and the reaction stirred further for 9 days. The disappearance of IR peaks at 2130 and 1820 cm^{-1} was used as evidence for complete reaction. After removal of dicyclohexylurea by filtration, the solvent and excess thiol were removed by rotary evaporation. Et_2O (35 mL) was added and the solution washed sequentially with $NaHCO_3$, with 1 M H_2SO_4, and again with saturated $NaHCO_3$. After drying and rotary evaporation, the thioester product was vacuum distilled as reported above. GC analysis showed that the crude product (85% yield) contain 19% *N*-acylurea and <2% *tert*-butyl thiocrotonate. Approximately 1% H-D exchange occurred at C-2. Even at 10 mtorr, thermal decomposition (presumably of the *N*-acylurea) made it impossible to obtain pure 1-d_2, even by repeated vacuum distillation.

Increasing amounts of DMAP led to product uncontaminated by *N*-acylurea but which contained substantial amounts of *tert*-butyl thiocrotonate and an increasing degree of H-D exchange at C-2. When no DMAP was used, the reaction became sluggish and *N*-acylurea accounted for 35% of the crude product. Using Et_2O or excess thiol as solvent did not produce a more successful reaction.

Acknowledgment. Grateful acknowledgment is made to the Research Corporation and to the donors of the Petroleum Research Fund, administered by the American Chemical Society, for support of this research.

Registry No. (*R*,R**)-(±)-1, 79069-05-9; (±)-1-d_2, 79069-06-0; *trans*-(±)-2, 13737-02-5; trans-(±)-2 K salt, 79069-07-1; (*R*,R**)-(±)-3, 79069-08-2; (*R*,R**)-(±) 3 Na salt, 79069-09-3; (*R*,R**)-(±)-4, 79069-10-6; (±)-5, 79069-11-7; *trans*-crotonic acid, 110-17-8; (±)-2-hydroxybutanoic acid, 600-15-7; (±)-3-hydroxybutanoic acid, 625-71-8; (±)-3-acetoxybutanoic acid, 24621-58-7; methyl acetoacetate, 105-45-3; (±)-3-acetoxybutanoic acid-2-d_2, 79069-12-8; 2-methyl-2-propanethiol, 75-66-1.

Synthetic Routes to Benz[*a*]anthracenes via Transient 1-Benzylisobenzofuran Derivatives

James G. Smith,* Sudha S. Welankiwar, Noreen G. Chu, Eric H. Lai, and Susan J. Sondheimer

Department of Chemistry, University of Waterloo, Waterloo, Ontario N2L 3G1 Canada

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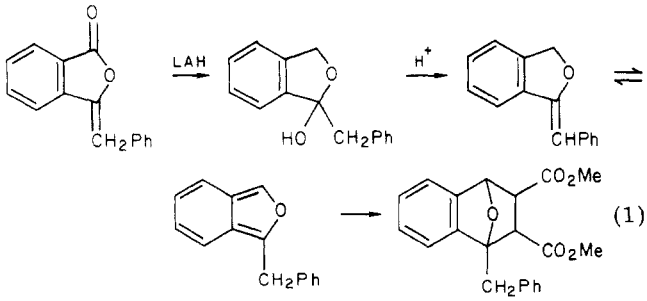
A synthetic route to 7-acetoxybenz[*a*]anthracenes is described based on the generation of 1-benzylisobenzofurans and their capture with methyl acrylate in a Diels-Alder reaction. The 1,4-epoxy-1,2,3,4-tetrahydronaphthalene derivatives so formed are aromatized to naphthoate esters under acidic conditions and hydrolyzed to the naphthoic acids, and these are cyclized to the 7-acetoxybenz[*a*]anthracenes with zinc chloride in acetic anhydride.

Lately, considerable interest has been shown[1] in the synthesis of benz[*a*]anthracene derivatives bearing methyl and/or hydroxy groups in specific locations. An interesting report[2] by Gomez described a one-step synthesis of benz[*a*]anthracene derivatives from appropriately substituted 1,4-epoxy-1,2,3,4-tetrahydronaphthalene derivatives (i.e., **1a** → **3a**, Scheme I) using polyphosphoric acid. Presumably this reaction proceeds through the naphthalene derivative **2a**.

This report interested us since compounds such as 1 are readily prepared[3] via benzylisobenzofurans (eq 1). The

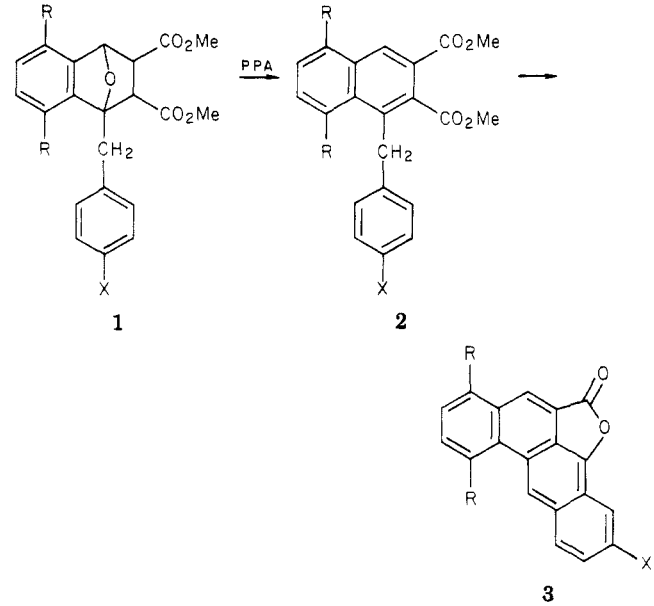


(1)

overall sequence appeared to be a direct route to benz[*a*]anthracene derivatives and therefore it was reinvestigated and confirmed. Three additional examples of the preparation of benz[*a*]anthracenes (i.e., **3b-d**) by this method are reported here. Thus this route appears to be a general one.

While the lactone ring is potentially a functional group useful for further elaborating **3**, it was decided instead to modify the synthetic route to obtain a product without this

Scheme I. Formation of Benz[*a*]anthracenes



a, R = H; X = H
b, R = Me; X = H
c, R = Ph; X = H
d, R = H; X = OMe

(1) (a) Morreal, C. E.; Alks, V. *J. Org. Chem.* **1975**, *40*, 3411. (b) Rosen, B. I.; Weber, W. P. *Ibid.* **1977**, *42*, 3463. (c) Manning, W. B.; Tomaszewski, J. E.; Muschik, G. M.; Sato, R. I. *Ibid.* **1977**, *42*, 3465. (d) Manning, W. B.; Muschik, G. M.; Tomaszewski, J. E. *Ibid.* **1979**, *44*, 699. (e) Newman, M. S.; Khanna, J. M.; Kanakarajan, K.; Kumar, S. *Ibid.* **1978**, *43*, 2553. (f) Fu, P. P.; Cortez, C.; Sukumaran, K. B.; Harvey, R. G. *Ibid.* **1979**, *44*, 4265. (g) Newman, M. S.; Kanakarajan, K. *Ibid.* **1980**, *45*, 2301.

(2) Mavoungou Gomês, M. L. *Compt. Rend. Acad. Sci., Ser. C* **1974**, *279*, 417.

(3) Smith, J. G.; Welankiwar, S. S.; Shantz, B.; Lai, E.; Chu, N. *J. Org. Chem.* **1980**, *45*, 1817.

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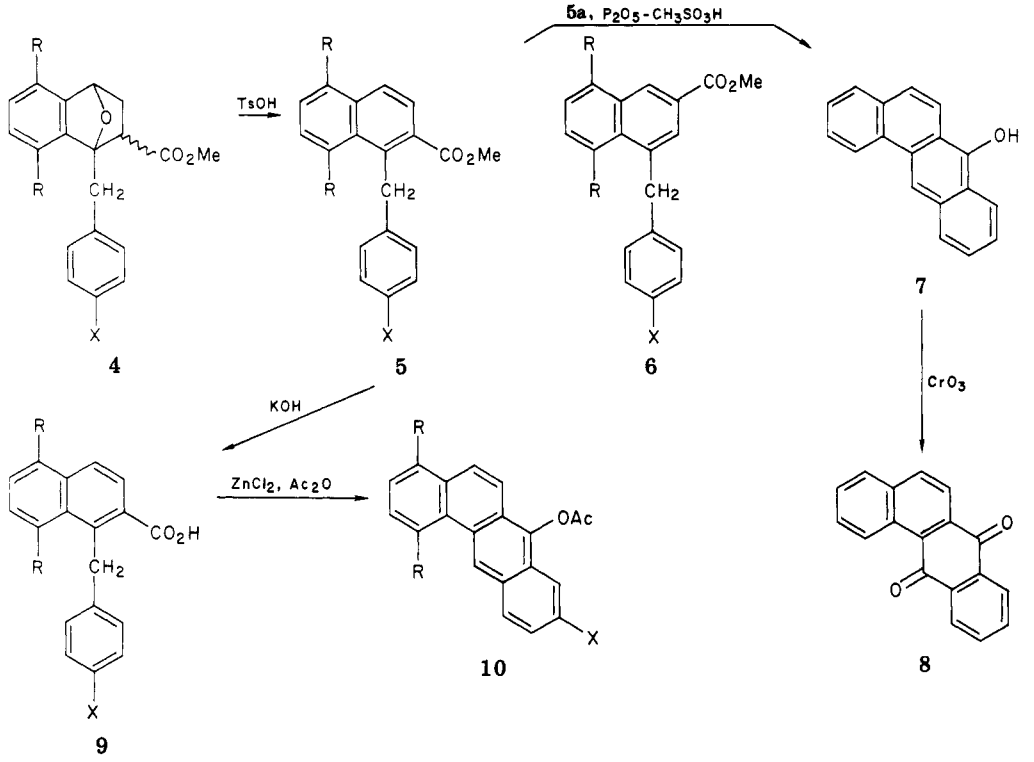
Scheme II. Formation of 7-Acetoxybenz[a]anthracenes



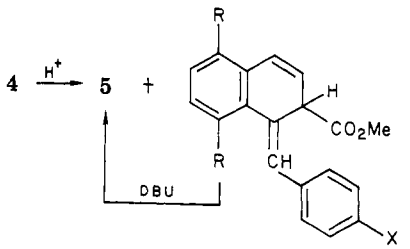
a, R = H; X = H
b, R = Me; X = H
c, R = H; X = OMe
d, R = Me; X = OMe

structural feature. The appropriate epoxytetrahydronaphthalenes, **4** were readily prepared by a Diels–Alder reaction of methyl acrylate with the transient isobenzofuran (Scheme II). At this stage, the exo and endo isomers of **4** were separated and characterized. The stereochemistry of these compounds was established by the similarity of the characteristic patterns shown by the aliphatic protons in the NMR spectra of **4b–d** compared to those of the known[3] *endo*- and *exo*-**4a**.

Unfortunately, attempts to transform **4a** or **5a** to benz[*a*]anthracene derivatives by treatment with hot polyphosphoric acid failed to produce any characterizable product. However, that this route was viable was demonstrated in a stepwise manner by aromatizing **4a** to the naphthoate ester **5a**, hydrolyzing the ester to the carboxylic acid **9a**, and cyclizing this to 7-acetoxybenz[*a*]anthracene, **10a**, using the conditions employed by Fieser[4] in an analogous reaction.

It was found that replacing polyphosphoric acid with phosphorus pentoxide–methanesulfonic acid[5] gave a product believed to be **7** from **5a**. As noted elsewhere,[4] this substance readily degrades and the product could not be characterized. Oxidation of the crude **7** immediately after formation produced 7,12-benz[*a*]anthraquinone, **8**, establishing that a successful cyclization of **5a** to a benz[*a*]anthracene derivative had occurred. An attempt to convert the epoxytetrahydronaphthalene, **4a**, by this procedure (i.e., P_2O_5–CH_3SO_3H, followed by oxidation) directly to **8** was also successful but the yield was lower. For reasons to be discussed below, it was decided to adopt the Fieser[4] method of cyclization of the naphthoic acids, **9**, as the means of obtaining benz[*a*]anthracene derivatives.

Since separation of the *endo*- and *exo*-**4** was tedious, and since both gave the same aromatized product, **5**, it was expedient to aromatize the crude Diels–Alder reaction mixture. There were two consequences of this decision. Firstly, vinyl protons were observed in the NMR spectra of the crude aromatized **5**. This was particularly noticeable in the cases of **4b** and **4c** where the steric effect of the methyl substituents facilitated the formation of the nonnaphthalenic dehydration product,[3,7] **11** (eq 2). Conse-



(2)

11

quently, after acid-catalyzed aromatization, the crude product was treated with 1,8-diazabicyclo[5.4.0]undec-7-ene (DBU) to effect isomerization[3] of **11** to **5**. Secondly, the NMR spectrum of the aromatized product (after DBU isomerization) clearly indicated that two isomeric naphthoate esters were present, **5** and **6**, since two signals were observed for the benzyl protons in a ratio of **5**:**6** ≈ 3:1. The isomeric naphthoate ester, **6**, obviously arose from a Diels–Alder adduct regioisomeric to **4** (not shown in Scheme II), which had not been detected during the isolation of *endo*- and *exo*-**4**. Indeed, on further examination of these reaction mixtures, it was possible to isolate only one, the Diels–Alder adduct regioisomeric to **4d**.

(4) Fieser, L. F.; Hershberg, E. B. *J. Am. Chem. Soc.* **1937**, *59*, 1028.
(5) Eaton, P. E.; Carlson, G. R.; Lee, J. T. *J. Org. Chem.* **1973**, *38*, 4071.
(6) Traxler, J. T. *Synth. Commun.* **1977**, *7*, 161.
(7) Smith, J. G.; Wikman, R. T. *J. Org. Chem.* **1974**, *39*, 3648.

Table I. Analytical Data

compd	molecular formula	calcd % C	calcd % H	found % C	found % H
3b	$C_{21}H_{14}O_2$	84.54	4.46	84.57	4.46
3c	$C_{31}H_{18}O_2$	88.12	4.30	88.04	4.46
3d	$C_{20}H_{12}O_3$	79.98	4.04	79.81	3.91
endo-4b	$C_{21}H_{22}O_3$	78.23	6.88	77.95	6.82
exo-4b	$C_{21}H_{22}O_3$	78.23	6.88	78.35	6.76
endo-4c	$C_{20}H_{20}O_4$	74.06	6.21	73.96	6.28
exo-4c	$C_{20}H_{20}O_4$	74.06	6.21	74.33	6.21
endo-4d	$C_{22}H_{24}O_4$	74.98	6.86	74.87	6.85
exo-4d	$C_{22}H_{24}O_4$	74.98	6.86	75.17	6.70
5b	$C_{21}H_{20}O_2$	82.58	6.93	82.81	6.72
5c	$C_{20}H_{18}O_3$	*m/e* 306.1251		*m/e* 306.1257	
5d	$C_{22}H_{22}O_3$	79.02	6.63	79.29	6.77
6d	$C_{22}H_{22}O_3$	*m/e* 334.1563		*m/e* 334.1562	
10b	$C_{22}H_{18}O_2$	84.05	5.77	83.99	5.79
10c	$C_{21}H_{16}O_3$	79.72	5.11	79.75	5.01
10d	$C_{23}H_{20}O_3$	80.21	5.85	80.49	5.86

The isomeric naphthoate esters **5** and **6** proved difficult to separate. While pure samples of **5a–d** were isolated by a rather wasteful crystallization of the reaction mixture of chromatographic fractions, pure samples only of **6c** and **6d** were obtained.

Consequently, the mixed esters **5** and **6** were hydrolyzed to the corresponding naphthoic acids, and this mixture was subjected to cyclization. Since only **9** can cyclize, the unreacted acid corresponding to **6** was readily separated from the final product by a basic wash. By this reaction sequence, four 7-acetoxybenz[*a*]anthracenes, **10**, were prepared.

Further elaboration of these benz[*a*]anthracenes at the 7-position is possible, using the latent carbonyl group[4] (acetoxy group). Alternatively, oxidation of **10** to the corresponding 7,12-benz[*a*]anthraquinone[1e] would permit elaboration at the 7,12-positions.[1d,g] The synthetic route to benz[*a*]anthracenes via isobenzofurans appears therefore to be a viable one which merits further attention.

Experimental Section

Melting points were measured with a Mel-temp apparatus in open capillaries and are uncorrected. Infrared spectra were recorded on a Beckman IR-10 spectrometer and NMR spectra were determined on a Varian T-60 or Brucker WP-80 spectrometer using deuteriochloroform solutions (unless otherwise specified) with chemical shifts reported in δ units downfield from internal tetramethylsilane. High-resolution mass spectra were determined on a VG-7070 mass spectrometer. Analyses were performed by MHW Laboratories, Phoenix, AZ. All new compounds gave satisfactory analyses.

3-Benzalphthalide, 4,7-dimethyl-3-benzalphthalide, 3-(*p*-methoxybenzal)phthalide, and 3-(*p*-methoxybenzal)-4,7-dimethylphthalide were prepared by a standard method.[8] All but the last are known compounds,[3] this had mp 127–129 °C (from EtOH); NMR 2.58 (s, 3 H), 2.67 (s, 3 H), 3.83 (s, 3 H), 6.32 (s, 1 H), 6.7–7.9 (m, 6 H); IR (Nujol) 1770, 1520, 1510, 1250, 1180, 1020, 980 cm^{-1}. Anal. Calcd for $C_{18}H_{16}O_3$: C, 77.12; H, 5.75. Found: C, 77.32; H, 5.77.

Preparation of Benz[*a*]anthracene-6,7-carbolactone (3a). General Procedure. The conversion of **1a** to **3a** was effected by heating 1 g of **1a** with slow stirring in 25 mL of polyphosphoric acid (PPA) at 90 °C for 3 h (see, however, **3c**). The reaction mixture solidified to a paste and, after cooling, this was added to 100 mL of water, the mixture was stirred to solubilize the PPA, and the product was filtered off and washed with water. For removal of any residual PPA, the crude product was dissolved in a large volume of chloroform, washed with dilute aqueous $NaHCO_3$ solution, dried, and evaporated to give **3a**, 0.70 g (92%), mp 230–231 °C (lit.[2] mp 230 °C).

Preparation of 1,4-Dimethylbenz[*a*]anthracene-6,7-carbolactone (3b). The product prepared as described from **1b** amounted to 0.75 g (94%), mp 272–276 °C. Recrystallisation from acetonitrile provided an analytical sample: mp 279–281 °C; NMR δ 2.80 (s, 3 H), 3.20 (s, 3 H), 7.4–8.2 (m, 6 H), 8.7 (s, 1 H), 8.93 (s, 1 H); IR (KBr) 1780 (C=O), 1180, 980, 970, 740 cm^{-1}.

Preparation of 1,4-Diphenylbenz[*a*]anthracene-6,7-carbolactone (3c). In this case conversion of **1c** to **3c** required 16 h of heating at 130 °C. The crude reaction product (0.84 g) was dissolved in chloroform and the solution evaporated onto 5 g of silica gel. This was added to the top of a column of silica gel (deactivated with 5% water) and eluted with benzene containing 5% ethyl acetate. Evaporation of the eluate gave 0.80 g (95%) of **3c** as an orange red solid, mp 294–295 °C. Recrystallisation from acetonitrile gave an analytical sample: mp 304–305 °C; NMR δ 7.4–8.0 (m, 17 H), 8.63 (s, 1 H); IR (KBr) 1780 (C=), 1260, 800, 750, 690 cm^{-1}.

Preparation of 9-Methoxybenz[*a*]anthracene-6,7-carbolactone (3d). The crude reaction product from **1d** (**3d**, 0.70 g, mp 258–259.5 °C) was recrystallized from a large volume of acetonitrile to give 0.62 g (78%) of **3d** as an orange solid: mp 260–261 °C; NMR δ 3.97 (s, 3 H), 7.2–8.8 (m, 9 H); IR (KBr) 1770 (C=O), 1610, 1480, 1260, 1230, 1190, 910 cm^{-1}.

Preparation of 2-(Carbomethoxy)-1,4-epoxy-1-(*p*-methoxybenzyl)-1,2,3,4-tetrahydronaphthalene (4c). General Procedure for the Diels–Alder Reaction. The 3-(*p*-methoxybenzal)phthalide (2 g, 8.4 mmol) was placed in a Soxhlet extractor attached to a 1-L flask containing 300 mL of ether and 0.48 g (12.7 mmol) of lithium aluminum hydride. The ether was refluxed under nitrogen so that the extractor cycled about once every 15 min and the reduction was continued for 18–20 h. After the reaction mixture was hydrolyzed with ethyl acetate and then water, the ether layer was decanted and the inorganic solid washed by decantation 3 times with ether. The combined ether layers were washed with water, dried ($MgSO_4$), and concentrated to dryness.

The residue, which consisted of the corresponding hydroxyphthalan or this mixed with the corresponding benzalphthalan, was dissolved in 250 mL of toluene containing 2.17 g (0.025 mol. of methyl acrylate and 3 drops of concentrated HCl was added to ensure dehydration of any hydroxyphthalan. The solution was refluxed under nitrogen for 20 h and cooled, and the solvent was removed under vacuum, giving 2.91 g of residual oil.

The oil was treated overnight with 30 mL of 30–60 °C petroleum ether, the petroleum ether was then removed, and the insoluble material was recrystallized from methanol to give as a first crop 0.07 g of *endo*-**4c**: mp 118–119 °C; NMR δ 1.82 (dd, J_1 = 4 Hz, J_2 = 11 Hz, 1 H), 2.0–2.5 (m, 1 H), 2.98 (dd, J_1 = 4 Hz, J_2 = 10 Hz, 1 H), 3.48 (s, 3 H), 3.50 and 3.77 (ABq, 2 H), 3.77 (s, 3 H), 5.30 (d, J = 4 Hz, 1 H), 6.7–7.5 (m, 8 H); IR (Nujol) 1740, 1510, 1250, 1190, 1170, 990, 840, 865, 860 cm^{-1}.

Concentration of the filtrate from the *endo*-**4c** gave 0.67 g of a second crop, a mixture of endo and exo isomers, and finally 0.19 g of crude *exo*-**4c**, mp 128–131 °C. Recrystallization from methanol gave an analytical sample: mp 131–132.5 °C; NMR δ 1.68 (dd, J_1 = 10 Hz, J_2 = 13 Hz), 2.4–2.8 (m, 2 H), 3.27 and 3.63 (ABq, J = 16 Hz, 2 H), 3.63 and 3.70 (two s, 6 H), 5.48 (d, J = 5 Hz, 1 H), 6.6–7.4 (m, 8 H); IR (Nujol) 1730, 1510, 1240, 1190, 1170, 1020, 810, 750 cm^{-1}.

An additional quantity of **4c** (endo–exo mixture) was isolated from the petroleum ether originally used to crystallize the oily Diels–Alder reaction product.

Preparation of 1-Benzyl-2-(carbomethoxy)-1,4-epoxy-1,2,3,4-tetrahydronaphthalene (4a). The endo and exo isomers of **4a** have already been described.[3]

Preparation of 1-Benzyl-2-(carbomethoxy)-1,4-epoxy-5,8-dimethyl-1,2,3,4-tetrahydronaphthalene (4b). The crude reaction product (0.56 g) from a 1.7-mmol run of 3-benzal-4,7-dimethylphthalide was chromatographed on silica gel, eluting with 3:1 benzene/30–60 °C petroleum ether graded to benzene. *endo*-**4b** (0.15 g, 27%) eluted first, an oil that crystallized in 30–60 °C petroleum ether. Two recrystallizations from the same solvent gave an analytical sample: mp 66–68 °C; NMR δ 1.6–2.2 (m, 2 H), 2.28 and 2.33 (two s, 6 H), 3.05 (dd, J_1 = 4 Hz, J_2 = 10 Hz, 1 H), 3.53 (s, 3 H), 3.68 and 4.05 (ABq, J = 14 Hz, 2 H), 5.32 (d,

(8) Weiss, R.; "Organic Synthesis", Collect. Vol. 2; Blatt, A. H., Ed.; Wiley: New York, 1943.

J = 4 Hz, 1 H), 6.83 (s, 2 H), 7.1–7.6 (m, 5 H); IR (Nujol) 1740, 1500, 1340, 1190, 1170, 950, 800, 720 cm^{-1}.

Following this, a fraction containing both *endo*- and *exo*-**4b** eluted (0.2 g) and finally *exo*-**4b** (0.06 g, 11%) was collected. This last fraction crystallized on treatment with 30–60 °C petroleum ether (mp 108–111 °C) and was recrystallized from 80–100 °C petroleum ether: mp 115–117 °C; NMR δ 1.62 (dd, J_1 = 9.5 Hz, J_2 = 13 Hz, 1 H), 2.14 (s, 3 H), 2.30 (s, 3 H), 2.4–2.8 (m, 2 H), 3.42 and 3.79 (ABq, J = 17 Hz, 2 H), 3.77 (s, 3 H), 5.62 (d, J = 4.5 Hz, 1 H), 6.71 and 6.86 (ABq, J = 8 Hz, 2 H), 7.1–7.4 (m, 5 H); IR ($CHCl_3$) 1730, 1500, 1450, 1430, 1350, 1280, 1160, 990, 690 cm^{-1}.

Preparation of 2-(Carbomethoxy)-1,4-epoxy-1-(*p*-methoxyphenyl)-5,8-dimethyl-1,2,3,4-tetrahydronaphthalene (4d). The crude reaction product from a 3.56-mmol run of 3-(*p*-methoxybenzal)-4,7-dimethylphthalide (1.29 g, 1:1 *endo*-**4d**/*exo*-**4d**) was chromatographed on silica gel, using 3:1 benzene/30–60 °C petroleum ether graded to benzene. The *endo*-**4d** (0.49 g, 39%) eluted first and was crystallized from benzene/60–80 °C petroleum ether: mp 108–109.5 °C; NMR δ 1.4–2.2 (m, 2 H), 2.27 and 2.30 (two s, 6 H), 3.02 (dd, J_1 = 4 Hz, J_2 = 10 Hz), 3.53 (s, 3 H), 3.77 (s, 3 H), 3.76 and 3.94 (ABq, J = 17 Hz, 2 H), 5.30 (d, J = 4 Hz, 1 H), 6.6–7.4 (m, 6 H); IR (Nujol) 1740, 1500, 1240, 1170, 1030, 990, 830, 820,810 cm^{-1}.

Following the *endo*-**4d**, a small amount (20 mg) of 3-(carbomethoxy)-1,4-epoxy-1-(*p*-methoxyphenyl)-5,8-dimethyl-1,2,3,4-tetrahydronaphthalene was obtained as an oil: NMR δ 1.7–2.1 (m, 2 H), 2.23 (s, 3 H), 2.34 (s, 3 H), 3.1–3.4 (m, 1 H), 3.48 (s, 3 H), 3.61 (s, 2 H), 3.77 (s, 3 H), 5.55 (d, J = 5 Hz, 1 H), 6.83 (s, 2 H), 6.80 and 7.23 (ABq, J = 9 Hz, 4 H); IR (neat) 1740, 1510, 1450, 1240, 1200, 1180, 1030, 800, 750 cm^{-1}. An analytically pure sample could not be obtained.

The next fractions contained *exo*-**4d** (0.34 g, 27%): mp (from 80–100 °C petroleum ether) 128–130 °C; NMR δ 1.56 (dd, J_1 = 9 Hz, J_2 = 12 Hz, 1H), 2.13 (s, 3 H), 2.25 (s, 3 H), 2.3–2.8 (m, 2 H), 3.28 and 3.72 (ABq, J = 14 Hz) *plus* 3.63 and 3.72 (two s, total 8 H), 5.54 (d, J = 5 Hz, 1 H), 6.5–7.4 (m, 6 H); IR (Nujol) 1740, 1510, 1250, 1190, 1170, 1070, 1030, 810 cm^{-1}.

Preparation of 2-(Carbomethoxy)-1-(*p*-methoxyphenyl)-naphthalene (5c). General Procedure for the Aromatization of Diels–Alder Adducts. The crude Diels–Alder adduct from methyl acrylate and 1-(*p*-methoxybenzal)phthalan (originally derived by LAH reduction of 2.34 g (9.3 m mol) of 3-(*p*-methoxybenzal)phthalide was dissolved in 100 mL of toluene and 0.8 g of *p*-toluenesulfonic acid added. After the solution was refluxed for 2 h under nitrogen, the solution was cooled, washed with water, and dried ($MgSO_4$). After the drying agent was filtered off, 0.2 mL of DBU was added and the solution was refluxed 1 h. After the toluene solution was washed with water and dried ($MgSO_4$) and the solvent removed, NMR indicated that the product consisted of a 3:1 mixture of **5c** and its isomer, 3-(carbomethoxy)-1-(*p*-methoxyphenyl)naphthalene (**6c**). Column chromatography on silica gel eluting with methylene chloride gave 0.5 g (18%) of the isomer **6c**: NMR 3.75 (s, 6 H), 4.39 (s, 2 H), 6.7–8.1 (m, 10 H). This compound was not further investigated. Following **6c**, there was obtained 1.6 g (56%) of **5c** still containing some of the isomeric **6c**. Rechromatography of a sample on silica gel and elution with 1:1 diethyl ether/30–60 °C petroleum ether provided an analytical sample as an oil which slowly crystallized when covered with hexane at 10 °C: mp 67–68 °C; NMR δ 3.68 (s, 3 H), 3.88 (s, 3 H), 4.80 (s, 2 H), 6.7–8.3 (m, 10 H); IR (neat) 1720, 1510, 1270, 1240, 1125, 760.

Preparation of 1-Benzyl-2-(carbomethoxy)-5,8-dimethylnaphthalene (5b). After the DBU treatment, the crude ester (1.10 g, from 4.9 mmol of the appropriate benzalphthalide) consisted of 70–75% of **5b** and 25–30% of the isomeric 1-benzyl-3-(carbomethoxy)-5,8-dimethylnaphthalene (**6b**). Chromatography on silica gel eluting with hexane plus 2% ethyl acetate effected only partial separation. The first fraction (0.12 g) contained about 60% of the isomer **6b** whose NMR spectrum could be deduced by substracting that of **5b**: NMR 2.70 (s, 6 H), 3.90 (s, 3H, 4.68 (s, 2 H), 6.7–7.5 (m, 7 H), 7.83 (d, J = 2 Hz, 1 H), 8.65 (d, J = 2 Hz, 1 H).

The following fractions (0.86 g) consisted chiefly of **5b** with varying amounts of the isomeric **6b**. An analytical sample of **5b** was obtained by recrystallization from chloroform/30–60 °C petroleum ether: mp 82–83.5 °C; NMR δ 2.63 and 2.70 (two s, total 6 H), 3.67 (s, 3 H), 4.93 (s, 2 H), 6.8–7.4 (m, 7 H), 7.68 and 8.00 (ABq, J = 9 Hz, 2 H); IR (Nujol) 1725, 1240, 1180, 1120, 990, 820, 750, 730, 720, 690 cm^{-1}.

Preparation of 2-(Carbomethoxy)-1-(*p*-methoxybenzyl)-5,8-dimethylnaphthalene (5d). The aromatized ester (0.99 g, originally from 3 mmol of the corresponding benzalphthalide) after DBU treatment consisted of 75% **5d** and 25% of the isomeric 3-carbomethoxy derivative **6d**. Chromatography on silica gel eluting with benzene containing 5% of 60–80 °C petroleum ether gave first the isomeric ester **6d** (0.12 g, 12% yield based on the original phthalide). This was dissolved in hot methanol and the solution separated from an insoluble gum. A second recrystallization gave **6d**: mp 97–98 °C; NMR δ 2.77 (s, 6 H), 3.73 (s, 3 H), 3.95 (s, 3 H), 4.63 (s, 2 H), 6.7–7.3 (m, 6 H); IR (Nujol) 1720, 1510, 1270, 1250, 1240, 1215, 1030, 820, 800, 760 cm^{-1}.

Following **6d**, **5d** (0.60 g, 60% yield based on the original phthalide) was collected. An analytical sample (from benzene-/60–80 °C petroleum ether) had mp 115–116.5 °C: NMR δ 2.67 and 2.73 (two s, total 6 H), 3.70 and 3.75 (two s, total 6 H), 4.88 (s, 2 H), 3.8–7.3 (m, 6 H), 7.71 and 8.04 (ABq, J = 9 Hz, 2 H); IR (Nujol) 1725, 1610, 1270, 1250, 1240, 1120, 1030, 820, 800 cm^{-1}.

Preparation of 7,12-Benz[a]anthraquinone (8). The compound **5a** (1 g, 3.6 m mol) was added to 80 mL of the phosphorus pentoxide–methanesulfonic acid[5] reagent and the reaction was stirred under nitrogen for 4 H. Water was added to quench the reaction and the product was isolated by extraction with chloroform. After the chloroform extract was washed with water and dilute sodium bicarbonate solution and dried ($MgSO_4$), the solution was concentrated to dryness. The residue, a yellow solid, was treated with a solution of 1 g of chromium trioxide in 50 mL of glacial acetic acid containing 10 drops of water and heated to boiling for 2 min. The oxidation product was isolated by precipitating it with water, filtering it off, and drying and purified by vacuum sublimation at 130 °C, 0.55 g (60%), mp 165–167 °C (reported[9] mp 167–169 °C).

This experiment was repeated with *endo*-**4a** as starting material. a 25% yield of **8** was obtained.

Preparation of 7-Acetoxybenz[a]anthracene (10a). The Diels–Alder adduct **4a** (1g, 3.4 m mol, 1:1 *exo*/*endo*) was aromatized and isomerized by DBU as previously described. The crude aromatic ester **5a** was hydrolyzed with excess potassium hydroxide in refluxing 1:1 methanol/water and the carboxylic acid **9a** isolated by acidifying the final solution with aqueous HCl. The acid **9a** was filtered off, washed with water, and dried, 0.84 g (94%).

The crude acid was dissolved in a solution of 0.046 g (0.34 mmol) of anhydrous zinc chloride in 100 mL of 1:1 v/v acetic acid/acetic anhydride and the solution refluxed for 1 h. Addition of water precipitated the product, which was filtered, washed with water, and dried, 0.82 g, mp 158–160 °C. After recrystallization from 1:1 acetic acid/water, 0.76 g (78% based on **4a**) of **10a**, mp 162–163 °C (reported[4] mp 163–163.5 °C), was obtained: NMR δ 2.60 (s, 3 H), 7.0–8.8 (m, 10 H), 8.97 (s, 1 H); IR (Nujol) 1770, 1350, 1210, 1150, 1060, 870, 790, 730, 720 cm^{-1}.

Preparation of 7-Acetoxy-9-methoxybenz[a]anthracene (10c). The ester **5c** (1.14 g, 3.7 mmol) was similarly hydrolyzed and cyclized to give 1.02 g (86%) of **10c**, mp 176–180 °C. Two recrystallizations from toluene gave an analytical sample: mp 184–6 °C; NMR δ 2.63 (s, 3 H), 3.98 (s, 3 H), 7.0–8.9 (m, 9 H), 9.03 (s, 1 H); IR (Nujol) 1750, 1635, 1220, 1210, 1200, 1170, 1010, 870, 820, 800, 790 cm^{-1}.

Preparation of 7-Acetoxy-9-methoxy-1,4-dimethylbenz[a]anthracene (10d). In this case no product was purified from the initial 3-(*p*-methoxybenzal)-4,7-dimethylphthalide to the final product **10d**. Thus, 2.9 g (10.9 mmol) was reduced with LAH and reacted with methyl acrylate under acidic conditions in toluene and concentrated under vacuum to give 3.7 g of crude **4d**. This was aromatized as previously described to give a mixture of **5d** and **6d** (3:1 ratio). Hydrolysis of the aromatized ester was effected as described, and the mixed acids were subjected to the cyclization

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conditions. The crude reaction product was stirred for 1 h with 5% aqueous sodium carbonate solution, filtered, washed with water, and dried, 2.1 g (56% based on phthalide), mp 183–190 °C.

An analytical sample was obtained by recrystallization from toluene: mp 196–197 °C; NMR 2.65 (s, 3 H), 2.72 (s, 3 H), 3.17 (s, 3 H), 4.00 (s, 3 H), 7.1–8.1 (m, 7 H), 9.18 (s, 1 H); IR (Nujol) 1760, 1630, 1200, 1180, 1010, 860, 810, 800 cm^{-1}.

Preparation of 7-Acetoxy-1,4-dimethylbenz[*a*]anthracene (10b). Beginning with 2.4 g of 3-benzal-4,7-dimethylphthalide, there was obtained, after LAH reduction, Diels-Alder reaction with methyl acrylate, aromatization, and DBU isomerization, 2.3 g of the naphthoate derivative **5b**. Trouble was encountered in attempting to continue the sequence without purification. Therefore 1.1 g of crude **5b** was chromatographed on silica gel, eluting with 1:1 methylene chloride/30–60 °C petroleum ether graded to methylene chloride. After elution of 115 mg of material of uncertain structure, 670 mg of a 3:1 mixture of **5b/6b** (46% yield based on the phthalide) was collected followed by 120 mg of the unaromatized Diels-Alter adduct *endo*-**4b** (8% yield based on the phthalide).

The mixture of **5b** and **6b** was hydrolyzed and cyclized and the crude product washed with dilute $NaHCO_3$ as described to give 0.493 g (71% yield based on the naphthoate ester **5b/6b**) of **10b**, mp 202–204 °C. One recrystallization from toluene, and an additional bicarbonate wash followed by another recrystallization gave the analytical sample: mp 212–214 °C; NMR ($CDCl_3$) 2.61 (s, 3 H) 2.69 (s, 3 H), 3.15 (s, 3 H), 7.3–8.3 (m, 8 H), 9.32 (s, 1 H); IR (Nujol) 1755, 1210, 860, 790, 775, 720 cm^{-1}.

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Registry No. **1a**, 54933-15-2; **1b**, 78963-13-0; **1c**, 78963-14-1; **1d**, 78963-15-2; **2c**, 73194-66-8; **3a**, 54892-75-0; **3b**, 78891-76-6; **3c**, 78891-77-7; **3d**, 78891-78-8; *endo*-**4a**, 73245-14-4; *exo*-**4a**, 73194-98-6; *endo*-**4b**, 78891-79-9; *exo*-**4b**, 78963-16-3; *endo*-**4c**, 78891-80-2; *exo*-**4c**, 78963-17-4; *endo*-**4d**, 78891-81-3; *exo*-**4d**, 78963-18-5; **5a**, 73194-63-5; **5b**, 78891-82-4; **5c**, 78891-83-5; **5d**, 78891-84-6; **6b**, 78891-85-7; **6c**, 78891-86-8; **6d**, 78891-87-9; **8**, 2498-66-0; **9a**, 73194-80-6; **10a**, 25040-01-1; **10b**, 78919-59-2; **10c**, 78919-60-5; **10d**, 78919-61-6; 3-(*p*-methoxybenzal)phthalide, 4767-61-7; methyl acrylate, 96-33-3; 3-benzal-4,7-dimethylphthalide, 78919-62-7; 3-(*p*-methoxybenzal)-4,7-dimethylphthalide, 78919-63-8; 3-(carbomethoxy)-1,4-epoxy-1-(*p*-methoxyyphenyl)-5,8-dimethyl-1,2,3,4-tetrahydronaphthalene, 78919-64-9; 1-(*p*-methoxybenzal)phthalan, 64421-15-4.

Synthesis with Tin Templates: Preparation of Macrocyclic Tetralactones

Abraham Shanzer,*† N. Mayer-Shochet,† F. Frolow,‡ and D. Rabinovich‡

Departments of Organic and Structural Chemistry, The Weizmann Institute of Science, Rehovet, Israel

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A new approach toward the preparation of macrocyclic lactones is introduced. The method is based on the use of tin derivatives as covalent templates. The latter are capable of directing the condensation of acyclic diols and diacyl dihalides to provide macrocyclic tetralactones as the sole ring products. The usefulness of the method is demonstrated by the preparation of a series of symmetric (**6–9**) as well as mixed (**10**) lactones in high yields. The mechanistic implications of the method will be discussed as will the structural regularities of the newly synthesized compounds.

Polyfunctional macrocyclic compounds are receiving increasing attention because they may selectively bind a large range of metal ions.[1,2] Macrocyclic compounds are therefore being used as catalysts in synthesis (capable of solubilizing salts in organic solvents) and as key components in various metal separation techniques. The growing need for macrocyclic ligands has stimulated extensive research efforts toward their efficient preparation and much progress has been made in this field.[3] Yet, the synthesis of polyfunctional macrocycles still poses serious difficulties and generally provides mixtures of cyclic and acyclic products. The preparation of one class of polyfunctional systems, polylactones, has hitherto been achieved by two major methods: by condensation of dibasic acid derivatives with glycols or dihalides using high dilution techniques[4] or by depolymerization of linear polyesters.[5] Both methods provide mixtures of macrocyclic dilactones and tetralactones, the ratio of which is determined by the relative stability of the two ring systems. In this publication we introduce a new method for the preparation of macrocyclic lactones which yields tetralactones as sole ring products. In addition, we describe the structural regularities of the synthesized polyfunctional systems.

In an attempt to provide an efficient method for the preparation of macrocyclic polylactones, we undertook the use of tin derivatives as covalent templates. The use of a template was believed to favor ring formation, and the choice of tin as the template was based on its chemical properties. Tin, like other metalloids, does readily react with difunctional organic residues to give heterocyclic intermediates such as cyclic stannoxanes. The latter are highly reactive chemical entities which are expected to condense efficiently with difunctional organic substrates to provide ring products.[6] This expectation was indeed realized. By use of a series of four different cyclic stan-

† Department of Organic Chemistry.
‡ Department of Structural Chemistry.

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