

Anal. Calcd. for $C_{11}H_{13}NO_3$: C, 63.75; H, 6.32; N, 6.76. Found: C, 63.72; H, 6.25; N, 6.85.

Stability of *cis*-Stilbene Oxide.—*cis*-Stilbene³⁴ (n_D^{25} 1.6185, lit.³⁴ n_D^{25} 1.6183) was oxidized to *cis*-stilbene oxide according to the procedure of Curtin and Kellom³⁵ except that peracetic acid³⁶ was used in place of the perbenzoic acid. The epoxide crystallized from 70% aqueous ethanol as a colorless mass, m.p. 37.5–38° (lit.³⁵ m.p. 37–37.5°).

(34) R. E. Buckles and N. G. Wheeler, *Org. Syn.*, **33**, 88 (1953).

(35) D. Y. Curtin and D. B. Kellom, *J. Am. Chem. Soc.*, **75**, 6011 (1953).

(36) F. G. Greenspan, *ibid.*, **68**, 907 (1946).

To a solution of 0.78 g. (4 mmoles) of *cis*-stilbene oxide in 35 ml. of anhydrous THF cooled to -70° under a blanket of nitrogen was added 2 mmoles of a hexane solution of butyllithium. The solution was stirred for 2 hr. at -70° , warmed to room temperature over 2 hr., then stirred for an additional hour before being poured into 100 ml. of water. Extraction with ether and chromatography of the organic products afforded, using a 1:1 benzene-hexane eluent, 0.76 g. (97%) of crude *cis*-stilbene oxide which crystallized from 70% aqueous ethanol, m.p. 37–38°, and was identified by its infrared spectrum and mixture melting point.

Repetition of the above reaction using 1.0 g. (5.1 mmoles) of *cis*-stilbene oxide and 5.1 mmoles of butyllithium solution led to the recovery of 0.88 g. (88%) of *cis*-stilbene oxide.

[CONTRIBUTION FROM THE NATIONAL INSTITUTE OF ARTHRITIS AND METABOLIC DISEASES, NATIONAL INSTITUTES OF HEALTH, BETHESDA 14, MD.]

The Structure of 2,3,4,6-Tetra-*O*-acetyl- β -D-galactopyranosyl Cyanide and Some Derivatives Therefrom. Synthesis of 1-Deoxy-D-galacto-heptulose

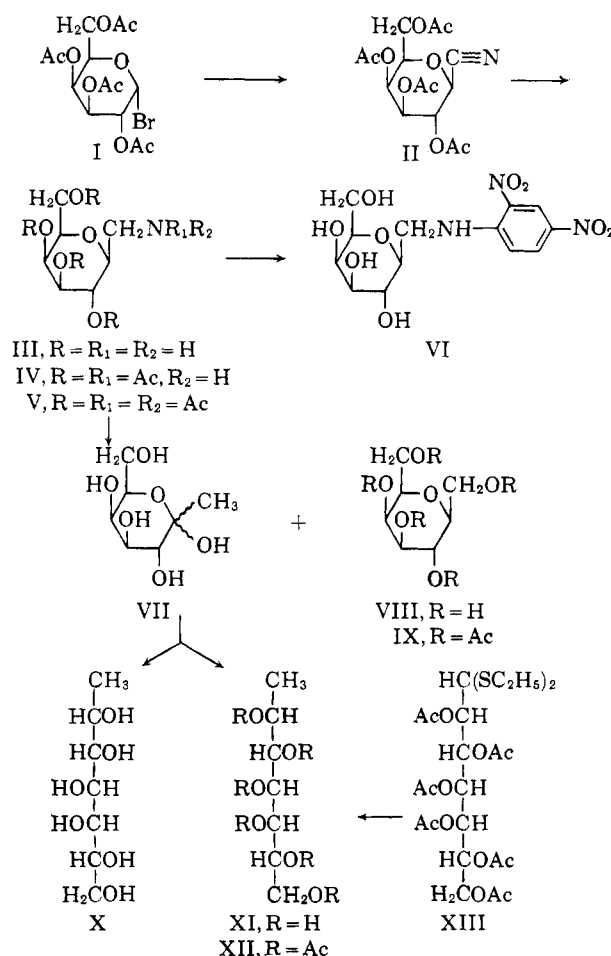
BY BRUCE COXON AND HEWITT G. FLETCHER, JR.

RECEIVED SEPTEMBER 6, 1963

Reduction of 2,3,4,6-tetra-*O*-acetyl- β -D-galactopyranosyl cyanide with lithium aluminum hydride has led to the isolation of 1-amino-2,6-anhydro-1-deoxy-D-glycero-L-manno-heptitol. Deamination of this amine with nitrous acid gives two substances. One of these is an anhydroheptitol which periodate oxidation studies have shown to be 2,6-anhydro-D-glycero-L-manno-heptitol. The structure of this anhydride confirms the structure assigned to the parent cyanide. The second product from the deamination is a reducing sugar which was isolated as its 2,5-dichlorophenylhydrazone. Reduction of the sugar with sodium borohydride affords a mixture of 1-deoxy-D-glycero-L-manno-heptitol and 1-deoxy-D-glycero-L-gulo-heptitol; the sugar is, therefore, 1-deoxy-D-galacto-heptulose. The mechanism of the formation of this 1-deoxyheptulose from 1-amino-2,6-anhydro-1-deoxy-D-glycero-L-manno-heptitol is discussed.

It has recently been shown¹ that condensation of 2,3,4,6-tetra-*O*-acetyl- α -D-glucopyranosyl bromide with mercuric cyanide in nitromethane solution results in the formation of 2,3,4,6-tetra-*O*-acetyl- β -D-glucopyranosyl cyanide in 12% yield and of 3,4,6-tri-*O*-acetyl-1,2-*O*-(1-cyanoethylidene)- α -D-glucopyranose in 11.5% yield. Under similar conditions 2,3,4,6-tetra-*O*-acetyl- α -D-galactopyranosyl bromide (I) has been reported^{2–4} to yield only one product; the presence of four alkalisaponifiable ester groups and the presumed mechanism of the condensation is the basis for the assumption that the substance is 2,3,4,6-tetra-*O*-acetyl- β -D-galactopyranosyl cyanide (II). We have now repeated this condensation and obtained a substance whose physical properties agree with those reported by the earlier authors.^{2,3} Particularly noteworthy is the marked contrast here between the glucose and the galactose series; in the latter, only one product was isolated and this in 83% yield. We wish now to report an investigation of the structure and configuration of this nitrile.

Reduction of the presumed 2,3,4,6-tetra-*O*-acetyl- β -D-galactopyranosyl cyanide (II) with lithium aluminum hydride afforded a crystalline product with the elementary composition of an amino-anhydro-deoxyheptitol. The substance was further characterized through the preparation of a variety of crystalline derivatives: the hydrochloride, a salt with *p*-toluenesulfonic acid, an *N*-2,4-dinitrophenyl derivative, a pentaacetyl, and a hexaacetyl derivative. Periodate oxidation of the *N*-2,4-dinitrophenyl derivative indicated the presence of a 2,6-anhydro-ring; the optical rotation of the oxidized solution was quite close to that obtained in a parallel experiment with 2,6-anhydro-1-deoxy-1-(2,4-dinitrophenylamino)-D-glycero-D-gulo-heptitol,¹ suggesting that the two substances had identical configurations at C-2 and C-6.



However, the amino-anhydro-deoxyheptitol, in agreement with the results obtained previously¹ for the periodate oxidation of 1-amino-2,6-anhydro-1-deoxy-D-glycero-D-gulo-heptitol, underwent an anomalous

(1) B. Coxon and H. G. Fletcher, Jr., *J. Am. Chem. Soc.*, **85**, 2637 (1963).

(2) N. Constantzas and J. Kocourek, *Chem. Listy*, **52**, 1629 (1958); *Collection Czech. Chem. Commun.*, **24**, 1099 (1959).

(3) B. Helferich and K. L. Bettin, *Chem. Ber.*, **94**, 1159 (1961).

(4) J. Kocourek, *ibid.*, **94**, 3346 (1961).

lous overoxidation with periodate, and the results obtained were not characteristic of the 2,6-anhydro ring structure.

Hough and Shute⁵ have described the dehydration of 1-deoxy-1-nitro-D-glycero-L-manno-heptitol to a substance which they designated as β -D-galactopyranosyl-nitromethane (2,6-anhydro-1-deoxy-1-nitro-D-glycero-L-manno-heptitol) on the basis of its rotation and behavior with periodate. They also reduced this anhydride to a primary amine⁶ which they isolated as a salt of *p*-toluenesulfonic acid. A sample of this product, kindly provided by Dr. Hough, was found to be identical with the corresponding salt of our amino-anhydro-deoxy-heptitol.

Treated with aqueous nitrous acid, the amine gave a product which reduced Fehling solution; paper chromatography showed the presence of two major components. With 2,5-dichlorophenylhydrazine, the mixture yielded a crystalline deoxyheptose 2,5-dichlorophenylhydrazone while the mother liquor gave a crystalline anhydroheptitol which was further characterized through the preparation of its pentaacetate. The anhydroheptitol reduced two molar equivalents of periodate, liberating one molar equivalent of formic acid with complete loss of optical activity. These facts point unequivocally to structure VIII, 2,6-anhydro-D-glycero-L-manno-heptitol, and confirm the β -configuration of the 2,3,4,6-tetra-*O*-acetyl-D-galactopyranosyl cyanide (II) since the α -anomer of II would have given an epimer of VIII which would have retained optical activity on periodate oxidation. It is appropriate to note that II may with equal propriety be designated as 3,4,5,7-tetra-*O*-acetyl-2,6-anhydro-D-glycero-L-manno-heptononitrile.

Attention was now turned to the deoxyheptose which had been isolated as its 2,5-dichlorophenylhydrazone. The free sugar was readily obtained in sirupy form by scission of the 2,5-dichlorophenylhydrazone moiety with hot aqueous acetaldehyde. Reduction of the deoxyheptose with sodium borohydride led to the isolation of two deoxyheptitols. One of these proved to be 1-deoxy-D-glycero-L-manno-heptitol (X), a substance first prepared by Fischer and Piloty⁷ from L-rhamnose. The second was found to be 1-deoxy-D-glycero-L-gluco-heptitol (XI); an authentic sample was synthesized from 2,3,4,5,6,7-hexa-*O*-acetyl-D-glycero-L-gluco-heptose diethyl dithioacetal (XIII)⁸ by Raney nickel reductive desulfurization and subsequent deacetylation.

The isolation of the two 1-deoxyheptitols (X and XI), epimeric at C-2, unequivocally demonstrates that the deoxyheptose is 1-deoxy-D-galacto-heptulose (VII). The pentaacetate of the *keto*-form of this sugar has been described by Wolfrom and Brown.⁹

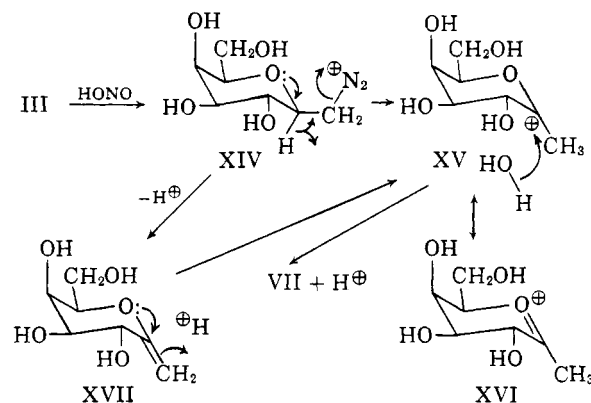
Discussion

As expected, the major product of the deamination of 1-amino-2,6-anhydro-1-deoxy-D-glycero-L-manno-heptitol (III) with aqueous nitrous acid was the anhydroheptitol VIII, formed no doubt by direct substitution of the intermediate diazonium ion XIV by hydroxyl.

With regard to the formation of 1-deoxy-D-galacto-heptulose (VII), however, two alternative mechanisms appear to be possible. In theory at least, because of free rotation about the C-1-C-2 bond of the diazonium ion XIV, either the ring oxygen, or C-3, or the hydrogen

atom at C-2, could adopt a *trans*-antiparallel orientation with respect to the departing nitrogen function.

In this case, the latter possibility seems to be preferred. Rearrangement of the diazonium ion XIV by hydride transfer from C-2 to C-1, assisted by the ring oxygen, would give the carbonium ion XV, stabilization of which is possible by resonance with the oxonium ion XVI. Streitwieser¹⁰ has commented that a 1,2-hydride shift apparently only takes place to an important extent when the resulting carbonium ion is more stable than that which would arise by elimination of nitrogen without rearrangement. Reaction of XV with a water molecule would then yield the 1-deoxy-heptulose (VII).



Alternatively, elimination of the proton from C-2 of the diazonium ion XIV would give rise to the vinyl ether XVII which under the somewhat acidic conditions of the reaction might be expected to suffer addition of a water molecule to the double bond *via* the carbonium ion XV, the direction of the reaction being controlled by the electromeric effect of the ring oxygen.

One might expect that the two alternative pathways (XIV → XV → VII and XIV → XVII → XV → VII) would be readily distinguishable through deamination in a deuterated solvent, deuterium being incorporated if XVII an intermediate but not incorporated if the conversion proceeds *via* a hydride shift. The deamination was, therefore, carried out using 20% CH₃-CO₂D in D₂O. Mass spectrometric analysis of the water from the combustion of the total product revealed the presence of 0.3 ± 0.1% of deuterium. Assuming a yield of 25% of the 1-deoxyheptulose (VII) and 100% incorporation in it of one atom of deuterium from the solvent, a deuterium content of 1.8% would be expected in the water from the combustion of the total deamination product. The results obtained suggest that both mechanisms may be operative. However, such a conclusion must be regarded with extreme reservation in view of the experimental difficulties involved. For instance, the possibility of the exchange of the protons α to the carbonyl group in the ketose VII under the conditions of the reaction cannot at present be excluded. The question of the two alternative pathways must, therefore, remain an open one.

Experimental¹¹

2,3,4,6-Tetra-*O*-acetyl- β -D-galactopyranosyl Cyanide (II).—Reaction of 2,3,4,6-tetra-*O*-acetyl- α -D-galactopyranosyl bromide (I) with mercuric cyanide in nitromethane solution according to the procedure of Helferich and Bettin³ gave 2,3,4,6-tetra-*O*-

(5) L. Hough and S. H. Shute, *J. Chem. Soc.*, 4633 (1962).

(6) Drs. Hough and Shute inform us that they have also observed the overoxidation of this substance by periodate.

(7) E. Fischer and O. Piloty, *Ber.*, **23**, 3102 (1890); E. Fischer, *ibid.*, **23**, 3827 (1890).

(8) R. M. Hann and C. S. Hudson, *J. Am. Chem. Soc.*, **56**, 2080 (1934).

(9) M. L. Wolfrom and R. L. Brown, *ibid.*, **65**, 1516 (1943).

(10) A. Streitwieser, *J. Org. Chem.*, **22**, 861 (1957).

(11) Melting points are corrected. All evaporations and drying procedures were carried out at reduced pressure. Specific rotations in acidified ammonium molybdate solution were measured using the technique of N. K. Richtmyer and C. S. Hudson [*J. Am. Chem. Soc.*, **73**, 2249 (1951)] on a reduced scale (total volume of 5 ml.).

Selected absorption maxima of the infrared spectra are given with prob-

acetyl- β -D-galactopyranosyl cyanide in 83% yield, m.p. 166–167°, $[\alpha]^{20}_D + 37.8^\circ$ (CHCl_3 , c 0.98). Recrystallized from boiling ethanol and then from methanol, the pure nitrile was obtained as irregular hexagonal prisms, m.p. 169° and $[\alpha]^{20}_D + 36.4^\circ$ (CHCl_3 , c 1.95). Constantzas and Kocourek² as well as Helferich and Bettin³ reported m.p. 168–169° and $[\alpha]^{20}_D + 37.2^\circ$ (CHCl_3) for this substance. The substance shows $\nu_{\text{max}}^{\text{Nujol}}$ (cm^{-1}) 1760 s (OAc) but no absorption in the 2000–2300 cm^{-1} region, the $\text{C}\equiv\text{N}$ absorption being quenched.¹²

Anal. Calcd. for $\text{C}_{15}\text{H}_{19}\text{NO}_9$ (357.31): C, 50.42; H, 5.36; N, 3.92; Ac, 48.2. Found: C, 50.49; H, 5.43; N, 4.21; Ac, 47.9.

1-Amino-2,6-anhydro-1-deoxy-D-glycero-L-manno-heptitol (III).—A solution of 2.4 g. of 2,3,4,6-tetra-O-acetyl- β -D-galactopyranosyl cyanide in 100 ml. of dry tetrahydrofuran was added dropwise at a rapid rate to a stirred suspension of 1.6 g. of lithium aluminum hydride in 25 ml. of dry tetrahydrofuran. The reaction mixture was boiled for 0.25 hr. under reflux and then ethanol was cautiously added until the excess of hydride was decomposed. Water was added, followed by concentrated ammonium hydroxide (d 0.9, 40 ml.) and Filter-Cel (previously washed with water, 5 N ammonium hydroxide, and ethanol); the mixture was then stirred and filtered through a thin layer of Filter-Cel (washed as described above). The solid was washed with 300 ml. of 5 N ammonium hydroxide and the combined filtrate and washings were concentrated to a volume of 120 ml. Lithium was found to be present (flame test) and so the solution was passed down a column (2.5×18 cm.) of Amberlite IR-120 (H). The resin was washed with ca. 2 l. of water and the product then rapidly eluted with 2 l. of 0.5 N ammonium hydroxide. Concentration of the eluate afforded a pale yellow sirup which crystallized during two distillations with absolute ethanol. The solid was extracted with 6×60 -ml. portions of boiling absolute ethanol and the hot extracts were filtered through Filter-Cel. On concentration and cooling to -5° the solution gave colorless clusters of rods: 0.913 g. (70%), m.p. 189–191° dec. (with preliminary sintering). A second crop, 0.108 g. (8%), m.p. 185–188° dec., was obtained. Recrystallization of the first crop from methanol and then twice from aqueous ethanol gave the pure amino alcohol as fine needles: m.p. 191–192° dec. (with preliminary sintering; varied with rate of heating), $[\alpha]^{20}_D + 30.0^\circ$ (water, c 1.61). The substance was chromatographed on paper using system A and visualized with periodate-silver nitrate or ninhydrin (purple spot): R_f 0.46; infrared spectrum: $\nu_{\text{max}}^{\text{Nujol}}$ (cm^{-1}) 3410–3280 s (OH and NH), 1620 m (NH_2), 1600 w.

Anal. Calcd. for $\text{C}_7\text{H}_{15}\text{NO}_5$ (193.20): C, 43.51; H, 7.83; N, 7.25. Found: C, 43.76; H, 7.80; N, 7.16.

A solution of 0.288 g. of 1-amino-2,6-anhydro-1-deoxy-D-glycero-L-manno-heptitol in 3 ml. of 1.01 N hydrochloric acid was diluted with 50 ml. of absolute ethanol and then evaporated to a thin sirup which crystallized as clusters of needles. The solid mass was dried by two distillations with absolute ethanol and then recrystallized from methanol-ethanol to give **III hydrochloride** as long colorless prisms: 0.246 g. (72%), m.p. 210–211°. Recrystallized from aqueous ethanol and then from methanol, the salt had m.p. 211° and $[\alpha]^{20}_D + 31.3^\circ$ (water, c 0.53); infrared spectrum: $\nu_{\text{max}}^{\text{Nujol}}$ (cm^{-1}) 3230 s (OH and NH), 1598 s, and 1518 s (NH_3^+).

Anal. Calcd. for $\text{C}_7\text{H}_{16}\text{ClNO}_5$ (229.67): C, 36.60; H, 7.02; Cl, 15.44; N, 6.10. Found: C, 36.87; H, 7.20; Cl, 15.27; N, 6.38.

A solution containing 0.403 g. of 1-amino-2,6-anhydro-1-deoxy-D-glycero-L-manno-heptitol and 0.397 g. of *p*-toluenesulfonic acid monohydrate in 5 ml. of water was evaporated three times with absolute ethanol to give a sirup which, crystallized from ethanol-ether, afforded the *p*-toluenesulfonic acid salt of **III** as colorless rosettes: 0.531 g. (70%), m.p. 143–144°, $[\alpha]^{20}_D + 19.2^\circ$ (water, c 2.2). Recrystallization from isopropyl alcohol-ether and then from ethanol-ether gave the pure salt: 0.41 g., m.p. 143–144°, $[\alpha]^{20}_D + 20.0^\circ$ (water, c 2.19). Hough and Shute⁵ reported m.p. 141–143° and $[\alpha]^{20}_D + 19.7^\circ$ (water, c 1.5); admixture of the material prepared as described above with a sample kindly provided by Dr. Hough gave m.p. 141–143°; infrared spectrum: $\nu_{\text{max}}^{\text{Nujol}}$ (cm^{-1}) 3450 (shoulder) and 3320 s (OH and NH), 1640 m and 1540 m (NH_3^+), 1600 w and 1497-w (Ar). The

able assignments, intensities being indicated as s (strong), m (medium), and w (weak); Ar designates an aromatic residue.

Paper chromatography was carried out using the descending method with either system A (ethyl acetate-acetic acid-water, 9:2:2 (v./v./v.)) or system B (1-butanol-pyridine-water, 10:3:3 (v./v./v.)).

N.m.r. spectra were determined on either a Varian A-60 or V-4302 spectrometer and refer to ca. 0.7 M solutions in chloroform unless otherwise specified, tetramethylsilane being used as an internal standard at 10.0 p.p.m.; τ -values for selected proton resonances are given with probable assignments.

(12) L. J. Bellamy, "The Infra-red Spectra of Complex Molecules," Methuen & Co., Ltd., London, 1956, p. 225.

spectrum was identical with that of the specimen provided by Dr. Hough.

Anal. Calcd. for $\text{C}_{14}\text{H}_{23}\text{NO}_5\text{S}$ (365.39): C, 46.02; H, 6.34; N, 3.83; S, 8.77. Found: C, 45.88; H, 6.62; N, 3.80; S, 8.47.

2,6-Anhydro-1-deoxy-1-(2,4-dinitrophenylamino)-D-glycero-L-manno-heptitol (VI).—Powdered calcium carbonate (10 g.) was added to a stirred solution of 0.818 g. of 1-amino-2,6-anhydro-1-deoxy-D-glycero-L-manno-heptitol in 50 ml. of water and 0.789 g. of 2,4-dinitrofluorobenzene (one molecular equivalent with respect to the amine) was washed into the stirred mixture with 50 ml. of ethanol. After being stirred at room temperature for 27 hr., the mixture was filtered through a layer of Filter-Cel, the solid being washed with ethanol until the washings were colorless. Concentration of the combined filtrate and washings gave a bright yellow sirup which crystallized from aqueous ethanol as sheaves of long, fine, bright yellow needles. Recrystallization from ethanol at -5° yielded the nearly pure derivative: 1.46 g. (96%), m.p. 162–164°. After two further recrystallizations from ethanol, the product was obtained as bright yellow needles of m.p. 163–164° which showed $[\alpha]^{20}_D - 10^\circ$ (acetone, c 1.09) and $[\alpha]^{20}_D + 12^\circ$ (20% v./v. dioxane-water, c 0.82).

Anal. Calcd. for $\text{C}_{13}\text{H}_{17}\text{N}_3\text{O}_9$ (359.29): C, 43.46; H, 4.77; N, 11.70. Found: C, 43.61; H, 5.02; N, 11.62.

A sample of VI was dried at 75–80° for 48 hr. and 40.4 mg. then made up to 5.0 ml. with a solution prepared from 596 mg. of sodium metaperiodate in 50 ml. of 20% (v./v.) dioxane in water. In a 2-dm. polarimeter tube the optical rotation, α^{20}_D , of the solution decreased from -0.67° (3 min.) to -0.42° (79 hr.) at which point a 4.0-ml. aliquot was removed and diluted to 5.0 ml. with 20% aqueous dioxane (v./v.) which was 1 N in sulfuric acid. The optical rotation of the solution then decreased further from -0.34° (80 hr.) to -0.32° (95 hr., constant).

In a parallel experiment, the same quantity of 2,6-anhydro-1-deoxy-1-(2,4-dinitrophenylamino)-D-glycero-D-gulo-heptitol¹ mutarotated from -0.22° (3 min.) to -0.34° (2 hr., constant); upon acidification as described above, the solution showed -0.28° (28.5 hr.) and -0.30° (43.5 hr., constant).

1-Acetamido-3,4,5,7-tetra-O-acetyl-2,6-anhydro-1-deoxy-D-glycero-L-manno-heptitol (IV).—Acetylation of 1-amino-2,6-anhydro-1-deoxy-D-glycero-L-manno-heptitol (902 mg.) with acetic anhydride in pyridine solution at room temperature gave a pale yellow sirup which, from ether containing a little ethanol, yielded 1.443 g. (77%) of fine needles melting at 153–154°. Recrystallized from ethanol-ether and then from ether containing a little dichloromethane, the pentaacetyl derivative melted at 153–154° and showed $[\alpha]^{20}_D + 1.3^\circ$ (CHCl_3 , c 1.03); infrared spectrum: $\nu_{\text{max}}^{\text{Nujol}}$ (cm^{-1}) 3190 m and 1573 s (NH), 1744 s (OAc), 1640 s (NAC); n.m.r. data: τ 8.04, 8.02, 7.96, 7.94, and 7.86 (NAC and OAc). The substance was surprisingly soluble in water. A sample was dried at 100° for analysis.

Anal. Calcd. for $\text{C}_{17}\text{H}_{25}\text{NO}_{10}$ (403.38): C, 50.61; H, 6.25; N, 3.47; OAc, 42.68; total Ac, 53.35. Found: C, 50.80; H, 6.39; N, 3.44; OAc, 44.24; total Ac, 53.35.

Di-N-acetyl-3,4,5,7-tetra-O-acetyl-1-amino-2,6-anhydro-1-deoxy-D-glycero-L-manno-heptitol (V).—A mixture of 1.03 g. of 1-amino-2,6-anhydro-1-deoxy-D-glycero-L-manno-heptitol, 25 ml. of redistilled acetic anhydride, and 1 g. of powdered anhydrous sodium acetate was boiled under reflux for 2 hr., cooled, and poured into a mixture of ice-water and sodium bicarbonate. Extraction with 3×75 ml. of chloroform, followed by washing of the combined extracts twice with water and then concentration, gave a sirup which crystallized spontaneously. After decolorization in hot ethanolic solution with Darco X, the product was crystallized from isopropyl alcohol at -5° as clusters of plates: 1.86 g. (78%), m.p. 156–160° (with preliminary sintering). Recrystallization from isopropyl alcohol and then from aqueous ethanol gave the pure **hexaacetyl derivative** as a mixture of rectangular prisms and striated plates, m.p. 162° (after preliminary sintering), $[\alpha]^{20}_D - 40.4^\circ$ (CHCl_3 , c 1.19); infrared spectrum: $\nu_{\text{max}}^{\text{Nujol}}$ (cm^{-1}) 1745 s (OAc), 1712 s, and 1694 s [$\text{N}(\text{Ac})_2$]; no absorption was present in those parts of the spectrum normally associated with NH: n.m.r. data: τ 8.03, 7.98, 7.89, and 7.87 (OAc), 7.61 (x2) [$\text{N}(\text{Ac})_2$]. The analytical sample was dried at 100°.

Anal. Calcd. for $\text{C}_{19}\text{H}_{27}\text{NO}_{11}$ (445.42): C, 51.23; H, 6.11; N, 3.15; OAc, 38.66; total Ac, 57.99. Found: C, 51.26; H, 6.34; N, 3.32; OAc, 37.62; total Ac, 57.87.

Treatment of 1-acetamido-3,4,5,7-tetra-O-acetyl-2,6-anhydro-1-deoxy-D-glycero-L-manno-heptitol (207 mg.) with acetic anhydride and sodium acetate in the manner described above afforded 172 mg. (75%) of crystalline product which was recrystallized from isopropyl alcohol and then from aqueous ethanol: m.p. 161–162°, $[\alpha]^{20}_D - 40.8^\circ$ (CHCl_3 , c 0.97). The infrared spectrum of the product was identical with that of the hexaacetyl derivative made from **III**; a mixture m.p. was undepressed.

Deamination of 1-Amino-2,6-anhydro-1-deoxy-D-glycero-L-manno-heptitol (III).—A solution containing 8.02 g. of 1-amino-

2,6-anhydro-1-deoxy-D-glycero-L-manno-heptitol and 8.6 g. of sodium nitrite in 220 ml. of ice-cold 20% acetic acid was kept at 0° for 1 hr. and then at room temperature for 5 hr. The pale yellow solution was then deionized by stirring with a mixture of Amberlite IR-120(H) and IR-45(OH). After filtration, the solution was evaporated to a thin sirup from which toluene was distilled several times to remove residual acetic acid and water. Dried at 60°, the pale-yellow sirup (8.06 g.) reduced hot Fehling solution and displayed ν_{\max}^{film} (cm.⁻¹) 3400 s (OH), 1710 w (C=O), and 1550 w. Paper chromatography in system A (periodate-silver nitrate spray) revealed that the sirup contained at least three components which had R_{glucose} 2.6 (minor amount), 1.6, and 1.3. A mixture of 4.91 g. of the sirupy product, 5.01 g. of 2,5-dichlorophenylhydrazine, and 30 ml. of methanol was boiled on the steam bath almost to dryness. The light brown sirup was diluted with a further 30 ml. of methanol and the process repeated (total time of heating 0.75 hr.). Trituration of the sirup with 75 ml. of ether gave a hard, solid mass which was broken up, the brown supernatant solution being discarded. The solid was extracted six times further with 75-ml. portions of ether to give a flocculent white material which was then extracted with 370 ml. of water. The residue was filtered off, washed with water, and recrystallized from aqueous methanol; the ether-washed, needle-like crystals of 1-deoxy-D-galacto-heptulose 2,5-dichlorophenylhydrazone (2.06 g., 23% based on III) showed m.p. 185° dec. Recrystallization from aqueous methanol gave 1.93 g. of very fine long needles, m.p. 186.5° dec., unchanged by further recrystallization. In dry pyridine (c 2.07) the substance showed $[\alpha]^{20}_{\text{D}} - 22.6^\circ$ (3 min.) $\rightarrow -20.1^\circ$ (24 hr.) $\rightarrow -16.7^\circ$ (48 hr.) $\rightarrow -13.1^\circ$ (72 hr.) with the production of a light brown color; infrared spectrum: ν_{\max}^{NaCl} (cm.⁻¹) 3450 m (shoulder), 3410 s, 3320 s, and 3125 m (shoulder) (OH and NH); 1602 s and 1510 m (Ar). The n.m.r. spectrum of a solution in pyridine displayed a singlet at τ 7.81 (C-CH₃).

Anal. Calcd. for C₁₈H₁₈Cl₂N₂O₆ (353.20): C, 44.20; H, 5.14; Cl, 20.08; N, 7.93; C-CH₃, 7.66. Found: C, 44.39; H, 5.14; Cl, 19.91; N, 7.84; C-CH₃ (Kuhn-Roth), 8.11.

The aqueous extract from the crude 2,5-dichlorophenylhydrazone was deionized by passage through columns (2 \times 11 cm.) of Amberlites IR-120(H) and IR-45(OH) and evaporated to a clear sirup (3.37 g.) which was dissolved in hot water and the solution diluted with acetone to incipient turbidity. At -5° the 2,6-anhydro-D-glycero-L-manno-heptitol (VIII) hemihydrate crystallized as rectangular plates: 2.51 g. (49%, based on III), m.p. 118-120° (with preliminary sintering), $[\alpha]^{20}_{\text{D}} + 32.8^\circ$ (water, c 2.17). Two recrystallizations from aqueous acetone gave a mixture of rhombohedral and hexagonal plates which was dried at 60°: m.p. 121-122°, $[\alpha]^{20}_{\text{D}} + 32.6^\circ$ (water, c 1.32); infrared spectrum: ν_{\max}^{NaCl} (cm.⁻¹) 3600 m and 3270 s (OH), 1650 m (H₂O). In system A the substance had R_{glucose} 1.3, periodate-silver nitrate spray being used.

Anal. Calcd. for C₇H₁₄O₆·1/2H₂O (203.19): C, 41.38; H, 7.44. Found: C, 41.60; H, 7.66. Drying at 120° overnight gave an anhydrous but partially melted solid.

Anal. Calcd. for C₇H₁₄O₆ (194.18): C, 43.29; H, 7.27. Found: C, 43.31; H, 7.36.

When 0.1013 g. of 2,6-anhydro-D-glycero-L-manno-heptitol hemihydrate was made up to a volume of 5.0 ml. with a solution prepared from 2.672 g. of sodium metaperiodate made up to 50 ml. with water, the optical rotation of the resulting solution in a 2-dm. polarimeter tube changed as: $\alpha^{20}_{\text{D}} + 1.21^\circ$ (4 min.) $\rightarrow +0.02^\circ$ (4.5 hr.) $\rightarrow +0.01^\circ$ (15.5 hr.) $\rightarrow \pm 0^\circ$ (22 hr., constant).

1,3,4,5,7-Penta-O-acetyl-2,6-anhydro-D-glycero-L-manno-heptitol (IX).—2,6-Anhydro-D-glycero-L-manno-heptitol hemihydrate (0.426 g.) was dried by azeotropic distillation of its hot ethanolic solution with benzene and then finally at 100° over silica gel. Acetylation with acetic anhydride-pyridine, followed by crystallization from water at 0° yielded 0.652 g. (77%) of 1,3,4,5,7-penta-O-acetyl-2,6-anhydro-D-glycero-L-manno-heptitol, m.p. 55-57°. Three recrystallizations from water failed to change the m.p.; the substance rotated $[\alpha]^{20}_{\text{D}} + 14.2^\circ$ (CHCl₃, c 1.04); infrared spectrum: ν_{\max}^{NaCl} (cm.⁻¹) 1740 s (OAc); n.m.r. data: τ 8.00, 7.94 (x2), 7.88, and 7.82 (OAc).

Anal. Calcd. for C₁₇H₂₄O₁₁ (404.36): C, 50.49; H, 5.98; Ac, 53.23. Found: C, 50.65; H, 6.05; Ac, 52.8.

1-Deoxy-D-galacto-heptulose (VII).—A solution of 1.846 g. of 1-deoxy-D-galacto-heptulose 2,5-dichlorophenylhydrazone in 140 ml. of 1:1 (v./v.) aqueous acetaldehyde was heated in a sealed bottle at 80-85° for 3 hr., cooled, diluted with 100 ml. of water, and partially concentrated (bath temperature, 30°) to remove the acetaldehyde. The aqueous solution was extracted with three 50-ml. portions of dichloromethane and then concentrated to a small volume which was deionized by passage through columns (2 \times 10 cm.) of Amberlites IR-120(H) and IR-45(OH); evaporation gave 1-deoxy-D-galacto-heptulose (0.917 g., 90%) as a pale yellow sirup which reduced hot Fehling solution and showed $[\alpha]^{20}_{\text{D}} + 65^\circ$ in water (c 0.85, no significant mutarotation). In

solvent system A the deoxyheptulose showed R_{glucose} 1.6 (yellow spots with *p*-anisidine hydrochloride and orcinol-hydrochloric acid sprays); infrared spectrum: ν_{\max}^{film} (cm.⁻¹) 3350 s, broad band (OH), and 1710 m (C=O). The n.m.r. spectrum of a deuterium oxide solution showed a singlet at τ 8.05 (C-CH₃) (tetramethylsilane as external reference).

Anal. Calcd. for C₇H₁₄O₆ (194.18): C-CH₃, 13.93. Found: C-CH₃, 12.75.

Reduction of 1-Deoxy-D-galacto-heptulose (VII) with Sodium Borohydride.—A solution of 0.40 g. of sirupy 1-deoxy-D-galacto-heptulose in 20 ml. of water was added dropwise over the course of 1.25 hr. to an ice-cold, stirred solution of 0.159 g. of sodium borohydride in 20 ml. of water, the solution being washed in with a further 10 ml. of water. After stirring at 0° for 2 hr., the mixture was allowed to warm gradually to room temperature; after a total of 19 hr. a Fehling test on a small, acidified portion of the reaction mixture was negative. Acetic acid (1 ml.) was added to the solution which was then deionized by stirring with Amberlite IR-120(H). Concentration of the filtered solution gave a semi-solid mass which was freed of boric acid by five distillations with absolute methanol. Crystallization of the residue from boiling ethanol yielded colorless clusters of needles of 1-deoxy-D-glycero-L-manno-heptitol (X): 0.177 g. (44%), m.p. 165-173° (with preliminary sintering). Two recrystallizations from ethanol gave pure material with m.p. 179-180° (preliminary sintering), $[\alpha]^{20}_{\text{D}} + 12.6^\circ$ in water (c 0.86) and $[\alpha]^{20}_{\text{D}} - 161^\circ$ in acidified ammonium molybdate (c 0.52). In solvent system B the substance showed R_f 0.39; infrared peak: ν_{\max}^{NaCl} (cm.⁻¹) 3270 s (OH).

Anal. Calcd. for C₇H₁₆O₆ (196.20): C, 42.85; H, 8.22; C-CH₃, 13.79. Found: C, 42.92; H, 8.30; C-CH₃ (Kuhn-Roth) 13.83.

A sample of 1-deoxy-D-glycero-L-manno-heptitol which had been prepared some years ago in this Laboratory by the late Dr. E. L. Jackson was recrystallized from aqueous ethanol: m.p. 179-181° (preliminary sintering), $[\alpha]^{20}_{\text{D}} + 12.8^\circ$ in water (c 2.47) and $[\alpha]^{20}_{\text{D}} - 164^\circ$ in acidified ammonium molybdate (c 0.51). This material migrated at the same rate in solvent system B as the deoxyheptitol prepared from VII; a mixture melting point showed no depression and their infrared spectra were identical. Fischer and Piloty⁷ reported m.p. 173° (after sintering at 170°) and $[\alpha]^{20}_{\text{D}} + 11.6^\circ$ in water for "rhamnohexitol"; Fischer⁷ later gave $[\alpha]^{20}_{\text{D}} + 14^\circ$ in water.

On concentration, the mother liquor from the sodium borohydride reduction yielded colorless rosettes (0.114 g., 28%) of 1-deoxy-D-glycero-L-gluco-heptitol (XI), m.p. 142-145° (preliminary sintering). After recrystallization from ethanol-ethyl acetate the material had m.p. 144-146° (preliminary sintering) and $[\alpha]^{20}_{\text{D}} - 2^\circ$ (water, c 1.88). Further recrystallization from ethanol-ethyl acetate and then from ethanol gave clusters of needles, m.p. 146-147° (after sintering) and $[\alpha]^{20}_{\text{D}} - 47^\circ$ in acidified ammonium molybdate (c 0.37). In solvent system B the substance had R_f 0.33. Its infrared spectrum was identical with that of an authentic sample, prepared as described later in this paper; a mixture melting point was undepressed.

The material XI in the acidified ammonium molybdate solution was recovered by deionization and combined with all of the mother liquors from the borohydride reduction (save those resulting from recrystallization of XI), and the solvent-free material (0.177 g.) acetylated with acetic anhydride and sodium acetate to give 0.347 g. of a solid which was recrystallized from ethanol. The 2,3,4,5,6,7-hexa-O-acetyl-1-deoxy-D-glycero-L-gluco-heptitol (XII) was in the form of clusters of lustrous plates: 0.211 g., m.p. 164-167° (sintering from 150°). Successive recrystallizations from ethanol-isopropyl ether containing a little dichloromethane and from ethanol-ether afforded the hexaacetate as brilliant rhombohedral plates (0.149 g.), m.p. 168-170° and $[\alpha]^{20}_{\text{D}} + 11.4^\circ$ (CHCl₃, c 1.87). A mixture melting point with authentic material, prepared as described later in this paper, was undepressed; the infrared spectra of the samples from the two sources were identical.

2,3,4,5,6,7-Hexa-O-acetyl-1-deoxy-D-glycero-L-gluco-heptitol (XII) from 2,3,4,5,6,7-Hexa-O-acetyl-D-glycero-L-gluco-heptose Diethyl Dithioacetal (XIII).—A mixture of 1.01 g. of 2,3,4,5,6,7-hexa-O-acetyl-D-glycero-L-gluco-heptose diethyl dithioacetal,⁸ approximately 10 g. of Raney nickel, and 50 ml. of ethanol was boiled under reflux for 3 hr. The supernatant liquid was decanted and the nickel extracted with 5 \times 50 ml. of boiling ethanol; filtration of the combined supernatant solution and extracts through Filter-Cel, followed by concentration and cooling of the pale green filtrate, gave 0.51 g. (64%) of 2,3,4,5,6,7-hexa-O-acetyl-1-deoxy-D-glycero-L-gluco-heptitol as lustrous rhombohedral plates, m.p. 158-161°. Successive recrystallization of the product, thrice from ethanol, from isopropyl ether-dichloromethane, isopropyl alcohol, and twice from ethanol-ether gave the pure ester with m.p. 168-170° (slight preliminary sintering) and $[\alpha]^{20}_{\text{D}} + 11.9^\circ$ (CHCl₃, c 0.79); infrared peak: ν_{\max}^{NaCl} (cm.⁻¹) 1738 s (OAc).

TABLE I
 PERIODATE OXIDATIONS

Compound		Time, hr.						
		0.25	0.75	1.5	3	7	24	48
1-Amino-2,6-anhydro-1-deoxy-D-glycero-L-manno-heptitol (III)	Uptake	3.02	3.47	3.74	3.98	4.21	4.51	4.86 ^a
	Acid	0.48	0.78	0.47	1.14	1.37	1.67	2.24 ^a
2,6-Anhydro-1-deoxy-1-(2,4-dinitrophenylamino)-D-glycero-L-manno-heptitol (VI)	Uptake	1.68	1.81	1.84	1.88	1.92	1.98	2.01
	Acid	0.59	0.72	0.78	0.80	0.82	0.87	0.89
2,6-Anhydro-D-glycero-L-manno-heptitol (VIII) hemihydrate	Uptake	1.59	1.70	1.80	1.90	1.98	2.00	2.01
	Acid	0.41	0.49	0.55	0.61	0.66	0.73	0.76

^a At 102 hr.

Anal. Calcd. for C₁₉H₂₈O₁₂ (448.41): C, 50.89; H, 6.29; Ac, 57.60. Found: C, 50.85; H, 6.52; Ac, 57.36.

1-Deoxy-D-glycero-L-gluco-heptitol (XI).—A sample (0.59 g.) of the hexaacetate XII was deacetylated with barium methoxide to give from ethanol 0.151 g. of clusters of needles, m.p. 138–149°. Repeated recrystallization of this material failed to remove a minor impurity (*R_f* 0.69 in solvent system A); the mixture was therefore chromatographed on a sheet of Whatman No. 31 paper (extra thick) in solvent system A. After deionization, the eluate was concentrated and the residue crystallized from ethanol as clusters of needles (0.156 g., 60%), m.p. 148–149° (preliminary sintering), unchanged by two recrystallizations from ethanol. The material showed $[\alpha]^{20}_D -2^\circ$ in water (*c* 2.94), $[\alpha]^{20}_D -45^\circ$ in acidified ammonium molybdate (*c* 0.38), and *R_f* 0.33 in system B; infrared peak: $\nu_{\text{max}}^{\text{NaCl}}$ (cm.⁻¹) 3285 s (OH).

Anal. Calcd. for C₇H₁₆O₆ (196.20): C, 42.85; H, 8.22; C-CH₃, 13.79. Found: C, 43.04; H, 8.17; C-CH₃ (Kuhn-Roth), 13.52.

The same substance was also made through the reductive desulfurization of D-glycero-L-gluco-heptose diethyl dithioacetal⁸ with Raney nickel.

Oxidations with Periodate.—Oxidations with sodium metaperiodate in unbuffered solution were carried out using conventional techniques; the results, expressed in moles of oxidant consumed and moles of formic acid produced per mole of substrate, are listed in Table I.

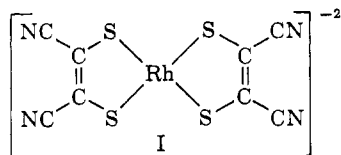
Acknowledgment.—We are indebted to Mr. Harry W. Diehl for the preparation of a quantity of 2,3,4,6-tetra-*O*-acetyl-β-D-galactopyranosyl cyanide and to the Analytical Services Unit of this Laboratory, under the direction of Mr. H. G. McCann, for analyses and infrared absorption spectra. Nuclear magnetic resonance spectra were provided by Mr. R. B. Bradley of this Institute and Dr. L. D. Hall of the University of Ottawa.

COMMUNICATIONS TO THE EDITOR

The Electronic Structures of Square-Planar Metal Complexes. IV. A Square-Planar Rhodium(II) Complex¹

Sir:

The reaction between anhydrous rhodium(II) acetate, disodium maleonitriledithiolate (Na₂MNT), and (n-C₄H₉)₄NOH in methanol yields a red solution and a green crystalline precipitate. Analytical and conductance data established that the formula of the green solid is [(n-C₄H₉)₄N]₂[Rh(MNT)₂]. The X-ray powder diffraction pattern of the complex shows it to be isostructural and presumably isostructural with [(n-C₄H₉)₄N]₂[Ni(MNT)₂]. Since Ni(MNT)₂⁻² is known to be truly square-planar,² a square-planar structure (I) for Rh(MNT)₂⁻² is established.



The pertinent data are given in Table I.

Although there has been a revival of interest in the complex chemistry of rhodium, most of the work has been on Rh(III)³ and Rh(I),⁴ and to date there has been no report of a well-characterized, mononuclear complex of Rh(II).^{5,6} The Rh(MNT)₂⁻² complex is

(1) The support of the National Science Foundation and the National Institutes of Health is gratefully acknowledged. We thank Dr. James Bolton for help with the e.s.r. measurements and Dr. Susan A. Johnson for a sample of Rh(OAc).

(2) R. Eisenberg, J. A. Ibers, R. J. H. Clark, and H. B. Gray, *J. Am. Chem. Soc.*, **86**, 113 (1964).

(3) (a) S. A. Johnson, F. Basolo, and R. G. Pearson, *ibid.*, **85**, 1741 (1963); (b) S. A. Johnson and F. Basolo, *Inorg. Chem.*, **1**, 925 (1962), and references therein.

(4) See for example, S. S. Bath and L. Vaska, *J. Am. Chem. Soc.*, **85**, 3500 (1963), and references therein.

 TABLE I
 COMPARISON OF THE [(n-C₄H₉)₄N]₂[Rh(MNT)₂] AND [(n-C₄H₉)₄N]₂[Ni(MNT)₂] COMPLEXES

Complex	X-Ray ^a	Δ ^b	μ _{eff} , B.M.	E.s.r.
[(n-C ₄ H ₉) ₄ N] ₂ [Rh(MNT) ₂] ^c	12.28, 9.71,	150	1.91	<i>g</i> ₁ = 1.950
	8.85, 7.90,			<i>g</i> ₂ = 2.015
	7.25, 6.87,			<i>g</i> ₃ = 2.35
	6.15, 5.04,			
	4.90, 4.50,			
	4.21, 3.77,			
	3.62, 3.45,			
	3.10			
[(n-C ₄ H ₉) ₄ N] ₂ [Ni(MNT) ₂]	12.12, 9.70,	165	Diamagnetic	...
	8.93, 7.83,			
	7.20, 6.11,			
	5.04, 4.88,			
	4.50, 4.17,			
	3.77, 3.72,			
	3.45, 3.12			

^a Interplanar spacings (Å.) of the most prominent peaks.

^b For 0.0001 *M* nitromethane solutions at 25°, expressed in cm.² mole⁻¹ ohm.⁻¹. ^c *Anal.* Calcd. for C₄₀H₇₂N₆S₄Rh: C, 55.33; H, 8.36; N, 9.48. Found: C, 55.52; H, 8.74; N, 9.68.

the first reported example of a square-planar complex of rhodium(II).

The magnetic moment of solid [(n-C₄H₉)₄N]₂[Rh(MNT)₂] is 1.91 B.M. The e.s.r. spectrum of polycrystalline [(n-C₄H₉)₄N]₂[Rh(MNT)₂] is shown in Fig. 1. The three *g* values obtained are: *g*₁ = 1.950, *g*₂ = 2.015, *g*₃ = 2.35. The three-line spectrum is very similar to the frozen solution spectra obtained for the electronically similar Ni(TDT)₂⁻, Ni(MNT)₂⁻,

(5) There are several examples of diamagnetic Rh(II) complexes, which presumably are binuclear. See, for example (a) S. A. Johnson, H. R. Hunt, and H. M. Neumann, *Inorg. Chem.*, **2**, 960 (1963); (b) B. Martin, W. R. McWhinnie, and G. M. Waind, *J. Inorg. Nucl. Chem.*, **23**, 207 (1961).

(6) The structure of Rh(py)₄Cl, reported by F. P. Dwyer and R. S. Nyholm [*J. Proc. Roy. Soc. N. S. Wales*, **76**, 275 (1943)], is not known.