REACTION OF TRIALKYL PHOSPHITES AND α-HALOKETONES IN APROTIC MEDIA (PERKOW-ARBUZOV REACTION) AND IN PROTIC SOLVENTS

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Abstract

The authors suggest a new reaction mechanism for the Perkow-Arbuzov reaction yielding vinyl phosphates and β-keto phosphonates. For the reaction of α-halo-acetophenones and trialkyl phosphites in alcohol or acetic acid giving 3 products a uniform mechanism involving again a common intermediate was assumed. In the course of our work the applicability of Hammett's equation has been extended for studying parallel and braching reactions, as well.

Phosphorus was known to the majority of chemists solely as a constituent of inorganic reagents and industrial products, as well as that of various stinking preparates, in spite of the fact that already the alchemists suspected its significance in the living organism. This opinion has changed basically in the last decades and by these days the field of organic phosphate complexes became an intensely cultivated area of chemistry. One of the reasons is their increasing industrial importance: large amounts of pesticides, tensides, emollients, antioxidants and flame-retardants containing phosphorus have entered the practical life, and phosphorus compounds are among the new reagents and catalysts of synthetic organic chemical industry. Another reason for the popularity of organic phosphorus research is that it plays a fundamental role in life processes: energy transfer, biochemical reactions, cell division and heredity, discovered not long ago.

Naturally their home application has also started. As an interesting fact it can be mentioned that some 70—80% of insecticides used in Hungarian agriculture are phosphoric acid esters.

Our department has played a significant role in the research of organic phosphorus compounds. In the following we report on our research work revealing kinetic and non-kinetic aspects of the relevant reaction mechanisms.

Vinyl phosphates employed in hundreds of tons all over the world constitute a significant group of phosphoric acid ester insecticides [1]. β-keto-phosphonates are the reagents of the Wittig-Horner reaction [2]. The two groups of compounds are connected by their common synthesis. Namely, α-

haloketones reacting with trialkyl phosphites in aprotic medium yield these two types of compounds in a ratio depending on the reaction conditions and on the substituents of reactants. The production of vinyl phosphates is called in the literature after its discoverer as Perkow reaction [3, 4] while the production of β-keto-phosphonates is mentioned as a special case of the more common Arbuzov reaction (reaction of trialkyl phosphites and alkyl halides) [5, 6].

Due to the practical importance of the products, their synthesis has also been widely studied. For the explanation of the reaction mechanism several theories have arosen. Their common feature is that the process is regarded as composed two parallel reactions: the trialkyl phosphite attacks the α-halo-acetophenone at different points and the two products are due to this fact [7—10].
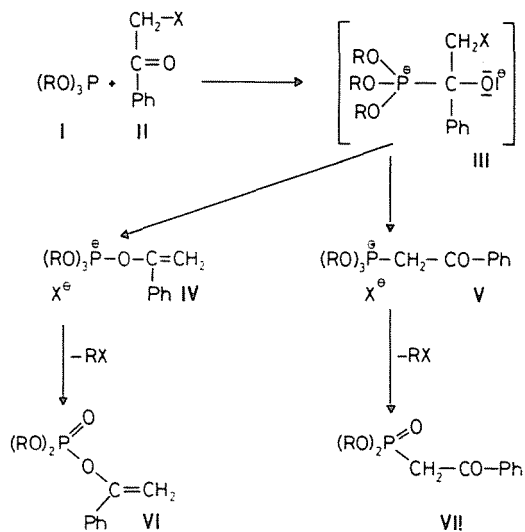
Reaction of α-chloro-, bromo- or iodo- acetophenones (containing various substituents in their aromatic nucleus) with trialkyl phosphites have been examined in detail in an aprotic solvent. It has been established that the ratio of ketophosphonate and vinyl phosphate changes in the sequence Cl < Br < I according to the halogen atom and the rate of reaction increases also in this sequence, however, the change in the ratio of products differs from that expected based on the increase of reaction rate. This led to the conclusion that the ratio of the two products is not determined solely by the rate controlling process but depends on other factors, too.

On the basis of reaction rate constants and activation enthalpy and entropy data we established that the nucleophilic attack of phosphite is controlling the reaction rate. The reaction rate constants combined with the product distribution were plotted in Hammett diagram and it was concluded that this step is identical in the two reactions yielding both products. Accordingly a common intermediate is assumed. This was also supported by the linearity of the activation entropy — enthalpy function. The common intermediate is the betaine (III) produced by the attack of phosphite at the carbonyl carbon atom. This step yields two additional intermediates: either by 1,2 C→0 phosphoryl migration, the IV. vinil oxyphosphonium salt, or by 1,2 C_1→C_2 phosphoryl migration the V. ketophosphonium salt [11, 12].

In the course of our later studies the presence of IV and V type salts has been proved by ^{31}P-NMR examinations and in some cases they were also isolated. We similarly established that from vinyloxyphosphonium salts only vinyl phosphate, from the ketophosphonium salt solely β-keto-phosphonate is formed [8].

The course of reaction was examined in protic media, as well, using as solvent alcohol containing an alkyl group the same as that in the phosphite or acetic acid.

In the literature several parallel reactions have been suggested in which the various compounds are produced due to the different points of attack of the phosphite upon the α-haloketone [7, 8].

$$\text{(RO)}_3\text{P} + \underset{\text{II}}{\overset{\begin{array}{c}\text{CH}_2{-}\text{X}\\|\\\text{C}={O}\\|\\\text{Ph}\end{array}}{}} \longrightarrow \left[\begin{array}{cc}\text{RO} & \text{CH}_2\text{X}\\\text{RO}{-}\overset{\oplus}{\text{P}}{-} & \overset{|}{\text{C}}{-}\overset{\ominus}{\underset{|}{\text{O}}}{}^{\ominus}\\\text{RO} & \text{Ph}\end{array}\right]$$

I   II   III

$$\underset{\text{X}^{\ominus} \quad \text{Ph IV}}{\text{(RO)}_3\overset{\oplus}{\text{P}}{-}\text{O}{-}\underset{|}{\text{C}}{=}\text{CH}_2} \qquad \underset{\text{X}^{\ominus} \qquad \text{V}}{\text{(RO)}_3\overset{\oplus}{\text{P}}{-}\text{CH}_2{-}\text{CO}{-}\text{Ph}}$$

$$\downarrow -\text{RX} \qquad\qquad\qquad \downarrow -\text{RX}$$

$$\underset{\text{Ph} \quad \text{VI}}{\text{(RO)}_2\text{P}\overset{\displaystyle\nearrow^{O}}{\underset{\searrow_{O}}{}}\underset{\text{Ph}}{\overset{}{\text{C}{=}\text{CH}_2}}} \qquad \underset{\text{VII}}{\text{(RO)}_2\text{P}\overset{\displaystyle\nearrow^{O}}{\underset{\searrow}{}}\text{CH}_2{-}\text{CO}{-}\text{Ph}}$$

X: Cl, Br, I
R: Me, Et, iPr, Bu, neopentyl
Ph: phenyl, 4-Me-phenyl, 4-Et-phenyl, 4-Cl-phenyl, 4-Br phenyl 4-NO$_2$ phenyl

Scheme 1

In the reaction three compounds are formed from α-chloro and α-bromo acetophenones: vinyl phosphate, α-hydroxy-phosphonate and acetophenone [14]. Accordingly, no β-keto-phosphonate forms, in contrast to literature data. Our method used for the Perkow-Arbuzov reaction have been completed to extend the Hammett equation for the product ratio of parallel reactions. The results repeatedly yielded a common intermediate generally arising in an equilibrium step, depending on the models. This intermediate must be betaine (III) which is suggested in the case of Perkow-Arbuzov reaction as well. Vinyloxyphosphonium salt (IV), the intermediate of vinyl phosphate, is formed from betaine (III) in a parallel reaction and also another intermediate (VIII) which yields two further endproducts: α-hydroxyphosphonate and acetophenone again in simultaneous reactions. In our explanation the intermediate VIII., a quasiphosphonium salt is formed in reaction of the betaine with the solvent has been suggested from which the products can be derived [15].
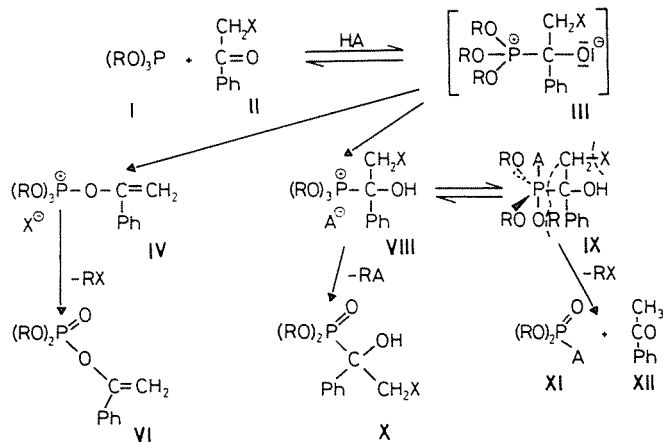
R: Me, Et, iPr,
Ph: phenyl, 4-Me-phenyl, 3,4-diMe-phenyl, 4-Cl-phenyl, 4l-phenyl
HA: ROH, CH₃COOH
X: Cl, Br

Scheme 2

Acknowledgement

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