Synthesis of 4,7-Dimethoxy-1,3,6-trimethylphenanthrene and 4,5-Dimethoxy-1,3,6,8-tetramethylphenanthrene by Photolysis of *trans*-5,5′-Dimethoxy-2,2′,4,4′-tetramethylstilbene[1]

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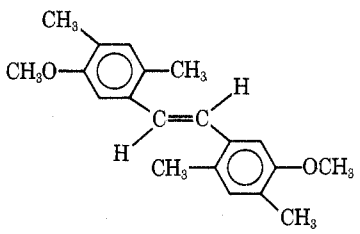
The synthesis of *trans*-5,5′-dimethoxy-2,2′,4,4′-tetramethylstilbene (1) starting from 2,5-dimethylfuran and dimethyl acetylenedicarboxylate is described. Photolysis of 1 in the presence of oxygen and iodine afforded 4,5-dimethoxy-1,3,6,8-tetramethylphenanthrene (2) in 4.5% yield and 4,7-dimethoxy-1,3,6-trimethylphenanthrene (3) in 15.5% yield, by loss of the elements of methane rather than hydrogen.

The main objective of this work was to synthesize *trans*-5,5′-dimethoxy-2,2′,4,4′-tetramethylstilbene (1) in the expectation that, on photolysis, 4,5-dimethoxy-1,3,6,8-tetramethylphenanthrene (2) would be obtained in good



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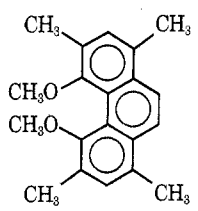

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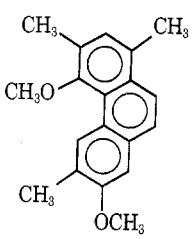
yield. As shown in Chart I, the synthesis of 1 was accomplished in excellent overall yield starting from the adduct between 2,5-dimethylfuran and dimethyl acetylenedicarboxylate,[3] 7, and proceeding through the known[3] compounds dimethyl 3-hydroxy-4,6-dimethylphthalate (8) and 3-hydroxy-4,6-dimethylphthalic acid (9). Unfortunately for our purposes, the photolysis of 1 yielded more 4,7-dimethoxy-1,3,6-trimethylphenanthrene (3, 15.5%) than 2



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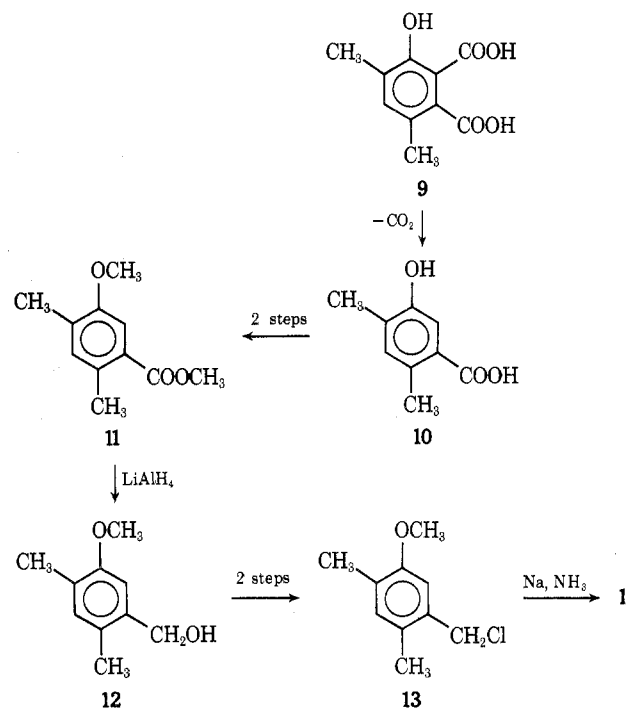
(4.3%), by loss of the elements of methane rather than hydrogen. Accordingly, a better synthesis of 2 is now being sought in our laboratories.

The successful photolyses of a variety of stilbenes in the presence of air or iodine to form phenanthrenes have been studied extensively,[4-6] although relatively few cases of phenanthrene formation have been studied with stilbenes which have a group (or groups) which end up in the 4 (or 5) position of phenanthrene. Only in the case of 5,5′-difluoro-2,2′-dimethylstilbene[7] (4) has the loss of methane been noted. In this case the yield of 4,5-difluoro-1,8-dimethylphenanthrene (5) was 49% (loss of H, H) and of 4,7-difluoro-1-methylphenanthrene (6) (loss of CH_3, H) was 13%. Possibly the reason why cyclization to 2 occurred to such a small extent in the case of 1 is that the two methoxy groups which would end up in the 4 and 5 positions of 2 are each buttressed by adjacent methyl groups and the resulting steric effect is responsible.

The synthesis of 1 is outlined in Chart I and the experimental details are described in the Experimental Section.

Chart I



The rearrangement of 7 to 8 on a small scale has been described and discussed.[3] On a much larger scale we have obtained 8 in 85% yield. After hydrolysis of 8 to 9, selective decarboxylation to 10 was readily effected by heating with copper in quinoline.[8] The conversion of 10 to 11 was best effected in 86% overall yield by esterification with methanol[9] followed by methylation of the sodium phenolate with methyl iodide in methanol–DMSO. The conversion of 12 to 13 was accomplished in excellent yield by treatment of the mesylate with sodium chloride by phase-transfer catalysis.[10] On treatment with sodium amide in liquid ammonia, 13 was converted into 1 in 76% yield.[11] Although many photochemical experiments were tried, the maximum yield of 2 was never greater than 4.3%.

Experimental Section[12]

Dimethyl 3-Hydroxy-4,6-dimethylphthalate (8). A total of 127 g (1.31 mol) of 2,5-dimethylfuran[13] and 187 g (1.32 mol) of freshly distilled dimethyl acetylenedicarboxylate,[14] bp 110° (29 mm), was sealed in seven Pyrex tubes which were held at 100° for 10 hr in an oven.[15] The contents of the tubes were combined and added with stirring to 400 ml of distilled trifluoroacetic acid, bp 72°, at 0°. Cooling was necessary to keep the temperature below 10°. After 72 hr at room temperature the trifluoroacetic acid was recovered by vacuum distillation and the residue yielded 257 g (85% overall)[16] of 8, bp 115° (0.4 mm), which had ir, nmr, and mass spectra as described.[3]

2,4-Dimethyl-5-hydroxybenzoic Acid (10). The above ester was hydrolyzed to 3-hydroxy-4,6-dimethylphthalic acid (9) as described[3] in 97% yield (crude). The crude acid was used for decarboxylation. In the best of several experiments, a stirred mixture of 38.5 g of 9, 1 g of copper powder,[17] and 150 ml of distilled quinoline was heated from 200 to 230° during 3 hr, at which time 90% of the theoretical amount of CO_2 had been collected and no more was being evolved. After the usual work-up, crystallization of the residue from toluene–cyclohexane (1:3) yielded 27.6 g (90%) of 10,[18] mp 187–188°, nmr δ 2.24 (s, 3, CH_3), 2.48 (s, 3, CH_3), 7.02 (s, 1, Ar), and 7.49 (s, 1, Ar).

Anal.[19] Calcd for $C_9H_{10}O_3$: C, 65.0; H, 6.1. Found: C, 65.2; H, 6.1.

Methyl 2,4-Dimethyl-5-methoxybenzoate (11). A mixture of 40 g of anhydrous $CaSO_4$ (40–80 mesh dried at 130° under reduced pressure), 72.5 g of 10, 19 g of cation resin (AG 50W-X4, Biological and Radiation Laboratories, Richmond, Calif.), and 100 ml of absolute methanol was stirred and refluxed into a Soxhlet extractor containing 50 g of $CaSO_4$ for 15 hr. The cooled mixture was filtered and the solid was washed with 100 ml of methanol and 100 ml of ether. The solvents were removed on a rotary evaporator and the product was worked up as usual to yield 6 g (8%) of recovered 10 and 73.7 g (87%) of methyl 2,4-dimethyl-5-hydroxybenzoate, mp 88–89°, nmr methyl singlets (1 each) at δ 2.25, 2.49, and 3.87, ArH (1 each) at 6.98 and 7.43, after recrystallization from benzene–cyclohexane (1:3).

Anal. Calcd for $C_{10}H_{12}O_3$: C, 66.7; H, 6.7. Found: C, 66.5; H, 6.7.

A solution of 146.7 g of the above ester in 500 ml of pure DMSO was added at 0° to a solution under nitrogen prepared by treating 29 g of sodium with 150 ml of methanol and 500 ml of DMSO. To the above solution was added 243 g of methyl iodide during 20 min while maintaining the temperature below 35°. After heating to 80° for 8 hr the NaI was collected by filtration and washed with benzene. After adding 2 l. of benzene and 1 l. of water to the filtrate, there was obtained 156.7 g (99%) of 11 as colorless needles suitable for reduction. A sample purified by vaporization to a cold finger melted at 36–37°, nmr methyl singlets (1 each) at δ 2.25, 2.49, 3.78, and 3.80, ArH (1 each) at 6.85 and 7.31.

In another similar experiment vacuum distillation of the crude product before crystallization afforded 11, bp 72° (0.2 mm), in 91% yield.

Anal. Calcd for $C_{11}H_{14}O_3$: C, 68.0; H, 7.3. Found: C, 68.2; H, 7.2.

2,4-Dimethyl-5-methoxybenzyl Alcohol (12). To the solution obtained by refluxing 1 l. of pure THF and 42 g of $LiAlH_4$ overnight was added dropwise a solution of 154.8 g of 11 in 300 ml of THF. The stirred mixture was held at reflux until tlc on silica gel showed that no 11 (R_f, $CHCl_3$, 0.92, C_6H_6, 0.68) remained (5 hr). After the usual work-up, crystallization from 1 l. of hexane yielded 122 g (92%) of 12, mp 56–57°, nmr methyl singlets at δ 2.17, 2.20, and 3.78, CH_2OH (s, 4.58), ArH at 6.83 and 6.90. Distillation of the material in the residue afforded 7 g (6%) of 2, bp 110–115° (0.5 mm).

Anal. Calcd for $C_{10}H_{14}O_2$: C, 72.3; H, 8.5. Found: C, 72.5; H, 8.4.

2,4-Dimethyl-5-methoxybenzyl Chloride (13). To a stirred solution of 5.4 g of 12 and 4.5 g of triethylamine in 20 ml of benzene was added 7.0 g of methanesulfonyl chloride. After stirring at room temperature for 4 hr the precipitated salt was removed by filtration and washed with benzene. The combined filtrate and washings were washed twice with cold saturated brine. To the resulting benzene solution was added 0.2 g of Aliquat-336,[20] 30 ml of saturated KCl, and 20 g of powdered KCl. After stirring for 20 hr the benzene layer was worked up in the usual way to afford 5.5 g (93%) of crude 13 as a yellowish oil. Because of sensitivity to moisture and heating, attempts to obtain an analytically pure sample were not made. The nmr spectrum, methyl singlets (1 each) at δ 2.24 and 3.70, CH_2Cl (s, 4.49), ArH (1 each) at 6.72 and 6.89, was consistent with that to be expected from 13. The mass spectrum showed a parent peak at *m/e* 184 (calcd 184) and P + 2, 186, 31.5% (lit.[21] 32.6%). Our experience showed that for best yields in the next reaction the chloride should be used as soon as isolated with no attempts at purification.

***trans*-5,5′-Dimethoxy-2,2′,4,4′-tetramethylstilbene (1).** In the best of several experiments, a solution of 15.9 g of 13 in 30 ml of dry ether was added rapidly to a stirred suspension at −78° of sodium amide prepared from 3.7 g of sodium and 300 ml of liquid NH_3 (distilled from Na). After the solution was maintained at −78° for 2.5 hr, 4 g of NH_4Cl was added and the ammonia was allowed to evaporate overnight. The usual work-up afforded a yellow residue which was chromatographed on a 15 × 0.75 in. column of Woelm grade A alumina using 3 l. of 1:1 benzene–cyclohexane to yield a colorless solid. On crystallization from 500 ml of 1:6 benzene–ethanol there was obtained 9.7 g (76%) of 1: mp 168–169°; nmr CH_3 singlets at δ 2.23, 2.35, and 3.88, ArH and vinyl H, 6.98–7.14; uv (cyclohexane) 227 nm (ε 16,000), 292 (12,700), 330 (15,300); mass spectrum *m/e* 296 (calcd, 296).

Anal. Calcd for $C_{20}H_{24}O_2$: C, 81.0; H, 8.1. Found: C, 81.2; H, 8.0.

When the crude, but quite pure, bromide corresponding to 13, prepared in over 90% yield by using a solution of sodium bromide instead of sodium chloride, was treated similarly with sodium amide, there was isolated by chromatography 11% of 1 and 22% of 5,5′-dimethoxy-2,2′,4,4′-tetramethyldibenzyl, mp 122–123°, nmr methyl singlets at δ 2.17, 2.21, and 2.81, methylene H at 3.75, and ArH at 6.02 and 6.59.

Anal. Calcd for $C_{20}H_{26}O_2$: C, 80.5; H, 8.8. Found: C, 80.5; H, 8.8.

4,5-Dimethoxy-1,3,6,8-tetramethylphenanthrene (2) and 4,7-Dimethoxy-1,3,6-trimethylphenanthrene (3). A solution of 3.4 g (0.0115 mol) of 1 and 1.60 g (0.0063 mol) of iodine in 2 l. of distilled cyclohexane was flushed with oxygen for 1 hr in a three-necked photolysis tube of quartz, equipped with an oxygen inlet, condenser, thermometer, and a 450-W Hanovia high-pressure mercury lamp. After the oxygen flow was discontinued, irradiation was conducted at 33–35° during which uv spectra were taken every 30 min. Irradiation was stopped after 4 hr when the ratio of phenanthrene absorbance at *ca.* 265 mμ and of stilbene absorbance at *ca.* 225 mμ was about three. The photolysis solution was washed with aqueous sodium bisulfite to remove iodine and worked up in the usual manner. The yellow residue was passed through a dry alumina column (10 × 0.5 in., Woelm alumina for dry-column chromatography, Waters Associates, Inc.) and eluted with cyclohexane until the lowest blue fluorescent band nearly reached the bottom of the column. After the top yellow and rainbow bands were removed by application of air pressure to the bottom of the column, the remainder was extracted with cyclohexane, ethanol, and ether. The solvent (about 1000 ml) was rotary evaporated. The residue was recrystallized from 10 ml of ethanol at room temperature for 2 days to give 0.20 g of solid and mother liquor. The solid was recrystallized twice from 5 ml of ethanol to give 0.15 g (4.3%) of 2: mp 130–131°; ir 6.12, 6.23, 9.05, 9.81, and 9.99 μ; nmr CH_3 singlets at δ 2.47, 2.63, and 3.27, ArH (2 each) at 7.24, 7.67; uv λ_{max} (cyclohexane) 223 mμ (ε 13,200), 262 (33,600), 295 (13,200), and 335 (9400); exact mass 294.16190940 (calcd, 294.16240925).

Anal. Calcd for $C_{20}H_{22}O_2$: C, 81.6; H, 7.5. Found: C, 81.4; H, 7.6.

From the above mother liquor 0.8 g of crude 3 was obtained by further crystallization from ethanol. Recrystallization from 10 ml of ethanol yielded 0.5 g (15.5%) of 3: mp 84–85°; ir 6.15, 6.36, 9.16, 9.78, and 10.05 μ; nmr CH_3 singlets at δ 2.47, 2.48, 2.62, 3.69, and 3.71, ArH singlets at 7.04 and 7.13, AB pattern at 7.49 and 7.69 (J = 9 Hz), and a singlet at 9.38 (the H at position 5 due to deshielding by the 4-OCH_3); uv λ_{max} (cyclohexane) 230 mμ (ε 16,300), 259 (55,400), 265 (64,900), 283 (14,400), 301 (11,100), and 313 (11,100); exact mass 280.14654235 (calcd, 280.14632020).

Anal. Calcd for $C_{19}H_{20}O_2$: C, 81.4; H, 7.2. Found: C, 81.2; H, 7.2.

When Pyrex was used instead of quartz there was obtained a small amount of *cis*-5,5′-dimethoxy-2,2′,4,4′-tetramethylstilbene: mp 88–89°; nmr, two $ArCH_3$ singlets at δ 2.11 and 2.15, OCH_3 singlet at 3.40, three singlets, vinyl H, ArH at 6.49, 6.65, and 6.86; uv λ_{max} (cyclohexane) 226 mμ (ε 16,500), 230 (15,900), and a broad flat band at 250–305 (7100). When the irradiation was carried out in ethanol under similar conditions, no phenanthrene derivatives were formed.

Registry No.—*trans*-1, 50790-94-8; *cis*-1, 50790-95-9; 2, 50790-66-4; 3, 50790-67-5; 7, 762-42-5; 8, 22481-09-0; 10, 50790-68-6; 11, 32644-91-0; 12, 32644-92-1; 13, 50790-69-7; 13 bromide, 50790-70-0; 2,5-dimethylfuran, 625-86-5; methyl 2,4-dimethyl-5-hydroxybenzoate, 50790-71-1; methanesulfonyl chloride, 124-63-0; 5,5′-dimethoxy-2,2′,4,4′-tetramethyldibenzyl, 50790-72-2.

References and Notes

(1) This work was supported by Grant GP-12445 of the National Science Foundation.

(2) This research formed part of the M.S. Thesis presented by H. M. Chung to The Ohio State University in 1972.

(3) P. Vogel, B. Willham, and H. Prinzbach, *Helv. Chim. Acta*, **52**, 593 (1969). See H. Prinzbach, P. Vogel, and W. Auge, *Chimia*, **21**, 469

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(12) All melting points and boiling points are uncorrected. Ir spectra were recorded using a Perkin-Elmer Infracord using NaCl disks or KBr pellets. Nmr spectra were recorded on a Varian A-60 instrument and are reported as δ units (TMS = 0) in $CDCl_3$. Uv spectra were run using a Cary 14 recording spectrophotometer. The phrase "worked up in the usual way" means that an ether–benzene solution of the products was washed with dilute acid and/or base, with saturated NaCl solution. The ether–benzene solution was then filtered through a cone of $MgSO_4$ and the solvent was removed on a rotary evaporator.
(13) Used as obtained from the Chemical Samples Co., Columbus, Ohio.
(14) Obtained from the Aldrich Chemical Co., Milwaukee, Wis.
(15) If desired the crude product may be purified by distillation to yield 7 bp 90° (0.3 mm), in 95% yield. However, the yield of 8 is the same if the crude product is used.
(16) In a similar experiment at 125° a very low yield of adduct 7 was obtained.
(17) Venus 44-F, obtained from the U. S. Bronze Powders, Inc., Flemington, N. J. In a similar experiment in which the copper was omitted, the yield was 81%. Hence studies in which copper is replaced by other solids may be of interest.
(18) J. Meisenheimer, R. Haussen, and A. Wachterowitz, *J. Prakt. Chem.*, [2] **119**, 315 (1928).
(19) All analyses by Chemalytics, Inc., Tempe, Ariz.
(20) Methyltricaprylammonium chloride, obtained from General Mills Chemicals, Kankakee, Ill.
(21) R. M. Silverstein and G. C. Bassler, "Spectrometric Identification of Organic Compounds," 2nd ed, Wiley, New York, N. Y., 1967, p 29.

Mechanistic Aspects of 2,3-Benzofulvene Formation from Sensitized Irradiation of 7-Azabenzonorbornadienes

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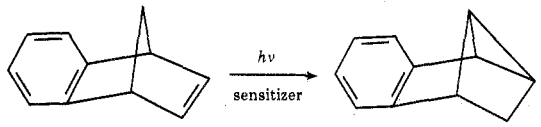
The singlet and triplet photochemistry of 7-*tert*-butoxycarbonyl-2,3-benzo-7-azabicyclo[2.2.1]hepta-2,5-diene (**3c**) has been studied. While direct excitation of **3c** at 300 nm affords *tert*-butyl 3-benzazepine-3-carboxylate (**6c**) with low efficiency (Φ = 0.05), acetone-sensitized irradiation yields 5-*tert*-butoxycarbonyl-5-azatetracyclo[5.4.0.$0^{2,4}$.$0^{3,6}$]undeca-1(7),8,10-triene (**7c**) in high synthetic yield (93%) and with high efficiency (Φ = 0.93). The structure assignment for **7c** is supported by spectroscopic data and its hydrogenation and acid-catalyzed rearrangement reactions. The general mechanism for 2,3-benzofulvene formation from triplet-sensitized rearrangement of 7-azabenzonorbornadienes is discussed.

The photochemical rearrangement of various benzonorbornadiene derivatives to tetracyclic products *via* the di-π-methane reaction is well characterized (*i.e.*, 1 → 2).[2]



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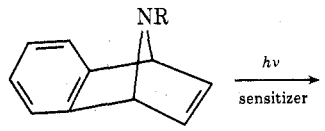
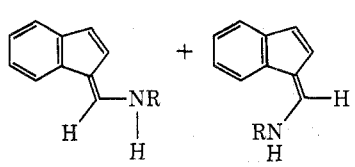
However, a photochemical study of the 7-aza derivative **3a** did not afford tetracyclic products analogous to **2**, but instead benzofulvene derivatives **4** and **5**.[3] We wish



3a, R = CO_2CH_3
b, R = NTs
c, R = CO-*t*-Bu



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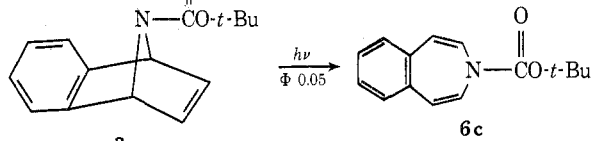
to report here the details of the direct and photosensitized rearrangement of **3c** and the establishment of one mechanistic pathway for the production of benzofulvene derivatives from sensitized irradiation of 7-azabenzonorbornadienes.

Irradiation of 7-*tert*-Butoxycarbonyl-7-azabenzonorbornadiene (3c). Direct irradiation of **3c** in cyclohexane at low conversion produces *tert*-butyl 3-benzazepine-3-carboxylate in low quantum efficiency. However, acetone-sensitized irradiation of **3c** results in rapid loss of **3c** and the



3c **6c**

formation of an acid and thermally labile product. While initial attempts at isolation of this material were complicated by product decomposition during irradiation and attempted purification, by using base-washed apparatus and maintaining the temperature below 30° a colorless liquid could be isolated in 94% yield after chromatography on activity IV basic alumina. This material, which was isomeric with **3c**, showed a carbonyl absorption (5.85 μ) in the ir and exhibited four distinct one-proton signals in the nmr in addition to the aromatic and *tert*-butyl absorptions:[1d] τ 5.17 (1 H, d), 6.14 (1 H, distorted t), 6.60 (1 H, m), 7.43 (1 H, m). The absence of olefinic absorption in the adduct suggests a tetracyclic structure, for which **7c** seemed most reasonable. This structural assignment is further supported by its hydrogenation and acid-catalyzed rearrangement studies reported below.

Several attempts at clean partial hydrogenation of **7c** were made. The most successful of these employed atmospheric hydrogenation in ethyl acetate using 5% Pd/C as catalyst. The uptake of 1–1.5 equiv of hydrogen followed by work-up yielded 20–30% of an impure crystalline mate-