Tetrahedron, 1967, Vol. 23, pp. 2973 to 2978. Pergamon Press Ltd. Printed in Northern Ireland

REACTION BETWEEN TRIPHENYLPHOSPHINE AND METHYL 5-METHOXYFURAN-2,3,4-TRICARBOXYLATE

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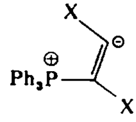
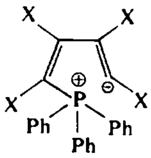
(*Received in Japan 15 August 1966; accepted for publication 18 October 1966*)

Abstract—Triphenylphosphine reacts with methyl 5-methoxyfuran-2,3,4-tricarboxylate to give a red 1:2 adduct. This adduct has a zwitterionic structure and on the basis of physical and chemical evidence, structure XII is proposed.

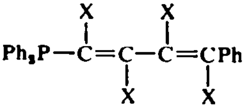
IT HAS been shown[1] that dimethyl acetylenedicarboxylate will add to triphenylphosphine (probably *via* a 1:1 adduct such as I) to give a 2:1 adduct which is probably a zwitterionic form of methyl 1,1,1-triphenylphosphole-2,3,4,5-tetracarboxylate (II) although this is disputed by Hendrikson *et al.*[2] who prefer the five-covalent phosphorus structure. This compound, however, is unstable and rearranges at room temperature to III by means of a phenyl shift. In an effort to extend the scope of this type of reaction, we attempted to generate the adduct I in the presence of other unsaturated linkages. Trial experiments using diphenylacetylene as the unsaturated linkage and unpurified commercial dimethyl acetylenedicarboxylate gave the products previously obtained[1], unreacted diphenylacetylene and small quantities of a dark red compound, m.p. 217°. This last product was not formed when redistilled ester was used and was therefore due to an impurity in the ester.



I

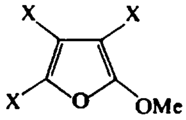


II



$\mathrm{Ph_3P{-}\overset{X}{C}{=}\underset{X}{C}{-}\overset{X}{C}{=}\underset{X}{C}Ph}$

III



IV

$X = CO_2Me$

Careful distillation of the ester at low pressure followed by trituration of the residue with a mixture of ether and petroleum ether gave a small quantity of a colourless solid, m.p. 121°, which was identical with (m.p., IR and UV) a substance isolated[3] some years ago from a sample of the ester which had been stored for some time. On the basis of IR, UV, PMR and mass spectral data, these workers proposed the structure methyl 5-methoxyfuran-2,3,4-tricarboxylate (IV) for this compound. The same compound has recently been isolated from reactions of certain cyclic dienes with dimethyl acetylenedicarboxylate[4] and from the copper catalysed oxidation of this ester[5] and the structure has been confirmed.

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[1] A. W. Johnson and J. C. Tebby, *J. Chem. Soc.* 2126 (1961).

[2] J. B. Hendrikson, R. E. Spenger and J. J. Sims, *Tetrahedron Letters* 477 (1961).

[3] G. W. Brown, R. C. Cookson and D. W. Jones, unpublished results; G. W. Brown, personal communication.

[4] C. F. Huebner, E. Donoghue, L. Dorfman, F. A. Stuber, N. Danieli and E. Wenkert, *Tetrahedron Letters* 1185 (1966).

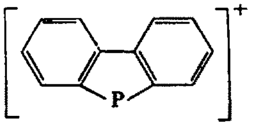
[5] E. Winterfeldt and G. Giesler, *Angew. Chem.* (International Ed.) 5, 579 (1966).

Treatment of the pure furan with pure triphenylphosphine in ether gave an immediate precipitate of the red compound in high yield. The UV spectrum of this compound in chloroform shows λ_{max}(log ε) at 260(3·92), 266(3·89), 274(3·81), 345(3·42) and 468(3·84) mμ. The first three peaks are shoulders on a rapidly rising curve and the longest wavelength maximum is a very broad absorption with a long "tail off" to about 600 mμ. This last maximum is shifted hypsochromically to 458 mμ in ethanol solution.

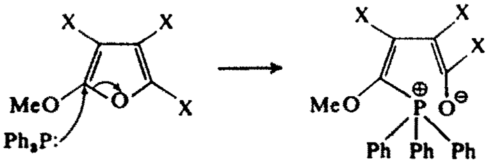
Analyses suggest that the compound is a 2:1 adduct of the furan with triphenylphosphine. This is confirmed by the PMR spectrum which shows 15 aromatic protons in the region τ = 1·9–2·8 and 24 methoxyl protons as a complex multiplet at τ = 5·9–7·2, and by the mass spectrum. The mass spectrum also shows intense peaks at *m/e* 262 and 278 which are strongly suggestive of $[Ph_3P]^+$ and $[Ph_3PO]^+$ respectively. The presence of an intact triphenylphosphine grouping was confirmed chemically by alkaline hydrolysis of the red compound which gave triphenylphosphine oxide as one of the products. This shows that there has been no phenyl migration of the type found[1] in the rearrangement of II to III. There is another strong peak in the mass spectrum at *m/e* 272 which, together with peaks at *m/e* 241 and 154, suggests the furan, the furan minus a MeO group and the furan minus two methoxycarbonyl groups. These assignments have been confirmed by accurate mass determinations. This indicates that at least one molecule of the furan is incorporated in the adduct in a form which allows it to be easily regenerated on electron impact.

The fragmentation of the triphenylphosphine portion of the molecule on electron impact is also of interest since it appears to follow two courses. The first of these is the expected one which is $[Ph_3P]^+ \rightarrow [Ph_2P]^+ \rightarrow [PhP]^+ \rightarrow [Ph]^+$. This is shown by a series of fairly intense peaks at *m/e* 262, 185, 108 and 77. This is reminiscent of the photolysis of triphenylphosphine in alcoholic solution where diphenylphosphine and phenylphosphine are produced.[6] The second fragmentation pattern seems to be $[Ph_2P]^+ \rightarrow$ the 9-phosphafluorenyl ion (V) $\rightarrow$ the biphenylene cation as shown by a series of peaks at *m/e* 185, 183 and 152. The *m/e* 185 → 183 fragmentation is confirmed by a metastable peak at m^* 181 and although a metastable peak for the fragmentation *m/e* 183 → 152 is not present in the mass spectrum of the red adduct, we have noticed such a peak at m^* 127 in the spectrum of another compound containing the triphenylphosphine grouping recorded under somewhat different conditions.[7] We are currently carrying out a separate investigation of the mass spectra of certain phosphines.

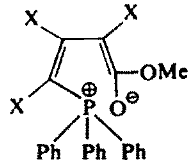
The UV spectrum shows that electrons can be excited relatively easily and a survey of the large number of possible reactions shows that very few of these lead to appreciable conjugation in the product and that all of these structures are zwitterionic.



V



VI



VII

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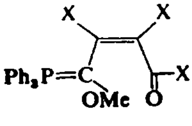
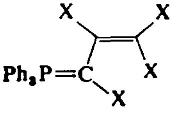
[6] L. Horner and J. Dörges, *Tetrahedron Letters* 763 (1965).

[7] A. N. Hughes, unpublished results.

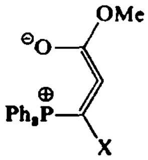
The most obvious first step is nucleophilic attack of triphenylphosphine on either the 2- or the 5-position of the furan ring in IV. At first sight, the 2-position would appear to be the more likely since it is probably more electron deficient than the 5-position and there is little difference in the steric hindrance to attack at these positions (Dreiding models). However, it has recently been shown that in the alkaline hydrolysis of IV, the 5-MeO group is displaced by hydroxide ion[6] and it therefore seems likely that the triphenylphosphine will attack at the same position. Attack at the 2- or 5-position would give initial 1:1 adducts which could exist either in an unstrained six-membered "ring" enolate form (VI or VII) or in an alkylidenephosphorane form (VIII or IX). A similar but presumably less stable enolate form X has been proposed[8] rather than I for the 1:1 adduct which has been isolated from triphenylphosphine and dimethyl acetylenedicarboxylate although Johnson and Tebby[1] were able to isolate a 1:1 adduct only in combination with CO_2 and in a form which suggested I as the intermediate.



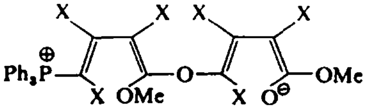
VIII



IX

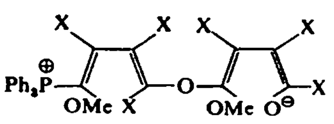


X

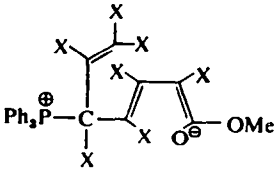


XI

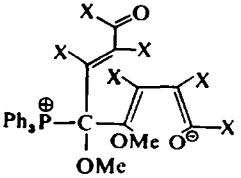
The next stage would then probably be further nucleophilic attack of the initial adduct on another molecule of the furan IV, either in the enolate form to give XI or XII, or in the ylid form to give XIII or XIV depending upon whether attack takes place at the 2- or the 5-position. We prefer to write these adducts in the zwitterionic form rather than the cyclic form because cyclization would destroy the degree of conjugation and mobility of charge required to account for the UV spectrum. Further support for a zwitterionic form is provided by the hypsochromic shift of the UV longest wavelength maximum on changing from chloroform to ethanol as solvent and by the total disappearance of the longest wavelength band in acetic acid solution due to protonation of the enolate group. The red compound can be recovered from acetic acid on careful neutralization. The absence of the P—O—C vibration in the IR spectrum, which should occur as a strong absorption[9] in the range 1050 cm^{-1} to 950 cm^{-1}, also offers evidence for a zwitterionic structure.



XII



XIII



XIV

There is one other remotely possible mode of attack which could give a conjugated

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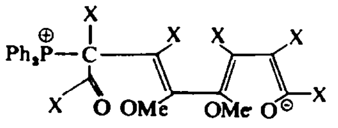
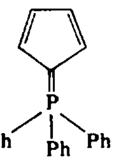
[8] L. Horner and H. Hoffman, *Angew. Chem.* 68, 473 (1956).

[9] C. N. R. Rao, *Chemical Applications of Infrared Spectroscopy* p. 294. Academic Press (1963).

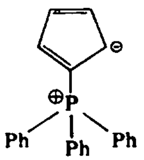
trienolate system. In this reaction, the first stage would be attack of triphenylphosphine on the 3- or 4-position of the furan ring followed by attack of the product at the 2- or 5-position of the second molecule of the furan to give structures of type XV. This seems most unlikely as there is no apparent reason why two molecules of the same furan should undergo attack at different positions. Thus, structures of type XV can be ruled out on the grounds that the reaction sequence is very unlikely. This leaves structures XI–XIV as possibilities.



XV

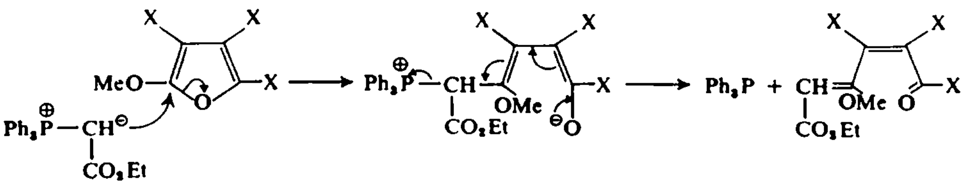


XVII



XVIII

Carbethoxymethylenetriphenylphosphorane ($Ph_3P{=}CHCO_2Et$) has some structural and electronic features in common with the initial 1:1 adduct. If it reacts with the furan IV, it would almost certainly react in the ylid form since no enolate type reactions of this phosphorane have so far been observed but it should be possible to distinguish between ylid and enolate attack by PMR examination of the product. It was found that this phosphorane does react with the furan in ether at room temperature but much more slowly than does triphenylphosphine and the initial 1:1 adduct. The solution became pale orange after 30 min and started to deposit crystals after about 10 hr. Crystal deposition did not appear to be complete for a further 14 hr. However, rather surprisingly, the final product (obtained in poor yield) was identical (IR, UV, PMR and m.p.) with that obtained from triphenylphosphine and the furan. Obviously an initial slow reaction occurs which liberates triphenylphosphine which then reacts rapidly with unreacted furan to give the observed product. This can be explained by considering ylid attack upon the furan according to the following probable sequence. Ylid attack at the 2-position or enolate attack at the 2- or 5-position could give similar results except that in the latter case, ethoxyacetylene would be eliminated as well as triphenylphosphine. Examination of the residue after removal of crystalline adduct and solvent showed traces of triphenylphosphine oxide and the adduct. No other products could be isolated from the remaining red gum.



XVI

X = CO_2Me

Such eliminations of triphenylphosphine from initial adducts of alkylidenephosphoranes with other molecules are not uncommon. For example, this occurs in the reaction of butoxymethylenetriphenylphosphorane ($Ph_3P{=}CHOBu$) with butyraldehyde[10] and the reaction of alkylidenephosphoranes with certain hindered ketones,[11] diazoketones,[12] azides[13] and *p*-dimethylaminonitrosobenzene.[14]

We attempted to confirm the site of attack on the furan ring under non-hydrolysing conditions by reaction of IV with methoxide ion followed by chemical and physical examination of the product. On adding the furan in anhydrous methanol to ice-cold anhydrous methanolic sodium methoxide, a deep orange colour appeared which changed to pale yellow on careful neutralization with potassium hydrogen phthalate. This indicated formation of an enolate ion but careful work up of the products, either by chromatography on neutral alumina or by attempted fractional crystallization from various solvents, gave only resinous materials and it is evident that the enol ether, if formed by methoxide ion attack, is too reactive to be isolated.

Thus, of the possible structures XI–XIV for the adduct, structure XII is the most likely for the following reasons. Nucleophilic attack almost certainly takes place at the 5-position of the furan ring as shown by the alkaline hydrolysis.[5] This is strong evidence against structures XI and XIII. Furthermore, structures XIII and XIV are structurally similar to the initial product XVI of the reaction between carbethoxymethylenetriphenylphosphorane and the furan and might therefore be expected to decompose by elimination of triphenylphosphine whereas structure XII could not do this. For the same reason, structures of type XV would be expected to undergo a similar elimination. Also if IX reacted with the furan in the ylid form, the reaction would be slower than the reaction of carbethoxymethylenetriphenylphosphorane with the furan because the electron density at the carbon atom adjacent to the phosphorus atom should be lower in IX than in $Ph_3P{=}CHCO_2Et$ although this may not be the case in VIII. This is also evidence against structure XIII since the reaction is observed to be very much faster. It is also worth noting that both the positive and negative charges in XII can be stabilised to some extent by distribution over several atoms which is in agreement with the relatively long time (7 hr) required for alkaline hydrolysis of the adduct to give triphenylphosphine oxide. Finally, although nearly all alkylidenephosphoranes react at the carbon atom adjacent to the phosphorus atom, reaction at other sites is not unknown since cyclopentadienylidenetriphenylphosphorane (XVII) reacts at the carbon atom β to the phosphorus atom,[15,16] presumably *via* the resonance contributor XVIII. Therefore, although there is as yet no record of a methoxycarbonyl substituted alkylidenephosphorane reacting in the enolate form, structure VI could be expected to be a substantial contributor to the resonance hybrid of the initial 1:1 adduct of the furan with triphenylphosphine since it could form a stable "ring" with only small charge separation which resembles the zwitterion II.

The structure of the adduct is therefore probably XII although structure XIV cannot be rigorously excluded.

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[10] G. Wittig and W. Böll, *Chem. Ber.* **95**, 2526 (1962).

[11] J. P. Freeman, *Chem. & Ind.* 1254 (1959).

[12] G. Märkl, *Tetrahedron Letters* 811 (1961).

[13] H. Hoffman, *Chem. Ber.* **95**, 2563 (1962).

[14] S. Trippett, *Quart. Revs.* **17**, 430 (1963).

[15] F. Ramirez and S. Levy, *J. Am. Chem. Soc.* **79**, 6167 (1957).

[16] H. Depoorter, J. Nys and A. Van Dormael, *Tetrahedron Letters* 199 (1961).

EXPERIMENTAL

IR measurements were made with a Perkin–Elmer 237 instrument in Nujol and UV spectra were recorded with a Unicam SP 800A spectrophotometer. PMR spectra were recorded in $CDCl_3$ soln with a Varian A60 spectrometer and the mass spectrum was measured with an AEI MS9 mass spectrometer.

Isolation of methyl 5-methoxyfuran-2,3,4-tricarboxylate. Commercial (Aldrich) dimethyl acetylenedicarboxylate (25 ml), about 1 year old, was distilled slowly at 0·5 mm Hg until only a viscous yellow liquid remained. This was cooled, dissolved in ether and slowly treated with pet. ether (40–60°) until precipitation of a semi-solid mass began. The mixture was cooled to 0° and stirred until solidification occurred. The crude solid was filtered off, washed with ice-cold ether and recrystallized from hot MeOH to give colourless plates (3·8 g) of the furan IV, m.p. 121° (lit.[6] m.p. 121°). Smaller quantities of the furan could be prepared by heating the pure ester on a water bath in the presence of air for several weeks.

Reaction of triphenylphosphine with IV. The furan (45 mg) in ether (6 ml) was treated at room temp with triphenylphosphine (23 mg)in ether (2 ml). The soln immediately became deep orange and began to deposit crystals almost at once. After 3 hr, the crystals were filtered from the pale orange mother liquor to give the pure *adduct* XII (55 mg, 83%), m.p. 215–217°. (Found: C, 59·7; H, 4·8; P, 3·7. $C_{40}H_{39}O_{16}P$ requires: C, 59·6; H, 4·8; P, 3·8%.) The adduct can be recrystallized from benzene.

Hydrolysis of the red adduct (425 mg) in boiling NaOHaq (25 ml, 20%) for 7 hr followed by extraction with benzene gave triphenylphosphine oxide (38 mg, 26%).

Reaction of carbethoxymethylenetriphenylphosphorane with IV. The furan (100 mg) in ether (10 ml) was treated with the phosphorane (130 mg) in ether (5 ml). After about 30 min, the soln became pale orange and after about 10 hr, crystal deposition commenced and was complete after a further 14 hr. Filtration followed by washing with ice-cold ether gave the adduct XII as chunky red crystals (45 mg), m.p. 214–216°, identical in all respects with the adduct obtained from triphenylphosphine and the furan IV.

Acknowledgement—We wish to thank Dr. I. G. M. Campbell for the PMR spectra, Dr. F. M. Dean and Dr. J. Goodchild for the mass spectrum and the Rockefeller Foundation and the National Research Council of Thailand for generous financial support.