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CONCLUSIVE EVIDENCE FOR AND STEREOCHEMISTRY OF PROTONATION OF COMPOUNDS CONTAINING A BRIDGEHEAD DOUBLE BOND IN A SEVEN-MEMBERED RING[1]

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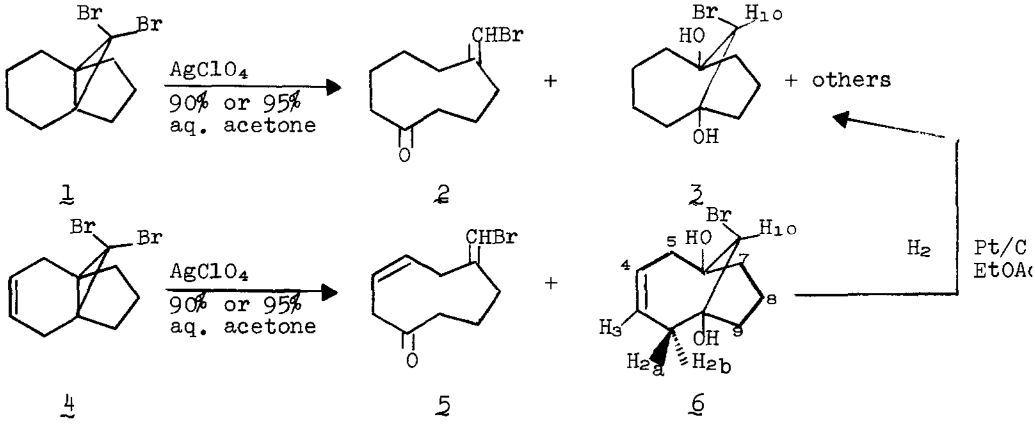
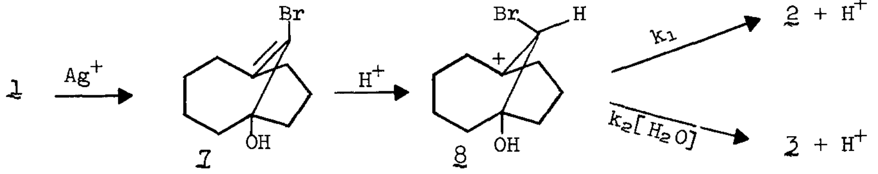
We have been interested in the cationic generation of bridgehead double bonds.[3] Recently, while our work was in progress, a report[4] of the intermediate formation of such a moiety, via the silver-assisted solvolysis of 1, appeared. However, since the product observed, 2, was a ring-opened monocycle, one could not be sure of its mode of formation. Furthermore, the stereochemistry of 2 was unknown. We now report a more extensive investigation of the solvolysis of 1 and 4 (reported to yield 5[4]), establishing the intermediacy of a species with a bridgehead double bond.[5,11]



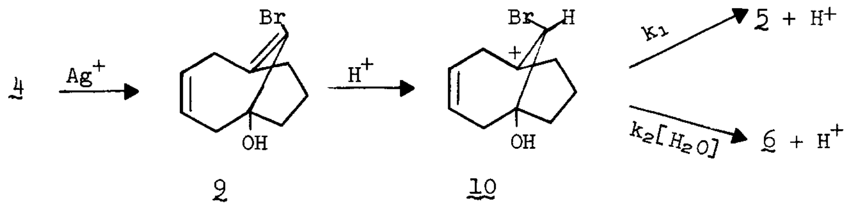
Fortunately, we began our investigation with the study of 4. After workup of the solvolysate formed by treatment of 4 with varying amounts of $AgClO_4$ in 95% aqueous acetone, attempted dissolution in CCl_4 led to the formation of a white precipitate [mp 174-176° (partial decomposition, sealed tube)]. The mass spectrum gave a parent ion for 6. 6 proved soluble in $CDCl_3$; ir and especially nmr [δ 5.44, mult. (vinylic H's); δ 4.54 (H_{10}); δ2.87 (H_{2a} and H_{5a}, $|J_{2a,2b}| \cong |J_{5a,5b}| = 16$ Hz); δ 2.31 (H_{2b} and H_{5b} (shown to be coupled to vinylic H's); δ1.4-2.3 ($2H_7$, $2H_8$, $2H_9$ and 2 hydroxyl H's) were in complete accord with structure 6, as was the analysis. Of prime interest is the stereochemistry of 6 at C_{10}. Long-range, W-type coupling between H_{2b} (but not H_{2a}) and H_{10} ($|J| = 2$Hz) showed that the bromine atom resides syn to the four-carbon bridge.

In order to absolutely prove the stereochemistry of 6, a single crystal x-ray analysis was performed. Crystals obtained from hot CCl_4 solution were of the space group $P2_1/c$ (C_{2h}^5); there were eight molecules in a unit cell of dimension a=11.84(1), b=12.52(1), c=16.19(1)Å and β=120.99(3)°. The structure was solved by heavy atom methods and fully refined to a discrepancy index of 0.087 for the 1806 diffractometer measured structure factors. Both molecules in the asymmetric unit are the same and have mirror symmetry within experimental error (0.02Å and 1°). All bond distances and angles appear normal. The six-membered ring is in the chair conformation, while six of the seven carbons of the seven-membered ring (C_1-C_6) are almost in a plane, with the bouble bond tipped slightly away from C_{10}.[6] The C_1-C_6 distance is 2.58±0.02Å.

With the structure of 6 unequivocally established, it was felt that another look at the solvolysis of 1 would show that the minor, unidentified product (ca 5%) reported by Reese[4] was 3. Catalytic hydrogenation (Pt/C, EtOAc) of 6 gave a quantitative yield of 3 [mp 148-150°, sealed tube; mass spec, analysis, ir and nmr (δ 4.39, H_{10}; δ1.5-2.4, 16 H, aliphatics and hydroxyls) in accord with the structure]. Nmr showed 3 was, indeed, the other product. Table I gives the yields of the key products under the conditions studied. Also, since the mechanism illustrated by equations (1) and (2) seems most likely,[7] the derived ratios of rate constants for intermolecular collapse (k_2) and unimolecular fragmentation (k_1) are given



(1)



(2)

Table I. Absolute yields of solvolysis products from 1 and 4.

Starting Material[a]	Products (Yield)[b]	Solvent	k_2/k_1[c]	Ref.
1	2(50%), 3(ca. 5%), 11(15%)[d]	95%aq.>=O	0.036	e
1	2(43%), 3(15%), 11 (13%)[d]	90%aq.>=O	0.065	this work
4	5(44%), 6(18%)	95%aq.>=O	0.15	this work
4	5(27%), 6(44%)	90%aq.>=O	0.30	this work

[a] For [starting material] between 0.02M and 0.06M and between 1 and 2 equivalents of $AgClO_4$; note $[H_2O] = 2.78M$ or $5.56M$; [b] Both 5 and 6 were independently subjected to the reaction conditions (simulated by allowing bromoethane to react with $AgClO_4$ in the presence of 5 or 6 in 90% aqueous acetone). In each case, an 80% yield of the starting material (5 or 6) was reisolated, with no observable amounts of interconversion between 5 and 6. Therefore the observed product ratios are those of kinetic control. [c] Refer to eqs (1) and (2); the absolute values of k_2 and k_1 may be different in each case; [d] 11 is $\Delta^{1,7}$ bicyclo[5.3.0]-decen-2-one, formed via an alkyl shift route; [e] Reference 4.

As is consistent with expectations for a more polar solvent, the rate of intermolecular collapse of both 8 and 10 approximately doubled, relative to the fragmentation rate, upon doubling the water content. More importantly, however, 10 was persistently some 5 times more prone to intermolecular collapse than 8, as compared to fragmentation. This means that 10 is longer lived (i.e. more stable) than 8, and we attribute this to homoallylic delocalization in 10. At this point, we are unsure whether the bridgehead double bonds of 7 and 9 are rehybridized,[8,9] since the stereochemistry of protonation can be explained on the basis of steric approach control.

Lastly, we comment on the rates of silver-assisted solvolysis of 1 and 4. The statement[4] that both are rapid at room temperature in the presence of excess $AgClO_4$ is misleading. We have studied the reaction semiquantitatively in the presence of from one to ten equivalents of $AgClO_4$. The reaction of 1 is rapid (in 90% aq. acetone, room temp., over in 20-30 min) even in the presence of 1 equivalent of $AgClO_4$. However, with 1 equivalent of $AgClO_4$, **4** (at an initial concentration of 0.03*M*) requires *ca.* 3 days at room temperature for complete reaction (90% aqueous acetone), and follows roughly *first-order* kinetics ($t_{1/2} \approx$ 14-15 hrs). With a large excess of $AgClO_4$ (4-5 fold), **4** reacts rapidly. This behavior is expected if a fast complexation equilibrium of Ag^+ with the double bond of **4** occurs, and if the equilibrium constant is reasonably large (*i.e.*, > 1); this sort of complexation has precedence.[10]

REFERENCES

1. We thank the donors of the Petroleum Research Fund, administered by the American Chemical Society, and the Atomic Energy Commission for support of this research.
2. Camille and Henry Dreyfus Foundation Teacher-Scholar Grant Awardee, 1972-1977; Fellow of the Alfred P. Sloan Foundation, 1973-1975.
3. P. Warner, R. LaRose, C. Lee and J. Clardy, *J. Amer. Chem. Soc.*, **94**, 7607 (1972).
4. C. B. Reese and M. R. Stebles, *Chem. Commun.*, 1231 (1972).
5. Our results in HOAc and CF_3CO_2H (both catalyzed and uncatalyzed) initially led us to question the completeness of Reese's report;[2] these results will be published soon.
6. This is in accord with the very small $J_{2a,3}$ observed by nmr.
7. Other evidence (R. LaRose, unpublished results) indicates that a competitive synchronous addition of H_2O to **9** is unlikely.
8. (a) W. L. Mock, *Tetrahedron Lett.*, 475 (1972); (b) L. Radom, J. A. Pople and W. L. Mock, *Ibid.*, 479 (1972).
9. In a recent case [C. Batich, O. Ermer, E. Heilbronner and J. R. Wiseman, *Ang. Chem. Int. Ed. Eng.*, **12**, 312 (1973)], photoelectron spectroscopy has failed to give a definitive answer to the question of π-bond deformation.
10. J. Solodar and J. Petrovich, *Inorg. Chem.*, **10**, 395 (1971).
11. A referee has suggested that maybe a partially opened cyclopropyl cation is formed from **1** or **4**, which in turn gives **3** or **6** without the intermediacy of **7** or **9**. This is, however, inconsistent with the solvent dependence of the 2:3 and 5:6 ratios; we feel **8** and **10** are required intermediates, but how are they formed? Can a cationic species add H_2O synchronously to give **8** or **10**? Possibly, but it should be noted that we observe some dimer formation from **9-OAc** in HOAc (P. Warner, unpublished results).