OXIDATION OF 9-BORABICYCLO[3.3.1]NONANE AND ITS DERIVATIVES WITH PYRIDINIUM CHLOROCHROMATE†

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Abstract - The oxidation of 9-borabicyclo[3.3.1]nonane (1) with chromic acid or pyridinium chlorochromate (PCC) affords a mixture of products, predominantly cyclooctanone (> 65%). However, *cis*-1,5-cyclooctanediol (2), readily obtained from 1 by oxidation with alkaline hydrogen peroxide, is oxidized by these reagents to provide 9-oxabicyclo[3.3.1]nonan-1-ol (4). Under more drastic conditions, 2 and 4 can be transformed by PCC into 1,5-cyclooctanedione (5). Consequently, it is now possible to proceed easily from 1,5-cyclooctadiene via hydroboration-oxidation to *cis*-1,5-cyclooctanediol (2), to 9-oxabicyclo-[3.3.1]nonan-1-ol (4) and 1,5-cyclooctanedione (5).

The oxidation of organoboranes with alkaline hydrogen peroxide affords the corresponding alcohols in nearly quantitative yields.[1] Organoboranes containing secondary alkyl groups provide ketones upon oxidation with chromic acid ($Na_2Cr_2O_7$, H_2O, H_2SO_4, Et_2O: Brown-Garg method).[2] The new reagent, pyridinium chlorochromate ($Pyr{\cdot}HCl{\cdot}CrO_3$, PCC), as an oxidizing agent,[3] has recently found useful application for the oxidation of organoboranes to ketones[4] and aldehydes.[5] In connection with our continued interest in the application of boron chemistry for the synthesis of cyclic molecules,[6,7] we undertook to examine the reactions of 9-borabicyclo[3.3.1]nonane (9-BBN, 1) and its derivatives with PCC and chromic acid as a convenient route to cyclic derivatives.

9-BBN is an unusual bicyclic dialkylborane which often exhibits properties quite different from those of other dialkylboranes.[8] Previous studies on the oxidation of 1 have revealed the formation of a variety of products. Thus, with alkaline hydrogen peroxide, 1 affords *cis*-1,5-cyclooctanediol, whereas the reaction with chromic acid forms cyclooctanone (Eq 1).[9]

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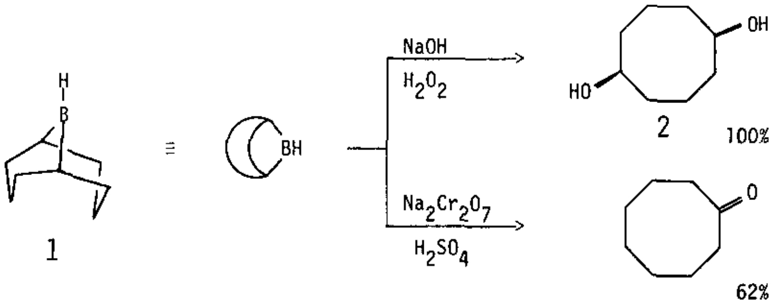
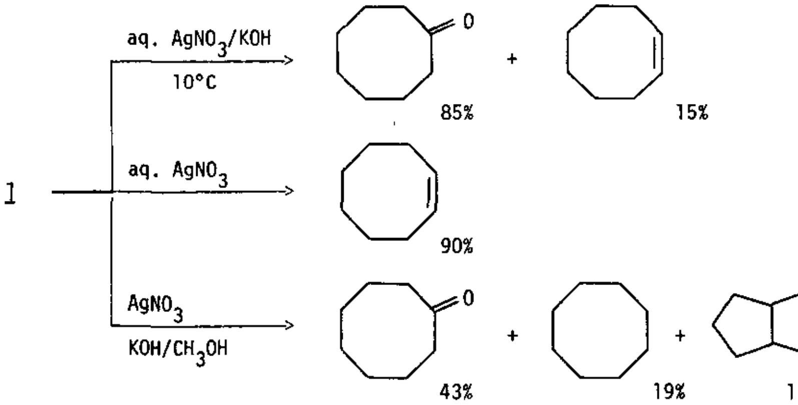
† Dedicated to Professor Herbert C. Brown, an inspiring teacher, on the occasion of his 70th birthday.



(1)

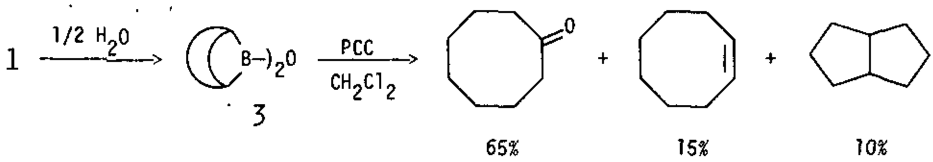
The reaction with silver nitrate under different conditions provides a mixture of products (Eq 2).[10]



(2)

This paper reports a study of the oxidation of 9-BBN and its derivatives with PCC and chromic acid.

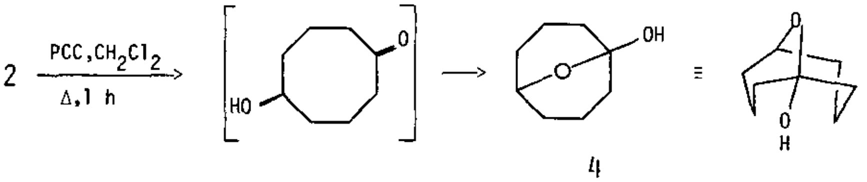
The reaction of 1 or its hydrolysis product (3: ^{11}B nmr δ 53, characteristic of R_2BO– moiety; absence of OH in ir)[11] with PCC forms a mixture of three products (Eq 3).[12]



(3)

A re-examination of the oxidation of 1 by the Brown-Garg procedure[9] revealed the formation of these products: cyclooctanone, 75%; cyclooctene, 5%; bicyclooctane, 10%.[12,13] *B*-Ethyl-9-BBN and 9-BBN itself, upon reaction with PCC, gives the same products in comparable ratios (± 5%). Although the formation of cyclooctanone proceeds via a known mechanism involving a protonation-oxidation sequence,[9] the minor products are the same as those previously obtained in the silver nitrate oxidation.[10] At this stage, we do not wish to propose any mechanism for the formation of these products.

The oxidation of *cis*-1,5-cyclooctanediol (2), readily prepared from 1 by oxidation with alkaline hydrogen peroxide, also exhibits some interesting features. With one mole of PCC, 2 affords 9-oxabicyclo[3.3.1]nonan-1-ol (4) in 79% isolated yield (Eq 4).

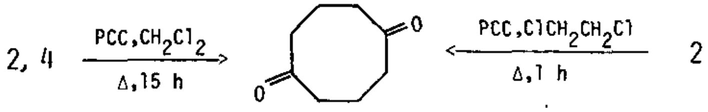


4

(4)

Evidently, the hydroxyketone resulting from oxidation of one of the alcoholic groups cyclizes rapidly to 4. It has been shown recently by ir that the hemiketal is more stable than the corresponding hydroxyketone.[14] The chromic acid oxidation[2] of 2 provides 4 in somewhat lower yields. This bicyclic hemiketal (4) was previously obtained as a by-product in the catalytic oxidation of cyclooctane.[15] It was also prepared by the high dilution cyclization reaction[16] or by the Jones' oxidation of 1,5-cyclooctanediol.[14,16]

Under more drastic conditions (CH_2Cl_2, 15 h, under reflux), PCC further oxidizes 4 cleanly to 1,5-cyclooctanedione (5) in excellent yield (81% isolated). The direct oxidation of 2 to 5 is also accomplished under these conditions (Eq 5).



5

(5)

Fortunately, in 1,2-dichloroethane solvent, the conversion of 2 to 5 was complete in less than 1 h under reflux (85°C). In view of the numerous applications of 1,5-cyclooctanedione,[16] the present method offers great advantages for a convenient preparation of 5.

It is interesting that even in the presence of an excess of PCC 2 yields only 4 in 1 h (CH_2Cl_2, reflux). Apparently the formation of 4 is very facile, whereas the subsequent oxidation to 5 is relatively slow. On the contrary, the treatment of 2 with a sufficient quantity of PCC in 1,2-dichloroethane (reflux, 85°C) provides the diketone, 5, in 1 h. Presumably, both factors, the higher reaction temperature and the higher solubility of PCC in this solvent, are responsible for a rapid oxidation to 5. However, the attempted conversion of 2 or 4 to 5 with sodium dichromate and sulfuric acid either in water (100°C, 2 h) or in 90% acetic acid (25°C, 24 h) was unsuccessful.[17]

In conclusion, the oxidation of *B*-alkyl-9-BBN, 9-BBN and the corresponding borinic acid (3) with PCC or chromic acid provides cyclooctanone along with small quantities of cyclooctene and bicyclo[3.3.0]octane. It is now possible to proceed easily from 1,5-cyclooctadiene via hydroboration-oxidation to *cis*-1,5-cyclooctanediol (2) to 9-oxabicyclo[3.3.1]nonan-1-ol (4) and 1,5-cyclooctanedione (5).

EXPERIMENTAL

The gas chromatographic analyses were carried out on a Varian 1400 instrument using a 12 ft x 1/8 in column packed with 10% SE-30 on Varaport-30. The ^{1}H nmr spectra were recorded on a Varian T-60; ^{13}C and ^{11}B nmr spectra on Varian FT-80A instrument. Pyridinium chlorochromate (labeled 98% pure), 9-BBN and *cis*-1,5-cyclooctanediol from Aldrich Chemical Company were used without further purification. *B*-Ethyl-9-BBN was prepared by passing ethylene gas through a solution of 9-BBN in THF. The preparation of 3 was carried out by stirring 100 mM of 9-BBN in THF with 50 mM of water for 2 h. Following removal of THF, the residue was diluted with CH_2Cl_2 to make a standard solution, which was utilized for the reactions studied.

Oxidation of 3 with PCC

To a suspension of 6.5 g (30 mM, excess) of PCC in CH_2Cl_2 (50 ml) was added a solution of 3 (5 mM) in CH_2Cl_2 dropwise. After the initial vigorous reaction subsided, the reaction mixture was heated under reflux for 1 h, *n*-tetradecane (2.0 mM, an internal standard for gc analysis) was added, diluted with Et_2O (100 ml) and filtered through Florisil. The gc analysis revealed the presence of cyclooctanone (65%), cyclooctene (15%) and bicyclo[3.3.0]octane (10%).

The reactions of 1 and of *B*-ethyl-9-BBN with PCC were carried out in the same manner, except that 50 mM of PCC was taken in each case.

The chromic acid oxidation (Brown-Garg method) was carried out as described elsewhere.[2]

Oxidation of 1,5-Cyclooctanediol. gc Analysis

In a 100-ml round-bottom flask equipped with a magnetic stirring bar and a reflux condenser were placed 3.24 g (15 mM) of PCC, 10 ml of CH_2Cl_2 and 0.65 ml (2.5 mM) of *n*-tetradecane (an internal standard for gc analysis). A solution of 0.72 g (5 mM) of *cis*-1,5-cyclooctanediol in CH_2Cl_2 (20 ml) was added slowly and the mixture was heated under reflux. At definite intervals of time, 0.5 ml of the reaction mixture was withdrawn and diluted with 2 ml of Et_2O, allowed to settle and the clear supernatant liquid was analyzed by gc for the amounts of 4 and 5 formed. After 1 h, only 4 was formed in 100% yield and gradually the amount of 4 decreased, forming pure 5 in 15 h.

Preparation of 9-Oxabicyclo[3.3.1]nonan-1-ol (4)

In a 500-ml reaction flask were placed 13 g (60 mM) of PCC and 100 ml of CH_2Cl_2. To the well-stirred suspension was added a solution of 7.2 g (50 mM) of 1,5-cyclooctanediol in 150 ml of CH_2Cl_2 slowly (exothermic). After complete addition, the mixture was heated under reflux for 1.5 h, diluted with 200 ml of anhydrous ether and was filtered through 10 g of Florisil contained in a 500-ml separatory funnel. The tarry residue in the flask was washed with ether (3 x 50 ml) and the washings passed through the same funnel. The solvents were removed on a rotary evaporator and the residue was recrystallized from a mixture of hexane and ethyl acetate using activated charcoal. On cooling the colorless filtrate to -78°C, 5.7 g crystals separated, a yield of 79%; mp 99-100°C [lit.[15] mp 99-100°C]; ^{1}H and ^{13}C nmr were consistent with the structure of 4.

Preparation of 1,5-Cyclooctanedione (5) from 4

According to the procedure described above, 50 mM of 4 was treated with 60 mM of PCC in 200 ml of CH_2Cl_2. The mixture was heated under reflux for 15 h. The usual workup provided 81% yield of 5, mp 68-69°C (from pentane-Et_2O; lit.[16,18] mp 71-72°C). ^{1}H and ^{13}C nmr spectra were consistent with the structure.

Preparation of 5 from 2

The reaction of 50 mM of 2 with 120 mM of PCC in 200 ml of CH_2Cl_2 for 15 h under reflux afforded a 77% yield of 5, mp 69-70°C.

Alternatively, the oxidation in 1,2-dichloroethane (1 h under reflux) provided 83% of the crude 5; recrystallization from Et_2O-pentane mixture afforded colorless crystals, mp 70-71°C.

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11. Dialkylborinic acids, R_2BOH, are known to exist as the corresponding anhydrides, R_2BOBR_2.

12. The remaining 10% constitutes **4** and other minor products. Overall yields were 80-90%.

13. Apparently, the volatile products, bicyclo[3.3.0]octane and cyclooctene, escaped detection by the previous workers.[9] We could separate these compounds from the solvents using a 14 ft x 1/8 in column packed with 10% SE-30 on Varaport-30. The products were identified using the authentic samples. The material obtained by careful removal of the solvents revealed the presence of cyclooctanone and cyclooctene unambiguously (^1H nmr).

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17. It is interesting that treatment with $Na_2Cr_2O_7/H_2SO_4$ failed to convert **4** to **5**, whereas, Jones' oxidation was successful.[14,15]

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