The Preparation of Anthraquinones and Anthracyclinones via the Reaction of Haloarenes and Cyanophthalides under Aryne-Forming Conditions

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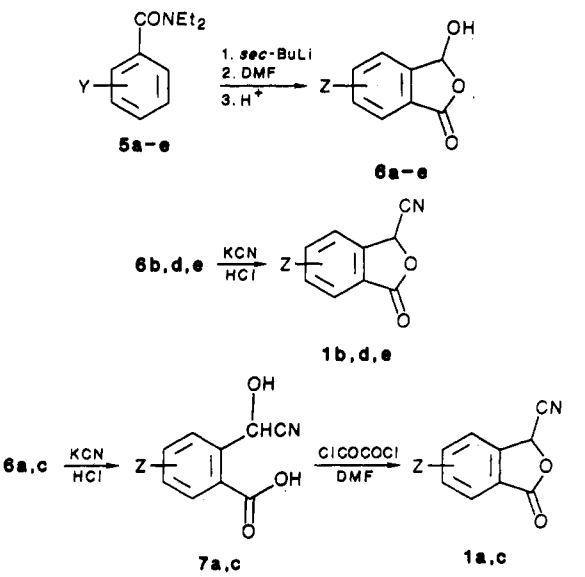
Annulative reactions of arynes generated in situ from haloarenes **2a–n** and LDA in THF with appropriately substituted lithiated 3-cyano-1(3*H*)-isobenzofuranones **6a–e** afford the corresponding anthraquinones **4a–y** in good to moderate yields. Regioselective addition of lithiocyanophthalides is observed in most reactions involving unsymmetric arynes; however, in those reactions in which such addition is not observed, the regioisomers are readily separated by flash column chromatography. Short and efficient syntheses of the naturally occurring islandicin, digitopurpone, pachybasin, chrysophanol, ziganein, helminthosporin, and catenarin have been achieved in fair to good yields. The utility of this approach for the synthesis of anthracyclinones is demonstrated by its use in the preparation of tetracyclic intermediate **10** for 4-demethoxydaunomycinone synthesis.

Anthraquinones are widely distributed in plants and insects[1a] and have been the object of considerable interest because of the antileukemic activity[1b] and cytotoxicity[1c] exhibited by several of their members. The important anticancer activity of the structurally related anthracycline antibiotics has stimulated development for a diversity of approaches to anthraquinone synthesis.[2] Of those methods, we were particularly intrigued by the one[3] that involved the annulation of arynes by lithiated 1(3*H*)-isobenzofuranones. In those reactions, the arynes, generated in situ from bromoarenes with lithium diisopropylamide (LDA), react with lithiated 1(3*H*)-isobenzofuranones to yield adducts, presumably lithium salts of 10-hydroxyanthrone, that subsequently undergo air oxidation slowly (approximately 20 h) to the appropriate anthraquinone. Lithiated 3-cyano-1(3*H*)-isobenzofuranones (hereafter referred to as 3-cyanophthalides) **1** have been shown recently to be superior annulation reagents in the synthesis of anthraquinones and analogues of anthracyclinones.[4] In that method, functionalized quinone monoketals are combined with suitably substituted 3-cyanophthalide anions to give the desired anthracyclinones, after removal of the ketal group. In each of these annulation reactions, the phthalides function as 1,4-dipole equivalents and the arynes or quinone monoketals serve as 1,2-dipole equivalents.

Our recent studies[5] on nitrile anion addition to arynes combined with Swenton's[6] elegant synthesis of 3-cyanophthalides prompted us to investigate the use of lithiated 3-cyanophthalides **1** as annulating agents for arynes. Consequently, the reaction of various haloarenes **2** and LDA in THF with **1** were studied[7] to see if the intermediate arynes **3** were annulated to anthraquinones **4** more readily by **1** than by lithiated 1(3*H*)-isobenzofuranone itself.

Scheme I



	benzamide Y	cyanophthalide Z
a	H	H
b	2-MeO	7-MeO
c	3-MeO	4-MeO
d	2-MeO, 4-Me	7-MeO, 5-Me
e	3,5-$(MeO)_2$	4,6-$(MeO)_2$

Results and Discussion

Synthesis of 3-Cyanophthalides. The required cyanophthalides **1a–e** were prepared according to the method of Swenton[6] (see Scheme I) in which benzamides **5b–e** were converted to the corresponding 3-hydroxyphthalide **6b–e** by the action of *sec*-butyllithium and DMF. Hydroxyphthalides **6b**, **6d**, and **6e**, upon treatment with KCN and

(1) (a) Thomson, R. H. *Naturally Occurring Quinones*, 2nd ed.; Academic Press: New York, 1971. (b) Kupchan, S. M.; Karim, A. *Lloydia* **1976**, *39*, 223. (c) Chang, P.; Lee, K. H. *J. Nat. Prod.* **1985**, *48*, 948 and references cited therein.

(2) (a) For a comprehensive review of synthetic studies published through early 1979, see: Kelly, T. R. *Ann. Rep. Med. Chem.* **1979**, *14*, 288. (b) For more recent synthetic contributions, see inter alia: Kelly, T. R.; Vaya, J.; Ananthasubramanian, L. *J. Am. Chem. Soc.* **1980**, *102*, 5983. (c) Genot, A.; Florent, J.; Monneret, C. *J. Org. Chem.* **1987**, *52*, 1057. (d) Kende, A. S.; Rizzi, J.; Riemer, J. *Tetrahedron Lett.* **1979**, 1201. (e) Hauser, F. M.; Rhee, R. P. *J. Am. Chem. Soc.* **1977**, *99*, 4533. (f) Hauser, F. M.; Mal, D. *J. Am. Chem. Soc.* **1984**, *106*, 1862. (g) Harwood, L. M.; Hodgkinson, L. C.; Sutherland, J. K. *J. Chem. Soc., Chem. Commun.* **1978**, 712. (h) Krohn, K.; Radeloff, M. *Chem. Ber.* **1978**, *111*, 3823. (i) Sibi, M. P.; Altinas, N.; Snickus, V. *Tetrahedron* **1984**, *40*, 4593. (j) Baldwin, J. E.; Bair, K. W. *Tetrahedron Lett.* **1978**, 2559. (k) Forbes, I.; Pratt, R. A.; Raphael, R. A. *Tetrahedron Lett.* **1978**, 3965. (l) Cameron, D. W.; Feutrill, G. F.; Gamble, G. B.; Stavrakis, J. *Tetrahedron Lett.* **1986**, *27*, 4999. (m) Hauser, F. M.; Rhee, R. P. *J. Org. Chem.* **1978**, *43*, 178. (n) Hauser, F. M.; Rhee, R. P. *J. Am. Chem. Soc.* **1979**, *101*, 1628. (o) Hauser, F. M.; Prasanna, S. *J. Org. Chem.* **1979**, *44*, 2596. (p) Kraus, J. A.; Sugimoto, S. *Tetrahedron Lett.* **1978**, 2263. (q) Kraus, J. A.; Pezzanite, J. *J. Org. Chem.* **1979**, *44*, 2480. (r) Broom, P. J. N.; Sammes, P. G.; Dodsworth, D. J. *J. Chem. Soc., Chem. Commun* **1979**, 33.

(3) Dodsworth, D. J.; Calcagno, M.; Ehrmann, E. U.; Devadas, B.; Sammes, P. G. *J. Chem. Soc., Perkins Trans. 1*, **1981**, 2120.

(4) (a) Chenard, B. L.; Dolson, M. G.; Sercel, A. D.; Swenton, J. S. *J. Org.* Chem. **1984**, *49*, 318. (b) Swenton, J. S.; Freskos, J. N.; Morrow, G. W.; Sercel, A. D. *Tetrahedron* **1984**, *40*, 4625.

(5) Khanapure, S. P.; Biehl, E. R. *J. Org. Chem.* **1987**, *52*, 1333 and references therein.

(6) (a) Freskos, J. N.; Morrow, G. W.; Swenton, J. S. *J. Org. Chem.* **1985**, *50*, 805. (b) Morrow, G. W.; Swenton, J. S.; Filppi, J. A.; Wolgemuth, R. L. *J. Org. Chem.* **1987**, *52*, 713 and references therein.

(7) A preliminary account of this work has already been presented: Khanapure, S. P.; Reddy, R. T.; Biehl, E. R. *Abstracts of Papers*, 193rd American Chemical Society Meeting, Denver, CO, April 5–10; American Chemical Society: Washington, D.C.; ORGN 217.

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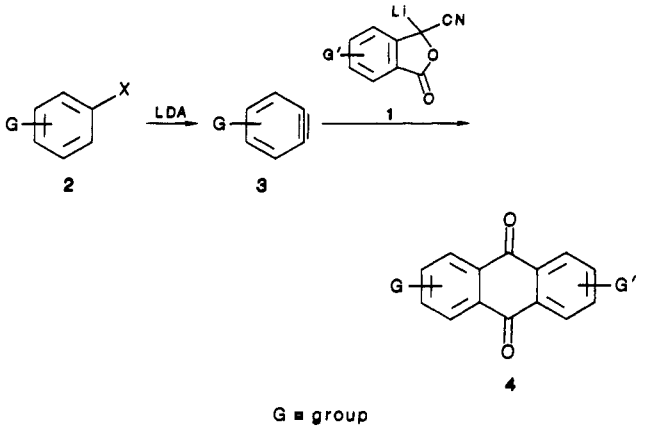
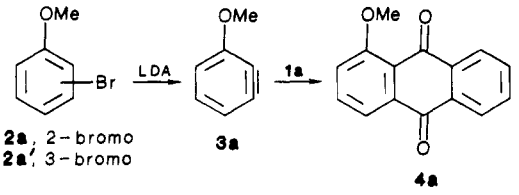


HCl, afforded 3-cyanophthalides **1b**, **1d**, and **1e** directly. However, hydroxyphthalides **6a** and **6c** upon similar treatment gave the cyanohydrins **7a** and **7c**, which were reacted further with oxalyl chloride and DMF to yield the desired 3-cyanophthalides **1a** and **1c**.

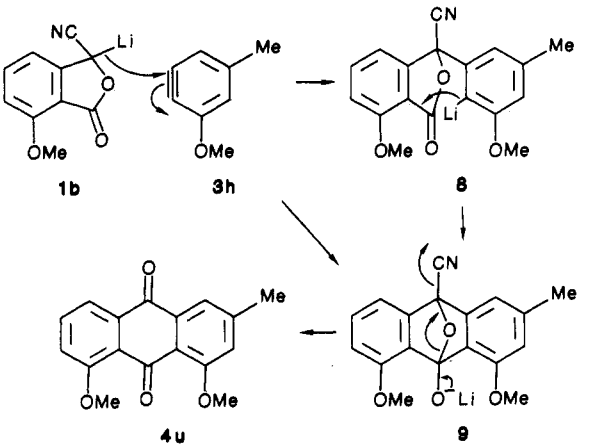
General Approach. The reaction of unsubstituted 3-cyanophthalide (**1a**) with haloarenes **2a–n** and LDA was examined first since only one anthraquinone would be produced from these reactions regardless of if the aryne intermediate were symmetric or unsymmetric. The results listed in Table I show that the substitution pattern of one of the rings in the anthraquinones **4a–n** reflects that of the corresponding haloarene. Further, these anthraquinones were obtained upon the usual workup in good to fair yields; anthrone salts similar to those obtained in lithiated 1(3*H*)-isobenzofuranone-mediated aryne annulations were not observed. For example, the methyl ether of the naturally occurring pachybasin[8] (**4h**) (1-methoxy-3-methylanthraquinone) was prepared from the reaction of 2-chloro-5-methylanisole (**2h**) and **1a** with LDA via the unsymmetrical 3-methoxy-5-methylbenzyne (**3h**) in 40% yield (entry 9). Similarly, **1a** reacts with 4-bromo-1,2-dimethoxybenzene (**2c**) via 3,4-dimethoxybenzyne (**3c**) to give 1,2-dimethoxyanthraquinone (**4c**) in 40% yield (entry 4). Interestingly, the reaction of **1a** and LDA with 2-bromo- (**2a**) and 3-bromoanisole (**2a'**), both of which produce the same aryne intermediate **3a**, supplies 1-meth-



oxyanthra-5,10-quinone (**4a**) in yields of 35% and 40%, respectively. In contrast, Jung[9] observed that of these two bromoanisoles, only **2a'** underwent the aryne reaction with lithiated nitriles under similar conditions.

The data listed in Table I also reveal that functionalized anthraquinones other than methoxy-substituted ones can be prepared by the aryne reaction. For example, the reaction of **1a** with several halobenzaldehyde dimethyl acetals and LDA introduced the aldehyde functionality onto the 1-position of the corresponding anthraquinone, after hydrolysis of the acetal group (entries 10–12). For instance, the dimethyl acetal of 6-bromoveratraldehyde (**2j**) was converted to 1-formyl-3,4-dimethoxyanthra-5,10-quinone (**4j**) in 63% overall yield. Polynuclear haloarenes

Scheme II



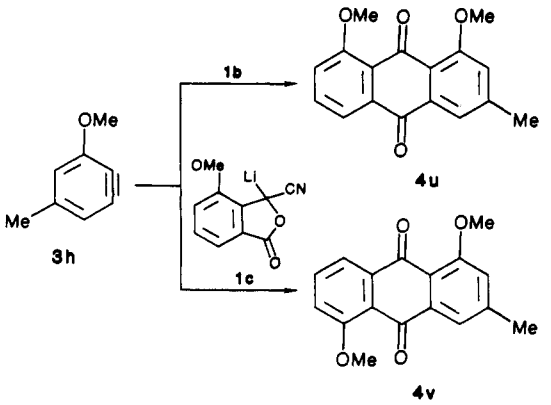
also reacted smoothly with **1a** and LDA to afford the corresponding benzanthraquinones (entries 13–15). In fact, the reported yield (75%) of dibenz[*a*,*c*]anthracene-9,14-dione (**4n**), prepared from 9-bromophenanthrene (**2n**), is one of the highest obtained in this study.

Finally, that both 4-bromo-1,2-dimethoxybenzene (**2c**) and 4-bromo-1,2,3-trimethoxybenzene (**4f**) react readily with lithiated 3-cyanophthalide (**1a**) in the presence of LDA in THF is noteworthy since these bromoarenes, upon treatment with nitrile anions and sodamide in liquid ammonia, do not give desired nitrile products but rather undergo amination.[10-12]

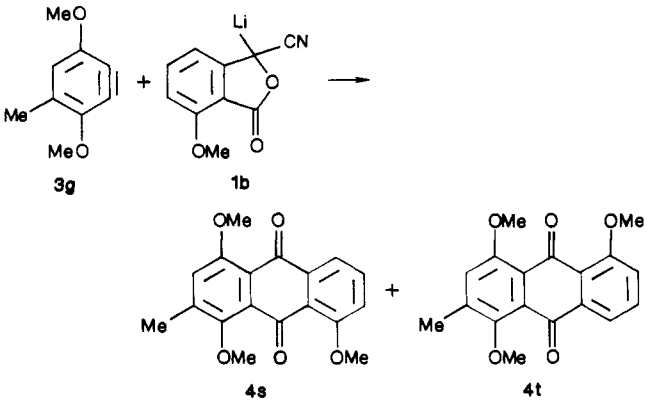
Regioselective Anthraquinone Synthesis. The reaction of haloarenes, from which unsymmetrical arynes are generated, with substituted derivatives of cyanophthalides **1b–e** were next studied, and the results are listed in Table II. These reactions can, in principle, give rise to two regioisomers. However, additions to 3-arynes possessing strong electron-withdrawing groups (EWG), such as methoxy, are regioselective[13] with the addition occurring predominantly to position 1 of the aryne. Most of the entries listed in Table II support this general principle. The dimethyl ethers of the natural products chrysophanol[14] (**4u**) and ziganein[14] (**4v**), thus, were synthesized (entries 6 and 7, respectively) by the regioselective addition of lithiated 3-cyano-7-methoxyphthalide (**1b**) and 3-cyano-4-methoxyphthalide (**1c**) to aryne **3h**, generated from **2h** by LDA, in yields of 30% and 39%, respectively. Only trace amounts of the other regioisomer formed in each of these reactions were obtained.

The mechanism and regioselectivity of these aryne reactions, using the synthesis of the dimethyl ether of chrysophanol (**4u**) as a typical example, are illustrated in Scheme II. As shown, the lithiocyanophthalide **1b** adds to aryne **3h**, forming either the tricyclic compound **9** directly or adduct **8** which then rearranges to **9**. In either case, the observed regioselectivity indicates a high degree of carbanionic character on the carbon atom ortho to methoxy. Collapse of **9** with concommitant loss of cyanide ion yields the observed product **4u**. The final step in this scheme accounts for the superiority of **1a** and its derivatives over lithiophthalides as aryne annulating agents. The

(8) (a) Shibata, S.; Takido, M. *Chem. Pharm. Bull.* **1955**, *3*, 156. (b) Pavanram, S. K.; Hofer, P.; Linde, H.; Meyer, K. *Helv. Chim. Acta* **1963**, *46*, 1377.
(9) Jung, M. E.; Lowen, G. T. *Tetrahedron Lett.* **1986**, *27*, 5319.
(10) Han, Y. X.; Jovanovic, M. V.; Biehl, E. R. *J. Org. Chem.* **1985**, *50*, 1334.
(11) Razzuk, A.; Biehl, E. R. *J. Org. Chem.* **1987**, 52, 2619.
(12) We are investigating currently the use of LDA in THF as base for aryne reaction of **2c**, **2h**, and other haloarenes that generate unsymmetric arynes with various carbon nucleophiles.
(13) Hoffmann, R. W. *Dehydrobenzene and Cycloalkynes*; Academic Press: New York, 1969; pp 134–150.
(14) Imre, S.; Oztune, A.; Buyuktimkin, N. *Phytochemistry* **1974**, *31*, 681.

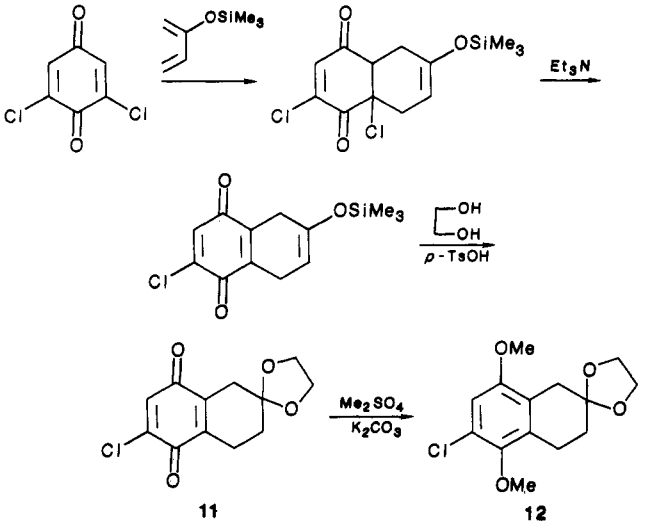


intermediate 3,6-dimethoxy-4-methylbenzyne (**3g**) generated from 2-bromo-1,4-dimethoxy-5-methylbenzene (**2g**) is representative of an aryne in which the regioselectivity is determined not by the stronger directing methoxy groups (since the directing effect of each methoxy group is cancelled by the other) but by the weaker directing methyl group. Owing to the weakly directing ability of the methyl group, the reaction of **1b** with aryne **3g** gave as expected, a mixture of the two regioisomers, digitopurpone trimethyl ether (**4s**) and islandicin trimethyl ether (**4t**), which were separated from each other by flash column chromatography (entry 5). Since these trimethyl ethers have been previously demethylated by using boron tribromide[15,16] to digitopurpone and islandicin, respectively, the reaction of **1b** and **2g** with LDA constitutes a formal synthesis of these natural products, which are valuable intermediates in the synthesis of anthracyclines.[17]

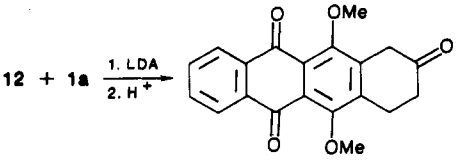


Polysubstituted derivatives of **1** are versatile annulating agents for the synthesis of other naturally occurring anthraquinones. For example, the reaction of lithiated 3-cyano-7-methoxy-5-methyl-1(3*H*)-isobenzofuranone (**1d**) with bromobenzene (**2o**), 3-bromoanisole (**2a′**), and 2-bromo-1,4-dimethoxybenzene (**2b**) with LDA (entries 8, 9, and 10, respectively) gave pachybasin methyl ether (**4h**) (30%), chrysophanol dimethyl ether (**4u**) (34%), and the trimethyl ether of natural product helminthosporin[18] (**4w**) (53%). As expected, the reaction of 3,6-dimethoxy-4-methylbenzyne (**3g**) with lithiated 3-cyano-4,6-dimethoxy-1(3*H*)-isobenzofuranone (**1e**) (entry 11) gave a mixture of the tetramethyl ether of catenarin[19] (**4y**) and 1,4,7,9-tetramethoxy-2-methylanthra-5,10-quinone (**4x**). However, **4y** was readily isolated by chromatography in 30% yield. The anthraquinone **4y** has been converted previously to erythroglaucin by the selective demethylation of the peri position methoxy groups using BBr_3.[20]

Scheme III



Preparation of Tetracyclic Intermediate 10 for 4-Demethoxydaunomycinone Synthesis. In light of the ease of anthraquinone formation via the aryne reaction discussed herein, we decided to extend this method to the preparation of the tetracyclic intermediate **10**, which is a valuable precursor used[21] in the synthesis of 4-demethoxydaunomycinone, an aglycon of the widely used antineoplastic drug 4-demethoxydaunomycin. The straightforward synthesis of the requisite aryne **12** is outlined in Scheme III. With the aryne precursor **12** on hand, it was treated with LDA and **1a** to yield **10** in an overall yield of 37%, after removal of the protecting group by aqueous acid.



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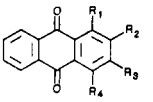
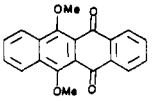
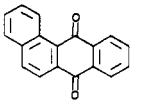
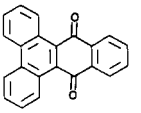
In conclusion, the reaction of cyanophthalides and haloarenes with LDA in THF provides a convenient way of preparing a wide range of anthraquinones and anthracyclinones. Even in those reactions in which mixtures of anthraquinones are obtained, each isomer may be readily separated by flash column chromatography.

Experimental Section

General Comments. Melting points were determined on an electrothermal apparatus and are uncorrected. Infrared spectra were recorded on a Perkin-Elmer 283 grating spectrometer. High field (200-MHz) proton and carbon-13 spectra were taken on an IBM-Bruker WP200-SY spectrometer. NMR spectra were run in $CDCl_3$ solution and chemical shifts were related to Me_4Si. Gas

(15) Kende, A. S.; Belletire, J. L.; Hermamann, J. L.; Romanet, R. F.; Hume, E. L.; Schlessinger, R. H.; Fayos, J.; Clardy, J. C. *Synth. Commun.* **1973**, *3*, 387.
(16) Kende, A. S.; Belletire, J. L.; Hume, E. L. *Tetrahedron Lett.* **1973**, 2935.
(17) (a) Suzuki, F.; Trenbeath, S.; Gleim, R. D.; Sih, C. J. *J. Org. Chem.* **1978**, *43*, 4159. (b) Braun, M. *Angew. Chem., Int. Ed. Engl.* **1978**, *17*, 945. (c) Kim, K. S.; Vanotti, E.; Suarato, A.; Johnson, F. *J. Am. Chem. Soc.* **1979**, *101*, 2483. (d) Gleim, R. D.; Trenbeath, S.; Suzuki, F.; Sih, C. J. *J. Chem. Soc., Chem. Commun.* **1978**, 242.
(18) Chandrasenan, K.; Neelakantan, S.; Seshadri, T. R. *J. Indian Chem. Soc.* **1961**, *38*, 907.
(19) (a) Chandrasenan, K.; Neelkantan, S.; Seshadri, T. R. *Proc. Indian Acad. Sci., Sect. A* **1960**, *51*, 296. (b) Shibata, S.; Natori, S. *Chem. Pharm. Bull.* **1953**, *1*, 160.
(20) deSilva, S. O.; Watanabe, M.; Snickus, V. *J. Org. Chem.* **1979**, *26*, 4802.
(21) (a) Gupta, D. N.; Hodge, P.; Khan, N. *J. Chem. Soc., Perkins Trans. 1*, **1981**, 689. (b) Kende, A. S.; Curran, D. P.; Tsay, Y.; Mills, J. E. *Tetrahedron Lett.* **1977**, 3537.

Table I. Reaction of Haloarenes 2 with Lithiated 3-Cyanophthalide (1a)

entry	haloarene	product	yield, %
			
1	**2a**, 2-bromoanisole	**4a**, R_1 = OMe; R_2 = R_3 = R_4 = H	35
2	**2a'**, 3-bromoanisole		40
3	**2b**, 2-bromo-1,4-dimethoxybenzene	**4b**, R_1 = R_4 = OMe; R_2 = R_3 = H	75
4	**2c**, 2-bromoveratrole	**4c**, R_1 = R_2 = OMe; R_3 = R_4 = H	40
5	**2d**, 2-bromo-4-(methoxymethyl)anisole	**4d**, R_1 = OMe; R_2 = R_3 = H; R_4 = CH_2OMe	46
6	**2e**, 2-bromo-1,5-dimethoxybenzene	**4e**, R_1 = R_3 = OMe; R_2 = R_4 = H	41
7	**2f**, 4-bromo-1,2,3-trimethoxybenzene	**4f**, R_1 = R_2 = R_3 = OMe; R_4 = H	32
8	**2g**, 2-bromo-5-methyl-1,4-dimethoxybenzene	**4g**, R_1 = R_4 = OMe; R_2 = CH_3; R_3 = H	68
9	**2h**, 2-chloro-5-methylanisole	**4h**, R_1 = OMe; R_3 = Me, R_2 = R_4 = H	40
10	**2i**, dimethylacetal of 2-chlorobenzaldehyde	**4i**, R_1 = CHO; R_2 = R_3 = R_4 = H	60
11	**2j**, dimethyl acetal of 6-bromoveratraldehyde	**4j**, R_1 = CHO; R_2 = H; R_3 = R_4 = OMe	63
12	**2k**, dimethyl acetal of 6-bromopiperonal	**4k**, R_1 = CHO; R_2 = H; R_3,R_4 = OCH_2O	43
13	**2l**, 2-bromo-1,4-dimethoxynaphthalene	 **4l**	47
14	**2m**, 1-bromonaphthalene	 **4m**	50
15	**2n**, 9-bromophenanthrene	 **4n**	70

chromatographic analysis and mass spectra (70 eV) were obtained on a Hewlet-Packard Model 5988A spectrometer using 0.2 mm 12 m capillary column containing cross-linked methyl silicone of 0.33-μm film thickness. Data reported are the m/z values for the most abundant peaks. E. Merck silica gel 9385 (230–400 mesh) was used for flash column chromatography. Tetrahydrofuran (THF) and diisopropylamine were obtained from Aldrich Chemical Co. and dried and distilled prior to use. Haloarenes and benzamides were either obtained from Aldrich Chemical Co. or prepared by standard procedures and distilled or recrystallized. *n*-Butyllithium (*n*-BuLi) and *sec*-butyllithium (*sec*-BuLi) were obtained from Aldrich Chemical Co. All reactions were carried out in a flame-dried flasks under nitrogen atmosphere and aliquots were taken. Since the reactions are all similar in many respects, typical reactions are described as specific examples.

Preparation of Substituted 3-Hydroxyphthalides 6b–e and Cyanophthalides 1a–e. Hydroxyphthalides **6b–e** and cyanophthalides **1a–e** were prepared by following standard literature[6a] procedures.

3-Hydroxy-7-methoxy-1(3*H*)-isobenzofuranone (6b): mp 151–153 °C (lit.[6a] mp 151–153 °C).

3-Hydroxy-4-methoxy-1(3*H*)-isobenzofuranone (6c): white crystals (from water); mp 154–155 °C (lit.[6a] mp 155–156 °C).

3-Hydroxy-7-methoxy-5-methyl-1(3*H*)-isobenzofuranone (6d): white crystals (from H_2O) (yield 39%); mp 165 °C; ^{1}H NMR ($CDCl_3$) δ 2.47 (s, 3 H), 3.96 (s, 3 H), 6.5 (s, 1 H), 6.79 (br s, 2 H), 6.98 (s, 1 H); IR ($CHCl_3$) 1730, 1680 cm^{-1}; MS, m/z 194 ($M^{+\cdot}$). Anal. Calcd for $C_{10}H_{10}O_4$: C, 61.83; H, 5.19. Found: C, 61.52; H, 5.22.

3-Hydroxy-4,6-dimethoxy-1(3*H*)-isobenzofuranone (6e): white solid recrystallized from H_2O (yield 40%); mp 165 °C; ^{1}H NMR ($CDCl_3$) δ 3.86 (s, 6 H), 6.62 (s, 1 H), 6.71 (s, 2 H), 6.91 (s, 1 H); IR ($CHCl_3$) 1730, 1680 cm^{-1}; MS, m/z 210 ($M^{+\cdot}$). Anal. Calcd for $C_{10}H_{10}O_5$: C, 57.13; H, 4.48. Found: C, 57.47; H, 4.46.

3-Cyano-1(3*H*)-isobenzofuranone (1a): light yellow crystals (from EtOAc); mp 65–66 °C (lit.[6a] mp 65–67 °C).

3-Cyano-7-methoxy-1(3*H*)-isobenzofuranone (1b): white crystals; mp 151–153 °C (lit.[6a] mp 154–156 °C).

3-Cyano-4-methoxy-1(3*H*)-isobenzofuranone (1c): white crystals; mp 161–163 °C (lit.[6a] mp 162–163 °C).

3-Cyano-7-methoxy-5-methyl-1(3*H*)-isobenzofuranone (1d): white crystals (from EtOAc) (yield 71%); mp 187 °C; ^{1}H NMR ($CDCl_3$) δ 2.54 (s, 3 H), 4.02 (s, 3 H), 5.95 (s, 1 H), 6.88 (s, 1 H), 7.03 (s, 1 H); IR ($CHCl_3$) 1730, 1680 cm^{-1}; MS, m/z 203 ($M^{+\cdot}$). Anal. Calcd for $C_{11}H_{19}O_3N$: C, 65.00; H, 4.46; N, 6.9. Found: C, 65.30; H, 4.52; N, 6.8.

3-Cyano-4,6-dimethoxy-1(3*H*)-isobenzofuranone (1e): white solid recrystallized from EtOAc (yield 90%); mp 189 °C; ^{1}H NMR ($CDCl_3$) δ 3.96 (s, 3 H), 3.98 (s, 3 H), 5.95 (s, 1 H), 6.8 (s, 1 H), 6.98 (s, 1 H); IR ($CHCl_3$) 1730, 1680, 1600 cm^{-1}; MS, m/z 219 ($M^{+\cdot}$). Anal. Calcd for $C_{11}H_9O_4N$: C, 60.26; H, 4.14; N, 6.39. Found: C, 59.89; H, 4.22; N, 6.36.

General Procedure for the Reaction of Haloarenes 2a–n with Cyanophthalides 1a–e. In a flame-dried flask flushed with nitrogen, LDA (15 mmol) was prepared by adding diisopropylamine (18 mmol) into a −78 °C solution of *n*-BuLi (15 mmol, 2.5 M in hexane) in THF (25 mL) under a nitrogen atmosphere (using septum cap technique). After solution was stirred for 10 min at −78 °C, the appropriate cyanophthalide (5 mmol) in THF (25 mL) was added dropwise over 20 min. The reaction mixture was stirred at −78 °C for 10 min and then allowed to warm to −40 °C. A solution of haloarene (5 mmol) in THF (25 mL) was added dropwise over 20 min at −40 °C. The reaction mixture was stirred further and allowed to warm to room temperature slowly over a period of 2 h. The dark reddish brown solution was then quenched with saturated aqueous ammonium chloride solution, THF was evaporated under reduced pressure, and the residue was extracted with methylene chloride (3 × 50 mL). The combined extracts were washed with brine, dried (Na_2SO_4), and concentrated (rotary evaporator) to provide crude products that consisted of anthraquinone products and varying amounts of dehalogenated products of **2a–n**. Purification of the products was accomplished by flash column chromatography using a mixture of hexane/EtOAc [9:1 or 4:1, depending on the polarity of the anthraquinone product] as eluant. The yields are given in Tables I and II. The anthraquinone products obtained in the reaction of **1a** with dimethyl acetals of halobenzaldehyde (entries 10–12) were subsequently converted to 1-formylanthraquinones **4i–j** by treating them with few drops of concentrated HCl in THF solution.

1-Methoxyanthra-5,10-quinone (4a): yellow crystals (from benzene); mp 168–169 °C (lit.[22] mp 169.5 °C); ^{1}H NMR ($CDCl_3$) δ 4.06 (s, 3 H), 7.33–7.37 (d, 1 H, J = 8.5 Hz), 7.65–7.80 (m, 3 H), 7.2–7.25 (m, 1 H), 8.21–8.29 (m, 2 H); ^{13}C NMR ($CDCl_3$) δ 56.5, 117.96, 119.76, 121.56, 126.51, 127.19, 132.48, 133.16, 134.17, 134.94, 135.03, 135.23, 160.38, 182.42, 183.36; IR ($CHCl_3$) 1670, 1585, cm^{-1}; MS, m/z 238 ($M^{+\cdot}$).

1,4-Dimethoxyanthra-5,10-quinone (4b): yellow needles (from benzene); mp 165–166 °C (lit.[23] mp 170–171 °C); ^{1}H NMR ($CDCl_3$) δ 3.99 (s, 3 H), 7.33 (s, 2 H), 7.71 (dd, 2 H, J = 8 and 2.5 Hz), 8.16 (dd, 2 H, J = 8 and 2.5 Hz); ^{13}C NMR ($CDCl_3$) δ 56.93, 120.24, 122.99, 126.30, 133.17, 134.15, 154.08, 183.24; IR ($CHCl_3$) 1670, 1600 cm^{-1}; MS, m/z 268 ($M^{+\cdot}$).

1,2-Dimethoxyanthra-5,10-quinone (4c): yellow needles (from benzene); mp 212–214 °C (lit.[24] mp 215 °C); ^{1}H NMR ($CDCl_3$) δ 4.01 (s, 6 H), 7.26–8.3 (m, 6 H); IR ($CHCl_3$) 1670 cm^{-1}; MS, m/z 268 ($M^{+\cdot}$).

1-Methoxy-4-(methoxymethyl)anthra-5,10-quinone (4d): yellow needles (from benzene); mp 166–168 °C; ^{1}H NMR ($CDCl_3$) δ 3.56 (s, 3 H), 4.05 (s, 3 H), 5.0 (s, 2 H), 7.38 (d, 1 H, J = 9 Hz), 7.7–7.78 (m, 2 H), 8.09 (d, 1 H, J = 9 Hz), 8.16–8.23 (m, 2 H); ^{13}C NMR ($CDCl_3$) δ 56.56, 58.81, 73.00, 118.00, 121.00, 126.33, 126.68, 132.52, 133.15, 133.76, 134.45, 134.75, 159.38, 184.19, 185.67; IR ($CHCl_3$) 1670, 1600, 1380, 1265 cm^{-1}; MS, m/z 282 ($M^{+\cdot}$). Anal. Calcd for $C_{17}H_{14}O_4$: C, 72.32, H, 4.96. Found: C, 71.96; H, 4.92.

1,3-Dimethoxyanthra-5,10-quinone (4e): light yellow solid (from EtOH); mp 158–160 °C; ^{1}H NMR ($CDCl_3$) δ 3.97 (s, 3 H), 4.00 (s, 3 H), 6.77 (d, 1 H, J = 1 Hz), 7.435 (d, 1 H, J = 2 Hz), 7.73 (m, 2 H), 8.22 (m, 2 H), ^{13}C NMR ($CDCl_3$) δ 55.87, 56.47, 103.32, 104.68, 116.05, 126.42, 127.14, 132.73, 133.33, 134.22, 135.09, 137.46, 162.56, 164.68, 181.11, 183.36; IR ($CHCl_3$) 1670, 1600 cm^{-1}; MS, m/z 268 ($M^{+\cdot}$).

1,2,3-Trimethoxyanthra-5,10-quinone (4f): greenish yellow needles (from EtOH); mp 166–168 °C (lit.[25] mp 167–169 °C); ^{1}H NMR ($CDCl_3$) δ 4.01 (s, 6 H), 4.05 (s, 3 H), 7.69–7.74 (m, 3 H), 8.23 (m, 2 H); IR ($CHCl_3$) 1670, 1600 cm^{-1}.

1,4-Dimethoxy-2-methylanthra-5,10-quinone (4g): yellow needles (from benzene); mp 131–132 °C; ^{1}H NMR ($CDCl_3$) δ 2.44 (s, 3 H), 3.9 (s, 3 H), 4.01 (s, 3 H), 7.2 (s, 1 H), 7.71 (m, 2 H), 8.16 (m, 2 H); IR ($CHCl_3$) 1670, 1600, 1335 cm^{-1}; MS, m/z 282 ($M^{+\cdot}$). Anal. Calcd for $C_{17}H_{14}O_4$: C, 72.32; H, 4.96. Found: C, 72.67; H, 4.93.

1-Methoxy-3-methylanthra-5,10-quinone (pachybasin methyl ether) (4h): yellow solid (from EtOH); mp 186–188 °C (lit.[26] mp 189 °C; ^{1}H NMR ($CDCl_3$) δ 2.52 (s, 3 H), 4.05 (s, 3 H), 7.15 (s, 1 H), 7.78 (m, 3 H), 8.26 (m, 2 H); IR ($CHCl_3$) 1665, 1600, 1330, 1270 cm^{-1}; MS, m/z 252 ($M^{+\cdot}$).

1-Formylanthra-5,10-quinone (4i): light yellow needles (from EtOH); mp 163–165 °C; ^{1}H NMR ($CDCl_3$) δ 7.8–7.95 (m, 3 H), 8.1 (dd, 1 H, J = 6.4 and 1 Hz), 8.31 (m, 2 H), 8.54 (dd, 1 H, J = 6.6 and 1.1 Hz), 10.8 (s, 1 H); IR ($CHCl_3$) 1695, 1665 cm^{-1}; MS, m/z 236 ($M^{+\cdot}$). Anal. Calcd for $C_{15}H_8O_3$: C, 76.25; H, 3.41. Found: C, 76.7; H, 3.46.

1-Formyl-3,4-dimethoxyanthra-5,10-quinone (4j): light yellow crystals (from EtOH); mp 198–200 °C; ^{1}H NMR ($CDCl_3$) δ 4.06 (s, 3 H), 4.07 (s, 3 H), 7.57 (s, 1 H), 7.79 (m, 2 H), 8.23 (m, 2 H), 10.63 (s, 1 H); IR ($CHCl_3$) 1740, 1685 cm^{-1}; MS, m/z 296 ($M^{+\cdot}$). Anal. Calcd for $C_{17}H_{12}O_5$: C, 68.9; H, 4.08. Found: C, 68.46; H, 4.14.

1-Formyl-3,4-(methylenedioxy)anthra-5,10-quinone (4k): greenish yellow needles (from EtOH); mp 245–247 °C; ^{1}H NMR ($CDCl_3$) δ 6.41 (s, 2 H), 7.51 (s, 1 H), 7.82–7.87 (m, 2 H), 8.27–8.29 (m, 2 H) 10.64 (s, 1 H); IR ($CHCl_3$) 1730, 1675 cm^{-1}; MS, m/z 280 ($M^{+\cdot}$). Anal. Calcd for $C_{16}H_{10}O_5$: C, 68.56; H, 2.88. Found: C, 68.1; H, 2.91.

6,11-Dimethoxynaphthacene-5,12-dione (4l): yellow crystals (from benzene); mp 182–184 °C (lit.[27] mp 183–184 °C); ^{1}H NMR ($CDCl_3$) δ 4.15 (s, 6 H), 7.76 (m, 4 H), 8.28 (m, 2 H), 8.43 (m, 2 H); ^{13}C NMR ($CDCl_3$) δ 63.14, 120.78, 124.77, 126.72, 129.90, 132.75, 133.51, 134.90, 155.80, 182.75; IR ($CHCl_3$) 1670, 1600 cm^{-1}; MS, m/z 318 ($M^{+\cdot}$). Anal. Calcd for $C_{20}H_{14}O_4$: C, 75.45; H, 4.43. Found: C, 74.96; H, 4.47.

Benz[*a*]anthracene-7,12-dione (4m): greenish yellow crystals (from benzene); mp 168–170 °C (lit.[28] mp 168 °C).

Dibenz[*a*,*c*]anthracene-9,14-dione (4n): yellow solid, crystallized from benzene; mp 164–165 °C; ^{1}H NMR ($CDCl_3$) δ 7.76–7.78 (m, 6 H), 8.24 (m, 2 H), 8.74 (m, 2 H), 9.22 (m, 2 H); IR ($CHCl_3$) 1665, 1600 cm^{-1}; MS, m/z 308 ($M^{+\cdot}$). Anal. Calcd for $C_{22}H_{12}O_2$: C, 85.7, H, 3.92. Found: C, 85.22; H, 3.96.

1,9-Dimethoxyanthra-5,10-quinone (4o): yellow solid, crystallized from benzene; mp 217–218 °C (lit.[29] mp 219 °C); ^{1}H NMR ($CDCl_3$) δ 4.05 (s, 6 H), 7.2–8.1 (m, 6 H); IR 1665 cm^{-1}; MS, m/z 268 ($M^{+\cdot}$).

1,4,6-Trimethoxyanthra-5,10-quinone (4p): yellow crystals (from EtOH); mp 198–200 °C (lit.[3] mp 204–205 °C); ^{1}H NMR ($CDCl_3$) δ 3.97 (s, 6 H), 3.99 (s, 3 H), 7.19–7.31 (m, 3 H), 7.5–7.7 (m, 2 H); IR ($CHCl_3$ 1670, 1600 cm^{-1}; MS, m/z 298 ($M^{+\cdot}$).

1,9-Dimethoxy-4-methylanthra-5,10-quinone (4q): yellow needles (from EtOH); mp 184–188 °C; ^{1}H NMR ($CDCl_3$) δ 2.7 (s, 3 H), 4.01 (s, 3 H), 4.02 (s, 3 H), 7.15 (d, 1 H, J = 8.3 Hz), 7.24 (d, 1 H, J = 8.3 Hz), 7.47 (d, 1 H, J = 8 Hz), 7.63 (m, 1 H), 7.78 (dd, 1 H, J = 8 and 1.1 Hz); IR ($CHCl_3$) 1670, 1600 cm^{-1}; MS, m/z 282 ($M^{+\cdot}$).

1,9-Dimethoxy-4-(methoxymethyl)anthra-5,10-quinone (4r): yellow solid, crystallized from EtOH; Mp 163–165 °C; ^{1}H NMR ($CDCl_3$) δ 3.55 (s, 3 H), 4.01 (s, 6 H), 4.95 (s, 2 H), 7.26 (dd, 1 H, J = 9 and 1 Hz), 7.33 (d, 1 H, J = 9 Hz), 7.64 (m, 1 H), 7.72 (dd, 1 H, J = 9 and 1 Hz), 7.96 (d, 1 H, J = 9 Hz); IR ($CHCl_3$) 1670, 1600 cm^{-1}; MS, m/z 312 ($M^{+\cdot}$). Anal. Calcd for $C_{18}H_{16}O_5$: C, 69.21; H, 5.17. Found: C, 68.88; H, 5.23.

1,4,9-Trimethoxy-2-methylanthra-5,10-quinone (Digitopurpone trimethyl ether) (4s) and 1,4,6-Trimethoxy-2-methylanthra-5,10-quinone (Islandicin trimethyl ether) (4t). The reaction of 2-bromo-5-methyl-1,4-dimethoxybenzene (**2g**) with 3-cyano-7-methoxyphthalide (**1b**) under the conditions as described above upon workup afforded a mixture of digitopurpone trimethyl ether (**4s**) and islandicin trimethyl ether (**4t**). The mixture was chromatographed over silica gel with hexane/ethyl acetate (9:1) as eluant. The less polar compound obtained as a yellow solid (crystallized from EtOH) in 34% yield was identified as islandicin trimethyl ether (**4t**) on the basis of its melting point, 161 °C (lit.[20] mp 161 °C), and spectral data: ^{1}H NMR ($CDCl_3$) δ 2.39 (s, 3 H), 3.88 (s, 3 H), 3.95 (s, 3 H), 3.98 (s, 3 H), 7.12 (s, 1 H, C-3 H) 7.25 (m, 1 H, C-8 H), 7.7 (dd, 1 H, J = 8 and 1 Hz, C-7 H), 7.7 (dd, 1 H, J = 8 and 1 Hz, C-9 H); reported[20] ^{1}H NMR ($CDCl_3$) δ 2.40 (s, 3 H), 3.84 (s, 3 H), 3.97 (s, 3 H), 4.00 (s, 3 H), 7.0–7.72 (m, 4 H); IR ($CHCl_3$) 1670, 1600 cm^{-1}; MS, m/z 312 ($M^{+\cdot}$).

The more polar compound obtained as yellow solid (from EtOH) in 29% yield was characterized as digitopurpone trimethyl ether (**4s**) on the basis of its melting point, 168–169 °C (lit.[20] mp 166–167 °C), and spectral data: ^{1}H NMR ($CDCl_3$) δ 2.39 (s, 3 H), 3.91 (s, 3 H), 3.96 (s, 3 H), 3.97 (s, 3 H), 7.06 (s, 1 H, C-3 H), 7.18 (m, 1 H, C-8 H), 7.58 (m, 1 H, C-7 H), 7.72 (dd, 1 H, J = 8 and 1 Hz C-6 H); reported[20] ^{1}H NMR ($CDCl_3$) δ 2.48 (s, 3 H), 3.96 (s, 3 H), 4.0 (s, 6 H), 7.08–7.88 (m, 4 H); IR ($CHCl_3$) 1670, 1600 cm^{-1}; MS, m/z 312 ($M^{+\cdot}$).

1,9-Dimethoxy-3-methylanthra-5,10-quinone (chrysophanol dimethyl ether) (4u): yellow solid (from benzene); mp 181–185 °C; ^{1}H NMR ($CDCl_3$) δ 2.47 (s, 3 H), 3.99 (s, 3 H), 4.01 (s, 3 H), 7.10 (s, 1 H, C-2 H), 7.29 (dd, 1 H, J = 8.4 and 1 Hz, C-8 H), 7.64 (m, 2 H, C-4 and C-7 H) 7.82 (dd, 1 H, J = 7.7 and 1 Hz, C-6 H); IR ($CHCl_3$) 1670, 1600 cm^{-1}; MS, m/z 282 ($M^{+\cdot}$).

1,6-Dimethoxy-3-methylanthra-5,10-quinone (ziganein dimethyl ether) (4v): yellow crystals (from benzene); mp 207–208 °C; ^{1}H NMR ($CDCl_3$) δ 2.49 (s, 3 H), 4.02 (s, 3 H), 4.03 (s, 3 H), 7.47 (s, 1 H), 7.69 (s, 1 H), 7.95–8.2 (m, 3 H); IR ($CHCl_3$) 1670, 1600 cm^{-1}; MS, m/z 282 ($M^{+\cdot}$), 267 ($M - CH_3$).

1,4,9-Trimethoxy-7-methylanthra-5,10-quinone (helminthosporin trimethyl ether) (4w): yellow crystals (from EtOH); mp 205 °C; ^{1}H NMR ($CDCl_3$) δ 2.47 (s, 3 H), 3.97 (s, 3 H), 3.98

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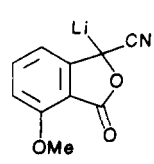
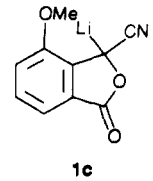
Table II. Reaction of Haloarenes with Substituted Lithio-3-cyanophthalides



1b



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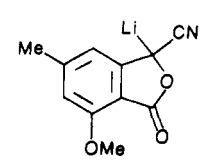
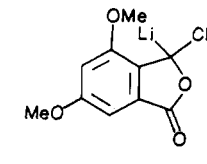
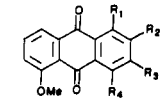
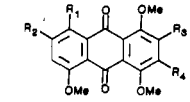


1d



1e

entry	haloarene	cyanophthalide	product	yield, %
				
1	2a′	1b	4o, $R_1 = R_2 = R_3 = H$; $R_4 = OMe$	45
2	2b	1b	4p, $R_1 = R_4 = OMe$; $R_2 = R_3 = H$	36
3	2c	1b	4q, $R_1 = Me$; $R_2 = R_3 = H$; $R_4 = OMe$	31
4	2d	1b	4r, $R_1 = CH_2OMe$; $R_2 = R_3 = H$; $R_4 = Me$	21
5	2g	1b	4s, $R_1 = R_4 = OMe$; $R_2 = H$; $R_3 = Me$	29
			4t, $R_1 = R_4 = OMe$; $R_2 = Me$; $R_3 = H$	34
6	2h	1b	4u, $R_1 = R_3 = H$; $R_2 = Me$; $R_4 = OMe$	30
7	2h	1c	4v, $R_1 = OMe$; $R_2 = R_4 = H$; $R_3 = Me$	39
8	2m	1d	4h	30
9	2a′	1d	4s	34
				
10	2b	1d	4w, $R_1 = R_3 = R_4 = H$; $R_2 = Me$	53
11	2g	1e	4x, $R_1 = R_3 = H$; $R_2 = OMe$; $R_4 = Me$	30
			4y, $R_1 = R_4 = H$; $R_2 = OMe$; $R_3 = Me$	30

(s, 3 H), 3.99 (s, 3 H), 7.15 (m, 1 H, C-8 H), 7.28 (s, 2 H, C-2 and C-3 H), 7.43 (m, 1 H, C-6 H); IR ($CHCl_3$) 1670, 1600 cm^{-1}; MS, m/z 312 ($M^{+\cdot}$).

1,4,6,8-Tetramethoxy-2-methylanthra-5,10-quinone (Catenarin tetramethyl ether) (4y) and 1,4,7,9-Tetramethoxy-2-methylanthra-5,10-quinone (4x). The reaction of haloarene **2g** with cyanophthalide **1e** under the aryne-forming conditions (as described in the general procedure) furnished a mixture of catenarin tetramethyl ether (**4y**) and 1,4,7,9-tetramethoxy-2-methylanthra-5,10-quinone. This mixture was separated by flash column chromatography over silica gel using hexane/EtOAc (9:1) as eluant. The more polar compound after crystallization from EtOH was obtained as a yellow solid in 30% yield and was identified as catenarien tetramethyl ether (1,4,6,8-tetramethoxy-2-methylanthra-5,10-quinone) (**4y**) on the basis of its melting point, 189 °C (lit.[20] mp 191 °C), and spectral data: ^1H NMR ($CDCl_3$) δ 2.42 (s, 3 H), 3.93 (s, 3 H), 3.94 (s, 3 H), 3.96 (s, 3 H), 3.98 (s, 3 H), 6.7 (d, J = 2 Hz, C-7 H), 7.07 (s, 1 H, C-4 H), 7.26 (d, J = 2 Hz, C-9 H); reported[20] ^1H NMR ($CDCl_3$) δ 2.33 (s, 3 H), 3.86 (s, 3 H), 3.93 (s, 9 H), 6.66 (d, 1 H, J = 2.4 Hz), 7.09 (s, 1 H), 7.20 (d, 1 H, J = 2.4 Hz); IR ($CHCl_3$) 1670, 1600 cm^{-1}; MS, m/z 342 ($M^{+\cdot}$). The less polar compound was obtained as a yellow solid in 30% yield was identified as 1,4,7,9-tetramethoxy-2-methylanthra-5,10-quinone (**4x**): yellow crystals (from EtOH); mp 183–185 °C; ^1H NMR ($CDCl_3$) δ 2.40 (s, 3 H), 3.89 (s, 3 H), 3.94 (s, 3 H), 3.96 (s, 3 H), 6.72 (m, 1 H), 7.14 (s, 1 H), 7.26 (d, 1 H, J = 1.2 Hz); IR ($CHCl_3$) 1670 cm^{-1}; MS, m/z 342 ($M^{+\cdot}$).

2-Chloro-6,6-(ethylenedioxy)-5,6,7,8-tetrahydro-1,4-naphthoquinone (11). Naphthoquinone **11** was prepared according to a reported procedure[30] and was purified by column chromatography over silica gel: while crystals (from hexane); mp 148–149 °C (lit.[30] mp 149–150 °C); ^1H NMR ($CDCl_3$) δ 1.27 (t, 2 H, J = 6.5 Hz), 2.67 (s, 2 H), 2.80 (m, 2 H), 4.02 (s, 4 H), 6.96 (s, 1 H).

2-Chloro-6,6-(ethylenedioxy)-1,4-dimethoxy-5,6,7,8-tetrahydronaphthalene (12). A solution of naphthoquinone **11** (254 mg, 1 mmol) and dimethyl sulfate (604 mg, 4 mmol) in dry acetone (100 mL) in the presence of anhydrous potassium carbonate (5 g) was heated at reflux for 15 h. The mixture was cooled and filtered and the filtrate evaporated (rotary evaporator) to give haloarene **12** as a viscous oil. A solution of this crude material in CH_2Cl_2 (50 mL) was washed with brine, dried (Na_2SO_4), and evaporated to dryness to afford a thick oil which upon purification by column chromatography over silica gel [hexane/EtOAc (19:1)] gave 185 mg of pure haloarene **12** (65% yield) as a colorless thick oil: ^1H NMR ($CDCl_3$) δ 1.27 (t, 2 H, J = 6 Hz), 2.82 (s, 2 H), 3.0 (t, 2 H, J = 6 Hz), 3.78 (s, 3 H), 3.79 (s, 3 H), 4.05 (s, 4 H), 6.7 (s, 1 H); MS m/z 284 ($M^{+\cdot}$).

6,11-Dimethoxy-7,8-dihydronaphthalene-5,9(10*H*),12-trione (10). Haloarene **12** (1 mmol) was treated with lithiophthalonitrile (**1a**) and LDA according to conditions described in the general procedure to furnish 145 mg of 9,9-(ethylenedioxy)-6,11-dimethoxy-7,8,9,10-tetrahydronaphthalene-5,12-dione after purification by column chromatography (silica gel). The pure product obtained was dissolved in THF (5 mL) and treated with few drops of concentrated HCl. The mixture was stirred at room temperature under a nitrogen atmosphere for 2 h. The usual workup provided a yellow solid which upon crystallization from EtOH afforded 125 mg (37% overall yield) of **10**: mp 175–180 °C; ^1H NMR ($CDCl_3$) δ 2.62 (t, 2 H, J = 7.2 Hz), 3.30 (t, 2 H, J = 7.2 Hz), 3.74 (s, 2 H), 3.92 (s, 3 H), 3.94 (s, 3 H), 7.76 (m, 2 H), 8.2 (m, 2 H); IR ($CHCl_3$) 1710, 1670 cm^{-1}; MS m/z 336 ($M^{+\cdot}$).

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Registry No. **1a**, 95384-95-5; **1b**, 111210-32-3; **1c**, 111210-33-4; **1d**, 111210-21-0; **1e**, 111210-22-1; **2a**, 578-57-4; **2a′**, 2398-37-0; **2b**, 25245-34-5; **2c**, 5424-43-1; **2d**, 111210-24-3; **2e**, 17715-69-4; **2f**, 10385-36-1; **2g**, 13321-74-9; **2h**, 73909-16-7; **2i**, 70380-66-4; **2j**, 70461-33-5; **2k**, 74879-22-4; **2l**, 64648-81-3; **2m**, 90-11-9; **2n**, 573-17-1; **4a**, 82-39-3; **4b**, 6119-74-0; **4c**, 6003-12-9; **4d**, 111210-25-4; **4e**, 1989-42-0; **4f**, 5953-90-2; **4g**, 52541-72-7; **4h**, 15512-59-1; **4i**, 91323-92-1; **4j**, 111210-26-5; **4k**, 111210-27-6; **4l**, 36831-93-3; **4m**, 2498-66-0; **4n**, 3228-74-8; **4o**, 6407-55-2; **4p**, 52541-76-1; **4q**, 111210-28-7; **4r**, 111210-29-8; **4s**, 51837-73-1; **4t**, 50457-06-2; **4u**, 71013-35-9; **4v**, 111210-30-1; **4w**, 98324-34-6; **4x**, 111210-31-2; **4y**, 72003-92-0; **5d**, 111210-20-9; **5e**, 38228-27-2; **6d**, 111210-19-6; **6e**, 99059-36-6; **10**, 111210-35-6; **11**, 83043-87-2; **12**, 111210-34-5; 9,9-(ethylenedioxy)-6,11-dimethoxy-7,8,9,10-tetrahydronaphthalene-5,12-dione, 111237-57-1.

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