

Perhydroindan Derivatives. XIV. Derivatives of 6-Methoxyindene^{1a}HERBERT O. HOUSE,*^{1b} CHRISTOPHER B. HUDSON, AND ELIA J. RACAH^{1c}

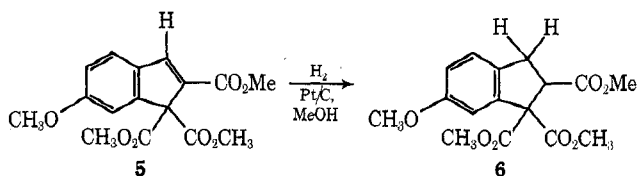
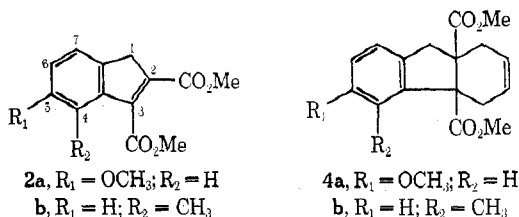
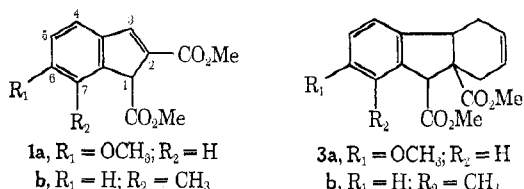
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The isomeric 2-carbomethoxyindenes **16** and **17** have been synthesized and studied as dieneophiles in the Diels-Alder reaction to form tetrahydrofluorenes **26** and **27**. Although the indenes isomerize under the conditions of the Diels-Alder reaction, it was possible to prepare the desired 7-methoxytetrahydrofluorene derivative **26** in reasonable yield when the indene precursor **17** had a carbomethoxy substituent at C-7.

In seeking a preparative route to the tetrahydrofluorene derivatives **3**² (Scheme I) as potential precursors

SCHEME I



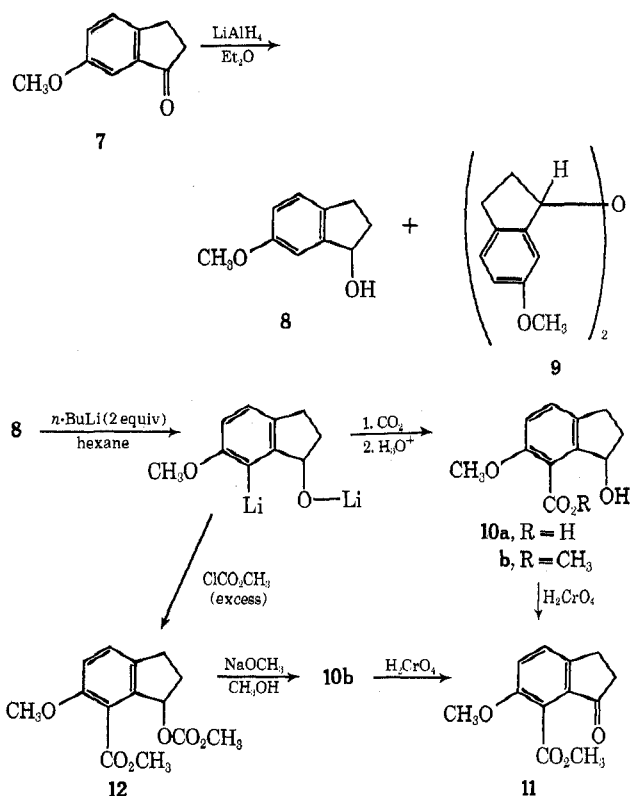
sors for the gibberellins, we found that, although the 7-methylindene derivative **1b** reacted with butadiene to form the expected Diels-Alder adduct **3b**,^{2a} the 6-methoxyindene diester **1a** formed adduct **4a**, an isomer of the desired product **3a**.^{2b} It was apparent that the starting indene **1a** was equilibrating with its double bond isomer **2a** under the rather vigorous conditions required for the Diels-Alder reaction. The formation of largely (if not exclusively) the adduct **4a** suggested that the indene **2a** was more stable than **1a**, that the indene **2a** was a more reactive dienophile than **1a**, or that some combination of these two factors determined the principal course of this reaction. An initial attempt to solve this problem by the preparation and use of the indene triester **5** (prepared from **1a** with NaH and ClCO₂CH₃) was not satisfactory because we were unable to isolate any pure adduct from reaction of butadiene with the sterically hindered triester **5**. Consequently, we have examined the use of various substituents to control the proportions of 6-methoxyindene derivatives and their double bond isomers which are present in reaction mixtures.

(1) (a) This research has been supported by Public Health Service Grant R01-CA-12634 from the National Cancer Institute. (b) Department of Chemistry, Georgia Institute of Technology, Atlanta, Ga. 30332. (c) National Institutes of Health Predoctoral Fellow, 1968-1971.

(2) (a) H. O. House, F. J. Sauter, W. G. Kenyon, and J. J. Riehl, *J. Org. Chem.*, **33**, 957 (1968); (b) H. O. House, J. K. Larson, and H. C. Müller, *ibid.*, **33**, 961 (1968).

The successful use of the indene **1b** to form the desired tetrahydrofluorene **3b** has been attributed² to the fact that isomerization of **1b** to the indene **2b** (the precursor of **4b**) would be opposed by a serious steric interaction between the two coplanar peri substituents (R₂ and CO₂CH₃) in **2b**.³ Consequently, in our further study of 6-methoxyindene precursors for the tetrahydrofluorenes **3**, we elected to introduce a C-7 carbomethyl group into the indene; this substituent, which would be useful at a later stage in our synthetic scheme, was expected to favor the desired indene double bond isomer (*i.e.*, **1** rather than **2**) for the steric reason discussed above. To prepare an appropriate synthetic intermediate **11**, the procedures outlined in Scheme II

SCHEME II



were employed. This scheme, starting with the methoxyindanone **7**,⁴ utilizes the selective ortho metalation⁵ of the alcohol **8** to introduce the desired car-

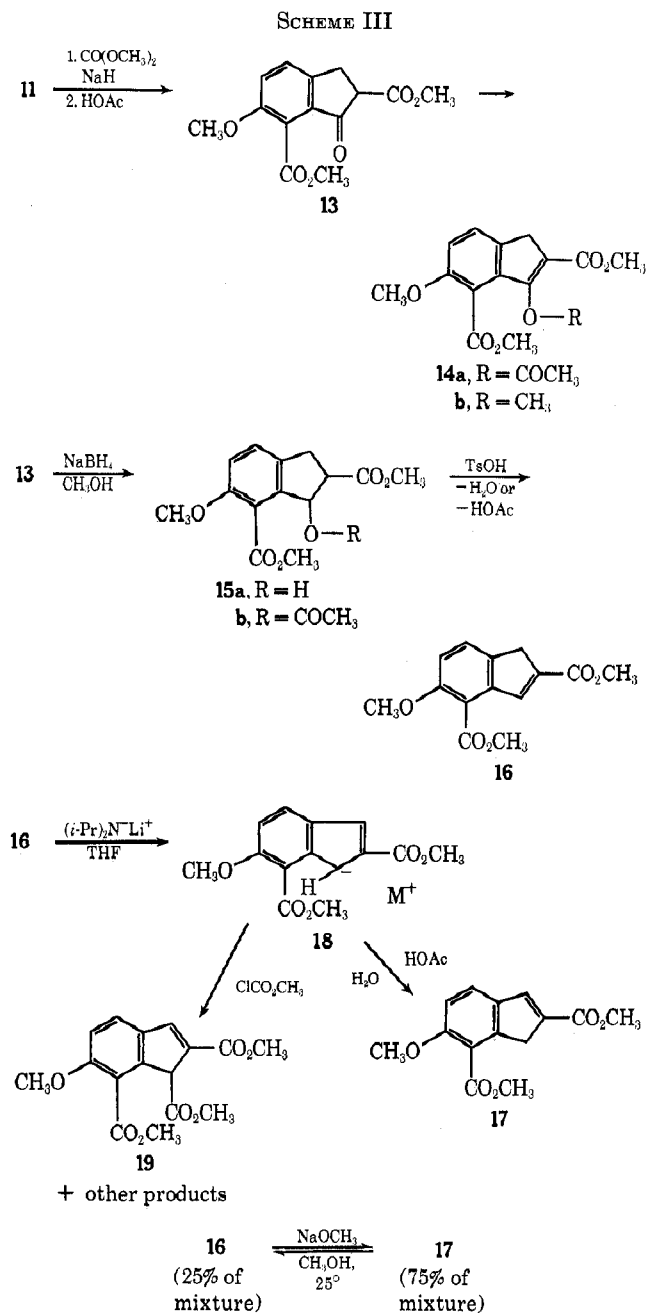
(3) (a) In the absence of such a steric interaction, the two isomeric indenes are of about equal stability: D. G. Lindsay, B. J. McGreevy, and C. B. Reese, *Chem. Commun.*, 379 (1965). (b) When alkyl substituents are present at the 1 and 3 positions of indene, the favored double-bond isomer is the one with the smaller alkyl group at the double bond: J. Almy and D. J. Cram, *J. Amer. Chem. Soc.*, **91**, 4459 (1969).

(4) H. O. House and C. B. Hudson, *J. Org. Chem.*, **35**, 647 (1970).

(5) See H. O. House, T. M. Bare, and W. E. Hanners, *J. Org. Chem.*, **34**, 2209 (1969), and references cited therein.

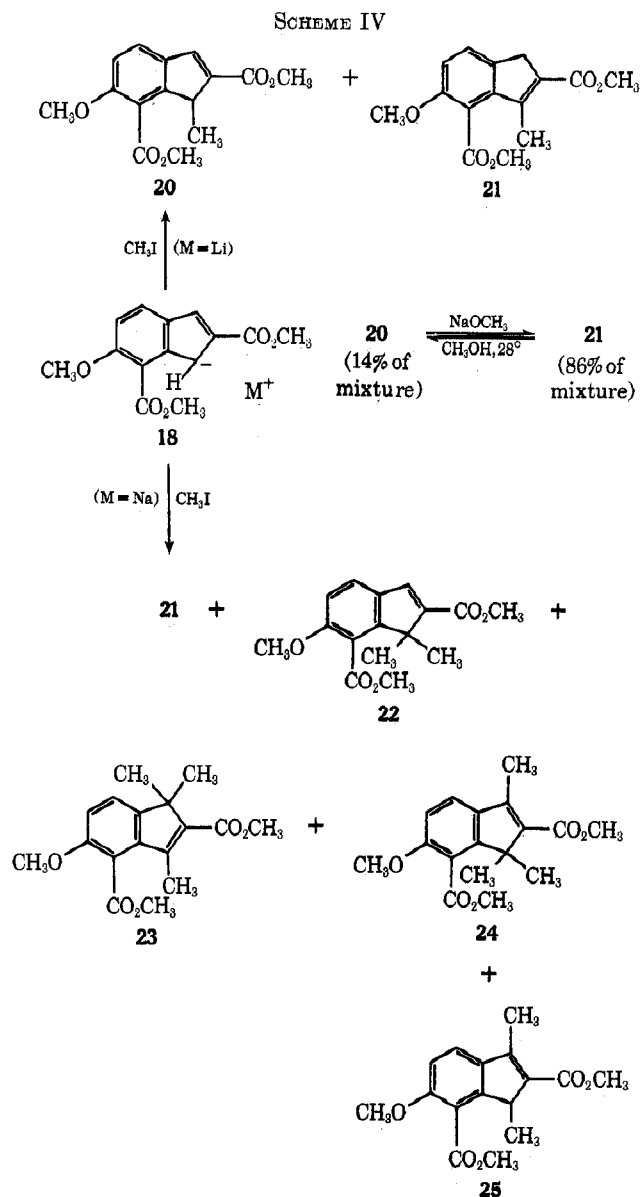
boxyl function at C-7. By formation of the crude diester **12** followed by alcoholysis and oxidation the indanol **8** was converted to the keto ester **11** in an overall yield of 58%.

The further conversion of the keto ester **11** to the indenediester **16** is summarized in Scheme III. When the



indanyl anion **18** (M = Li) formed from this ester **16** was protonated under kinetically controlled conditions, the major product (80–85% of the mixture) was the desired indene **17**. At equilibrium (25° in MeOH), the mixture of these two indenenes contained 25% of **16** and 75% of **17**. Although we were able to obtain the triester **19** from the anion **18** in poor yield, we have thus far been unsuccessful in forming a tricarboxylic acid derivative in high yield. Methylation (Scheme IV) of

(6) The uv spectra of the isomeric indenenes **16** [244 mμ (ε 15,600), 283 (14,300), 330 (6100)] and **17** [245 mμ (ε 8550), 307 (20,000)] differ sufficiently to allow us to assign structures to other derivatives that have one of these two chromophores.



the indanyl anion **18** (M = Li) produced the 1-methylindene **20** which isomerized with great ease to the isomer **21**,⁶ at equilibrium (28° in MeOH), the mixture contained 14% of **20** and 86% of **21**. This equilibrium composition is unexpected on steric grounds since the major component **21** possesses the same unfavorable steric interaction between coplanar CH₃ and CO₂CH₃ groups which is believed to destabilize the indene **2b** with respect to its isomer **1b**. It appears that the general tendency of indene isomers to be more stable with a substituent at the olefinic C-3 position rather than C-1,⁸ is sufficiently great to overcome the unfavorable steric interaction. Methylation of the sodium derivative of the indanyl anion **18** (M = Na) produced both the monomethyl product **21** and a series of di- and trimethylated products believed to possess structures

(7) For example, see (a) K. Bott, *Tetrahedron Lett.*, 4569 (1965); (b) O. Meth-Cohn and S. Gronowitz, *Chem. Commun.*, 81 (1966); (c) A. Melera, M. Claesen, and H. Vanderhaeghe, *J. Org. Chem.*, **29**, 3705 (1964); (d) R. C. Kerber and M. Hodos, *ibid.*, **33**, 1169 (1968).

(8) From studies of the equilibration of 1-methylindene and 3-methylindene, it is clear that the equilibrium mixture contains at least 90% of the 3-methyl isomer: H. Christol, F. Plenat, and C. F. Huebner, *Bull. Soc. Chim. Fr.*, 2640 (1964); A. M. Weidler and G. Bergson, *Acta Chem. Scand.*, **18**, 1487 (1964), and references cited therein.

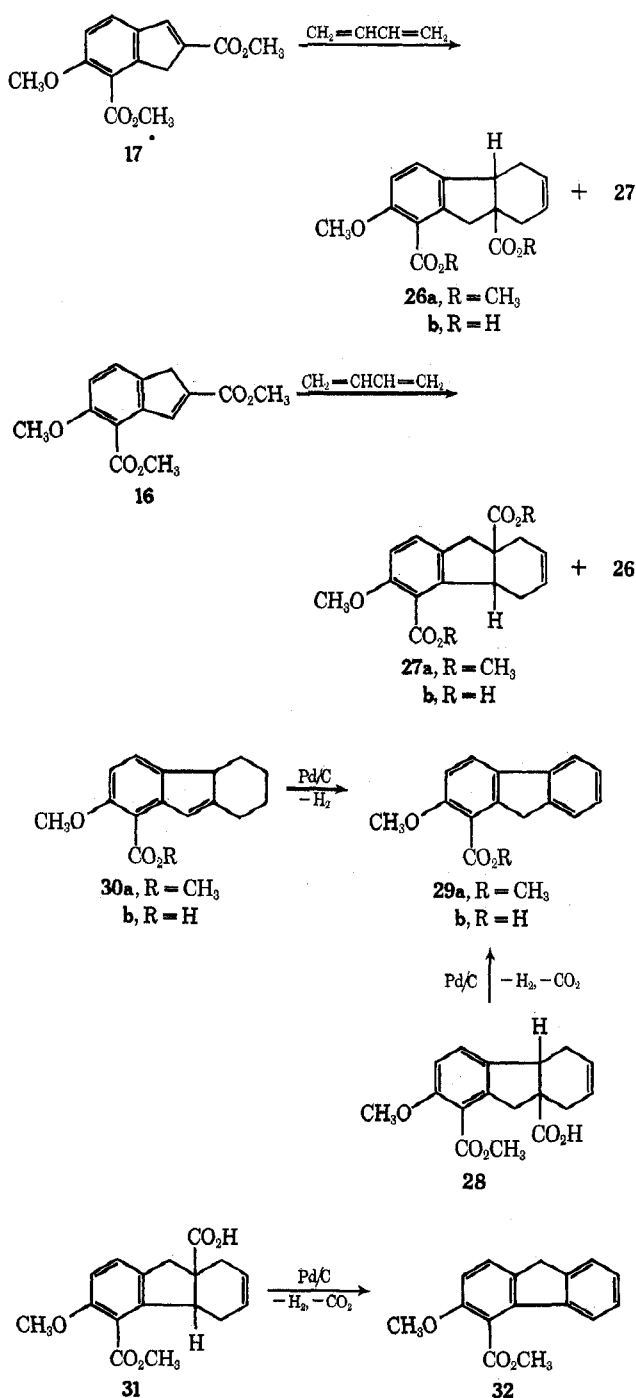
22-25. Although we did not obtain sufficient amounts of these materials for complete characterization, it is pertinent to observe that the dimethyl product **25**⁶ does appear to exist predominantly as the indicated double bond isomer, which avoids the previously discussed steric interaction.

The foregoing data led us to select the indene **17** for study as a dienophile with butadiene. As illustrated in Scheme V, the conditions required to effect the Diels-

were performed on a small scale in sealed glass vessels, each of the double bond isomers **16** and **17** gave a slight excess of the expected tetrahydrofluorene **26a** or **27a**. However, in preparative scale reactions performed in an autoclave, equilibration of the indenenes⁹ clearly occurred more rapidly than the Diels-Alder reaction so that the same mixture of tetrahydrofluorenes **26a** and **27a** was obtained from either indene **16** or **17**. Each of the adducts **26a** and **27a** appeared to be stable to the conditions of the Diels-Alder reaction.

The mixture of diesters **26a** and **27a** produced in this reaction could be separated effectively by saponification and fractional crystallization of the diacids **26b** and **27b**. Fortunately, the desired tetrahydrofluorene **26b** was the less soluble and consequently the more easily isolated. Although the structures of the two tetrahydrofluorenes were tentatively assigned from the results of small-scale Diels-Alder reactions (**17** → mainly **26a** and **16** → mainly **27a**), further verification of the structure for adducts **26** was clearly desirable. For this reason we dehydrogenated the crude monoester **28** (from **26b** and 1 equiv of CH_2N_2) to form the fluorene ester **29a**, which was also prepared by dehydrogenation of the known⁵ tetrahydro ester **30a**. The corresponding dehydrogenation-decarboxylation reaction applied to the crude isomeric monoester **31** (from **27b** and 1 equiv of CH_2N_2) produced the previously unknown fluorene ester **32**.

SCHEME V



Experimental Section¹⁰

Preparation of the Triester 5.—To a suspension of 1.1 g (46 mmol) of NaH (previously washed with pentane) in 10 ml of 1,2-dimethoxyethane (DME) was added a solution of 2.6 g (10 mmol) of the diester **1a**, mp 96–99° (lit.^{2b} mp 97–98.5°). After the H₂ evolution (215 ml or 0.87 equiv) ceased, the pale green suspension was treated with 2.86 g (30 mmol) of ClCO_2Me and the resulting mixture was refluxed for 5 hr. After the solution had been cooled and neutralized with 5 ml of HOAc, it was poured onto ice. The solid product was collected and combined with the benzene extract of the filtrate after the extract had been washed (aqueous NaHCO_3 and aqueous NaCl), dried, and concentrated. Crystallization from MeOH afforded 2.8 g (88%) of fractions of the crude triester, melting range 138–149.5°. Recrystallization (MeOH) separated 2.33 g (73%) of the triester **5** as tan needles, mp 149–150.5°. Sublimation at 140° (0.05 mm) afforded the pure triester **5** as white needles: mp 149–150°; ir (CCl_4) 1740 (unconjugated ester C=O) and 1720 cm^{-1} (conjugated ester C=O); nmr (CDCl_3) δ 6.8–7.8 (4 H m, aryl and vinyl CH), 3.85 (3 H s, OCH_3), 3.83 (3 H s, OCH_3), and 3.72 (6 H s, OCH_3); mass spectrum m/e (rel intensity) 320 (18, M⁺), 57 (31), 56 (39), 55 (25), 44 (100), 43 (23), 41 (73), and 39 (29); uv (95% EtOH) 241 $\text{m}\mu$ (ϵ 13,400), 310 (13,700), and 323 (13,900); uv (95% EtOH with added 0.1 M aqueous NaOH) 240 $\text{m}\mu$ (ϵ 13,200), 310 (13,600), and 323 (13,700). For comparison the corresponding values for the starting diester **1a** with an acidic H atom are uv (95% EtOH) 237 $\text{m}\mu$ (ϵ 11,500), 308 (16,200), and 318 (16,200); uv (95% EtOH with added EtOK) 260 $\text{m}\mu$ (sh, ϵ 14,900), 289 (23,200), and 340 (11,700). When this latter basic solution was acidified (aqueous HCl), it exhibited the same spectrum as the original diester **1a**.

Alder reaction were sufficiently vigorous to cause interconversion of the isomeric indenenes **16** and **17**.⁹ When the reactions of each of the isomeric indenenes **16** and **17**

(9) We presume that this interconversion is not a thermal process but, rather, was catalyzed by traces of either acidic or basic substances which were present in the reaction mixtures.

(10) All melting points are corrected and all boiling points are uncorrected. Unless otherwise stated, magnesium sulfate was employed as a drying agent. The infrared spectra were determined with a Perkin-Elmer Model 237 infrared recording spectrophotometer fitted with a grating. The ultraviolet spectra were determined with a Cary recording spectrophotometer, Model 14. The nmr spectra were determined with a Varian Model A-60, T-60, or HA-100 nmr spectrometer. The chemical shift values are expressed either in Hertz or δ values relative to a tetramethylsilane internal standard. The mass spectra were obtained with a Hitachi (Perkin-Elmer) mass spectrometer. All reactions involving strong bases or organometallic intermediates were performed under a nitrogen atmosphere.

Anal. Calcd for $C_{18}H_{18}O_7$: C, 60.00; H, 5.04. Found: C, 59.89; H, 5.04.

Hydrogenation of the Triester 5.—A solution of 409 mg (1.28 mmol) of the unsaturated ester **5** in 45 ml of MeOH was hydrogenated at 45° and 1 atm over 45 mg of a 5% Pt/C catalyst. After an H_2 uptake of 47.7 ml (1.2 equiv), the reaction was stopped and the mixture was filtered and concentrated. Crystallization of the residual oil from a benzene-hexane mixture separated 275 mg (67%) of the triester **6** as tan prisms, mp 75–76°. Recrystallization from MeOH gave the pure triester **6** as colorless needles: mp 76–77°; ir (CHCl₃) 1740 cm^{-1} (ester C=O); uv (95% EtOH) 283 $m\mu$ (ϵ 3060); nmr (CDCl₃) δ 6.7–7.3 (3 H m, aryl CH), 3.77 (3 H s, OCH₃), 3.74 (3 H s, OCH₃), 3.66 (6 H s, OCH₃), with a multiplet centered at δ 4.08 (1 H, CH) and a broad doublet (both J values \sim 8 Hz) centered at 3.23 (2 H, benzylic CH₂); mass spectrum m/e (rel intensity) 322 (18, M⁺), 263 (29), 262 (100), 212 (23), 211 (40), 168 (27), 154 (35), 78 (23), 56 (22), and 43 (28).

Anal. Calcd for $C_{16}H_{16}O_7$: C, 59.62; H, 5.63. Found: C, 59.53; H, 5.71.

6-Methoxy-1-indanol (8).—The methoxyindanone **7**⁴ was reduced with ethereal LiAlH₄ to produce the alcohol **8** in 92–94% yield. The pure alcohol **8** crystallized from hexane as colorless plates, mp 46–47.5° (lit.¹¹ mp 47–48.5°), ir (CCl₄) 3590 and 3340 cm^{-1} (free and associated OH).

When a partially purified sample of this alcohol **8** was allowed to stand for several months, partial decomposition (presumably acid-catalyzed) of the sample was evident. Two recrystallizations (MeOH) of this crude product separated the dimeric ether **9** as white needles: mp 91.5–92°; ir (CCl₄) no OH or C=O in 3 or 6 μ regions; uv (95% EtOH) 283 $m\mu$ (ϵ 6560) and 288 (sh, 5950); nmr (CDCl₃) δ 6.6–7.3 (6 H m, aryl CH), 5.03 (2 H t, J = 6 Hz, >CHO), 3.68 (6 H s, OCH₃), and 1.8–3.4 (8 H m, aliphatic CH); mass spectrum m/e (rel intensity) 146 (100), 131 (50), 91 (17), and 77 (16).

Anal. Calcd for $C_{20}H_{22}O_8$: C, 77.39; H, 7.14. Found: C, 77.64; H, 6.93.

Preparation of the Hydroxy Acid 10.—A mixture of 26.4 g (0.161 mol) of the alcohol **8** and 31.0 g (0.323 mol) of freshly sublimed *tert*-BuONa in 500 ml of hexane was metalated with 0.323 mol of *n*-BuLi in 135 ml of hexane and the resulting mixture was carbonated with Dry Ice.¹² After acidification the acid **10a** (31.1 g, mp 159° dec) was collected; extraction of the aqueous filtrate with EtOAc separated an additional 7.95 g of the crude acid **10a**. From the various hexane and Et₂O solutions of neutral products, the unchanged alcohol **8** was recovered as 725 mg of colorless plates from hexane, mp 46–47.5°. The yield of acid **10a** based on unrecovered alcohol **8** was 89%. A pure sample of the acid **10a** was obtained as colorless prisms from EtOAc: the decomposition point varied within the range 150–151° to 160–161° (dependent on rate of heating); ir (CHCl₃) 3500 and 3240 (associated OH) and 1725 cm^{-1} (carboxyl C=O); uv (95% EtOH) 296 $m\mu$ (ϵ 3200); nmr (pyridine-*d*₅) δ 11.07 (1 H s, COOH, exchanged with D₂O), 7.42 (1 H d, J = 8.5 Hz, aryl CH), 7.09 (1 H d, J = 8.5 Hz, aryl CH), 5.96 (1 H m, >CHO), 3.84 (3 H s, OCH₃), and 2.2–3.3 (5 H m, aliphatic CH and OH, 1 H exchanged with D₂O).

Anal. Calcd for $C_{11}H_{12}O_4$: C, 63.45; H, 5.81. Found: C, 63.41; H, 5.78.

In a subsequent preparation¹² a solution of 192 mmol of *n*-BuLi in 120 ml of hexane was added, dropwise and with stirring, to a suspension of 15.68 g (96 mmol) of the alcohol **8** in 300 ml of hexane. The bright red mixture was stirred at 25° for 1 hr and then added to excess Dry Ice. After the usual isolation procedure, manipulation of the neutral fraction separated 4.18 g (26.5%) of the starting alcohol **8**, mp 45–47°. Acidification, filtration, and subsequent extraction (EtOAc) of the aqueous phase separated a total of 13.25 g (66.5% or 91% based on unrecovered alcohol **8**) of fractions of the acid **10a** with decomposition points in the range 157–158 to 160–161°.

After 8.43 g (40.5 mmol) of the acid **10a** had been esterified with excess ethereal CH₃N₂, the residual neutral product (9.19 g, mp 55–56°) was recrystallized (pentane) to give the pure ester **10b** as colorless rods: mp 55–55.5°; ir (CCl₄) 3590 and 3530 (free and

associated OH), 1740 (w), and 1700 cm^{-1} (s) (ester C=O); uv (95% EtOH) 204 $m\mu$ (ϵ 26,400) and 292 (3400); nmr (CDCl₃) δ 7.22 (1 H d, J = 8.5 Hz, aryl CH), 6.82 (1 H d, J = 8.5 Hz, aryl CH), 5.21 (1 H m, CHO), 3.90 (3 H s, OCH₃), 3.78 (3 H s, OCH₃), and 2.0–3.3 (5 H m, OH and aliphatic CH); mass spectrum m/e (rel intensity) 222 (23, M⁺), 194 (50), 189 (100), 173 (25), 162 (50), 161 (20), 115 (25), 105 (25), 104 (39), 103 (29), 91 (32), 77 (29), 63 (20), 51 (20), and 39 (20).

Anal. Calcd for $C_{12}H_{14}O_4$: C, 64.85; H, 6.35. Found: C, 64.96; H, 6.29.

Preparation of the Keto Ester 11.—To a cold (0°), stirred solution of 1.55 g (7.0 mmol) of the hydroxy ester **10b** in 15 ml of acetone was added 2.5 ml of acidic aqueous 2.67 *M* H₂CrO₄ reagent.¹³ The excess oxidant was consumed with *i*-PrOH and the mixture was partitioned between H₂O and EtOAc. The organic layer was washed (aqueous NaCl), dried, and concentrated to leave the crude ketone **11** as 1.43 g (93%) of yellow solid, mp 125–126°. Recrystallization (acetone-hexane mixture) afforded the pure keto ester **11** as colorless prisms: mp 127–127.5°; ir (CHCl₃) 1735 (ester C=O) and 1715 cm^{-1} (C=O); uv (95% EtOH) 248 $m\mu$ (ϵ 7100) and 322 (4700); nmr (CDCl₃) δ 7.45 (1 H d, J = 8.5 Hz, aryl CH), 7.20 (1 H d, J = 8.5 Hz, aryl CH), 3.95 (3 H s, OCH₃), 3.85 (3 H s, OCH₃), and 2.5–3.2 (4 H m, aliphatic CH); mass spectrum m/e (rel intensity) 220 (38, M⁺), 205 (38), 189 (100), 103 (26), 89 (22), 78 (21), and 77 (26).

Anal. Calcd for $C_{12}H_{12}O_4$: C, 65.44; H, 5.49. Found: C, 65.75; H, 5.47.

In subsequent experiments the hydroxy acid **10a** was esterified (CH₃N₂) and oxidized without isolation of the intermediate. Thus, 13.25 g of the acid **10a** was converted to 11.42 g (81.5%) of the keto ester **11**, mp 126–127°.

Preparation of the Diester 12.—After a mixture of 44 mmol of *n*-BuLi and 3.18 g (19.6 mmol) of the indanol **8** in 128 ml of hexane had been allowed to react for 4 hr at 25° as previously described, the mixture was added to a cold (0°), stirred solution of 9.5 ml (95 mmol) of ClCO₂Me in 50 ml of hexane. The resulting white suspension was acidified (HOAc) and partitioned between Et₂O and aqueous NaHCO₃, and the ethereal layer was washed with aqueous NaCl and then dried and concentrated. After further concentration under reduced pressure (0.3 mm and 40–50° to remove methyl valerate), the residual orange liquid (4.95 g) contained (tlc, silica gel coating and a PhH-Et₂O eluent) the desired diester **12** and a more rapidly eluted impurity. A benzene solution of this crude product was filtered through Florisil and a 2.53-g aliquot of the resulting crude product was chromatographed on 400 g of silica gel (Davison No. 922) packed in a 3.8 × 50 cm column of nylon tubing. After the chromatogram had been developed with a hexane-Et₂O mixture (2.5:1 v/v), the column was scanned with a uv lamp and the sections containing the diester **12** were removed and washed with Et₂O. The diester **12** was obtained as a yellow oil which crystallized on standing in the cold. Recrystallization from cold Et₂O afforded the partially purified diester **12** as white needles, mp 41–42°, which rapidly discolored on standing; ir (CCl₄) 1750 cm^{-1} (broad, ester C=O); uv max (95% EtOH) 296 $m\mu$ (ϵ 3610) with intense end absorption (ϵ 31,500 at 204 $m\mu$); nmr (CCl₄) δ 7.13 (1 H d, J = 8.2 Hz, aryl CH), 6.80 (1 H d, J = 8.2 Hz, aryl CH), 6.0–6.3 (1 H m, benzylic CHO), 1.8–3.2 (4 H m, aliphatic CH), and three 3 H singlets at δ 3.77, 3.73, and 3.70 (three OCH₃ groups); mass spectrum m/e (rel intensity) 280 (3, M⁺), 204 (41), 189 (24), 173 (51), 172 (100), 115 (23), and 59 (45).

A solution of 1.08 g (3.99 mmol) of the diester **12** in 10 ml of MeOH was treated with 6 mmol of NaOMe in 6 ml of MeOH. After the resulting solution had been stirred at 25° for 3.5 hr, it was acidified (HOAc) and partitioned between Et₂O and aqueous NaHCO₃. The ethereal layer was washed with aqueous NaCl, dried (Na₂SO₄), and concentrated to leave 0.9 g of orange liquid containing (tlc) primarily the hydroxy ester **10b**. Crystallization from pentane separated 573 mg (66%) of the hydroxy ester **10b**, mp 50–54.5°. Recrystallization gave the pure ester **10b**, mp 53–54.5°.

The most efficient preparative route to the keto ester **11** involved the successive conversion of the indanol **8** to the diester **12**, the hydroxy ester **10b**, and the ketone **11** without purification of intermediates. In a typical preparation 24.05 g (147 mmol) of the indanol **8** was metalated with *n*-BuLi and *tert*-BuOLi [from 14.6 g (154 mmol) of *tert*-BuOH and 510 mmol of *n*-BuLi], acylated with 80 ml (1.0 mol) of ClCO₂CH₃, transesterified with

(11) J. C. Winter, D. D. Godse, and P. K. Gessner, *J. Org. Chem.*, **30**, 3231 (1965).

(12) This carboxylation procedure was described previously.⁸ In this study we have been able to achieve the same specificity without adding *tert*-BuONa. In this way the tedious purification of *tert*-BuONa is avoided.

(13) D. C. Kleinfelter and P. v. R. Schleyer, *Org. Syn.*, **42**, 79 (1962).

154 mmol of NaOMe in 177 ml of MeOH (containing 0.5 ml of HCO_2Me to remove any NaOH), and oxidized with 150 mmol of H_2CrO_4 in 300 ml of acidic aqueous acetone to give 29.5 g of the crude ketone 11 as a yellow solid. Recrystallization (CCl_4) separated 17.92 g of the keto ester 11 as tan prisms, mp 120–124.5°; 920 mg (3.9%) of 6-methoxyindanone 7 (mp 100–105°, needles from hexane) and 1.84 g of the keto ester, mp 120–124° (prisms from CCl_4), were recovered from the mother liquors. Thus, the overall yield of the keto ester 11 was 19.76 g (57.9% based on the indanol 8).

Preparation of the Keto Diester 13.—A solution of 4.06 g (18.5 mmol) of the keto ester 11 in 30 ml of PhH was added, dropwise and with stirring over 1 hr, to a warm (55–60°) mixture of 1.20 g (50 mmol) of NaH, 9.9 g (110 mmol) of $(\text{MeO})_2\text{CO}$, and 30 ml of PhH. After the resulting mixture had been stirred at 60° for 30 min, it was cooled, neutralized with 5 ml of HOAc, poured into ice water, and acidified with HCl to pH 2. The organic layer was separated, combined with the PhH extract of the aqueous phase, and then washed (aqueous NaHCO_3 and aqueous NaCl), dried, and concentrated. Crystallization of the residue from MeOH separated 4.125 g (80.5%) of a mixture of keto and enol forms of the keto diester 13 as orange prisms: mp 120–125°; the broad melting range was not altered by recrystallization; ir (CHCl_3) 1735 (br, ester C=O) and 1655 cm^{-1} (enol C=C); uv (95% EtOH), 217 $\text{m}\mu$ (ϵ 17,700), 251 (6400), 301 (6200), and 322 (br, 6600); nmr (CDCl_3) δ 10.2 (ca. 0.2 H br, enol OH), 6.8–7.2 (2 H m, aryl CH), a series of singlets at 3.88, 3.75, and 3.68 (total 9 H, OCH_3), and 3.0–4.6 (ca. 3 H m, aliphatic CH).

Anal. Calcd for $\text{C}_{14}\text{H}_{14}\text{O}_6$: C, 60.43; H, 5.07. Found: C, 60.45; H, 5.09.

A mixture of 1.39 g (5.0 mmol) of the keto diester 13, 3.0 ml of Ac_2O , and 10 ml of CCl_4 was treated with 1 drop of aqueous 70% HClO_4 . The crystalline product began to separate from the resulting red solution after 1 min. After the mixture had been partitioned between aqueous NaHCO_3 and CHCl_3 , the organic layer was dried and concentrated. Recrystallization of the solid residue (1.602 g) from MeOH separated the 1.417 g (89%) of the pure enol acetate 14a as colorless prisms: mp 166–167°; ir (CHCl_3) 1790 (enol ester C=O), 1730 and 1710 cm^{-1} (ester C=O); uv (95% EtOH) 240 $\text{m}\mu$ (ϵ 12,600), 281 (17,100), and 322 (6050); nmr (CDCl_3) δ 7.44 (1 H d, $J = 8.5$ Hz, aryl CH), 6.98 (1 H d, $J = 8.5$ Hz, aryl CH), 3.94 (3 H s, OCH_3), 3.83 (3 H s, OCH_3), 3.78 (3 H s, OCH_3), 3.64 (2 H s, benzylic CH_2), and 2.33 (3 H s, COCH_3).

Anal. Calcd for $\text{C}_{16}\text{H}_{16}\text{O}_7$: C, 60.00; H, 5.04. Found: C, 59.98; H, 5.24.

A cold (0°) solution of 2.69 g (10.3 mmol) of the keto diester 13 in 15 ml of DME was treated with excess ethereal CH_2N_2 and allowed to stand at 0° for 2 hr. After the resulting mixture had been concentrated and diluted with hexane, the enol ether 14b was collected as 2.91 g (96.5%) of crystalline fractions melting within the range 132–135.5°. Recrystallization from PhH afforded the pure enol ether 14b as pale gray prisms: mp 135.5–136°; ir (CCl_4) 1745 and 1715 cm^{-1} (ester C=O); uv (95% EtOH), 222 $\text{m}\mu$ (ϵ 14,400), 285 (16,400), and 315 (sh, 9000); nmr (CDCl_3) δ 7.28 (1 H d, $J = 8.4$ Hz, aryl CH), 6.85 (1 H d, $J = 8.4$ Hz, aryl CH), 4.10 (3 H s, OCH_3), 3.90 (3 H s, OCH_3), 3.83 (3 H s, OCH_3), 3.78 (3 H s, OCH_3), and 3.50 (2 H s, benzylic CH_2); mass spectrum m/e (rel intensity) 292 (59, M^+), 262 (29), and 234 (100).

Anal. Calcd for $\text{C}_{15}\text{H}_{16}\text{O}_6$: C, 61.64; H, 5.52. Found: C, 61.87; H, 5.56.

Preparation of the Indenes 16 and 17.—A suspension of 2.78 g (10 mmol) of the enolic keto ester 13 in cold (–50°), neutral MeOH was treated with 950 mg (25 mmol) of NaBH_4 and the resulting mixture was stirred successively at –50° for 15 min, –35° for 30 min, and –20° for 1 hr. The mixture was neutralized with 1.5 ml of HOAc and then partitioned between aqueous NaHCO_3 and EtOAc. After the organic solution had been washed (aqueous NaCl) and dried, concentration left the crude alcohol 15a as a pale brown gum which partially crystallized on standing. A portion of this crude product from a comparable experiment was recrystallized from a PhH–hexane mixture to separate one pure stereoisomer of the alcohol 15a as colorless needles: mp 158–159.5°; ir (CHCl_3) 3520 (br, OH), 1735, and 1705 cm^{-1} (sh) (ester C=O); uv (95% EtOH) 295 $\text{m}\mu$ (ϵ 4900); nmr (CDCl_3) δ 7.18 (1 H d, $J = 8.5$ Hz, aryl CH), 6.80 (1 H d, $J = 8.5$ Hz, aryl CH), 5.35 (1 H partially resolved multiplet, CHO), 3.95 (3 H s, OCH_3), 3.85 (3 H s, OCH_3), 3.78 (3 H s, OCH_3), and 3.0–3.6 (4 H m, aliphatic CH and OH).

Anal. Calcd for $\text{C}_{14}\text{H}_{16}\text{O}_6$: C, 59.99; H, 5.75. Found: C, 60.03; H, 5.82.

A solution of the crude alcohol 15a described above and 203 mg of TsOH in 35 ml of PhH was refluxed with continuous separation of H_2O for 16 hr and then washed successively with aqueous NaHCO_3 and aqueous NaCl. After the resulting solution had been dried and concentrated, successive recrystallization of the neutral yellow solid from an acetone–hexane mixture and then from MeOH separated 2.113 g (80% based on the ketone 13) of the indene 16 as fractions melting within the range 116–120.5°. Recrystallization (MeOH) afforded the pure indene 16 as yellow needles: mp 120–121°; ir (CHCl_3) 1735 (sh) and 1715 cm^{-1} (ester C=O); uv (95% EtOH) 244 $\text{m}\mu$ (ϵ 15,600), 283 (14,300), and 330 (6100); nmr (CDCl_3) δ 7.90 (1 H br, vinyl CH), 7.50 (1 H d, $J = 8.5$ Hz, aryl CH), 6.95 (1 H d, $J = 8.5$ Hz, aryl CH), 3.98 (3 H s, OCH_3), 3.90 (3 H s, OCH_3), 3.85 (3 H s, OCH_3), and 3.60 (2 H br, CH_2); mass spectrum m/e (rel intensity) 262 (38, M^+), 231 (38), 230 (100), 173 (21), and 43 (24).

Anal. Calcd for $\text{C}_{14}\text{H}_{14}\text{O}_5$: C, 64.11; H, 5.38. Found: C, 64.15; H, 5.47.

To a cold (–78°) solution of (*i*-Pr) $_2\text{NLi}$ [from 3.2 mmol of *n*-BuLi and 400 mg (4.0 mmol) of (*i*-Pr) $_2\text{NH}$] in 5 ml of THF was added a solution of 262 mg (1.0 mmol) of the indene 16 in 5 ml of THF. The resulting mixture, containing the red indenyl anion 18 partially in solution and partially as a suspension, was neutralized by passing a stream of CO_2 through the reaction mixture and then partitioned between Et_2O and aqueous Na_2CO_3 . After the neutral Et_2O layer had been dried and concentrated, recrystallization of the residual solid (238 mg) from MeOH separated 219 mg (84%) of the indene 17 as yellow rods, mp 98–101°. Recrystallization (MeOH) gave the pure indene 17 as yellow rods: mp 100.5–101°; ir (CCl_4) 1735 (sh) and 1715 cm^{-1} (ester C=O); uv (95% EtOH) 245 $\text{m}\mu$ (ϵ 8550) and 307 (20,000); nmr (CDCl_3) δ 7.60 (br, 1 H, vinyl CH), 7.55 (1 H d, $J = 8.5$ Hz, aryl CH), 6.95 (1 H d, $J = 8.5$ Hz, aryl CH), 3.95 (3 H s, OCH_3), 3.90 (3 H s, OCH_3), 3.82 (3 H s, OCH_3), and 3.80 (2 H m, CH_2); mass spectrum m/e (rel intensity) 262 (43, M^+), 230 (45), 229 (100), 214 (24), 200 (23), 197 (20), 171 (34), 140 (20), 115 (33), 114 (24), 101 (24), and 44 (29).

Anal. Calcd for $\text{C}_{14}\text{H}_{14}\text{O}_5$: C, 64.11; H, 5.38. Found: C, 64.31; H, 5.48.

In subsequent mixtures of the indenenes 16 and 17 obtained by equilibration the approximate compositions were determined by integration of the nmr vinyl CH peaks at δ 7.90 (for 16) and 7.60 (for 17). A solution of 105 mg (0.4 mmol) of the indene 16 and 0.04 mmol of NaOMe in 10 ml of MeOH was allowed to stand at 25° for 24 hr and then neutralized with HOAc. The recovered neutral product (100 mg) contained ca. 25% of 16 and 75% of 17. When the sodium indenyl anion was generated from indene 16 (3.14 g or 12 mmol), NaH (480 mg or 20 mmol), and 0.2 ml of MeOH in 80 ml of THF and then neutralized with 1.5 ml of HOAc, the recovered neutral product (3.02 g) contained ca. 20% of 16 and 80% of 17. Similarly, the lithium salt from 262 mg (1.0 mmol) of indene 16 and 1.2 mmol of (*i*-Pr) $_2\text{NLi}$ in 30 ml of THF was neutralized with HOAc to give a neutral mixture (255 mg) containing ca. 18% 16 and 82% 17. Reaction of 262 mg (1.0 mmol) of the indene 16 with 1.1 mmol of MeLi in 35 ml of cold (–50°) THF also produced the lithium salt of the red anion 18. After this mixture had been neutralized with HOAc, the crude neutral product (263 mg) was chromatographed (SiO_2). The indene 17 (192 mg or 73%) was recovered from fractions eluted with 5% MeOAc in PhH. From the fractions eluted with 15% MeOAc in PhH, recrystallization (CH_2Cl_2 –hexane) afforded 22 mg of yellow needles, mp 146–147°, with spectral properties suggesting that this unidentified material is a monoester monoketone: ir (CHCl_3) 1725 (ester C=O) and 1660 cm^{-1} (conjugated ketone C=O); uv (95% EtOH) 251 $\text{m}\mu$ (ϵ 6800) and 323 (21,800); nmr (CDCl_3) δ 7.5–7.6 (2 H m, vinyl CH and aryl CH), 7.00 (1 H d, $J = 8.5$ Hz), 3.97 (3 H s, OCH_3), 3.96 (3 H s, OCH_3), 3.80 (2 H d, $J = 1.6$ Hz, CH_2), and 2.42 (3 H s, COCH_3).

The most efficient preparative procedure for converting the keto diester 13 to the indene 16 involved the successive preparations of alcohol 15a, acetate 15b, and the olefin 16 without purification of intermediates. In a typical preparation, 18.2 g (65.6 mmol) of the ketone 13 was reduced with 6.50 g (187 mmol) of NaBH_4 in 300 ml of MeOH and then acidified (44 ml of HOAc). The crude alcohol 15a (18.4 g of orange solid) was dissolved in 200 ml of cold (0°) CH_2Cl_2 containing 5.7 ml (71 mmol) of pyridine and treated with 5.3 ml (74 mmol) of AcCl. After the resulting solution had been stirred at 25° for 2.5 hr, it was washed suc-

cessively with H₂O, aqueous 1 M HCl, and H₂O, and then dried and concentrated. An 18.8-g portion of the crude acetate **15b** (20.4 g of brown liquid) was distilled in a short-path still (0.15 mm and 95–105°) to separate 17.8 g of the crude acetate **15b** as a yellow liquid: ir (CCl₄) 1745 cm⁻¹ (broad, ester C=O); uv max (95% EtOH) 295 mμ (ε 3400); nmr (CCl₄) δ 6.4–7.5 (3 H m, aryl CH and benzylic CHO), 2.9–4.0 (12 H m, three OCH₃ groups and aliphatic CH), and two singlets at 2.00 and 1.92 (3 H, CH₃CO of stereoisomeric acetates). A solution of this acetate **15b** in 250 ml of PhH containing 1.36 g (8.6 mmol) of *p*-toluenesulfonic acid was refluxed for 24 hr and then cooled and washed successively with aqueous Na₂CO₃ and aqueous NaCl. The aqueous phases were extracted with EtOAc and the combined organic layers were dried and concentrated. Recrystallization of the residual solid (12.7 g) from MeOH afforded 8.41 g (53% based on the ketone **13**) of the indene **16**, mp 118.5–120°.

Preparation of the Triester 19.—A cold (0°) solution of the lithium indenyl anion **18**, prepared from 633 mg (2.4 mmol) of the indene **16** and 3.0 mmol of (*i*-Pr)₂NLi in 40 ml of THF, was treated with 470 mg (5.0 mmol) of ClCO₂Me. After 2 min the red color was discharged and the solution was neutralized (HOAc) and partitioned between Et₂O and aqueous NaHCO₃. The Et₂O solution was washed (aqueous NaCl), dried, and concentrated to leave 884 mg of orange liquid. Crystallization from MeOH separated 191 mg of the crude triester **19**, mp 152–160°. Recrystallization afforded 100 mg (17%) of the pure triester **19**, as pale yellow needles: mp 167–168°; ir (CHCl₃) 1740 and 1715 cm⁻¹ (ester C=O); uv (95% EtOH) 238 mμ (ε 9600) and 308 (19,800); nmr (CDCl₃) δ 7.70 (1 H d, *J* = 1.6 Hz, vinyl CH), 7.50 (1 H d, *J* = 8.5 Hz, aryl CH), 6.95 (1 H d, *J* = 8.5 Hz, aryl CH), 4.90 (1 H d, *J* = 1.6 Hz, benzylic CH), and four 3 H singlets (OCH₃) at 3.95, 3.90, 3.83, and 3.65.

Anal. Calcd for C₁₆H₁₆O₇: C, 60.00; H, 5.04. Found: C, 60.16; H, 5.17.

Methylation of the Indenyl Anion 18. A. The Lithium Salt.—To a cold (-50°), stirred solution of (*i*-Pr)₂NLi [prepared from 2.08 mmol of *n*-BuLi and 0.50 ml (3.5 mmol) of (*i*-Pr)₂NH] in 50 ml of THF was added a solution of 524 mg (2.0 mmol) of the indene **16** in 10 ml of THF. The resulting red solution was stirred at -20° for 10 min and then warmed to 0°, and 5 ml of CH₃I was added dropwise and with stirring during 15 min. The resulting mixture was neutralized (2.0 ml of HOAc) and then partitioned between H₂O and Et₂O. After the Et₂O layer had been washed (aqueous NaCl) and dried, concentration left a yellow oil which was immediately crystallized from MeOH. The indene **20** separated as 245 mg (44.5%) of yellow prisms, mp 99–104°. The melting range, which may be the result of the equilibration **20** → **21** during the melting point determination, was not improved by recrystallization: ir (CCl₄) 1740 and 1715 cm⁻¹ (ester C=O); uv (95% EtOH) 243 mμ (ε 8700) and 308 (20,800); nmr (CCl₄) δ 7.2–7.5 (2 H m, vinyl CH and aryl CH), 6.85 (1 H d, *J* = 8.5 Hz, aryl CH), 3.87 (3 H s, OCH₃), 3.83 (3 H s, OCH₃), 3.74 (3 H s, OCH₃), 3.4–3.9 (1 H m, benzylic CH), and 1.25 (3 H d, *J* = 7.5 Hz, CH₃C); mass spectrum *m/e* (rel intensity) 276 (12, M⁺), 244 (16), 185 (18), 58 (43), 44 (30), and 43 (100).

Anal. Calcd for C₁₅H₁₆O₃: C, 65.21; H, 5.84. Found: C, 65.03; H, 5.81.

A solution of the mother liquors from this separation in 6 ml of MeOH was treated with 0.07 mmol of NaOMe. After the solution had been allowed to stand for 16 hr at 28°, it was neutralized with HOAc and the neutral material was recovered in the usual manner. Recrystallization of the crude residual solid (268 mg) from MeOH separated 175 mg (32%) of fractions of the indene **21** melting within the range 125–130.5°. Recrystallization afforded the pure indene **21** as colorless prisms: mp 130–130.5°;¹⁴ ir (CCl₄) 1740 and 1715 cm⁻¹ (ester C=O); uv (95% EtOH) 219 mμ (ε 12,800), 241 (12,500), 282 (16,500), and 317 (6300); nmr (CCl₄) δ 7.28 (1 H d, *J* = 8.5 Hz, aryl CH), 6.77 (1 H d, *J* = 8.5 Hz, aryl CH), 3.82 (3 H s, OCH₃), 3.78 (3 H s, OCH₃), 3.72 (3 H s, OCH₃), 3.50 (2 H m, benzylic CH₂), and 2.40 (3 H t, *J* = 2.4 Hz, vinyl CH₂); mass spectrum *m/e* (rel intensity) 276 (3, M⁺), 116 (5), 91 (7), 58 (44), 44 (24), 43 (100), and 42 (12).

Anal. Calcd for C₁₅H₁₆O₃: C, 65.21; H, 5.84. Found: C, 65.02; H, 5.95.

In a comparable methylation reaction starting with 262 mg (1.0 mmol) of the indene **16** where the crude product was distilled in a short-path still (0.1 mm and 170° bath) before crystallization,

the product separated after one recrystallization (139 mg, mp 118–119°) contained (nmr analysis) about equal amounts of the methylindenes **20** and **21**. After equilibration of the mixture with NaOMe the pure indene **21** was isolated, mp 130–130.5°.¹⁴ Attempts to analyze mixtures of the methylindenes **20** and **21** by glpc (silicone 710 column) also resulted in partial or complete equilibration of the double bond isomers either in the injection port or on the glpc column. Therefore the compositions of mixtures of the two methylindenes were estimated by integrating the areas under the nmr peaks at δ 2.40 (from **21**) and 1.25 (from **20**). To study the equilibration of the indenes **20** and **21** a solution of 126 mg (0.45 mmol) of the indene **20** in 8 ml of MeOH containing 0.06 mmol of NaOMe was allowed to stand for 16 hr at 28° and then neutralized and the crude neutral product (119 mg) was separated in the usual way. This neutral material contained (nmr analysis) ca. 14% of **20** and 86% of **21**. Recrystallization of this material from MeOH separated 47 mg of the pure indene **21**.

B. The Sodium Salt.—A mixture of 262 mg (1 mmol) of the indene **16**, 257 mg (10.7 mmol) of NaH, 0.5 ml of MeOH, and 35 ml of THF was stirred at 0° for 10 min, at which time H₂ evolution had ceased. The resulting red solution was added, dropwise with stirring, to a cold (0°) solution of 5 ml of CH₃I in 10 ml of THF. After the mixture had been neutralized (HOAc), it was partitioned between H₂O and Et₂O, and the Et₂O layer was washed successively with aqueous NaHCO₃ and aqueous NaCl and then dried and concentrated. A solution of the brown, semi-solid residue (280 mg) in an Et₂O-PhH mixture was filtered through a column of silica gel and the filtrate was concentrated and distilled in a short path still (0.1 mm and 160° bath). The liquid distillate (258 mg) contained (glpc, silicone 710) four components: ca. 24% of a component thought to be the dimethylindene **22** (retention time 48.8 min), ca. 5% of a component thought to be the trimethylindene **23** (42.0 min), ca. 36% of the trimethylindene **24** (63.5 min), and ca. 35% of the dimethylindene **25** (73.6 min). A collected (glpc) sample of the first eluted component thought to be **22** was recrystallized from MeOH to give colorless prisms, mp 84.5–85°, with the following spectral properties: ir (CCl₄) 1735 and 1710 cm⁻¹ (ester C=O); uv (95% EtOH) 235 mμ (ε 8500) and 310 (19,500); nmr (CCl₄) δ 7.2–7.4 (2 H m, vinyl and aryl CH), 6.80 (1 H d, *J* = 8.5 Hz, aryl CH), 3.88 (3 H s, OCH₃), 3.85 (3 H s, OCH₃), 3.75 (3 H s, OCH₃), and 1.40 (6 H s, CH₃C); mass spectrum *m/e* (rel intensity) 290 (59, M⁺), 259 (36), 258 (36), 232 (26), 231 (100), 230 (41), 199 (58), 177 (34), 77 (24), 73 (24), 58 (25), 44 (20), and 43 (66).

A collected sample of the component eluted second which would appear to be the trimethylindene **23** exhibited the following abundant mass spectral peaks: *m/e* (rel intensity) 304 (41, M⁺), 255 (33), 242 (68), and 213 (100).

A collected sample of the component eluted third crystallized from methanol as pale yellow prisms, mp 123–124°, and is believed to be the trimethylindene **24**: ir (CCl₄) 1740 and 1705 cm⁻¹ (ester C=O); uv (95% EtOH) 230 mμ (ε 8600) and 310 (20,800); nmr (CCl₄) δ 7.35 (1 H d, *J* = 8.5 Hz, aryl CH), 6.85 (1 H d, *J* = 8.5 Hz, aryl CH), 3.90 (3 H s, OCH₃), 3.88 (3 H s, OCH₃), 3.78 (3 H s, OCH₃), 2.40 (3 H s, vinyl CH₃C), and 1.40 (6 H s, CH₃C).

The component eluted last crystallized from MeOH as yellow prisms, mp 107–108°, believed to be the dimethylindene **25**: ir (CCl₄) 1740 and 1705 cm⁻¹ (ester C=O); uv (95% EtOH) 240 mμ (sh, ε 9100) and 308 (21,800); nmr (CCl₄) δ 7.35 (1 H d, *J* = 8.5 Hz, aryl CH), 6.85 (1 H d, *J* = 8.5 Hz, aryl CH), 3.90 (3 H s, OCH₃), 3.87 (3 H s, OCH₃), 3.77 (3 H s, OCH₃), 3.6–3.8 (1 H m, benzylic CH), 2.42 (3 H d, *J* = 2.0 Hz, vinyl CH₃C), and 1.25 (3 H d, *J* = 7.0 Hz, CH₃C).

In a second similar methylation of the sodium indenyl anion **18**, the crude distilled product contained (glpc, silicone 710) the four previously described components, namely materials thought to be **22** (36.5 min), **23** (42.0 min), **24** (46.0 min), **25** (53.7 min, the major component present), and also the methylindene **21** (57.8 min). Crystallization of this sample from MeOH separated a small amount of the monomethyl derivative **21**, mp 130–130.5°, which was identified with the previously described sample by a mixture melting point determination.

Diels-Alder Reactions with the Indene Diesters 16 and 17.—A sealed glass tube containing a solution of 45 mg (0.17 mmol) of the indene **16**, 5 mg of diphenyl sulfide (as an inhibitor), and 1.5 ml (ca. 17 mmol) of liquid butadiene in 1.0 ml of toluene was heated to 185–195° for 41 hr. The resulting solution was cooled,

(14) In certain cases this material separated in a different crystal modification which melted at 119–120°, resolidified, and remelted at 128–129°.

mixed with 10 mg of phenanthrene (an internal standard), and partitioned between petroleum ether (bp 30–60°) and acetonitrile. The acetonitrile layer (in which the polymerized butadiene was insoluble) was concentrated for analysis. Analysis (glpc, silicone no. 710 on Chromosorb P) indicated the presence of phenanthrene (8.4 min), 53% of the indenenes 16 and 17 (26.1 min, not resolved), 23% of the adduct 27a (38.6 min), and 8% of the adduct 26a (47.8 min).

An analogous experiment was performed by heating a solution of 46 mg (0.18 mmol) of an indene mixture containing (uv analysis) 17% of 16, 83% of 17, 5 mg of diphenyl sulfide, and 1.5 ml (ca. 17 mmol) of liquid butadiene in 1.0 ml of toluene to 185–195° for 41 hr. Application of the previously described isolation and analytical procedures indicated the presence of phenanthrene, 39% of the indenenes 16 and 17 (not resolved), 11% of the adduct 27a, and 18% of the adduct 26a.

A collected (glpc) sample of the ester 26a (51 mg) was dissolved in a mixture of 0.8 ml of toluene and 1.0 ml of liquid butadiene and the solution was heated to 180–195° in a sealed tube for 109 hr. Use of the previously described isolation and analysis procedures indicated that the ester 26a was recovered unchanged and none of the isomeric ester 27a was detected.

Samples of each of the esters 26a and 27a were collected (glpc) for partial characterization. The diester 26a was obtained as a colorless liquid: ir (CCl₄) 1735 cm⁻¹ (broad, ester C=O); uv max (95% EtOH) 301 mμ (ε 2700); nmr (CCl₄) δ 7.06 (1 H d, *J* = 9 Hz, aryl CH), 6.70 (1 H d, *J* = 9 Hz, aryl CH), 5.5–5.9 (2 H m, vinyl CH), 3.5–3.8 (1 H m, benzylic CH), 3.83 (3 H s, OCH₃), 3.80 (3 H s, OCH₃), 3.68 (3 H s, OCH₃), 3.16 (1 H d, *J* = 15 Hz, part of benzylic CH₂), 2.89 (1 H, d, *J* = 15 Hz, part of benzylic CH₂), and 1.6–2.8 (4 H m, allylic CH₂); mass spectrum *m/e* (rel intensity) 316 (17, M⁺), 285 (24), 284 (46), 262 (53), 230 (100), and 225 (26). A 200-mg (0.63 mmol) sample of the collected (glpc) diester 26a was saponified with 1 ml of aqueous 15% NaOH in 10 ml of refluxing MeOH for 9.5 hr. The resulting mixture was partitioned between H₂O and Et₂O and the aqueous phase was acidified and extracted with EtOAc. After this organic extract had been dried and concentrated the residual brown solid (205 mg) was fractionally crystallized (CHCl₃) and the mother liquors were chromatographed (silica gel, EtOAc–CHCl₃ eluent) to separate 78 mg of fractions of the crude diacid 26b melting within the range 199–205° dec. Recrystallization (CHCl₃) afforded the pure diacid 26b as white needles: mp 206–208° dec; ir (CHCl₃) 1735 (intramolecularly H-bonded carboxyl C=O) and 1700 cm⁻¹ (carboxyl C=O); uv max (95% EtOH) 297 mμ (ε 2750); nmr (CD₃SOCD₃) δ 7.16 (1 H d, *J* = 9 Hz, aryl CH), 6.86 (1 H d, *J* = 9 Hz, aryl CH), 5.4–5.8 (2 H m, vinyl CH), 3.75 (3 H s, OCH₃), 3.4–3.8 (1 H m, benzylic CH), 3.20 (1 H d, *J* = 15 Hz, part of benzylic CH₂), 2.87 (1 H d, *J* = 15 Hz, part of benzylic CH₂), and 1.4–2.6 (4 H m, allylic CH₂); mass spectrum *m/e* (rel intensity), 288 (M⁺, 11), 234 (61), 216 (100), 172 (28), 115 (24), 44 (22), and 39 (20).

Anal. Calcd for C₁₆H₁₆O₄: C, 66.66; H, 5.59. Found: C, 66.94; H, 5.61.

The diester 27a was obtained as a colorless liquid: ir (CCl₄) 1735 cm⁻¹ (broad, ester C=O); uv max (95% EtOH) 293 mμ (ε 3110); nmr (CCl₄) δ 7.03 (1 H d, *J* = 8 Hz, aryl CH), 6.58 (1 H, d, *J* = 8 Hz, aryl CH), 5.6–6.0 (2 H m, vinyl CH), 3.78 (3 H s, OCH₃), 3.70 (3 H s, OCH₃), 3.54 (3 H s, OCH₃), 3.7–4.0 (1 H m, benzylic CH), 3.21 (1 H d, *J* = 15 Hz, part of benzylic CH₂), 2.76 (1 H d, *J* = 15 Hz, part of benzylic CH₂), and 1.7–2.6 (4 H m, allylic CH₂); mass spectrum *m/e* (rel intensity) 316 (14, M⁺), 285 (26), 284 (100), 230 (57), 225 (97), and 223 (20). A 220-mg (0.70 mmol) sample of the collected (glpc) diester 27a was saponified with 2 ml of aqueous 15% NaOH in 10 ml of refluxing MeOH for 20 hr. The reaction mixture was subjected to the previously described isolation and purification procedures to separate the diacid 27b as tan prisms from EtOAc–hexane: mp 193–194° dec; ir (CHCl₃) 1738 (intramolecularly H-bonded carboxyl C=O) and 1700 cm⁻¹ (carboxyl C=O); uv max (95% EtOH) 292.5 mμ (ε 1930); nmr (CD₃SOCD₃) δ 7.18 (1 H d, *J* = 8 Hz, aryl CH), 6.81 (1 H d, *J* = 8 Hz, aryl CH), 5.6–5.9 (2 H m, vinyl CH), 3.74 (3 H s, OCH₃), and 1.6–3.8 (7 H m, allylic and benzylic CH); mass spectrum *m/e* (rel intensity) 288 (14, M⁺), 270 (82), 242 (27), 234 (26), 225 (100), 224 (36), 216 (98), 172 (42), 165 (34), 152 (30), 115 (32), 77 (22), and 43 (34).

Anal. Calcd for C₁₆H₁₆O₅: C, 66.66; H, 5.59. Found: C, 66.42; H, 5.60.

Samples of each of the diacids 26b and 27b were esterified with

excess ethereal CH₂N₂ to form the corresponding esters 26a and 27a which were identified with previously described samples by comparison of glpc retention times.

A solution of 8.30 g (31.7 mmol) of the indene 16, 0.25 ml of diphenyl sulfide, and 40 ml of liquid butadiene in 65 ml of toluene was placed in a glass liner in a stainless steel autoclave and heated to 130–150° for 48 hr. At intervals after 48, 118, 160, 304, and 371 hr the autoclave was cooled and opened, and the low-boiling products formed from butadiene, which distilled out of the glass liner, were removed. Additional 50-ml quantities of liquid butadiene were added and heating was continued. Each time the autoclave was opened aliquots were removed for glpc analysis; after 118 hr the mixture contained 41% of the indenenes 16 and 17, 28% of the adduct 27a, and 31% of the adduct 26a. After 379 hr the mixture contained 11% of the indenenes 16 and 17, 38% of the adduct 27a, and 51% of the adduct 26a. The final reaction mixture was concentrated under reduced pressure and then extracted with six portions of boiling MeOH. The MeOH extract was concentrated and the residue was fractionally distilled in a short-path still. The products were contained in a 7.65-g fraction of yellow liquid collected at 165–175° (0.15 mm). Aliquots of this distillate were mixed with known weights of phenanthrene for glpc analysis; the calculated yields were 8% of the indenenes 16 and 17, 26% of the adduct 27a, and 32% of the adduct 26a.

This procedure was repeated with 12.45 g (47.5 mmol) of the indene 16, 0.4 ml of diphenyl sulfide, 50 ml of liquid butadiene, and 100 ml of toluene. After reaction periods at 170–180° of 60, 126, 202.5, 268, and 308 hr, the lower boiling products were removed and additional 40-ml portions of liquid butadiene were added. Use of the previously described isolation procedure separated 11.52 g of yellow liquid, bp 165–175° (0.15 mm), which contained (glpc) 2% of the indenenes 16 and 17, 50% of adduct 27a, and 48% of adduct 26a. A 11.5-g (36.5 mmol) sample of this crude product was saponified with 50 ml of aqueous 15% NaOH in 250 ml of refluxing MeOH. The crude acidic product, 9.0 g of brown liquid separated in the usual way, was crystallized from PhH to separate 4.16 g of solid diacid. Fractional crystallization of this material from EtOAc separated 1.80 g (13.2%) of the diacid 26b as tan prisms, mp 205–209.5° dec, and 1.10 g (8.2%) of the diacid 27b as white prisms, mp 190–193° dec.

In another experiment, the crude acidic product (5.8 g of brown semisolid) obtained by saponification of 6.60 g of the crude mixture of Diels-Alder adducts 26a and 27a was chromatographed on silica gel (CHCl₃–EtOAc eluent) and the resulting tan solid was subjected to a series of fractional crystallizations from EtOAc and from CHCl₃–hexane. From the less soluble fractions we separated 474 mg of the acid 26b as white prisms, mp 205.5–209° dec. An MeOH solution of the mother liquors was decolorized with carbon and then subjected to fractional recrystallization from EtOAc to separate a sample of the more soluble diacid 27b as white prisms, mp 192–194° dec. Each of these diacids was identified with the previously described materials by a mixture melting point determination and by esterification (etheral CH₂N₂) and subsequent glpc analysis.

From a comparable Diels-Alder reaction employing 6.69 g (25.2 mmol) of a mixture of indenenes (ca. 83% of 17 and 17% of 16), with 0.6 ml of diphenyl sulfide, a total of 170 ml of liquid butadiene, and 60 ml of toluene at 180–190° for 143 hr, the crude distilled product (6.62 g) contained (glpc) 27% of the indenenes 16 and 17, 30% of the adduct 27a, and 43% of the adduct 26a.

Dehydrogenation of the Tetrahydrofluorenes 30. A. Preparation of the Ester 29a.—A mixture of 446 mg (1.73 mmol) of the previously described⁸ ester 30a and 55 mg of 30% Pd/C catalyst was heated to 205–215° for 2.5 hr while a slow stream of N₂ was passed through the reaction mixture. The resulting mixture was extracted with a CHCl₃–MeOH mixture and the extract was filtered and concentrated to leave 395 mg of solid. Recrystallization from MeOH separated 162 mg (36%) of the fluorene ester 29a as white needles: mp 95–97°; ir (CHCl₃) 1725 cm⁻¹ (conjugated ester C=O); uv max (95% EtOH) 215 mμ (ε 17,500), 271 (16, 800), 279 (inflection, ε 13,900), and 321 mμ (ε 3360); nmr (CDCl₃) δ 6.8–7.9 (6 H m, aryl CH), 3.98 (5 H, OCH₃ and benzylic CH₂), and 3.92 (3 H s, OCH₃); mass spectrum *m/e* (rel intensity) 254 (60, M⁺), 223 (36), 222 (100), 179 (23), 165 (53), 164 (62), 152 (41), and 151 (28).

Anal. Calcd for C₁₆H₁₄O₃: C, 75.57; H, 5.55. Found: C, 75.67; H, 5.41.

B. Preparation of the Acid 29b.—A mixture of 810 mg (3.28

mmol) of the known⁵ acid **30b** and 200 mg of 30% Pd/C catalyst was heated to 175–190° for 1.75 hr while a slow stream of N₂ was passed through the reaction mixture. The resulting mixture was extracted with EtOAc and the extract was filtered through Celite and then extracted with aqueous NaHCO₃. After the aqueous solution had been acidified, it was extracted with EtOAc. The crude acid product (400 mg), obtained after drying and concentrating the final EtOAc extract, was fractionally crystallized from CHCl₃-hexane, to separate 83 mg (11%) of the crude fluorene acid **29b**, mp 172–176°. Recrystallization gave the pure acid **29b** as white prisms: mp 176–178°; ir (CHCl₃) 1735 cm⁻¹ (intramolecularly H-bonded carboxyl C=O); uv max (95% EtOH) 213 mμ (ε 28,500), 271 (20,500), 281 (inflection, 16,000), and 319 (4500); nmr (CD₃SOCD₃ + CDCl₃) δ 6.9–8.0 (6 H m, aryl CH), 3.91 (2 H s, benzylic CH₂), and 3.78 (3 H s, OCH₃); mass spectrum *m/e* (rel intensity), 240 (62, M⁺), 222 (100), 179 (30), 165 (33), 164 (78), 152 (47), and 151 (38).

Anal. Calcd for C₁₅H₁₂O₃: C, 74.99; H, 5.03. Found: C, 75.08; H, 5.03.

A sample of the acid **29b** was esterified with ethereal CH₂N₂ to form the ester **29a** as white needles from MeOH, mp 95–97°; this sample was identified with the previously described material by comparison of ir spectra.

Conversion of the Diacid 26b to the Fluorene 29a.—A solution of 720 mg (2.5 mmol) of the diacid **26b** in 20 ml of THF was treated with 27 ml of an Et₂O solution containing 2.5 mmol of CH₂N₂. The resulting solution was concentrated and the residue was partitioned between Et₂O and aqueous NaHCO₃. Concentration of the Et₂O phase left 150 mg (19%) of the crude diester **26a** (tlc analysis) as an orange liquid. After the aqueous phase had been acidified and extracted with EtOAc, the organic extract was washed (aqueous NaCl), dried (Na₂SO₄), and concentrated. Chromatography of the residue (619 mg of tan semi-solid) on 20 g of silica gel separated 388 mg of the crude monoester **28** in fractions eluted with EtOAc-CHCl₃ (1:49 v/v). Later fractions from the chromatograph afforded 122 mg (17%) of the starting diacid **26b** as prisms from EtOAc, mp 207–208° dec. Recrystallization of the monoester separated 265 mg (35%) of the monoester **28** as white prisms: mp 142.5–144°; ir (CHCl₃) 1725 (ester C=O) and 1705 cm⁻¹ (carboxyl C=O); uv max (95% EtOH and 95% EtOH containing excess NaOH)¹⁵ 212 mμ (ε 18,100) and 299 (2850); nmr (CDCl₃) δ 11.8 (1 H s, CO₂H), 7.16 (1 H d, *J* = 9 Hz, aryl CH), 6.80 (1 H d, *J* = 9 Hz, aryl CH), 5.7 (2 H broad, vinyl CH), 3.88 (3 H s, OCH₃), 3.81 (3 H s, OCH₃), and 1.7–3.8 (7 H m, aliphatic CH); mass spectrum *m/e* (rel intensity) 302 (M⁺, 13), 270 (25), 249 (46), 216 (100), 172 (24), and 115 (20).

Anal. Calcd for C₁₇H₁₄O₃: C, 67.54; H, 5.70. Found: C, 67.81; H, 5.93.

A mixture of 141 mg of the monoester **28** and 31 mg of 30% Pd/C catalyst was heated to 170–175° for 2.5 hr. After a CHCl₃ solution of the crude reaction mixture had been filtered, it was washed with aqueous NaHCO₃ to separate 70 mg of the crude starting monoester **28**, mp 136–138°. This material was combined with an additional 30 mg of monoester **28** and heated with

30 mg of 30% Pd/C catalyst to 165–172° for 12 hr. After following the previously described isolation procedure, the combined neutral fractions from the two reactions were sublimed (95° and 0.1 mm) to separate 45 mg (31%) of the crude fluorene **29a**, mp 87–88°. Recrystallization from aqueous MeOH afforded the pure ester **29a** as white needles, mp 98–99°, which was identified with the previously described sample by a mixture melting point determination and by comparison of ir spectra.

Conversion of the Diacid 27b to the Fluorene 32.—After a solution of 303 mg (1.05 mmol) of the diacid **27b** in 20 ml of EtOAc had been treated with 13.6 ml of an Et₂O solution containing 1.06 mmol of CH₂N₂, the reaction mixture was concentrated and partitioned between Et₂O and aqueous NaHCO₃. The crude diester **27a** separated amounted to 83 mg (25%). The aqueous phase was acidified and extracted with EtOAc and the organic extract was washed (aqueous NaCl), dried (Na₂SO₄), and concentrated. Chromatography of the residue (231 mg of colorless liquid) on 7.0 g of silica gel separated 151 mg of the crude monoester **31** in fractions eluted with EtOAc-CHCl₃ (3:97 v/v). Later chromatographic fractions contained 36 mg (12%) of the starting diacid **27b**, mp 190–192° dec. The crude monoester was crystallized from Et₂O-hexane to separate 92 mg (29%) of the monoester **31** as white needles: mp 161–163°; ir (CHCl₃) 1725 (ester C=O) and 1705 cm⁻¹ (carboxyl C=O); uv max (95% EtOH and 95% EtOH containing excess NaOH)¹⁶ 212 mμ (ε 16,700) and 294 (3150); nmr (CDCl₃) δ 11.8 (1 H, CO₂H), 7.17 (1 H d, *J* = 9 Hz, aryl CH), 6.70 (1 H d, *J* = 9 Hz, aryl CH), 5.8 (2 H broad, vinyl CH), 3.92 (3 H s, OCH₃), 3.79 (3 H s, OCH₃) and 1.7–3.7 (7 H m, aliphatic CH).

A mixture of 37 mg (0.12 mmol) of the monoester **31** and 14 mg of the 30% Pd/C catalyst was heated to 185° for 1.5 hr and then subjected to the previously described isolation procedure. The crude neutral product (15 mg) was recrystallized from MeOH, subjected to preparative thin layer chromatography, and again recrystallized from MeOH to separate 10 mg (33%) of the pure fluorene **32** as colorless prisms: mp 133–133.5°; ir (CHCl₃) 1725 cm⁻¹ (ester C=O); uv max (95% EtOH), 235 mμ (ε 10,600), 262 (10,200), 269 (10,000), 304 (inf, 6600), and 314 (7600); nmr (CDCl₃) δ 7.1–7.7 (5 H m, aryl CH), 6.78 (1 H d, *J* = 9 Hz, aryl CH), 4.02 (3 H s, OCH₃), 3.86 (3 H s, OCH₃), 3.79 (2 H s, benzylic CH); mass spectrum *m/e* (rel intensity) 254 (M⁺, 100), 223 (61), 222 (65), 195 (81), 180 (23), 166 (41), 165 (68), 164 (60), 152 (56), 151 (25), 83 (28), 73 (35), 71 (35), 69 (45), 60 (37), 57 (80), and 55 (55); high-resolution mass measurement, *m/e* 254.09287 (calcd for C₁₆H₁₄O₃: *m/e* 254.09429).

Registry No.—**1a**, 15378-00-4; **5**, 33521-56-1; **6**, 33521-57-2; **7**, 13623-25-1; **8**, 3469-09-8; **9**, 33521-60-7; **10a**, 33521-61-8; **10b**, 33521-62-9; **11**, 33521-63-0; **12**, 33521-64-1; **13**, 33521-65-2; **14a**, 33521-66-3; **14b**, 33521-67-4; **15a**, 33521-68-5; **15b**, 33521-69-6; **16**, 33521-70-9; **17**, 33521-71-0; **19**, 33608-26-3; **20**, 33521-72-1; **21**, 33521-73-2; **22**, 33521-74-3; **23**, 33521-75-4; **24**, 33521-76-5; **25**, 33521-77-6; **26a**, 33536-19-5; **26b**, 33536-20-8; **27a**, 33536-21-9; **27b**, 33536-22-0; **28**, 33536-23-1; **29a**, 33521-78-7; **29b**, 33521-79-8; **32**, 33521-80-1.

(15) The lack of change in the uv spectrum of the sample with added base indicates that the aromatic carboxyl function has been esterified. The corresponding addition of NaOH to an EtOH solution of the diacid **26b** caused the longer wavelength maximum to shift from 297 to 287 mμ.