

[CONTRIBUTION FROM THE NATIONAL INSTITUTE OF ARTHRITIS AND METABOLIC DISEASES, NATIONAL INSTITUTES OF HEALTH, PUBLIC HEALTH SERVICE]

### 2-Deoxy-D-ribose. III. The Anomeric 1,3,4-Tri-*O*-benzoyl-2-deoxy-D-riboses, the Anomeric 1,3,5-Tri-*O*-benzoyl-2-deoxy-D-riboses and Certain Other Derivatives<sup>1</sup>

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The crystalline, anomeric benzyl 2-deoxy-D-ribofuranosides have been prepared and characterized through a series of derivatives. Hydrogenolysis of the dibenzoates of these glycosides gives 3,4-di-*O*-benzoyl-2-deoxy-D-ribose; benzoylation of this ester affords the two anomeric 1,3,4-tri-*O*-benzoyl-2-deoxy-D-riboses. Direct benzoylation of 2-deoxy-D-ribose at a low temperature gives the same two isomers. Condensation of 5-*O*-benzoyl-2-deoxy-D-ribose diisopropyl dithioacetal with silver benzoate gives the anomeric 1,5-di-*O*-benzoyl-2-deoxy-D-riboses; benzoylation of these esters affords the corresponding 1,3,5-tri-*O*-benzoyl-2-deoxy-D-riboses.

Owing to their relative stability, benzoyl derivatives of the simpler carbohydrates have been shown by many workers to have marked advantages over other acyl derivatives<sup>2</sup> and, since they have proved to be particularly useful for synthetic purposes in the D-ribose series,<sup>3</sup> we have turned our attention to the synthesis of the four cyclic tribenzoates of 2-deoxy-D-ribose (2-deoxy-D-*erythro*-pentose).

Three tribenzoates of 2-deoxy-D-ribose have been reported in the literature and are here listed in Table I.<sup>3a</sup> Allerton and Overend<sup>4</sup> described a 2-deoxy-D-ribose tribenzoate obtained through the direct benzoylation of the free sugar. Zinner, Nimz and Venner<sup>5</sup> obtained 3,4,5-tri-*O*-benzoyl-2-deoxy-*aldehydo*-D-ribose by conventional methods. Zinner and Nimz<sup>6</sup> demercaptalated a variety of 5-*O*-benzoyl-2-deoxy-D-ribose dialkyl dithioacetals to 5-*O*-benzoyl-2-deoxy-D-ribose and then benzoylated this amorphous substance to obtain a crystalline, dextrorotatory 1,3,5-tri-*O*-benzoyl-2-deoxy-D-ribose which they designated as the  $\alpha$ -anomer, the crude material in the mother liquor being more levorotatory.

Compound	M.p., °C.	$[\alpha]_D^{20}$	Ref.
2-Deoxy-D-ribose tribenzoate	127	$[\alpha]_D^{20} - 65^\circ$ (CHCl <sub>3</sub> )	4
3,4,5-Tri- <i>O</i> -benzoyl-2-deoxy- <i>aldehydo</i> -D-ribose	118-119	$[\alpha]_D^{19} - 2.8^\circ$ (C <sub>6</sub> H <sub>6</sub> N)	5
1,3,5-Tri- <i>O</i> -benzoyl-2-deoxy- $\alpha$ -D-ribose	111-111.5	$[\alpha]_D^{19} + 78^\circ$ (CHCl <sub>3</sub> )	6

A variety of unequivocal pathways to fully benzoylated aldopyranoses and aldofuranoses is available. However, the good crystallinity of the benzyl glycosides, the ease with which their ring structures may be ascertained and the ready hydrogenolysis of their esters to give partially acylated sugars of known structure, make them among the most attractive intermediates for such syntheses as was shown earlier in the D-ribofuranose<sup>7</sup> and D-ribo-

furanose<sup>8</sup> series. 2-Deoxy-D-ribose was therefore allowed to react with benzyl alcohol containing hydrogen chloride until mutarotation had ceased. Two crystalline benzyl 2-deoxy-D-ribosides, one levorotatory (45% yield) and one dextrorotatory (9.6% yield) were obtained; periodate oxidation showed both to be pyranosides. The  $\alpha$ -anomer I was further characterized by its dimesylate II, ditosylate IV and dibenzoate III. The  $\beta$ -anomer V gave a dimesylate VI and ditosylate VIII; attempts to crystallize the dibenzoate VII failed. Hydrogenolysis of amorphous benzyl 3,4-di-*O*-benzoyl-2-deoxy- $\beta$ -D-riboside (VII) afforded a crystalline 3,4-di-*O*-benzoyl-2-deoxy-D-ribose which showed a dextrorotation and is therefore, presumably, the  $\beta$ -anomer IX. In another run the dibenzoate of the anomeric glycoside III was similarly hydrogenolyzed and then benzoylated to yield, after chromatography on alumina, two 2-deoxy-D-ribofuranose tribenzoates, X and XI, whose properties are listed in Table II.

2-Deoxy-D-ribose derivative	M.p., °C.	$[\alpha]_D^{20}$ (CHCl <sub>3</sub> )
1,3,4-Tri- <i>O</i> -benzoyl- $\alpha$ -	151-152	+41.6°
1,3,4-Tri- <i>O</i> -benzoyl- $\beta$ -	159-161	-195
1,3,5-Tri- <i>O</i> -benzoyl- $\alpha$ -	110-112	+75.3
1,3,5-Tri- <i>O</i> -benzoyl- $\beta$ -	84-87	-19.8
1,5-Di- <i>O</i> -benzoyl- $\alpha$ -	89-90	+44.5
1,5-Di- <i>O</i> -benzoyl- $\beta$ -	108-111	-17.6

The direct benzoylation of 2-deoxy-D-ribose in pyridine solution with benzoyl chloride at 0° afforded a very high yield of crystalline product. By extensive and wasteful fractional crystallization this was resolved into the two anomeric 1,3,4-tri-*O*-benzoyl-2-deoxy-D-riboses which had been made by the benzoylation of IX; doubtless, careful chromatography would have provided a more efficient separation of these substances.

Attention was now turned to the tribenzoates of 2-deoxy-D-ribofuranose. Here a new synthetic method, first described in the paper<sup>9</sup> immediately preceding this one, was used. 5-*O*-Benzoyl-2-deoxy-D-ribose diisopropyl dithioacetal (XII), a derivative reported recently by Zinner and Nimz,<sup>6</sup> was treated in hot acetonitrile with silver benzoate and two di-*O*-benzoyl-2-deoxy-D-riboses thus ob-

(1) 2-Deoxy-D-ribose. II, D. L. MacDonald and H. G. Fletcher, Jr., *THIS JOURNAL*, **81**, 3719 (1959).

(2) *Cf.*, for instance, I. J. Haynes and F. H. Newth, *Advances in Carbohydrate Chem.*, **10**, 207 (1955).

(3) H. G. Fletcher, Jr., *Record Chem. Progr. Kresge-Hooker Sci. Lib.*, **19**, 147 (1958).

(3a) NOTE ADDED IN PROOF, APRIL 4, 1960.—While this communication was in press H. Zinner, H. Nimz and E. Wittenburg [*Chem. Ber.*, **93**, 340 (1960)] described direct benzoylation procedures whereby three of the tribenzoates of 2-deoxy-D-ribose may be prepared from the sugar in varying yields.

(4) R. Allerton and W. G. Overend, *J. Chem. Soc.*, 1480 (1951).

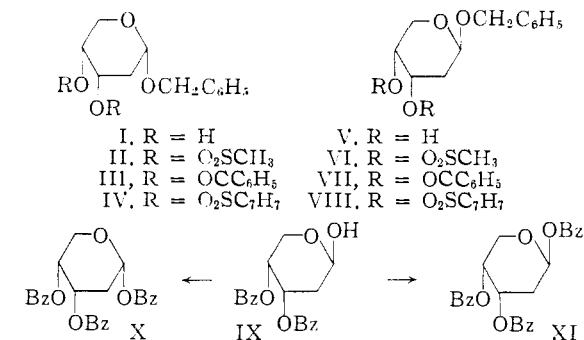
(5) H. Zinner, H. Nimz and H. Venner, *Chem. Ber.*, **91**, 148 (1958).

(6) H. Zinner and H. Nimz, *ibid.*, **91**, 1657 (1958).

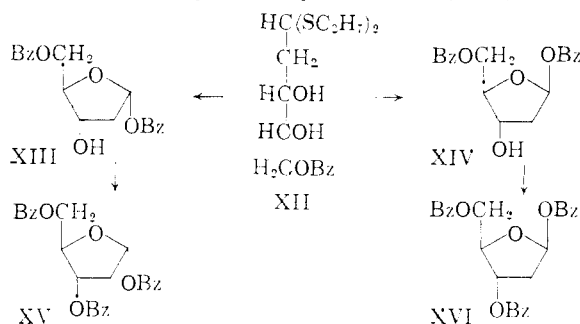
(7) H. G. Fletcher, Jr., and R. K. Ness, *THIS JOURNAL*, **76**, 760 (1954).

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

(9) C. Pedersen and H. G. Fletcher, Jr., *ibid.*, **82**, 3215 (1960).



tained. On the not unreasonable assumption that the original 5-*O*-benzoyl group had not migrated and that the newly introduced benzoyl group had entered at carbon one, the dextrorotatory dibenzoate may be assigned structure XIII and the levorotatory dibenzoate structure XIV. Neither substance exhibited mutarotation. Benzoylation of XIII afforded a dextrorotatory tribenzoate, 1,3,5-tri-*O*-benzoyl-2-deoxy- $\alpha$ -D-ribose (XV), while benzoylation of XIV led to a levorotatory tribenzoate, 1,3,5-tri-*O*-benzoyl-2-deoxy- $\beta$ -D-ribose (XVI). The



physical constants of the two anomers, XV and XVI, are listed in Table II. The value for the  $\alpha$ -anomer are in fairly close agreement with those reported by Zinner and Nimz<sup>9</sup> (Table I). The constants reported by Allerton and Overend<sup>4</sup> for their 2-deoxy-D-ribose tribenzoate do not agree with any of the five other isomers here mentioned; it seems highly probable that these authors were dealing with a mixture of the two anomeric 2-deoxy-D-ribofuranose tribenzoates (X and XI).

#### Experimental<sup>10</sup>

**The Anomeric Benzyl 2-Deoxy-D-ribofuranosides (I and V).**—Four grams of pure, powdered 2-deoxy-D-ribose was dissolved in 100 ml. of freshly distilled benzyl alcohol by warming to about 60°. The solution was cooled to 25° and 1.04 g. of hydrogen chloride passed in, the temperature being kept below 32°. Polarimetric observation of the mixture showed the reaction to be essentially complete after 1.5 hr. After 2 hr., the clear, colorless solution was neutralized with 8 g. of silver carbonate, filtered through a thin layer of decolorizing carbon and concentrated at 0.05 mm. pressure and 60–65° (bath). The resulting sirup was dissolved in 42 ml. of benzene and further diluted with 30 ml. of pentane. Crystallization was rapid; after 30 min. at room temperature the needle-like crystals were removed and washed with pentane-benzene (4:6). The crude benzyl 2-deoxy- $\beta$ -D-ribofuranoside thus obtained (4.4 g.) melted at 69–103° and showed  $[\alpha]^{20D} -134^\circ$  in chloroform. Recrystallized from 40 parts of isopropyl ether and then from 5 parts of ethyl acetate the pure glycoside (3.0 g., 45%) was obtained as plates melting at 106–107° and rotating  $[\alpha]^{20D} -174^\circ$  in chloroform ( $c$  0.82).

(10) Melting points are corrected.

*Anal.* Calcd. for C<sub>12</sub>H<sub>16</sub>O<sub>4</sub>: C, 64.27; H, 7.19. Found: C, 64.50; H, 7.04.

The combined mother liquors and washings were concentrated *in vacuo* to a sirup which was dissolved in 8 ml. of acetone. At -5° the solution deposited 0.64 g. (9.6%) of plate-like crystals melting at 117–119°. Recrystallized from 8 parts of acetone, the pure benzyl 2-deoxy- $\alpha$ -D-ribofuranoside melted at 122–123° and rotated  $[\alpha]^{20D} +130^\circ$  in chloroform ( $c$  0.95).

*Anal.* Calcd. for C<sub>12</sub>H<sub>16</sub>O<sub>4</sub>: C, 64.27; H, 7.19. Found: C, 64.55; H, 7.26.

Benzyl 2-deoxy- $\alpha$ -D-ribofuranoside was found to reduce 1.04 molar equivalents of sodium metaperiodate in 22 hr.; the  $\beta$ -anomer consumed 1.05 molar equivalents of this oxidant in 18 hr.

**Benzyl 2-Deoxy-3,4-di-*O*-methylsulfonyl- $\alpha$ -D-ribose (II).**—Benzyl 2-deoxy- $\alpha$ -D-ribofuranoside (100 mg.) was mesylated with 0.076 ml. of methanesulfonyl chloride in 0.5 ml. of pyridine at 45° for 1 hr. Water was added to the cooled reaction mixture and a sample of the gum thus precipitated rubbed with alcohol. The seeds thus obtained allowed the main batch to crystallize: 150 mg. (88%). Recrystallized from warm, absolute ethanol the product (120 mg.) melted at 79–80° and showed  $[\alpha]^{20D} +55.6^\circ$  in chloroform ( $c$  0.94).

*Anal.* Calcd. for C<sub>14</sub>H<sub>20</sub>O<sub>8</sub>S<sub>2</sub>: C, 44.20; H, 5.30; S, 16.86. Found: C, 44.33; H, 5.56; S, 16.86.

**Benzyl 3,4-Di-*O*-benzoyl-2-deoxy- $\alpha$ -D-ribose (III).**—A sample (100 mg.) of the pure glycoside was benzoylated with benzoyl chloride in pyridine at 45° for 20 min. On cooling and dilution with water the mixture gave a crystalline product (170 mg., 88%) which melted at 80–82°. Recrystallized from 6 parts of warm, absolute ethanol the pure ester (130 mg.) was obtained as thick needles melting at 91–92° and showing  $[\alpha]^{20D} +8.3^\circ$  in chloroform ( $c$  0.96).

*Anal.* Calcd. for C<sub>26</sub>H<sub>4</sub>O<sub>6</sub>: C, 72.21; H, 5.59. Found: C, 72.20; H, 5.85.

**Benzyl 2-Deoxy-3,4-di-*O*-*p*-tolylsulfonyl- $\alpha$ -D-ribose (IV).**—The pure glycoside (100 mg.) was dissolved in 1 ml. of dry pyridine and treated with 340 mg. of tosyl chloride. After 2.5 hr. at 45° the reaction mixture was cooled and the product precipitated in crystalline form through the addition of water: 180 mg. (76%), m.p. 123–132°. Recrystallized from 32 parts of absolute ethanol the pure ester (120 mg.) was obtained as plates melting at 125–126° and rotating  $[\alpha]^{20D} +43^\circ$  in chloroform ( $c$  1.0).

*Anal.* Calcd. for C<sub>26</sub>H<sub>28</sub>O<sub>8</sub>S<sub>2</sub>: C, 58.63; H, 5.30; S, 12.04. Found: C, 58.72; H, 5.41; S, 12.06.

**Benzyl 2-Deoxy-3,4-di-*O*-methylsulfonyl- $\beta$ -D-ribose (VI).**—The pure glycoside (200 mg.) was dissolved in 1 ml. of pyridine and treated with 0.152 ml. of methanesulfonyl chloride. After 1 hr. at 45° the reaction mixture was cooled and diluted with water. Seeds were obtained by rubbing a sample of the precipitated sirup with ethanol. The aqueous layer was decanted and the sirup (seeded) left in contact with fresh water until crystallization was complete: 310 mg. (91%). Recrystallized from 26 parts of absolute alcohol the pure product (210 mg.) was obtained as needles melting at 63–64° and rotating  $[\alpha]^{20D} -161^\circ$  ( $c$  0.93) in chloroform.

*Anal.* Calcd. for C<sub>14</sub>H<sub>20</sub>O<sub>8</sub>S<sub>2</sub>: C, 44.20; H, 5.30; S, 16.86. Found: C, 44.41; H, 5.33; S, 16.71.

**Benzyl 2-Deoxy-3,4-di-*O*-tolylsulfonyl- $\beta$ -D-ribose (VIII).**—The pure glycoside (100 mg.) was dissolved in 1 ml. of dry pyridine and treated with 340 mg. of toluenesulfonyl chloride. After standing at 45° for 2.5 hr. the reaction mixture was cooled and diluted with water. The sirup thus precipitated was dissolved in methylene chloride and washed successively with cold 3 *N* sulfuric acid and aqueous sodium bicarbonate. Moisture was removed with sodium sulfate and the solution concentrated *in vacuo* to a sirup. From 1 ml. of absolute ethanol the product (100 mg., 42%) separated as needles, m.p. 103–104°. Recrystallized from 20 parts of absolute ethanol, the ester (80 mg.) melted at 107–108° and rotated  $[\alpha]^{20D} -132^\circ$  in chloroform ( $c$  1.1).

*Anal.* Calcd. for C<sub>26</sub>H<sub>28</sub>O<sub>8</sub>S<sub>2</sub>: C, 58.63; H, 5.30; S, 12.04. Found: C, 58.34; H, 5.30; S, 12.29.

**3,4-Di-O-benzoyl-2-deoxy- $\beta$ -D-ribose (IX) from Amorphous Benzyl 3,4-Di-O-benzoyl-2-deoxy- $\beta$ -D-ribose (VII).**—Three grams of crystalline benzyl 2-deoxy- $\beta$ -D-ribofuranoside was benzoylated with an excess of benzoyl chloride in pyridine solution and the excess reactants removed in conventional fashion to yield 6 g. of sirupy product. This was dissolved in 39 ml. of dioxane and the solution added to a suspension of hydrogen-saturated palladium black (12 g.) in 75 ml. of dioxane. After shaking at room temperature under a slight pressure of hydrogen until the theoretical amount of hydrogen had been absorbed, the solution was separated from the catalyst and concentrated *in vacuo* (40° bath) to a sirup. The product was dissolved in 10 ml. of benzene, the solution filtered through carbon and diluted with 10 ml. of pentane. Crystallization was rapid: 2.65 g., m.p. 102–103°. A second crop, m.p. 75–83°, raised the total yield to 3.70 g. (81%). Recrystallized once from benzene-pentane, the 3,4-di-O-benzoyl-2-deoxy- $\beta$ -D-ribose was obtained as cotton-like needles, melting at 105–106° and rotating  $[\alpha]^{20D} -162^\circ$  (9 min.)  $\rightarrow -144^\circ$  (48 hr., constant) (CHCl<sub>3</sub>, *c* 0.97). Further recrystallization from ethyl acetate-pentane failed to change these values.

*Anal.* Calcd. for C<sub>19</sub>H<sub>18</sub>O<sub>6</sub>: C, 66.66; H, 5.30. Found: C, 66.60; H, 5.50.

**The Anomeric 1,3,4-Tri-O-benzoyl-2-deoxy-D-riboses (X, XI) from Benzyl 2-Deoxy- $\alpha$ -D-ribofuranoside Dibenzoate (III).**—Crystalline benzyl 2-deoxy- $\alpha$ -D-ribofuranoside dibenzoate (800 mg.) was hydrogenolyzed in dioxane solution in the presence of palladium black as was described above for the amorphous  $\beta$ -anomer. A small sample of the sirup thus obtained gave, from ethyl acetate-pentane, fine, needle-like crystals melting at 105–106° either alone or in admixture with the 3,4-di-O-benzoyl-2-deoxy- $\beta$ -D-ribose prepared from benzyl 2-deoxy- $\beta$ -D-ribofuranoside dibenzoate as described earlier. The remainder of the sirup was dissolved in 2 ml. of pyridine, the solution cooled in an ice-bath and treated with 0.24 ml. of benzoyl chloride. After 1 hr. at 0° and 45 min. at room temperature, the excess benzoyl chloride was decomposed with a chip of ice and, after 10 min., more ice was added. The precipitated sirup crystallized and the crude product, was washed, first with water and, second, with cold aqueous methanol (1:1): 530 mg. (64%), m.p. 110–126°. The two anomeric 2-deoxy-D-ribofuranoside tribenzoates were separated by flowing chromatography on acid-washed Alorco alumina. Elution with benzene-cyclohexane (1:1) afforded 165 mg. of the  $\beta$ -anomer. Recrystallization from warm methanol gave, with little loss, pure 1,3,4-tri-O-benzoyl-2-deoxy- $\beta$ -D-ribose melting at 159–161° and rotating  $[\alpha]^{20D} -195^\circ$  (CHCl<sub>3</sub>, *c* 0.96).

*Anal.* Calcd. for C<sub>26</sub>H<sub>22</sub>O<sub>7</sub>: C, 69.94; H, 4.97. Found: C, 69.97; H, 5.20.

Elution of the alumina with benzene afforded 56.5 mg. of the  $\alpha$ -anomer. Recrystallized from methanol it melted at 151–152° and rotated  $[\alpha]^{20D} +41.6^\circ$  (CHCl<sub>3</sub>, *c* 0.83).

*Anal.* Calcd. for C<sub>26</sub>H<sub>22</sub>O<sub>7</sub>: C, 69.94; H, 4.97. Found: C, 69.93; H, 5.03.

**Benzoylation of 2-Deoxy-D-ribose at 0°.**—A mixture of 1.43 ml. of benzoyl chloride and 4 ml. of pyridine was cooled to 0° and 500 mg. of pure 2-deoxy-D-ribose added. The mixture was stirred until solution was complete and then left overnight at +5°. A chip of ice was added to destroy the excess benzoyl chloride and, after about 10 min. more ice was added, precipitating a sirup which, after washing with cold fresh water, crystallized. The crude product (1.60 g., 96%), melting at 78–104°, was recrystallized twice from absolute alcohol and once from methyl Cellosolve to give 220 mg. of material melting at 156–157°. A second recrystallization from methyl Cellosolve raised the melting point to 158–159°, the product (110 mg.) then showing  $[\alpha]^{20D} -196^\circ$  (CHCl<sub>3</sub>, *c* 0.84). The 1,3,4-tri-O-benzoyl-2-deoxy- $\beta$ -D-ribose prepared through the hydrogenolysis of benzyl 2-deoxy- $\alpha$ -D-ribofuranoside dibenzoate did not depress the melting point of this product.

The mother liquors from the first recrystallization from methyl Cellosolve gave, on standing at room temperature, 80 mg. of crystalline material melting at 148–151°. Recrystallization of this from 2 ml. of methyl Cellosolve afforded 30 mg. of product which melted at 152–153° and did not depress the melting point of 1,3,4-tri-O-benzoyl-2-deoxy- $\alpha$ -

D-ribose prepared through the hydrogenolysis of benzyl 2-deoxy- $\alpha$ -D-ribofuranoside dibenzoate.

**1,5-Di-O-benzoyl-2-deoxy- $\alpha$ -D-ribose (XIII) and 1,5-Di-O-benzoyl-2-deoxy- $\beta$ -D-ribose (XIV) from 5-O-Benzoyl-2-deoxy-D-ribose Diisopropyl Dithioacetal (XII).**—Five grams of 5-O-benzoyl-2-deoxy-D-ribose diisopropyl dithioacetal, prepared according to a minor modification of the method of Zinner and Nimz,<sup>6</sup> was dissolved in 80 ml. of dry acetonitrile and treated with 12.3 g. (4 molar equivalents) of silver benzoate. The reaction mixture was stirred under reflux for 2 hr., cooled and filtered, the solid being washed with 20 ml. of acetonitrile. The combined filtrate and washings were then treated with 9.2 g. (3.04 molar equivalents) of silver benzoate and boiled under reflux for a further 2 hr. After cooling, the precipitate was filtered off and washed with ether. The combined filtrate and washings were concentrated *in vacuo* and the residue dissolved in 50 ml. of methylene chloride. Hydrogen sulfide was used to remove the remaining silver ions, the silver sulfide being filtered off on a pad of decolorizing carbon. Evaporation *in vacuo* afforded a sirup which was dissolved in ca. 25 ml. of methylene chloride and washed with saturated aqueous sodium bicarbonate (2 × 25 ml.) and with water (2 × 25 ml.). Moisture was removed with sodium sulfate and the solution concentrated to a brown sirup (4.42 g.) which was dissolved in 15 ml. of ether and seeded with 1,5-di-O-benzoyl-2-deoxy- $\beta$ -D-ribose.<sup>11</sup> After standing overnight at +5° the crude product (0.75 g.) was removed and recrystallized from ether-pentane to give 0.60 g. (13%) of 1,5-di-O-benzoyl-2-deoxy- $\beta$ -D-ribose as thick needles melting at 109–112°. After two further recrystallizations from ether the product melted at 108–111° and showed  $[\alpha]^{20D} -17.6^\circ$  (CHCl<sub>3</sub>, *c* 0.60).

*Anal.* Calcd. for C<sub>19</sub>H<sub>18</sub>O<sub>6</sub>: C, 66.66; H, 5.30. Found: C, 66.59; H, 5.30.

The original mother liquor from the above preparation was concentrated to dryness, dissolved in benzene-ether (1:1) and adsorbed on 50 g. of acid-washed Alorco alumina. Elution with benzene-ether (1:1, 150 ml.) gave 212 mg. of sirupy material which was discarded. Elution with 650 ml. of ether afforded 1.356 g. of sirup which crystallized spontaneously. Recrystallized from a mixture of 15 ml. of ether and 15 ml. of pentane it gave 1.15 g. (25%) of pure 1,5-di-O-benzoyl-2-deoxy- $\alpha$ -D-ribose as flat needles melting at 89–90°. Two recrystallizations from ether-pentane failed to change this value. The ester showed  $[\alpha]^{20D} +44.5^\circ$  (CHCl<sub>3</sub>, *c* 0.65).

*Anal.* Calcd. for C<sub>19</sub>H<sub>18</sub>O<sub>6</sub>: C, 66.66; H, 5.30. Found: C, 66.70; H, 5.47.

**1,3,5-Tri-O-benzoyl-2-deoxy- $\alpha$ -D-ribose (XV) from 1,5-Di-O-benzoyl-2-deoxy- $\alpha$ -D-ribose (XII).**—1,5-Di-O-benzoyl-2-deoxy- $\alpha$ -D-ribose (100 mg.) was added to a cold mixture of benzoyl chloride (0.1 ml.) and pyridine (2 ml.) and the whole kept at room temperature overnight. The excess of benzoyl chloride was destroyed with a few drops of water and, 30 min. later, 15 ml. of methylene chloride was added. The solution was washed successively with 3 *N* sulfuric acid (3 × 10 ml.), saturated aqueous sodium bicarbonate (2 × 10 ml.) and water (2 × 10 ml.). Moisture was removed with sodium sulfate, the solution filtered through decolorizing carbon and then concentrated *in vacuo* to yield a sirup. From ether-pentane 1,3,5-tri-O-benzoyl-2-deoxy- $\alpha$ -D-ribose (95 mg., 73%), melting at 110–112° and rotating +75.3° (CHCl<sub>3</sub>, *c* 0.38), was obtained as fine needles. Two recrystallizations from ether-pentane failed to alter these values. Zinner and Nimz<sup>6</sup> reported a 1,3,5-tri-O-benzoyl-2-deoxy- $\alpha$ -D-ribose melting at 111–111.5° and rotating  $[\alpha]^{15D} +78.0^\circ$  in chloroform (*c* 1.52).

*Anal.* Calcd. for C<sub>26</sub>H<sub>22</sub>O<sub>7</sub>: C, 69.94; H, 4.97. Found: C, 70.12; H, 5.07.

**1,3,5-Tri-O-benzoyl-2-deoxy- $\beta$ -D-ribose (XVI) from 1,5-Di-O-benzoyl-2-deoxy- $\beta$ -D-ribose (XIV).**—1,5-Di-O-benzoyl-2-deoxy- $\beta$ -D-ribose (300 mg.) was benzoylated in a fashion similar to that described for its anomer to give, from ether-pentane, needles (343 mg., 88%) melting at 84–87° and rotating  $[\alpha]^{20D} -20.0^\circ$  in chloroform (*c* 1.09). After two recrystallizations from ether-pentane the melting point was unchanged and the rotation was  $[\alpha]^{20D} -19.8^\circ$  in chloroform (*c* 1.15).

(11) Seed crystals were obtained through flowing chromatography on alumina of the crude product from a preliminary preparation.

Anal. Calcd. for  $C_{26}H_{42}O_7$ : C, 69.94; H, 4.97. Found: C, 69.76; H, 5.11.

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## The Isolation of an Octulose and an Octitol from Natural Sources: D-glycero-D-manno-Octulose and D-erythro-D-galacto-Octitol from the Avocado and D-glycero-D-manno-Octulose from *Sedum* Species<sup>1,2</sup>

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From the avocado, a long-known source of D-manno-heptulose and perseitol (D-glycero-D-galacto-heptitol), we have isolated small amounts of D-glycero-D-manno-octulose and D-erythro-D-galacto-octitol, and have obtained strong evidence for the presence also of D-talo-heptulose. From *Sedum* species, a well-known source of sedoheptulose (D-althro-heptulose), we have isolated small amounts of the same D-glycero-D-manno-octulose and also of  $\beta$ -sedoheptitol (D-glycero-D-gluco-heptitol). We have established the structures of the first known naturally occurring octulose and octitol by degradation studies and by the cyanohydrin synthesis from D-glycero-D-manno-heptose.

Nature has given us two heptitols and two heptuloses that have been known for a long time: perseitol (D-glycero-D-galacto-heptitol, I) from the avocado<sup>4</sup>; volemitol (D-glycero-D-manno-heptitol, III), discovered in the mushroom *Lactarius volemus* Fr.<sup>5</sup> and found later in the roots of several species of *Primula*,<sup>6</sup> in lichens,<sup>7</sup> and in brown and red algae<sup>8</sup>; D-manno-heptulose (II) from the avocado<sup>9</sup>; and sedoheptulose (D-althro-heptulose, IV), discovered in *Sedum spectabile* Bor.<sup>10</sup> and in other *Sedum* species, where it accumulates to the extent of about 1%, and found later to be widely distributed in nature (though usually in very small amounts) and to be a fundamental factor in plant and animal metabolism.<sup>11</sup> Thus, perseitol (I) and D-manno-heptulose (II) occur together in the avocado, and, in 1951, Nordal and Öiseth<sup>12</sup> isolated both volemitol (III) and sedoheptulose (IV), the latter being identified as the crystalline di-O-benzylidene derivative of sedoheptulosan, from the dried root stock of *Primula elatior* (L) Hill. We wish to announce that a third naturally occurring combination of heptitol and heptulose has now been established by our discovery that  $\beta$ -sedoheptitol (D-glycero-D-gluco-heptitol, V) accompanies sedo-

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(2) A preliminary communication appeared in THIS JOURNAL, **81**, 1512 (1959).

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