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The assignment of the carbon-13 nmr resonances of a series of oxetanes derived from the photoaddition of benzophenone and 2-naphthaldehyde to furan and some of its methyl derivatives and of benzophenone to 2,5-dimethylthiophene has been made. The assignments were made by chemical shift arguments, by the use of C-13 labelling when required and different decoupling techniques. This information may be useful in the identification of new compounds with analogous carbon skeleton.

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The synthesis of oxetanes derived from heterocycles has been a major field of research in this laboratory. Since the structural assignments have always been made on the basis of proton nmr spectra it appeared very convenient for future studies to broaden the scope of the techniques available for structure elucidation.  $^{13}\text{C}$ -nmr spectroscopy is a logical and powerful tool to be explored in this connection. Just as the knowledge of proton nmr spectra of certain key oxetanes has been useful to establish analogies when new compounds are synthesized, the  $^{13}\text{C}$ -nmr data derived from the representative series of oxetanes studied in this paper may very well provide additional information to be used as a model in the identification of new compounds.

The compounds studied in this paper are depicted in Table I. They are oxetanes derived from the cycloaddition of benzophenone to 2-methyl-, 2-hydroxymethyl-, 3-hydroxymethyl-, 2,5-dimethylfuran, furan and 2,5-dimethylthiophene, as well as the oxetane derived from 2-naphthaldehyde and furan. Except for compound 7 all these photoproducts were reported previously (1) but no  $^{13}\text{C}$  techniques were available at the time. The assignments of chemical shifts for the different carbon atoms were made in some instances by comparison with compounds possessing analogous structural features which have already been thoroughly studied and reported in the literature (2), by the use of gated-decoupling and in some instances  $^1\text{H}$  single-frequency selective decoupling techniques. Unequivocal assignments of tertiary and quaternary carbon atoms were achieved by changing substituents and observing the corresponding variations in chemical shifts, coupling constants and multiplicity and when necessary by  $^{13}\text{C}$  labelling of the position under consideration.

The  $^{13}\text{C}$ -nmr data obtained confirm the structures already proposed in previous papers for the photoproducts namely, structure 1 (1,3). Structures 2 and 3 are discarded as they were before when  $^1\text{H}$ -nmr spectra were employed in structure elucidation.

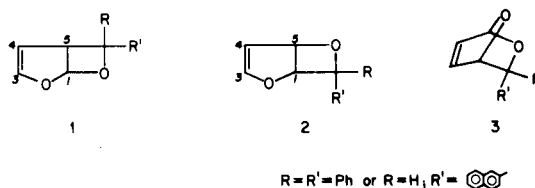


Fig. 1

The resonances corresponding to the aromatic carbon atoms which are present in all the compounds are found between 122 and 130 ppm and are not discussed because they are less relevant in the structure elucidation of these compounds.

The resonance at about  $\delta = 147.5$  ppm, the lowest in the spectrum, was assigned to C-3 in structures 4, 5, 6, 7 and 9. This value is analogous to that of C- $\alpha$  in furan,  $\delta = 142.7$  ppm, and the coupling constant  $^1J_{\text{CH}} = 194.6$  Hz has also a great resemblance to  $^1J_{\text{CH}} = 201.0$  Hz corresponding to the C- $\alpha$  of furan (4). Furthermore, this assignment is supported by the fact that when the proton bonded to that carbon atom is substituted by a methyl group C-3 as in compound 8, becomes a quaternary carbon atom and the chemical shift is displaced down field to  $\delta = 157.4$  ppm. This value is analogous to that of the vinylic C- $\alpha$  to the oxygen atom in compound 11,  $\delta = 141.8$  ppm (2a). Furan, as is well known, is the least aromatic of the common five-membered heterocyclics and from its chemical behavior in cycloaddition reactions it may be considered as a diene system with very small delocalization of its double bond electrons (5). Therefore, when benzophenone adds to one of its double bonds the remaining one should be very much like the same double bond in the unreacted furan. This statement is corroborated by the correlations mentioned above.

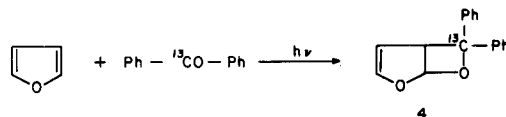


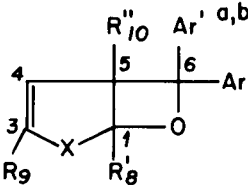
Fig. 2

The resonances found at  $\delta = 52-59$  ppm, with coupling constants  $^1J_{CH} = 147.9-149$  Hz have been assigned to tertiary carbon C-5 in structures **4**, **5**, **6**, **8** and **9**. This assignment was made first on the basis of  $H_s$  selective decoupling and on the other hand by substituting  $H_s$  with a

hydroxymethyl group as in compound **7**. This substitution changes C-5 from a tertiary carbon atom to a quaternary carbon atom and therefore its chemical shift is displaced downfield to  $\delta = 66.5$  ppm.

The resonances exhibited in the range of  $\delta = 91.6 - 96.5$

Table 1  
 $^{13}C$ -NMR DATA ON THE OXETANES

	CARBON ATOMS <sup>c</sup>							
	C-3	C-4	C-5	C-1	C-6	C-8	C-9	C-10
4	148.1	102.7	56.1	105.2	94.6			
	194.6	178.0	149.6	183.6				
5	147.8	102.8	57.4	112.9	91.6	23.0		
R' = CH <sub>3</sub>	194.1	177.1	147.8			127.6		
6	148.3	103.3	54.3	113.3	93.0	63.1		
R' = CH <sub>2</sub> OH	194.3	178.1	152.3			144.6		
7	147.5 (144.4) <sup>c</sup>	105.9 (107.4)	66.5 (67.3)	105.5 (106.7)	96.5 (97.2)			61.9 (61.4)
R'' = CH <sub>2</sub> OH	194.6	178.1		182.6				141.8
8	157.4	97.7	58.7	112.6	91.0	23.1	13.7	
R = CH <sub>3</sub>		174.4	146.9			127.6	127.6	
R' = CH <sub>3</sub>								
9	148.5	104.2	52.5	108.3	92.8			
Ar = 2-Naphthyl	194.6	179.9	146.9	184.5	154.2			
Ar' = H								
10	146.1	116.8	66.3	103.1	93.3	28.7	16.7	
X = S		169.0	146.0			118.0	128.5	
R = CH <sub>3</sub>								
R' = CH <sub>3</sub>								

a) R, R', R'' = H; X = O; Ar = Ar' = Ph unless otherwise stated

b) All the aromatic resonances are found between 122 and 130 ppm

c) All spectra were measured in CDCl<sub>3</sub> (TMS). The spectrum of **7** was also measured in acetone d<sub>6</sub> and the corresponding resonances are included in parenthesis. This compound is more soluble in the latter and the spectrum improves considerably.

ppm by compounds **4**, **5**, **6** and **8** may safely be assigned to quaternary carbon atom C-6 for two reasons: 1) In compound **9** where one of the two aryl groups is replaced by H it becomes a tertiary resonance at  $\delta = 92.8$  ppm ( $^1J_{CH} = 154.2$  Hz) and 2) when compound **4** is synthesized using labeled benzophenone (carbonyl  $^{13}C$ , 90%) the spectrum exhibits a very remarkable enhancement of the resonance at  $\delta = 94.6$  ppm. The labeled oxetane was diluted with unlabeled compound (10% dilution) and the spectrum recorded under those conditions appears to be identical with that of the unlabeled material except for the fact that the above mentioned resonance at  $\delta = 94.6$  is considerably enhanced.

Attribution of C-4 and C-1 is not as straightforward; they exhibit resonances in the range of  $\delta = 97$ -113 ppm and have to be differentiated from each other. The argument employed to establish the difference between the two of them may be as follows: In compounds **5**, **6** and **8** C-4 is a tertiary carbon atom while C-1 is quaternary. Therefore the doublets observed at  $\delta = 102.8$  ppm ( $^1J_{CH} = 177.1$  Hz), 103.3 ppm ( $^1J_{CH} = 178.1$  Hz) and 97.7 ppm ( $^1J_{CH} = 174.4$  Hz), respectively, may be due to C-4 while the singlets at  $\delta = 112.9$ , 113.3 and 112.6 ppm may be due to C-1.

Less obvious is the assignment for carbon atoms C-1 and C-4 in compounds **4**, **7** and **9** where both carbon atoms are tertiary. However, they may be differentiated by means of their coupling constants as follows:

The doublets whose coupling constants  $^1J_{CH}$  are analogous to those of C-4 in compounds **5**, **6** and **8**, namely  $\delta = 102.7$  ppm ( $^1J_{CH} = 178.0$  Hz) and  $\delta = 105.9$  ppm ( $^1J_{CH} = 178.1$  Hz) and  $\delta = 104.2$  ppm ( $^1J_{CH} = 179.9$  Hz) are consequently assigned to C-4 in **4**, **7** and **9**, respectively. On the other hand, the doublets whose  $J_{CH}$  has a higher frequency, namely,  $\delta = 105.2$  ppm ( $^1J_{CH} = 182.6$  Hz) and  $\delta = 108.3$  ppm ( $^1J_{CH} = 184.5$  Hz) should correspond to C-1 which is reasonable considering that C-1 is located between two oxygen atoms.

Due to the fact that C-1 and C-4 in compound **7** give rise to overlapping resonances, namely,  $\delta = 105.5$  and  $\delta = 105.9$  respectively it was necessary to perform a selective decoupling to confirm these two values. The same procedure was followed with compounds **4** and **9** in order to confirm the assignments corresponding to the same two resonances of C-1 and C-4.

These results strongly support structure **1** which has always been proposed as the correct one (1,3) for these compounds. Structure **2** may be rejected by inspection of the characteristic  $^{13}C$ -nmr features of carbon atoms C-1 and C-5. In structure **1** carbon atom C-1 is flanked by two oxygen atoms, which represent electron attracting groups, while C-5 is only under the influence of the neighboring vinylic carbon atom C-4. In structure **2** both C-1 and C-5 are next to an oxygen atom but C-5 in addition to this in-

fluence continues to be, as before, under the influence of the vinylic C-4. Therefore, the coupling constant  $^1J_{CH}$  of C-1 in structure **1** must be significantly larger than that of C-5 in the same structure (**6**). On the other hand the coupling constant  $^1J_{CH}$  of C-5 in structure **2** should be much larger than that of C-1 in the same structure. Thus, the observed values  $^1J_{C_1H_1} = 184.5$ -182.6 Hz and  $^1J_{C_5H_5} = 146.3$ -152.3 Hz speak very clearly in favor of structure **1**.

It may be noticed that throughout all this argument only one bond ( $^1J_{CH}$ ) coupling constant data has been used to support the assignments made. Unfortunately, the excellent opportunity to employ long range coupling constants, much to the authors' distress, has been missed because they could not be resolved due to the influence of the aryl groups attached to C-6. This disturbance affects particularly the resonances corresponding to C-1, C-4 and C-6.

From the standpoint of chemical shift, comparison of the observed values with the resonances of analogous carbon atoms in model substances strengthen the assignments already made.

Resonances for C-1 in the different oxetanes  $\delta = 105.2$ -113.2 ppm have a good agreement with the values found for compound **12** (**7**) and **13** (**2b**) with O-C-O-type bonds.

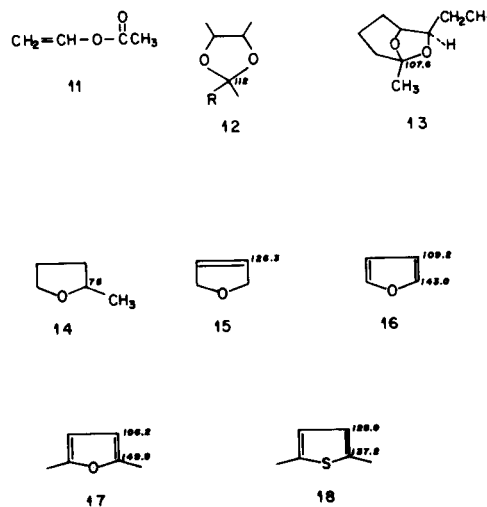


Fig. 3

The chemical shift assignment to C-1 in the series of oxetanes presented here is displaced approximately 30 ppm downfield relative to that for the tertiary  $\alpha$ -carbon atom of 2-methyltetrahydrofuran **14** (**2c**). This is indicative of the fact that C-1 in the oxetanes is presumably less shielded than carbon atoms C-1 and C-5 in structure **2**; carbon atoms C-1 and C-5 in structure **2** should have chemical shifts presumably similar to that of the tertiary  $\alpha$ -carbon atom in 2-methyltetrahydrofuran ( $\delta = 75.0$  ppm) if it had been formed in the photochemical reaction.

Comparing the features of structures **3** and **1** it may be found that both have a carbon atom between two oxygen atoms and both have two vinylic carbon atoms as well. However, structure **3** may be discarded on the grounds that its vinylic carbon atoms should not be so different from each other as far as chemical shift is concerned as it has actually been observed in the spectra of the oxetanes,  $\delta = 147$  ppm and 103 ppm for C-3 and C-4 respectively. If structure like **3** were present one would expect for the vinylic carbon atoms a value of around  $\delta = 126$  ppm as it is observed for the vinylic carbon atoms in structure **15** (2d). The vinylic carbon atoms in structure **1** are in fact very similar to the carbon atoms of furan itself, **16** (2e) as far as chemical shift is concerned as it has been suggested above.

Once the assignments have been made for the series of oxetanes from furan and its methyl derivatives it is possible to study structure **10**, namely, the oxetane derived from 2,5-dimethylthiophene and benzophenone. Compound **8** is a good oxygen analog of the thiophene derivative.

Table I shows the similarities between the chemical shifts of compound **10** and the furan derivatives which allowed to reasonably assign the different values to each one of the carbon atoms in compound **10**.

It is interesting to note that the differences between chemical shifts of carbon atoms 3 and 4 in the oxetanes,  $\Delta(\delta C_3 - \delta C_4)$  is of the order of 45 while the difference between the chemical shifts for the carbon atoms  $\alpha$  and  $\beta$ ,  $\Delta(\delta C_\alpha - \delta C_\beta)$  in 2,5-dimethylfuran **17** and furan itself is 44 and 34, respectively which are not so different from the former. However, when this correlation is considered for the oxetane derived from 2,5-dimethylthiophene and benzophenone,  $\Delta(\delta C_3 - \delta C_4) = 29.3$  as compared to  $\Delta(\delta C_\alpha - \delta C_\beta) = 12$  for 2,5-dimethylthiophene **18**, the difference between the two values is quite large; in fact, the relationship is more than twice ( $29.3/12 > 2$ ).

This relatively larger difference observed in the chemical shifts under consideration, in the thiophene derivatives, compared to that of the furan analogs, seems to indicate that 2,5-dimethylthiophene undergoes a more drastic change in its electronic configuration when benzophenone adds to one of its double bonds than the furan analogs when subjected to the same photochemical reaction. This explanation may be reasonable when one considers the great differences in aromaticity that exist between the two heterocycles.

The study of the  $^{13}\text{C}$ -nmr spectra of the oxetanes derived from carbonyl compounds and five-membered ring, oxygen and sulfur, heterocycles may be useful in future studies on oxetanes derived from heterocycles other than furan and thiophene. Such compounds could, for example, be derivatives of pyrrole and selenophene. There are other cycloaddition compounds which do not have the oxetane

ring but have an analogous carbon skeleton to these compounds and could be easily studied by applying the knowledge acquired in this investigation.

## EXPERIMENTAL

The  $^1\text{H}$ -nmr spectra were measured at approximately  $30^\circ$  with a Varian 90 MHz 360 Nmr spectrometer, TMS as an internal standard.

The  $^{13}\text{C}$ -nmr spectra were determined at 15.08 MHz (deuteriochloroform, TMS) using a Bruker WP60 fourier spectrometer equipped with an internal deuterium lock. In all the measurements the pulse width was 2,7  $\mu\text{s}$ , flip angle  $30^\circ$  and sweep width 3750 Hz, the FIDs were collected in 8K of data points, which gives an acquisition time of 1 s and a computer resolution of 0,917 Hz/point. Broad band decoupled spectra were taken using a noise decoupling pulse of 4w power with a repetition rate of 2 s. Gated decoupling spectra were measured with a pulse delay of 4 s. For selective decoupled spectra the power was 0,3 w.

### Synthesis of Oxetanes.

The general procedure used for the preparation of the oxetanes consisted in dissolving 1 g of the carbonyl compound in 75 ml of the heterocyclic compound. The reaction mixture was irradiated with a Hanovia 450 w mercury arc in a quartz apparatus with a pyrex filter sleeve at  $-10^\circ$  (Colora Kälte Thermostat). Nitrogen was bubbled through the solution before and during the irradiation. The exposure time to uv light varied from 8 to 20 hours according to the individual procedures developed for each oxetane as reported in previous papers. After the appropriate exposure time the irradiation was stopped and the solvent distilled under vacuum. In most cases the residue readily crystallized; in case it did not solidify, treatment with methanol induced crystallization. The compounds were identified and their purity verified by their mass and  $^1\text{H}$ -nmr spectra.

The mass spectrum of compound **7** was determined in a Dupont 21492B mass spectrometer; the elementary analysis of compound **7** was performed by Pascher Microanalytisches Laboratorium, Bonn, Germany.

### 5-Hydroxymethyl-6,6-diphenyl-2,7-dioxabicyclo[3.2.0]- $\Delta^3$ -heptene (**7**).

Benzophenone (3.13 g, 0.0017 mole) was dissolved in 50 ml of 3-furan-methanol and irradiated following the general procedure described above. After 16 hours irradiation, the solvent was distilled under vacuum and the resulting residue crystallized from methanol giving 0.364 g (8%) of white crystals, mp 170-172° nmr (acetone- $d_6$ ):  $\delta$  7.1-7.8 (m, aromatic, 10H); 6.37 (dd, H-1, 1H,  $J_{3,4} = 3.0$ ,  $J_{3,1} = 0.9$  Hz); 6.20 (d, H-3, 1H,  $J_{1,3} = 0.9$  Hz), 5.40 (d, H-4, 1H,  $J_{4,3} = 3.0$  Hz); 3.6 (s broad, OH, 1H); 3.48 (m,  $\text{CH}_2$ , 2H); ms ( $25^\circ\text{C}$ ): 280 ( $M^+$ , 2); (M-46,5), 182 ( $\text{Ph}_2\text{CO}$ , 27), 105 ( $\text{PhCO}$ , 100), 98 ( $\text{C}_6\text{H}_6\text{O}_2$ , 97), 77 ( $\text{Ph}$ , 55).

Anal. Calcd. for  $\text{C}_{18}\text{H}_{16}\text{O}_3$ ; C, 77.12; H, 5.75. Found: C, 77.23; H, 5.74.

## REFERENCES AND NOTES

- (1) Gagnaire and E. Payo-Subiza, *Bull. Soc. Chem. France*, 2623 (1963); C. Rivas and E. Payo, *J. Org. Chem.*, **32**, 2918 (1967); C. Rivas, M. Vélez and O. Crecente, *Chem. Commun.*, 1474 (1970); C. Rivas and R. A. Bolívar, *J. Heterocyclic Chem.*, **10**, 967 (1973).
- (2) L. F. Johnson and W. E. Jankowsky, "Carbon-13 NMR Spectra," Wiley-Interscience, New York, 1972, pp (a) 61; (b) 359; (c)123; (d) 59; (e) 48.
- (3) E. B. Whipple and G. R. Evanega, *Tetrahedron*, **24** 1299 (1968).
- (4) F. W. Wehrli and T. Wirthlin "Interpretation of Carbon-13 NMR Spectra", Heyden and Son, Inc., New York, 1976, p 55; E. Breitmaier and G. Bauer, " $^{13}\text{C}$ -NMR Spektroskopie", G. Thieme Verlag, Stuttgart, 1977, p 228.
- (5) L. A. Paquette, "Principles of Modern Heterocyclic Chemistry", W. A. Benjamin, Inc., New York, 1968, p 136.
- (6) J. B. Stothers, "Carbon-13 NMR Spectroscopy", Organic Chemistry Series, Vol. 24, Academic Press, New York, 1972, p 332.
- (7) M. Alonso, unpublished results.