Annulation of Ethyl [Bis(ethylthio)methyl]benzoate and Ethyl 2-[1,3]Dithiolan-2-yl-benzoate with α,β-Unsaturated Carbonyl Compounds: A New Synthesis of Naphthalene and Anthracene Derivatives[1)]

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Several kinds of fused cyclic compounds were obtained by tandem Michael–Claisen condensation of ethyl 2-[bis(ethylthio)methyl]benzoate and ethyl 2-[1,3]dithiolan-2-yl-benzoate with α,β-unsaturated carbonyl compounds. Treatment of the annulated products with mercury(II)perchlorate trihydrate or *N*-chlorosuccinimide gave naphthoquinones, naphthalenes, and anthracenes.

Key words [2C+4C] annulation; naphthalene; anthracene; tandem Michael–Claisen condensation; synthesis

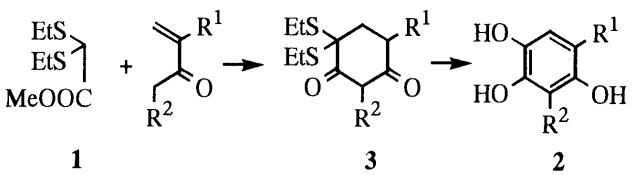
Many naturally occurring and biologically active compounds contain phenolic rings. In previous papers, we have reported effective preparations of a variety of basic phenolic compounds,[2)] such as benzene-1,2-diols, benzene-1,3-diols and benzene-1,2,4-triols, *via* annulations of aliphatic compounds and we have employed them in total syntheses of natural products such as pterocarpans and aporphine alkaloids.[3)] This paper deals with a new procedure for synthesis of condensed aromatic compounds such as naphthalenes and anthracenes by [2C+4C] annulation.

Methyl bis(ethylthio)acetate (**1**) is useful in the preparation of benzene-1,2,4-triols (**2**).[2b)] The anion of **1** is the initiator of the [2C+4C] annulation to give six-membered rings (**3**), which are converted to aromatic rings (**2**) by sequential hydrolysis and isomerization. Similar reactivity was expected with the vinylogous compound, ethyl 2-[bis(ethylthio)methyl]benzoate (**4**), which was prepared in good yield from 2-formylbenzoic acid (**5a**) *via* thioacetalization and esterification.

Although the anion of **1** was generated easily by sodium hydride (NaH) in tetrahydrofuran (THF) at 0 °C, that of **4** was not obtained in this way. It was formed by treatment of **4** with lithium diisopropylamide in THF at −78 °C. Reaction of the anion with methyl acrylate (**6**) in the presence of hexamethylphosphoramide (HMPA) gave 4,4-bis(ethylthio)-1-oxo-1,2,3,4-tetrahydronaphthalene-2-carboxylic acid methyl ester (**7**) in 95% yield, through both Michael reaction at the β-carbon and Claisen reaction at the α carbon of **6**.[4)] Several α,β-unsaturated carbonyl compounds such as methyl crotonate (**8**), butenolide (**9**), 2-cyclohexen-1-one (**10**), and 3-buten-2-one (**11**) were examined for reaction with **4**. The yields of condensed products (**7**, **12**—**14**) were good, as shown in Table 1. Although a similar annulated product, 2-acetyl-4,4-bis-(ethylthio)-3,4-dihydro-2*H*-naphthalen-1-one (**15a**) was expected to be obtained *via* the condensation of **4** with **11**, the reaction gave 2-acetyl-4-ethylthio-1-naphthalenol (**15b**) after purification. Inspection of the spectral data of the crude product showed the presence of compound **15a**. This result indicated that compound **15a** is labile under the ambient conditions, affording **15b** by oxidative elimination. The cyclic keto esters **7** and **12** were also easily converted to the naphthalenes **25** and **29**, respectively, on standing at room temperature. On the other hand, compounds **13** and **14** were stable, presumably because the existence of the third ring hinders the reaction of sulfur with atmospheric oxygen.

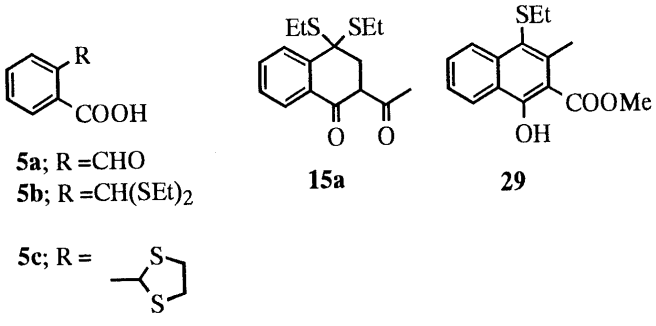
The thioacetal analog, ethyl 2-[1,3]dithiolan-2-yl-benzoate (**16**), could be obtained similarly from **5a**. Condensation of the ester **16** with α,β-unsaturated carbonyl compounds (**6**, **8**—**11**) was carried out to compare the reactivity of **4** and **16**.[5)] The products (**17**—**21**) are shown in Table 1. The yields of the condensed products from compound **4** were higher than those from **16**.

As compared with the cyclic thioacetal structure of compound **16**, the two ethylthio groups in compound **4** have greater flexibility. The structural latitude of **4** is advantageous for the annulation reaction. Instability of the condensed products such as **7**, **12**, and **15a** was attributed to the same flexibility of the substituents on the ring. In contrast, the fixed cyclic thioacetal compounds (**17**, **18**, **21**) corresponding to the bis(ethylthio)acetals (**7**, **12**, **15a**) were stable in contact with the atmosphere at



1 **3** **2**

Chart 1



5a; R =CHO
5b; R =$CH(SEt)_2$
5c; R =

15a **29**

Chart 2

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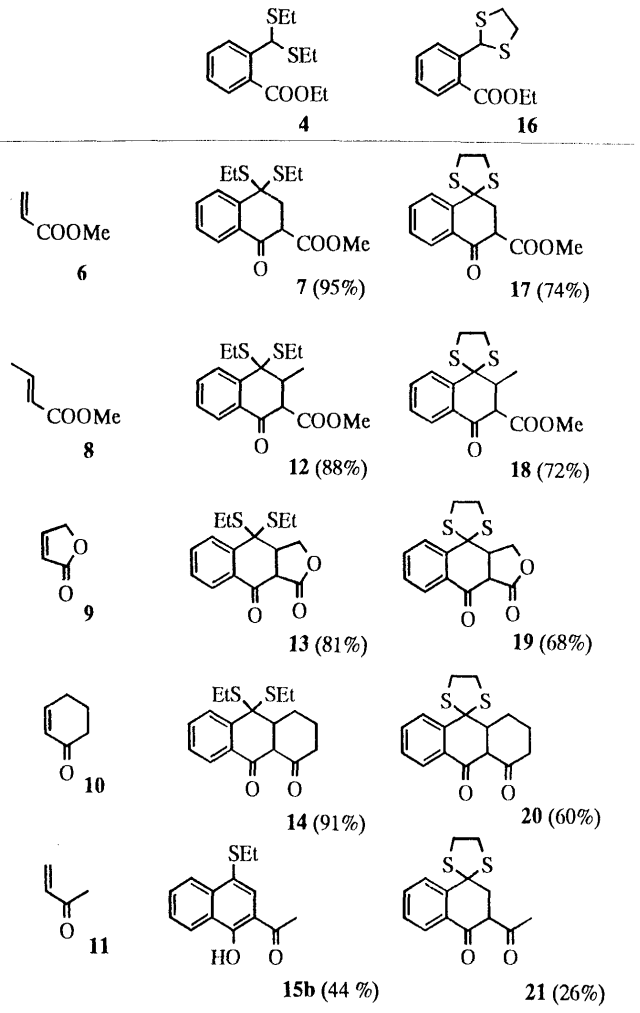
Table 1. Tandem Michael–Claisen Reaction of the Benzoates **4** and **16**



room temperature.

In preceding investigations, we have established the conversion of six-membered rings with ethylthio groups to aromatic rings by sequential hydrolysis and isomerization.[2b,c,3] Similar transformation was applied to the annulated products (**7**, **12**—**14**, **17**—**20**) to obtain naphthalene and anthracene derivatives. *N*-Chlorosuccinimide (NCS)/acetone–H_2O[6] and mercury(II)perchlorate trihydrate (MPC)/methanol–THF[7] were used for hydrolysis of the thioacetals, as shown in Table 2.

Depending upon the combination of the thioacetals and the reagents, the reactions gave several kinds of aromatic compounds bearing two hydroxyl groups (**22**, **23**), quinone carbonyl groups (**24**), a thio group (**25**—**28**), a chloro group (**30**—**33**), and a methoxyl group (**34**). Hydrolysis of **7** and **20** gave **22** and **23**, respectively. The quinone **24** was the oxidative product of 2-methyl-1,4-naphthalenediol genecrated from the thioacetals (**12**, **18**). Compounds having a thio group (**25**, **26**, **27**, **28**) were formed by incomplete hydrolysis of the acetals (**7**, **13**, **14**, **17**, respectively). The chlorine atom on **30**—**32** was derived from NCS. The methoxyl group on **34** came from methyl alcohol used as the solvent.[2c] In methanolysis of the lactones (**13**, **19**), an intermediate such as 4,4-dimethoxy-3,3a,4,9a-tetrahydronaphtho[2,3-*c*]furan-1,9-dione might suffer elimination to give compound **34**. The yields of aromatic compounds from the bis(thioethyl) derivatives (**7**, **12**—**14**) with NCS or MPC were higher than those from the [1,3]dithiolan derivatives (**17**—**20**). The reactions of the open chain thioacetals (**7**, **12**—**14**) and MPC gave especially good yields.

In conclusion, ethyl 2-[bis(ethylthio)methyl]benzoate (**4**) and ethyl 2-[1,3]dithiolan-2-yl-benzoate (**16**) were subjected to the tandem Michael–Claisen reaction. The reaction with several kinds of α,β-unsaturated carbonyl compounds (**6**, **8**—**11**) gave polycyclic compounds (**7**, **12**—**14**, **15b**, **17**—**21**). Treatment of some of the condensed thioacetal derivatives with MPC or NCS gave naphthoquinone (**24**), naphthalenes (**22**, **25**, **26**, **28**, **31**—**34**), and anthracenes (**23**, **27**, **30**). The preparation of these aromatic compounds *via* annulation reactions demonstrates the utility of compounds **4** and **16** in syntheses of multifunctional condensed aromatic compounds.

Experimental

IR spectra were recorded on a Hitachi 270-30 infrared spectrometer. ^{1}H-NMR spectra were recorded with a JEOL JNM-PMX 60si spectrometer (60 MHz) or a JNM-GX270 FT spectrometer (270 MHz) using tetramethylsilane as an internal standard. Melting points were measured on a Yanaco model MP micro melting point apparatus and are uncorrected. High-resolution mass spectra (HRMS) were obtained on a JEOL JMS-DX300 mass spectrometer. All organic extracts were dried over anhydrous $MgSO_4$. Column chromatography was performed with Kieselgel 60 (70—230 mesh).

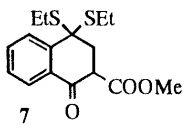
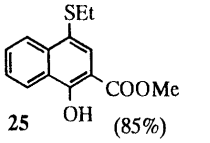
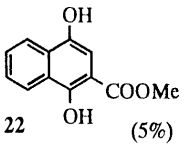
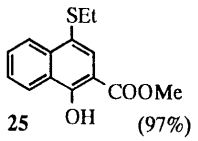
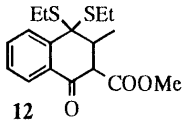
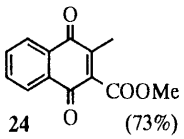
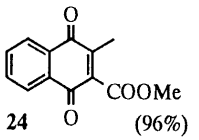
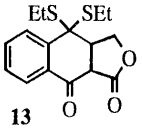
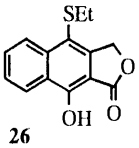
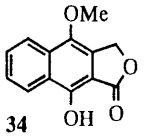
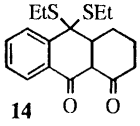
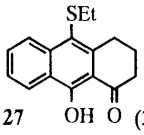
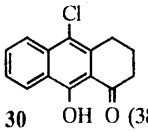
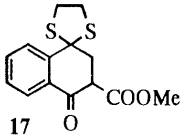
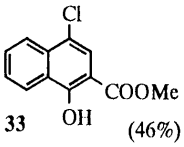
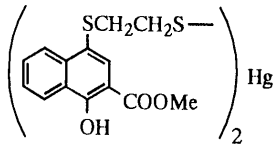
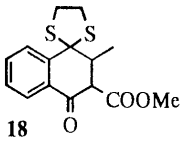
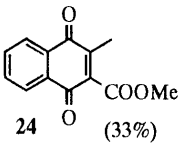
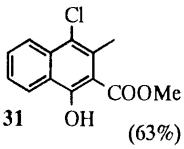
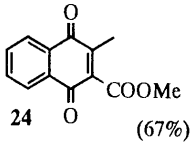
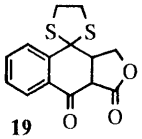
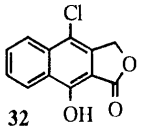
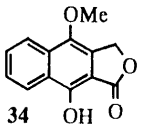
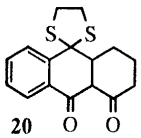
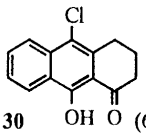
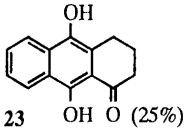
Ethyl [2-Bis(ethylthio)methyl]benzoate (4) A mixture of compound **5b** (16.5 g), anhydrous EtOH (200 ml), and H_2SO_4 (0.5 ml) was refluxed for 15 h. After evaporation of EtOH, water was added to the residue, and the product was extracted with AcOEt. The organic extract was washed with saturated aqueous $NaHCO_3$ and brine, dried, and then evaporated. The residue was subjected to column chromatography on silica gel with AcOEt–hexane (1 : 9, v/v) to give the title compound (**4**) as a colorless oil (15.0 g, 82%). IR (neat): 1720 cm^{-1}. ^{1}H-NMR (60 MHz, $CDCl_3$) δ: 1.13—1.52 (9H, m, $CO_2CH_2C\underline{H}_3$, $SCH_2C\underline{H}_3\times2$), 2.62 (4H, q, J=7 Hz, $SC\underline{H}_2CH_3\times2$), 4.38 (2H, q, J=7 Hz, $CO_2C\underline{H}_2CH_3$), 6.28 [1H, s, $C\underline{H}(SCH_2CH_3)_2$], 7.08—7.98 (4H, m, aromatic protons). *Anal.* Calcd for $C_{14}H_{20}O_2S_2$: C,59.12; H, 7.09. Found: C, 59.37; H, 7.04.

2-[Bis(ethylthio)methyl]benzoic Acid (5b) A mixture of 2-formylbenzoic acid (10.0 g) and *p*-toluenesulfonic acid (1.1 g) in ethanethiol (40 ml) was refluxed with stirring for 8 h. Excess ethanethiol was evaporated off under reduced pressure, then water was added to the residue and the product was extracted with AcOEt. The organic extract was washed with brine, dried, and evaporated *in vacuo*. The residue was crystallized from hexane to give **5b** (15.9 g, 94%) as colorless needles, mp 98.0—99.0 °C. IR (Nujol): 1684 cm^{-1}. ^{1}H-NMR (60 MHz, $CDCl_3$) δ: 1.30 [6H, t, J=7 Hz, $CH(SCH_2C\underline{H}_3)_2$], 2.67 [4H, q, J=7 Hz, $CH(SC\underline{H}_2CH_3)_2$], 6.40 [1H, s, $C\underline{H}(SCH_2CH_3)_2$], 7.15—8.13 (4H, m, aromatic protons). HRMS Calcd for $C_{12}H_{16}O_2S_2$ (256.0591). Found: *m/z* 256.0582 (M^+).

2-[1,3]Dithiolan-2-yl-benzoic Acid (5c) Titanium(IV) chloride (25.3 g) was added to a mixture of 2-formylbenzoic acid (20.0 g) and 1,2-ethanedithiol (18.9 g) in CH_2Cl_2 (200 ml) at 0 °C. The mixture was stirred at room temperature for 12 h, then poured into water. The organic layer was washed with water and brine, dried, and concentrated *in vacuo*. The residue was crystallized from benzene to give the title compound (**5c**) (28.3 g, 94%) as colorless needles, mp 161—162 °C. IR (Nujol): 1680 cm^{-1}. ^{1}H-NMR (60 MHz, $CDCl_3$) δ: 3.40 (4H, br s, $SC\underline{H}_2C\underline{H}_2S$), 6.75 (1H, s, $SC\underline{H}S$), 7.6—8.2 (4H, m, aromatic protons). HRMS Calcd for $C_{10}H_{10}O_2S_2$ (226.0122). Found: *m/z* 226.0125 (M^+). *Anal.* Calcd for $C_{10}H_{10}O_2S_2$: C, 53.07; H, 4.45. Found: C, 53.09; H, 4.37.

4,4-Bis(ethylthio)-1-oxo-1,2,3,4-tetrahydronaphthalene-2-carboxylic Acid Methyl Ester (7) and 4-Ethylthio-1-hydroxynaphthalene-2-carboxylic Acid Methyl Ester (25) A solution of diisopropylamine (3.3 ml) in dry THF (30 ml) was cooled to −78 °C in an atmosphere of Ar, and a

Table 2. Hydrolysis of Thioacetals Using NCS or MPC

Thioacetals	NCS	MPC
 7	 25 (85%)  22 (5%)	 25 (97%)
 12	 24 (73%)	 24 (96%)
 13	 26 (75%)	 34 (81%)
 14	 27 (39%)  30 (38%)	 27 (82%)
 17	 33 (46%)	 28 (40%)
 18	 24 (33%)  31 (63%)	 24 (67%)
 19	 32 (37%)	 34 (42%)
 20	 30 (60%)  23 (25%)	

1.6 M solution of *n*-BuLi (23.3 mmol) in hexane was added dropwise. A solution of compound **4** (3.0 g, 10.6 mmol) and HMPA (1.8 ml) in dry THF (15 ml) was added to the reaction mixture over 10 min. Then a solution of methyl acrylate (2.3 ml) in dry THF (3 ml) was added dropwise at −90 °C. Stirring was continued for 8 h at room temperature, and 10% HCl was added. The product was extracted with AcOEt, and the organic extract was washed with saturated aqueous $NaHCO_3$, water, and brine, and then dried. After evaporation *in vacuo*, the residue was crystallized from MeOH to give the title compound (**7**) as colorless needles (3.3 g, 95%), mp 61.5—63.0 °C. IR ($CHCl_3$): 1656, 1624, 1596 cm^{-1}. ^{1}H-NMR (60 MHz, $CDCl_3$) δ: 1.13 (6H, t, J=7 Hz, $SCH_2C\underline{H}_3 \times 2$), 2.18—2.28 (4H, m, $SC\underline{H}_2CH_3 \times 2$), 3.15 [2H, br s, C(3)$H_2$], 3.83 (3H, s, $COOCH_3$), 7.16—8.00 (4H, m, aromatic protons). MS *m/z*: 262 ($M^+ - SEt$). *Anal.* Calcd for $C_{16}H_{20}O_3S_2$: C, 59.23; H, 6.21. Found: C, 59.45; H, 6.33. Compound **7** was allowed to stand in contact with the atmosphere for 10 d at room temperature, and the product was crystallized from MeOH–H_2O to give **25** as pale yellow needles, mp 93—94 °C (MeOH–H_2O). IR ($CHCl_3$): 1666, 1628, 1596 cm^{-1}. ^{1}H-NMR (60 MHz, $CDCl_3$) δ: 1.23 (3H, t, J=7 Hz, $SCH_2C\underline{H}_3$), 2.85 (2H, q, J=7 Hz, $SC\underline{H}_2CH_3$), 3.98 (3H, s, $COOCH_3$), 7.8—8.2 [2H, m, C(6)H, C(7)H], 8.00 [1H, s, C(3)H], 8.3—8.6 [2H, m, C(5)H, C(8)H]. HRMS Calcd for $C_{14}H_{14}O_3S$ (262.0663). Found: *m/z* 262.0662 (M^+). *Anal.* Calcd for $C_{14}H_{14}O_3S$: C, 64.10; H, 5.38. Found: C, 63.99; H, 5.40.

4,4-Bis(ethylthio)-3-methyl-1-oxo-1,2,3,4-tetrahydronaphthalene-2-carboxylic Acid Methyl Ester (12) and 4-Ethylthio-1-hydroxy-3-methylnaphthalene-2-carboxylic Acid Methyl Ester (29) Compound **12** was prepared from **4** and methyl crotonate (**8**) in the same manner as described for **7** in 88% yield. Purification was performed by column chromatography [AcOEt–hexane (1 : 19, v/v)] to afford a pale yellow oil. IR ($CHCl_3$): 1650, 1622 cm^{-1}. ^{1}H-NMR (270 MHz, $CDCl_3$) δ: 0.94, 1.35 (each 3H, t, J=7.4 Hz, $SCH_2C\underline{H}_3 \times 2$), 1.07 [3H, d, J=6.9 Hz, C(3)-CH_3], 2.03 [1H, m, C(3)H], 3.10, 2.79 (each 2H, q, J=7.4 Hz, $SC\underline{H}_2CH_3 \times 2$), 3.85 (3H, s, OCH_3), 7.37, 7.42 [each 1H, ddd, J=2, 7.5, 7.5 Hz, C(6)H, C(7)H], 7.59, 7.90 [each 1H, dd, J=2, 7.5, 7.5 Hz, C(5)H,

C(8)H]. MS *m/z*: 277 ($M^+ - SEt$). After 2 weeks at room temperature, the product was crystallized from MeOH to give **29** as colorless needles, mp 84—87 °C. IR (Nujol): 1652 cm^{-1}. ^{1}H-NMR (60 MHz, $CDCl_3$) δ: 1.15 (3H, t, J=7 Hz, $SCH_2C\underline{H}_3$), 2.68 (2H, q, J=7 Hz, $SC\underline{H}_2CH_3$), 2.99 [3H, s, C(4)CH_3], 4.02 (3H, s, $COOCH_3$), 7.4—7.8 [2H, m, C(6)H, C(7)H], 8.4—8.8 [2H, m, C(5)H, C(8)H]. HRMS Calcd for $C_{15}H_{16}O_3S$ (276.0820). Found: *m/z* 276.0811 (M^+).

4,4-Bis(ethylthio)-3,3a,4,9a-tetrahydronaphtho[2,3-*c*]furan-1,9-dione (13) Compound **13** was prepared from **4** and butenolide (**9**) in the same manner as described for **7** in 81% yield. Purification was performed by column chromatography (CH_2Cl_2), mp 115—119 °C. IR (Nujol): 1784, 1596 cm^{-1}. ^{1}H-NMR (270 MHz, $CDCl_3$) δ: 1.00, 1.28 (each 3H, t, J=7 Hz, $SCH_2C\underline{H}_3 \times 2$), 2.75 (4H, q, J=7 Hz, $SC\underline{H}_2CH_3 \times 2$), 4.59 [1H, dd, J=8.0, 9.9 Hz, C(3)H], 4.64 [1H, dd, J=9.9, 13 Hz, C(3)H], 7.45—7.99 (4H, m, aromatic protons). *Anal.* Calcd for $C_{16}H_{18}O_3S_2$: C, 59.60; H, 5.63. Found: C, 59.34; H, 5.64.

10,10-Bis(ethylthio)-2,3,4,4a,9a,10-hexahydroanthracene-1,9-dione (14) Compound **14** was prepared from **4** and 2-cyclohexen-1-one (**10**) in the same manner as described for **7** in 91% yield. Purification was performed by column chromatography [AcOEt–hexane (3:97, v/v)], mp 118—119 °C. IR (Nujol): 1610 cm^{-1}. ^{1}H-NMR (60 MHz, $CDCl_3$) δ: 0.90, 1.22 (each 3H, t, J= 7Hz, $SCH_2C\underline{H}_3 \times 2$), 1.5—2.9 (8H, m), 3.27 (4H, q, J= 7 Hz, $SC\underline{H}_2CH_3 \times 2$), 7.2—7.6 [2H, m, C(6′)H, C(7′)H], 7.8—8.2 [2H, m, C(5′)H, C(8′)H]. MS *m/z*: 334 (M^+). *Anal.* Calcd for $C_{18}H_{22}O_2S_2$: C, 64.63; H, 6.63. Found: C, 64.39; H, 6.62.

2-Acetyl-4-ethylthio-1-naphthalenol (15b) Compound **15b** was prepared from **4** and 3-buten-2-one (**11**) in the same manner as described for **7** in 44% yield. Purification was performed by column chromatography [AcOEt–hexane (1:9, v/v)] to afford pale yellow needles, mp 61—62 °C (MeOH). IR ($CHCl_3$): 1628, 1592 cm^{-1}. ^{1}H-NMR (60 MHz, $CDCl_3$) δ: 1.23 (3H, t, J=7 Hz, $SCH_2C\underline{H}_3$), 2.71 (3H, s, $COCH_3$), 2.84 (2H, q, J=7 Hz, $SC\underline{H}_2CH_3$), 7.65 [2H, m, C(6)H, C(7)H], 7.96 [1H, s, C(3)H], 8.45 [2H, m, C(5)H, C(8)H]. *Anal.* Calcd for $C_{14}H_{14}O_2S$: C, 68.26; H, 5.73. Found: C, 68.07; H, 5.71. The IR and NMR data of the unpurified product indicated the presence of 2-acetyl-4,4-bis(ethylthio)-3,4-dihydro-2*H*-naphthalen-1-one (**15a**). IR ($CHCl_3$): 1626 cm^{-1}. ^{1}H-NMR (60 MHz, $CDCl_3$) δ: 1.10 (6H, t, J=7 Hz, $SCH_2C\underline{H}_3 \times 2$), 1.20 (3H, s, $COCH_3$), 2.45, 2.50 (each 2H, q, J=7 Hz, $SC\underline{H}_2CH_3 \times 2$), 3.15 [2H, br s, C(3)$H_2$], 7.40 [2H, m, C(6)H, C(7)H], 7.85 [2H, m, C(5)H, C(8)H].

2-[1,3]Dithiolan-2-yl-benzoic Acid Ethyl Ester (16) A mixture of compound **5c** (21.0 g) and H_2SO_4 (1.0 ml) in EtOH (250 ml) was refluxed for 15 h. After evaporation of EtOH, water was added to the residue, and the product was extracted with AcOEt. The organic extract was washed with saturated aqueous $NaHCO_3$ and brine, dried, and then evaporated. The residue was subjected to column chromatography on silica gel with AcOEt–hexane (3:17, v/v) to give the title compound (**16**) as a colorless oil (20.3 g, 86%). IR (neat): 1720 cm^{-1}. ^{1}H-NMR (60 MHz, $CDCl_3$) δ: 1.40 (3H, t, J=7 Hz, $COOCH_2C\underline{H}_3$), 3.37 (4H, br s, $SC\underline{H}_2C\underline{H}_2S$), 4.37 (2H, q, J=7 Hz, $COOC\underline{H}_2CH_3$), 6.57 [1H, s, $C\underline{H}(SCH_2CH_2S)$], 7.10—8.03 (4H, m, aromatic protons). HRMS Calcd for $C_{12}H_{14}O_2S_2$ (254.0435). Found: *m/z* 254.0452 (M^+). *Anal.* Calcd for $C_{12}H_{14}O_2S_2$: C, 56.66; H, 5.55. Found: C, 56.51; H, 5.55.

Spiro[1,3-dithiolane-2,4′-1′-oxo-1′,2′,3′,4′-tetrahydronaphthalene-2′-carboxylic Acid Methyl Ester] (17) Compound **17** was prepared from **16** and methyl acrylate (**6**) in the same manner as described for **7**, in 74% yield. Purification was performed by column chromatography [AcOEt–hexane (1:19, v/v)] to afford pale yellow needles, mp 89—90 °C (MeOH). IR($CHCl_3$): 1660, 1628 cm^{-1}. ^{1}H-NMR (60 MHz, $CDCl_3$) δ: 3.27 [2H, br s, C(3)H_2], 3.40 (4H, br s, SCH_2CH_2S), 3.80 (3H, s, OCH_3), 7.2—8.0 (4H, m, aromatic protons). HRMS Calcd for $C_{14}H_{14}O_3S_2$ (294.0384). Found: *m/z* 294.0373 (M^+). *Anal.* Calcd for $C_{14}H_{14}O_3S_2$: C, 57.12; H, 4.79. Found: C, 57.06; H, 4.68.

Spiro[1,3-dithiolane-2,4′-3′-methyl-1′-oxo-1′,2′,3′,4′-tetrahydronaphthalene-2′-carboxylic Acid Methyl Ester] (18) Compound **18** was prepared from **16** and methyl crotonate (**8**) in the same manner as described for **7**, in 72% yield. Purification was performed by column chromatography [AcOEt–hexane (1:19, v/v)] to afford colorless needles, mp 94—95 °C (MeOH). IR ($CHCl_3$): 1650, 1622 cm^{-1}. ^{1}H-NMR (60 MHz, $CDCl_3$) δ: 1.00 [3H, d, J=7 Hz, C(3′)-CH_3], 3.40 (4H, br s, SCH_2CH_2S), 3.80 (3H, s, OCH_3), 7.2—8.0 (4H, m, aromatic protons). HRMS Calcd for $C_{15}H_{16}O_3S_2$ (308.0541). Found: *m/z* 308.0545 (M^+). *Anal.* Calcd for $C_{15}H_{16}O_3S_2$: C, 58.42; H, 5.23. Found: C, 58.37; H, 5.18.

Spiro[1,3-dithiolane-2,4′-3′,3′a,4′,9′a-tetrahydronaphtho[2′,3′-*c*]furan-1′,9′-dione] (19) Compound **19** was prepared from **16** and butenolide (**9**) in the same manner as described for **7**, in 68% yield. Purification was performed by column chromatography (CH_2Cl_2), mp 200—201 °C (MeOH). IR (Nujol): 1714, 1666 cm^{-1}. ^{1}H-NMR (270 MHz, $CDCl_3$) δ: 3.52 (4H, m, SCH_2CH_2S), 4.44 [1H, dd, J=8.0, 9.0 Hz, C(3′)H], 4.55 [1H, dd, J=9.0, 9.2 Hz, C(3′)H], 7.2—8.2 (4H, m, aromatic protons). HRMS Calcd for $C_{14}H_{12}O_3S_2$ (292.0228). Found: *m/z* 292.0215 (M^+).

Spiro[1,3-dithiolane-2,10′-2′,3′,4′,4′a,9′a,10′-hexahydroanthracene-1′,9′-dione] (20) Compound **20** was prepared from **16** and 2-cyclohexene-1-one (**10**) in the same manner as described for **7**, in 60% yield. Purification was performed by column chromatography [AcOEt–hexane (1:4, v/v)] to afford colorless needles, mp 122—123 °C (MeOH). IR ($CHCl_3$): 1594 cm^{-1}. ^{1}H-NMR (60 MHz, $CDCl_3$) δ: 1.6—2.5 (7H, m), 3.1—3.6 (5H, m), 7.2—7.6 [2H, m, C(6′)H, C(7′)H], 7.8—8.2 [2H, m, C(5′)H, C(8′)H]. HRMS Calcd for $C_{16}H_{16}O_2S_2$ (304.0591). Found: *m/z* 304.0564 (M^+). *Anal.* Calcd for $C_{16}H_{16}O_2S_2$: C, 63.13; H, 5.30. Found: C, 63.11; H, 5.25.

Spiro[2-acethyl-bis(ethylthio)-3,4-dihydro-2*H*-naphthalen-1-one-4,2′-[1,3]dithiolane] (21) Compound **21** was prepared from **16** and 3-buten-2-one (**11**) in the same manner as described for **7**, in 26% yield. Purification was performed by column chromatography [AcOEt–hexane (1:9, v/v)]. Pale yellow needles, mp 109—110 °C (EtOH). IR ($CHCl_3$): 1614 cm^{-1}. ^{1}H-NMR (60 MHz, $CDCl_3$) δ: 2.21 (3H, s, $COCH_3$), 3.30 [2H, br s, C(2)H_2], 3.38 (4H, s, SCH_2CH_2S), 7.40 [2H, m, C(6)H, C(7)H], 7.90 [2H, m, C(5)H, C(8)H]. HRMS Calcd for $C_{14}H_{14}O_2S_2$ (278.0435). Found: *m/z* 278.0415 (M^+). *Anal.* Calcd for $C_{14}H_{14}O_2S_2$: C, 60.40; H, 5.07. Found: C, 60.55; H, 5.15.

Reaction of Compound 7 with NCS: Formation of Compound 25 and 1,4-Dihydroxynaphthalene-2-carboxylic Acid Methyl Ester (22) A solution of NCS (3 mmol) in H_2O–acetone (1:99, v/v) (5 ml) was added to a solution of **7** (1.5 mmol) in H_2O–acetone [5 ml (1:99, v/v)] at 20 °C. The mixture was stirred for 3 h at room temperature, then 5% aqueous Na_2SO_3 was added and the product was extracted with CH_2Cl_2. The organic extract was washed with water and brine, dried, and then evaporated *in vacuo*. The residue was subjected to column chromatography on silica gel with CH_2Cl_2 to give **25** and **22** in 85% and 5% yields, respectively. **22**: Pale yellow needles, mp 180—183 °C (MeOH), (lit.[8] mp 192—193 °C). IR ($CHCl_3$): 1668 cm^{-1}. ^{1}H-NMR (60 MHz, $CDCl_3$) δ: 3.95 (3H, s, OCH_3), 4.06 (2H, br s, OH×2), 7.10 [1H, s, C(3)H], 7.6—7.8 [2H, m, C(6)H, C(7)H], 8.1—8.5 [2H, m, C(5)H, C(8)H]. MS *m/z*: 218 (M^+).

Reaction of Compound 7 with MPC: Formation of Compound 25 A solution of mercury(II)perchlorate trihydrate (0.71 mmol) in MeOH–THF (3:1, v/v) (5 ml) was added to a solution of **7** (0.36 mmol) in MeOH–THF (3:1, v/v) (5 ml) with stirring at room temperature. Stirring was continued for 6 h, then saturated aqueous $NaHCO_3$ and CH_2Cl_2 (20 ml) were added to the reaction mixture, and the whole was filtered. The filtrate was separated and the organic layer was washed with water and brine, dried, and then evaporated. The residue was subjected to column chromatography on silica gel with CH_2Cl_2 to give the title compound (**25**) in 97% yield.

Reaction of Compound 12 with NCS: Formation of 3-Methyl-1,4-dioxo-1,4-dihydronaphthalene-2-carboxylic Acid Methyl Ester (24) Compound **12** was treated with NCS to give **24** in 73% yield in the same manner as described for **7**. Purification was performed by column chromatography [AcOEt–hexane (1:9, v/v)]. **24**: Pale yellow needles, mp 75—77 °C (MeOH), (lit.[9] mp 70 °C). IR ($CHCl_3$): 1740, 1668 cm^{-1}. ^{1}H-NMR (60 MHz, $CDCl_3$) δ: 2.15 [3H, s, C(3)CH_3], 3.92 (3H, s, OCH_3), 7.6—7.9 [2H, m, C(6)H, C(7)H], 7.9—8.2 [2H, m, C(5)H, C(8)H]. HRMS Calcd for $C_{13}H_{10}O_4$ (230.0579). Found: *m/z* 230.0576 (M^+).

Reaction of Compound 12 with MPC Compound **12** was treated with MPC to give **24** in 96% yield in the same manner as described for **7**. Purification was performed by column chromatography [AcOEt–hexane (1:9, v/v)].

Reaction of Compound 13 with NCS: Formation of 4-Ethylthio-9-hydroxy-3*H*-naphtho[2,3-*c*]furan-1-one (26) Compound **13** was treated with NCS to give **26** in 75% yield in the same manner as described for **7**. Purification was performed by column chromatography [AcOEt–hexane (1:4, v/v)]. **26**: Pale yellow needles, mp 149—155 °C (MeOH). IR (Nujol): 3388, 1756, 1640, 1595 cm^{-1}. ^{1}H-NMR (60 MHz, $CDCl_3$) δ: 1.17 (3H, J=7 Hz, $SCH_2C\underline{H}_3$), 2.73 (2H, J=7 Hz, $SC\underline{H}_2CH_3$), 5.43 (2H, s, $-CH_2O$), 7.5—7.9 [2H, m, C(6)H, C(7)H], 8.2—8.6 [2H, m, C(5)H,

C(8)H]. *Anal.* Calcd for $C_{14}H_{12}O_3S$: C, 64.60; H, 4.65. Found: C, 64.30; H, 4.56.

Reaction of Compound 13 with MPC: Formation of 9-Hydroxy-4-methoxy-3*H*-naphtho[2,3-*c*]furan-1-one (34) Compound **13** was treated with MPC to give **34** in 81% yield in the same manner as described for **7**. Purification was performed by column chromatography [AcOEt–hexane (1 : 4, v/v)]. **34**: A pale yellow oil. IR ($CHCl_3$): 3448, 1736 cm^{-1}. ^{1}H-NMR (60 MHz, $CDCl_3$) δ: 3.97 (3H, s, OCH_3), 5.51 (2H, s, CH_2O), 7.5—7.8 [2H, m, C(6)H, C(7)H], 8.0—8.4 [2H, m, C(5)H, C(8)H]. HRMS: Calcd for $C_{13}H_{10}O_4$ (230.0579). Found: *m/z* 230.0578 (M^+).

Reaction of Compound 14 with NCS: Formation of 10-Ethylthio-9-hydroxy-3,4-dihydro-2*H*-anthracen-1-one (27) and 10-Chloro-9-hydroxy-3,4-dihydro-2*H*-anthracen-1-one (30) Compound **14** was treated with NCS to give **27** and **30** in 39% and 38% yields, respectively in the same manner as described for **7**. Purification was performed by column chromatography [AcOEt–hexane (1 : 9, v/v)]. **27**: Pale yellow needles, mp 116—118 °C (MeOH). IR (Nujol): 1634, 1580 cm^{-1}. ^{1}H-NMR (60 MHz, $CDCl_3$) δ: 1.16 (3H, J=7 Hz, $SCH_2C\underline{H}_3$), 2.20 [2H, m, C(3)H_2], 2.70 [4H, m, C(4)H_2, $SC\underline{H}_2CH_3$], 3.10 [2H, br t, C(2)H_2], 7.1—7.6 [2H, m, C(6)H, C(7)H], 7.9—8.2 [2H, m, C(5)H, C(8)H]. *Anal.* Calcd for $C_{16}H_{16}O_2S$: C, 70.56; H, 5.92. Found: C, 70.34; H, 5.98. **30**: Pale yellow needles, mp 194—195 °C. IR ($CHCl_3$): 1622 cm^{-1}. ^{1}H-NMR (60 MHz, $CDCl_3$) δ: 2.19 [2H, m, C(3)H_2], 2.68 [2H, br t, C(4)H_2], 3.12 [2H, br t, C(2)H_2], 7.1—7.7 [2H, m, C(6)H, C(7)H], 7.9—8.3 [2H, m, C(5)H, C(8)H]. HRMS Calcd for $C_{14}H_{11}ClO_2$ (246.0447). Found: *m/z* 246.0461 (M^+).

Reaction of Compound 14 with MPC: Formation of Compound 27 Compound **14** was treated with MPC to give **27** in 82% yield in the same manner as described for **7**. Purification was performed by column chromatography [AcOEt–hexane (1 : 19, v/v)].

Reaction of Compound 17 with NCS: Formation of 3-Chloro-4-hydroxynaphthalene-2-carboxylic Acid Methyl Ester (33) Compound **17** was treated with NCS to give **33** in 46% yield in the same manner as described for **7**. Purification was performed by column chromatography [AcOEt–hexane (1 : 9, v/v)]. **33**: Pale yellow needles, mp 121 °C. IR ($CHCl_3$): 1672 cm^{-1}. ^{1}H-NMR (60 MHz, $CDCl_3$) δ: 4.01 (3H, s, CH_3), 7.5—7.8 [2H, m, C(6)H, C(7)H], 7.88 [1H, s, C(3)H], 8.2—8.5 [2H, m, C(5)H, C(8)H]. HRMS Calcd for $C_{12}H_9ClO_3$ (236.0239). Found: *m/z* 236.0211 (M^+).

Reaction of Compound 17 with MPC: Formation of Bis[(4-hydroxy-3-methoxycarbonyl-1-naphthyl)thioethylthiolato]mercury (28) Compound **17** was treated with MPC to give **28** in 90% yield in the same manner as described for **7**. Purification was performed by column chromatography [AcOEt–hexane (1 : 4, v/v)]. Pale yellow needles, mp 178—179 °C (Acetone). IR ($CHCl_3$): 1670 cm^{-1}. ^{1}H-NMR (270 MHz, $CDCl_3$) δ: 3.10 (4H, m, $SC\underline{H}_2C\underline{H}_2S$), 3.92 (3H, s, OCH_3), 7.60 [2H, m, C(6)H and C(7)H], 7.91 [1H, s, C(3)H], 8.30 [2H, m, C(5)H and C(8)H]. MS *m/z*: 586 ($M^+ - C_{12}H_9O_3$). *Anal.* Calcd for $C_{28}H_{26}HgO_6S_4$: C, 42.71; H, 3.33. Found: C, 42.64; H, 3.36.

Reaction of Compound 18 with NCS: Formation of Compound 24 and 4-Chloro-1-hydroxy-3-methylnaphthalene-2-carboxylic Acid Methyl Ester (31) Compound **18** was treated with NCS to give **24** and **31** in 33% and 63% yields, respectively in the same manner as described for **7**. Purification was performed by column chromatography [AcOEt–hexane (1 : 9, v/v)]. **31**: Pale yellow needles, mp 71 °C (MeOH). IR ($CHCl_3$): 1652 cm^{-1}. ^{1}H-NMR (60 MHz, $CDCl_3$) δ: 2.67 [3H, s, C(3)CH_3], 3.96 (3H, s, $COOCH_3$), 7.3—7.8 [2H, m, C(6)H, C(7)H], 8.0—8.3 [2H, m, C(5)H, C(8)H]. HRMS Calcd for $C_{13}H_{11}ClO_3$ (250.0396). Found: *m/z* 250.0393 (M^+).

Reaction of Compound 18 with MPC: Formation of Compound 24 Compound **18** was treated with MPC to give **24** in 67% yield in the same manner as described for **7**. Purification was performed by column chromatography [AcOEt–hexane (1 : 9, v/v)].

Reaction of Compound 19 with NCS: Formation of 4-Chloro-9-hydroxy-3*H*-naphtho[2,3-*c*]furan-1-one (32) Compound **19** was treated with NCS to give **31** in 72% yield in the same manner as described for **7**. Purification was performed by column chromatography (CH_2Cl_2). **32**: Pale yellow needles, mp 238 °C (MeOH). IR (Nujol): 3412, 1748, 1648, 1608 cm^{-1}. ^{1}H-NMR (60 MHz, $CDCl_3$) δ: 5.44 (2H, s, $-CH_2O$), 7.6—7.9 [2H, m, C(6)H, C(7)H], 8.2—8.5 [2H, m, C(5)H, C(8)H]. HRMS Calcd for $C_{12}H_7ClO_3$ (234.0084). Found: *m/z* 234.0087 (M^+).

Reaction of Compound 19 with MPC: Formation of Compound 34 Compound **19** was treated with MPC to give **34** in 42% yield in the same manner as described for **7**. Purification was performed by column chromatography [AcOEt–hexane (1 : 4, v/v)].

Reaction of Compound 20 with NCS: Formation of Compound 30 and 9,10-Dihydroxy-3,4-dihydro-2*H*-anthracen-1-one (23) Compound **20** was treated with NCS to give **30** and **23** in 60% and 25% yields, respectively in the same manner as described for **7**. Purification was performed by column chromatography [AcOEt–hexane (1 : 4, v/v)]. **23**: Pale yellow needles, mp 172—173 °C (MeOH), (lit.[10] mp 170—171 °C). IR ($CHCl_3$): 1622 cm^{-1}. ^{1}H-NMR (60 MHz, $CDCl_3$) δ: 2.15 [2H, m, C(3)H_2], 2.75 [2H, br t, C(4)H_2], 3.17 [2H, br t, C(2)H_2], 7.5—7.9 [2H, m, C(6)H, C(7)H], 8.1—8.5 [2H, m, C(5)H, C(8)H]. MS *m/z*: 224 (M^+).

References and Notes

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