2-Deoxy-D-*erythro*-pentose. IX.[1] Some Relationships among the Rotations of Acylated Aldopentoses, Aldopentosyl Halides, and Anhydropentitols

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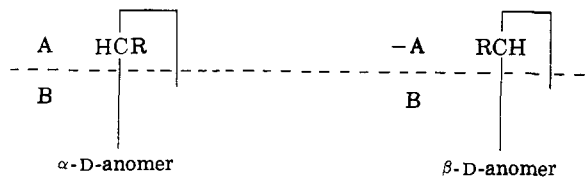
Optical rotatory data for a number of previously reported as well as new pentose derivatives are tabulated. Comparisons among these rotations lead to certain generalizations, especially regarding the relationship of the rotations of the pentose derivatives with those of the corresponding anhydropentitol derivatives. No anomalies are shown by those derivatives of 2-deoxy-D-*erythro*-pentose considered here. Based on rotatory considerations, evidence for the anomeric configuration of a number of pentose derivatives is discussed.

The evidence that certain nucleosides and their derivatives, containing 2-deoxy-D-*erythro*-pentose moieties constitute exceptions[2,3] to Hudson's rule[4] appears incontrovertible. Whatever may be the cause of these exceptions, it seems imperative to examine the rotations of a variety of 2-deoxy-D-*erythro*-pentose derivatives, other than the deoxynucleosides, in order to ascertain whether Hudson's useful rule is valid in this area.

It will be recalled that Hudson[4] viewed the rotation of an aldose derivative as the sum of the rotatory contribution of the anomeric carbon atom (A) and of the rest of the asymmetric carbon atoms (B). Thus, the rotation of the α-D-anomer of an anomeric pair of aldose derivatives may be designated as A + B while the



β-D-anomer is −A + B. Subtraction of the molecular rotations of a pair of anomers therefore yields a value for 2A. For any given substituent (R) at carbon one, such 2A values, derived from a series of closely related anomeric pairs, are normally of approximately the same order of magnitude. Inasmuch as the fully benzoylated derivatives of the aldopentoses are largely known and of considerable utility in synthetic work, we shall first consider the rotations of these substances. In Table I the 2A values for a variety of aldopentose benzoates are listed in separate columns, depending upon whether they are derived from anomeric pairs of pyranose derivatives or of furanose derivatives. It will be noted that, with the exception of the value derived from the D-lyxopyranose tetrabenzoates (50,900), the 2A values for the furanoses are notably lower than those for the pyranoses. Attention is drawn to the 2A values derived from the rotations of the two anomeric pairs of 2-deoxy-D-*erythro*-pentose tribenzoates; these values are obviously normal when compared with others in the table derived from aldopentose tetrabenzoates.

Hudson's rule, concerning the relationships between the rotations of anomers, as well as some other such

TABLE I: ALDOPENTOSE BENZOATES

Tetrabenzoate of	$[\alpha]^{20}D$ ($CHCl_3$)	$[M]^{20}D$	2A (furanoses)	2A (pyranoses)
α-D-Arabinofuranose	+27.9[5]	+15,800		
			69,700	
β-D-Arabinofuranose	−95.2[5]	−53,900		
α-D-Arabinopyranose	−114.4[6]	−64,800		
				118,000
β-D-Arabinopyranose	−322.7[6]	−182,800		
α-D-Lyxofuranose	+55.1	+31,200		
			49,800	
β-D-Lyxofuranose	−32.8	−18,600		
α-D-Lyxopyranose	−49.0[7]	−27,800		
				50,900
β-D-Lyxopyranose[8]	−139	−78,700		
α-D-Ribofuranose	+90.7[9]	+51,400		
			41,800	
β-D-Ribofuranose	+17.0[10]	+9,630		
α-D-Ribopyranose (not known in pure form)[11]	−102[12]	−57,800		
α-D-Xylofuranose	+170[13]	+96,300		
			89,800	
β-D-Xylofuranose	+11.4[13]	+6,460		
α-D-Xylopyranose	+149.5[14]	+84,700		
				108,600
β-D-Xylopyranose	−42.1[14]	−13,900		
Tribenzoate of				
2-Deoxy-α-D-*erythro*-pentofuranose	+78.0[15,16]	+34,800		
			41,600	
2-Deoxy-β-D-*erythro*-pentofuranose	−19.8[15]	−8,840		
2-Deoxy-α-D-*erythro*-pentopyranose	+48.5[16,17]	+21,700		
				113,000
2-Deoxy-β-D-*erythro*-pentopyranose	−204.0[16,17]	−91,100		

(1) 2-Deoxy-D-ribose. VIII: D. L. MacDonald and H. G. Fletcher, Jr., *J. Am. Chem. Soc.*, **84**, 1262 (1962). In contrast to the usage in previous papers of this series, we employ the more precise name "2-deoxy-D-*erythro*-pentose" here.

(2) See J. J. Fox and I. Wempen, *Advan. Carbohydrate Chem.*, **14**, 340 (1959).

(3) R. U. Lemieux and M. Hoffer, *Can. J. Chem.*, **39**, 110 (1961).

(4) C. S. Hudson, *J. Am. Chem. Soc.*, **31**, 66 (1909).

(5) R. K. Ness and H. G. Fletcher, Jr., *ibid.*, **80**, 2007 (1958).

(6) H. G. Fletcher, Jr., and C. S. Hudson, *ibid.*, **69**, 1145 (1947).

(7) H. G. Fletcher, Jr., R. K. Ness, and C. S. Hudson, *ibid.*, **73**, 3698 (1951).

(8) Deleted in proof.

(9) R. K. Ness and H. G. Fletcher, Jr., *J. Am. Chem. Soc.*, **78**, 4710 (1956). The substance has been obtained only as a chromatographically homogeneous sirup.

(10) R. K. Ness, H. W. Diehl, and H. G. Fletcher, Jr., *ibid.*, **76**, 763 (1954).

(11) Attempts to obtain this substance in pure form by chromatography have always given dextrorotatory fractions, however.

(12) R. Jeanloz, H. G. Fletcher, Jr., and C. S. Hudson, *J. Am. Chem. Soc.*, **70**, 4052 (1948).

(13) H. G. Fletcher, Jr., *ibid.*, **75**, 2624 (1953).

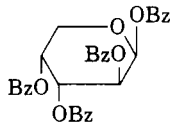
(14) H. G. Fletcher, Jr., and C. S. Hudson, *ibid.*, **69**, 921 (1947).

(15) H. Zinner and H. Nimz, *Chem. Ber.*, **91**, 1657 (1958).

(16) C. Pedersen, H. W. Diehl, and H. G. Fletcher, Jr., *J. Am. Chem. Soc.*, **82**, 3425 (1960).

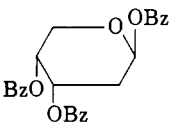
(17) H. Zinner, H. Nimz, and E. Wittenburg, *Chem. Ber.*, **93**, 340 (1960).

qualitative rules, have been combined and extended in an interesting form by Bose and Chatterjee.[18] Their rules usually allow prediction of the relationship between the rotations of isomers which are epimeric at one carbon atom. Thus, with the aldopentose benzoates we may predict that carbon atom two will make a positive contribution to the rotation when it has the D-configuration (written down in the usual orientation of the Haworth-type formula or on the right in the Fischer projection formula) and a negative contribution when it has the L-configuration. With no substituent at carbon two (*i.e.*, CH_2), the rotation should fall between those of the two corresponding substances epimeric at C-2. An example of this is shown by the three benzoates, I to III. All other known pairs of pentose benzoates (pyranose and furanose), epimeric at C-2, are also in agreement with the prediction based on the generalizations of Bose and Chatterjee.[18]



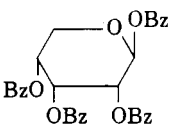
I

β-D-Arabinopyranose tetrabenzoate −182,800



II

2-Deoxy-β-D-*erythro*-pentopyranose tribenzoate −91,100



III

β-D-Ribopyranose tetrabenzoate −57,800

Let us now turn to a consideration of the role of carbon three. In the pyranose series the rule of Bose and Chatterjee[18] does not appear to be adequate to allow a prediction here. However, inspection of the values given in Table I clearly indicates that a D-configuration at C-3 in an aldopyranose benzoate involves a negative contribution to the rotation. Thus α-D-arabinopyranose tetrabenzoate, $[M]^{20}D$ −64,800, is more levorotatory than α-D-lyxopyranose tetrabenzoate, $[M]^{20}D$ −27,800. With aldofuranose tetrabenzoates, Bose and Chatterjee's rule predicts that of two isomers epimeric at C-3, that having a D-carbon will be more levorotatory. Three of the comparisons possible in Table I agree with this prediction but β-D-ribofuranose tetrabenzoate ($[M]^{20}D$ +9630) is more dextrorotatory than β-D-xylofuranose tetrabenzoate ($[M]^{20}D$ +6460).

With substances epimeric at C-4 an interesting contrast arises. In a pyranose derivative a D-carbon makes a *levorotatory* contribution. Thus α-L-lyxopyranose tetrabenzoate has $[M]^{20}D$ +27,800 while its C-4 epimer, β-D-ribopyranose tetrabenzoate has $[M]^{20}D$ −57,800. However, in the pentofuranose series, where C-4 is, of course, directly attached to the ring oxygen, C-4 makes *dextrorotatory* contribution when it has the D-configuration. Thus β-L-xylofuranose tetrabenzoate has $[M]^{20}D$ − 6460, while α-D-arabinofuranose tetrabenzoate has $[M]^{20}D$+15,800. As a consequence of this reversal of role of C-4 in going from a pyranose to a furanose, *all of the D-pentofuranose benzoates are more dextrorotatory than the corresponding D-pentopyranose benzoates having the same anomeric configuration.* For example, 2-deoxy-α-D-*erythro*-pentofuranose tribenzoate is more dextrorotatory ($[M]^{20}D$ +34,800) than 2-deoxy-α-D-*erythro*-pentopyranose tribenzoate ($[M]^{20}D$ +21,700).

The 1,5-anhydroglycitols and 1,4-anhydroglycitols may be construed, respectively, as pyranose and furanose derivatives in which the asymmetry at C-1 has been eliminated. One would expect that the rotation of any anhydroglycitol ester would fall between the rotations of the corresponding anomeric sugar esters. A series of anhydropentitol benzoates is listed in Table II and we may see, for instance, that the rotation of 1,4-anhydro-D-ribitol tribenzoate (+47,800) lies between the rotation of β-D-ribofuranose tetrabenzoate (+9630) and α-D-ribofuranose tetrabenzoate (+51,400); likewise, the relationships between the 2-deoxy-D-*erythro*-pentofuranose tribenzoates and 2-deoxy-D-*erythro*-pentopyranose tribenzoates with the corresponding anhydro-2-deoxy-D-*erythro*-pentitol dibenzoates is normal. 1,5-Anhydro-D-lyxitol tribenzoate appears to be the only exception, it being more levorotatory (−98,200) than either of the D-lyxopyranose tetrabenzoates (−27,800 and −78,700). Earlier, it was noted that the 2A value derived from these two tetrabenzoates is much smaller than the 2A values derived from other pentopyranose tetrabenzoates. These facts suggest that the new D-lyxopyranose tetrabenzoate whose preparation is described later in this paper may not be the pure β-anomer. However, the substance appears to be chromatographically homogeneous and is interconvertible by appropriate means with the α-anomer.

TABLE II

ANHYDROPENTITOL BENZOATES

Tribenzoate of	$[\alpha]^{20}D$ ($CHCl_3$)	$[M]^{20}D$
1,4-Anhydro-D-arabinitol	−77.5[19]	−34,600
1,5-Anhydro-D-arabinitol (= 1,5-anhydro-D-lyxitol)	−220[20]	−98,200
1,4-Anhydro-D-lyxitol	−36.1	−16,100
1,4-Anhydro-D-ribitol	+107	+47,800
1,5-Anhydroribitol	0[12]	0
1,5-Anhydroxylitol	0[14]	0
Dibenzoate of		
1,4-Anhydro-2-deoxy-D-*erythro*-pentitol	+59.4	+19,400
1,5-Anhydro-2-deoxy-D-*erythro*-pentitol	−65.1	−21,200

In Table III, the rotations of a variety of 2-deoxy-D-*erythro*-pentopyranose esters are listed while the rotations of the corresponding esters of 1,5-anhydro-2-deoxy-D-*erythro*-pentitol (= dihydro-D-arabinal) may be found in Table IV. In every case, the rotation of an ester of the anhydride is seen to fall between the rotations of the two corresponding, anomeric 2-deoxy-D-*erythro*-pentopyranose esters.

Table V lists the rotations of some 2-deoxy-D-*erythro*-pentofuranose esters while Table VI gives some of the corresponding esters of 1,4-anhydro-2-deoxy-D-*erythro*-pentitol. The agreement among the benzoates here was mentioned earlier; it will also be seen that the rotation of the di-*p*-nitrobenzoate of the anhydride falls between those of the two anomeric 2-deoxy-D-*erythro*-pentofuranose tri-*p*-nitrobenzoates. The only known 2-deoxy-tri-*O*-(*o*-methylbenzoyl)-D-*erythro*-pentofuranose, assigned the α-D-configuration by Zinner and Witten-

(18) A. K. Bose and B. G. Chatterjee, *J. Org. Chem.*, **23**, 1425 (1958).

(19) The amorphous enantiomorph of this substance is described later in this paper; the rotation was measured in dichloromethane.

(20) H. G. Fletcher, Jr., and C. S. Hudson, *J. Am. Chem. Soc.*, **69**, 1672 (1947).

TABLE III

ESTERS OF 2-DEOXY-D-*erythro*-PENTOPYRANOSE

	$[\alpha]^{20}D$	$[M]^{20}D$
Tri-*O*-acetyl-α-	+28.1 ($CHCl_3$)[21]	+7,310
Tri-*O*-acetyl-β-	−166.6 ($CHCl_3$)[22]	−43,400
Tri-*O*-benzoyl-α-	+48.5 ($CHCl_3$)[16,17]	+21,700
Tri-*O*-benzoyl-β-	−204.0 ($CHCl_3$)[16,17]	−91,100
Tri-*O*-(*p*-chlorobenzoyl)-α-	+30.7 ($CHCl_3$)[21]	+16,900
Tri-*O*-(*p*-chlorobenzoyl)-β-	−235.0 ($CHCl_3$)[21]	−129,000
Tri-*O*-(*p*-nitrobenzoyl)-α-	−2.7 (pyridine)[21]	−1,600
Tri-*O*-(*p*-nitrobenzoyl)-β-	−190.0 (pyridine)[17]	−110,000
Tri-*O*-(*o*-methylbenzoyl)-α-	+38.5 ($CHCl_3$)[21]	+18,800
Tri-*O*-(*o*-methylbenzoyl)-β-	−178.5 ($CHCl_3$)[21]	−87,200
Tri-*O*-(*p*-methylbenzoyl)-α-	+39.9 ($CHCl_3$)[21]	+19,500
Tri-*O*-(*p*-methylbenzoyl)-β-	−244.1 ($CHCl_3$)[21]	−119,000

TABLE IV

ESTERS OF 1,5-ANHYDRO-2-DEOXY-D-*erythro*-PENTITOL

	$[\alpha]^{20}D$	$[M]^{20}D$
Di-*O*-acetyl-	−47.3 ($CHCl_3$)	−9,560
Di-*O*-benzoyl-	−65.1 ($CHCl_3$)	−21,200
Di-*O*-(*p*-chlorobenzoyl)-	−90.0 ($CHCl_3$)	−35,600
Di-*O*-(*p*-nitrobenzoyl)-	−104 ($CHCl_3$)	−43,300
	−97.1 (pyridine)	−40,400
Di-*O*-(*o*-methylbenzoyl)-	−61.4 ($CHCl_3$)	−21,800
Di-*O*-(*p*-methylbenzoyl)-	−73 ($CHCl_3$)	−26,000

TABLE V

ESTERS OF 2-DEOXY-D-*erythro*-PENTOFURANOSE

	$[\alpha]^{20}D$ ($CHCl_3$)	$[M]^{20}D$
Tri-*O*-acetyl-β-	−139.4[22]	−36,300
Tri-*O*-benzoyl-α-	+78.0[15,16]	+34,800
Tri-*O*-benzoyl-β-	−19.8[16]	−8,840
Tri-*O*-(*p*-nitrobenzoyl)-α-	+70.7[23]	+41,100
Tri-*O*-(*p*-nitrobenzoyl)-β-	+17.1[23]	+9,940
Tri-*O*-(*p*-methylbenzoyl)-α-	+77.1[21]	+37,700

TABLE VI

ESTERS OF 1,4-ANHYDRO-2-DEOXY-D-*erythro*-PENTITOL

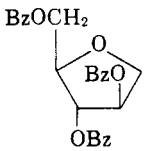
	$[\alpha]^{20}D$	$[M]^{20}D$
Di-*O*-benzoyl-	+59.4 (CH_2Cl_2)	+19,400
Di-*O*-(*p*-chlorobenzoyl)-	+68.1 (CH_2Cl_2)	+26,900
Di-*O*-(*p*-nitrobenzoyl)-	+65 (CH_2Cl_2)	+27,000
	+66.6 (DMF)	+27,700
Di-*O*-(*p*-methylbenzoyl)-	+63.5 (CH_2Cl_2)	+22,500

burg,[21] is more dextrorotatory than 1,4-anhydro-2-deoxy-di-*O*-(*o*-methylbenzoyl)-D-*erythro*-pentitol, a fact which supports the assumed anomeric configuration.

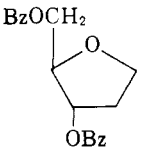
2-Deoxy-D-*erythro*-pentofuranose esters (Table V) are uniformly more dextrorotatory than the corresponding 2-deoxy-D-*erythro*-pentopyranose esters (Table III) of the same anomeric configuration while all the esters of 1,4-anhydro-2-deoxy-D-*erythro*-pentitol (Table VI) are more dextrorotatory than the esters of 1,5-anhydro-2-deoxy-D-*erythro*-pentitol (Table IV).

It may be noted at this point that there appears to be no evidence to suggest that 2-deoxy-D-*erythro*-pentose derivatives bearing an oxygen-attached function at C-1 do not conform to the normal rules of rotation.

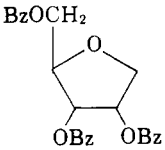
Some years ago, Fletcher and Hudson[24] showed that the rotation of a given 1,5-anhydro-2-deoxyglycitol falls between the rotations of the two corresponding 1,5-anhydroglycitols which are epimeric at C-2. This concept may now be extended to the 1,4-anhydroglycitol series where the following series is seen in agreement with it.



1,4-Anhydro-D-arabinitol tribenzoate
−34,600



1,4-Anhydro-2-deoxy-D-*erythro*-pentitol tribenzoate
+19,400



1,4-Anhydro-D-ribitol tribenzoate
+47,800

Attention is now directed to the acylated pentosyl halides and let us first compare the rotations of the tri-*O*-benzoyl-D-pentopyranosyl halides listed in Table VII with the rotations of the corresponding 1,5-anhydropentitol tribenzoates in Table II. In all cases the α-D-halides are more dextrorotatory than the corresponding anhydrides while the β-D-halides are more levorotatory. The anomeric configuration of the tri-*O*-benzoyl-D-arabinopyranosyl fluoride listed in Table VII deserves special comment. Pedersen and Fletcher[25] obtained a tri-*O*-benzoyl-L-arabinopyranosyl fluoride through brief treatment of β-L-arabinopyranose tetrabenzoate with liquid hydrogen fluoride at a low temperature. While these authors indicated that "the configuration at C-1 of the new crystalline fluoride cannot be stated with certainty," they noted that the molecular rotation of the substance was not very different from that of tri-*O*-acetyl-β-L-arabinopyranosyl fluoride[26] and, therefore, provisionally assigned the β-L-configuration to their new fluoride. It will be convenient to discuss this matter as though all of the known substances were in the D-series. First, one should note that tri-*O*-acetyl-D-arabinopyranosyl fluoride (−38,400) is more levorotatory than 1,5-anhydro-D-arabinitol triacetate (−19,300),[20] indicating that the β-configuration assigned by Brauns[26] is probably correct. On the other hand, the new tri-*O*-benzoyl-D-arabinopyranosyl fluoride (−48,800) is more dextrorotatory than 1,5-anhydro-D-arabinitol tribenzoate (−98,200)—pointing to the α-D-configuration which we now regard as more probable; conclusive proof must await further evidence.[27]

In Table VIII the known, crystalline tri-*O*-benzoyl-D-aldopentofuranosyl halides are listed. Among these the anomeric configurations of the benzoylated D-arabinofuranosyl bromides and chlorides are known with the greatest certainty: not only are crystalline anomeric

(21) H. Zinner and E. Wittenburg, *Chem. Ber.*, **94**, 2072 (1961).

(22) H. Venner and H. Zinner, *ibid.*, **93**, 137 (1960).

(23) R. K. Ness and H. G. Fletcher, Jr., *J. Am. Chem. Soc.*, **82**, 3434 (1960).

(24) H. G. Fletcher, Jr., and C. S. Hudson, *ibid.*, **71**, 3682 (1949).

(25) C. Pedersen and H. G. Fletcher, Jr., *ibid.*, **82**, 945 (1960).

(26) D. H. Brauns, *ibid.*, **46**, 1484 (1924).

(27) Mechanistic considerations as well as rotational observations suggest that the initial product formed when a fully acylated aldose is subjected to a hydrogen halide is that acylated aldosyl halide in which the halogen at C-1 is *trans* to the acyloxy group at C-2. Concommitantly, equilibration between the anomeric halides takes place and, if sufficient time is allowed, one normally finds that the same anomeric halide (particularly if bromide or chloride) predominates in a given series. However, if the reaction time is restricted, the initially formed halide may often be isolated in good yield even though it is the less stable form and is but a minor component of the eventual equilibrium mixture—see the preparation of tetra-*O*-acetyl-β-D-glucopyranosyl chloride [R. U. Lemieux and C. Brice, *Can. J. Chem.*, **33**, 109 (1955)]. It seems likely that the rate of equilibration between a pair of anomeric glycosyl fluorides in hydrogen fluoride may be significantly slower than the rates for chlorides and bromides in solutions of the corresponding hydrogen halides. While *cis* (β-D-) bromides and chlorides are the normal ones in the D-arabinopyranose series, it would not be surprising, therefore, if the conditions employed by Pedersen and Fletcher[25] led to the isolation of a *trans* α-D-fluoride as the rotatory relationships suggest.

TABLE VII

BENZOYLATED PENTOPYRANOSYL HALIDES

	$[\alpha]^{20}D$ ($CHCl_3$)	$[M]^{20}D$
-β-D-Arabinosyl bromide	−353.3[28]	−185,600
-α(?)-D-Arabinosyl fluoride	−105[29]	−48,800
-β-D-Ribosyl bromide	−202[30]	−106,000
-β-D-Ribosyl chloride	−147[30]	−70,700
-β-D-Ribosyl fluoride	−51.5[31]	−23,900
-α-D-Ribosyl fluoride	+38.3[31]	+17,800
-α-D-Ribosyl chloride	+60[30]	+29,000
-α-D-Ribosyl bromide	+78[30]	+41,000
-α-D-Xylosyl bromide	+118.7[14]	+62,400

pairs available in both cases but the behavior of the *trans* halide on hydrolysis clearly distinguishes it from the α-halide, 1,3,5-tri-*O*-benzoyl-β-D-arabinose being formed.[32] Among these halides the β-D-anomers are more levorotatory than 1,4-anhydro-D-arabinitol tribenzoate (−34,600) and the α-D-anomers more dextrorotatory than this anhydride.

TABLE VIII

BENZOYLATED PENTOFURANOSYL HALIDES

	$[\alpha]^{20}D$	$[M]^{20}D$
-β-D-Arabinosyl bromide	−138 (CH_2Cl_2)[5]	−72,500
-β-D-Arabinosyl chloride	−112.8 (CH_2Cl_2)[33]	−54,200
-α-D-Arabinosyl fluoride	−54.2 ($CHCl_3$)	−25,200
-α-D-Arabinosyl chloride	+30.6 (CH_2Cl_2)[33]	+14,700
-α-D-Arabinosyl bromide	+84.8 (CH_2Cl_2)[5]	+44,500
-β-D-Ribosyl fluoride	+105 ($CHCl_3$)[31]	+48,800
-α-D-Ribosyl fluoride	+122 ($CHCl_3$)[31]	+56,700

Several years ago, Dr. C. Pedersen in this laboratory treated methyl α-D-arabinofuranoside tribenzoate with hydrogen fluoride and isolated a tri-*O*-benzoyl D-arabinofuranosyl fluoride as described in the Experimental. The substance is more dextrorotatory (−25,200) than the corresponding anhydride (−34,600) and may, therefore, provisionally be assigned the α-D-configuration.[34]

The tri-*O*-benzoyl-D-ribofuranosyl fluorides, originally reported by Pedersen and Fletcher[31] as the first known pair of anomeric acylated furanosyl fluorides, present some challenging facts. While each was made by a different route, their structures as tri-*O*-benzoyl-D-ribofuranosyl fluorides appear firmly established through routine conversion to known D-ribofuranose derivatives. However, the melting points, X-ray diffraction patterns, solubilities, and infrared spectra of the two fluorides are essentially identical and they do not depress each other's melting point significantly. They can be distinguished through their proton magnetic resonance spectra and the rotations shown in Table VIII. Three comments should be made regarding the rotations of these substances which lie surprisingly close together. First, as Hudson[35] pointed out, the rotations of the halides of a given sugar should show the following sequence: β-D-iodide < β-D-bromide < β-D-chloride < β-D-fluoride < α-D-fluoride < α-D-chloride < α-D-bromide < α-D-iodide. A number of examples of this are known; the benzoylated D-ribopyranosyl halides listed in Table VII will serve as a further illustration. An obvious corollary is that the difference between the rotations of an anomeric pair of fluorides is smaller than that between pairs of chlorides or bromides.

Second, as we pointed out earlier with the aldopentose tetrabenzoates, the 2A values for furanose anomers are usually smaller than for pyranose anomers—*i.e.*, the rotations for furanose anomers fall more closely together than do those of pyranose anomers. With the benzoylated pentosyl halides this may be seen from Tables VII and VIII. Thus the two anomeric tri-*O*-benzoyl-D-ribopyranosyl bromides differ by 147,000 while the tri-*O*-benzoyl-D-arabinofuranosyl bromides differ by 117,000. The differences of the corresponding chlorides are 99,700 and 68,900, respectively.

The first and second considerations above both lead one to expect the rotations of an anomeric pair of acylated glycofuranosyl fluorides to lie quite close together and, in the absence of other evidence, Pedersen and Fletcher[31] appeared justified in concluding that their substances constituted an anomeric pair. Now, however, we must compare the rotations of these two fluorides (48,800 and 56,700) with that of 1,4-anhydro-D-ribitol tribenzoate (+47,800). Here the rotation of the anhydride falls outside the range between the two fluorides and we must therefore now regard it likely that the tri-*O*-benzoyl-β-D-ribofuranosyl fluoride reported earlier[31] is a mixture of anomers or, possibly, a molecular compound of the two anomers. As a practical matter, the separation of substances which resemble each other as closely as these fluorides presents great difficulties.

In passing it may be noted that, in all cases where comparisons are possible, the rotation of a given tri-*O*-benzoyl-D-pentofuranosyl halide is more dextrorotatory than that of the corresponding tri-*O*-benzoyl-D-pentopyranosyl halide of the same anomeric configuration.

Let us now turn our attention to the acylated 2-deoxy-D-*erythro*-pentopyranosyl chlorides which have recently been reported by Zinner and Wittenburg[21]; the rotations of these substances are listed in Table IX. First, it will be noted that all of these halides are markedly more levorotatory than the corresponding esters of 1,5-anhydro-2-deoxy-D-*erythro*-pentitol (Table IV), suggesting that they are β-D-halides as Zinner and Wittenburg[21] believed them to be. Comparison of the rotations of these chlorides with the corresponding chlorides of the D-ribopyranose and D-arabinopyranose series would be illuminating; unfortunately the requisite data are lacking.

TABLE IX

ACYLATED 2-DEOXY-D-*erythro*-PENTOPYRANOSYL CHLORIDES

	$[\alpha]^{20}D$	$[M]^{20}D$
Di-*O*-(*p*-chlorobenzoyl)-β-	−240.2 ($CHCl_3$)[21]	−103,200
Di-*O*-(*p*-nitrobenzoyl)-β-	−219.8 ($CHCl_3$)[21]	−99,080
Di-*O*-(*o*-methylbenzoyl)-β-	−271.2 ($CHCl_3$)[21]	−105,400
Di-*O*-(*p*-methylbenzoyl)-β-	−325.0 ($CHCl_3$)[21]	−126,000

(28) H. G. Fletcher, Jr., and C. S. Hudson, *J. Am. Chem. Soc.*, **72**, 4173 (1950).

(29) The data given by Pedersen and Fletcher (ref. 25) for the L-series are used here with changed sign.

(30) R. K. Ness, H. G. Fletcher, Jr., and C. S. Hudson, *J. Am. Chem. Soc.*, **73**, 959 (1951).

(31) C. Pedersen and H. G. Fletcher, Jr., *ibid.*, **82**, 941 (1960).

(32) See ref. 5 for the case of the bromide; the hydrolysis of the chloride of the L-series is described in the Experimental of the present paper.

(33) The enantiomorph of this substance is described in the Experimental.

(34) Two further considerations tend to support this assignment of configuration. First, as pointed out earlier, one might expect the *trans* α-anomer to be formed first. Second, in analogous preparations the α-chloride and α-bromide were found to predominate at equilibrium.

(35) C. S. Hudson, *J. Am. Chem. Soc.*, **46**, 462 (1924).

In Table X, some rotations for two crystalline acylated 2-deoxy-D-*erythro*-pentofuranosyl chlorides are listed. It will be seen that 2-deoxy-di-*O*-(*p*-nitrobenzoyl)-D-*erythro*-pentofuranosyl chloride (+50,500) is more dextrorotatory than 1,4-anhydro-2-deoxy-D-*erythro*-pentitol di-*p*-nitrobenzoate (+27,000) suggesting that this chloride is an α-anomer. Likewise, the 2-deoxy-di-*O*-(*p*-methylbenzoyl)-D-*erythro*-pentofuranosyl chloride (+42,000) is more dextrorotatory than the corresponding ester of 1,4-anhydro-2-deoxy-D-*erythro*-pentitol (+22,500). Finally, 2-deoxy-3,5-di-*O*-(*p*-methylbenzoyl)-D-*erythro*-pentofuranosyl bromide is more dextrorotatory than the corresponding chloride as one would expect with α-D-halides.

TABLE X

ACYLATED 2-DEOXY-D-*erythro*-PENTOFURANOSYL HALIDES

	[α]D	[M]D
Di-*O*-(*p*-nitrobenzoyl) chloride	+112 (CH_2Cl_2)[36]	+50,500
	+84 (extrap.) →	+38,000 →
	+27 (DMF)[37]	+12,000
bromide	+124 (CH_2Cl_2, extrap.)	+61,400
Di-*O*-(*p*-methylbenzoyl) chloride	+108 →	+42,000 →
	+65 (DMF)[38,39]	+25,000
	+108 ($CHCl_3$)[40]	+42,000
	+125 (CH_2Cl_2)[40]	+48,600
	+115[41,42]	+44,700
	+104 (C^6H^6)[42]	+40,400

A few comments regarding the anomeric configurations of acylated glycosyl halides in general may be appropriate here. Haynes and Newth[43] pointed out that the predominating form of an acylated pentopyranosyl halide will be that one in which the halogen is *trans* to the acyloxy group at C-3; this generalization is in agreement with the conclusion that the 2-deoxy-D-*erythro*-pentopyranosyl halides in Table IX are members of the β-D- series. Haynes and Newth[43] also remark that "it seems a reasonable prediction that the stable[44] forms of the acetohalogeno-D-aldopentofuranoses will all be α compounds." While β-D-pentofuranosyl halides have since been obtained (see Table VIII) experience has so far shown that the α-D-pentofuranosyl halides appear to predominate under the usual conditions used for their preparation.[45]

The preparation of a number of substances, whose rotations were needed for the above comparisons, is described below.

Experimental[46]

β-D-Lyxopyranose Tetrabenzoate.—Ten grams of pure D-lyxose which had partially mutarotated in the dry crystalline state on long storage[47] was benzoylated in pyridine solution with benzoyl chloride as described by Fletcher, Ness, and Hudson.[7] α-D-Lyxopyranose tetrabenzoate was isolated in 61% yield by the procedure described in the earlier paper. The amorphous material remaining in the mother liquor was dissolved in benzene and adsorbed on a column of neutralized alumina. Elution with benzene–ether (4:1) gave, first, more α-D-lyxopyranose tetrabenzoate and then a second substance which crystallized from carbon tetrachloride–pentane. Recrystallized from ether–pentane and then from ethanol, the stubby needles melted at 118–122° and showed [α]^{20}D −139° in chloroform (*c* 0.57). Further recrystallization failed to alter either value.

Anal. Calcd. for $C_{33}H_{26}O_9$ (566.54): C, 69.96; H, 4.63. Found: C, 69.79; H, 4.74.

A sample (0.2628 g.) of β,-D-lyxopyranose tetrabenzoate was dissolved in 0.4 ml. of dichloromethane and the solution, after dilution with 5.0 ml. of 32% hydrogen bromide in glacial acetic acid, observed polarimetrically. At equilibrium the rotation corresponded to [α]^{20}D −74.0°; a parallel exeriment with the α-D-anomer gave [α]^{20}D −72.1°. The amorphous tri-*O*-benzoyl-D-lyxopyranosyl bromide from the β-D-anomer was freed of acetic and hydrobromic acids and treated with silver benzoate to give, in 11% yield, a crystalline product which gave [α]^{20}D −55° in chloroform and melted at 135–136°; its melting point was not depressed on admixture with authentic α-D-lyxopyranose tetrabenzoate. α-D-Lyxopyranose tetrabenzoate was converted to its β-D-anomer in *ca.* 50% yield by the following sequence: α-D-lyxopyranose tetrabenzoate → tri-*O*-benzoyl-D-lyxopyranosyl bromide → 2,3,4-tri-*O*-benzoyl-D-lyxopyranose → β-D-lyxopyranose tetrabenzoate, none of the intermediates being isolated. The product was identical with that made as described above through the direct benzoylation of D-lyxose.

Both anomeric D-lyxopyranose tetrabenzoates were chromatographed on a thin layer of Silica Gel G (E. Merck, Darmstadt) using benzene for development. On spraying with 6 *N* sulfuric acid, the spots became visible under ultraviolet light; brief heating at 100° of the spots thus sprayed made them readily visible in ordinary light. Both anomers proved to be chromatographically homogeneous and readily separable from each other.

α,D-Lyxofuranose Tetrabenzoate.—Ten grams of anhydrous D-lyxose was dissolved in 260 ml. of 0.254 *N* hydrogen chloride in absolute methanol and the progress of the ensuing reaction monitored by periodic Fehling tests.[48] After 2.5 hr. the solution was nonreducing and the acid was then neutralized through the addition of 37 ml. of dry pyridine. Solvent was removed *in vacuo* at 50° (bath) and the residue diluted with 30 ml. of pyridine. The solution was again concentrated, finally being held at 70° (bath) and <1 mm. pressure to ensure complete removal of the methanol. The crude methyl D-lyxofuranoside was benzoylated in the usual manner using 31 ml. of benzoyl chloride and 75 ml. of dry pyridine. After being worked up in the conventional fashion the crude sirupy methyl D-lyxofuranoside tribenzoate was treated with 20 ml. of 32% hydrogen bromide in glacial acetic acid. After 40 min. at room temperature, the reaction mixture was diluted with dichloromethane and the solution washed successively with water and aqueous sodium bicarbonate. It was then dried with magnesium sulfate, filtered, and added, with good stirring, to 20.3 g. of silver benzoate. Stirring was continued for 45 min., a test for readily hydrolyzable halogen then being negative. After filtration, the solution was concentrated *in vacuo* and the resulting sirup dissolved in 450 ml. of absolute ethanol. The solution was filtered through decolorizing carbon; on standing overnight at +5° it deposited

(36) R. K. Ness, D. L. MacDonald, and H. G. Fletcher, Jr., *J. Org. Chem.*, **26**, 2895 (1961).

(37) Measurement made in course of present research, *c* 1.7.

(38) M. Hoffer, *Ber.*, **93**, 2777 (1960); M. Hoffer, R. D. Duschinsky, J. J. Fox, and N. Yung, *J. Am. Chem. Soc.*, **81**, 4112 (1959).

(39) H. Zinner and M. Pfeifer, *Chem. Ber.*, **94**, 2792 (1961).

(40) *c* 1. We are indebted to Dr. Max Hoffer of Hoffmann-La Roche, Inc., for these values.

(41) In either tetrahydrofuran or 1:10 (v./v.) CH_2Cl_2—CH_3CN.

(42) Private communication from Dr. D. L. MacDonald.

(43) L. J. Haynes and F. H. Newth, *Advan. Carbohydrate Chem.*, **10**, 232 (1955).

(44) As two of us have pointed out elsewhere (ref. 5), the proportions of anomeric halides formed when a sugar ester is treated with a hydrogen halide is probably thermodynamically controlled. The word "stability," as used here, frequently connotes reactivity in solvolytic reactions. The *predominating halide formed from a sugar ester is not necessarily the less* reactive of an anomeric pair. Indeed, D-ribopyranose gives predominately tri-*O*-benzoyl-β-D-ribopyranosyl bromide, a *trans* halide much more reactive in solvolytic reactions than its anomer. A similar situation prevails in the D-arabinofuranose series.

(45) Hoffer, *et al.* (ref. 38), as well as Ness, MacDonald, and Fletcher (ref. 36), crystallized acylated 2-deoxy-D-*erythro*-pentofuranosyl chlorides from media containing a large excess of hydrogen chloride. It might be argued that the least soluble (rather than the predominating) anomeric form could have been obtained under these conditions. However, Zinner and Pfeifer (ref. 39) obtained 2-deoxy-di-*O*-(*p*-methylbenzoyl)-α-D-*erythro*-pentofuranosyl chloride under more conventional circumstances in 80% yield. It seems likely, then, that the α-form actually predominates in this case.

(46) Melting points are corrected.

(47) H. G. Fletcher, Jr., in R. L. Whistler and M. L. Wolfrom, "Methods in Carbohydrate Chemistry," Vol. 1, Academic Press, New York, N. Y., 1962, p. 78.

(48) See ref. 10 for a description of the technique used here.

a mixture of sirup and crystals. The solution was decanted and the sirup dissolved in 350 ml. of absolute ethanol; filtration gave 6.96 g. of crystalline product while succeeding crops from the mother liquors subsequently raised the total yield to 14.72 g. (39%). Recrystallization from ethanol involved very little loss and afforded pure α-D-lyxofuranose tetrabenzoate melting at 97–98° and showing $[\alpha]^{20}D$ +55.3° in chloroform (*c* 1.3).

Anal. Calcd. for $C_{33}H_{26}O_9$ (566.54): C, 69.96; H, 4.63. Found: C, 70.17; H, 4.93.

Upon further recrystallization from ethanol, the substance spontaneously changed to a *dimorphic form* which melted at 131–132° and showed $[\alpha]^{20}D$ +55.1° in chloroform (*c* 1.94).

Anal. Calcd. for $C_{33}H_{26}O_9$ (566.54): C, 69.96; H, 4.63. Found: C, 69.77; H, 4.83.

β-D-Lyxofuranose Tetrabenzoate.—Pure α-D-lyxofuranose tetrabenzoate (1.00 g.) was dissolved in 2 ml. of 32% hydrogen bromide in glacial acetic acid and the solution kept at room temperature for 1 hr. Dichloromethane was then added and the solution washed with cold aqueous sodium bicarbonate. After removal of the solvent, the sirupy tri-*O*-benzoyl-D-lyxofuranosyl bromide was dissolved in 22 ml. of aqueous acetone (1:10) and allowed to stand for 30 min. Acid was neutralized through the addition of a little sodium bicarbonate and the solution concentrated *in vacuo* to remove the acetone. Dichloromethane was added and the moisture removed with magnesium sulfate. Filtration and concentration then gave 0.857 g. of sirupy D-lyxofuranose tribenzoate[49] which was benzoylated with 5 ml. of pyridine and 1 ml. of benzoyl chloride. After standing at +5° overnight, the reaction mixture was worked up in the usual manner to give a sirup which was dissolved in 10 ml. of absolute ethanol and the solution seeded with α-D-lyxofuranose tetrabenzoate. After removal of 0.369 g. of α-D-lyxofuranose tetrabenzoate (m.p. 127–130°), the solution was concentrated to a sirup which was dissolved in 2 ml. of ether and precipitated as an oil through the addition of 30 ml. of pentane: 0.565 g., $[\alpha]^{20}D$ −12.4° in chloroform. The material was adsorbed on a column of 40 g. of neutralized Alorco alumina and the column eluted with benzene and then 9:1 benzene–ether to remove the α-D-lyxofuranose tetrabenzoate. Elution with 9:1 benzene–ether also brought off some of the β-anomer; more was removed with 4:1 and 1:1 benzene–ether. Recrystallized from ethanol, the β-D-lyxofuranose tetrabenzoate (0.198 g., 20%) melted at 95–96° and showed $[\alpha]^{20}D$ −32.8° in chloroform (*c* 0.96). Further recrystallization from ethanol failed to alter these values.

Anal. Calcd. for $C_{33}H_{26}O_9$ (566.54): C, 69.96; H, 4.63. Found: C, 70.05; H, 4.73.

Methyl α-D-Lyxofuranoside.—The sirupy tri-*O*-benzoyl-D-lyxofuranosyl bromide, prepared from 1.00 g. of crystalline α-D-lyxofuranose tetrabenzoate, as described above in the preparation of β-D-lyxofuranose tetrabenzoate, was dissolved in 10 ml. of absolute methanol. After 2 hr. at room temperature, the product was debenzoylated by the addition of a catalytic amount of barium methoxide in methanol and allowed to stand for 30 min. The solution was then concentrated to dryness and the residue dissolved in water to remove methyl benzoate, the aqueous layer being extracted with dichloromethane. Water was removed *in vacuo* and the residue dissolved in ethanol; some insoluble material was removed by filtration and the alcoholic solution concentrated to a sirup. When benzene was added to this sirup and then distilled *in vacuo*, the material crystallized; recrystallization from ethanol afforded 33 mg. (11%) of product. Recrystallized from *ca.* 400 parts of benzene, the material was obtained as long, narrow plates melting at 95–97° and showing $[\alpha]^{20}D$ +131° in water (*c* 0.35). A mixed melting point with authentic methyl α-D-lyxofuranoside,[50] kindly supplied by Dr. M. Nys, was undepressed. Nys and Verheijden[50] reported $[\alpha]^{20}D$ +135° in benzene; our preparation was not sufficiently soluble in this solvent at room temperature to confirm this value.

1,4-Anhydro-D-lyxitol Tribenzoate.—A procedure similar to that which Zervas and Zioudrou[51] used for the preparation of 1,5-anhydrohexitols was employed. Tri-*O*-benzoyl-D-lyxofuranosyl bromide, prepared from 2.00 g. of α-D-lyxofuranose tetrabenzoate, was dissolved in 10 ml. of pure ethyl acetate and the solution added to a hydrogen-saturated suspension of 10% palladium on charcoal in 10 ml. of ethyl acetate containing 0.6 ml. of triethylamine. The solution was then shaken with hydrogen, absorption being complete before 1 hr. The catalyst was removed by filtration and washed with dichloromethane, the combined filtrate and washings being washed with aqueous sodium bicarbonate. Moisture was removed with magnesium sulfate and the solution concentrated *in vacuo* to a sirup which was dissolved in 5 ml. of benzene and chromatographed on 20 g. of Brockmann grade III alumina (Woelm, neutral). Elution with 26 ml. of benzene afforded 1.05 g. of sirup from which crystalline 1,4-anhydro-D-lyxitol tribenzoate was readily obtained: 0.717 g. (45%), m.p. 112–116°. Successive recrystallizations from ethyl acetate–pentane, ethanol, and ethyl acetate–pentane gave pure material melting at 117–118° and rotating $[\alpha]^{20}D$ −36.1° in chloroform (*c* 1.73).

Anal. Calcd. for $C_{26}H_{22}O_7$ (446.44): C, 69.94; H, 4.97. Found: C, 70.21; H, 5.20.

1,4-Anhydro-D-lyxitol.—1,4-Anhydro-D-lyxitol tribenzoate (0.360 g.) was debenzoylated by treatment with 2.0 ml. of 0.046 *N* barium methoxide for 2 hr. The solvent was then removed, water added and the solution extracted several times with ether. The aqueous solution was then treated with Dowex 50W-X8 and concentrated to dryness to give a sirup which showed $[\alpha]^{20}D$ −0.5° in water (*c* 0.78) and was shown to be homogeneous by paper chromatography in isopropyl alcohol–ammonia–water (6:3:1) as well as in water–acetone (1:9). Cifonelli, Cifonelli, Montgomery, and Smith[52] prepared both enantiomorphs of 1,4-anhydrolyxitol (= 2,5-anhydroarabinitol) in amorphous form. For the D-isomer they reported $[\alpha]^{23}D$ −1.4 ± 0.5° (H_2O, *c* 0.9); for the L-isomer $[\alpha]^{28}D$ +0.2° (H_2O, *c* 5.9).

1,4-Anhydro-D-ribitol Tribenzoate.—1-*O*-Acetyl-2,3,5-tri-*O*-benzoyl-β-D-ribose (5.02 g.) was dissolved in 20 ml. of dichloromethane and hydrogen bromide passed into the solution for 3.5 min. Solvent was removed *in vacuo* and the remaining sirup, dissolved in 100 ml. of dry ether, added gradually to a suspension of 6.2 g. of lithium aluminum hydride in 100 ml. of ether. When the addition was complete the solution was boiled under reflux for 50 min. and the excess of hydride destroyed with water. Carbon dioxide was passed in until neutrality was reached and the ether solution was then extracted with water. The aqueous layer was filtered, the filtrate concentrated *in vacuo* to dryness and the residue extracted with several batches of boiling absolute ethanol. Upon concentrating the combined alcoholic extracts an oil was obtained. Paper chromatography in butanol–pyridine–water (6:2:3), followed by development with sodium periodate and benzidine sprays, showed only one component; ribitol was absent. Benzoylation of the amorphous 1,4-anhydro-D-ribitol with pyridine (20 ml.) and benzoyl chloride (9 ml.), followed by the usual purification, afforded a sirup which, after three extractions with 100 ml. portions of pentane (to remove benzyl benzoate), weighed 2.95 g. From its solution in 50 ml. of methanol, the product (1.16 g., 26%, m.p. 71–73°) crystallized; two recrystallizations from absolute ethanol afforded pure 1,4-anhydro-D-ribitol tribenzoate melting at 73–75° and showing $[\alpha]^{20}D$ +107° in chloroform (*c* 1.71).

Anal. Calcd. for $C_{26}H_{22}O_7$ (446.44): C, 69.94; H, 4.97. Found: C, 69.86; H, 5.26.

1,4-Anhydro-D-arabinitol Tribenzoate.—1,4-Anhydro-D-arabinitol tri-*p*-nitrobenzoate[53] (1.00 g.) was dissolved in 15 ml. of 0.04 *N* barium methoxide and the solution left at room temperature for 16 hr. The alkali was then neutralized with carbon dioxide and the solution concentrated *in vacuo* to dryness. Water was added, the methyl *p*-nitrobenzoate removed by extraction with dichloromethane and the aqueous solution concentrated to a sirup which was successively extracted with 20 ml. of hot ethyl acetate and then with 10 ml. of hot absolute ethanol. The sirup was dissolved in pyridine and the solution concentrated *in vacuo* to remove traces of alcohol. More pyridine (5 ml.) was then added and benzoylation conducted with 1.5 ml. of benzoyl chloride. After the usual purification the resulting product (0.875 g.) was dissolved in benzene–cyclohexane (4:13) and chromatographed on 20 g. of neutral Woelm alumina (grade III). Seventy percent of the material was eluted with the first two 50-ml. portions of 4:13 benzene–cyclohexane; without

(49) It is possible that this sirup was a mixture of 2,3,5-tri-*O*-benzoyl-D-lyxose and of 1,3,5-tri-*O*-benzoyl-β-D-lyxose. The latter compound would arise in the hydrolysis of tri-*O*-benzoyl-α-D-lyxofuranosyl bromide, the benzoyl group at C-2 migrating to the β-C-1 position. *Cf.* the analogous cases in the D-ribofuranose series (ref. 9) and D-arabinofuranose series (ref. 5).

(50) M. Nys and J. P. Verheijden, *Bull. soc. chim. Belges*, **69**, 57 (1960).

(51) L. Zervas and C. Zioudrou, *J. Chem. Soc.*, 214 (1956).

(52) M. Cifonelli, J. A. Cifonelli, R. Montgomery, and F. Smith, *J. Am. Chem. Soc.*, **77**, 121 (1955).

(53) R. Barker and H. G. Fletcher, Jr., *J. Org. Chem.*, **26**, 4605 (1961).

rigorous drying, these showed $[\alpha]^{20}D$ +71° +76° in dichloromethane. The second fraction, dried at 90° and 0.3 mm. for 1 hr., gave $[\alpha]^{20}D$ +77.5° in dichloromethane (*c* 0.64). Attempts to obtain the 1,4-anhydro-L-arabinitol tribenzoate in crystalline form failed.

Anal. Calcd. for $C_{26}H_{22}O_7$ (446.44): C, 69.94; H, 4.97. Found: C, 69.66; H, 5.11.

1,4-Anhydro-2-deoxy-D-*erythro*-pentitol Dibenzoate.—Five grams of 2-deoxy-D-*erythro*-pentitol tetrabenzoate (m.p. 130–132°, $[\alpha]^{20}D$ −14.5° in CH_2Cl_2[54]) was debenzoylated catalytically with barium methoxide in methanol and the barium then removed by passage of the solution through a column of Amberlite IR-50. Removal of the solvent gave a sirup which was dissolved in water and freed of methyl benzoate by extraction with dichloromethane. The aqueous solution was concentrated *in vacuo* to give 1.45 g. of sirupy 2-deoxy-D-*erythro*-pentitol; conversion of this to the anhydroglycitol was carried out by the method which Baddiley, Buchanan, and Carss[55] used for the conversion of ribitol to 1,4-anhydro-DL-ribitol. The sirup, dissolved in 30 ml. of water, was transferred to a 1.5-dm. polarimeter tube and the solution then treated with 6 ml. of concentrated hydrochloric acid. The solution then showed $\alpha^{20}D$ −0.91°; after heating at 95° for 72 hr. mutarotation had ceased at a value of $\alpha^{20}D$ +2.26°. The reaction mixture was concentrated and the acid removed by evaporating water and then ethanol from the residue which was finally held in a high vacuum: 0.9 g., $[\alpha]^{20}D$ +39° in ethanol (*c* 2.5). After distillation at 105–115° (vapor) and 0.02 mm., the 1,4-anhydro-2-deoxy-D-*erythro*-pentitol was obtained as a clear, colorless sirup showing $[\alpha]^{20}D$ +48.1° in water (*c* 1.18). It was dissolved in dry pyridine and benzoylated with benzoyl chloride in the customary manner. 1,4-Anhydro-2-deoxy-D-*erythro*-pentitol dibenzoate crystallized from ether–pentane as colorless prisms after seeding with crystals initially obtained by flowing chromatography on acidic alumina: 1.025 g. (35%), m.p. 47–48°, $[\alpha]^{20}D$ −59.4° in dichloromethane (*c* 1.2).

Anal. Calcd. for $C_{19}H_{18}O_5$ (326.33): C, 69.93; H, 5.56. Found: C, 69.82; H, 5.84.

1,4-Anhydro-2-deoxy-D-*erythro*-pentitol Di-*p*-chlorobenzoate.—1,4-Anhydro-2-deoxy-D-*erythro*-pentitol (348 mg.) prepared as described above, was acylated with *p*-chlorobenzoyl chloride in the conventional fashion to give an amorphous product which was adsorbed on alumina. Elution with cyclohexane–benzene (1:1) afforded a fraction which showed $[\alpha]^{20}D$ +62° in dichloromethane and crystallized from isopropyl ether–pentane: m.p. 60–61°, $[\alpha]^{20}D$ +68.1° in dichloromethane (*c* 1.03).

Anal. Calcd. for $C_{19}H_{16}Cl_2O_5$ (395.23): Cl, 17.94. Found: Cl, 18.02.

1,4-Anhydro-2-deoxy-D-*erythro*-pentitol Di-p-nitrobenzoate.—1,4-Anhydro-2-deoxy-D-*erythro*-pentitol dibenzoate (0.82 g.) was debenzoylated in the usual manner to give 0.28 g. of sirupy 1,4-anhydro-2-deoxy-D-*erythro*-pentitol. One half of this sirup was acylated with *p*-nitrobenzoyl chloride in pyridine solution to give a crystalline product when the reaction mixture was poured in water: 0.48 g. (92%), m.p. 135–136°. Recrystallized from ethanol, the ester was obtained as yellowish, flat needles melting at 137–138° and showing $[\alpha]^{20}D$ +65° in dichloromethane (*c* 0.89) and +66.6° in dimethylformamide (*c* 2.7).

Anal. Calcd. for $C_{19}H_{16}N_2O_9$ (416.34): C, 54.81; H, 3.87; N, 6.73. Found: C, 55.07; H, 4.03; N, 6.71.

1,4-Anhydro-2-deoxy-D-*erythro*-pentitol Di-*p*-methylbenzoate.—The other half of the 1,4-anhydro-2-deoxy-D-*erythro*-pentitol, prepared as mentioned above, was acylated with *p*-methylbenzoyl chloride in pyridine. Recrystallized twice from ether–pentane, the product (0.26 g., 58%) was obtained as needles which melted at 63–65° and showed $[\alpha]^{20}D$ +63.5° in dichloromethane (*c* 0.45).

Anal. Calcd. for $C_{21}H_{22}O_5$ (354.39): C, 71.17; H, 6.26. Found: C, 71.45; H, 6.29.

1,5-Anhyrdo-2-deoxy-D-*erythro*-pentitol (= Dihydro-D-arabinal).—1,5-Anhydro-2-deoxy-D-*erythro*-pentitol diacetate was prepared from tri-*O*-acetyl-D-arabinopyranosyl bromide by well known procedures[24,56,57] as a distilled sirup which showed $[\alpha]^{20}D$ −47.3° in chloroform (*c* 4.78). The ester (22.0 g.) was deacetylated in methanol solution using barium methoxide and the solution then deionized and concentrated *in vacuo* to a viscous, colorless, hygroscopic sirup (13.2 g.) which crystallized on standing. One gram was removed and recrystallized from ethyl acetate: 0.8 g., m.p. 42–44°, $[\alpha]^{20}D$ −51.4° in water (*c* 1.85).

Anal. Calcd. for $C_5H_{10}O_3$ (118.13): C, 50.83; H, 8.53. Found: C,50.60; H, 8.33.

The rotation of amorphous 1,5-anhydro-2-deoxy-L-*erythro*-pentitol has been reported as $[\alpha]D$ +48.2° in water by Felton and Freudenberg[58] and $[\alpha]^{20}D$ +64° in water by Brimacombe, Foster, Stacey, and Whiffen.[59] As far as we are aware, the substance (at least in the D-form) was first crystallized in the course of the present research.

1,5-Anhydro-2-deoxy-D-*erythro*-pentitol Dibenzoate.—1,5-Anhydro-2-deoxy-D-*erythro*-pentitol (1.02 g., crystalline and anhydrous but unrecrystallized) was benzoylated with benzoyl chloride in pyridine solution to give 2.06 g. (73%) of its dibenzoate, crystallized as clear, quadrilateral plates from 30 ml. of warm hexane: m.p. 88–90°. Recrystallized from 5 ml. of methanol, the ester melted at 89–91° and showed $[\alpha]^{20}D$ −65.1° in chloroform (*c* 0.78).

Anal. Calcd. for $C_{19}H_{18}O_5$ (326.33): C, 69.93; H, 5.56. Found: C, 69.94; H, 5.76.

1,5-Anhydro-2-deoxy-D-*erythro*-pentitol Di-*p*-chlorobenzoate.—1,5-Anhydro-2-deoxy-D-*erythro*-pentitol (1.01 g., crystalline and anhydrous but unrecrystallized) was acylated with *p*-chlorobenzoyl chloride in pyridine solution to give (from ether–methanol) 2.6 g. (77%) of the di(*p*-chlorobenzoate) melting at 85–87°. Recrystallized from acetone–methanol (1:2), the ester was obtained as rods melting at 97–98° and rotating $[\alpha]^{20}D$ −90.1° in chloroform (*c* 1.2).

Anal. Calcd. for $C_{19}H_{16}Cl_2O_5$ (395.23): C, 57.73; H, 4.08; Cl, 17.94. Found: C, 57.49; H, 4.28; Cl, 17.83.

1,5-Anhydro-2-deoxy-D-*erythro*-pentitol Di-*p*-nitrobenzoate.—1,5-Anhydro-2-deoxy-D-*erythro*-pentitol (1.02 g., crystalline and anhydrous but unrecrystallized) was acylated with *p*-nitrobenzoyl chloride in pyridine solution to give, from ethyl acetate–pentane, 1.85 g. of crystalline product. The material remaining in the mother liquor afforded 0.84 g. more crystalline product from its solution in ethyl acetate–ethanol: 2.69 g. total, 75%. Recrystallized from ethyl acetate–ethanol (1:2) and dried *in vacuo*, the di-*p*-nitrobenzoate melted at 117–119° and showed $[\alpha]^{20}D$ −104° in chloroform (*c* 1.5) and $[\alpha]^{20}D$ −97.1° in anhydrous pyridine (*c* 1.4).

Anal. Calcd. for $C_{19}H_{16}N_2O_9$ (416.34): C, 54.81; H, 3.87; N, 6.73. Found: C, 54.93; H, 4.11; N, 6.77.

1,5-Anhydro-2-deoxy-D-*erythro*-pentitol Di-*o*-methylbenzoate.—1,5-Anhydro-2-deoxy-D-*erythro*-pentitol (1.0 g., crystalline and anhydrous but not recrystallized) was acylated with *o*-methylbenzoyl chloride in pyridine solution to give, from methanol solution, 1.3 g. (43%) of crystalline product melting at 55–60°. Recrystallized from methanol, the di-*o*-methylbenzoate melted at 54–55° and showed $[\alpha]^{20}D$ −61.4° in chloroform (*c* 1.13).

Anal. Calcd. for $C_{21}H_{22}O_5$ (354.39): C, 71.17; H, 6.26. Found: C, 71.38; H, 6.26.

1,5-Anhydro-2-deoxy-D-*erythro*-pentitol Di-*p*-methylbenzoate.—One gram of 1,5-anhydro-2-deoxy-D-*erythro*-pentitol (crystalline and anhydrous but not recrystallized) was acylated with *p*-methylbenzoyl chloride in pyridine solution and the resulting ester worked up in the usual fashion. Efforts to obtain the product in crystalline form were unsuccessful; a sample was distilled *in vacuo* (0.002 mm., 170° bath) as a colorless glass which showed $[\alpha]^{20}D$ −73° in chloroform (*c* 0.53).

Anal. Calcd. for $C_{21}H_{22}O_5$ (354.39): C, 71.17; H, 6.26. Found: C, 71.29; H, 6.43.

The Anomeric Tri-*O*-benzoyl-L-arabinofuranosyl Chlorides.—A current of hydrogen chloride was passed into a suspension of 10 g. of methyl α-L-arabinofuranoside tribenzoate[5,60] in 100 ml. of glacial acetic acid for 4 hr., the reaction mixture being cooled in ice toward the end of this period. After 68 hr. the solution was diluted with dichloromethane, washed with water and with aqueous sodium bicarbonate, and dried with magnesium sulfate. Concentration *in vacuo* (40° bath) gave a sirup which was dissolved in ether and the solution filtered through decolorizing

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carbon; on standing for 6 hr. at room temperature the solution gave 7.0 g. (69%) of colorless prisms, m.p. 115–117°. Two recrystallizations from ether–pentane (2:1) afforded pure tri-*O*-benzoyl-α-L-arabinofuranosyl chloride melting at 116–117° and showing $[\alpha]^{20}D$ −30.6° in dichloromethane (*c* 1.2), no mutarotation being observed in this solvent over the course of 2 hr.

Anal. Calcd. for $C_{26}H_{21}ClO_7$ (480.89): C, 64.93; H, 4.40; Cl, 7.37. Found: C, 64.96; H, 4.63; Cl, 7.32.

Partial concentration of the main mother liquor, followed by the addition of pentane to turbidity, led to the crystallization of white needles melting at 125–135°. Two recrystallizations from ether gave pure tri-*O*-benzoyl-β-L-arabinofuranosyl chloride (0.35 g., 3.6%) melting at 133–135° and showing $[\alpha]^{20}D$ +112.8° in dichloromethane (*c* 0.96).

Anal. Calcd. for $C_{26}H_{21}ClO_7$ (480.89): C, 64.93; H, 4.40; Cl, 7.37. Found: C, 64.69; H, 4.62; Cl, 7.32.

1,3,5-Tri-*O*-benzoyl-β-L-arabinose from Tri-*O*-benzoyl-α-L-arabinofuranosyl Chloride.—To confirm its anomeric configuration, tri-*O*-benzoyl-α-L-arabinofuranosyl chloride was hydrolyzed (with concomitant benzoyl migration) to 1,3,5-tri-*O*-benzoyl-β-L-arabinose in the following manner.[61] Tri-*O*-benzoyl-α-L-arabinofuranosyl chloride (0.14 g.) was dissolved in 5 ml. of water–acetone (1:4) and the solution observed polarimetrically. After 20 min. mutarotation had ceased and the reaction mixture was concentrated *in vacuo* to a sirup which, from ether–pentane afforded 50 mg. of crystalline material melting at 119–120°. Recrystallization from ether–pentane afforded pure 1,3,5-tri-*O*-benzoyl-β-L-arabinose, melting at 120–122° and showing $[\alpha]^{20}D$ +10.1° in chloroform (*c* 1.09). Ness and Fletcher[5] reported m.p. 120–121° and $[\alpha]^{20}D$ −9.7° ($CHCl_3$) for the D-enantiomorph. To confirm the identity of the substance it was acetylated with acetic anhydride in dry pyridine to give, from ether–pentane, 2-*O*-acetyl-1,3,5-tri-*O*-benzoyl-β-L-arabinose melting at 133–134° and giving $[\alpha]^{20}D$ +60.5° in chloroform (*c* 0.82). Ness and Fletcher[5] reported m.p. 132–134° and $[\alpha]^{20}D$ −60.4° ($CHCl_3$) for the D-enantiomorph.

Tri-*O*-benzoyl-α-D-arabinofuranosyl Fluoride.[62]—One gram of methyl α-D-arabinofuranoside tribenzoate was dissolved in 5 ml. of liquid hydrogen fluoride and the solution kept at −8° for 18 min. It was then poured onto a mixture of ice, saturated sodium bicarbonate, and dichloromethane. The organic layer was washed with cold aqueous sodium bicarbonate, dried with sodium sulfate, and concentrated *in vacuo*. From *ca.* 7 ml. of ether the tri-*O*-benzoyl-α-D-arabinofuranosyl fluoride (0.65 g., 67%) crystallized readily: m.p. 127–129°. Recrystallized twice from the same solvent, it melted at 129–130° and showed $[\alpha]^{20}D$ −54.0° in chloroform (*c* 0.060).

Anal. Calcd. for $C_{26}H_{21}FO_7$ (464.43): C, 67.24; H, 4.76. Found: C, 66.95; H, 4.77.

2-Deoxy-3,5-di-*O*-*p*-nitrobenzoyl-D-*erythro*-pentosyl Bromide.—The preparative method was similar to that reported earlier for the corresponding chloride.[36] Crude methyl 2-deoxy-3,5-di-*O*-*p*-nitrobenzoyl-β-D-*erythro*-pentoside (5.04 g., $[\alpha]^{20}D$ +3°) was dissolved in 30 ml. of glacial acetic acid and the cooled solution treated with a stream of hydrogen bromide for 3 min. Four minutes later, 30 ml. of ether was added and crystallization began: 2.29 g., 41%. Recrystallized from dichloromethane–ether–pentane (1:1:1), the material melted at 87–90° dec. (in bath at 80°, 9°/min.) and gave in dry dichloromethane (*c* 1.6) $[\alpha]^{20}D$ +124° (extrap.), +100° (10 min.) and +94° (20 min.).

Anal. Calcd. for $C_{19}H_{15}BrN_2O_9$ (495.25): Br, 16.14; N, 5.66. Found: Br, 16.08; N, 5.54.

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(61) See ref. 5 for a similar reaction shown by tri-*O*-benzoyl-α-D-arabinofuranosyl bromide.

(62) This preparation was carried out several years ago in this laboratory by Dr. Christian Pedersen.

2-Deoxy-D-*erythro*-pentose. X.[1] Synthesis of 1,4-Anhydro-3,5-di-*O*-benzoyl-2-deoxy-D-*erythro*-pentose-1-enol.[2] Derivative of a Furanose-related Glycal

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The synthesis and some of the properties of 1,4-anhydro-3,5-di-*O*-benzoyl-2-deoxy-D-*erythro*-pentose-1-enol are described. As far as is known, this is the first reported example of a furanose-related glycal.

Since Fischer and Zach[3] first synthesized 3,4,6-tri-*O*-acetyl-1,5-anhydro-2-deoxy-D-*arabino*-hexose-1-enol (D-glucal triacetate), the glycals have become important as intermediates in the synthesis of a variety of carbohydrate derivatives.[4] Despite the key position which these substances occupy, the preparative method which Fischer and Zach used is still (with minor modifications[5,6]) the only significant one for the preparation of glycals, although Micheel[7] showed that the pyrolysis of certain 2,6-dideoxy-D-*ribo*-hexosides ("digitoxosides") gives 1,5-anhydro-2,6-dideoxy-D-*ribo*-hexose-1-enol ("6-deoxy-D-allal") and Zorbach and Durr[8] have recently shown that 2,6-dideoxy-3,4-di-*O*-*p*-nitrobenzoyl-β-D-*ribo*-hexosyl chloride may be dehydrohalogenated through the action of silver carbonate to a substance which is apparently the corresponding glycal.

As far as we are aware, all of the known glycals are what might be called "pyranals," derivatives of the pyranose forms of the aldoses. We wish now to describe the synthesis of a "furanal," related to 2-deoxy-D-*erythro*-pentofuranose. Attempts to apply various modifications of Fischer and Zach's[3] method to the most readily available crystalline furanosyl halide, tri-*O*-benzoyl-α-D-arabinofuranosyl bromide,[9] were without success.[10] Attention was then turned toward a wholly different approach. 3,5-Di-*O*-benzoyl-2-*O*-*p*-

(1) 2-Deoxy-D-*erythro*-pentose. IX: A. K. Bhattacharya, R. K. Ness and H. G. Fletcher, Jr., *J. Org. Chem.*, **28**, 428 (1963).

(2) The nomenclature employed here for glycals follows one of the proposals currently under consideration by the Committee on Carbohydrate Nomenclature of the Division of Carbohydrate Chemistry of the American Chemical Society.

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