of anhydride (1.0 mmol) in anhydrous THF (16 mL) was added dropwise at 0 °C, and the mixture was allowed to warm to room temperature and stirred for the period indicated in Table I. The reaction mixture was quenched with saturated aqueous NH_4Cl and partitioned between dilute HCl and CH_2Cl_2. The organic layer was washed with brine, dried, and concentrated under reduced pressure. The residue was purified by prep TLC to give the cycloadduct.

9-Hydroxy-10-(methoxycarbonyl)-1,2,3,4-tetrahydrophenanthrene (21a). This was prepared from **18a** (13.9 mg, 0.0463 mmol). Purification by prep TLC (hexane) gave **21a** (6.4 mg, 54%) as colorless crystals: mp 110.5–111.5 °C (hexane); IR 2940, 2850, 1640, 1620, 1580 cm^{-1}; ^1H NMR δ 1.75–1.82 (m, 2 H, 2-CH_2 or 3-CH_2), 1.88–1.94 (m, 2 H, 2-CH_2 or 3-CH_2), 3.02 (t, 2 H, J = 6.7 Hz, 1-CH_2), 3.06 (t, 2 H, J = 6.7 Hz, 4-CH_2), 3.99 (s, 3 H, OCH_3), 7.47 (dd, 1 H, J = 8.6, 6.7 Hz, 7-CH), 7.62 (dd, 1 H, J = 8.6, 6.7 Hz, 6-CH), 7.90 (d, 1 H, J = 8.6 Hz, 8-CH), 8.43 (d, 1 H, J = 8.6 Hz, 5-CH), 12.24 (s, 1 H, OH); MS, m/e 256 (M^+). Anal. Calcd for $C_{16}H_{16}O_3$: C, 74.98; H, 6.29. Found: C, 74.95; H, 6.16.

5-Hydroxy-4-(methoxycarbonyl)-2,3-dihydro-1*H*-benz[*e*]indene (21b). This was prepared from **18b** (23.2 mg, 0.0811 mmol). Purification by prep TLC gave **21b** (4.5 mg, 24%) as colorless crystals: mp 104–109 °C dec (hexane); IR 2955, 1650, 1625 cm^{-1}; ^1H NMR δ 2.19 (quint, 2 H, J = 7.3 Hz, 2-CH_2), 3.14 (t, 2 H, J = 7.6 Hz, 3-CH_2), 3.34 (t, 2 H, J = 7.6 Hz, 1-CH_2), 3.99 (s, 3 H, OCH_3), 7.47 (td, 1 H, J = 8, 1.3 Hz, 7-CH), 7.61 (td, 1 H, J = 8, 1.3 Hz, 8-CH), 7.69 (dd, 1 H, J = 8, 1.3 Hz, 6-CH), 8.41 (dd, 1 H, J = 8, 1.3 Hz, 9-CH), 12.42 (s, 1 H, OH); exact mass calcd for $C_{15}H_{14}O_3$ 242.0941, found 242.0934.

10-Acetyl-9-hydroxy-1,2,3,4-tetrahydrophenanthrene (21c). This was prepared from **18c** (42.8 mg, 0.151 mmol). Purification by prep TLC gave **21c** (23.3 mg, 64%) as pale yellow crystals: mp 126–127 °C (hexane); IR 2940, 1615 cm^{-1}; ^1H NMR δ 1.76–1.83 (m, 2 H, 2-CH_2 or 3-CH_2), 1.95–2.01 (m, 2 H, 2-CH_2 or 3-CH_2), 2.70 (s, 3 H, $COCH_3$), 3.01 (t, 2 H, J = 6 Hz, 1-CH_2), 3.03 (t, 2 H, J = 6 Hz, 4-CH_2), 7.47 (td, 1 H, J = 7.2, 1.4 Hz, 7-CH), 7.63 (td, 1 H, J = 7.2, 1.4 Hz, 6-CH), 7.87 (dd, 1 H, J = 8.2, 1.4 Hz, 8-CH), 8.45 (dd, 1 H, J = 8.2, 1.4 Hz, 5-CH), 13.61 (s, 1 H, OH); exact mass calcd for $C_{16}H_{16}O_2$ 240.1148, found 240.1148.

4-Formyl-5-hydroxy-2,3-dihydro-1*H*-benz[*e*]indene (21d). This was prepared from **18d** (27.0 mg, 0.105 mmol). Purification by prep TLC gave **21d** (8.0 mg, 36%) as pale yellow crystals: mp 109–111 °C (hexane–CH_2Cl_2); IR 2960, 2930, 1625 cm^{-1}; ^1H NMR δ 2.32 (quint, 2 H, J = 7.3 Hz, 2-CH_2), 3.15 (t, 2 H, J = 7.3 Hz, 3-CH_2), 3.31 (t, 2 H, J = 7.3 Hz, 1-CH_2), 7.48 (d, 1 H, J = 9 Hz, 6-CH), 7.64 (dd, 1 H, J = 9, 7.5 Hz, 7-CH), 7.66 (dd, 1 H, J = 9, 7.5 Hz, 8-CH), 8.43 (d, 1 H, J = 9 Hz, 9-CH), 10.07 (s, 1 H, CHO), 12.95 (s, 1 H, OH); MS m/e 212 (M^+). Anal. Calcd for $C_{14}H_{12}O_2$: C, 79.23; H, 5.70. Found: C, 78.99; H, 5.50.

3-(1-Hexynyl)-4-(methoxycarbonyl)-4-methyl-3,4-dihydroisocoumarin (24). This was prepared from 4-methylhomophthalic anhydride[15b] (**22**, 50 mg, 0.28 mmol) and hept-2-ynal[30] (**23**, 31 mg, 0.28 mmol) by the same procedure described for the preparation of **21a–d**. Esterification by diazomethane gave crude **24**. Purification by column chromatography on silica gel (hexane–AcOEt, 10:1) gave **24** (51.7 mg, 62%) as a mixture of diastereomers (3:1): IR 2950, 2940, 2860, 2240, 1735, 1730, 1600 cm^{-1}; ^1H NMR δ 0.64–1.56 (m, 7 H, $CH_2CH_2CH_3$), 1.67 (s, $^9/_4$ H, $CCH_3 \times {}^3/_4$), 1.72 (s, $^3/_4$ H, $CCH_3 \times {}^1/_4$), 2.02–2.24 (m, 2 H, $C{\equiv}CCH_2$), 3.63 (s, $^3/_4$ H, $OCH_3 \times {}^1/_4$), 3.69 (s, $^9/_4$ H, $OCH_3 \times {}^3/_4$), 5.03 (t, $^1/_4$ H, J = 2 Hz, OCH × $^1/_4$), 5.51 (t, $^3/_4$ H, J = 2 Hz, OCH × $^1/_4$) H, 7.11–7.64 (m, 3 H, ArH × 3), 7.98–8.09 (m, 1 H, ArH); exact mass calcd for $C_{18}H_{20}O_4$ 300.1399, found 300.1362.

4-Hydroxy-5-(methoxycarbonyl)-6,7,8,9-tetrahydronaphtho[2,1-*b*]thiophene (25a). This was prepared by a one-pot procedure from the dicarboxylic acid (7.00 mg, 0.0216 mmol), obtained from **19a**, by the same procedure as described for the preparation of **17a**. Purification by prep TLC (hexane) gave **25a** (3.8 mg, 67%) as colorless crystals: mp 133–135 °C (hexane); IR 2950, 1720, 1650, 1600 cm^{-1}; ^1H NMR δ 1.77–1.88 (m, 4 H, 7-CH_2 and 8-CH_2), 2.97 (t, 2 H, J = 6.8 Hz, 6-CH_2), 3.06 (t, 2 H, J = 6.8 Hz, 9-CH_2), 3.98 (s, 3 H, OCH_3), 7.34 (d, 1 H, J = 5.5 Hz, 1-CH), 7.62 (d, 1 H, J = 5.5 Hz, 2-CH), 11.90 (s, 1 H, OH); exact mass calcd for $C_{14}H_{14}O_3S$ 262.0661, found 262.0650. Anal. Calcd for $C_{14}H_{14}O_3S$: C, 64.10; H, 5.38. Found C, 64.38; H, 5.64.

6-Hydroxy-5-(methoxycarbonyl)-1,2,3,4-tetrahydronaphtho[2,1-*b*][1]benzofuran (25b). This was prepared from **20b** (18.2 mg, 0.0535 mmol). Purification by prep TLC gave **25b** (6.5 mg, 41%) as colorless crystals: mp 216–218 °C (hexane–CH_2Cl_2); IR 2950, 1730, 1670 cm^{-1}; ^1H NMR δ 1.82–1.87 (m, 2 H, 2-CH_2 or 3-CH_2), 1.91–1.97 (m, 2 H, 2-CH_2 or 3-CH_2), 3.10 (t, 2 H, J = 6.5 Hz, 4-CH_2), 3.22 (t, 2 H, J = 6.5 Hz, 1-CH_2), 4.01 (s, 3 H, OCH_3), 7.36 (t, 1 H, J = 8 Hz, 9-CH), 7.51 (td, 1 H, J = 8, 1.2 Hz, 10-CH), 7.67 (dd, 1 H, J = 8, 1.2 Hz, 8-CH), 8.06 (d, 1 H, J = 8 Hz, 11-CH), 11.40 (s, 1 H, OH); exact mass calcd for $C_{18}H_{16}O_4$ 296.1046, found 296.1031.

Supplementary Material Available: NMR spectra of title compounds (31 pages). Ordering information is given on any current masthead page.

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