TABLE II

COMPARISONS OF ACYLATIONS WITH MIXED ANHYDRIDE, EQUIMOLAR MIXTURE OF SIMPLE ANHYDRIDES, AND EQUIMOLAR MIXTURE OF ACYL CHLORIDES[a]

Acylating agent(s)	Molar proportions of acylating agent(s): thiophene:$SnCl_4$	Approx total ketone yield, %	Mole % of each thienone		Mole % of higher phenone in comparable acylations of benzene[b]
			Acetothienone	Higher thienone	
Acetic butyric anhydride	1:1:3.15	77.0	38.7	61.3	72.9
Acetic anhydride and butyric anhydride	(0.5 + 0.5):1:3.15	69.2	42.6	57.4	63.6
Acetyl chloride and butyryl chloride	(1 + 1):1:2.10	61.1	52.9	47.1	43.7

[a] Except in the right-hand column, aromatic component was thiophene; catalyst was $SnCl_4$; reaction temperature was 0–5°; reaction time was 5 hr. [b] Data in this column were taken from ref 2. Aromatic component was benzene; catalyst was $AlCl_3$; reaction time was 3 hr; other conditions were similar to those of the present work.

should determine the ratio of the ultimate ketones by their influences on (a) the relative rates of formation of the two possible complexes of anhydride and catalyst, and (b) the relative rates of the subsequent nucleophilic displacements of these complexes.

Experimental Section

Mixed acetic anhydrides were prepared from ketene and the appropriate carboxylic acids, without solvent, following the earlier procedure,[2,7] with minor modifications, for all except acetic pivalic anhydride. They were not distilled. Their authenticities were verified in every run by determinations of their neutralization constants and by comparisons of their refractive indices with previously reported values.

Pivalic acid, a solid, was warmed slightly above its melting point (35.5°) and ketenized in the molten state for 5–10 min. Ketenization was then completed at 0–5°, the reaction mixture remaining liquid, after which the product was treated like the other anhydrides. A typical preparation, using 35.0 g of pivalic acid, gave 21.8 g (44.1%) of acetic pivalic anhydride: $n^{20}D$ 1.4027 (not previously reported); neut equiv, 73.1 (calcd, 72.1).

Anal. Calcd for $C_7H_{12}O_3$: C, 58.31; H, 8.39. Found: C, 58.48; H, 8.61.

Acylations of Thiophene.—Essentially, the procedure paralleled the acylations of benzene described in the earlier paper,[2] up to the point at which the molar ratios of the products were determined. In most runs, the quantity of the mixed anhydride was 0.12–0.17 mole, and the dropwise addition of the equimolar amount of thiophene required about 30 min. Total reaction time, from the first drop of thiophene to the ultimate quenching with ice and hydrochloric acid, was 5 hr; this gave total ketone yields approximating those achieved in 3 hr, with benzene and aluminum chloride, in the earlier work.

After washing and drying the reaction products and removing carbon disulfide, ether, and any unreacted thiophene by distillation, the relative proportions of acetothienone and the higher thienone in the residual liquid were determined by gas chromatography. For this purpose, a Beckman GC-2 gas chromatograph was employed, with, in most cases, a 6-ft 20% silicone SF 96 on 30–60 Silocel column. Calibration was achieved and validities were established by comparable measurements of mixtures containing known amounts of the same materials; general accuracy was within 0.5 mole %.

To obtain some measure of the yields of the two thienones, the residual liquid was then distilled under reduced pressure, using a vacuum jacketed Vigreux column 7 cm high and 1.5 cm in diameter, and the distillate boiling over a range which spanned their two boiling points was collected. This fraction was regarded as a crude mixture containing practically all of both ketones and no significant quantity of any other substance, and the approximate yields were calculated from its weight and from the chromatographically determined relative proportions. Pure samples of the thienones (with the exception of pivalothienone) were then obtained from these mixtures by repeated fractional distillations, using a vacuum jacketed column 20 cm high and 1.5 cm in diameter, packed with glass pearls or stainless steel helices. Their identities were established by comparisons of their chromatographic retention times, infrared spectra, and refractive indices, and the melting points of their crystalline derivatives with those of authentic samples of the same compounds or with values reported in the literature.

Because of the small quantity formed, pivalothienone was not isolated in a pure state. Its chromatographic retention time was identical with that of a reference specimen, prepared from pivalyl chloride, thiophene, and stannic chloride, at 0°; the infrared spectrum of the residue, after removal of acetothienone from the reaction products by distillation, showed all of the significant bands of the reference material. This residue, treated with 2,4-dinitrophenylhydrazine, gave a small amount of a yellow solid, mp 172.5–173.5° after recrystallization from ethanol. From the reference material there was obtained a 2,4-dinitrophenylhydrazone, mp 173–174°; a mixture of the two also melted at 173–174°.[8]

Anal. (reference hydrazone). Calcd for $C_{15}H_{16}O_4N_4S$: N, 16.09; S, 9.20. Found: N, 16.30; S, 9.40.

The acylations with the simple anhydride mixture and with the acyl chloride mixture (Table II) were preformed as nearly as possible in the same manner as those with the mixed anhydrides. To minimize any interaction between them, leading to formation of the mixed anhydride,[9] the two simple anhydrides were cooled separately and combined at the last moment.

The data in both tables are averages of the values obtained in three reasonably agreeing runs made with each mixed anhydride and with each mixture of simple anhydrides or acyl chlorides. Results were discarded in any run in which total thienone yield was abnormally low.

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(7) C. D. Hurd and M. F. Dull, *J. Am. Chem. Soc.*, **54**, 3427 (1932).

(8) Melting points were determined on a Fisher-Johns melting point block and are uncorrected.

(9) See L. Brown and I. F. Trotter, *J. Chem. Soc.*, 87 (1951), for a study of the equilibrium between acetic butyric anhydride and the two simple anhydrides.

Some Observations on the Steroid Ring-D-Fission C-Aromatization Reaction

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Cross, Carpio, and Crabbé[1] have described an unusual reaction of estrone methyl ether with chloranil: treatment of the reactants in a refluxing mixture of dioxane and *t*-butyl alcohol for 40 hr gave, in addition to the expected 9,11-dehydro compound, a by-product which proved to be the substituted dihydrophenanthrene I (R = *t*-Bu). We also encountered this reaction in a somewhat different system which is noteworthy

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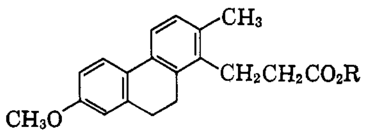
(1) A. D. Cross, H. Carpio, and P. Crabbé, *J. Chem. Soc.*, 5539 (1963).

CHART I



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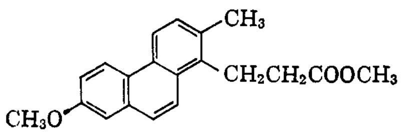

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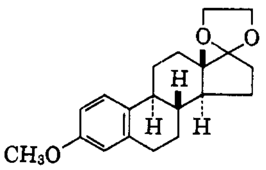

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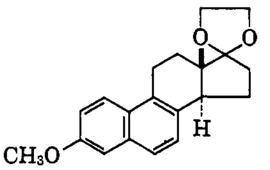


IV

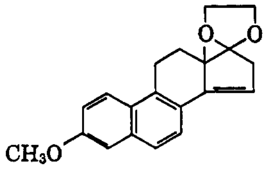
because it affords the ring-opened substance as the major product under very mild reaction conditions.[2]

Treatment of the cycloethylene ketal III of estrone methyl ether with excess 2,3-dichloro-5,6-dicyano-1,4-benzoquinone in benzene *at room temperature for 5 min* gave, after chromatography and crystallization, a 77% yield of the hydroxy ester I (R = CH_2CH_2OH), mp 102–104°. The recrystallized material melted at 105–106°. Evidence for the structure I (R = CH_2CH_2OH), Chart I, was provided by compositional analysis, by the infrared, ultraviolet, and (unique) nmr spectra described in the Experimental Section, and by the chemical behavior (see below), in particular the dehydrogenation to a phenanthrene derivative.

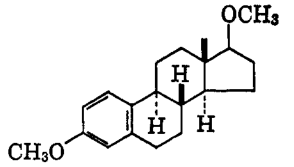
Acetylation of the hydroxy ester I (R = CH_2CH_2OH) afforded the acetyl derivative I (R = CH_2CH_2OAc), mp 89–90°. Saponification of the hydroxy ester gave the acid I (R = H), mp 169–170° (lit.[1] mp 174–175°), which was converted, with diazomethane, into the methyl ester I (R = CH_3), mp 85–86°. Dehydrogenation of the methyl ester over palladium on carbon afforded the methoxymethylphenanthrylpropionate II, mp 135–136°, with characteristic phenanthrene absorption in the ultraviolet. The nmr spectrum was also uniquely consistent with structure II.

To our surprise the ring-opening reaction failed with the ketal IV, mp 130–132°, of *dl*-equilenin methyl ether. Instead, the major product was the 14,15-dehydro compound V (Chart II), mp 122–123°. The ring-opening reaction also failed with estradiol dimethyl ether (VI), there being no recognizable major products. When the ketal VII[3] of *dl*-9-iso-18-nor-D-homoestrone methyl ether was treated with dichlorodicyanobenzoquinone in benzene, it reacted relatively slowly, but, after 5 hr at 25°, the crude dihydrophenanthrene derivative VIII (R = CH_2CH_2OH) was isolated in 47% yield. Saponification afforded the acid VIII (R = H), mp 138.5–139°. It is of special interest that the reaction occurred in a system capable of undergoing aromatization without ring opening. It is also remarkable that in all successful cases the ring-opening reaction stops at the dihydrophenanthrene stage, even in the presence of excess dehydrogenating agent.

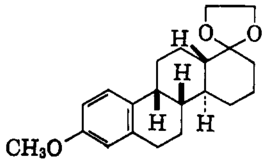
CHART II



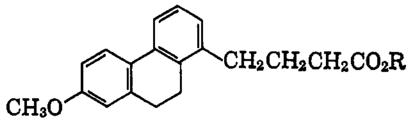
V



VI



VII



VIII

Experimental Section[4]

2-Hydroxyethyl β-(2-Methyl-7-methoxy-9,10-dihydro-1-phenanthryl)propionate (I, R = CH_2CH_2OH).—To a solution of 0.17 g of the cycloethylene ketal of estrone methyl ether,[5] mp 97–102°, in 25 ml of benzene was added 0.34 g of 2,3-dichloro-5,6-dicyano-1,4-benzoquinone. The initially yellow solution changed to olive green, then to pale yellow as the beige hydroquinone precipitated. After a total reaction time of 5 min at 25°, the solution was filtered, and the filtrate was washed thoroughly with 5% potassium hydroxide solution, then with water followed by saturated brine, and finally was dried over anhydrous sodium sulfate. The residue obtained on removal of the solvent at reduced pressure amounted to 0.18 g of a yellow oil which was chromatographed on 10 g of silicic acid. The fraction eluted with 20% ether in benzene amounted to 0.16 g of a colorless solid. Crystallization from ether–petroleum ether gave 0.13 g of colorless plates, mp 102–104°. Two recrystallizations gave material, mp 105–106°, $\lambda_{max}^{CHCl_3}$ 2.82 (OH) and 5.76 μ (ester C=O), λ_{max}^{MeOH} 278 mμ (ε 23,800).[6] The nmr spectrum[4b] showed maxima for five aromatic protons at 6.78–7.72 ppm, four protons as a multiplet (symmetrical A_2B_2 pattern) centered at 4.23 and 3.82 ppm ($RCO_2CH_2CH_2OH$), three protons as a singlet at 3.81 ppm $ArOCH_3$), four protons as a singlet at 2.82 ppm ($-CH_2CH_2-$ at C-9 and C-10), and three protons as a singlet at 2.34 ppm ($Ar-CH_3$).

Anal. Calcd for $C_{21}H_{24}O_4$: C, 74.09; H, 7.11. Found: C, 74.0; H, 7.35.

The **acetate**, prepared by the acetic anhydride–pyridine method, crystallized from ether–petroleum ether as colorless prisms, mp 89–90°.

Anal. Calcd for $C_{23}H_{26}O_5$: C, 72.23; H, 6.85. Found: C, 72.3; H, 7.1.

When the reaction of the ketal and quinone was allowed to proceed for 6 hr at 25°, the yield dropped to 48%. After a 10-hr reaction period, the yield was only 18% of product isolated as the acid I (R = H).

Methyl β-(2-Methyl-7-methoxy-9,10-dihydro-1-phenanthryl)propionate (I, R = CH_3).—Treatment of the hydroxy ester I (R = CH_2CH_2OH) with aqueous methanolic potassium hydroxide gave the hydroxy acid I (R = H) which, after crystal-

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[2] S. L. Gray, Ph.D. Dissertation, Stanford University, 1963.

[3] J. E. Cole, Jr., W. S. Johnson, P. A. Robins, and J. Walker, *J. Chem. Soc.*, 244 (1962).

(4) (a) Melting points were taken on a Kofler hot-stage microscope calibrated against totally immersed Anschutz thermometers. (b) Nmr spectra were determined on a Varian Associates A-60 nmr spectrometer under the supervision of Dr. L. J. Durham. Deuteriochloroform was employed as the solvent with tetramethylsilane as the internal reference. The chemical shifts are reported as δ values in parts per million relative to tetramethylsilane = 0. (c) The elution order used in column chromatography was petroleum ether (bp 60–68°), benzene, ether, ethyl acetate, and acetone.

(5) P. DeRuggieri, *Gazz. Chim. Ital.*, **87**, 795 (1957).

(6) Note the similarity of the ultraviolet spectrum with that of what is probably 8-methoxy-1,2,3,4,5,6-hexahydrochrysene, $\lambda_{max}^{95\%\ EtOH}$ 280 mμ (ε 22,700): W. S. Johnson, I. A. David, H. C. Dehm, R. J. Highet, E. W. Warnhoff, W. D. Wood, and E. T. Jones, *J. Am. Chem. Soc.*, **80**, 661 (1958).

lization from ether–petroleum ether, was obtained in 95% yield as colorless needles, mp 169–170°.

Anal. Calcd for $C_{19}H_{20}O_3$: C, 77.00; H, 6.80; neut equiv, 296. Found: C, 77.1; H, 6.8; neut equiv, 292.

Treatment of the acid with an ethereal solution of diazomethane afforded, after crystallization from ether–petroleum ether, a 91% yield of the methyl ester as colorless prisms, mp 82–84°. Repeated recrystallizations gave material, mp 85–86°, $\lambda_{max}^{CHCl_3}$ 5.78 μ (ester C═O). The nmr spectrum[4b] showed maxima for five aromatic protons at 6.83–7.78 ppm, three protons as a singlet at 3.85 ppm ($ArOCH_3$), three protons as a singlet at 3.74 ppm ($COOCH_3$), four protons as a singlet at 2.85 ppm ($-CH_2-CH_2-$ at C-9 and C-10), and three protons as a singlet at 2.38 ppm ($ArCH_3$).

Anal. Calcd for $C_{20}H_{22}O_3$: C, 77.39; H, 7.14. Found: C, 77.6; H, 7.2.

Methyl β-(2-Methyl-7-methoxy-1-phenanthryl)propionate (II).—A 0.110-g sample of the aforementioned ester I (R = CH_3), mp 84–85°, was heated in a sublimation apparatus under nitrogen at 286–292° for 15 min with 0.1 g of 5% palladium on carbon (Davison Chemical Co.). After cooling, the mixture was diluted with benzene and filtered, and the catalyst was washed thoroughly with hot ethyl acetate. The combined filtrate and washings were concentrated under reduced pressure, and the residue was crystallized from ether–petroleum ether to give 0.032 g of colorless prisms, mp 134.5–135.5°. Chromatography of the oily residue obtained from the mother liquor on 5 g of silicic acid yielded, on elution with benzene, an additional 0.04 g, mp 133–135°. Recrystallization of the major fraction gave material: mp 135–136°; $\lambda_{max}^{CHCl_3}$ 5.76 μ (ester C═O); $\lambda_{max}^{95\%\ EtOH}$ 302 mμ (ε 10,200), 290 (14,600), 279 (19,700), 258 (72,200), 234 (21,000), and 224 (21,300). The nmr spectrum[4b] showed maxima for seven aromatic protons at 7.10–8.54 ppm, three protons as a singlet at 3.82 ppm ($ArOCH_3$), three protons as a singlet at 3.65 ppm ($COOCH_3$), and three protons as a singlet at 2.46 ppm ($ArCH_3$).

Anal. Calcd for $C_{20}H_{20}O_3$: C, 77.90; H, 6.54. Found: C, 78.15; H, 6.8.

The Cycloethylene Ketal of *dl*-Equilenin Methyl Ether.—A solution of 3.1 g of *dl*-equilenin methyl ether,[7] mp 187–188°, 6 ml of ethylene glycol, and 0.01 g of *p*-toluenesulfonic acid monohydrate in 200 ml of benzene was stirred with heating at reflux (atmosphere of nitrogen) in a system containing a water separator filled with Drierite. After 7 hr the solution was cooled and added to 5% potassium hydroxide solution. The organic layer was washed thoroughly with water, followed by saturated brine, and then dried over anhydrous sodium sulfate. The oily residue obtained on removal of the solvent under reduced pressure was triturated with ether. The resulting solid was crystallized from methylene chloride–methanol to give 2.84 g of the ketal, mp 131–132°. Repeated recrystallizations from ether–petroleum ether afforded colorless needles, mp 130–132°.

Anal. Calcd for $C_{21}H_{24}O_3$: C, 77.75; H, 7.46. Found: C, 77.9; H, 7.3.

The Cycloethylene Ketal (V) of *dl*-14,15-Dehydroequilenin Methyl Ether.—A 0.160-g specimen of the aforementioned ketal of *dl*-equilenin methyl ether, mp 131–132°, was treated with 0.23 g of dichlorodicyanobenzoquinone in 25 ml of benzene for 10 min at 25°. The mixture was processed as described above for the preparation of I (R = CH_2CH_2OH). Trituration of the crude product with ether, followed by crystallization from ether–petroleum ether, gave 0.12 g of colorless rods, mp 122–123°. Recrystallization afforded material: mp 122–123°; $\lambda_{max}^{CHCl_3}$ 9.62, 9.72 (C—O), and 10.5 μ (ethylenedioxy); $\lambda_{max}^{95\%\ EtOH}$ 352 mμ (ε 1900), 336 (1930), 304 (24,400), 292 (25,800), 281 (18,700), 263 (67,600), 253 (67,700), and 245 (49,600). The nmr spectrum[4b] showed maxima for five aromatic protons at 7.02–7.95 ppm, one proton as a triplet at 5.98, 6.03, and 6.08 ppm (C-15 H split by protons at C-16), four protons as a singlet at 3.98 ppm (ethylenedioxy), three protons as a singlet at 3.85 ppm ($ArOCH_3$), and three protons as a singlet at 1.09 ppm (C-18 CH_3).

Anal. Calcd for $C_{21}H_{22}O_3$: C, 78.23; H, 6.88. Found: C, 78.1; H, 6.6.

γ-(7-Methoxy-9,10-dihydro-1-phenanthryl)butyric Acid (VIII, R = H).—A 0.073-g sample of the cycloethylene ketal of *dl*-9-iso-18-nor-D-homoestrone methyl ether,[3] mp 131–132°, was treated with 0.16 g of dichlorodicyanobenzoquinone in 25 ml of benzene for 5 hr at 25°. The mixture was processed as described above for the preparation of I (R = CH_2CH_2OH), and the crude product was chromatographed on 5 g of basic alumina. The fraction eluted with 50% ether in ethyl acetate amounted to 0.035 g of crude hydroxy ester VIII (R = CH_2CH_2OH). Attempts to crystallize this material failed; therefore, it was saponified with aqueous methanolic potassium hydroxide to give crude solid acid in quantitative yield. Repeated recrystallizations from ether–petroleum ether gave colorless prisms, mp 138.5–139°, $\lambda_{max}^{CHCl_3}$ 5.85 μ, λ_{max}^{MeOH} 280 mμ (ε 18,400).

Anal. Calcd for $C_{19}H_{20}O_3$: C, 77.00; H, 6.80. Found: C, 76.75; H, 7.0.

Acknowledgment.—Acknowledgment is made to the U. S. Public Health Service and the National Science Foundation for support of this research. We also wish to thank Dr. George Rosenkranz of Syntex S. A. for a gift of extremely pure estrone methyl ether.

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[7] Prepared by the method of W. S. Johnson, J. W. Petersen, and C. D. Gutsche [*J. Am. Chem. Soc.*, **69**, 2942 (1947)] under the auspices of the Wisconsin Alumni Research Foundation whom we thank for a gift of material.

The Synthesis of (2,4-Dinitrophenyl)- and (2,4,6-Trinitrophenyl)methylenephosphoranes

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Received October 20, 1965

As part of a program directed toward the preparation of stable methylenephosphoranes, we were interested in synthesizing disubstituted methylenephosphoranes, $(C_6H_5)_3P{=}CR_1R_2$, in which one of the substituents was a phenyl ring containing one or more nitro groups. In particular, compounds were desired in which the nitro groups were *ortho* and *para* since this positioning would allow greater delocalization of the negative charge on the methylene carbon and would, consequently, lead to enhanced stabilization of the methylenephosphorane system.[1]

Our initial approach involved the arylation of monosubstituted methylenephosphoranes I with the appropriate mono- or polynitrohalobenzene. Although monosubstituted methylenephosphoranes have been alkylated with alkyl halides[2] and acylated with acid chlorides,[3] no reaction of this type has been reported with aryl halides.[4,5]

Reaction of Ia and Ib with picryl chloride occurred readily in refluxing benzene and resulted in good yields (52–57%) of the disubstituted methylenephosphoranes IIa and b. Compounds IIa and b proved to be quite stable, being recovered unchanged on prolonged treatment with hot methanolic potassium hydroxide.

Extension of this synthesis to 2,4-dinitro-1-chlorobenzene gave less satisfactory results. A diminished

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[1] F. Kröhnke, *Chem. Ber.*, **83**, 291 (1950).

[2] (a) F. Ramirez and S. Dershowitz, *J. Org. Chem.*, **22**, 41 (1957); (b) H. J. Bestmann and H. Schulz, *Tetrahedron Letters*, **No. 4**, 5 (1960). (c) *Chem. Ber.*, **95**, 2921 (1962).

[3] (a) H. J. Bestmann, *Tetrahedron Letters*, **No. 4**, 7 (1960); (b) S. Trippett and D. M. Walker, *J. Chem. Soc.*, 1266 (1961); (c) H. J. Bestmann and B. Arnason, *Chem. Ber.*, **95**, 1513 (1962); (d) H. J. Bestmann and H. Schulz, *Ann.*, **674**, 11 (1964).

[4] A. Maercker, *Org. Reactions*, **14**, 291 (1965).

[5] E. Zbiral [*Tetrahedron Letters*, **No. 52**, 3963 (1964)] has reported the arylation of monosubstituted methylenephosphoranes with benzyne. Rearranged products were isolated with no apparent formation of the disubstituted methylenephosphoranes.