wt (mass spectrometry), 282.1462 (calcd for $C_{15}H_{22}O_5$, 282.1466). There was insufficient material for an elementary analysis. Acidification of the aqueous layer, from the original extraction, followed by extraction with chloroform and the usual work-up gave an additional 20 mg of **8b**, mp 118–120°.

**B.**—A solution of 50 mg of **6**, 30 mg of sodium bicarbonate, and 10 ml of 80% aqueous methanol was stirred at room temperature for 8 hr. The solvent was removed at reduced pressure and the residue was subjected to preparative tlc after the usual work-up. The major fraction was recrystallized from ethyl acetate–hexane, melted at 124–126°, yield 15 mg, and was identified as **8b**.

**Acetylation of 8b.**—A solution of 15 mg of **8b** in 1 ml of pyridine and 0.5 ml of acetic anhydride was left overnight at room temperature and then worked up in the usual way. Recrystallization from ethyl acetate–hexane gave 10 mg of **6**: mp 164–166°; mixture melting point undepressed; nmr and ir spectra superimposable on that of an authentic sample.

**Acetylation of 9a.**—**9a** (4 mg), 0.1 ml of acetic anhydride, and 0.15 ml of pyridine was allowed to stand overnight and worked up in the usual manner. The residue was a gum (**9b**): wt 4 mg; nmr spectrum (see Table I); mol wt (mass spectrum), 366.1668 (calcd for $C_{19}H_{26}O_7$, 366.1677).

**Oxidation of 8b.**—A solution of 20 mg of **8b** in acetone containing a few drops of Jones reagent was stirred at 0° for 0.5 hr. Excess reagent was destroyed by addition of methanol and solvents were removed at reduced pressure. The residue **10** was purified by preparative tlc but remained a gum and had ir bands at 1775, 1724, 1708, and 1658 $cm^{-1}$.

*Anal.* Calcd for $C_{19}H_{26}O_6$: C, 65.13; H, 7.48; O, 27.40. Found: C, 64.48; H, 7.46; O, 27.61.

**Isomerization of 7.**—A solution of 0.5 g of **7** in benzene was placed on a column of 5 g of basic alumina and left overnight. Elution with chloroform gave 0.35 g of gum (**11**) which had ir bands at 1770, 1735, 1728, 1700, and 1633 $cm^{-1}$; $\lambda_{max}$ 235 nm ($\epsilon$ 9850); mol wt (mass spectrum), 394.2006 (calcd for $C_{21}H_{30}O_7$, 394.1990).

**Hydrolysis of 7.**—A solution of 99 mg of **7** in 4 ml of 80% aqueous methanol was hydrolyzed in the same manner as **6**. The crude product was purified by preparative tlc. Fraction 1, 20 mg, was a gum which had ir bands at 1775, 1725, 1638, and 1629 $cm^{-1}$; $\lambda_{max}$ 237 nm ($\epsilon$ 7700). Fraction 2 was a solid (**12**) and was recrystallized from ethyl acetate–hexane: mp 169–172°; yield 35 mg; ir bands at 3480, 1768, 1728, 1680, and 1637 $cm^{-1}$; $\lambda_{max}$ 243 nm ($\epsilon$ 6300).

*Anal.* Calcd for $C_{19}H_{28}O_6$: C, 64.75; H, 8.01; O, 27.24; mol wt, 352.1884. Found: C, 64.42; H, 7.98; O, 27.31; mol wt, 352.1896.

**Preparation of 13 and 14.**—A solution of 80 mg of **6** in 7 ml of acetic acid containing 2 drops of perchloric acid was stirred with 40 mg of platinum oxide for 5 hr. Work-up as described for **5** and preparative tlc gave two fractions. Fraction 1 (**14**) was recrystallized from ethyl acetate–hexane: yield 8 mg; mp 172–175°; ir bands at 1762 and 1723 $cm^{-1}$.

*Anal.* Calcd for $C_{17}H_{26}O_5$: C, 65.78; H, 8.44; O, 25.77; mol wt, 310.1779. Found: C, 64.96; H, 8.12; O, 26.20; mol wt (mass spectrum), 310.1824.

Fraction 2 (**13**) was recrystallized from ethyl acetate–hexane: yield 41 mg; mp 196–198°; ir bands at 1765 and 1723 $cm^{-1}$ (double intensity).

*Anal.* Calcd for $C_{21}H_{32}O_7$: C, 63.62; H, 8.14; O, 28.25. Found: C, 63.78; H, 8.52; O, 28.02.

**Oxidation of Erioflorin.**—A solution of 0.190 g of erioflorin (**15**) in 10 ml of acetone was mixed with 0.2 ml of Jones reagent and stirred at room temperature for 10 min. Excess reagent was destroyed by addition of methanol, the solvent removed *in vacuo*, the residue diluted with water and extracted with chloroform. The washed and dried chloroform extract was evaporated and the residue was recrystallized from ethyl acetate–hexane. The yield of **17** was 0.165 g: mp 169–172°; ir bands at 1763, 1718, 1705, 1662, and 1630 $cm^{-1}$. The analysis was not satisfactory, mol wt (mass spectrum), 346.1548 (calcd for $C_{19}H_{22}O_6$, 346.1530).

**Hydrogenation of 17.**—A solution of 0.052 g of **17** in 25 ml of ethyl acetate was hydrogenated with 0.54 g of 5% $Pd/BaSO_4$ for 4 hr at atmospheric pressure. Filtration and evaporation gave a solid (**18**) which was recrystallized from ethyl acetate–hexane: yield 0.039 g; mp 183–186°; ir bands at 1770, 1775, and 1720 $cm^{-1}$; CD curve $\lambda_{max}$ 285 nm ($\theta$ +6390) (*c* 0.29 mg/ml).

*Anal.* Calcd for $C_{19}H_{28}O_6$: C, 64.75; H, 8.01; O, 27.24. Found: C, 64.88; H, 7.87; O, 27.48.

**Extraction of *Bahia dissecta*.**—Finely ground *Bahia dissecta* (Gray) Britton, wt 0.75 kg, collected by Mr. R. Barr on Sept 17, 1963, at Big Lake 10 miles south of Eager, Apache Co., Arizona (Barr No. 63-477, on deposit in herbarium of Florida State University), was extracted with chloroform and worked up in the usual way. The crude gum, wt 12 g, was chromatographed over 200 g of silicic acid as described for the extract of *B. woodhousei*, the eluate being monitored by tlc. All fractions showed several spots on tlc.

**Registry No.**—**1**, 33143-54-3; **2**, 33143-55-4; **3**, 33143-56-5; **4**, 33143-57-6; **5**, 33143-58-7; **6**, 33143-59-8; **7**, 33143-60-1; **8a**, 33143-61-2; **8b**, 33143-62-3; **9a**, 33143-63-4; **9b**, 33143-64-5; **10**, 33143-65-6; **11**, 33143-66-7; **12**, 33143-67-8; **13**, 33143-68-9; **14**, 33143-69-0; **17**, 33143-70-3; **18**, 33143-71-4.

# Notes

## A New Etherification Method

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While carrying out research on phosphorus-bearing steroids,[1] we found that the presence of catalytic amounts of acid, in a solution of a steroidal alcohol in dialkyl phosphite, caused the unexpected formation of the corresponding ether. In the absence of acid, the mixed steroidal alkyl phosphite, whose formation can be easily explained, is the main product. Thus, if cholesterol (**1**) is heated for several hours in $HOP(OCH_3)_2$, cholesteryl methyl phosphite (**2**) is the main product. The structure of compound **2** is unequivocally deduced from its nmr spectrum [$\delta$ 3.74 d, $J$ = 12 Hz, $P(O)(OCH_3)$; 6.81 d, $J$ = 696 Hz, P(O)H; and 4.24 m, C-3$\alpha$ H], mass spectrum [$m/e$ 386 (100%), $M\cdot^+ - P(O)(OCH_3)$; 368 (57%), $M\cdot^+ - HOP(O)(OCH_3)H$ ("McLafferty" rearrangement); and 353 (29%), $M\cdot^+ - 96 - CH_3\cdot$], ir, and elemental analysis (see Experimental Section). If, on the other hand, *p*-TsOH (or some other acid) is present in the dimethyl phosphite solution, 3$\beta$-methoxycholest-5-ene (**3**)[2] is the

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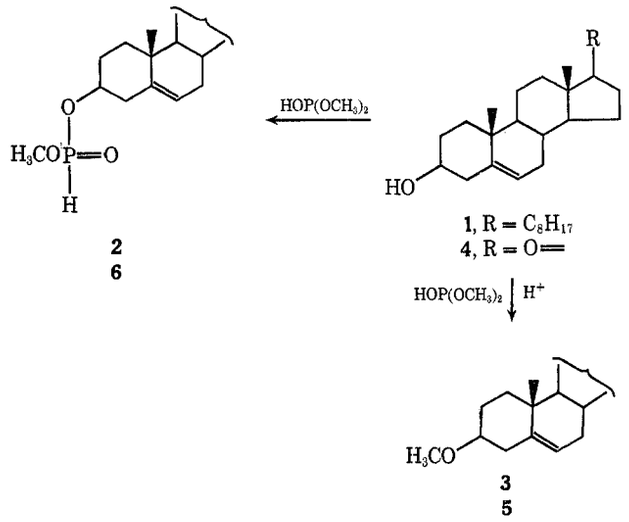


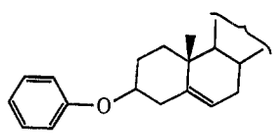

2
6

3
5

main product (*ca.* 60% yield). Hindered or $\alpha,\beta$-unsaturated ketones which do not react with $HOP(OCH_3)_2$[1,3] do not interfere with the etherification process. Thus 17-ketoandrost-5-en-3$\beta$-ol (**4**) yielded upon heating in $HOP(OCH_3)_2$ containing *p*-TsOH the 3$\beta$-methoxy derivative **5**,[4] while in the absence of the acidic catalyst, as in the case of compound **1**, the mixed phosphonate **6** was obtained: nmr $\delta$ 3.76 [d, $J$ = 12 Hz, P(O)$(OCH_3)$], 6.81 [d, $J$ = 694 Hz, P(O)H]; mass spectrum *m/e* 366 (0.15%), $M\cdot^+$, 288 (1.5%), $M\cdot^+ - P(O)(OCH_3)$, 270 (100%), $M\cdot^+ - HOP(O)(OCH_3)H$, and 255 (20%), $M\cdot^+ - 96 - CH_3\cdot$.

The potential utility of phosphites, like compounds **2** and **6**, as intermediates in the preparation of mixed phosphates is now further examined.

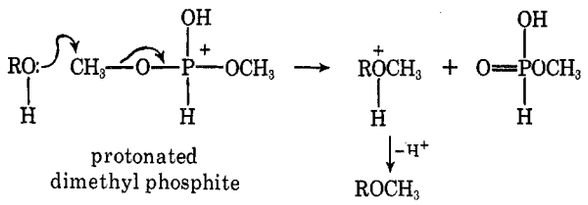
An interesting, although limited, application of this etherification method is the possibility of preparing phenyl ethers, which under other methods are obtained with great difficulty. Heating of cholesterol in diphenyl phosphite in the presence of *p*-TsOH yielded the hitherto unknown 3$\beta$-phenoxycholest-5-ene (**7**)



7

[($C_{33}H_{48}O$; nmr $\delta$ 4.10 (m, C-3$\alpha$ H), 7.25 (m, 2 H), and 6.88 (m, 3 H, phenyl group)]. However, this O-arylation is limited to $\Delta^5$-3-hydroxy steroids which can produce a homoallylic cation. When, for example, cholestanol was submitted to these reaction conditions no ether was obtained ($\Delta^2$-cholestane, the elimination product, was the only product isolated).[5]

The most appealing explanation for the mechanism of this O-arylation is firstly the formation of a homoallylic cation[6,7] which then attacks the phosphonate phenoxy group. This in turn gives rise to the 3$\beta$ ether, known to be the most stable alkoxy isomer obtained from such homoallylic cations, under strong acidic reaction conditions.[7,8] As cholestanol (**8**) does undergo O-methylation with $HOP(OCH_3)_2$ + *p*-TsOH to give the 3$\beta$-methoxycholestane[9] (**9**) (60–70% yield) another possible mechanism must exist in the case of the O-alkylation.




From preliminary studies we have found that, in the case of molecules containing more than one alcoholic group, selective etherification phosphorylation occurs, *i.e.*, submitting 3$\beta$,17$\beta$-androst-5-enediol to the acidic $HOP(OCH_3)_2$ conditions yielded among other products its 3$\beta$-methoxy-17$\beta$-methylphosphonate derivative [nmr $\delta$ 3.32 (s, $OCH_3$), 3.05 (m, C-3$\alpha$ H), 4.2 (m, C-17$\alpha$ H), and 3.75 (d, $J$ = 12 Hz, P(O)$(OCH_3)$]. The potential applications of this reaction are being further investigated.

## Experimental Section

Melting points were taken on a Unimelt Thomas-Hoover capillary melting point apparatus and are uncorrected. Nmr spectra were taken on a Varian HA-100 spectrometer on 5–10% solutions in $CDCl_3$ containg TMS as an internal standard. Mass spectra were determined with a Hitachi Perkin-Elmer RMU-6 instrument. Ir spectra were recorded on a Perkin-Elmer Model 337. Optical rotations were determined on a Perkin-Elmer Model 141 automatic polarimeter in $CHCl_3$ solution.

The following general procedure was used for the etherification process.

**General Procedure.**—A steroidal alcohol (1.0 g) dissolved in a minimum amount of dialkyl phosphite (2–10 ml) was left overnight at 90–100°, in the presence of catalytic amounts of *p*-TsOH. The cooled solution was poured into water and the steroid was etherified. The ethereal solution was washed several times with water, aqueous $NaHCO_3$, and again with water and then dried ($Na_2SO_4$). The solvent was evaporated and the residue was chromatographed through a short silica gel column from which the ether was eluted by hexane.

**3$\beta$-Methoxycholest-5-ene (3), 3$\beta$-Methoxy-17-oxoandrost-5-ene (5), and 3$\beta$-Methoxycholestane (9).**—These ethers, prepared according to the above procedure, were identical in all respects ($[\alpha]^{25}D$, melting point, ir and nmr) with the known ones.[2,4,9]

**3$\beta$-Phenoxycholest-5-ene (7).**—Compound **7** was prepared according to the general procedure, using diphenyl phosphite, in 50% yield: mp 149° (ethanol); $[\alpha]^{25}D$ −25° (*c*, 0.05, $CHCl_3$); ir (KBr) 1600, 1500, 1240, 1080, 1050, 810, 770, 700 $cm^{-1}$; nmr ($CDCl_3$) 0.71 (s, C-18 $CH_3$), 1.08 (s, C-19 $CH_3$), 4.10 (m, C-3$\alpha$ H), 2.45 (m, C-4 protons), 5.38 (m, C-6 H), 6.88 [*m*-Ph (2 H)], and 7.25 [m, Ph (3 H)]. *Anal.* Calcd for $C_{33}H_{50}O$: C, 86.03; H, 10.50. Found: C, 85.89; H, 10.70.

**3$\beta$-Cholesteryl Methyl Phosphite (2).**—Heating of cholesterol (1.0 g) in dimethyl phosphite (3 ml) for 4 hr, followed by the same work-up as described above for the ethers, yielded compound **2**: low-melting crystals; $[\alpha]^{25}D$ −31° (*c* 0.05, $CHCl_3$); ir (neat) 2400, 1240, 1180, 1050, 1030, 970, 820, 750 $cm^{-1}$; nmr ($CDCl_3$) 0.68 (s, C-18 $CH_3$), 1.02 (s, C-19 $CH_3$), 3.74 [d, $J$ = 12 Hz, P(O)$(OCH_3)$], 6.81 [d, $J$ = 696 Hz, P(O)H], 4.24 (m, C-3 H), 2.43 (double m, C-4 protons), 5.37 (m, C-6 H), and 1.90 (m, C-7 protons). *Anal.* Calcd for $C_{28}H_{49}O_3P$: C, 72.37; H, 10.63; P, 6.66. Found: C, 72.00; H, 10.29; P, 6.41.

**3$\beta$-(17-Ketoandrost-5-enyl) Methyl Phosphite (6).**—Following the same procedure described for compound **2**, compound **4** yielded compound **6** (50% yield): mp 136–138° (hexane); $[\alpha]^{25}D$

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+5° (c 0.05, $CHCl_3$); ir (KBr) 2400, 1760, 1270, 1190, 1030, 990, 820, 540 $cm^{-1}$; nmr ($CDCl_3$); 0.89 (s, C-18 $CH_3$), 1.05 (s, C-19 $CH_3$), 3.76 [d, $J$ = 12 Hz, P(O)($OCH_3$)], 6.81 [d, $J$ = 694 Hz, P(O)H)], 4.30 (m, C-3α H), 2.48 (double m, C-4 protons), and 5.42 (m, C-6 H). *Anal.* Calcd for $C_{20}H_{31}O_4P$: C, 65.56; H, 8.52; P, 8.45. Found: C, 65.90; H, 8.32; P, 8.36.

**Registry No.**—2, 33066-23-8; 6, 33066-24-9; 7, 13913-60-5.

**Acknowledgment.**—The excellent technical assistance of Mrs. A. Rudi is gratefully acknowledged.

## The Kinetics and Mechanism of the Decomposition of Potassium Cyanide in Aqueous Alkaline Medium. Hydrolysis of the Simplest Nitrile, HCN

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Cyanide ion is known to decompose slowly in aqueous alkaline solution to yield formate ion and ammonia.[2] In acidic medium the products are formic acid and ammonium ion.[3] In connection with some earlier studies[4] involving aqueous cyanide solutions, we sought to determine the extent and pathway by which this decomposition competed with the reactions under investigation.

$$CN^- + 2H_2O \xrightarrow{OH^-} HCO_2^- + NH_3$$

Krieble[3,5,6] studied the rate of decomposition of hydrogen cyanide in various strongly acidic media. Noting that aqueous cyanide solutions used in electroplating lost strength with "an apparent regularity" upon standing, Leftin[7] found that solutions about 0.25 $N$ in cyanide lost about 0.000240 $N$/day in cyanide concentration at room temperature. This loss was nearly constant over a period of 180 days. Other workers[8,9] also have discussed the loss of cyanide from electroplating solutions.

In a more definitive study Ricca and D'Amore determined the rate of the decomposition in aqueous solutions through which a stream of $CO_2$-free air was passed to remove HCN, formed in the hydrolysis of cyanide ion, and the ammonia resulting from the decomposition itself.[2,10] The first-order rate constants for the disappearance of cyanide ion at 30, 50, and 80° were found to be $0.122 \times 10^{-6}$, $0.366 \times 10^{-6}$, and $2.72 \times 10^{-6}$ $sec^{-1}$, respectively. Addition of a 30-fold excess of NaCl was found to retard the rate of the reaction.

More recently, several studies have dealt with the hydrolysis and polymerization of HCN in aqueous solution as a means for removal of HCN from crude coal gas[11] and as a possible means of formation of purine precursors under primitive earth conditions.[12,13]

We present here the results of a more extensive kinetic study of this decomposition and the mechanistic implications of these results.

### Results

Experimental procedure differed from that of Ricca and D'Amore in that no air was passed through the solutions during the course of the reaction. Instead, the reaction was carried out under a nitrogen atmosphere in tightly stoppered flasks. Potassium hydroxide was added to suppress the polymerization of HCN, the pH being adjusted to a value of 11 or greater for all runs.[14]

The overall decomposition was found to be cleanly first order with respect to the cyanide ion concentration throughout the range of temperatures and concentrations studied. That the rate was independent of the concentration of hydroxide ion was shown by comparison of the volume of titrant used in simultaneous runs at 33.1 and 49.5° in which the concentration of hydroxide ion was varied. At 49.5°, for example, simultaneous runs 0.0680 and 0.0340 $M$ in KOH required the same volume of titrant, within experimental error, over more than 60% of the reaction.

Effects of added salt and of changes in solvent polarity were also observed. Addition of a tenfold excess of $KNO_3$ resulted in a small but significant decrease in the overall rate. This effect is the same as was observed earlier for added NaCl.[10] A marked increase in rate was observed when the solvent polarity was diminished by the addition of small amounts of ethanol. The overall rate constants for the decomposition under various conditions are presented in Table I.

### Discussion

The kinetic data clearly preclude a reaction mechanism involving direct attack of hydroxide ion upon cyanide ion in the rate-determining step, or one in which two or more hydroxide ions are consumed before the slow step in the reaction. Two reaction pathways are consistent with these data, one involving the direct attack of water upon cyanide ion in the rate-determining step (eq 1), and the other the rapid hydrolysis of

$$CN^- + H_2O \xrightarrow[\text{slow}]{k_b} [\text{activated complex}] \xrightarrow[\text{fast}]{\text{rel}} \text{products} \quad (1)$$

cyanide ion to HCN (eq 2), with subsequent attack of

$$CN^- + H_2O \overset{K_h}{\rightleftharpoons} HCN + OH^- \quad (2)$$

hydroxide ion upon the HCN in the rate-determining step (eq 3).

$$HCN + OH^- \xrightarrow[\text{slow}]{k_s} \begin{bmatrix}\text{activated}\\ \text{complex}\end{bmatrix} \xrightarrow[\text{fast}]{\text{rel}} \text{products} \quad (3)$$

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(14) Below pH 10 polymerization of HCN competes with hydrolysis, and at high cyanide concentrations and low pH becomes the predominant reaction pathway.[11,13]