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NMR STUDIES OF SOME CHROMONE-KETENE DIMETHYL ACETAL PHOTOADDUCTS. LONG RANGE SPIN-SPIN COUPLING AND CONFORMATIONAL ANALYSIS OF FUSED CYCLOBUTANES.

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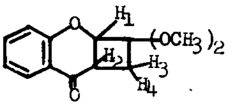
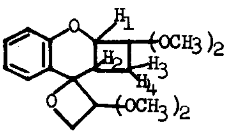
Proton-proton coupling is not normally detected across four bonds in saturated systems since effects transmitted solely through the σ framework decrease by a factor of 10-20 per bond.(1) However, recently a number of examples of stereospecific inter-proton spin-spin coupling across four single bonds have been reported in the literature.(2)

We wish to report another interesting example of long range proton-proton interaction across four single bonds. Recently two chromone-ketene dimethyl acetal photoaddition products (I and II) were prepared in this laboratory.(3)



I



II

While the nmr spectrum of adduct I was essentially normal, that of adduct II was unique. Using the Swalen-Reilly program(4) for a four spin system, the coupling constants for the cyclobutane hydrogens in adduct II were precisely determined. The values obtained are given below. The initial approximations of the coupling constants and chemical shifts for the cyclobutane hydrogens, as well as the location of the frequencies of the individual transitions, was easily accomplished due to the significant chemical shift differences between the hydrogens involved. The coupling constants for adduct I were read directly from its spectrum and are also shown below.

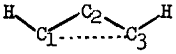
Adduct I	Adduct II
$J_{12} = 9$ cps	$J_{12} = 8.2$ cps
$J_{13} = < 1$ cps	$J_{13} = 3.5$ cps
$J_{14} = < 1$ cps	$J_{14} = 0.6$ cps
$J_{23} = 9$ cps	$J_{23} = 8.9$ cps
$J_{24} = 3.2$ cps	$J_{24} = 9.1$ cps
$J_{34} = -13$ cps	$J_{34} = -12.9$ cps

From the calculated coupling constants for adduct II, it can be seen that the nmr spectrum of this compound exhibits two rather unusual features. First, long range coupling (J_{13}) of appreciable magnitude is observed over four saturated bonds. Secondly, the addition of a mole of ketene dimethyl acetal to adduct I has so altered the conformation of the cyclobutane ring that in addition to introducing the long range coupling, the vicinal cis and trans proton couplings (J_{23} and J_{24}) have become essentially equal and quite large.

Unfortunately the observation of long range coupling in adduct II by itself does not appear to shed much light on the conformational change in the cyclobutane ring. While several examples of this type of coupling have been observed,(2) the actual mechanism of the long range coupling still remains in doubt. Indeed it is possible that there may be more than one mechanism by which this interaction can occur.(5) It was initially concluded that the Fermi or contact potential was largely responsible for proton spin-spin coupling because of the s-electrons surrounding the hydrogen nuclei.(6) Using this approach the coupling constant should be proportional to the square of the overlap integrals for the two carbon-hydrogen bond orbital wave functions.(7,8) Wiberg,(8) however, has shown that this relationship does not appear to be valid for the long range coupling observed in certain bicyclo[2.1.1]hexane derivatives. From his calculations he concludes that the Fermi contact potential may not be the most important contributor to long range coupling.

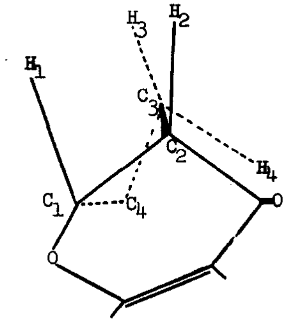
Barfield(5) has investigated the angular dependence of long range proton-proton coupling. He states that both "direct" ("through space") and "indirect" ("through-the-bond") coupling paths may be important contributors to the coupling constant. This indirect coupling is related to the importance of the vicinal exchange interaction in paraffins.(9) Numerous experimental results(2,10) have shown that long range coupling over four saturated bonds is most pronounced when the atoms assume a "W" orientation. Barfield suggests that for some conformations of this model the large separation between the two hydrogens would indicate a negligible contribution from the "direct" coupling path and it is the "indirect" coupling which is responsible for long range interaction. However, his calculations predict a maximum coupling of only 1.2 cps under ideal stereochemical conditions, when the two protons are in the C-C-C plane, a condition clearly not met in adduct II.

Meinwald(11) has also observed long range interaction in the nmr spectra of bicyclo[2.1.1]hexanes. He has suggested that this coupling may be due to a direct overlap between the small orbitals of the carbon atoms involved; i.e. that the interaction "across four bonds" does not involve the two carbon-carbon bonds at all. This would restrict this coupling to systems which can adopt the "W" orientation. However, it is not possible to

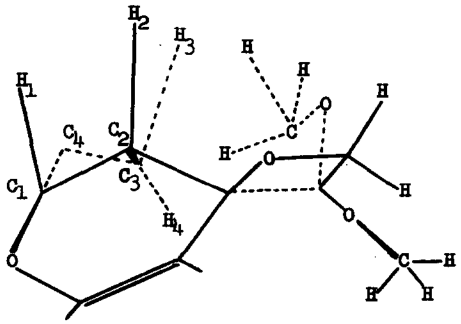


distinguish between a "Meinwald" type interaction and a "direct" ("through space") coupling. Indeed, Barfield(5) is careful to state that for an eclipsed conformation of a saturated hydrocarbon, the "direct" contribution to J_{HH} may be quite significant.

It appears that the real clue to the change in the conformation of the cyclobutane ring in going from adduct I to II is the vicinal coupling constants. While the *cis* vicinal coupling constant (J_{23}) remains 9 cps, the *trans* coupling (J_{24}) changes from 3.2 to 9.1 cps. Using the Karplus curve(12) to relate the coupling constant to the dihedral angle, this means that the dihedral angle for the *cis* hydrogens must remain close to 0°, but that for the *trans* hydrogens must approach closer to 180°. In addition, since the coupling between the geminal hydrogens (J_{34}) is the same in both adducts, the dihedral angle between the two geminal hydrogens must remain the same.(13) The proper dihedral angles for the *cis* and *trans* hydrogens in adduct II can be obtained by a "twisting" of the cyclobutane ring. As seen from the Karplus curve,(12) the change in the vicinal *trans* coupling (J_{24}) from 3.2 to 9.1 cps is accomplished by increasing the dihedral angle towards 180°. Normally this change would tend to increase the angle between the *cis* hydrogens resulting in a decrease of the *cis* coupling (J_{23}). However, this is not always the case and the following formula projections can be used to best accommodate all of the data.



Adduct I



Adduct II

In adduct I H_3 is slightly out of the H_2-C_2-C_3 plane as shown. Addition of a mole of ketene dimethyl acetal to I causes the cyclobutane ring to twist in the opposite direction so that H_3 moves through an eclipsed orientation to a new position slightly out of the H_2-C_2-C_3 plane on the other side. In this manner the dihedral angle between the two <u>cis</u> hydrogens, hence the coupling constant, remains essentially the same. In addition, this twisting of the cyclobutane ring has the effect of increasing the dihedral angle, and hence the coupling constant, between the <u>trans</u> hydrogens (H_2 and H_4) in adduct II. The cyclobutane ring is pictured as having C_3 twisted slightly upward in I and slightly downward in II.

If it is this type of "twisting" of the cyclobutane ring which explains the vicinal <u>cis</u> and <u>trans</u> couplings, it is most likely that the long range coupling between H_1 and H_3 (J_{13} = 3.5 cps) occurs by the "Meinwald" type mechanism, that is direct overlap between the small orbitals of the carbon atoms involved. Twisting the cyclobutane ring as indicated for adduct II would have the effect of orientating the small orbitals of the carbon atoms involved (C_1 and C_3) in a position more favorable for overlap.

The use of F.M.O. models$^{(14)}$ provides a plausible explanation for this suggested twisted cyclobutane. Addition of ketene dimethyl acetal to the carbonyl of adduct I is best accomplished by having the oxetane oxygen atom directed away from H_4. However, even in this configuration there is still steric interaction between H_4 and one group of methoxyl hydrogens. This hindrance is diminished by twisting the cyclobutane ring as described.

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