F. Benzaldehyde.—Finally, 5.3 g (0.05 mol) of benzaldehyde gave 5.7 g (78%) of 3-hydroxy-3-phenylpropanenitrile (**5**): bp 154–155° (1 mm); ir (neat), 3395 (OH), 2275 (C≡N), 1315 and 1095 (OH and CO); nmr (neat), δ 6.9 (s, 5, ArH), 4.38 (m, 2, CHOH), 2.12 (d, 2, CH_2CN).

Anal. Calcd for C_9H_9NO: C, 73.55; H, 6.11. Found: C, 73.50; H, 6.19.

Condensation of Acetonitrile and Benzophenone by Alkali Amides in Ammonia. A. Sodium Amide.—To a stirred suspension of 0.055 mol of sodium amide in 300 ml of commercial anhydrous liquid ammonia[16] [prepared from 1.27 g (0.055 g-atom) of sodium metal] was added during 5 min a solution of 2.05 g (0.05 mol) of acetonitrile in 50 ml of ether. After 30 min, the black solution was treated during 5 min with a solution of 9.1 g (0.05 mol) of benzophenone in 50 ml of ether. After 5 min, the now blue-black solution was poured into a magnetically stirred suspension of 20 g of ammonium chloride in 200 ml of ammonia. The ammonia was allowed to evaporate and the solid residue was hydrolyzed by the addition of 100 ml of 3 *N* hydrochloric acid. Work-up as in part A above afforded 10.3 g (93%) of β-hydroxynitrile **1**, mp and mmp 141–142°.

B. Lithium Amide.—This reaction was effected essentially as described for sodium amide above except that the amide ion was prepared from 0.385 g (0.055 g-atom) of lithium metal. In addition, the solution derived from acetonitrile and lithium amide was stirred for 1 hr before the ketone was added. Work-up gave 9.42 g (85%) of product **1**, mp and mmp 141–142°.

C. Potassium Amide.—This reaction was performed as in parts A and B using 2.15 g (0.055 g-atom) of potassium metal to form the amide ion; the ionization time before the addition of the ketone was 15 min. Work-up afforded 7.6 g (69%) of **1**, mp and mmp 141–142°.

Dehydration of β-Hydroxynitrile 1 to Afford Unsaturated Nitrile 6.—β-Hydroxynitrile **1** (3.0 g, 0.0134 mol) was suspended in 80 ml of 85% phosphoric acid; the magnetically stirred mixture was brought to reflux for 15 min; and all of the solid dissolved or oiled. The mixture was then poured into ice water and the product was extracted by three 50-ml portions of ether. After the crude product was dried and concentrated, distillation gave 1.8 g (65%) of 1-cyano-2,2-diphenylethene (**6**): bp 172–173° (5 mm); ir (neat), 2205 (C≡N), 832 (C=C); nmr ($CDCl_3$), δ 7.4 (m, 10, ArH), 5.7 (s, 1, =CHCN).

Anal. Calcd for $C_{15}H_{11}N$: C, 87.80; H, 5.36; N, 6.82. Found: C, 87.77; H, 5.49; N, 6.78.

Dehydration of β-Hydroxynitrile 2 to Afford Unsaturated Nitrile 7.—This dehydration was effected as described above except that 1.5 g of **2** and 40 ml of 85% phosphoric acid were employed. Work-up as above and subsequent recrystallization from methanol afforded 0.9 g (55%) of 1-cyano-2-fluorenylethene (**7**): mp 109–111°; ir (Nujol), 2190 (C≡N), 835 (C=C); nmr ($CDCl_3$), δ 7.48 (m, 8, ArH), 6.02 (s, 1, =CHCN).

Anal. Calcd for $C_{16}H_9N$: C, 88.67; H, 4.43. Found: C, 88.54; H, 4.60.

Registry No.—**1**, 3531-23-5; **2**, 17190-25-9; **3a**, 14368-31-1; **3b**, 17190-27-1; **4**, 14368-37-7; **5**, 17190-29-3; **6**, 3531-24-6; **7**, 4425-74-5; acetonitrile, 75-05-8; *n*-butyllithium, 109-72-8.

(16) See C. R. Hauser, F. W. Swamer, and J. T. Adams, *Org. Reactions*, **8**, 122 (1954).

Synthesis of Four Methoxy-Substituted 1,8-Naphthalic Anhydrides and of the Three Monomethyl-1,8-naphthalic Anhydrides[1]

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The 2-, 3-, and 4-methoxy-1,8-naphthalic anhydrides were synthesized by starting, respectively, with a Friedel–Crafts reaction on β-methoxynaphthalene, sulfonation of 1,8-naphthalic anhydride, and nitration of acenaphthene. 2,3-Dimethoxy-1,8-naphthalic anhydride was prepared in very low yield *via* the Friedel–Crafts reaction of diphenyloxalimide chloride with 2,3-dimethoxynaphthalene. The 2- and 4-methyl-1,8-naphthalic anhydrides were prepared, respectively, *via* the Friedel–Crafts reaction on β-methylnaphthalene and bromination of acenaphthene. Synthesis of 3-methyl-1,8-naphthalic anhydride *via* Friedel–Crafts methylation of acenaphthene failed. Although ethylation of acenaphthene yields 4-ethylacenaphthene, methylation yields 5-methylacenaphthene. Successful synthesis of 3-methyl-1,8-naphthalic anhydride followed the discovery that diborane reduction of 3-bromo-1,8-naphthalic anhydride yields 5-bromo-2,1,3-*peri*-naphthopyran. After the bromine had been converted into methyl *via* the carboxylic acid, oxidation yielded the 3-methyl-1,8-naphthalic anhydride. Numerous attempts to synthesize 3,4-dimethoxy-1,8-naphthalic anhydride failed. In the nmr spectra of the anhydrides, resonance for the methyl hydrogens in both the methyl-substituted and methoxy-substituted anhydrides followed the same pattern, highest field for the 3 position and lowest field for the 2 position.

In determining the structure of trimethylherqueinone B, a derivative of the naturally occurring pigment herqueinone, a tetramethoxymonomethyl-1,8-naphthalic anhydride was isolated as a degradation product.[2] In order to allow location of the substituents in the naphthalene ring by spectroscopic methods, methoxy- and methyl-substituted 1,8-naphthalic anhydrides were required as reference compounds. The present report is concerned with synthesis of these compounds.

Although the monomethoxy-1,8-naphthalic anhydrides have been reported in the literature, each of the three has been characterized poorly or not at all. The 2-methoxy-1,8-naphthalic anhydride has been obtained by us in high yield by oxidation of 3-methoxyacenaphthenequinone; however, this intermediate was obtained in relatively poor yield from a Friedel–Crafts reaction with β-methoxynaphthalene and diphenyloxalimide chloride. The best approach to the 3-methoxy-1,8-naphthalic anhydride[3] proved to be sulfonation of the parent anhydride. Alkali fusion and methylation yielded the desired compound. The 4-methoxy isomer could not be obtained in significant yield, proceeding by way of the sulfonation of acenaphthene;[4] however, nitration of acenaphthene proved to be a satisfactory approach. Reduction to the amine, high pressure hydrolysis to 5-acenaphthenol, methylation, and dichromate oxidation yielded the 4-methoxy-1,8-naphthalic anhydride.

In order to allow the desired deductions from spectra,

(1) This investigation was supported in part by a research grant (G 24347) from the National Science Foundation.

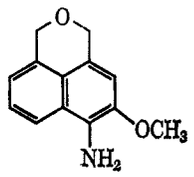
(2) J. Cason, J. S. Correia, R. B. Hutchison, and R. F. Porter, *Tetrahedron*, **18**, 839 (1962).

(3) A reaction using 3-methoxy-1,8-naphthalic anhydride has been reported by K. Dziewonski, W. Kohl, and W. Dymek, *Bull. Intern. Acad. Polon. Sci.*, 394 (1934); *Chem. Zentr.*, 2169 (1935I). No properties or method of synthesis are included in German or English abstracts.

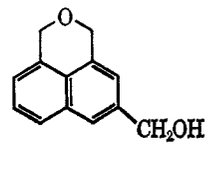
(4) K. Dziewonski and T. Stolyhwo, *Ber.*, **57**, 1540 (1924).

there was required at least one dimethoxy- or dimethyl-1,8-naphthalic anhydride with the substituents on adjacent carbons. The 2,3-dimethoxy-1,8-naphthalic anhydride proved accessible, although in extremely small yield, by way of the 3,4-dimethoxyacenaphthenequinone. This intermediate could be secured in minute yield by the Friedel–Crafts reaction with diphenyloxalimide chloride.

Although 3.4-dimethoxy-1,8-naphthalic anhydride has been reported,[5] persistent efforts on our part have failed to yield the compound.[6] Among the routes investigated was one proceeding *via* 3-methoxy-4-nitro-1,8-naphthalic anhydride, whose catalytic or chemical reduction to the 4-amino compound could not be accomplished. When the anhydride was reduced to the 2,1,3-*peri*-naphthopyran by means of diborane, it became possible to secure the amine, **1**; however, compound **1** could not be converted into the 5-methoxy-



1



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6-hydroxy-2,1,3-*peri*-naphthopyran. New compounds synthesized in these investigations are reported in the Experimental Section.

Although none of the methyl-1,8-naphthalic anhydrides appears to have been reported, the 2-methyl and 4-methyl isomers proved readily accessible. The 2-methyl isomer could be secured by way of the 3-methylacenaphthequinone, although the yield of this quinone was only about 3% in the Friedel–Crafts reaction between β-methylnaphthalene and oxalyl chloride. The 4-methyl-1,8-naphthalic anhydride was secured from 5-bromoacenaphthene. The Grignard reagent from this bromide reacted with methyl iodide to give a 20% yield of 5-methylacenaphthene, which could be oxidized in modest yield to the 4-methyl-1,8-naphthalic anhydride.

Synthesis of 3-methyl-1,8-naphthalic anhydride from the known 4-aminoacenaphthene[7] failed, for only an insignificant yield of 4-bromoacenaphthene could be obtained. An effort to obtain 4-methylacenaphthene by a Friedel–Crafts reaction on acenaphthene yielded principally 5-methylacenaphthene, with no detectable amount of the 4-methyl isomer. Since this result is in such sharp contrast with the literature report[8] that ethyl bromide gives a low yield of 4-ethylacenaphthene, the ethylation procedure was repeated and confirmed. Further, the structure of the 4-ethylacenaphthene was verified by oxidation to 3-carboxy-1,8-naphthalic anhydride, converted in turn by diborane reduction into 5-hydroxymethyl-2,1,3-*peri*-naphthopyran (**2**), which was synthesized by the alternate route described below. We believe that the sharp difference in position of predominant substitution of the methyl and ethyl groups should be ascribed to the greater steric requirement of ethyl. The significant hindrance at the 1 position in naphthalene has been observed frequently; indeed, this was a major factor which defeated some of our efforts to secure the 3,4-dimethoxy-1,8-naphthalic anhydride.

With the discovery that diborane reduces a 1,8-naphthalic anhydride to the 2,1,3-*peri*-naphthopyran, compound **2** becomes an effective intermediate for synthesis of the 3-methyl-1,8-naphthalic anhydride. A much better synthesis of compound **2** was developed, starting with bromination of 1,8-naphthalic anhydride.[9] The 3-bromo-1,8-naphthalic anhydride was reduced to 5-bromo-2,1,3-*peri*-naphthopyran, which could be readily converted *via* the nitrile into the corresponding carboxylic acid, whose reduction with lithium aluminum hydride yielded compound **2**. Catalytic hydrogenation of compound **2** with palladium catalyst yielded the 5-methyl-2,1,3-*peri*-naphthopyran, whose oxidation gave the desired 3-methyl-1,8-naphthalic anhydride.

It is of interest that 5-bromo-2,1,3-*peri*-naphthopyran could not be converted into the corresponding 5-methyl derivative by coupling the Grignard reagent or lithium derivative with either methyl iodide or dimethyl sulfate. Gas chromatography of the products showed 5% or less of the methylated product, and the principal product was dehalogenated starting material, *i.e.*, 2,1,3-*peri*-naphthopyran.

The locations of the methyl hydrogens on the nmr scale, for the anhydrides here reported, have already been published,[2] except for the 3-methyl-1,8-naphthalic anhydride. In trifluoroacetic acid, resonance for the methyl hydrogens in this compound was observed at τ 7.27, which is slightly upfield from the location of the 4-methyl anhydride, which is in turn higher than the 2-methyl isomer. Thus, the relative shifts are the same in the methyl-substituted and methoxy-substituted compounds, lowest field for the 2 position and highest field for the 3 position. The structure of the anhydride from degradation of trimethylherqueinone B, which was deduced in part from these spectral considerations, has been proved correct by synthesis.[10]

Experimental Section[11]

2-Methoxy-1,8-naphthalic Anhydride.—3-Methoxyacenaphthenequinone was prepared by the procedure of Staudinger and coworkers[13] from 3.38 g of 2-methoxynaphthalene and 5.80 g of diphenyloxalimide chloride.[14] The product obtained directly by acidification of the bisulfite extract amounted to 631 mg (27.5%), mp 224–226°. For oxidation, a 200-mg sample of

(5) K. Dziewonski, O. Geschwind, and L. Schimmer, *Bull. Intern. Acad. Polon. Sci., Ser. A*, 507 (1928); *Chem. Abstr.*, **23**, 4212 (1929).

(6) Nearly all the work here reported was completed in 1962, but has been reserved while one approach after the other has failed to reach the 3,4-dimethoxy-1,8-naphthalic anhydride.

(7) H. Rapoport, T. P. King, and J. B. Lavigne, *J. Amer. Chem. Soc.*, **73**, 2718 (1951).

(8) H. E. Nürsten and A. T. Peters, *J. Chem. Soc.*, 2389 (1950).

(9) H. G. Rule and S. B. Thompson, *ibid.*, 1764 (1937).

(10) J. Cason and D. M. Lynch, *J. Org. Chem.*, **31**, 1883 (1966).

(11) Melting points were determined on a Büchi Schmelzpunkbestimmungsapparat. Microanalyses were by the Microanalytical Division, Department of Chemistry, University of California at Berkeley. Infrared spectra of the 1,8-naphthalic anhydrides, determined in a Nujol mull or in chloroform solution where solubility was sufficient, exhibited two carbonyl bands near 5.65 and 5.75 μ, as is characteristic of 1,8-naphthalic anhydrides[2,12] not substituted in the 2 position with hydroxyl. The nmr spectra, all but one of which have been previously reported,[2] were determined in trifluoroacetic acid, using a Varian A-60 instrument, with TMS as an internal standard. This solvent, required to achieve sufficient solubility, was satisfactory if the spectra were determined within 2 hr after solution.

(12) D. H. R. Barton, P. de Mayo, G. A. Morrison, and H. Raistrick, *Tetrahedron*, **6**, 48 (1959).

(13) H. Staudinger, H. Goldstein, and E. Schlenker, *Helv. Chim. Acta*, **4**, 342 (1921).

(14) R. Bauer, *Ber.*, **40**, 2650 (1907).

this quinone was dissolved in 4 ml of absolute ethanol, 11 ml of 4 *N* aqueous sodium hydroxide was added, and the mixture was swirled as 11 ml of 30% hydrogen peroxide was added during 15 min. After the reaction mixture had stood at room temperature for 30 min, it was acidified with 6 *N* sulfuric acid. When the clear solution was cooled in ice, a white precipitate formed. One crystallization from 95% ethanol yielded white needles: wt, 195 mg (90.6%); mp 261–262° (lit.[15] mp 255°).

Anal. Calcd for $C_{13}H_8O_4$: C, 68.4; H, 3.5. Found: C, 68.2; H, 3.6.

2,3-Dimethoxy-1,8-naphthalic Anhydride.—The total yield of crude 3,4-dimethoxyacenaphthenequinone, prepared from 6.28 g of 2,3-dimethoxynaphthalene, was oxidized as described above to yield only 26.8 mg (0.45% over-all yield) of pure 2,3-dimethoxy-1,8-naphthalic anhydride, crystallized from acetic acid, mp 253–255°.

Anal. Calcd for $C_{14}H_{10}O_5$: C, 65.1; H, 3.9. Found: C, 65.05; H, 4.0.

3-Methoxy-1,8-naphthalic Anhydride.—1,8-Naphthalic anhydride was sulfonated as has been described[16] except that it was found necessary to use 30% fuming sulfuric acid (rather than 25%) and to heat at 120° for 1 hr (rather than 90° for 30 min). Fusion of the sulfonic acid with potassium hydroxide according to Dziewonski[4] and crystallization from absolute ethanol gave an average over-all yield of 40% of yellow needles of 3-hydroxy-1,8-naphthalic anhydride, mp 286–287° (lit.[4] mp 287°). Methylation with dimethyl sulfate in acetone in presence of potassium carbonate gave a 68% yield of 3-methoxy-1,8-naphthalic anhydride, mp 249–250°.

Anal.[17] Calcd for $C_{13}H_8O_4$: C, 68.4; H, 3.5. Found: C, 67.9; H, 3.3.

3-Hydroxy-4-nitro-1,8-naphthalic Anhydride.—A 4.28-g sample of 3-hydroxy-1,8-naphthalic anhydride was dissolved with stirring at room temperature in 63 ml of 100% sulfuric acid. The brown solution was stirred in an ice bath as a solution of 1.5 ml of concentrated nitric acid (d 1.42) in 7.5 ml of 100% sulfuric acid was added dropwise. After stirring had been continued for 1.5 hr the reaction mixture was poured over ice, and the resultant mixture was allowed to stand overnight in the refrigerator. The yellow product was collected by filtration, washed with water, dried, and crystallized from 100 ml of acetic acid to yield 4.15 g (80%) of yellow 3-hydroxy-4-nitro-1,8-naphthalic anhydride, mp 233–235° dec (lit.[18] mp 235–236°).

3-Methoxy-4-nitro-1,8-naphthalic Anhydride.—A solution of 3.88 g of 3-hydroxy-4-nitro-1,8-naphthalic anhydride in 115 ml of dry acetone was treated with 2 g of anhydrous potassium carbonate and 14 ml of dimethyl sulfate; then the mixture was heated under reflux with stirring for 1 hr. The resultant yellow solution (originally dark red) was diluted with 300 ml of water and stored overnight in the refrigerator. The yellow precipitate was collected, washed with water, and crystallized from 50 ml of acetic acid to yield 3.18 g (78%) of golden yellow needles, mp 204–205°.

Anal. Calcd for $C_{13}H_7O_6N$: C, 57.1; H, 2.6; N, 5.1. Found: C, 56.9; H, 2.7; N, 5.1.

5-Methoxy-6-nitro-2,1,3-*peri*-naphthopyran.—A solution of 546 mg of 3-methoxy-4-nitro-1,8-naphthalic anhydride in 7 ml of purified diglyme was stirred with cooling in an ice bath, under an atmosphere of nitrogen, as there was added dropwise 136 mg of sodium borohydride in 3 ml of purified diglyme. As stirring of the red-brown solution was continued at room temperature there was added dropwise during 30 min 680 mg of boron trifluoride etherate in 2 ml of diglyme. A precipitate formed near the end of the addition, but stirring was continued for an additional 2 hr, after which excess reagent was destroyed by addition of 60 ml of ice–water. The reaction mixture was extracted with three 100-ml portions of chloroform, and the extracts were washed with four portions of water. The residue remaining after removal of chloroform at reduced pressure was chromatographed on Woelm alumina (activity II) and eluted with benzene. Crystallization of the semisolid eluted product (wt, 382 mg) from methanol yielded 197 mg (40%) of the title compound, mp 141–142°.

Anal. Calcd for $C_{13}H_{11}O_4N$: C, 63.7; H, 4.5; N, 5.7. Found: C, 63.5; H, 4.7; N, 5.6.

5-Methoxy-6-amino-2,1,3-*peri*-naphthopyran (1).—A suspension of 245 mg of the above-described compound and 350 mg of powdered tin in 5 ml of methanol was stirred at 60° for 12 hr as a total of 3 ml of concentrated hydrochloric acid was added. To the resultant mixture (color white) were added 5 ml of water and 5 ml of 50% sodium hydroxide; then stirring was continued on the steam bath for 1 hr. The cooled reaction mixture was extracted with three portions of benzene; then the extract was washed with water and evaporated to dryness at reduced pressure. Crystallization of the resultant brown solid from 25 ml of hexane yielded 180 mg (84%) of the title compound, mp 107–108°.

Anal. Calcd for $C_{13}H_{13}O_2N$: C, 72.5; H, 6.1; N, 6.5. Found: C, 72.3; H, 5.9; N, 6.4.

Efforts to convert the amino into hydroxyl by way of either diazotization or high pressure acid-catalyzed hydrolysis gave only tarry reaction products. When the tarry products were subjected to the methylation procedure, isolation of a discrete product remained impossible.

5-Methoxyacenaphthene.—A solution of 3.44 g of 5-aminoacenaphthene[7] in 60 g of 10% sulfuric acid was heated in a pressure tube at 205 ± 5° for 4 hr. The solid present in the cooled reaction mixture was collected by filtration and dissolved in 100 ml of 10% potassium hydroxide solution. The solution was clarified with Supercel, then warmed on a steam bath for 2 hr with 5 ml of dimethyl sulfate. Recovery of the product by ether extraction and distillation yielded 1.5 g (40%) of oily white solid. Crystallization from methanol yielded buff-colored needles mp 61–62° (lit.[19] mp 66°).

When conversion into hydroxyl was accomplished by diazotization, our yield of 5-methoxyacenaphthene was only 16%, much lower than that which has been reported[19] for this route.

4-Methoxy-1,8-naphthalic Anhydride.—A solution of 200 mg of 5-methoxyacenaphthene in 4 ml of glacial acetic acid was swirled at 90° as 1.08 g of sodium dichromate was added during a few minutes. After the mixture had been heated under reflux for 2 hr it was cooled and treated with 10 ml of ice–water. The yellow-brown solid which precipitated was collected and crystallized from acetic acid to yield 166 mg (67%) of red-brown needles, mp 264–265° (lit.[19] mp 255–257°).

Anal.[17] Calcd for $C_{13}H_8O_4$: C, 68.4; H, 3.5. Found: C, 67.9; H, 3.5.

2-Methyl-1,8-naphthalic Anhydride.—3-Methylacenaphthenequinone was prepared approximately by the procedure of Lesser and Gad,[20] using 10 g of oxalyl dichloride and 10 g of β-methylnaphthalene. After purification through the bisulfite addition compound and sublimation at 0.05 mm of pressure, 0.46 g (3.3%) of pure product was secured, mp 197–199° (lit.[20] mp 198–199°, yield 3.6%). A solution of 50 mg of the quinone in 2 ml of acetic acid was heated to boiling and treated during 30 min with 100 mg of sodium dichromate. Heating under reflux was continued for an additional 1.5 hr, then 20 ml of ice–water was added to the cooled solution. The precipitate of white crystals, mp 232–233°, amounted to 50 mg (92%). The analytical sample was sublimed at 150–160° (0.01 mm), mp 235–236°.

Anal. Calcd for $C_{13}H_8O_3$: C, 73.6; H, 3.8. Found: C, 73.7; H, 4.0.

5-Methylacenaphthene.—A Grignard reagent was prepared, in an atmosphere of helium, from 2.34 g of 5-bromoacenaphthene[21] and 265 mg of magnesium in 50 ml of purified tetrahydrofuran. To the clear yellow solution of the Grignard reagent was added at room temperature a solution of 3.6 g of methyl iodide in 40 ml of tetrahydrofuran. The reaction mixture was heated with stirring at 55–60° for 18 hr. A usual work-up of the Grignard reaction yielded a dark brown semisolid which was triturated with hexane. The solid was removed from the solution by filtration. The material recovered from evaporation of the hexane solution was chromatographed on Woelm alumina (activity II), but this failed to separate the 5-methylacenaphthene from

(15) K. Dziewonski and A. Kocwa, *Bull. Intern. Acad. Polon. Sci.*, 405 (1928); *Chem. Abstr.*, **23**, 2435 (1929).

(16) F. Anselm and F. Zuckmayer, *Ber.*, **32**, 3283 (1899).

(17) As previously noted,[10] our work with derivatives of acenaphthene and 1,8-naphthalic anhydrides has frequently encountered an analytical difficulty in the form of low and highly variable values for carbon, when classical combustion analysis is used. A method depending on combustion in a sealed tube [C. W. Koch and E. Jones, *Mikrochem. Acta*, **4**, 734 (1963)] has given consistent results within 0.5% of theoretical values. This method was required for the presently cited compound.

(18) K. Dziewonski, *Bull. Intern. Acad. Polon. Sci., Ser. B*, 507 (1928); *Chem. Zentr.*, 1172 (1932II).

(19) G. A. R. Kon and H. R. Soper, *J. Chem. Soc.*, 790 (1939).

(20) R. Lesser and G. Gad, *Ber.*, **60**, 242 (1927).

(21) C. Graebe, *Ann.*, **327**, 77 (1903).

acenaphthene (ratio about 3:2). Separation was accomplished by gas chromatography on a 15 mm × 2 m silicone grease column, to yield 340 mg (20%) of 5-methylacenaphthene, mp 94–95°. Crystallization from ethanol raised the melting point to 95–96° (lit.[22] mp 95–96°).

4-Methyl-1,8-naphthalic Anhydride.—A 150-mg sample of 5-methylacenaphthene, dissolved in 6 ml of boiling acetic acid, was oxidized with 810 mg of sodium dichromate. Precipitation of the product by addition of water and crystallization from acetic acid yielded 95 mg (50%) of the title anhydride, mp 231–232°.

Anal. Calcd for $C_{13}H_8O_3$: C, 73.6; H, 3.8. Found: C, 73.2; H, 3.8.

4-Bromoacenaphthene.—A solution of 1.45 g of 4-aminoacenaphthene[7] in 14 ml of acetic acid was added dropwise with stirring at 0° to a solution of 3.4 ml of concentrated sulfuric acid in 19.5 ml of water. Diazotization was accomplished by addition of 690 mg of sodium nitrite in 5 ml of water during 20 min. After an additional 30 min at 0°, excess nitrite was destroyed with urea. The ice-cold diazonium solution was added to a boiling solution of 1.43 g of cuprous bromide in 4 ml of 48% hydrobromic acid. The hexane extract of the cooled, dark-colored reaction mixture was washed with water, sodium hydroxide solution, and water, and then evaporated to yield 100 mg of solid. After crystallization from ethanol and sublimation at 50° (0.05 mm), a few milligrams of 4-bromoacenaphthene was obtained, mp 65–66°.

Anal.[17] Calcd for $C_{12}H_9Br$: C, 61.8; H, 4.0. Found: C, 61.9; H, 3.9.

5-Bromo-2,1,3-*peri*-naphthopyran.—3-Bromo-1,8-naphthalic anhydride was prepared essentially as described by Rule and Thompson:[9] yield 22%; mp 241–242°. A 4.15-g sample of the anhydride was reduced with diborane by the procedure which has been described above for synthesis of 5-methoxy-6-nitro-2,1,3-*peri*-naphthopyran. When the reaction mixture was diluted, a solid precipitated and was removed by filtration. Chromatography on alumina (activity II) and elution with benzene yielded 1.46 g (38%) of the bromo ether, mp 94–97°. The analytical sample, secured by crystallization from hexane, had mp 98–99°.

Anal. Calcd for $C_{12}H_9OBr$: C, 57.85; H, 3.6; Br, 32.1. Found: C, 58.0; H, 3.8; Br, 32.3.

5-Cyano-2,1,3-*peri*-naphthopyran.—Replacement of halogen was best accomplished in dimethylformamide as solvent.[23] A solution of 1.25 g of 5-bromo-2,1,3-*peri*-naphthopyran in 6 ml of freshly distilled dimethylformamide was treated with 0.54 g of dried cuprous cyanide, and the mixture was heated under reflux for 6 hr. The resultant dark solution, while still hot, was poured into a solution of 3 ml of ethylenediamine in 9 ml of water. The resultant blue mixture was heated on a steam bath to about 70°, then extracted with three 100-ml portions of benzene. After the extracts had been washed with water, 10% sodium cyanide solution, and water, solvent was removed, and the residue was crystallized from 400 ml of hexane to give 800 mg (82%) of the title compound, mp 150.5–152°.

Anal. Calcd for $C_{13}H_9ON$: C, 80.0; H, 4.65. Found: C, 79.7; H, 4.4.

2,1,3-*peri*-Naphthopyran-5-carboxylic Acid.—A 600-mg sample of the nitrile was hydrolyzed by heating under reflux for 18 hr with a solution of 2.1 g of potassium hydroxide in 1 ml of water and 8.4 ml of Methyl Cellosolve. The reaction mixture was worked up for acidic material, which was crystallized from benzene and sublimed at 170° (0.05 mm) to yield 540 mg (82%) of the carboxylic acid, mp 235.5–237.5°.

Anal. Calcd for $C_{13}H_{10}O_3$: C, 72.9; H, 4.7. Found: C, 72.6; H, 4.8.

5-Hydroxymethyl-2,1,3-*peri*-naphthopyran (2).—To a solution of 95 mg of lithium aluminum hydride in 8 ml of purified tetrahydrofuran, stirred under nitrogen, was added during a few minutes a solution of 428 mg of the above described carboxylic acid in 5 ml of purified tetrahydrofuran. The reaction mixture was stirred at room temperature for 30 min; then excess $LiAlH_4$ was destroyed with water. The product was isolated from the acidified reaction mixture by ether extraction, then crystallized from ether–pentane to yield 324 mg (81%) of **2**, mp 102–104°.

Anal. Calcd for $C_{13}H_{12}O_2$: C, 78.0; H, 6.0. Found: C, 77.9; H, 6.0.

Alcohol **2** was also prepared by reduction of 3-carboxy-1,8-naphthalic anhydride (see below) with diborane according to the procedure described for synthesis of 5-methoxy-6-nitro-2,1,3-*peri*-naphthopyran. For 242 mg (1 mmol) of the anhydride there were used 36 mmol of sodium borohydride and 48 mmol of boron trifluoride etherate. The product, initially extracted with ether, was obtained in a pure condition, mp 102–104°, only after chromatography on Woelm alumina (activity III) and sublimation, yield 10.5%; the ir spectrum was identical with the product described above. This identity leaves no doubt of the position of ethylation of acenaphthene by the Friedel–Crafts reaction.

4-Methyl-2,1,3-*peri*-naphthopyran.—Hydrogenation of 300 mg of **2** was accomplished in 8 ml of absolute ethanol, using 300 mg of 5% palladium on barium sulfate catalyst, at low pressure. Filtration of catalyst, evaporation of solvent, and sublimation at 60° (5 mm) of the residue yielded 248 mg (90%) of the title compound, mp 70–71°.

Anal. Calcd for $C_{13}H_{12}O$: C, 84.75; H, 6.6. Found: C, 84.5; H, 6.4.

3-Methyl-1,8-naphthalic Anhydride.—A 184-mg sample of the above-described ether was oxidized in 5 ml of boiling acetic acid with 596 mg of sodium dichromate. Crystallization of the product from acetic acid yielded 76 mg (36%) of the anhydride, mp 242–243.5°.

Anal. Calcd for $C_{13}H_8O_3$: C, 73.6; H, 3.8. Found: C, 73.7; H, 3.9.

Friedel–Crafts Methylation of Acenaphthene.—A solution of 11.5 g of acenaphthene in 100 ml of carbon disulfide was cooled with stirring to −5°; then 8.5 g of methyl bromide was added. As stirring was continued at −5°, 9.5 g of anhydrous aluminum chloride was added during 2 hr, during which time the mixture turned black and tarry. The temperature of the mixture was finally raised to 20° for 1 hr; then it was heated under reflux for an additional hour. After the reaction mixture had been decomposed with ice and hydrochloric acid, the carbon disulfide layer was separated and dried and then evaporated to leave a dark brown oil. The pentane-soluble component of this oil was chromatograhed on Woelm alumina (activity III). The first five fractions eluted with pentane amounted to 3.57 g and were shown by glpc on a silicone column to consist of acenaphthene and methylacenaphthene in a 4:1 ratio (5.7% yield of methylacenaphthene). Recrystallization of fraction 1 from ethanol gave a 75% recovery of pure 5-methylacenaphthene, mp 94–95°, identical with the sample of this compound synthesized from 5-bromoacenaphthene.

The methylation was repeated except that methyl iodide was used so that the reaction could be run under reflux for 6 hr as was done in ethylation (see below). In this instance, the yield of methylacenaphthene determined by glpc on alumina-chromatographed material was about 6%. A 35-mg sample of the methylacenaphthene, separated by glpc, was oxidized as described above to yield methyl-1,8-naphthalic anhydride of mp 174–180°. The nmr spectrum of this low-melting product showed presence of the 2-methyl- and 5-methyl-1,8-naphthalic anhydrides, but not the 3-methyl isomer.

4-Ethylacenaphthene.—Following the procedure of Mayer and Kaufmann,[24] a mixture of 30 g of acenaphthene, 30 g of ethyl bromide, and 25 g of aluminum chloride was heated under reflux with stirring for 6 hr. After work-up as described in methylation, distillation yielded 9 g (25%) of material, bp 130–140° (1 mm). Analysis by glpc on a silicone column indicated an 85% content of 4-ethylacenaphthene, with the remainder being acenaphthene. Oxidation of the crude, distilled product with sodium dichromate gave 32% yield of 3-ethyl-1,8-naphthalic anhydride, mp 191–192° (lit.[8] mp 192–193°, yield 36%). Further oxidation with basic permanganate gave 20% yield of 3-carboxy-1,8-naphthalic anhydride, mp 287–289° (lit.[8] mp 289–290°, no yield reported).

Registry No.—**1**, 17190-32-8; **2**, 17190-33-9; 2-methoxy-1,8-naphthalic anhydride, 17193-94-1; 2,3-dimethoxy-1,8-naphthalic anhydride, 17193-95-2; 3-methoxy-1,8-naphthalic anhydride, 5289-78-1; 3-methoxy-4-nitro-1,8-naphthalic anhydride, 17190-34-0; 5-methoxy-6-nitro-2,1,3-*peri*-naphthopyran, 17190-35-1; 4-

(22) H. Lettré and M. Stratmann, *Z. Physiol. Chem.*, **288**, 25 (1951).

(23) L. Friedmann and H. Schechter, *J. Org. Chem.*, **26**, 2522 (1961).

(24) F. Mayer and W. Kaufmann, *Ber.*, **53**, 289 (1920). These authors assumed formation of the 5-ethylacenaphthene, but later investigation[8] established that substitution had occurred at the 4 position.

methoxy-1,8-naphthalic anhydride, 17190-36-2; 2-methyl-1,8-naphthalic anhydride, 17190-37-3; 5-methylacenaphthene, 17057-80-6; 4-methyl-1,8-naphthalic anhydride, 17190-39-5; 4-bromoacenaphthalene, 4657-98-1; 5-bromo-2,1,3-*peri*-naphthopyran, 17190-41-9; 5-cyano-2,1,3-*peri*-naphthopyran, 17190-42-0; 2,1,3-*peri*-naphthopyran-5-carboxylic acid, 17190-43-1; 4-methyl-2,1,3-*peri*-naphthopyran, 17190-44-2; 3-methyl-1,8-naphthalic anhydride, 17190-45-3; 4-ethylacenaphthene, 17190-46-4.

Hydrogen and Oxygen Exchange in Δ^2-Dihydropyran over Hot Alumina[1]

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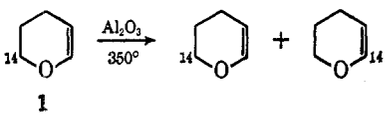
Δ^2-Dihydropyran in contact with hot alumina exchanges its oxygen atom, as well as the hydrogen atoms at the 3 and 5 positions. Doubly labeled dihydropyran, needed for one part of the work, was prepared as follows. Pyrolysis of paraformaldehyde-^{18}O gave formaldehyde-^{18}O, which yielded, when combined with 4-pentenylmagnesium bromide, 5-hexenol-^{18}O. A mixture of this with 5-hexenol-6-^{14}C was ozonized, and the resulting 2-hydroxytetrahydropyran-1-^{18}O-6-^{14}C was dehydrated to give Δ^2-dihydropyran-^{18}O-6-^{14}C. Exposing the doubly labeled material to alumina at 350° moved carbon-14 from the 6 to the 2 position and at the same time decreased the oxygen-18 content markedly. Allowing dihydropyran in the presence of tritiated water to flow over hot alumina introduced tritium into the organic substrate. By appropriate reactions, at least 75% of the tritium was located at the dihydropyran 3 and 5 positions. Alumina is necessary for these processes; neither carbon scrambling nor tritium insertions occur when glass wool is substituted for alumina. Interconversion with tetrahydropyran cannot be involved in any important way in the carbon scrambling nor presumably in the oxygen and hydrogen exchange. Thus, conditions that produced almost complete scrambling in the dihydropyran of a mixture of Δ^2-dihydropyran-6-^{14}C plus unlabeled tetrahydropyran were established. The same conditions transferred none of the radioactivity from tetrahydropyran to dihydropyran when the starting mixture was unlabeled dihydropyran plus tetrahydropyran-2-^{14}C. Mechanisms that accommodate the available facts are proposed.

Passing Δ^2-dihydropyran (1) labeled at the 6 position with carbon-14 over alumina at 350° distributes the



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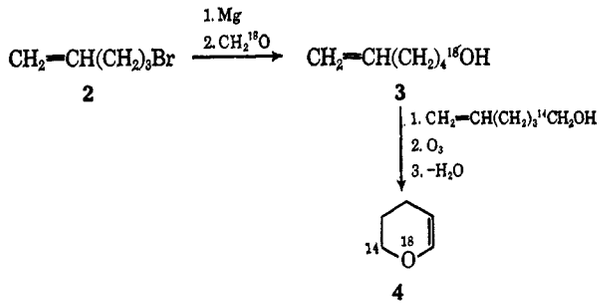
label between the 2 and 6 positions.[2] We have found that two other processes occur as well, namely, exchange of the dihydropyran oxygen and exchange of certain of the dihydropyran hydrogens. The present paper discusses these reactions as well as other related properties of dihydropyran.[3]

Dihydropyran-^{18}O, used in the oxygen-exchange study, was synthesized as follows. Paraformaldehyde-^{18}O was obtained by dissolving paraformaldehyde in oxygen-18 labeled water and recovering the polymer from solution.[4] The paraformaldehyde-^{18}O served as a source of formaldehyde-^{18}O, which, on combination with the Grignard reagent from 5-bromopropene (2),[2,5] gave 5-hexenol-^{18}O (3). A small quantity of 5-hexenol-1-^{14}C[2] was added at this stage, so that in effect the subsequent steps of ozonolysis to 5-hydroxypentanal (*i.e.*, 2-hydroxytetrahydropyran) followed by dehydration afforded doubly labeled Δ^2-dihydropyran-^{18}O-6-^{14}C (4). This material was passed over hot alumina.



The extent of scrambling between the 2 and 6 positions was determined by ozonizing the emergent dihydropyran and counting the cleavage fragments, one in the form of zinc formate (containing the dihydropyran 2 position) and the other in the form of the 2,4-dinitrophenylhydrazone of 4-hydroxybutanal (containing the dihydropyran 6 position). As Table I shows, the radioactivity in the dihydropyran, after contact with alumina, was almost equally divided between the 2 and 6 positions. At the same time, this emergent dihydropyran had lost about half its original content of oxygen-18 (Table I). Clearly, conditions that produce carbon scrambling also lead to oxygen exchange.

To make sure that alumina is necessary for the distribution of radioactivity between the 2 and 6 positions, Δ^2-dihydropyran-6-^{14}C was passed over glass wool at 350°. No scrambling was noted, the treated dihydropyran still retaining 100% of its activity at the 6 position.

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(2) W. J. Gensler, J. E. Stouffer, and R. G. McInnis, *J. Org. Chem.*, **32**, 200 (1967). Our use of "distributes" or "scrambles" does not imply that the terminal carbon atoms of the Δ^2-dihydropyran five-carbon chain have actually changed places.

(3) Part of this work has appeared as a preliminary report; *cf.* W. J. Gensler, G. L. McLeod, J. E. Stouffer, P. T. Manos, and R. G. McInnis, *Chem. Ind.* (London), 1658 (1963).

(4) The nature of paraformaldehyde in water is discussed by J. F. Walker in "Formaldehyde," American Chemical Society Monograph Series No. 120, 2nd ed, Reinhold Publishing Corp., New York, N. Y., 1953. R. N. Renaud and L. C. Leitch [*Can. J. Chem.*, **39**, 261 (1961)] have described a related but much less convenient way to prepare paraformaldehyde-^{18}O.

(5) P. Gaubert, R. P. Linstead, and H. N. Rydon, *J. Chem. Soc.*, 1971 (1937).