The thermal decomposition and kinetic method employed were as previously described,[3,4] except the concentration of **2b** was determined spectrophotometrically at λ 321, 323, 325, and 327 nm.

Trapping Experiment. The decomposition procedure was repeated as before except that when the decomposition solution was evaporated, the distillate was condensed by means of a Dry Ice–acetone trap and then refluxed with aqueous hydrochloric acid for 2 hr. Evaporation gave a 30% yield of *tert*-butylamine hydrochloride, mp 270–285° (lit.[11] mp 270–280°).

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Registry No.—**1**, 5387-50-8; **2b**, 53059-34-0; **3**, 5706-12-7; **7**, 13987-61-6; *N*-methyl-*tert*-butylamine, 14610-37-8; *N*-*tert*-butylformamide, 2425-74-3; *N*-methyl-d_2-*tert*-butylamine, 53059-35-1; *N*-methyl-*N*-nitroso-*tert*-butylamine, 2504-18-9; *N*-methyl-d_3-*N*-nitroso-*tert*-butylamine, 53059-36-2; *N*-methyl-d_3-*tert*-butylamine hydrochloride, 53059-37-3; 2-(α-*N*-methyl-d_2-*tert*-butylaminobenzyl)-1-indenone, 53059-38-4; 2-(α-*N*-methyl-d_3-*tert*-butylaminobenzyl)-1-indenone, 53059-39-5.

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Hexenopyranose Derivatives Obtained by Allylic Bromination of 6,8-Dioxabicyclo[3.2.1]oct-2-ene and 6,8-Dioxabicyclo[3.2.1]oct-3-ene and Subsequent Basic Solvolysis of the Product

Kurupati Ranganayakulu[1] and Robert K. Brown*[2]

Department of Chemistry, University of Alberta, Edmonton, Alberta, Canada

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The preparation from acrolein of the two isomeric bicyclic olefins 6,8-dioxabicyclo[3.2.1]oct-3-ene (**1**, Scheme I)[3,4] and 6,8-dioxabicyclo[3.2.1]oct-2-ene (**2**)[4] has permitted the formation of the corresponding epoxides **3** and **4** from which a number of 2- and 4-monodeoxy-[3,4] and dideoxy-DL-hexopyranoses[5,6] have been prepared. Rearrangement of the epoxide **3** to the allylic alcohol **7** with *n*-butyllithium has led to the preparation of DL-glucose,[7,8] DL-allose, and DL-galactose.[9] More recently,[10] the epoxides **3** and **4** have been converted by standard procedures to the epoxides **5** and **6** respectively. Reaction of *n*-butyllithium with epoxide **4** and of lithium diethylamide with the epoxides **5** and **6** gave the allylic alcohols **9**, **8**, and **10** respectively,[10] compounds which then by well-established procedures could provide the remaining isomeric DL-aldohexoses.

The reactions employed in converting **3** to **7** and **8**, and **4** to **9** and **10**, have permitted the introduction of a functional group (OH) not only at each of the olefinic carbon atoms in **1** and **2** but also at the saturated carbon atoms C-2 and C-4 in **1** and **2**, respectively. We have now examined the allylic bromination of olefins **1** and **2** and, as well, the reaction of the resulting allyl bromide with base to determine the value of such a scheme in producing one or more of the compounds **7–10**. This paper describes the results of our findings.

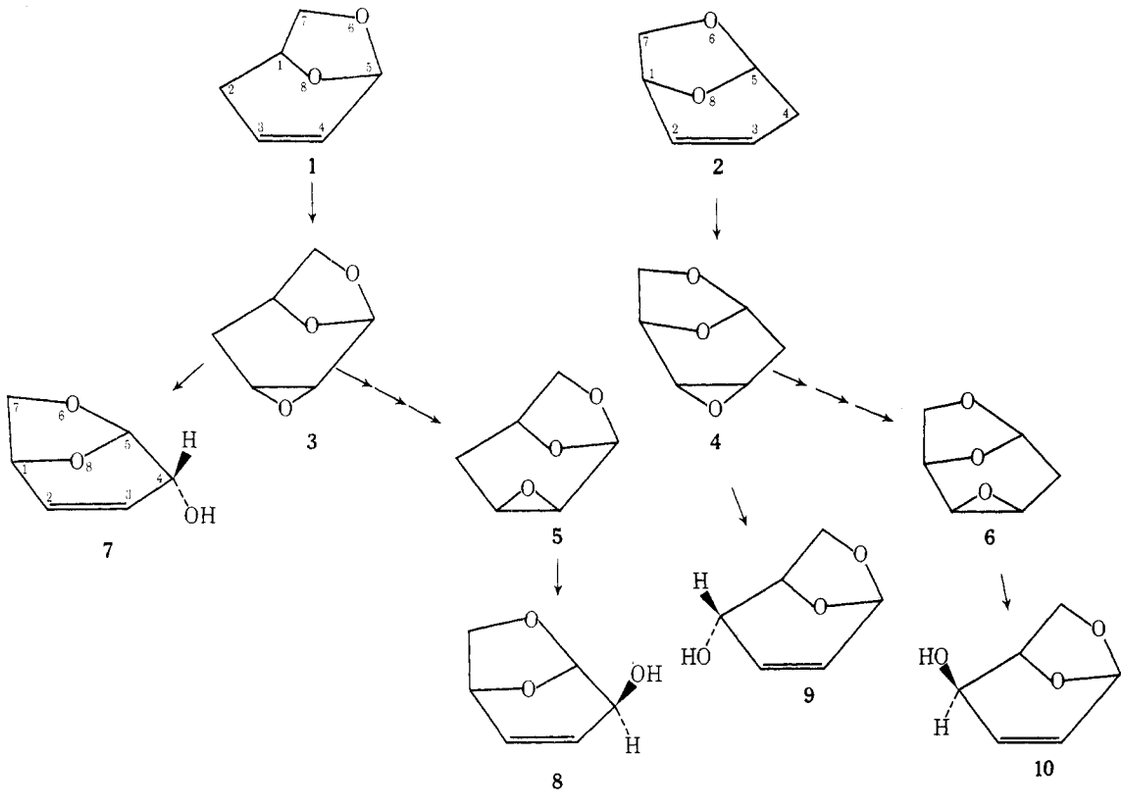
Results and Discussion

The benzoyl peroxide catalyzed reaction of *N*-bromosuccinimide (NBS) with either **1** or **2** in carbon tetrachloride gave, by final distillation, an excellent yield of 4-*exo*-bromo-6,8-dioxabicyclo[3.2.1]oct-2-ene[11] (**12**, Scheme II) of better than 98% purity according to the elemental analysis and both 100- and 220-MHz pmr spectra. Thin-layer chromatography showed only one spot. Accordingly only traces of impurity or of another isomer could be present. Analysis of the 100-MHz pmr spectrum, by double irradiation, identified the signals due to each proton and proved conclusively that the double bond was located between C-2 and C-3 of **12**. Furthermore, the narrow signal at δ 5.56 of $W/2 \approx 3.5$ Hz ($J_{5,4} \approx 0.5$ Hz, $J_{5,3} \approx 1.8$ Hz) due to the anomeric proton at C-5 provided good evidence that the proton at C-4 was endo. Thus, the Dreiding model of structure **12** showed a dihedral angle of about 85° between protons on C-4 and C-5. A small coupling is expected when the dihedral angle is in the neighborhood of 90° especially if the carbon atoms involved are also attached to highly electronegative elements. Unfortunately there was no access to the epimer of **12**, in which the proton is exo and in which the dihedral angle between the protons at C-4 and C-5 is about 35°; hence we were unable to corroborate our view concerning the exo disposition of the bromine atom at C-4, by comparison of the $J_{5,4}$ coupling in these two cases. However, we have recently prepared[10] the epimers **7** and **8** (Scheme I) by unequivocal routes. The anomeric proton of **7** at C-5 formed a dihedral angle of ~85° with the proton at C-4 and gave a narrow signal $W/2 \approx 4$ Hz ($J_{5,4} \approx 1.0$ Hz, $J_{5,3} \approx 2.0$ Hz) while the anomeric proton of **8** formed a dihedral angle of about 35° with the proton on C-4 and provided a signal which was clearly a triplet with $W/2 \approx 6.5$ Hz, $J_{5,4} \approx 3.0$ Hz, and $J_{5,3} \approx 2.0$ Hz. This comparison lends support to our view that the bromine atom in our product is exo as shown in **12**.

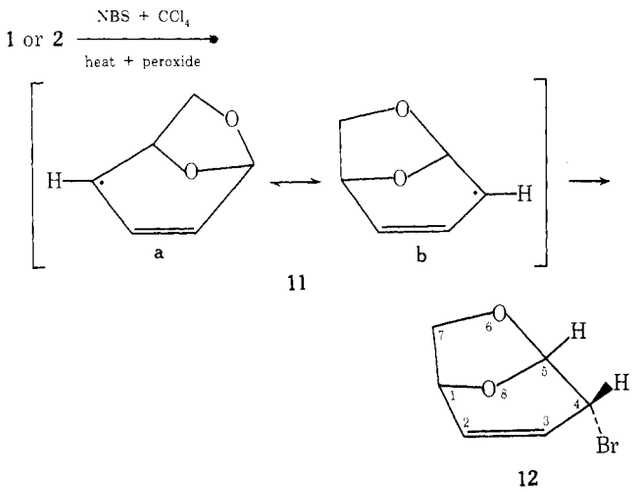
The benzoyl peroxide catalyzed bromination was clean and was completed well within 3 hr. The same product was obtained by heating the reactants in the absence of the peroxide, but these latter conditions required extensive heating for as long as 48 hr, involving a clearly apparent induction period, and resulted in concurrent polymerization and lower yields of the bromide **12**. The results obtained indicate that the reaction involves a free-radical mechanism, a view which is supported by the observation that the introduction of traces of hydroquinone markedly retards the reaction and leads to extensive decomposition during the longer heating period. The formation of apparently only one of the four possible isomers indicates a highly selective process in which **11b** (Scheme II) is the important radical species and that the endo approach of the brominating agent to C-4 is strongly inhibited by the rigidly attached 1,3-dioxolane ring.

Reaction of **12** with sodium methoxide in methanol was slow, requiring as long as 80 hr of continuous heating under reflux for completion. Shorter times gave unchanged bromide. Gas–liquid chromatography (glc) of the crude reac-

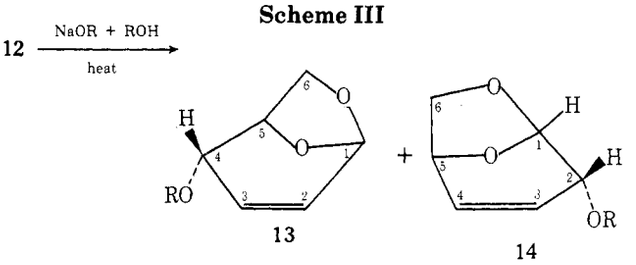
Scheme I



Scheme II



Scheme III



tion mixture showed that only two compounds **13** and **14** (R = CH_3, Scheme III) were present in the proportion 2:1, respectively. This was corroborated by the 100-MHz pmr spectrum of the crude mixture. These compounds could be separated in good yield by fractional distillation. The 100-MHz pmr spectrum of each of these two materials agreed completely with the structures shown by **13** and **14** (R = CH_3). Final confirmation that **13** (R = CH_3) was indeed 1,6-anhydro-2,3-dideoxy-4-*O*-methyl-β-DL-*erythro*-hex-2-enopyranose and **14** (R = CH_3) was 1,6-anhydro-3,4-dideoxy-2-*O*-methyl-β-DL-*erythro*-hex-3-enopyranose was obtained by comparison of their physical properties and ir and pmr spectra with those of the methyl derivatives of **13** (R = H)[10] and **14** (R = H)[7,8] each of which was obtained by unequivocal routes. No evidence could be obtained either by glc or pmr of the presence of the epimers of **13** (R = CH_3) and/or **14** (R = CH_3); hence the reaction is apparently clean and highly stereoselective.

Prolonged treatment of **12** with potassium hydroxide in water at 90° gave a 1:1 mixture of **13** and **14** (R = H) which we were unable to separate satisfactorily by either fractional distillation or column chromatography, although such separation no doubt could be achieved by tedious work. Identification of the products **13** and **14** (R = H) was made by comparison of the 100-MHz pmr spectrum of the reaction mixture with the pmr spectrum of a 1:1 mixture of authentic samples of **13** (R = H)[10] and **14** (R = H).[7,8]

Since both **13** and **14** (R = CH_3) have been found in separate experiments to be stable to the reaction conditions, their formation must occur by competitive attack by the base on **12** at C-2 and C-4. This could arise by initial slow ionization of **12** to yield an allyl carbonium ion which is then attacked by base at C-2 and C-4 from the least hindered (exo) side. The possibility exists also that some of **13** is formed by an S_N2' reaction.[12-16]

Experimental Section

Melting points and boiling points are uncorrected. Elemental analyses were made by Mrs. D. Mahlow of this department. The pmr spectra (tetramethylsilane as internal standard) and decoupling experiments were made with a Varian Associates HR-100 spectrometer by Mr. G. Bigam of this department. Observed couplings are reported. The 220-MHz spectra were made by the Ontario Research Foundation, Sheridan Park, Ontario, Canada.

Glc analyses were made with a Wilkins Autoprep Model A 700, using a column ⅛ in. × 10 ft packed with a 1:1 mixture of butanediol succinate and silicone rubber SE-30 (F & M Scientific Corp.,

Avondale, Pa.), total 20%, on Carbowax 4000 (W. H. Curtin & Co., Houston, Tex.). Helium was the carrier gas at a flow rate of 60–90 cm^3/min.

The ir spectra were obtained with a Perkin-Elmer 421 grating spectrometer by Mr. R. Swindlehurst of this department.

Solvents were removed by a rotary evaporator under water pump vacuum.

Reaction of NBS with 6,8-Dioxabicyclo[3.2.1]oct-3-ene, 1, or 6,8-dioxabicyclo[3.2.1]oct-2-ene, 2. To a solution of 8.96 g (0.08 mol) of **2**[4] in 400 ml of dry carbon tetrachloride was added 16.0 g (0.09 mol) of NBS along with a trace of peroxybenzoic acid catalyst. The mixture was heated under reflux for 3 hr, at which time the reaction was complete. The mixture was filtered from the supernatant succinimide and the solvent was removed from the filtrate. The residue, dissolved in 400 ml of ether, was washed thoroughly with a 10% aqueous solution of potassium carbonate and then with water. The collected water washings were extracted with ether (two 100-ml portions) and the combined ether solutions from the filtrate and extracts were dried ($MgSO_4$). Removal of the solvent and then the ether left a brown oil which was distilled in a micro fractional distillation apparatus to give 13.0 g (85%) of 4-*exo*-bromo-6,8-dioxabicyclo[3.2.1]oct-2-ene, **12**: bp 39–42° (0.05 mm), n^{25}D 1.5455.

Anal. Calcd for $C_6H_7O_2Br$: C, 37.72; H, 3.69; Br, 41.83. Found: C, 37.42; H, 3.97; Br, 42.02.

100-MHz pmr (CCl_4): δ 6.06 (d of d for H-2, $J_{1,2} \approx 4.5$ Hz, $J_{2,3} \approx 9.5$ Hz), 5.81 (d of q for H-3, $J_{3,5} \approx 1.8$ Hz, $J_{3,4} \approx 3.5$ Hz, $J_{3,2} \approx 9.5$ Hz, $J_{3,1} < 0.5$ Hz), 5.56 (narrow q for H-5, $W/2 \approx 3.5$ Hz, $J_{5,3} \approx 1.8$ Hz, $J_{5,4} \approx 0.5$ Hz), 4.68 (m for H-1, $J_{1,3} < 0.5$ Hz, $J_{1,2} \approx 4.5$ Hz), 4.63 (d of d for H-4, $J_{4,5} \approx 0.5$ Hz, $J_{4,3} \approx 3.5$ Hz, $J_{4,2} \approx 1.0$ Hz), 3.69 (two overlapping d for H-7 exo and H-7 endo, $J_{1,7\,endo} \approx 1.5$ Hz, $J_{1,7\,exo} \approx 3.0$ Hz, $J_{7\,exo,\,7\,endo} < 1.0$ Hz).

The reaction of *N,N*-dibromodimethylhydantoin with **2** gave an excellent yield of **12** as the only isolable product. Similar results were obtained by starting with compound **1**.

Reaction of 4-*exo*-Bromo-6,8-dioxabicyclo[3.2.1]oct-3-ene, 12, with Sodium Methoxide in Methanol. A solution of 5.73 g (0.03 mol) of **12** and 3.24 g (0.06 mol) of sodium methoxide in dry methanol was stirred while being heated under reflux for 80 hr. The mixture was then cooled and freed from methanol, and the residue was treated with 20 ml of water. The aqueous mixture was extracted repeatedly with ether and the combined ether extracts were dried ($MgSO_4$). Removal of the drying agent and ether gave an oily residue. Glc analysis of this crude material showed the presence of only two substances. Fractional distillation with a spinning-band column gave pure **13** (R = CH_3), bp 72–74° (2 mm), and pure **14** (R = CH_3), bp 67–69° (2 mm), in the proportion 2:1, respectively, and in a total yield of 70%. Products **13** and **14** were identical in all respects with the authentic compounds (see below).

Reaction of 4-*exo*-Bromo-6,8-dioxabicyclo[3.2.1]oct-2-ene, 12, with Aqueous Potassium Hydroxide. A mixture of the bromide **12** (7.64 g, 0.04 mol), 2.24 g (0.04 mol) of potassium hydroxide, and 100 ml of water was stirred at 90° for 48 hr and then heated under reflux for an additional 2 hr. The cooled solution was extracted continuously for 24 hr with methylene chloride. The organic layer was dried ($MgSO_4$) and then freed from solid and solvent, leaving an oily residue which distilled as a colorless oil, bp 49–53° (0.05 mm). Both glc and the pmr spectrum showed this oil to be a 1:1 mixture of only two substances. Attempts at separation by fractional distillation were unsuccessful. Glc separation resulted in decomposition of products. Only partial separation was obtained by the use of silica gel column chromatography.

The 100-MHz pmr spectrum of the mixture was identical with that of a 1:1 mixture of authentic **7**[7,8] and **9**.[10]

1,6-Anhydro-3,4-dideoxy-2-*O*-methyl-β-DL-*erythro*-hex-3-enopyranose, 14 (R = CH_3). Compound **14** (R = CH_3) was prepared by methylation of **7**[7,8] using the reported methylation procedure[17] with the following modification.

After the period of reflux, the solution was cooled and shaken with one-third of its volume of water. The aqueous layer was separated and extracted with ether (five 50-ml portions) to remove the somewhat water-soluble product. The ether extracts, combined with the organic layer from the cooled reaction mixture above, were dried ($MgSO_4$) and then freed from solid and solvent. The residue was distilled to give **14** (R = CH_3): yield 80%; bp 67–69° (2 mm); n^{25}D 1.4737.

Anal. Calcd for $C_7H_{10}O_3$: C, 59.14; H, 7.09. Found: C, 59.43; H, 7.15.

100-MHz pmr (CCl_4): δ 6.14 (d of q for H-4, $J_{4,3} \approx 10$ Hz, $J_{4,5} \approx 4.5$ Hz, $J_{4,1} < 1.0$ Hz), 5.67 (d of q for H-3, $J_{3,4} \approx 10$ Hz, $J_{3,2} \approx 3.5$ Hz, $J_{3,5} \approx 1.8$ Hz), 5.38 (m for H-1, $W/2 \approx 4.0$ Hz, $J_{1,2} < 1.0$ Hz, $J_{1,3} \approx 2.0$ Hz), 4.56 (m for H-5, $J_{5,3} \approx 1.8$ Hz, $J_{5,4} \approx 4.5$ Hz, $J_{5,6\,endo} \approx 1.5$ Hz, $J_{5,6\,exo} \approx 2.5$ Hz), 3.52 (d for H-6 exo and H-6 endo, $J_{6\,exo,\,6\,endo} < 0.5$ Hz), 3.33 (s for CH_3), 3.21 (complex d for H-2, $J_{2,3} \approx 3.5$ Hz, $J_{1,2} < 1.0$ Hz).

1,6-Anhydro-2,3-dideoxy-4-*O*-methyl-β-DL-*erythro*-hex-2-enopyranose, 13 (R = CH_3). Compound **9**[10] was methylated by the same procedure used to prepare **14** above: yield 80%; bp 42° (0.1 mm); n^{25}D 1.4759.

Anal. Calcd for $C_7H_{10}O_3$: C, 59.14: H, 7.09. Found: C, 58.98; H, 7.26.

100-MHz pmr (CCl_4): δ 6.04 (d of q for H-2, $J_{1,2} \approx 3.5$ Hz, $J_{2,3} \approx 10$ Hz, $J_{2,4} \approx 1.0$ Hz), 5.67 (d of q for H-3, $J_{3,2} \approx 10.0$ Hz, $J_{3,4} \approx 4.0$ Hz), at 5.34 (d for H-1, $J_{1,2} \approx 3.5$ Hz, $J_{1,3} < 0.5$ Hz), 4.58 (complex d for H-5, $J_{5,6\,exo} \approx 7.0$ Hz), 3.77 (d of d for H-6 exo, $J_{5,6\,exo} \approx 7.0$ Hz, $J_{6\,exo,\,6\,endo} \approx 8.0$ Hz), 3.35 (s for CH_3), 3.42–3.17 (complex m for H-4 and H-6 endo).

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Registry No.—**1**, 53152-84-4; **2**, 53152-85-5; **7**, 34685-53-5; **9**, 52630-80-5; **12**, 53111-75-4; **13** (R = Me), 53111-76-5; **14** (R = Me), 32445-57-1.

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(1) Postdoctoral Fellow.
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Stereochemistry of the Reduction of α-Amino Ketones

Calvin L. Stevens,* Kenneth J. TerBeek,[1] and P. Madhavan Pillai

Department of Chemistry, Wayne State University, Detroit, Michigan 48202

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Although the stereochemistry of the reduction of α-hydroxy ketones has been extensively investigated,[2] the reduction of α-amino ketones has received very little attention. In a few instances where the reduction of α-dimethylamino ketones was reported,[3,4] only the trans amino alcohol was isolated and the stereochemistry of the reduction was not completely established. The reductions of monoalkylamino ketones with sodium borohydride have also been reported to give only trans amino alcohols except in one case involving a bicyclic ring system where a mixture of cis and trans amino alcohols was obtained.[5] The addition of Grignard reagents to acyclic amino ketones[2a,6] is known to yield products predicted by Cram's rule of "steric control