Tetrahedron Letters No. 11, pp 941 - 944, 1978. Pergamon Press. Printed in Great Britain.

THE PERISELECTIVITY OF TROPONE CYCLOADDITIONS TO FULVENES.

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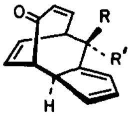
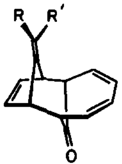
(Received in USA 28 November 1977; received in UK for publication 23 January 1978)

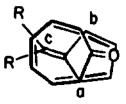
In 1970, we reported the first [6 + 4] cycloadditions of tropone to fulvenes.[1,2] Although a rapid 1,5-sigmatropic shift precluded isolation of the $[6^F + 4^T]$ adduct, 1, the intermediacy of this compound was shown unequivocally in one case by deuterium labeling studies and structural elucidation of the 2:1 adducts of tropone and various fulvenes. We also considered the possibility that the $[4^F + 6^T]$ adduct, 2, could be the kinetically controlled product of cycloaddition, but that 2 was rapidly converted to 1 by a [3,3]-sigmatropic shift, precluding detection of the primary adduct, 2.



1



2



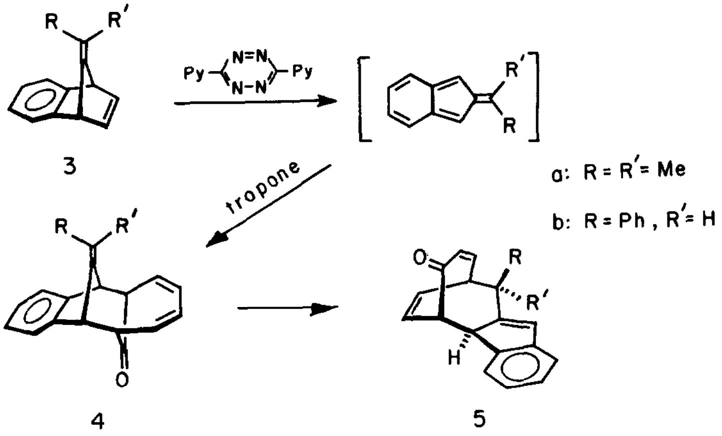
A

a: R = R' = Me ; b: R–R' = $-(CH_2)_4-$; c: R = Me, R' = H ; d: R = Ph, R' = H

The only evidence available at that time, which we interpreted as circumstantial evidence against the intermediacy of the $[4^F + 6^T]$ adduct, 2, was the stereochemistry of cycloadducts of 6-monosubstituted fulvenes.[2] Only derivatives of 1c and 1d were formed from 6-methyl or 6-phenyl fulvenes. This requires that the Cope rearrangements, if adducts 2 are involved at all, proceed through transition states with the methyl or phenyl substituent in quasi-axial, rather than quasi-equatorial, conformations.[2] Since Cope rearrangements are known to prefer transition states with quasi-equatorial substituents,[3] we concluded that 2 was not an intermediate in these reactions.

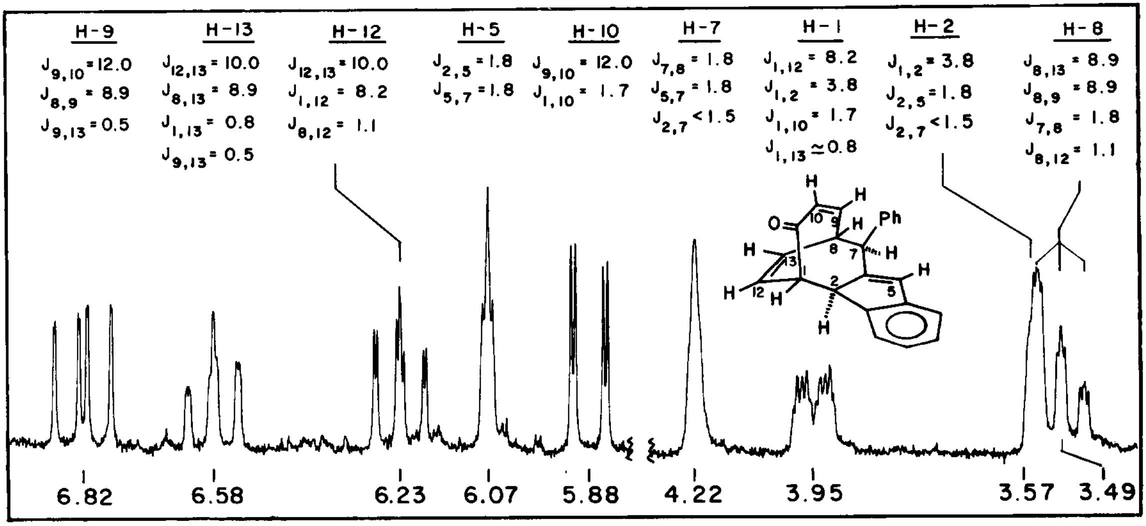
In 1972, Tanida and coworkers isolated the $[6^F + 4^T]$ adduct, 5a, upon reaction of dimethylisobenzofulvene with tropone.[4] Several years later, Warrener and Paddon-Row found that the $[4^F + 6^T]$ adduct, 4a, was the initial adduct formed in this reaction, but that 4a slowly rearranges to 5a in solution at room temperature.[5] By analogy, Paddon-Row and Warrener concluded that the monocyclic fulvenes also give the $[4^F + 6^T]$ adducts, 2, as primary products.[5-8] Since our stereochemical reasoning involved a gross extrapolation from acyclic systems, we decided to reopen the question of mechanism by preparing the $[4^F + 6^T]$ adduct, 4b, of phenylisobenzofulvene and tropone, and to determine the stereochemistry of an authentic Cope rearrangement of a close analog of the unobserved 2d.

When the previously unknown 8-phenylisobenzofulvene was generated, in tropone as solvent at room temperature,[9] thin layer chromatographic monitoring of the reaction mixture revealed formation of a single adduct, 4b, and subsequent development of a second adduct, 5b. Column chromatography of the mixture obtained after 20 hours gave a mixture of 4b and 5b, as well as a pure sample of 5b, mp 150-152°. Adduct 4b could not be isolated in pure form because of its ready thermal conversion to 5b, apparently accelerated by silica gel.



However, spectroscopic studies of the mixture of 4b and 5b revealed the structure of 4b. That is, this adduct has a carbonyl stretching absorption at 1715cm^{-1}, as expected for the bridged carbonyl in 4b, and nmr resonances at 3-4.4δ due to four aliphatic protons, and at 5.5-6.2δ due to five vinyl protons, in good agreement with those found for 4a.[5] Upon standing in solution at room temperature, the resonances assigned to 4b disappeared, while those assigned to 5b grew in intensity.

The structure of 5b was proven by analysis of nmr spectra taken in $CDCl_3$ and benzene-d_6 solvents at both 100 and 200 MHz,[10] double resonance experiments, and observations of LIS's using $Eu(fod)_3$. The 200 MHz nmr spectrum of 5b, assignments, and coupling constants follow:



The resonances due to H-1 and H-8 could be readily differentiated from those due to H-2 and H-7, due to the magnitude of the splittings observed. Thus, H-8 is coupled to both of the vicinal olefinic protons (H-9 and H-13) by 8.9 Hz, while H-1 has only one large coupling, 8.2 Hz, to H-12. H-1 and H-2 are coupled by 3.8 Hz, indicating the position of the H-1 resonance. The H-7 resonance is not fully resolved, but couplings of 1.8 Hz to both H-5 and H-8 were shown by double resonance experiments. There is also a 4-bond coupling of less than 1.5 Hz between H-7 and H-2. The small magnitude of the vicinal coupling, $J_{7,8}$ = 1.8 Hz, is indicative of the stereochemistry shown in the drawing of 5b. That is, in 5b the dihedral angle between H-7 and H-8 is approximately 80°, whereas the stereoisomer having an *endo* phenyl group would have a corresponding dihedral angle of about 30°, and consequently a larger $J_{7,8}$.

A comparison of the chemical shifts of 5a with those of 5b, like the similar comparison made earlier for derivatives of 1a and 1d,[2] provides further evidence for the *exo* nature of the phenyl group in 5b. Thus, in benzene-d_6, the resonances in 5b due to H-8, H-9, and H-10 are at lower field by 0.46, 0.15, and 0.22 ppm, respectively, than the corresponding resonances of 5a.

Thus, 4b undergoes a Cope rearrangement via the transition state in which the phenyl group assumes the quasi-axial conformation. Our previous contention that the phenyl group would adopt a quasi-equatorial conformation in the analogous Cope rearrangement of 2d to 1d must be incorrect, implying that the formation of 1d in reactions of phenylfulvene with tropone is consistent with initial formation of **2d** and subsequent Cope rearrangement to **1d**. Although there is still no direct evidence for formation of **1**, analogy with the formation of the positively identified **4** from isobenzofulvenes leads us to concur with Paddon-Row and Warrener that **2** is most probably the initial adduct of tropone with monocyclic fulvenes.

Acknowledgement. We are grateful to the National Science Foundation for financial support of this research, and to Professor Warrener for helpful discussions.

References and Notes

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2. K. N. Houk, L. J. Luskus, and N. S. Bhacca, *Tetrahedron Lett.*, 2297 (1972).
3. W. v. E. Doering and W. R. Roth, *Tetrahedron*, **18**, 67 (1967).
4. H. Tanida, T. Irie, and K. Tori, *Bull. Chem. Soc., Japan*, **45**, 1999 (1972).
5. M. N. Paddon-Row and R. N. Warrener, *Tetrahedron Lett.*, 3797 (1974).
6. The formation of **4a** rather than **5a** was rationalized[5] on the basis of perturbation molecular orbital theory using Hückel coefficients at interacting centers.[5,7] Theory at this level is hardly capable of predicting the relative energies of such closely related transition states. For example, the model transition state, A, would give the $[6^F + 4^T]$ adduct, **1**, by bond formation at a and c, but the $[4^F + 6^T]$ adduct, **2**, by bond formation at a and b. However, strong interactions occur simultaneously at a, b, and c, and excluding one of these from the calculation is arbitrary. Furthermore, theory at this level incorrectly predicts [6 + 4] adducts from all 1,3-dipolar cycloadditions to tropone, whereas experimentally, [4 + 2] adducts always predominate.[8]
7. M. N. Paddon-Row, *Australian J. Chem.*, **27**, 299 (1974).
8. D. Mukherjee and K. N. Houk, *J. Org. Chem.*, in press, and references therein.
9. The method of Warrener was used: P. L. Watson and R. N. Warrener, *Australian J. Chem.*, **26**, 1725 (1973) and references therein.
10. We thank Drs. M. Bramwell and C. Tanzer for the 200 MHz measurements, taken on a Bruker WP-200.