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BREDT'S RULE—I
STRAIN IN A BRIDGEHEAD OLEFIN*

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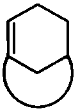
Abstract—The strain inherent in ethyl bicyclo[5.3.1]undec-7-en-11-one carboxylate is discussed in terms of bond angle and bond length distortions and warping of the double bond, which were detected by X-ray crystallographic measurements. An attempt is made to evaluate the strain. In the UV spectrum, non-planarity of the enone system leads to a low ε_{max} which is correlated with $\cos^2 \theta$.

SINCE Bredt first pointed out[1] that bridged bicyclic compounds of the camphane and pinane series are unable to tolerate a double bond which has one terminus at the bridgehead, Bredt's Rule has been invoked to explain the failure of a variety of elimination and enolization reactions in small bridged bicyclic systems.[2] Much effort has also been expended in attempting to define the limiting ring-size beyond which the rule is inoperative.[3] However, many of these experiments are no longer meaningful.[4, 5] Another attempt to formulate the limits of the rule in terms of an S-value[2] is equally uninformative, and has no rational basis.

The most illuminating comment yet made on this problem has been the suggestion by Wiseman[4] that the strain in a bridgehead olefin (I) is related to the strain in the corresponding *trans*-cycloalkene† (II), and available experimental evidence is consistent with this hypothesis.[4] The Wiseman hypothesis also offers a partial answer to another question which earlier workers could not answer; *viz.*, within any given bridged bicyclic molecule, are all of the double-bond isomers, i.e. (III)–(IV), equally strained? The hypothesis indicates, and enolization evidence[6] confirms, that IV is more strained than either III or V. However, the energy relationship between III and V is less well understood. On the basis of a single example,[7] it appears that type III may be more strained than type V, but this fact is not predictable by the Wiseman *trans*-cycloalkene hypothesis. If we are to arrive at a more precise under-

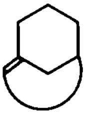
I

II



III

IV



V

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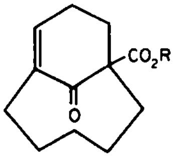
† This concept was apparently foreshadowed by Robinson 17 years ago, see Rodd, Chemistry of Carbon Compounds Vol IIa, p. 275, Elsevier, London (1955)

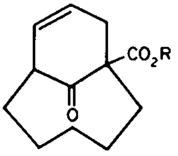
standing of the strain involved in bridgehead double bonds, Wiseman's rationalization of Bredt's rule must itself be qualified or restated in more fundamental terms.

As an initial step in this direction, we report here a detailed investigation of the bicyclo[5.3.1]undec-7-en-11-one system, designed to discover how the molecule accommodates the strain of a bridgehead double-bond.

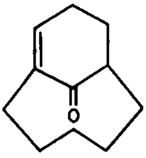
The bicyclic keto-ester VI is readily prepared from cyclooctanone[8] and being crystalline, it can be obtained free from its βγ-isomer VII, although equilibration yielded a 9:1 mixture of these respective enones. On hydrolysis followed by decarboxylation of the resulting acid, the same ester afforded the parent αβ-enone (VIII), required for other studies, but contaminated with 7% of the βγ-enone (IX). These were separable only by GLC, but the major component was characterized as its oxime.



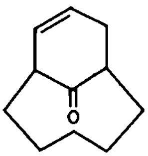
VI R = Et
VIa R = H



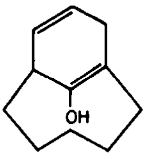
VII R = Et
VIIa R = H



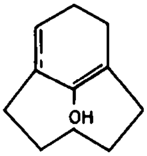
VIII



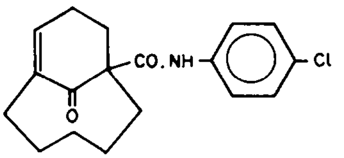
IX



X



XI



XII

Surprisingly, equilibration* of VIII yielded a 75:25% mixture of VIII and IX respectively, and it must be presumed that the discrepancy between the two equilibria reflects subtle differences in molecular geometry due to the ester function. The fact that decarboxylation afforded only 7% of the βγ-enone (IX) indicates that CO_2 was liberated directly from VIa (followed by partial equilibration) rather than *via* VIIa, with subsequent equilibration. This second mechanism might have been expected to take precedence, since the enol intermediate (X) in the decarboxylation, involves only one bridgehead double bond.† In fact, the reaction intermediate (XI) is doubly "anti-Bredt".

Although the keto-ester (VI) had been a poor source of the parent enone (VIII) it afforded a *p*-chloroanilide (XII) from which the exact geometry of the ring was determined by X-ray crystallography.[9] This examination revealed the bond angles (±1°) and bond lengths (±0·06 Å) shown in the figure. It also showed that the C(7)—C(8) double bond was warped about its axis by 8·6° and that the C=O group

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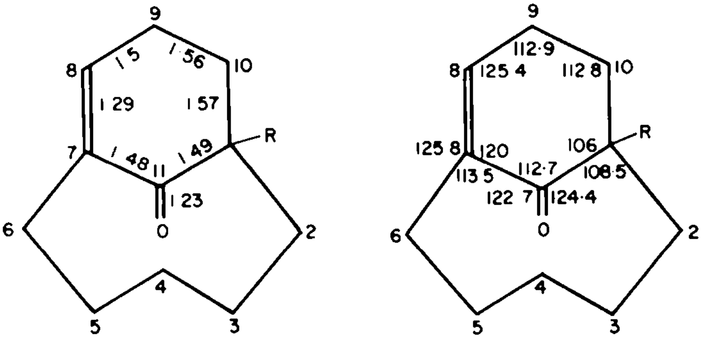
* See Part 2: following paper

† Such a mechanism is suggested in Ref. 8, footnote 14

was twisted about the C(7)—C(11) bond, 37·7° out of the plane of the olefinic double bond. The non-planarity of the αβ-enone system reduces the conjugation between the two π-bonds, and this is reflected in abnormal bond lengths (see Fig). The major discrepancies are in the C(7)—C(8) double bond, which is as short as an isolated double bond and in the C(7)—C(11) bond which is longer than expected—as long as the C(1)—C(11) bond, for example. Although these discrepancies are significant, they are in each case uncomfortably close to the outer limits of error ($\pm 0{\cdot}06$ Å).

Non-planarity of the same order is presumably present in VI and its UV spectrum (λ_{max}^{EtOH} 238 nm: ε 5630) shows the expected drop in ε. A correlation between the observed (ε) and expected (ε_0) extinction coefficients and the angle of twist (θ) has been expressed[10] by the empirical relationship $\varepsilon/\varepsilon_0 = \cos^2\theta$ but later criticised[11] and replaced by $\varepsilon/\varepsilon_0 = \cos\theta$. To our knowledge these have never been tested experimentally, and so it is of interest to note that in the present case they predict angles of 41·5° and 55° respectively, the former being remarkably close to the measured value (37·7 ± 1°). An independent estimate of the angle of twist by Professor J. B. Stothers (Western Ontario), based on the ^{13}C chemical shift of the CO function, gave a value of 35°, which also agrees well with the X-ray data.[12]



(R = CO.NH.C_6H_4Cl)

FIG. Bond lengths (estimated standard deviation $\pm 0{\cdot}02$ Å) and bond angles ($\pm 1°$)

Although the enone (VI) is able to tolerate a bridgehead double-bond, an examination of molecular models reveals that it is more strained than its βγ-isomer (VI) or its 7,8-dihydroderivative. The X-ray examination shows that the strain is expressed not only in warping of the C═C but also in bond angle deformation. A comparison of the bond angles observed (see Fig) with those expected[*] shows significant discrepancies of 5·3° and 3·8° in the C(1)—C(11)—C(7) and C(6)—C(7)—C(8) angles respectively, and presumably these two types of distortion are general for strained bridgehead olefins.

Having qualitatively identified the strain produced by the bridgehead double bond, it would be of interest to make a quantitative estimate. However, although the contributions of these deformations to the strain energy of the molecule can be

[*] See experimental values reported[13]

roughly estimated,* attendant changes in torsional and transannular strain—and so in overall enthalpy—are less readily computed. Nonetheless, it is interesting to observe that the strain energy (or, at least, that part which can be estimated) is equally shared between π-bond warping and angle deformation. This appears to be a plausible result.

EXPERIMENTAL

All m.ps are uncorrected. Routine IR spectra of liquid films and nujol mulls were recorded on a Unicam SP 200 spectrophotometer and quantitative spectra on a Perkin-Elmer Model 225. UV spectra, measured on a Unicam SP 800, refer to solutions in EtOH, unless otherwise stated. NMR spectra were obtained on the Varian T60 instrument using TMS as internal standard. GLC was carried out on Pye Argon and Perkin-Elmer F11 gas chromatographs. High resolution mass spectra were recorded on the AEI MS12 mass spectrometer.

Bicyclo[5.3.1]*undec-7-en-11-one carboxylic acid* (VIa). The enone ester (VI) (1·0 g) was refluxed for 12 hr in 25 ml 10% ethanolic NaOH. The cooled mixture was neutralized with dil. HCl, flooded with water and extracted with ether. The extract was washed, dried (Mg SO_4) and concentrated, yielding 0·91 g of residue. Recrystallization from high boiling petrol gave 0·85 g acid m.p. 157-158°. (Found: C, 68·97; H, 7·70. $C_{12}H_{22}O_3$ requires: C, 69·21; H, 7·74%) ν_{CO} 1759, 1700 cm^{-1}; NMR $-1{\cdot}1$ τ (1 × H) and 3·7 τ (1 × H: broad mult.). Mass spectrum *m/e* 208 (P) with a strong peak at *m/e* 164.

Equilibration. Using the literature method,[8] the mixture was analyzed by GLC. The 9:1 ratio observed is virtually identical with that reported.[8]

Decarboxylation.[16] The keto-acid (140 mg) in 15 ml quinoline was boiled under reflux for 2 hr, flooded with water and extracted with ether. The extract was washed with dil. HCl, then brine dried and evaporated to an oil (75 mg). Residual quinoline was removed by filtration in ether, through grade O silica. Comparison by TLC and GLC (QF1) with a known mixture† of VIII and IX showed that these enones were present in the ratio 93:7.

Oxime. The enone mixture (70 mg) in 1 ml EtOH was added to hydroxylamine hydrochloride (130 mg) in 1·5 ml 5% NaOH aq, refluxed for 6 hr, and then stood for 12 hr at room temperature. The mixture was neutralized, extracted with ether and the extract washed with brine, dried (Mg SO_4) and evaporated. The resulting oil (85 mg) slowly crystallized and was recrystallized from a small volume of $MeNO_2$, m.p. 118-120°. (Found: C, 73·75; H, 9·42; N, 7·88. $C_{11}H_{17}NO$ requires: C, 73·70; H, 9·56; N, 7·81%). ν^{CCl_4} 3600, 3100-3000, 1660 cm^{-1}; NMR 0·75 τ (1 × H broad) which disappeared on addition of D_2O, 4·3 τ (1 × H mult.) unchanged on addition of D_2O, *m/e* 179 (P).

p-*Chloroanilide* (XII). The carboxylic acid VIa (1·91 g) and redistilled $SOCl_2$ (6·5 ml) were refluxed for 30 min, excess reagent was removed by azeotroping with benzene, and the acid chloride b.p. 140-145/0·3 mm (1·393 g) in dry benzene (5 ml) was treated with *p*-chloroaniline (0·805 g) in dry benzene (5 ml): a white precipitate formed immediately. The mixture was allowed to stand under N_2, at 0° for 12 hr. The mixture was then poured into water (75 ml) extracted with ether, and the extract was washed with NH_2SO_4. The usual work-up afforded 1·68 g of crude product which was chromatographed on alumina (benzene-petrol) to give the anilide in 74% yield, m.p. 87-88° (EtOAc). (Found: C, 68·08; H, 6·39; N, 4·3. $C_{18}H_{20}O_2NCl$ requires: C, 68·02; H, 6·34; N, 4·41%). ν 3430, 1690, 1680, 1590, 1530, 1490, 835 cm^{-1}; NMR 2·6 (4H, q), 3·75 (1H, br. d, J = 2 Hz) τ.

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[*] The strain energy involved in warping the C═C can be found from the expression[14] $E_s = 8W^2$ cal/mole, and an 8·6° twist will cost approximately 0·5 kcal. Strain due to bond angle deformation has been evaluated from the expression $E_0 = 17{\cdot}5\,(\Delta\theta)^2$ cal/mole/degree^2 and if we assume the same force constant for in-plane bending of the C—C—C, C═C—C and $\mathrm{C{-}\overset{\|}{C}{-}C}$ bonds (see Garbish[15]) the above deformations cost a total of about 0·5 kcal

[†] See Part 2, following paper

REFERENCES

[1] J. Bredt, *Liebig's Ann.* **437**, 1 (1924)

[2] F. S. Fawcett, *Chem. Reviews* **47**, 219 (1950)

[3] V. Prelog, *J. Chem. Soc.* 420 (1950)

[4] J. R. Wiseman and W. A. Pletcher, *J. Am. Chem. Soc.* **92**, 956 (1970)

[5] G. L. Buchanan in *Topics in Carbocyclic Chemistry*, ed. D. Lloyd, p. 239, Logos Press, London (1969)

[6] H. O. House and H. C. Muller, *J. Org. Chem.* **27**, 4436 (1965); J. P. Ferris and N. C. Miller, *J. Am. Chem. Soc.* **85**, 1325 (1963): *Ibid.* **88**, 3522 (1966): H. Meerwein, *J. Prakt Chemie* **104**, 161 (1922): J. P. Schaeffer, L. S. Endres and M. D. Moran, *J. Org. Chem.* **32**, 3963 (1967)

[7] J. R. Wiseman, H-F. Chan and C. J. Ahola, *J. Am. Chem. Soc.* **91**, 2812 (1969)

[8] E. W. Warnhoff, C. M. Wong and W. T. Tai, *J. Org. Chem.* **32**, 2664 (1967)

[9] A. F. Cameron and G. Jamieson, *J. Chem. Soc.* (B), 1581 (1971)

[10] E. A. Bruade and F. Sondheimer, *J. Chem. Soc.* 3754 (1955)

[11] N. L. Allinger and E. S. Jones, *J. Org. Chem.* **30**, 2165 (1965): N. Heap and G. H. Whitman, *J. Chem. Soc.* (B), 164 (1966)

[12] Personal communication

[13] J. C. Bart and C. H. Macillvary, *Acta Cryst.* **24B**, 1587 (1968); R. Huber and W. Hoppe, *Chem. Ber.* **98**, 2403 (1965)

[14] F. J. Allen, E. D. Brown, D. Rogers and J. K. Sutherland, *Chem. Comm.* 1116 (1967)

[15] E. W. Garbisch, Jr., S. M. Schildcrout, D. B. Patterson and C. M. Sprecher, *J. Am. Chem. Soc.* **87**, 2932 (1965): F. H. Westheimer in *Steric Effects in Organic Chemistry*, Chapter 12, Ed. M. S. Newman, John Wiley and Sons Inc., New York (1956)

[16] cf. V. Prelog, P. Barman and M. Zimmermann, *Helv. Chim. Acta* **32**, 1284 (1949)