rate ratios by using the Arrhenius equation.[13] An iterative least-squares computer program leads to a best fit with an effective dielectric constant of 13.7 ±1.6 D and the fraction of charge on the *tert*-butoxy oxygen (f_0) equal to 0.85 ± 0.13 (with the remainder on C_β).[14] The calculations converge to the same values within the range 0–1.0 for f_0 and 5–50 for D_E. Calculations in which a significant charge is allowed to develop on the departing chlorine are not consistent with experimental results.[15] For example, in the elimination from **4**, by using the best-fit effective dielectric constant of 13.7 and assuming a 0.2 charge on chlorine (0.8 on the oxygen of the base), the calculated ratio **6**/**5** is 0.62. That is, the predicted regioselectivity is actually reversed.

There is a growing belief that bimolecular syn-periplanar eliminations involve transition states with considerable carbanion character.[16] Our results for both **3** and **4** (for which syn elimination is required) and as well as for **1** and **2** (which proceed from an anti-clinal conformation) suggest some carbanion character obtains (with little charge on chlorine) but with the majority of charge on the attacking base.

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(12) King, E. J. "Acid–Base Equilibria"; Pergamon Press: Oxford, 1965; p 160.

(13) The implicit assumption that differences in entropy of activation are negligible is supported by our observation that no measurable changes in product ratios were observed for elimination of HCl performed at 50 °C.

(14) Possible factors contributing to the magnitude of D_E and to the quality of agreement of calculated and experimental elimination ratios with use of a single D_E for the variety of transition-state interactions will be discussed in the full paper.

(15) With as little as 0.3 fraction of a unit charge on chlorine, calculations fail to converge. With a 0.1 charge on chlorine (0.53 on the base and 0.37 on C_β) convergence leads to a value of 10.2 ± 1.2 D for the dielectric constant, but the fit to experimental data is poorer.

(16) See: Bach, R. D.; Badger, R. C.; Lang, T. J. *J. Am. chem. Soc.* **1979**, *101*, 2845 and references cited therein.

Mechanism of Formation of Weiss' *endo*- and *exo*-Tetracyclo[5.5.1.0^{2,6}.0^{10,13}]tridecane-4,8,12-trione[1]

Steven H. Bertz* and Jay Kouba†

Department of Chemistry, Harvard University
Cambridge, Massachusetts 02138

Norman E. Sharpless

National Institute of Arthritis, Diabetes, and
Digestive and Kidney Diseases
Bethesda, Maryland 20205

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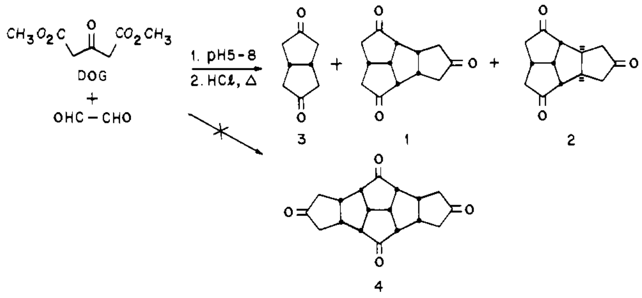
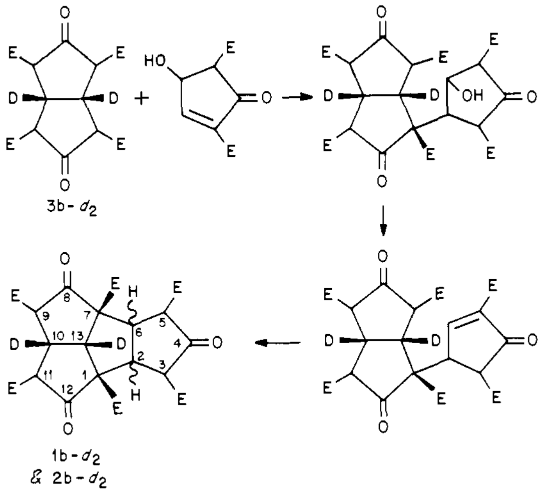
Scheme I



Scheme II



Now that the dodecahedrane story has reached denouement,[2] interest in polyquinane chemistry is keen and will undoubtedly continue to grow as the synthetic methodology that has been developed is applied to other "theoretically interesting" hydrocarbons and to the increasing number of known cyclopentanoid natural products.[3] This activity also promises to stimulate mechanistic investigations as unexpected new reactions are discovered. We are pleased to report the solution to a mechanistic mystery that has perplexed polyquinane chemists for a decade, viz., the reason that Weiss' *endo*-tetracyclic triketone **1**[4] (Scheme I) predominates (by ~2:1) over the *exo*-isomer, **2**.[5] These products accompany bicyclo[3.3.0]octane-3,7-dione (**3**) after hydrolysis–decarboxylation of the material that forms when dimethyl 3-oxoglutarate (DOG) and glyoxal are allowed to react in aqueous buffers.[4,5] Molecular mechanics calculations of the Westheimer type using the program GEMO[6] suggest that **1** is less stable than **2** by 8.1 kcal/mol, which is mainly attributable to torsion angle strain (4.9 kcal/mol) and bond angle strain (2.0 kcal/mol).

Compound **1** is an attractive precursor for dodecahedrane, as it possesses 13 of the requisite 20 carbon atoms, all in the proper positions. In addition, all the necessary activation for further construction is present at the nontertiary carbon atoms. Last, but no less important, **1** is prepared in two easy steps, albeit in low yield (~3%).[5] Even more tantalizing was the possibility that the hexacyclic tetraketone **4** with 18 of dodecahedrane's 20 carbon atoms in place might also be formed in an analogous manner. Unfortunately, no **4** could be isolated by meticulous chromatography or even detected by intensive spectroscopy.[7] Since the straightforward mechanism suggested[8] for the formation of **1** and **2** (Scheme II) makes the creation of some **4** (as well as two other stereoisomers) appear inevitable, the elucidation of the mechanism was imperative in order to understand why no **4** was found.

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*Author to whom correspondence should be sent at Bell Laboratories, Murray Hill, NJ 07974.

†Current address: Amoco Research Center, Naperville, IL 60540.

(1) Dedicated to Dr. Ulrich Weiss (NIH) on the occasion of his 75th birthday. Part 4 in a series on the Weiss reaction: parts 3, 2, and 1 are given in ref 9–11, respectively.

(2) Ternansky, R. J.; Balogh, D. W.; Paquette, L. A. *J. Am. Chem. Soc.* **1982**, *104*, 4503–4.

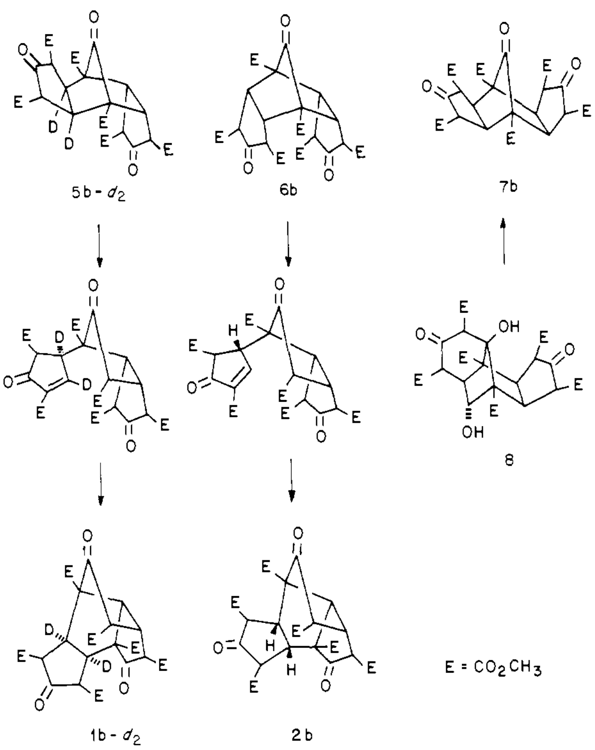
(3) Annis, G. D.; Paquette, L. A. *J. Am. Chem. Soc.* **1982**, *104*, 4504–6. Wrobel, J.; Takahashi, K.; Honkan, V.; Lannoye, G.; Cook, J. M.; Bertz, S. H. *J. Org. Chem.* **1983**, *48*, 139–41.

(4) Edwards, J. M.; Qureshi, I. H.; Weiss, U.; Akiyama, T.; Silverton, J. V. *J. Org. Chem.* **1973**, *38*, 2919–20. Akiyama, T.; Silverton, J. V. *Acta Crystallogr., Sect. B* **1975**, *B31*, 2336–8.

(5) Rice, K. C.; Sharpless, N. E.; Weiss, U.; Highet, R. J. *Tetrahedron Lett.* **1975**, 3763–6.

(6) Cohen, N. C. *Tetrahedron*, **1971**, *27*, 789–97.

Scheme III



A labeling study was devised to test the validity of the "straightforward" mechanism. First, an efficient preparation of 2,4,6,8-tetrakis(methoxycarbonyl)bicyclo[3.3.0]octane-3,7-dione (**3b**) was developed.[9] Then, **3b**-1,5-d_2 was prepared[10] from glyoxal-d_2 and allowed to react with 1 equiv each of DOG and glyoxal. All the usual products were harvested by using silica gel chromatography and fractional crystallization to obtain pure samples. Measurement of the deuterium content at the methine carbons of **1** and **2** by ^{1}H, ^{2}H, and ^{13}C NMR revealed that an amazing rearrangement takes place during the genesis of **1** and **2**. Thus, instead of appearing at C(10) and C(13) of **1** as predicted by the "straightforward" mechanism (Scheme II), at least 95% of the deuterium is located at C(2) and C(6) according to ^{2}H NMR (90% according to ^{1}H and ^{13}C NMR). In **2** the ratio of deuterium at C(10) and C(13) to that at C(2) and C(6) is *ca.* 1:1, measured by ^{1}H and ^{13}C NMR. These results are in harmony with the intermediacy of **5b** and **6b** (Scheme III), which rearrange via a retro-Michael reaction followed by a new Michael addition to yield **1b** and **2b**, respectively. The plane of symmetry in **6b** is responsible for the fact that the deuterium in **2** is scrambled among all of the possible positions. The predominance of **1** over **2** is a result of the fact that **5b** can arise by attack of a 1:1 intermediate[8,11] from DOG and glyoxal on the convex face of **3b**, whereas **6b** must derive from the less favorable attack of such an intermediate on the concave face of **3b**.

Support for this mechanism is also provided by the isolation of **7b**,[12] which due to its all syn stereochemistry cannot rearrange to either **1b** or **2b**. The assignment of structure **7b** on the basis of spectral data was confirmed by independent preparation from **8**,[12] the structure of which was established by X-ray crystallography.[13] When **7b** has been crystallized from the crude reaction mixture, the 1798-cm^{-1} band due to the C(13) carbonyl group is no longer present, precluding the presence of significant **5b** or **6b**.

Molecular mechanics calculations[6] performed on the desmethoxycarbonyl derivatives of **5b**, **6b**, and **7b** (**5**–**7**, respectively) indicate the order of increasing stability to be **6** < **5** < **7** < **1** < **2**, with energy differences of 16.7 (**6** − **5**), 1.7 (**5** − **7**), 2.1 (**7** − **1**), and 8.1 (**1** − **2**) kcal/mol.[14] In qualitative agreement with these results, Engler et al.[15] calculate that perhydrotriquinacene is 6.9 kcal/mol more stable than *exo*-perhydrodicyclopentadiene, which in turn is 4.5 kcal/mol more stable than the endo isomer. The difference between experimental enthalpies of formation[14] of *endo*-perhydrodicyclopentadiene and perhydrotriquinacene is 10.1 kcal/mol;[16,17] therefore, it is the release of the strain energy in the bicyclo[2.2.1] system that drives these rearrangements.

In summary, the yield of **1** is higher than that of **2** because **5b** and **6b** are formed first and then rearrange to **1b** and **2b**, respectively. It is not possible to convert **1b** into **4b** (the octakis(methoxycarbonyl) derivative of **4**) by such a mechanism, due to the presence of quaternary centers at C(1) and C(7) of **1b**. Therefore, **4** can be ruled out as a rapid entry into dodecahedrane chemistry, and attention can be now be focused on compounds such as **1** and **3** as starting materials for a practical synthesis of dodecahedrane.[18]

Acknowledgment. We are grateful to the late Prof. R. B. Woodward, in whose laboratories part of this work was completed, for his support, and the Francis Bitter National Magnet Laboratory for some of the ^{2}H NMR spectra. S.H.B. thanks the NSF for a predoctoral fellowship.

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[7] Both crude and purified products were analyzed by MS using a direct insertion probe and slowly raising the temperature. For example, in a crude mixture from the hydrolysis–decarboxylation of the unpurified product from the reaction of 3 equiv of DOG and 2 equiv of glyoxal, MS detected peaks at *m/e* 138 and 218 for **3** and **1**, respectively, but no peak at *m/e* 298 for **4** even with the highest amplification. All the techniques for maximizing a parent ion were used; see: Silverstein, R. M.; Bassler, G. C.; Morrill, T. C. "Spectrometric Identification of Organic Compounds", 4th ed.; Wiley: New York, 1981; pp 11–12.

[8] Yang-Lan, S.; Mueller-Johnson, M.; Oehldrich, J.; Wichman, D.; Cook, J. M.; Weiss, U. *J. Org. Chem.* **1976**, *41*, 4053–8.

[9] Bertz, S. H.; Rihs, G.; Woodward, R. B. *Tetrahedron* **1982**, *38*, 63–70.

[10] Bertz, S. H. *J. Org. Chem.* **1981**, *46*, 4088–90.

[11] Bertz, S. H.; Adams, W. O.; Silverton, J. V. *J. Org. Chem.* **1981**, *46*, 2828–30.

[12] The yield of **7b** from DOG and glyoxal is 4%; from **3b**, DOG, and glyoxal it is 17%; and from the rearrangement of **8** it is 38%. For experimental details, see: Bertz, S. H., Doctoral Dissertation, Harvard University, 1978.

[13] Rice, K. C.; Weiss, U.; Akiyama, T.; Highet, R. J.; Lee, T.; Silverton, J. V. *Tetrahedron Lett.* **1975**, 3767–70.

[14] Either enthalpies of formation or strain energies may be used to calculate these differences, as the isomers compared are isologous in every case; see ref 15.

[15] Engler, E. M.; Andose, J. D.; Schleyer, P. von R. *J. Am. Chem. Soc.* **1973**, *95*, 8005–25.

[16] Boyd, R. H.; Sanwal, S. N.; Shary-Tehrany, S.; McNally, D. *J. Phys. Chem.* **1971**, *75*, 1264–71.

[17] Clark, T.; Knox, T. Mc O.; McKervey, M. A.; Mackle, H.; Rooney, J. J. *J. Am. Chem. Soc.* **1979**, *101*, 2404–10.

[18] Baldwin and Beckwith (Baldwin, J. E.; Beckwith, P. L. M. *J. Chem. Soc., Chem. Commun.* **1983**, 279) report that **1** is a readily accessible starting material for a short synthesis of a useful C$_{19}$ heptaquinane which is "closely related to dodecahedrane". In addition, Prof. P. E. Eaton (private communication with S.H.B.) informs us that he now uses **3** as the starting material for the "peristylane approach" to dodecahedrane.