were recrystallized from ether to give 179 mg. (32%) of fine needles, m.p. 89–90°, $[\alpha]^{15}D$ −48° (in chloroform, *c* 0.59).

The product corresponded to VII and had resulted from hydrolysis, due to the acid developed by the decomposition of benzyl chloride.

Anal. Calcd. for $C_{16}H_{22}O_6$: C, 61.92; H, 7.15. Found: C, 61.65; H, 6.86.

Further elution with acetone gave 124 mg. (27%) of III.

1,6-Anhydro-3-*O*-benzyl-β-L-idopyranose (XII). From VI.—A solution of 282 mg. of partially purified VI in 10 ml. of 2 *N* sulfuric acid and 2 ml. of ethanol was heated for 7 hr. at 150° in a sealed tube. The mixture was partially evaporated and then extracted continuously overnight with chloroform, with lead carbonate added to the organic solvent. After filtration and drying, the solution was evaporated, and the residual product, dissolved in benzene, was chromatographed on silica gel. A mixture of ether and ethyl acetate, 2:1, eluted 48 mg. of crystalline material. It was recrystallized from a mixture of acetone and pentane to give 34 mg. (40%) of platelets, m.p. 157–157.5°, $[\alpha]^{20}D$ +42° (in chloroform, *c* 0.80).

Anal. Calcd. for $C_{13}H_{16}O_5$: C, 61.89; H, 6.39. Found: C, 61.73; H, 6.27.

From VII.—A solution of 50 mg. of VII in 0.5 ml. of ethanol and 1 ml. of *N* sulfuric acid was heated at 100° for 3 hr. The solution was evaporated to one-half and extracted continuously overnight with chloroform, with lead carbonate added to the organic solvent. The solution was evaporated after filtration. The crystalline residue was recrystallized from a mixture of acetone and pentane, giving 23 mg. (57%) of material identical to the product described previously.

1,6-Anhydro-3-*O*-benzyl-2,4-di-*O*-methyl-β-L-idopyranose (XIII).—A solution of 118 mg. of XII in 11 ml. of methyl iodide and 1 ml. of acetone was heated under reflux and stirred with 1.6 g. of silver oxide added in four portions over 3 days. The mixture was filtered, the residue washed with chloroform, and the solution evaporated. The residual product was dissolved in a mixture of hexane and benzene, 9:1, and chromatographed on silica gel. The major fraction (121 mg., 92%) of sirup was eluted with a mixture of benzene and ether, 4:1, $[\alpha]^{30}D$ +58° (in chloroform, *c* 2.0).

Anal. Calcd. for $C_{15}H_{20}O_5$: C, 64.27; H, 7.19; OCH_3, 22.15. Found: C, 64.15; H, 7.08; OCH_3, 22.45.

1,6-Anhydro-2,4-di-*O*-methyl-β-L-idopyranose (XIV).—A solution of 115 mg. of XIII in 50 ml. of methanol was stirred with 100 mg. of 2% palladized charcoal under a slight pressure of hydrogen for 8 hr., when the uptake of hydrogen ceased. The solution was filtered and evaporated, and the residual product crystallized from ether, giving 59 mg. (76%) of rectangular prisms, m.p. 82–83°, $[\alpha]^{25}D$ +91° (in chloroform, *c* 1.10).

Anal. Calcd. for $C_8H_{14}O_5$: C, 50.52; H, 7.42; OCH_3, 32.63. Found: C, 50.64; H, 7.37; OCH_3, 33.29.

1,6-Anhydro-2,4-di-*O*-methyl-3-*O*-*p*-phenylazobenzoyl-β-L-idopyranose (XV).—A solution of 15 mg. of XIV and 40 mg. of *p*-phenylazobenzoyl chloride in 0.5 ml. of pyridine was stored at 50° for 1 hr. then overnight at room temperature. A mixture of water and pyridine was added, and after 10 min. the mixture was extracted with chloroform. The chloroform solution was washed with ice-cold *N* sulfuric acid, with cold saturated sodium bicarbonate solution, and then with water, and dried over sodium sulfate. It was then passed through a column of neutral alumina, Brockman activity III. The material eluted with dry chloroform was recrystallized from a mixture of benzene and hexane to give 15 mg. (48%) of long orange needles, m.p. 172–173.5°, $[\alpha]^{15}D$ +27° (in chloroform, *c* 0.26).

Anal. Calcd. for $C_{21}H_{22}N_2O_6$: C, 63.31; H, 5.57; N, 7.03; OCH_3, 15.58. Found: C, 63.38; H, 5.55; N, 6.95; OCH_3, 15.85.

1,6-Anhydro-2,4-di-*O*-methyl-3-*O*-*p*-tolylsulfonyl-β-L-idopyranose (XVI).—A solution of 30 mg. of XIV in 0.2 ml. of dry pyridine was cooled and a solution of 100 mg. of *p*-toluenesulfonyl chloride in 0.05 ml. of dry pyridine and 0.1 ml. of ethylene dichloride was added. The solution was stored at room temperature for 1 week. Water was added to decompose the acid chloride, and the mixture was poured onto ice. It was extracted with chloroform, and the chloroform solution was washed with ice-cold *N* sulfuric acid, then with water, dried over sodium sulfate, and evaporated. The residue, dissolved in benzene, was chromatographed on silica gel. The crystalline fractions, eluted with mixtures of benzene and ether, 4:1 and 2:1, and with pure ether, were combined and recrystallized from ether and pentane to give 40 mg. (74%) of needles, m.p. 106–106.5°, $[\alpha]^{25}D$ +58° (in chloroform, *c* 1.01).

Anal. Calcd. for $C_{15}H_{20}O_7S$: C, 52.31; H, 5.86; OCH_3, 18.02. Found: C, 52.37; H, 5.85; OCH_3, 18.24.

Acknowledgment.—The authors wish to thank Miss E. Walker for the determination of the optical rotations.

Monophosphate Esters of D-Erythronic Acid

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The syntheses of D-erythronic acid 2-phosphate and 4-phosphate are described. The synthesis of erythronic acid 3-phosphate from 2-*O*-benzoyl erythronolactone was unsuccessful. Some properties of the phosphate esters and the synthetic intermediates are reported.

In a continuing study of the chemical and biochemical properties of a number of phosphate esters of mono- and polyhydroxy acids,[1] it was of interest to prepare the monophosphates of D-erythronic acid. The starting material for the synthesis was 2,4-*O*-ethylidene-D-erythrose (I).[2]

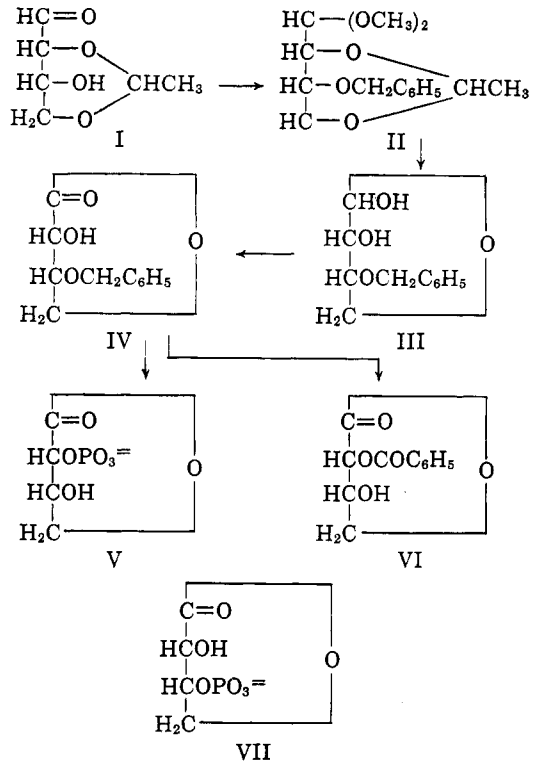
In the preparation of the 2-phosphate the following sequence of reactions was used.

I → 2,4-*O*-ethylidene-D-erythrose dimethyl acetal → 3-*O*-benzyl-2,4-*O*-ethylidene-D-erythrose dimethyl acetal (II) → 3-*O*-benzyl-D-erythrose (III) → 3-*O*-benzyl-D-erythronolactone (IV). This material, IV, was phosphorylated using diphenyl phosphorochloridate, which after hydrogenolysis of the benzyl and phenyl groups, gave D-erythronolactone 2-phosphate (V) which was isolated as the cyclohexylammonium salt.

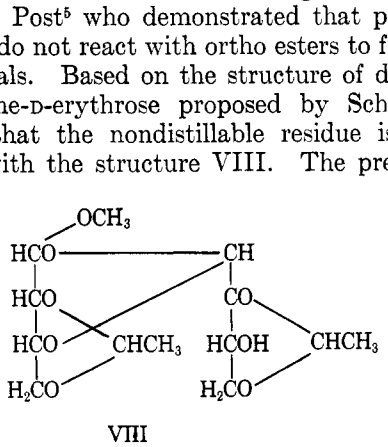
In attempts to prepare D-erythronic acid 3-phosphate (VII), IV was converted to 2-*O*-benzoyl-3-*O*-benzyl-D-erythronolactone which on hydrogenolysis gave 2-*O*-benzoyl-D-erythronolactone (VI). Attempts to phosphorylate this compound, using either diphenyl phosphorochloridate or the more reactive (less hindered) phosphorus oxychloride, gave extremely poor yields of phosphorylated products. Moreover, the properties of the products were not compatible with the expected properties of the desired 3-phosphate ester. Examination of space filling models offers no apparent reason for the low reactivity of the 2-*O*-benzoyl ester (VI) as compared to the 3-*O*-benzyl ether (IV).

(1) F. Wold and C. E. Ballou, *J. Am. Chem. Soc.*, **81**, 2368 (1959); F. Wold, *J. Org. Chem.*, **26**, 197 (1961).

(2) R. Barker and D. L. MacDonald, *J. Am. Chem. Soc.*, **82**, 2301 (1960).



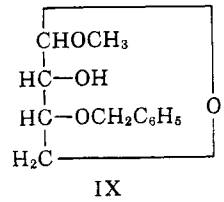
In the synthesis of IV a number of difficulties were encountered. The conversion of I to the dimethyl acetal was carried out by treating a solution of I in methanol–trimethyl orthoformate with ammonium chloride.[3] The yield of the desired product varied from 5 to 70% and appeared to depend upon the degree to which I had undergone dimerization. In all cases the product of the reaction was nonreducing. Treatment of an authentic sample of the dimer of I[4] under the same conditions gave a nonreducing, nondistillable product which had an infrared spectrum essentially identical to that of the residue obtained from the preparation of II. These results are in agreement with the findings of Post[5] who demonstrated that polymerized aldehydes do not react with ortho esters to form monomeric acetals. Based on the structure of dimeric 2,4-*O*-ethylidene-D-erythrose proposed by Schaffer, it is probable that the nondistillable residue is, in part, material with the structure VIII. The presence of a



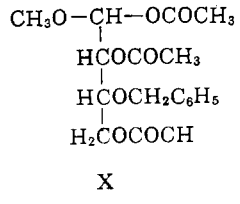
hydroxyl and a carbonyl absorption in the infrared spectrum indicates that in all probability some formylation of the hydroxyl group has occurred as reported by Anderson and Marvell[6] for the analogous β-hydroxylaldehydes. The amount of dimer present in a given preparation of I was not dependent only upon the age of the preparation, since some freshly prepared samples of I gave very poor yields of II; however, storage of I did decrease the yields of II which could be obtained from it.

The hydrolysis of II to give III was difficult to accomplish in good yield. A variety of acids, solvents, and temperatures was used with little effect on the yield of III. The ethylidene group was readily removed by all of the treatments used, provided that the acetaldehyde was allowed to escape from the reaction. The poor yields of III appear to be due to the formation of a methyl glycoside IX which is quite resistant to hydrolysis. Conditions which are sufficiently vigorous to hydrolyze the glycoside also appear to remove the benzyl group. A sample of the glycoside was obtained by chromatography on a Florisil column of the mixture obtained after hydrolysis and oxidation of II. It was found to be quite resistant to acid hydrolysis, being incompletely hydrolyzed by refluxing in 0.1 *N* sulfuric acid for twenty-four hours. Paper chromatography of the products of this hydrolysis indicated that only a very small amount of III was present and that a considerable portion of the material had lost all of its blocking groups and/or undergone polymerization. An attempt was made to obtain III by acetolysis of II followed by deacetylation of the resulting acetate. A crystalline tetra-*O*-acetyl-3-*O*-benzyl-D-erythrose was obtained in low yields, which on catalytic deacetylation gave a product which was reducing, contained vicinal hydroxyl groups, and which had the same R_f as 3-*O*-benzyl-D-erythrose.

Examination of the mother liquors from the crystallization of the tetraacetate indicated that, to some degree, acetolysis had resulted in the complete removal of both the *O*-methyl groups and the *O*-benzyl group, since chromatography of the deacetylated mixture indicated that a small proportion of free erythrose was present. The major component in the deacetylated mother liquors did not react with periodate and was reducing only after hydrolysis with dilute mineral acid. The latter treatment gave a mixture which contained both erythrose and 3-*O*-benzyl-D-erythrose, a behavior which is consistent with this component being a methyl glycoside. The low yield of the desired tetraacetate of 3-*O*-benzylerythrose is probably due to the formation of methyl hemiacetal(s) (X) during the acetolysis. This conclusion is supported by the finding that deacetylation of the sirupy acetates with hot alkali gave a strongly reducing product whereas cold alkali (or catalytic deacetylation) gave the glycoside described previously.



IX



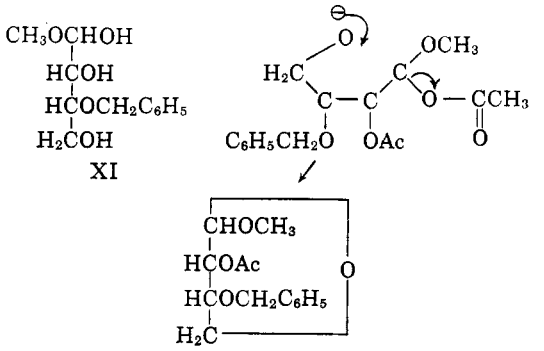
X

Montgomery, Hann, and Hudson[7] obtained such compounds from the acetolysis of methyl tri-*O*-acetyl-β-D-arabinopyranoside using zinc chloride as a catalyst.

(3) C. E. Ballou and H. O. L. Fischer, *J. Am. Chem. Soc.* **78**, 1659 (1956).
(4) R. Schaffer, *ibid.*, **81**, 2838 (1959).
(5) H. W. Post, *J. Org. Chem.*, **5**, 2449 (1940).
(6) E. R. Alexander and E. N. Marvell, *J. Am. Chem. Soc.*, **72**, 3944 (1950).
(7) E. M. Montgomery, R. M. Hann, and C. S. Hudson, *ibid.*, **59**, 1124 (1937).

These authors found that catalysis of acetolysis of furanosides with 4% sulfuric acid gave rise to aldehydo acetates[8] whereas pyranosides gave varying amounts of pyranose, acetates, and aldehydo acetates.

It is not surprising that the deacetylation of X proceeds to give a glycoside. It is probable that the methyl hemiacetal XI is not an intermediate in this deacetylation but that the primary hydroxyl group at C-4 is freed first and that an intramolecular reaction occurs with this hydroxyl group displacing an acetate ion from C-1 with the formation of XII which would undergo further deacetylation in a normal fashion to give IX. The facility with which a C-4 hydroxyl

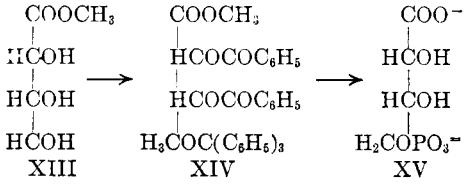


XI XII

group can participate in a displacement at C-1 has been pointed our previously.[9]

The oxidation of the mixtures containing III most easily was carried out using bromine in a slightly acidic medium.[10] No oxidation occurred when perpropionic acid[11] or hydrogen peroxide–ammonium molybdate[12] were used, and alkaline iodine oxidation[13] gave a product which was very difficult to separate from iodine containing contaminants.

In the synthesis of D-erythronic acid 4-phosphate (XV) the following sequence of reactions was used. I → D-erythronolactone → methyl-D-erythronate (XIII) → methyl 2,3-di-*O*-benzoyl-4-*O*-trityl-D-erythronate (XIV) → methyl 2,3-di-*O*-benzoyl-4-*O*-diphenylphosphoryl-D-erythronate → D-erythronic acid 4-phosphate cyclohexylammonium salt (XV).



XIII XIV XV

The conversion of erythronolactone to the ester (XIII) was achieved in 50% yield by treating a methanolic solution of the lactone with barium methylate.[14] The equilibrium favors the lactone since the latter could be recovered in low yield, despite the large molar proportion of methanol present. In all attempts to prepare the methyl esters by this procedure a proportion of the lactone was converted to the barium salt. In an attempt to improve the yield of ester XIII the lactone was hydrolyzed, and the free acid treated with diazomethane. The yield of the desired methyl esters was again 50%. The residue appeared to contain a considerable amount of *O*-methylated material.

The two phosphate esters were chromatographically pure in several solvent systems. The 4-phosphate consumed three equivalents of base (pK_a' <2, 3.6, 6.65) while the 2-phosphate consumed only two equivalents (pK_a' <2 and 6.9), showing that the lactone is still intact. When the free acids (treated with an excess of Dowex 50H+) were heated briefly or left at room temperature for twenty-four hours, both phosphate esters gave identical chromatographic behavior in several solvent systems. The two major components in each of these reaction mixtures cochromatographed with the original 2-phosphate and 4-phosphate, indicating that phosphate migration takes place in spite of the interference from the lactone. The reaction mixture should also contain 3-phosphate, which would not be expected to separate from the 2-phosphate on chromatography.

Experimental[15]

2,4,*O*-Ethylidene-D-erythrose Dimethyl Acetal.—To a solution of 75 g. of freshly prepared 2,4-*O*-ethylidene-D-erythrose in 200 ml. of dry methyl alcohol was added 200 ml. of freshly distilled trimethyl orthoformate and 10 g. of anhydrous ammonium chloride. The mixture was heated at 40 to 50° for 9 hr.; it was then dark brown and gave a negative Benedict's test. To the cooled reaction, 100 ml. of concentrated aqueous ammonia was added and the whole concentrated *in vacuo* to a dark brown sirup which was extracted with three 200-ml. portions of ethyl ether. The extracts were dried over sodium sulfate and concentrated to give 85.2 g. of a mobile, brown sirup which was fractionated by distillation. The fraction, boiling at 55° and 0.2 mm., crystallized spontaneously and weighed 69.7 g. (70.5%). It had $[\alpha]^{23}D$ −26.8° (*c* 4.7, methanol) and m.p. 40°.

Anal. Calcd. for $C_8H_{16}O_5$ (192.2): C, 50.0; H, 8.39. Found: C, 49.75; H, 8.40.

3-*O*-Benzyl-2,4,*O*-ethylidene-D-erythrose Dimethyl Acetal (II).—To a vigorously stirred solution of 67.5 g. of 2,4-*O*-ethylidene-D-erythrose dimethyl acetal in 500 ml. of benzene was added 170 g. of finely powdered potassium hydroxide[16] and 230 ml. of reagent grade α-chlorotoluene. The reaction mixture was heated to reflux with continued stirring for 14 hr. and then cooled, filtered through Celite, and the filtrate concentrated *in vacuo* at 70°. The residue was fractionated by distillation through a 30-cm. Vigreux column. The fraction (83.5 g.), boiling between 95° and 100° at 0.05 mm., was collected. Examination of this product by vapor phase[17] chromatography demonstrated that it was contaminated with a small amount (*ca.* 10%) of dibenzyl ether. Most, but not all, of this dibenzyl ether was removable by redistillation. A sample which from gas chromatography was estimated to contain *ca.* 5% dibenzyl ether had $[\alpha]^{23}D$ −30.6° (*c* 40.0, tetrahydrofuran), corrected $[\alpha]^{23}D$ −32.2°. The material showed no OH absorption in the infrared.

Anal. Calcd. for 95% $C_{15}H_{22}O_5$ + 5% $C_{14}H_{14}O$: C, 64.84; H, 7.76. Found: C, 64.84; H, 7.63.

1,1,2,4-Tetra-*O*-acetyl-3-*O*-benzyl-D-erythrose.—3-*O*-Benzyl-2,4-*O*-ethylidene-D-erythrose dimethyl acetal (II) (5.0 g.) was dissolved in an ice-cold mixture of 35 ml. of glacial acetic acid, 70 ml. of acetic anhydride, and 4 ml. of concentrated sulfuric acid. After 24 hr. at 4° the reaction mixture was poured over a slurry of ice in sodium bicarbonate solution and the mixture stirred for 30 min. with the addition of sufficient solid sodium bicarbonate to neutralize the acid. The mixture was extracted three times with 100-ml. portions of methylene chloride, the

(8) E. M. Montgomery and C. S. Hudson, *J. Am. Chem. Soc.* **56**, 2643 (1934).
(9) F. C. Hartman and R. Barker, *J. Org. Chem.*, **28**, 1004 (1963).
(10) C. S. Hudson and H. S. Isbell, *J. Am. Chem. Soc.*, **51**, 2225 (1929).
(11) J. d'Ans and W. Frey, *Ber.*, **45**, 1845 (1912).
(12) H. Zinner and K. H. Falk, *Chem. Ber.*, **88**, 566 (1955).
(13) E. E. Moore and K. P. Link, *J. Biol. Chem.*, **133**, 293 (1940).
(14) O. Touster and V. H. Reynolds, *ibid.*, **197**, 863 (1952).
(15) Melting points are corrected.
(16) Hooker Chemical Corp., Niagara Falls, N. Y.
(17) Column packing, 20% Dow-Corning high-vacuum grease on Chromosorb W (Johns Manville and Co.). Helium carrier gas with the column at 250°.

extracts were washed with water, dried over sodium sulfate, filtered, and concentrated to a sirup. Crystals were obtained by dissolution of the sirup in methylene chloride and addition of cyclohexane; yield 560 mg., m.p. 114–116°. After two recrystallizations from the same solvent the material had m.p. 116°, $[\alpha]^{23}D$ +5.4° (*c* 2.0 ethylacetate).

Anal. Calcd. for $C_{19}H_{24}O_9$ (396.4) C, 57.6; H, 6.05. Found: C, 57.50; H, 6.04.

The compound contained no methoxy groups and reduced Benedict's reagent. Treatment with ethanolic base at room temperature over night gave consistently a high base consumption (5 equiv. instead of 4). This is consistent with the known effect of alkali on reducing sugars.

3-*O*-Benzyl-D-erythronolactone (IV).—A solution of 3-*O*-benzyl-2,4-*O*-ethylidene-D-erythrose dimethyl acetal (II) (15.4 g.) in 670 ml. of 75% aqueous acetic acid was heated in an open flask on a steam cone for 5 hr. At this time the reducing sugar value had been constant for 1 hr. and no acetaldehyde could be detected. The solvents were removed at 50° *in vacuo* and the residue (11.8 g.) dissolved in 100 ml. of freshly distilled tetrahydrofuran. To this solution was added 100 ml. of water containing 10 g. of barium acetate and 3.0 ml. of bromine. After 18 hr. at 23° in the dark the reaction mixture gave a negative Benedict's test.

Bromine and tetrahydrofuran were removed by aerating the reaction mixture at 50°. The aqueous residue was extracted with five 50-ml. portions of methylene chloride. The extracts were combined, dried over sodium sulfate, and taken to dryness to give 12 g. of semicrystalline material. From this residue 1.5 g. of crystalline material (m.p. 70–73°) was obtained from ethyl acetate by the addition of hexane. More of the same material was obtained by chromatography of the mother liquors from the first crop on a column containing Florisil (60–100 mesh). The first fraction (3.0 g.), eluted with benzene, appeared to be a mixture of dibenzyl ether and starting material. The second fraction (1.75 g.) was eluted with ether and was essentially pure 3-*O*-benzylerythronolactone. Elution with methanol gave 3.7 g. of material which was neutral, contained a benzyl residue, was nonreducing, but which gave a reducing substance after treatment with hot aqueous acid. On the basis of these observations it is proposed that this substance is methyl (α or β) 3-*O*-benzyl-D-erythroside (IX).

The combined crops of 3-*O*-benzyl-D-erythronolactone after recrystallization from ethyl acetate–cyclohexane had m.p. 89°, $[\alpha]^{22}D$ −44.2° (*c* 1.13, ethyl alcohol); R_f in *n*-butyl alcohol–ethyl alcohol–water (10:1:2), 0.65.

Anal. Calcd. for $C_{11}H_{12}O_4$ (208.2); C, 63.5; H, 5.82. Found: C, 63.46; H, 6.13.

3-*O*-Benzyl-D-erythronic Acid.—3-*O*-Benzyl-D-erythronolactone (0.25 g.) was saponified with 2 meq. of aqueous potassium hydroxide. This reaction mixture was then acidified with 2 meq. of aqueous hydrochloric acid and the acidic aqueous solution extracted with ether several times. The extracts were dried and concentrated to give 0.25 g. of a sirup which deposited crystals (200 mg.) from ethyl acetate–petroleum ether. Recrystallization from the same solvent gave a material with m.p. 105° $[\alpha]^{25}D$ −4.5° (*c* 1.0, ethyl alcohol). R_f in *n*-butyl alcohol–ethyl alcohol–water (10:1:2), 0.43.

Anal. Calcd. for $C_{11}H_{14}O_5$ (226): C, 58.4; H, 6.25. Found: C, 58.25; H, 6.36.

D-Erythronolactone 2-Phosphate Dicyclohexylammonium Salt (V).—Diphenyl phosphorochloridate (2.3 ml., 10.8 mmoles) was added dropwise to an ice-cold solution of 1.91 g. of 3-*O*-benzyl-D-erythronolactone in 5 ml. of dry pyridine. The reaction was kept at 4° for 20 hr., chipped ice was added, and after a further 2 hr. at 4° the mixture was partitioned between methylene chloride and water. The methylene chloride layer was washed successively with 1 *N* sulfuric acid, saturated sodium bicarbonate, and water, dried over sodium sulfate, and concentrated to give the calculated weight of a colorless sirup. An ethyl acetate solution of the sirup was subjected to hydrogenolysis, first with palladium-on-carbon, and then with platinum catalysts. When the uptake of hydrogen was completed, the catalyst was removed by filtration and 1 ml. of cyclohexylamine was added to the filtrate. The resultant precipitate, which weighed 1.9 g., was purified by crystallization from water–acetone. A chromatographically pure sample (665 mg.) [R_f (*n*-butyl alcohol–acetic acid–water, 3:1:2), 0.26; R_f (methanol–ammonia–water, 6:1:3), 0.87; R_f (Methyl Cellosolve–pyridine–acetic acid–water, 8:4:1:1), 0.59; R_f (isobutyric acid–ammonia–water–66:10:20), 0.57] was obtained with $[\alpha]^{22}D$ −55.0 (*c* 0.43, 1 *N* HCl). Titration showed that the lactone was intact. In subsequent crops of crystals 10–20% of the free carboxylic acid was found to be present.

Anal. Calcd. for $C_{16}H_{33}N_2O_7P$ (396.4): C, 48.5; H, 8.4; N, 7.06; P, 7.81: Found: C, 47.23; H, 8.54; N, 7.14; P, 7.56.

2-*O*-Benzoyl-3-*O*-benzyl-D-erythronolactone was obtained in quantitative yield from 3-*O*-benzyl-D-erythronolactone. The esterification was carried out in pyridine at 24° using a 10% excess of benzoyl chloride. The product after three recrystallizations from ether–petroleum ether had m.p. 64–65°, $[\alpha]^{23}D$ −60.8° (*c* 1.4, ethyl acetate).

Anal. Calcd. for $C_{18}H_{18}O_5$ (312.2): C, 69.3; H, 5.16. Found: C, 68.80; H, 5.15.

2-*O*-Benzoyl-D-erythronolactone (VI).—Hydrogenolysis of an ethyl acetate solution of 2-*O*-benzoyl-3-*O*-benzyl-D-erythronolactone in the presence of freshly prepared palladium on carbon at 25° gave a quantitative yield of 2-*O*-benzoyl-D-erythronolactone, m.p. 124–126°. Two recrystallizations from ethyl acetate–petroleum ether gave material with m.p. 126–127°, $[\alpha]^{23}D$ −62.8° (*c* 2.0 ethyl acetate).

Anal. Calcd. for $C_{11}H_{10}O_5$ (222.2); C, 59.5; H, 4.54. Found: C, 59.60; H, 4.63. This compound could not be phosphorylated to any significant extent even at 70° for several hours.

Methyl D-Erythronate (XIII). A. From D-Erythronolactone.—To a solution of 6.7 g. of D-erythronolactone in 200 ml. of dry methyl alcohol was added sufficient barium methylate to make the solution basic to indicator paper. The continued addition of barium methylate was necessary. After 8 hr. the reaction was neutralized with carbon dioxide and filtered. The filtrate was concentrated to dryness at 40° *in vacuo* and the residue taken up in ethyl acetate from which solution 2.45 g. of crystals (m.p. 60–62°) were deposited. Further crystallizations from ethyl acetate gave a product which had m.p. 77°, $[\alpha]^{23}_D$ −20.2° (*c* 1.4, water).

Anal. Calcd. for $C_5H_{10}O_5$ (150.1); C, 40.0; H, 6.71. Found: C, 40.03; H, 6.78.

The mother liquors from the first crop of ester were shown by chromatography on Whatman no. 1 paper in *n*-butyl alcohol–ethyl alcohol–water (10:1:2) to contain a mixture of D-erythronolactone (R_f 0.36) and the methyl ester (R_f 0.46). The precipitate which formed during the reaction was probably barium D-erythronate, since chromatography of a sample after treatment with Dowex 50 (H^+) showed the presence of erythronic acid (R_f 0.08) and a small proportion of the lactone (R_f 0.36).

B. From D-Erythronic Acid.—To a solution of 5 g. of D-erythronolactone in 150 ml. of methyl alcohol was added 55 ml. of aqueous 0.88 *N* potassium hydroxide. The reaction mixture was left at 25° for 4 hr. and then 20 g. of dry Dowex 50 (H^+) was added. After shaking for 10 min., the resin was filtered off and the filtrate treated with an ethereal solution of diazomethane. A rapid gas evolution occurred and diazomethane addition was continued until a slight yellow color persisted in the reaction mixture. Removal of the solvents followed by crystallization from ether gave 2.4 g. of the methyl ester (m.p. 60–65°).

Examination of the mother liquors by chromatography on Whatman no. 1 using *n*-butyl alcohol–ethyl alcohol–water (10:1:2) showed that they contained some of each of the methyl ester, the lactone, and the free acid (or salt), and some fast moving spots. When examined by vapor phase chromatography on a column packed with Dow-Corning high vacuum silicone grease (20%) on firebrick at 210° it was apparent that small quantities of a number of other components were present, presumably produced by *O*-methylation of the acid, lactone, or ester. These components were not investigated further.

Methyl 2,3,*O*-Benzoyl-4-*O*-trityl-D-erythronate (XIV).—To a solution of 1.3 g. of methyl erythronate (XIII) in 7 ml. of dry pyridine at 25° was added 2.65 g. of trityl chloride. After 17 hr. the mixture was cooled to 0° and 2.2 ml. of benzoyl chloride was added. Chips of ice were added to the reaction mixture after 20 hr. and the product extracted into chloroform and washed in the usual fashion. After two recrystallizations from ether–petroleum ether and one from *n*-propyl alcohol, the product had m.p. 151–152°, $[\alpha]^{25}D$ −15.8° (*c* 1.0, chloroform).

Anal. Calcd. for $C_{38}H_{32}O_7$ (600.6); C, 75.88; H, 5.36; OCH_3, 5.12; Found: C, 75.81; H, 5.47; OCH_3, 5.46.

D-Erythronate 4-Phosphate Tricyclohexylammonium Salt (XV).—Methyl 2,3-di-*O*-benzoyl-4-*O*-trityl-D-erythronate (XIV) (2.5 g.) was dissolved with heating in 250 ml. of absolute ethyl alcohol. To the cooled solution was added 2.5 g. of freshly pre-

pared 10% palladium-on-carbon catalyst. Hydrogen uptake was complete in 10 hr. The catalyst was removed by filtration and the solvent removed *in vacuo* leaving a semicrystalline residue (2.5 g.).

A solution of 2.3 g. of the residue in 5 ml. of dry pyridine was treated with 1.28 g. of diphenyl phosphorochloridate. The reaction was kept 25° for 10 hr. and then worked up in the usual fashion to give 3.5 g. of a colorless sirup. The phenyl groups were removed by hydrogenation of the sirup in absolute ethanol solution over 0.7 g. of platinum oxide. When the uptake of hydrogen ceased (2.5 hr.) the catalyst was removed by filtration and 20 ml. of 1.02 *N* sodium hydroxide was added to tne filtrate. The saponification was complete in 4 hr.; the ethyl alcohol was removed *in vacuo* at 40°; and the aqueous residue was extracted with ether to remove the triphenylmethane. Sodium ions were removed on Dowex 50 (H+) and the majority of the benzoic acid by filtration. The clear aqueous solution was adjusted to pH 9.0 with cyclohexylamine and then concentrated to a small volume. Upon addition of acetone crystallization occurred and after 8 hr. a small crop of crystals was collected and identified as cyclohexylammonium benzoate. Addition of more acetone gave 1.15 g. of a crude crystalline product which on being fractionally crystallized from water–acetone gave 0.7 g. of material which gave a positive periodate test and a negative test for inorganic phosphate. The chromatographically pure material [R_f (*n*-butyl alcohol–acetic acid–water, 3:1:2), 0.23; R_f (methanol–ammonia–water, 6:1:3), 0.87; R_f (Methyl Cellosolve–pyridine–acetic acid–water, 8:4:1:1), 0.3; R_f (isobutyric acid–ammonia–water, 66:10:20), 041] had $[\alpha]^{25}D$ −20.0° (*c* 1.0, water) and analyzed as a dihydrate.

Anal. Calcd. for $C_{22}H_{45}N_3O_82H_2O$ (549) C, 48.1; H, 9.49; N, 7.65; P, 5.66. Found: C, 48.5; H, 9.70 N, 7.17; P, 5.65.

The Reactions of 4-Phenyl-2-butanone and 5-Phenyl-2-pentanone with Phosphorus Pentachloride[1]

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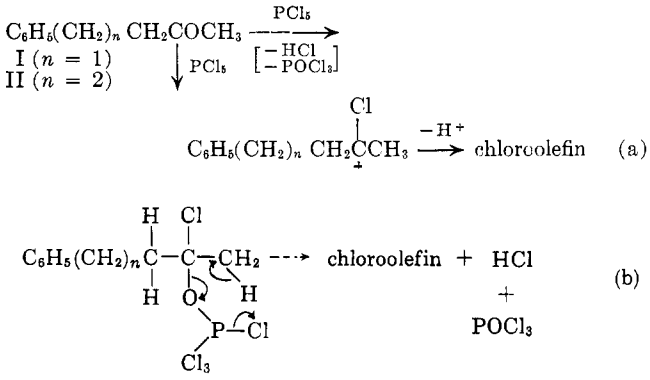
On treatment with phosphorus pentachloride at 25° in methylene chloride, 4-phenyl-2-butanone gave mixtures of 2-chloro-4-phenyl-1-butene (53%), *cis*-2-chloro-4-phenyl-2-butene (12%), and *trans*-2-chloro-4-phenyl-2-butene (35%). Similarly 5-phenyl-2-pentanone gave mixtures of 2-chloro-5-phenyl-1-pentene (43%), *cis*-2-chloro-5-phenyl-2-pentene (14%), and *trans*-2-chloro-5-phenyl-2-pentene (43%). These results indicate that chlorocarbonium ions are not involved in these reactions.

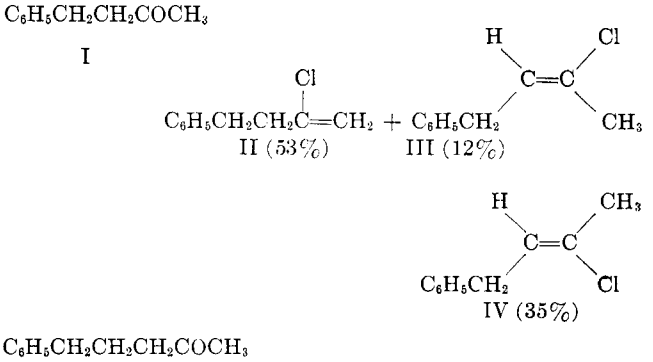
In a previous discussion of the mechanism of the reaction of ketones with phosphorus pentachloride two paths for the formation of chloroolefin were outlined: (a) loss of a proton from a chlorocarbonium ion; and (b) direct elimination of hydrogen chloride and phosphorus oxychloride from the addition product of the ketone and phosphorus pentachloride.[3] The work herein presented was done in order to shed light on the processes involved.



The two ketones chosen for study were 4-phenyl-2-butanone, I, and 5-phenyl-2-pentanone, V, since, if chlorocarbonium ions were involved in the reaction with phosphorus pentachloride (scheme a above), cyclization to 1-chloro-1-methylindane and 1-chloro-1-methyl-1,2,3,4-tetrahydronaphthalene would be expected.[4] Since no trace of either of these cyclic products (or of their dehydrochlorination products) was found, we believe that chlorocarbonium ions are not involved in these reactions with phosphorus pentachloride.

The main products, formed in well over 90% yield in each case, consisted of mixtures of chloroolefins (see Tables II and II). The large amounts of terminal olefins, 2-chloro-4-phenyl-1-butene, II (*ca.* 53% of total), and 2-chloro-5-phenyl-1-pentene, VI (*ca.* 43% of total), obtained provide another argument against the involvement of chlorocarbonium ions. If the latter were involved, much smaller amounts of terminal olefins would be expected in analogy with elimination of protons from ordinary carbonium ions.[5]

The remaining olefins consisted of *cis*-2-chloro-4-phenyl-2-butene, III (*ca.* 12%), and *trans*-2-chloro-4-phenyl-2-butene, IV (*ca.* 35%), in the case of I and of *cis*-2-chloro-5-phenyl-2-pentene, VIII (*ca.* 44%), and *trans*-2-chloro-5-phenyl-2-pentene, VIII (*ca.* 14%), in the case of V. These olefins were separated as described in Experimental.



C6H5CH2CH2CH2COCH3
V

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(2) This work formed part of the M.S. thesis of W. N. K. presented to the Ohio State University in June, 1962.

(3) M. S. Newman and L. L. Wood, Jr., *J. Am. Chem. Soc.*, **81**, 4300 (1959).

(4) Cyclization of ordinary carbonium ions to form five- and six-membered rings are known to occur readily, *e.g.*, D. Perlman, D. Davidson, and M. T. Bogart, *J. Org. Chem.*, **1**, 288 (1936).

(5) See discussion in E. S. Gould, "Mechanism and Structure in Organic Chemistry," H. Holt and Co., New York, N. Y., 1959, pp. 475–577.