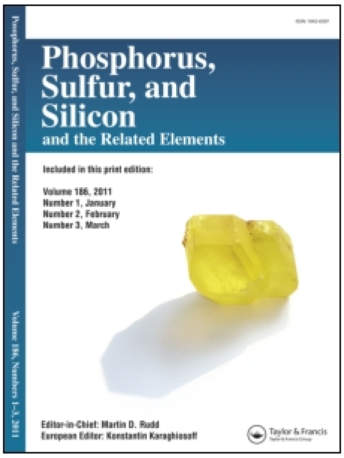

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Chemical Reactivity of Alkylidene Phosphoranes and the Relevant Phosphonium Salts Toward Some Carbon-Nitrogen Systems

Wafaa M. Abdou[a]
[a] National Research Centre, Cairo, Egypt

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CHEMICAL REACTIVITY OF ALKYLIDENE PHOSPHORANES AND THE RELEVANT PHOSPHONIUM SALTS TOWARD SOME CARBON-NITROGEN SYSTEMS

Wafaa M. Abdou
National Research Centre, Dokki-12622, Cairo, Egypt

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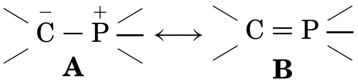
The published work on the main chemical reactions of alkylidene phosphoranes and the relevant phosphonium salts with different carbon-nitrogen systems are thoroughly discussed, whereas their importance as synthones in heterocyclic chemistry are indicated briefly, and the long controversy concerning their structure is only summarized in order to expose the latest results on the subject. The literature has been fully covered up the last two decades.

Keywords: Carbon-nitrogen systems; phosphorus ylides; reactions; synthesis heterocycles

INTRODUCTION

Phosphorus ylides behave chemically as carbanions, effecting both substitution and addition reactions. They represent a very useful synthetic tool in the field of preparative organic chemistry.[1–7] For many years,[5] the studies of phosphonium ylides have concentrated on the nature of the P=C bond and many unique physical and chemical properties of ylides have been attributed to the role of *d* orbital, including the invoking of *dsp*^{3} hybridization between a dipolar form **A** and a double bond form **B**. For the purpose of chemical reactivity, the dipolar form **A** is considered the more important. Previously, structure **B** was meant to indicate dπ-pπ bonding involving back-donation of/



A **B**

Address correspondence to Wafaa M. Abdou, National Research Centre, Dokki-12622, Cairo, Egypt.

electron density from a doubly occupied $2p$ orbital of the ylidic (anionic) carbon into the vacant phosphorus $3d$ orbital in an overlap scheme such as that discussed for phosphine oxides. Nevertheless, modern quantum mechanical calculations permit determination of the role of d-orbitals for these species.[1b] Based on the results of high-quality *ab* initio molecular orbital (MO) calculations,[8,9] one can conclude that the dominant resonance structure in the phosphonium ylides is the ionic one, and that these ylides should not be classified as hypervalent. Schmidbaur et al.[10] and others[11] have described the phosphonium ylide as an easily pyramidalized carbanion stabilized by an adjacent tetrahedral phosphonium center. There is clearly not a full separation of charge with a $+1.0$ on phosphorus and a -1.0 on carbon, but there is cationic phosphorus and an anionic carbon. The MO results also show that there is delocalization of the lone pair on the carbanion toward the phosphorus. The extent of this delocalization depends on the quality of the basis set and the level of the calculation. The most extensive calculation in terms of an n-particle treatment shows a significant amount of delocalization, which leads to mixing of the delocalized lone pair with the P—C σ bond and the formation of two highly polarized π bonds. In effect, the actual electron-density distribution in the P=C bond, is still a matter of debate. Notwithstanding, the concept of virtual d-orbital involvement in bonding of the main group elements has been discredited[8–11] but its use still persists.[12,13]

Alkylidene phosphoranes have been loosely classified according to their carbanionic stability and hence their reactivity. Stabilized ylides usually have strong electron withdrawing groups (CO_2R, COR, CN) on the ylidic carbon and usually favor the production of (E) alkenes. Semistabilized (or moderated) ylides bear mildly conjugated substituents (e.g. Ph or allyl) and often give no great preference one way or the other. Nonstabilized ylides lack such functionalities and may include alkylides ($RCH{=}PPh_3$, R=alkyl) which usually favor (Z)-alkenes. The phosphoranes ($Ph_3P{=}CR^1R^2$) and the relevant salts ($Ph_3P^+{-}CHR^3Br^-$) used in this monograph belong to any of these classes.

In general, the most dominant synthetic use of ylides is their reactions with carbonyl compounds, which regioselectively afford new carbon-carbon double bonds with the elimination of triphenylphosphine oxide (Wittig reaction). The synthetic applications of the Wittig reaction as well as its mechanism and stereochemistry have been reviewed many times.[1–7] However, as is to be expected from their unique molecular and electronic structures, phosphorus ylides react with a wide series of electrophiles (e.g. halogens, thiocarbonyl, activated olefins, alkyns and conjugated nitrogen compounds). In spite of these reactions which are very useful in general organic synthesis, only sporadic activity[1b,c,5c,6a,7b] has been placed on reviewing such electrophiles other than aldehydes and ketones.

Reactions of nitrogenous compounds with phosphorus ylides and their phosphonium salts have been a subject of extensive study in the past two decades. Numerous reports have appeared in the literature that highlight their chemical reactivity toward Wittig reagents and their uses. These advances warrant reviewing the chemical reactivity of carbon-nitrogen systems toward phosphonium ylides (alkylidenetriphenylphosphoranes). The classification is based upon the type of the nitrogen-functional group (amines, amides, thioamides, imides, imines, nitriles, isocyanates, etc.) in the given molecule regardless of the site of attack by the reagent. There are, however, some exceptions to this classification, some of which will emerge in the subsequent discourse.

The emphasis in this article will be placed on information added to this topic from 1980 to the end of 2000. The author has attempted to be encyclopedic with respect to the topics and chemistry covered but not in citing all examples of every reaction.

Nitrogen compounds in the presence of various ylides or their salts, undergo different courses of reactions to yield linear-, fused heterocycles, or unexpected products. The nature and the structure of the reacting ylide (substituents on phosphorus and carbanion), the reactant and the experimental conditions (solvent, catalyst, and temperature) most significantly affect the course of the reaction.

SYNTHESIS OF ALKYLIDENE PHOSPHORANES

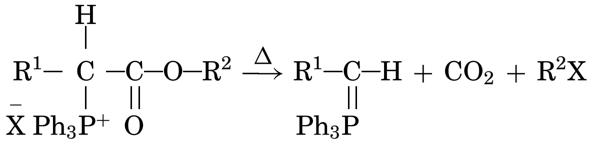
Preparation of phosphorus ylides could be achieved through many available methods. The most general and widely applicable is the salt method, which involves formation of the phosphonium salt **A**. Deprotonation of the latter with a base leads to the ylide **B**.[14–16]

$$R^1R^2CHX + Ph_3P \rightarrow \underset{\textbf{A}}{Ph_3\overset{+}{P}CHR^1R^2\ \overset{-}{X}} \rightarrow \underset{\textbf{B}}{Ph_3P{=}CR^1R^2}$$

R^1, R^2 = H, alkyl, aryl,...
X = Cl, Br, I

Some other methods used for preparing the phosphoranes are:

1. Pyrolysis of the phosphonium salts.[17] For example:



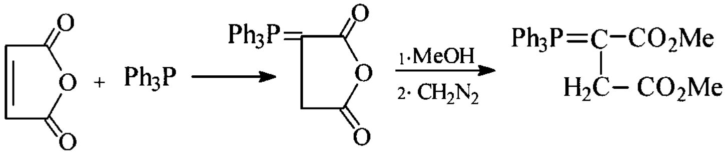
$$R^1-\underset{\overset{|}{\overset{-}{X}\,Ph_3P^+}}{\overset{\overset{H}{|}}{C}}-\underset{\overset{\|}{O}}{C}-O-R^2 \xrightarrow{\Delta} R^1-\underset{\overset{\|}{Ph_3P}}{C}-H + CO_2 + R^2X$$

2. Reaction of carbenes with triphenylphosphine.[18–20] For example:[19]

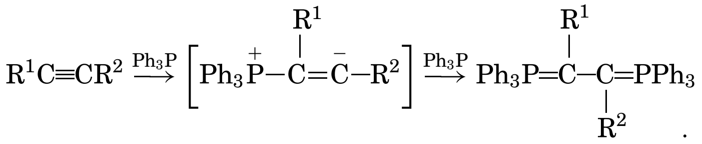
$$Ph_3P + CHX_3 \xrightarrow{^tBuOk} Ph_3P{=}CX_2$$

$$X = Cl, Br$$

3. Addition of phosphines to alkenes[21–23] and alkynes.[24,25] For example:[21]



and for example:[25]



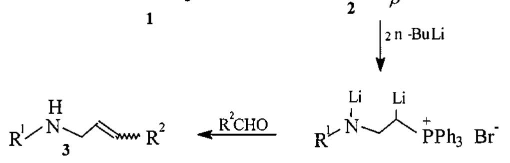
$$R^1C{\equiv}CR^2 \xrightarrow{Ph_3P} \left[Ph_3\overset{+}{P}-\overset{R^1}{C}=\overset{-}{C}-R^2\right] \xrightarrow{Ph_3P} Ph_3P{=}\overset{R^1}{C}-\underset{R^2}{C}{=}PPh_3\ .$$

REACTIONS OF ALKYLIDENE PHOSPHORANES AND THE RELEVANT PHOSPHONIUM SALTS WITH CARBON-NITROGEN SYSTEMS

Reactions with Amines

With Primary Amines

Primary amines undergo an addition reaction with unsaturated phosphonium ylides of type **1** to give β-aminophosphonium salts. The products are suitable precursors for elaborating secondary allyl amines via the Wittig reaction with aldehydes.[26–30] Through the approach outlined in Scheme 1, a series of *N*-alkyl-β-aminoethylphosphonium salts

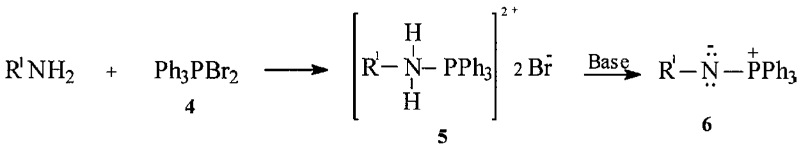


R¹= benzyl, (Me)$_2$C(SiMe$_2$)OCHPhCH$_2$,
R²= Ph, 4-Me-C$_6$H$_4$, MeCH=CHMe

SCHEME 1

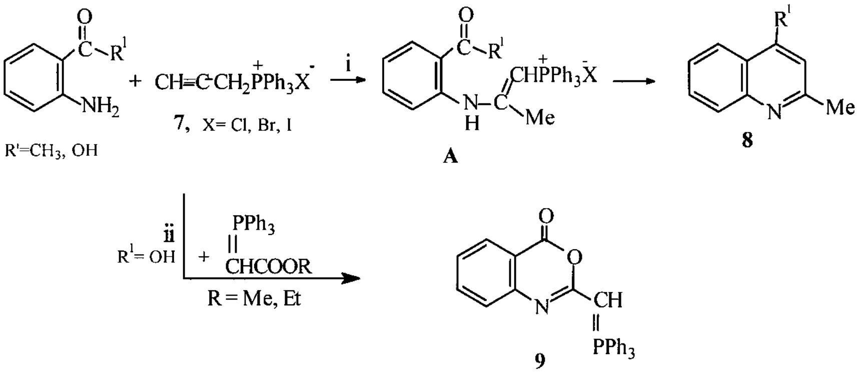
2 has been synthesized. The utilization of these functionalized salts in the preparation of secondary allyl amines **3** via the Wittig reaction is reported.[26] *trans*-Olefin selectivity was exhibited for allyl amine products **3** obtained from aromatic or unsaturated aldehydes, but not from aliphatic aldehydes.

It is of interest to mention that the reaction of a wide range of primary arylamines with triphenylphosphine dihalide of type [Ph_3PX_2] **4**, in the presence of two equivalents of triethylamine, afforded the iminophosphoranes **6** in high yields (Scheme 2).[31,32] The reaction is general, and has been developed, since 1958,[31a] providing an applicable methodology for the preparation of iminophosphoranes. The mechanism probably involved the attack of the amine on phosphorus to give the salt **5** followed by deprotonation. More insight into the latter reaction is, however, beyond this monograph as our interest is limited to the alkylidene phosphoranes.



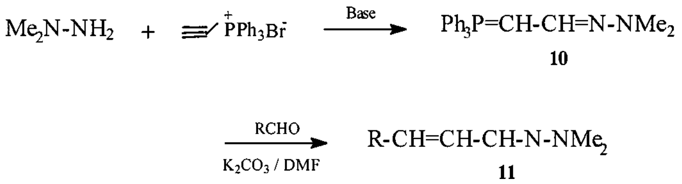
SCHEME 2

o-Aminobenzophenone or *o*-aminobenzoic acid adds to prop-2-ynyltriphenylphosphonium salt **7** to yield the phosphonium salts **A** which cyclizes in an intramolecular Wittig reaction to the quinolines **8** (Scheme 3).[33] Recently, *o*-aminobenzoic acid was reported to react with ester ylides and yielded new complex ylidene phosphorane **9**.[34] Apparently, the reaction of the activated amines with ylides is dependent upon the structure of the applied ylides (Scheme 3).



SCHEME 3

The closely related N,N-dimethylhydrazinehydrate also adds propargyltriphenylphosphonium bromide to give enhydrazinophosphonium salt in 88% yield. Conversion to the ylide phosphorane using a base and by reaction with aliphatic, heteroaromatic and aromatic aldehydes leads to the corresponding 1-azadienes **11** via the ylide **10** (Scheme 4).[35]



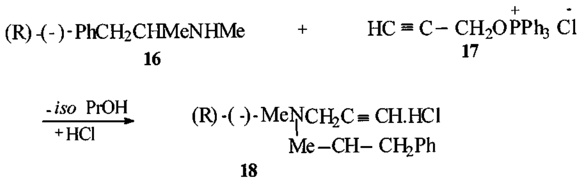
SCHEME 4

With Secondary Amines

In analogous fashion, secondary amines alkylate unsaturated phosphonium salt **12** to give the addition products **13** (Eq. 1).[30] When the reaction was carried out in the presence of triethylamine, the rearranged product **15** was isolated. Nesmeyanov et al.[30] presumed the rearrangement of the salt **12** to **14** in the first place (Eq. 2).

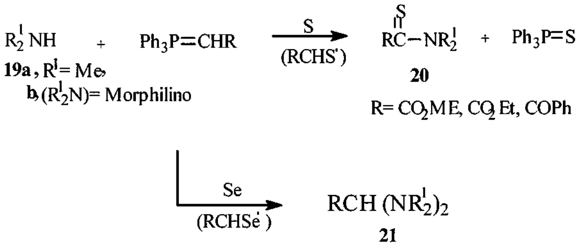
$$\begin{tikzcd}
R^1R^2NH + \underset{\mathbf{12}}{Ph_3\overset{+}{P}-CH_2-CH=CH_2\,\overset{-}{I}} \arrow[r] \arrow[d, "Et_3N"] & \underset{\mathbf{13}}{Ph_3\overset{+}{P}-(CH_2)_3-NR^1R^2\,I^-} & (1) \\
\underset{\mathbf{14}}{Ph_3\overset{+}{P}-CH=CHMe\,\overset{-}{I}} \arrow[r] & \underset{\mathbf{15}}{Ph_3\overset{+}{P}-CH_2-CHMeNR^1R^2\,\overset{-}{I}} & (2)
\end{tikzcd}$$

The anti-Parkinson agent selegiline hydrochloride (**18**) is similarly produced by the reaction of desoxyephedrine (**16**) with phosphonium salt **17** (generated from prop-2-ynyl alcohol, Ph_3P, and CCl_4 in situ). The reaction proceeds in a polar solvent in the presence of triethylamine, followed by treatment with HCl in *iso*-propyl alcohol (Scheme 5).[36] When MeCN replaced the polar solvent in an analogous example, the yield of (*R*)-(−)-**18** was reduced dramatically.



SCHEME 5

A further example of the reactivity of secondary amines is reported by Okuma et al.[37] When the amines **19** were allowed to react, in the presence of sulfur, with stabilized ylides, the thioamides **20** were obtained in high yields along with triphenylphosphine sulfide (Eq. 3). This result is rationalized in terms of the appearance of RCHS˙ moiety in the reaction. On repeating the reaction of **19b** with the same ylides, in the presence of Se, diamines **21** were obtained (Eq. 4).

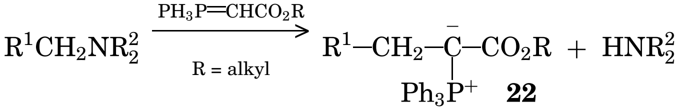


(3)

(4)

With Tertiary Amines

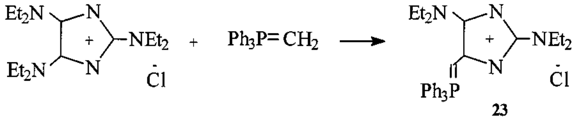
Tertiary amines (Mannich bases), on the other hand, undergo nucleophilic substitution by the elimination-addition mechanism. The alkylidene phosphorane is acting first as a base and then it reacts with the *o*-quinonemethanide-initially formed-according to Eq. 5.[5,38,39] Application of this reaction to the most common types of Mannich bases, derived from ketones, phenols and indoles, afforded the corresponding alkylated ylides of type **22** (Eq. 5).[38]



$$R^1CH_2NR^2_2 \xrightarrow[R\ =\ alkyl]{PH_3P{=}CHCO_2R} R^1{-}CH_2{-}\underset{Ph_3P^+}{\overset{-}{C}}{-}CO_2R + HNR^2_2 \quad (5)$$

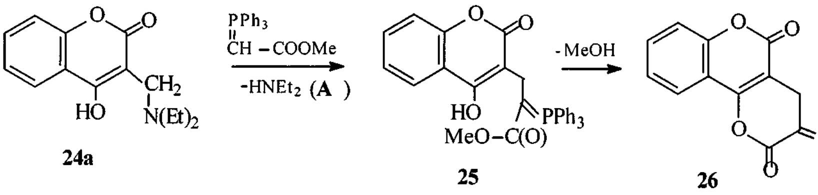
22

1,3-Diazafulven-6-yltriphenylphosphonium salt **23** was likewise reported as the product of the reaction of 1,3-diazacyclopentadienylium salt with methylenephosphorane (Scheme 6).[40]



SCHEME 6

o-Phenolic-Mannich bases are, on the other hand, of special interest owing to the participation of the phenolic hydroxyl. Thus, the alkylation process may be accompanied by lactonization (Eq. 6), or by a hemiketalization-dephosphorylation sequence (Eq. 7), that can be viewed as an internal Wittig reaction.[39]



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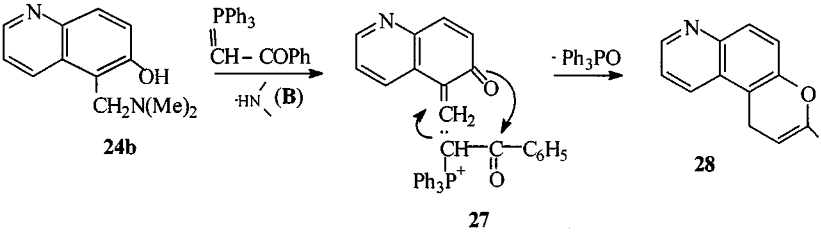
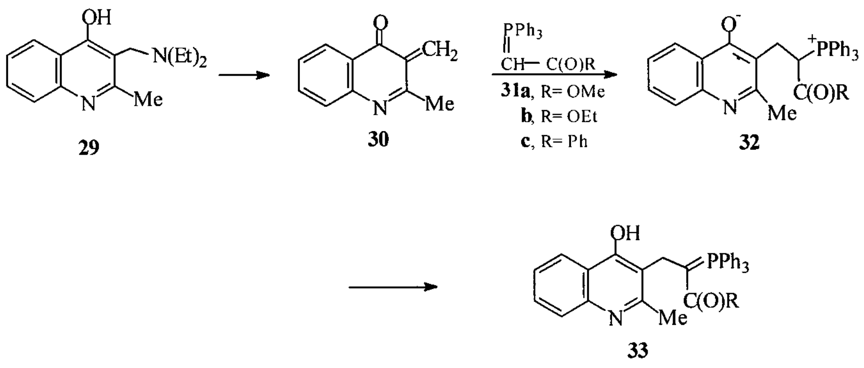


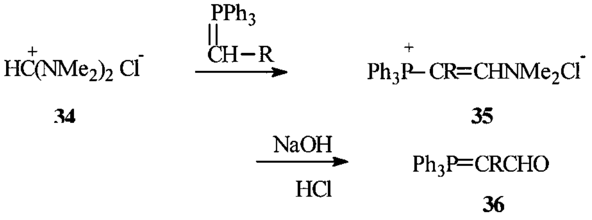
(7)

Meanwhile, when *N,N*-diethylaminomethyl-4-hydroxyquinolidine (**29**) was allowed to react with stabilized phosphoranes **31a–c**, new complex phosphonium ylides **33** were formed (Scheme 7).[41] The proposed mechanism to account for the formation of compounds **33** consists of: (a) loss of diethylamino group from **29** gives *o*-quinonemethanide like **30**, (b) reaction of the intermediate **30** with ylides **31** affords the corresponding betaine **32**, which is electron-withdrawing in nature, would stabilize formation of ylide structure **33** via migration of the α-proton to electron-rich center of the molecule (Hofmann transylidation).



SCHEME 7

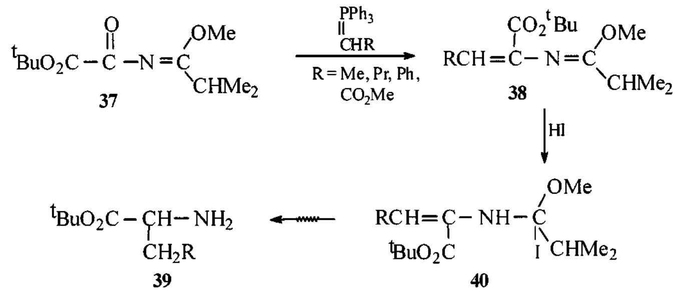
Tetramethylformamidine chloride (**34**) was reported to react with non-stabilized or semi-stabilized ylides to give the formylated ylides **36** by following the initial alkylated products **35** with hydrolysis (Scheme 8).[38] on the other hand, *N*,*N*-dialkyltrifluoroacetamides undergo Wittig reaction with stabilized ylides to give trifluoromethylated enamine derivatives.[42]



SCHEME 8

Reactions with Amides

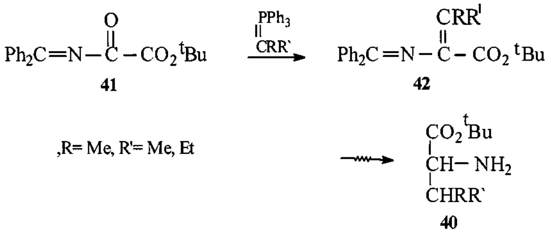
Reactions of ordinary amides with phosphonium ylides were reported for the first time in 1981. Two reactions described intramolecular Wittig reactions at the carbonyl group to form pyrroles,[5,43,44] and the third was also Wittig reaction at the carbonyl group of a β-lactam,[45] all rather than acylation reactions. In this respect, Le Corre group[46] reported the reaction of a variety of ylides, both stabilized and non-stabilized ylides, with oxamic esters **37** and obtained exclusively the product of Wittig reaction at the amide group, yielding the respective alkene **38** (Scheme 9). Subsequent reaction with HI provided protected α,β-dehydro-α-amino acids **39**. Two further steps yielded the α-amino acids **40**.



SCHEME 9

Oxalamide **41** was likewise olefinated with ylides to give the azadienes **42** which could be further reduced to α-amino acid derivatives

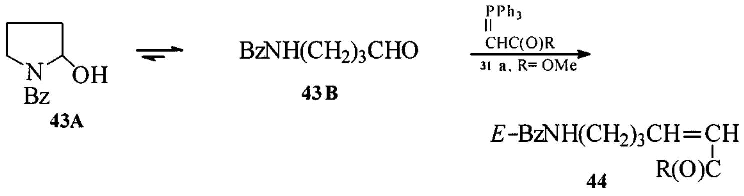
40 (Scheme 10).[47] As a result of Schemes **9** and **10**, Wittig reaction of amides provided a convenient access to α-amino acid derivatives. Thus, any potential side chain that can be assembled into an ylide form can be coupled to a glycine synthon.[48–51]



SCHEME 10

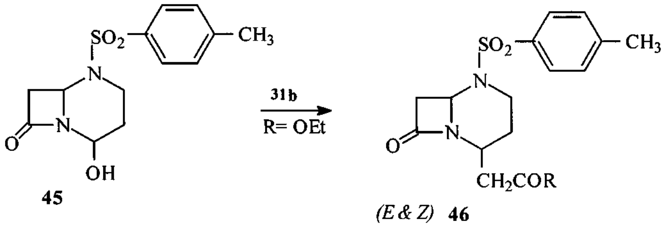
Giannis et al.[52] and others[53] similarly reported alkene formation from several unprotected carbohydrates, including acetamide derivatives, by reaction with benzylidenetriphenylphosphorane. A great number of enamines derived from Wittig reaction of the corresponding amides at the carbonyl group are also reported in the literature.[54–67]

N-Benzoyl-2-hydroxypyrrole was reported to react with ylide **31a** in refluxing xylene and yielded a quantitative yield of the corresponding open-chain ethylenic compound **44**, only in *E*-form (Eq. 8).[68] It was indicated that the hydroxylated substrate **43A** exists in equilibrium with the corresponding open-chain w-amidoaldehyde **43B**.



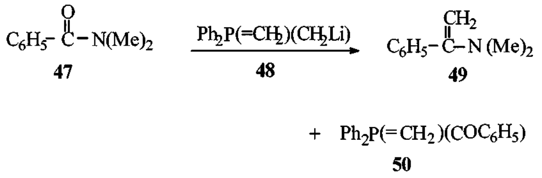
(8)

Meanwhile, the azetidinone **45** was reported to react with phosphorane **31b** to afford **46** as an inseparable diastereomeric mixture (Eq. 9).[69]



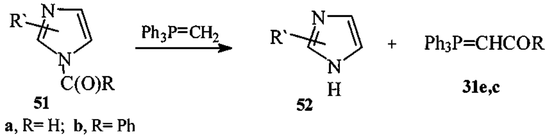
(9)

Although amides most frequently undergo Wittig reaction at the carbonyl group to produce enamines, they acylate ylides in some circumstances. Cristau and Rebeill[70] found that *N*,*N*-dimethylbenzamide reacted with diylide **48** and produced only 20% of the Wittig product **49** and 80% being benzoylated ylide **50** (Scheme 11). However, the reaction could be directed mainly to the Wittig products by protonation.



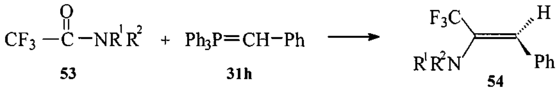
SCHEME 11

Conversely, *N*-formyl- and *N*-benzoylimidazoles **51** reacted with methylenetriphenylphosphorane to give an 81% yield of the acylated ylides **31e** and **31c**, respectively, along with the parent imidazole **52** (Scheme 12).[71,72] In both instances, the imidazole anion ejected upon ylide attack at the carbonyl group was sufficiently basic to remove the proton from the newly formed acylmethylenephosphorane, avoiding the consumption of an equivalent of ylide for that purpose. This process can be, however, exploited to enable the use of virtually any acyl group by initial reaction of an acid chloride with imidazole, followed by addition of any ylide species.



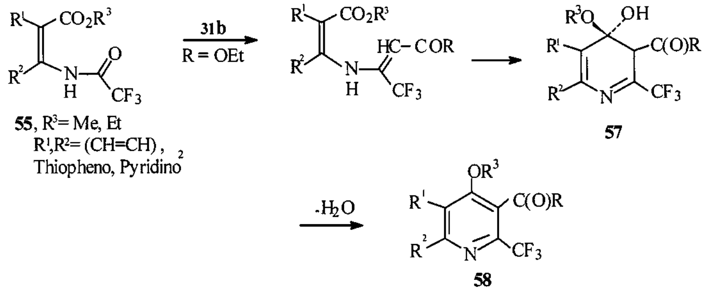
SCHEME 12

N,*N*-Disusbtituted amides of perfluorocarboxylic acids **53** reacted with benzylidene ylide **31h** to yield only the enamines **54** (Eq. 10).[42,73]



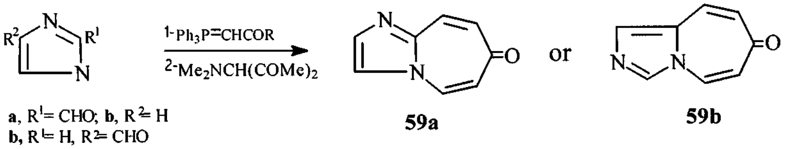
(10)

Wittig reaction of activated amides could be, on the other hand, accompanied by a ring closure leading to the construction of fused heterocycles.[74–77] Latham et al.[57] reported that Wittig reaction of fluorinated amides represented by the general structure **55** did not afford the expected enamines **56**. Instead, the substituted quinolines **58** were produced in moderate yields (Scheme 13). It was suggested that the enamines **56** were formed in the reaction but underwent an internal cyclization with the alkyl ester group, giving the intermediate **57** in which the most bulky C-3 and C-4 substituents i.e. carboalkoxy and alkoxy group, respectively, adopted an anti-relationship. Further elimination of water-rather than ethanol-from **57**, therefore, gave rise to the observed product **58**. In the case of thiophene and pyridine derivatives, the reaction was slow and applying forcing conditions (NaH) was therefore necessary to complete the transformation of **55** to **58**.



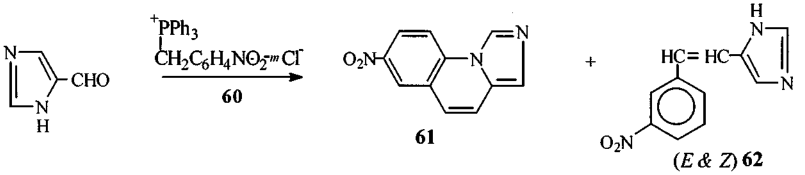
SCHEME 13

The imidazolazepin-7-ones **59a** and **59b** are likewise obtained from the Wittig reaction of imidazoles-2- and 4(5)-carboxyaldehyde with acetonylidene phosphorane **31d.** Treating the produced vinyl ketones with dimethoxymethyldimethylamine [Me_2N–$CH(OMe)_2$] afforded the final products (Eq. 11).[75]



(11)

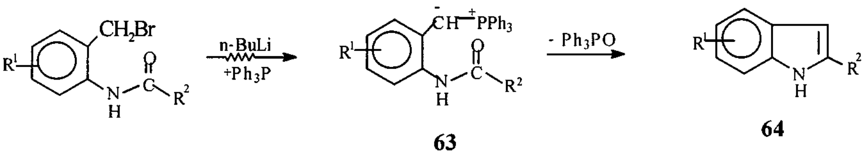
In a similar fashion, an internal cyclization reaction giving an imidazol[1,5-*a*]-quinoline ring system **61** was reported for the reaction of 4-formylimidazole with phosphonium salt **60**. The regeoselective (*E*- and *Z*-) Wittig product, styrene derivative **62**, was also isolated (Eq. 12).[76] It is likely that **61** is a product formed from *Z*-**62**.



(12)

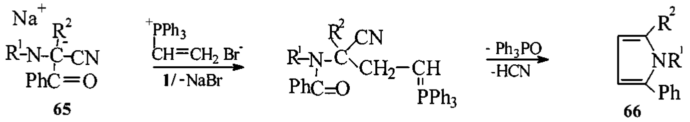
In a manner analogous to that in Equation 12, pyrrolo[1,2-*a*] indole and 3*H*-pyrrolizines were obtained from the reaction of 2-formylindoles or 2-acylpyrroles with vinyl ylide **1** respectively.[77,78]

In another interesting route, *o*-acylaminobenzylidenephosphoranes (**63**) led to indoles **64** in good yields by an intramolecular Wittig reaction with the amido-carbonyl group (Scheme 14).[79] Using this approach, a general method is described for the synthesis of indoles from *o*-nitrobenzyl bromide and *o*-aminobenzyl alcohol.[80]



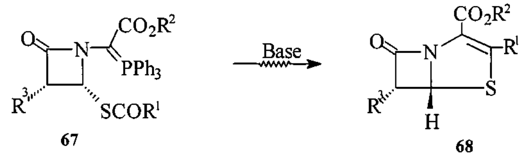
SCHEME 14

Synthesis of 1,2,5-trisubstituted pyrroles **66** was similarly, obtained in 50–100% yield by addition of the amido compounds **65** to vinyl salt **1** with subsequent cyclization by an internal Wittig reaction and base catalyzed elimination of HCN (Scheme 15).[44]



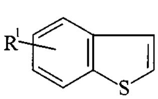
SCHEME 15

Further synthetic uses of intramolecular Wittig reaction for synthesis of the bicyclic penem system are being exploited. The first report was published in 1978 by Woodward et al.[81] describing the preparation of the biologically active β-lactams **68** from the phosphoranes **67** (Eq. 13). Following this breakthrough, since 1979,[82–85] and till to day[12,86–90] there have been several publications directed to elaborating synthetic routes to the penem family, which is closely related to naturally occurring antibiotics.

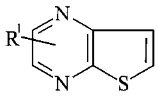


(13)

The internal Wittig reaction is the key cyclization step in all these reactions. Benzothiophenes[91] **69A** and thieno[2,3-*b*]pyrazines[92] **69B** were also prepared by the same approach whereby the thiol ester is attached in preference to an ester group.[93]

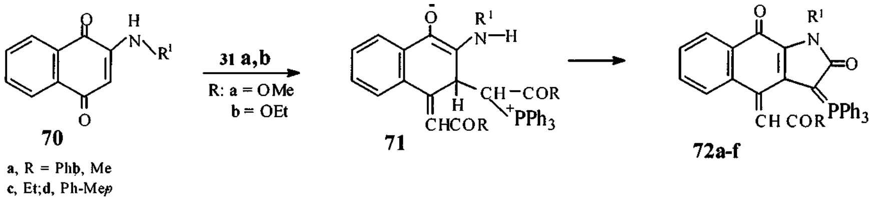


69A



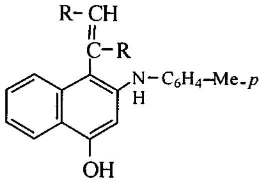
69B

In addition, phosphoranes undergo with amides a number of mechanistically related reactions of some synthetic potential. Conflicting results concerning the reaction of 1,4-naphthoquinone-2-amino derivatives were reported. For example, quinones **70a–c** were reported to react with ylides **31a,b** to give the corresponding pyrroline-phosphonium ylide derivatives **72a–f** via the intermediates **71** (Scheme 16).[94]

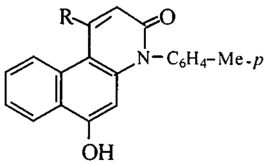


SCHEME 16

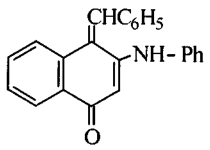
Later on, 2-*p*-toluidino-1,4-naphthoquinone (**70d**) was reported to react with **31a,b** in benzene at room temperature to yield exclusively the respective naphthols *E*-**73** whereas at elevated temperature, only the pyridinones **74** were obtained.[95] Nevertheless, earlier in 1969, Bestmann and Lang[96] found that compound **70a** reacted with benzylidene-phosphorane to form the olefin **75**.



(*E*-) **73**
, R = COOMe; COOEt

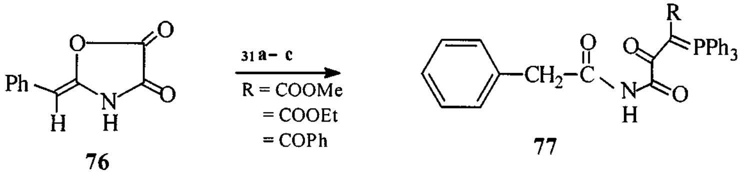


74



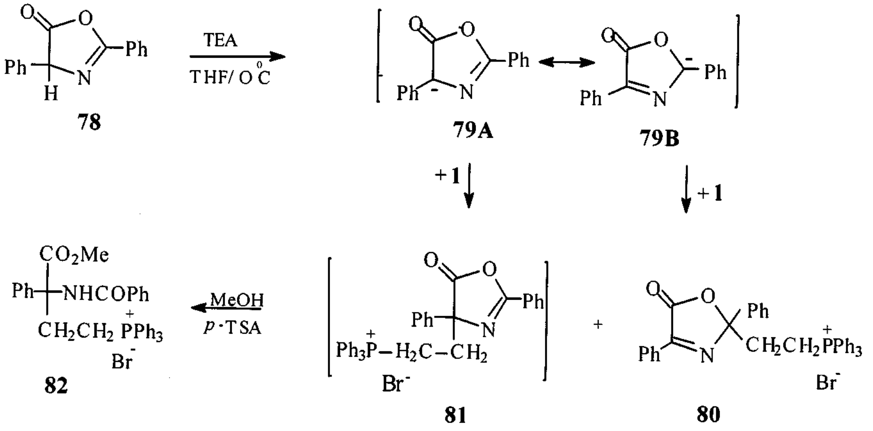
75

The cleavage-addition of ylides **31a–c** to (*E*-)-2-benzylideneoxazolidine-4,5-dione (**76**) occurred very readily and yielded new ylide phosphoranes **77** (Eq. 14).[97]



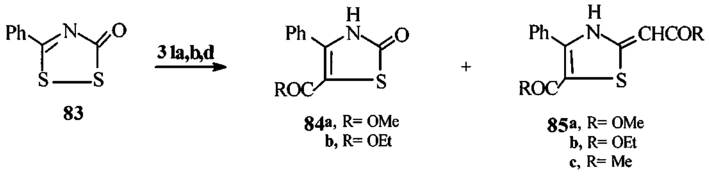
(14)

Conversely, Michael addition of two nucleophilic sites of the mesomeric carbanions **79A** and **79B** of the closely related oxazolone **78** to the vinylphosphonium bromide **1** was observed at 0°C in the presence of a catalytic amount of TEA. The reaction led to the formation of 5(4*H*)-oxazolone **81** and 5(2*H*)-oxazolone **80**. Compound **81** could be identified only in the product mixture and further quenched by methanol and weak acid to the corresponding ester **82** (Scheme 17).[98]



SCHEME 17

Similarly, ring cleavage was observed on treating 5-phenyl-1,2,4-dithiazol-3-one **83** with phosphonium ylides to yield different products, depending on the substituent of the ylide used. Thus, whereas the reaction of **31a**,**b** with *cis*-disulfide **83** has been reported to give a mixture of cyclic thiazole derivatives **84a**,**b** and **85a**,**b**, its reaction with acetonylidene phosphorane **31d** afforded only **85c**. These results have been explained by the preferred attack at the —S—S— linkage by the Wittig reagent. Side reactions, then, lead to the final products (Scheme 18).[99]



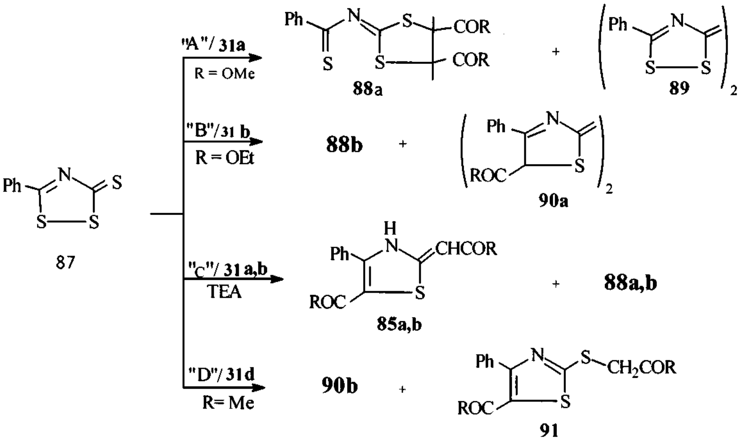
SCHEME 18

Also, dithiazole **83** reacted with benzoylidene-(**31c**) and formylidene-(**31g**) phosphoranes under more drastic conditions and afforde the dimeric product **86** (*E* & *Z*).[99]

E- **86** Z- **86**

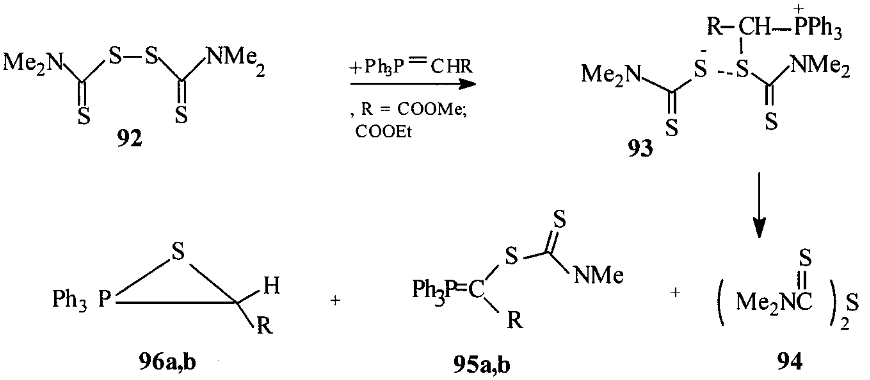
Reactions with Thioamides

In view of their electronic similarity to carbonyl compounds, thioamide substrates react with phosphorus ylides to eliminate triphenylphosphine sulfide and form the corresponding alkenes. Nevertheless, a preferable addition reaction of these ylides, rather than thiocarbonyl olefination, has been reported.[100,101] Their preeminence was shown by kinetic measurements of their cycloaddition with thiobenzophenones *S*-methide and diphenyldiazomethane as 1,3-dipoles.[100b] Thus, the thione-group is considered to be "superdipolarophiles." For example, 5-phenyl-3*H*-1,2,4-dithiazolethione (**87**), the thione analog of compound **83**, reacts with ylides **31a**,**b**,**d** via different routes in comparison with Scheme 18. The reactions are summarized in Scheme 19 and the results are explained in terms of the heightened reactivity of the C=S group to the addition reaction.[102,103] The findings also indicated that the basic medium (TEA) stimulates the course of the reaction at the strained —S—S— bond.[102]



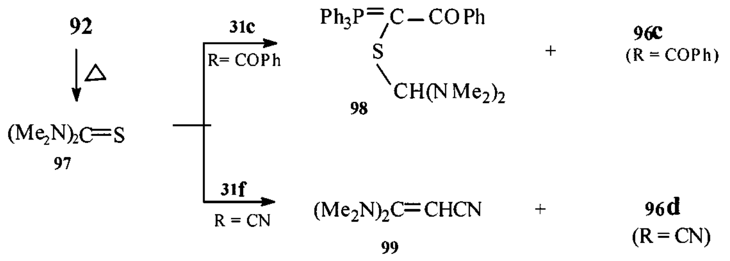
SCHEME 19

Tetramethylthiuram disulfide (**92**) undergoes direct and simple nucleophilic displacement reaction with stabilized ylides **31a**,**b**. The reaction results in the formation of the monosulfide **94**, the new ylides **95a**,**b** and the respective thiaphosphirans **96a**,**b** (Scheme 20).[104] The products are rationalized as proceeding via 1:1 intermediate, which can be envisaged as having the anionic form **93**, in turn relevant to the product structures.



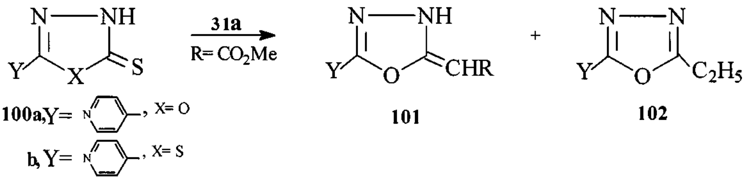
SCHEME 20

The reaction of the disulfide **92** with ylides **31c** and **31f**, on the other hand, led to the formation of the respective thiaphosphirans **96c**,**d** along with the ylide **98** or the olefin **99** respectively. It was assumed that compounds **98** and **99** are derived from thiourea **97** that generated from complete disproportionation of **92** due to applying drastic conditions (Scheme 21).[104]



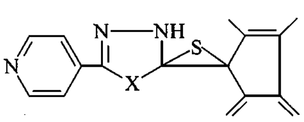
SCHEME 21

Much controversy involving the products of the reactions of 2-thio-5-pyridyl 1,3,4-oxadiazole **100a** with Wittig reagents was reported. Thus, the reaction of **100a** with phosphorane **31a** was reported and gave the adducts **101** and **102** in equal yields (45%) after being refluxed in toluene for 6 h (Scheme 22).[105] Contrary to these findings, it was claimed by the same author,[106] that attempts were made to study the chemical reactivity of the thione **100a** toward **31a** (or **31b**, R=CO_2Et) in toluene, but under all conditions the starting oxadiazole **100a** was separated practically unchanged.

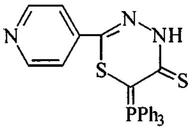


SCHEME 22

Oxa- and thiadiazoles **100a** and **100b** were reported to react with fluoren-9-ylidenetriphenylphosphorane (FTP) in toluene and afforded the corresponding episulfides **103a**,**b**. Meanwhile, **100b** reacted with **31a,b** to give the heterocycle ylide **104**.[106]

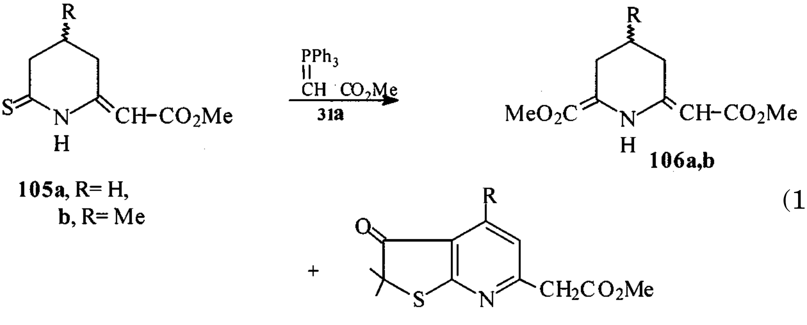


103, X= O, S



104

(6-Thioxo-2-piperidinylidene) acetates **105a** and **105b** were reported to react with ylide **31a** and yielded a mixture of the corresponding bis-enamine **106a** or **106b** and 3-oxo-2,3,4,5,6,7-hexahydrothieno[2,3-*b*] pyridin-6-ylidene) acetate **107a** or **107b**, respectively (Eq. 15).[107]



105a, R= H,
b, R= Me

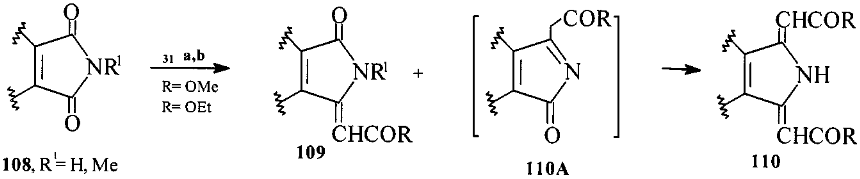
106a,b

107a,b

(15)

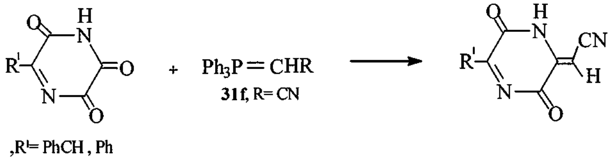
Reactions with Imides

In early work,[60,108–110] imides were not known as an effective source of an acyl group for transfer to ylides. In most cases, the result of such an attempt has been a Wittig reaction to alkenate one or both of the imide carbonyl groups. For example, Flitsch and Peters,[108] found that phthalimide (**108**, R^1=H) and the ester ylides **31a**,**b** at 140°C gave successively the lactam **109** (R^1=H) and the amine **110** (R^1=H). In contrast, *N*-methylphthalimide yielded only the lactam **109** (R^1=Me). The second stage with phthalimide probably proceeds via the *N*-acylimine **110A**. Similar reactions occurred with succinimide and *N*-methylsuccinimide. In both cases, the products from the *N*-methylimides were mixtures of geometrical isomers (Scheme 23).[108]



SCHEME 23

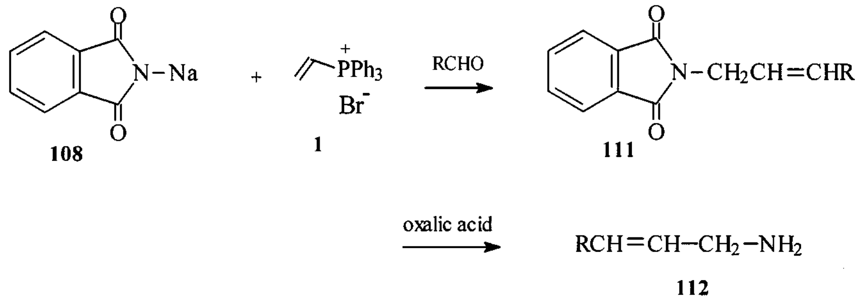
In the case of 5-substituted 2,3,6-piperazinetriones, the mono-olefin 3-alkylidene-2,5-piperazinediones is the only product from its reaction with cyanomethylenephosphorane **31f** (Eq. 16).[62a]



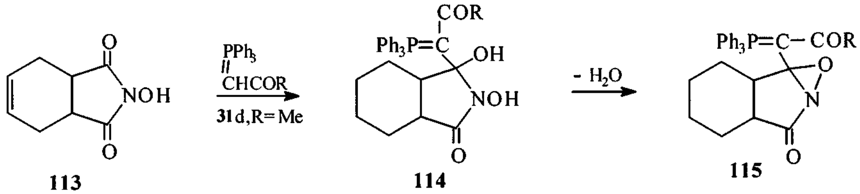
(16)

In addition to alkene formation,[62] Meyers et al.[111] have used phthalimide as a protected primary amine (Na^+, K^+, Li^+) for preparation of allyl amines **112**. Sodiophthalimide (**108**, R^1=Na) was added to the vinylphosphonium bromide-admixed with the aldehyde-to give allyl phthalimides **111**. Compounds **111** were readily cleaved by using hydrazine or sodium sulfide followed by oxalic acid to furnish the products **112** in greater than 95% yield (Scheme 24).

In another instance, the spiro-ylide phosphorane **115** was reported as a reaction product of *N*-hydroxy-4-cyclohexene-1,2-dicarboximide **113** and phosphonium ylide **31d**, possibly from the initially formed **114** (Scheme 25).[112]

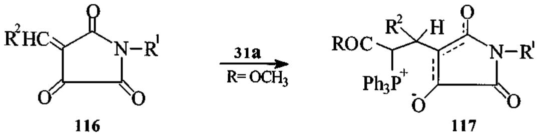


SCHEME 24



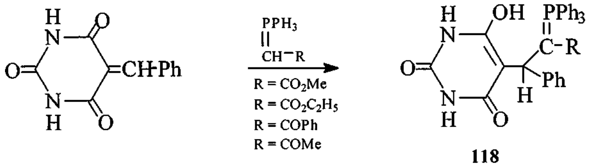
SCHEME 25

On the other hand, Michael addition of the ylide ester **31a** to (*Z*, *E*-) substituted-pyrrolidinetriones **116**, giving the betaine **117** has been reported (Eq. 17).[113]



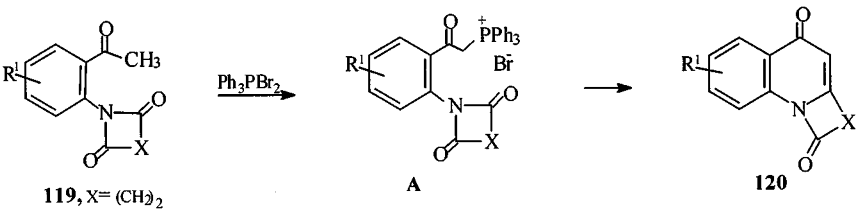
(17)

5-Benzylidenebarbituric acid was reported to add to stabilized ylides and afforded the corresponding Michael product **118** after the proton transfer (Eq. 18).[114]



(18)

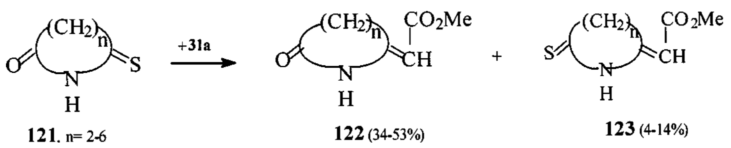
An internal Wittig reaction of the substituted aminoacetophenones of type **119** was used for the synthesis of novel quinoline derivatives **120** according to Scheme 26.[115]



SCHEME 26

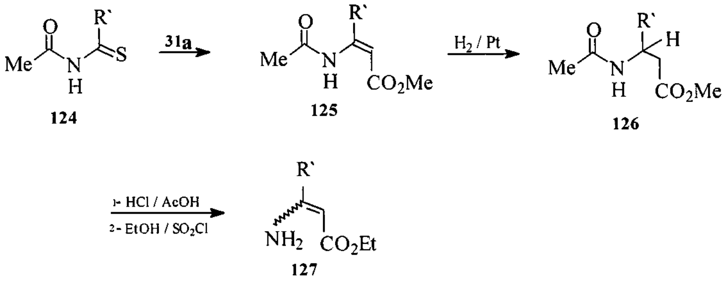
Reactions with Mono- and Dithioimides

With monothioimides, thio-olefination competes with carbonyl olefination,[116] and in the case of open-chain thioimides, thio-olefination often predominates[116,117] although this depends to some extent on the reaction conditions and environmental substituents.[118] Thus, cyclic monothioimides **121** reacted with an ester ylide **31a** to produce mainly alkylidene lactams **122**, along with its thiono analog **123** as a minor product (Eq. 19).[116]



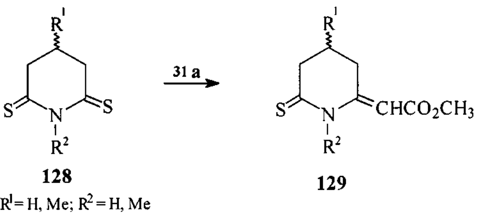
(19)

N-(Acetyl)thioimides **124** was reported to undergo regioselective thiocarbonyl olefination with ylide esters **31a** and gave 34–81% of the thio-olefinated products **125**. The latter compounds are readily accessible intermediates for the synthesis of *β*-amino acids that can be obtained therefrom by acid catalyzed hydrolysis (Scheme 27).[116,117] In general this discrimination of C=S group over the C=O group has been used in the synthesis of several *β*-amino acids **127** according to Scheme 27.[107,116,117]



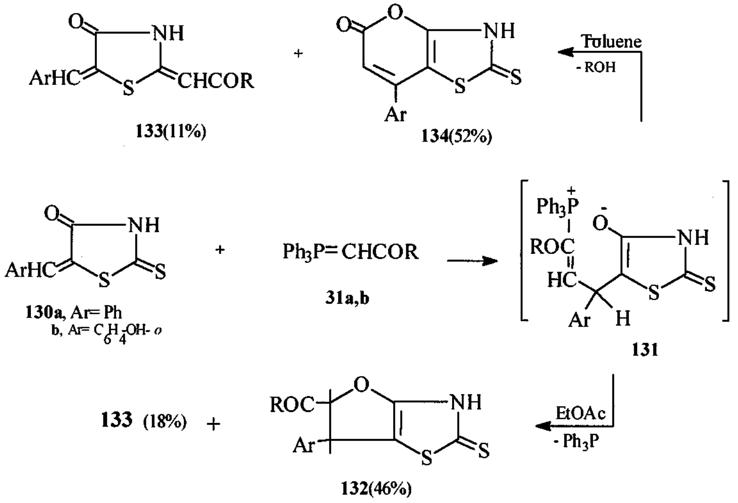
SCHEME 27

Dithioglutarimides **128** also reacted readily with ylide ester **31a** and yielded the alkenated products **129** (Eq. 20).[107]



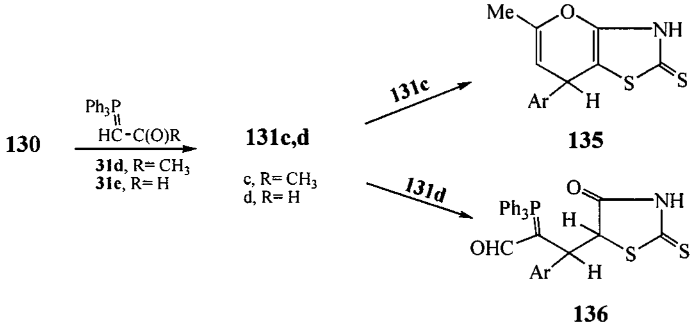
(20)

On applying ester ylides **31a**,**b** on thiazolidinones **130** in refluxing ethyl acetate and in the presence of TEA, conjugated dihydrofuro[2,3-*d*]thiazol-2-(3*H*)-ones **132** were obtained, whereas in refluxing toluene and also in the presence of TEA, the fused pyrone-derivatives **134** was formed. Both reactions afforded, in each instance, the corresponding thio-olefinated products **133**. It was assumed that **132** and **134** were produced via the initially formed dipolar intermediate **131** according to Scheme 28.[118] However, reactions of **130** with oxoylides **31d** and **31e** were reported to be completely regioselective, and yielded the cycloadduct **135** and the ylidic structure **136** via the intermediates **131c** and **131d** respectively (Scheme 29).[118]



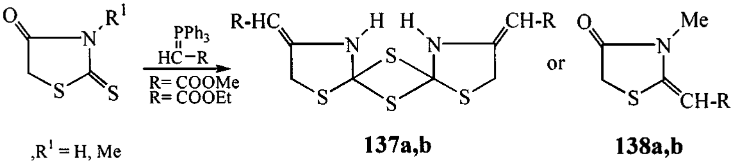
SCHEME 28

Recently, it has been reported that whereas the reaction of 2-thio-4-thiazolidinone (Rhodanine) with ester ylides **31a**,**b** proceeds in boiling



SCHEME 29

toluene and yields the dithiones **137a,b** the reaction of *N*-methyl Rhodanine with the same ylides gives the corresponding thio-olefinated compounds **138a,b** (Eq. 21).[119] Notwithstanding, 6-methyl-2-thiouracil is reported to be inactive toward stabilized ylides.[120]

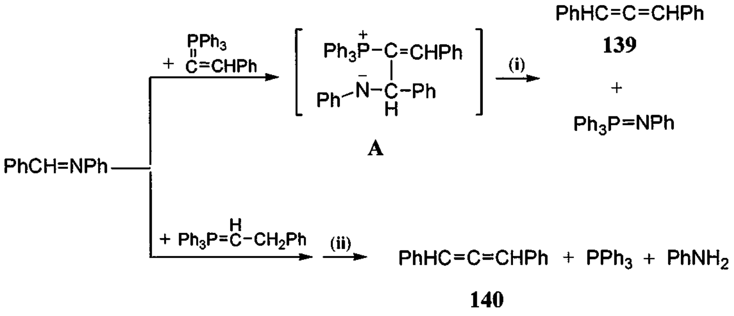


(21)

Reactions with Imines

With Anils

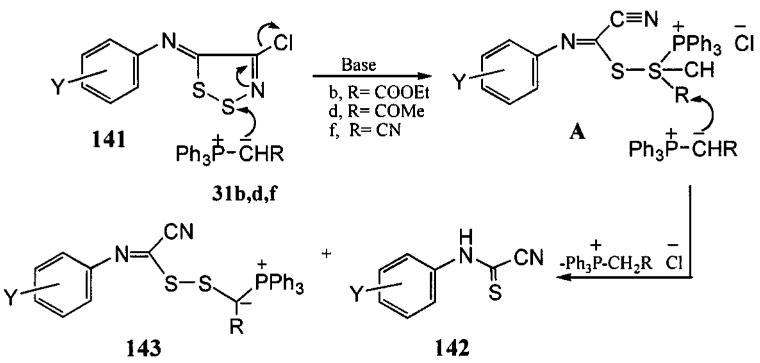
Phosphonium ylides are known to add to imines (Schiff bases) to form alkenes and iminophosphoranes. There have been, however, few reports[77,121–126] on the interaction of phosphonium ylides with anil compounds. Bestmann and Seng[121] found that benzylidene phosphorane would react with benzal aniline to afford stilbene **139** and *N*-phenyliminophosphorane (Scheme 30, i). The mechanism undoubtedly



SCHEME 30

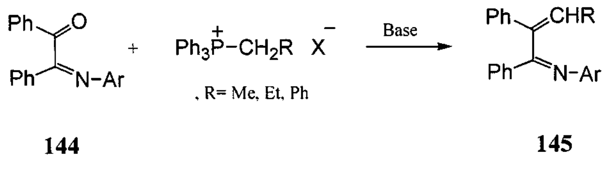
is very similar to that of the Wittig reaction and is known as Wittig-type reaction. Thus, the reaction probably involved the typical betaine intermediate **A** that collapsed by transfer of nitrogen from carbon to phosphorus. On using ylides with a β-proton, the reaction resulted in the formation of allenes **140** and aniline being by-products (Scheme 30, ii).[122]

Reaction of 5-arylimino-4-chloro-*5H*-1,2,3-dithiazoles **141** with 2-equivalents of stabilized ylides **31b**,**d**,**f** in the presence of pyridine in CH_2Cl_2 at room temperature was reported and gave a new type of the corresponding ylide with aryliminocyanomethyldithiomethylene moiety **143**, and the known *N*-phenylcyanothioformamide (**142**) via the phosphonium chloride intermediate **A** (Scheme 31).[77]



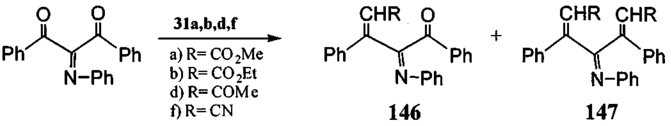
SCHEME 31

The Wittig products **145** were produced from for reaction of α-ketoarylimines **144** with alkyl-phosphonium salts (Scheme 32).[123]



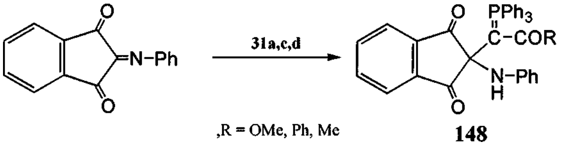
SCHEME 32

Recently, the Wittig products **146** and **147** were similarly obtained by treating 1,3-diphenyl-2-(phenylimino)-1,3-propanedione with stabilized ylides **31a**,**b**,**d**,**f** in refluxing toluene. When the reactions were carried out in boiling tetrahydrofuran, only the monoolefinated products **146** were isolated (Scheme 33).[124]



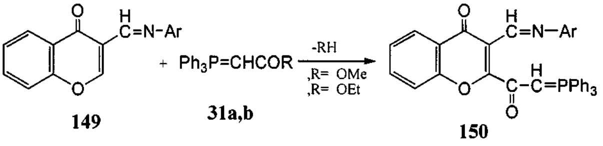
SCHEME 33

In contrast to this finding, 2-phenylimino-1,2,3-indantrione was reported to react with ylides **31a,c,d** and gave the new phosphoranes **148** (Eq. 22).[125]



(22)

Recently, new complex ylidene phosphoranes **150** were obtained by the treatment of 3-formylchromonemonoanils **149** with ester ylides **31a**,**b** via elimination of an alcoholic moiety (Eq. 23).[126]

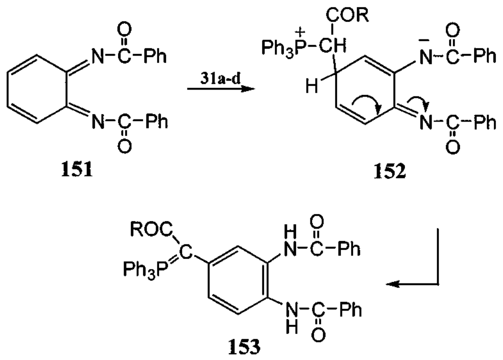


(23)

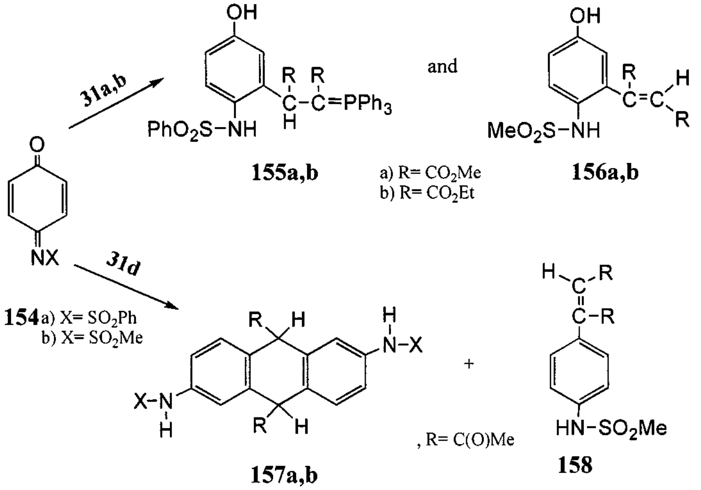
With Quinoneimines

o-, and *p*-Quinonimines, unlike *o*- and *p*-quinones, preferentially react with phosphonium ylides at the ring-carbon.[127,128] For example, ester ylides **31a–d** add to *N*,*N*-3,5-cyclohexadiene-1,2-diylidene-bis-(benzamide) (**151**) and yield the new ylide phosphoranes of type **153**. It was assumed that phenylamido derivatives were obtained exclusively by 1:4 addition, possibly via rearrangement of an intermediate like **152** (Scheme 34).[127]

In contrast, *p*-quinonemonoimines were reported to react with stabilized ylides according to 1:2-, 1:4- or 1:6-addition mechanisms depending on the nature of the carbanion. Thus, while *N*-(phenylsulfonyl)-(**154a**) and *N*-(methylsulfonyl)-1,4-benzoquinonemonoimine (**154b**) were reported to react with ester ylides **31a** and **31b** yielding, through 1:4 addition, the phenol products **155a**,**b** and **156a**,**b**, respectively,[128] it was indicated that acetylphosphorane **31d** reacted, through 1:6 addition, with **154a** and gave **157a** whereas with **154b** **157b** along with **158** were afforded (Scheme 35).[128]



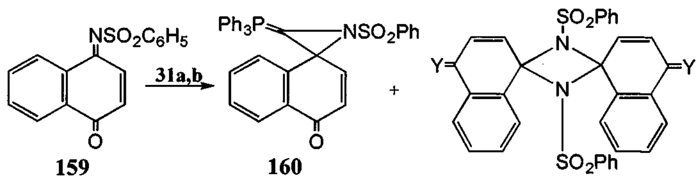
SCHEME 34



SCHEME 35

Contrary to the above, the reaction of 1,4-naphthoquinonemonobenzenesulfonimine (**159**) with the same ylides **31a**,**b** was reported and yielded, through 1:2 addition, the spiro-adduct **160** together with two dimeric products **161** and **162a**,**b** (Scheme 36).[129]

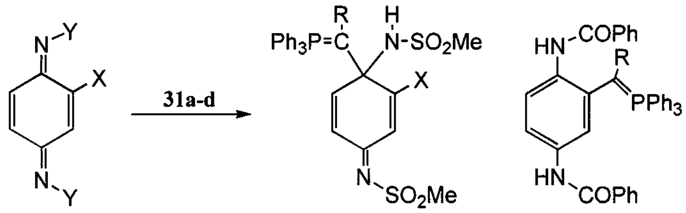
Furthermore, reaction of *N*,*N*′-2,5-cyclohexadiene-1,4-diylidene-bis[methanesulfonamide] (**163a**) and its 2-chloro derivative **163b** with ylides **31a–d** was reported and gave the corresponding new ylide phosphoranes **164** via 1:2 addition reaction.[130] On the other hand, *N*,*N*′-2,5-cyclohexadiene-1,4-diylidene-bis[benzamide] (**163c**) was reported to react with the same ylides and yielded the respective phosphoranes **165** via 1:4 addition (Scheme 37).[131]



159 **160**

161 Y= O
162a Y= $CHCO_2Me$
162b Y= $CHCO_2Et$

SCHEME 36



163a, Y= SO_2Me, X= H
163b, Y= SO_2Me, X= Cl
163c, Y= COPh, X= H

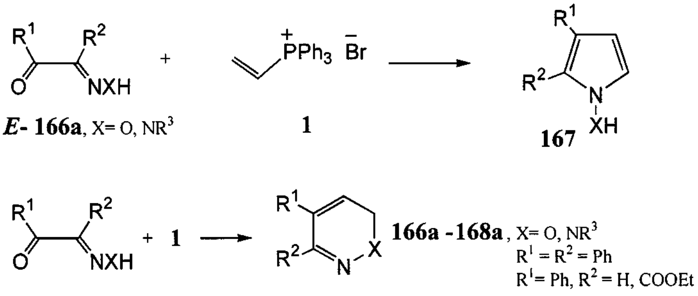
164 X= H, Cl

165

SCHEME 37

With Oximes and Hydrazones

Reaction of phosphorus ylides with oximes to form alkenes and iminophosphoranes is not as straightforward as implied by the examples described for Schiff bases in Scheme 30.[121,132] Later on, Schweizer and Kopay[133] elaborated a general Scheme for the reaction of α-imino ketones of type **166a** with vinyl salt **1** whereby the *E*-isomer leads to the 1-substituted pyrroles like **167** and the *Z*-isomer affords the pyridazines **168a** (Scheme 38).



E- **166a**, X= O, NR^3

1

167

166a -168a, X= O, NR^3
$R^1 = R^2 = Ph$
$R^1 = Ph$, $R^2 = H, COOEt$

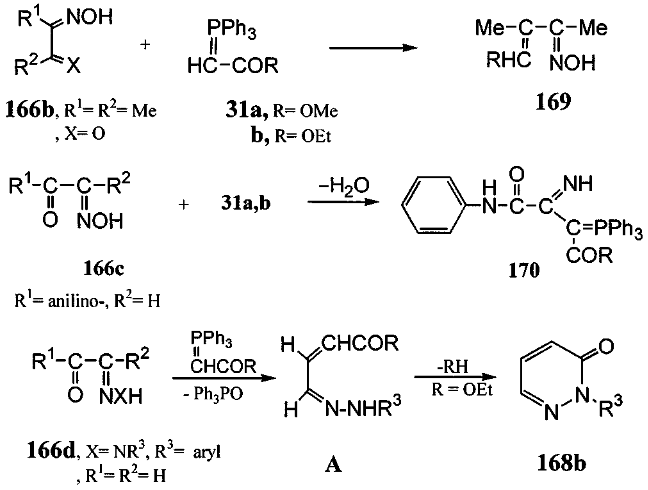
Z- **166a**

168

SCHEME 38

In contrast to the reports mentioned above, E1-Kateb and Abdel-Malek[134] reported that while diacetylmonoxime **166b** reacted with ester ylides **31a**,**b** and gave the products of Wittig reaction **169**, glyoxylanilide-2-oxime (**166c**) added to the same ylides and yielded the new phosphoranes **170** with concomitant loss of a molecule of water.

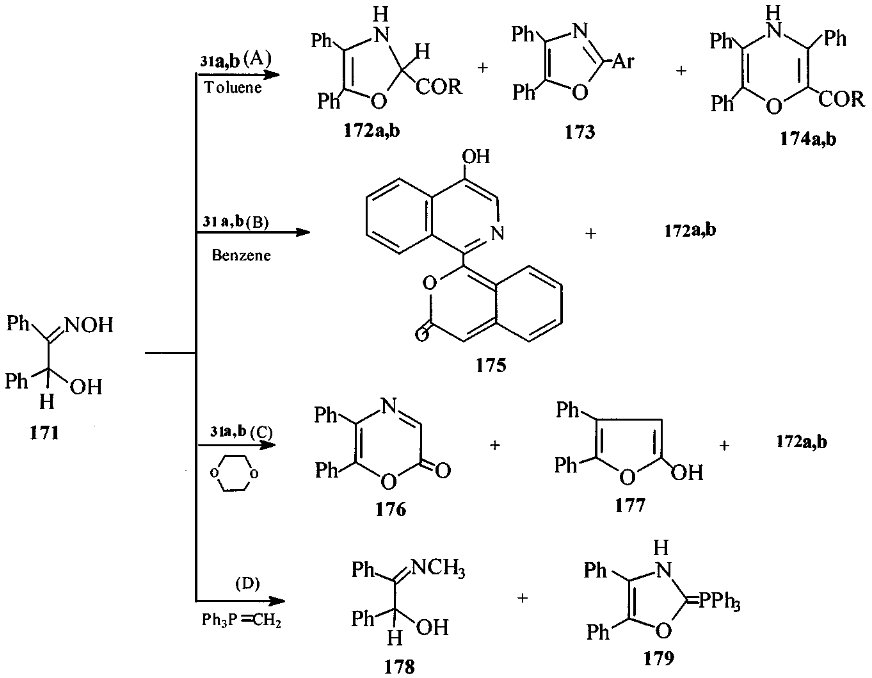
Earlier, it was reported that treatment of α-ketomonoimines, α-formylhydrazones with **31b** led to the formation of pyridizinones **168b** via the Wittig product **A** (Scheme 39).[135]



SCHEME 39

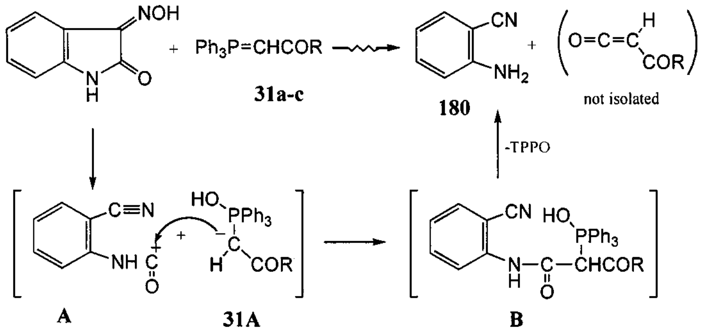
Recently, several different nitrogen-containing heterocycles such as oxazolines, oxazines and isoquinolines were synthesized directly from the reaction of α-benzoinmonoxime with stabilized- and reactive-ylides.[136] The reactions which were summerized in Scheme 40, dependend simply on the carbanionic nature of such ylides and the reaction conditions. It was indicated that the formation of oxazole ring of type **173** involved participation of the solvent toluene; presuming that the intermediates arose from homolytic scission of the aryl C—H bond of toluene were involved in this transformation (Pathway A). Wittig products were formed either as stable compounds like **178** (Pathway D) or as intermediates, which were further transformed to stable linear or fused heterocyclic derivatives like **172** and **176** or **175** respectively. Wittig-type reaction of oximino group leading to the formation of the furan **177** was also observed.[136]

Attack of ester ylides at the oxime group and ring opening has been reported[137] for isatinmonoxime producing *o*-aminobenzonitrile (**180**).



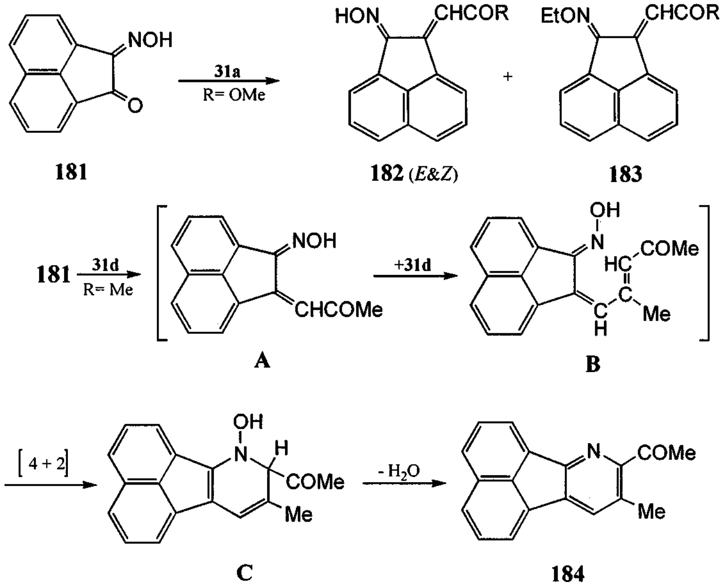
SCHEME 40

The mechanism for the formation of **180** is depicted in Scheme 41. The approach of the phosphonium center in **31** to the substrate would facilitate formation of the ion pair (**A** + **31A**) and further to structure **B** after catenation. The latter, in which phosphorus acts as a good leaving group, decomposes then to give the observed product.



SCHEME 41

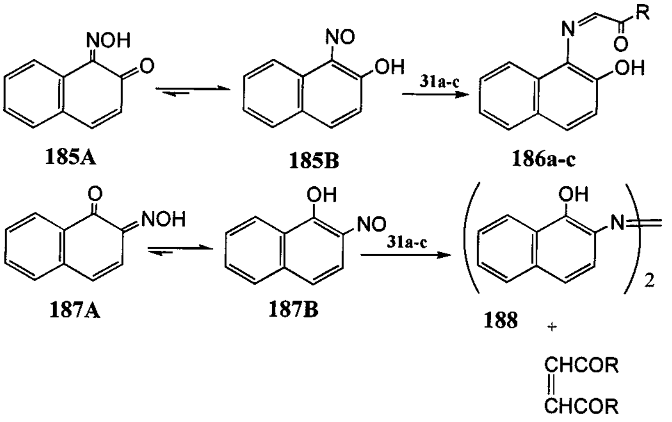
By applying Wittig reaction on acenaphthylene-1,2-quinonemonoxime **181** with ester ylide **31a**, stereoisomers of the oxime **182** and the alkylated oxime **183** were isolated whereas with ylide **31d** the pyridine derivative **184** was obtained (Scheme 42).[138]



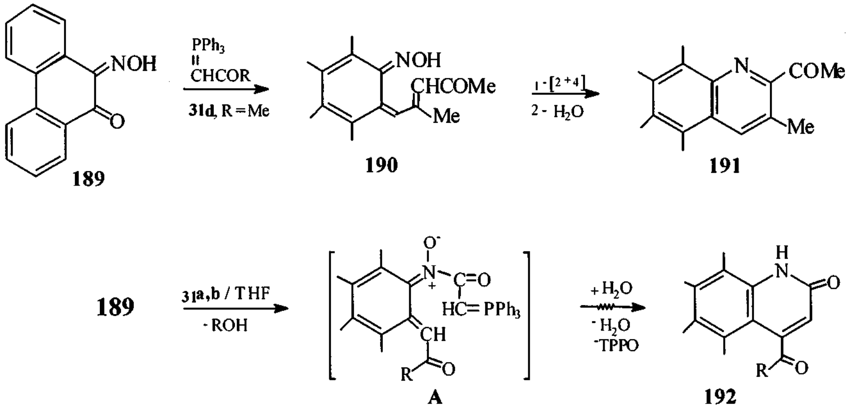
SCHEME 42

o-Naphthoquinonemonoxime (**185A** ⇌ **185B**) was reported to react in benzenoid form **185B** and not in the quinoid structure **185A** with ylide esters **31a–c** and gave the corresponding imines **186** (Scheme 43).[139] Meanwhile, β-nitroso-α-naphthol, however, was reported to react with the same ylides and afforded in each case the known azoderivative **188** and the appropriate symmetrically disubstituted ethylene (Scheme 43).[139]

The reaction of **189** with stabilized and moderated ylides has been reported in some details (Schemes 44, i and ii).[140] The structural products indicated that two positions in **189** are susceptible to nucleophilic attack. Hence, a competition between two options is available to ylide phosphoranes in their reactions with **189**; that is, olefination or conjugated-addition. Nevertheless, the findings showed that the aryl carbonyl is a preferable site of attack by ylides. Thus, the oxime **189** was reported to react with ylide **31d** in chloroform containing TEA yieldig the Wittig product **190** and the quinoline derivative **191**. It has been indicated that **190** exists in the *E*-form while **191** is derived from its

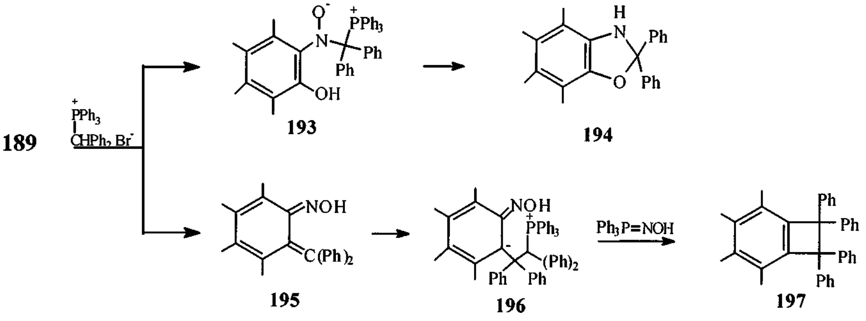


SCHEME 43



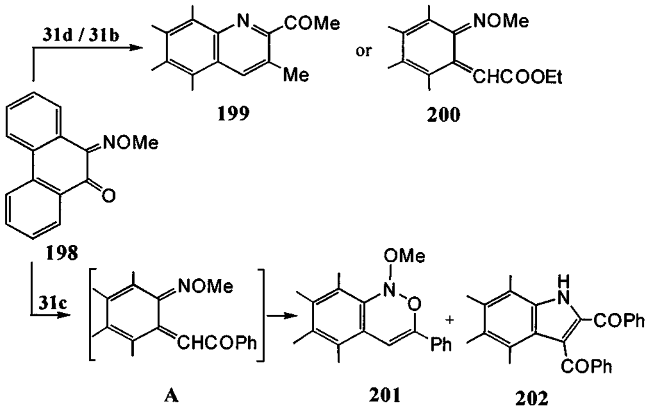
SCHEME 44, i

cis-configuration. On refluxing **189** and ylides **31a**,**b** in THF, the quinolone derivatives **192** was obtained excessively. It was assumed that the products **192** were produced via the attack of ylides on both the aryl carbonyl and the imino-group to produce the intermediate A followed by addition of a molecule of H_2O and subsequent release of triphenylphosphine oxide and a molecule of H_2O (Scheme 44, i). Furthermore, reaction of compound **189** with diphenylmethyltriphenylphosphorane bromide in refluxing ethanol, containing TEA, afforded the oxazole 194 and the cyclobutene **197**. It was assumed that the product **197** arose by further Michael addition to the initially formed Wittig product **195** followed by a Wittig-type reaction, and the releasing of hydroxyiminotriphenyl-phosphorane species (Ph_3P=NOH) afforded the final product (Scheme 44, ii).[140]



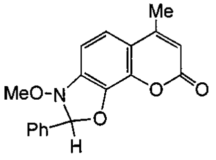
SCHEME 44, ii

10-(Methoxyimino)phenanthren-9-one (**198**) was reported to give the quinoline derivative **199** upon reacting with acetyl ylide **31d**,[141] whereas with **31b** the *o*-quinone-methineimine **200** was afforded (Scheme 45).[142] The oxazine **201** and the indole **202** were, however, obtained by treating **198** with benzoyl ylide **31c**.[143] In addition, 2-phenylphenanthro-[9,10-*b*]furan was produced in the latter reaction as a minor product.

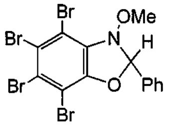


SCHEME 45

7-(Methoxyimino)-4-methyl-2*H*-chromene-2,8(7*H*)-dione[144] and 3,4,5,6-tetrabromo-2-methoxyimino-1-benzoquinone[145] were reported to react with benzyltriphenylphosphonium salt in dichloromethane containing LiOH and yielded the corresponding oxazoles **203** and **204** respectively.

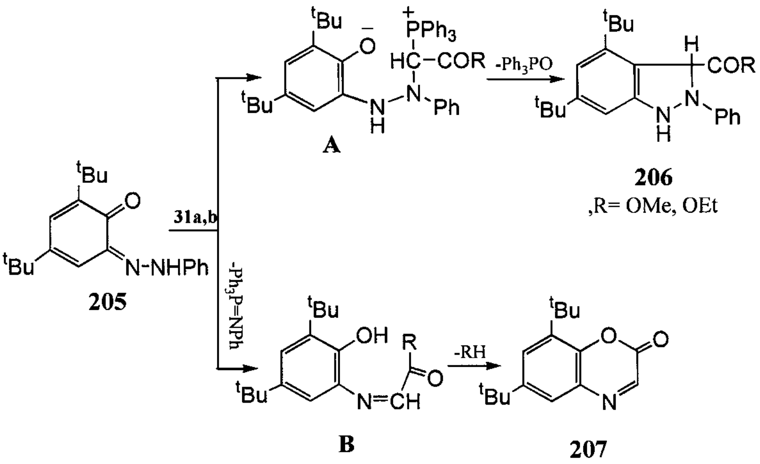


203



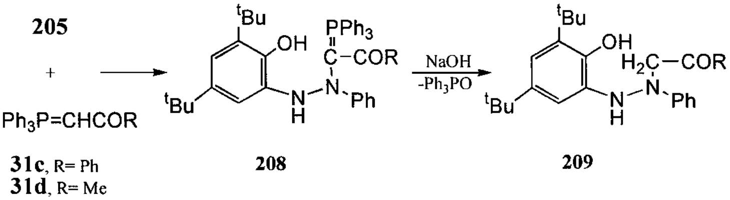
204

N-Phenyl-3,5-di-*tert*-butyl-1,2-benzoquinonemonohydrazone (**205**) was reported to react with ylide esters **31a**,**b** giving the pyrazoles **206** and oxazine **207**. The acylation of the hydrazone followed by Wittig reaction led to the formation of pyrazoles **206**, while typical Wittig-type reaction of Schiff base **205** with **31a**,**b** afforded the intermediate **B**, which further cyclized to oxazine **207** via elimination RH (Scheme 46).[146]

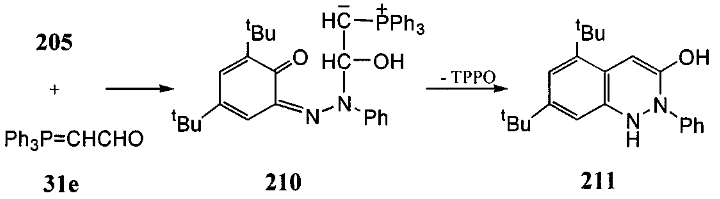


SCHEME 46

The hydrazone **205** also adds to keto-ylides **31c**,**d** to yield the new phosphoranes **208** in a quantitative yield. Alkali-hydrolysis of **208** gave the respective acylated hydrazones **209** (Eq. 24).[146] Meanwhile, the hydrazone in question **205** was found to reduce formyl phosphorane **31e** and generated the intermediate **210**. Further an intramolecular Wittig reaction gave the pyridazine derivative **211** (Eq. 25).[146]



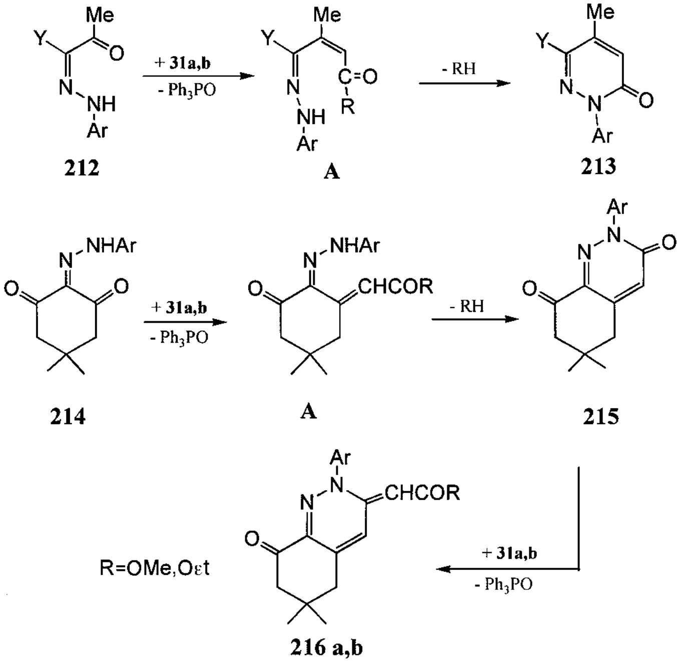
(24)



(25)

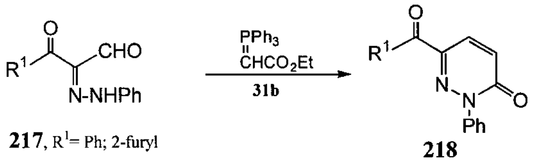
Furthermore, it was claimed that the aforementioned mechanisms would on steric reasons predict the attack of the carbanion center on the =N—N-system rather than the arylcarbonyl group in **205**. The effect of the neighboring *t*-Bu- on the C=O group would be expected to be quite unfavorable.[146]

On the other hand, pyridazinones **213** and tetrahydrocinnolinones **215** were synthesized via the Wittig reaction of different β-keto-**212** and α-keto-hydrazones **214**, respectively, with ylide esters **31a**,**b** according to Scheme 47.[147] Further Wittig reaction of **215** with **31a**,**b** afforded the olefins **216a**,**b**.



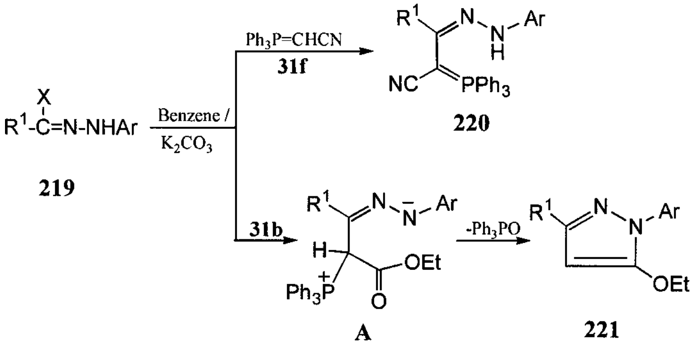
SCHEME 47

Similarly, pyridazinones **218** were obtained by treating of the hydrazone **217** with ylide **31b** (Eq. 26).[148]



(26)

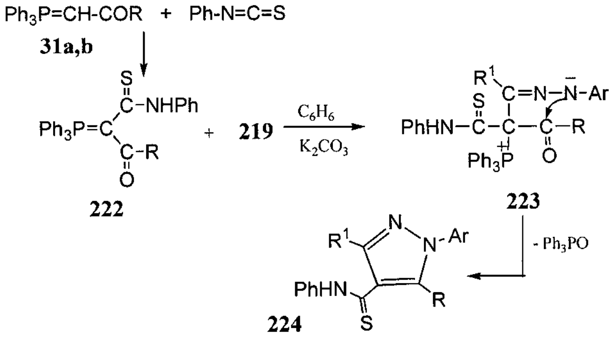
Recently, synthesis of α-substituted phosphonium ylides **220** and pyrazole systems **221** via the treatment of the hydrazonyl halides **219** with phosphoranes **31f** and **31b**, respectively, has been reported (Scheme 48).[149] It is assumed that the pyrazoles **221** were obtained through intramolecular Wittig reaction of the initially formed phosphorane intermediates **A**.



219-221	X	R^1	Ar
a	Cl	2-thienyl	$C_6H_4NO_2$-4
b	Br	CO-thienyl-2	C_6H_5
c	Br	CO-NHC_6H_5	C_6H_5

SCHEME 48

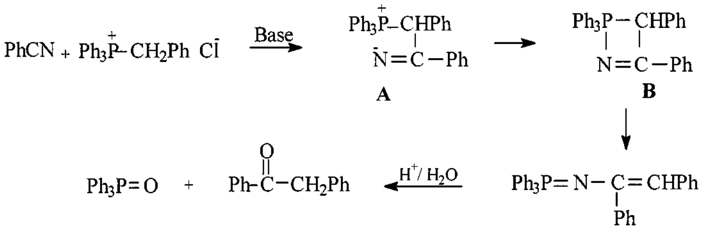
Hydarzonyl halides **219** were also reported to react with ylides **222**, prepared by coupling reaction of ester ylides **31a,b** with phenylisothiocyanate, and gave 1,3-cyclo-addition products **224** (Eq. 27).[150]



(27)

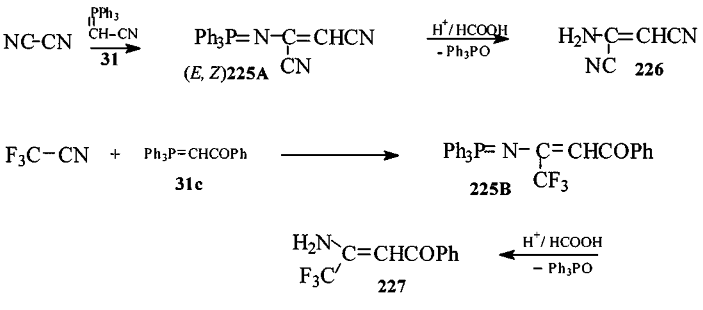
Reactions with Nitriles

Reaction of nitriles with alkylidene phosphoranes has been conveniently used as a useful tool for the preparation of stable iminophosphoranes.[151–153] Thus, both aliphatic and aromatic nitriles were found to add to nonstabilized ylides, prepared from the corresponding phosphonium salts, giving the iminophosphoranes; which on base- or acid-catalyzed hydrolysis, afforded ketones and phosphine oxides. The reaction is believed to proceed by a mechanism analogous to that of the reactions of phosphoranes with activated acetylenes. In effect, the nitrile group was inserted between the phosphonium group and the carbanion group of the starting ylide in an ylide interchange reaction (Scheme 49).[152,153] Vicente et al.,[154] however, effected the reaction of stabilized ylides **31a**,**b** with benzonitrile when the latter was complexed with platinum dichloride. The complexation apparently makes the nitrile more reactive.



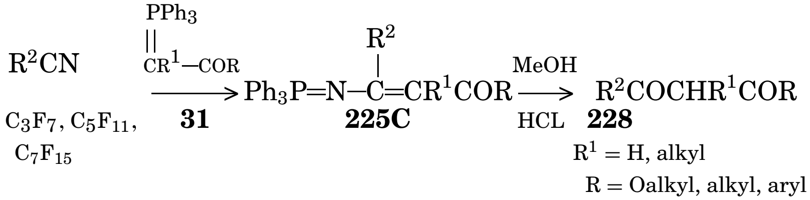
SCHEME 49

Stabilized ylides, which do not react with benzonitrile under normal conditions, form iminophosphoranes with activated nitriles, such as cyanogen and trifluoroacetonitrile. The resulting iminophosphoranes **225A** and **225B** are stable and afforded enamines **226** and **227**, respectively, instead of the expected ketones on hydrolysis with formic acid (Scheme 50).[153]



SCHEME 50

In a recent report, Trabelsi et al.[155] applied the same concept as a very high yield route to produce perfluoroketones. Thus, the reaction of a series of perfluoroalkyl nitriles with a series of stabilized ylides of type **31** gave mixtures of diastereomers **225C**. The latter were hydrolized in methanolic HCl to yield equilibrium of keto to enol forms of **228** (Eq. 28).



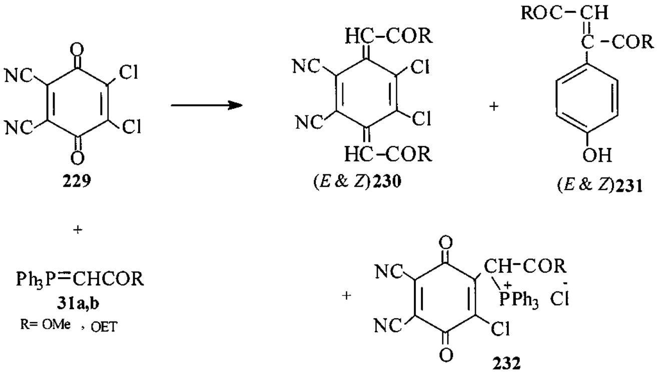
$$\underset{\substack{R^2 = C_3F_7,\, C_5F_{11},\\ C_7F_{15}}}{R^2CN} \xrightarrow[\mathbf{31}]{\overset{\overset{PPh_3}{\|}}{CR^1\text{—}COR}} \underset{\mathbf{225C}}{Ph_3P{=}N\text{—}\overset{\overset{R^2}{|}}{C}{=}CR^1COR} \xrightarrow[HCL]{MeOH} \underset{\mathbf{228}}{R^2COCHR^1COR}$$

R^1 = H, alkyl

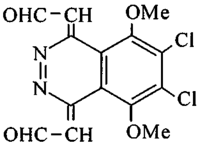
R = Oalkyl, alkyl, aryl

(28)

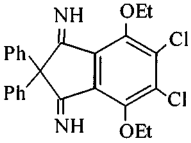
Activated nitriles with carbonyl groups were reported[10] to react with ester ylides, preferentially, via Wittig reaction. Recently, it has been shown that 2,3-dichloro-5,6-dicyanobenzoquinone (DDQ, **229**) react with ester ylides **31a**,**b** at rt in toluene to yield the Wittig products, mixtures of diastereomeric dimethanides **230** and substituted phenols **231** in almost equal yields (~22%), along with the corresponding phosphonium salts **232** in 20% yield (Scheme 51).[156] In contrast, with formyl-**31e** and diphenylmethylene(triphenyl)phosphorane ($Ph_3P{=}CPh_2$), prepared from the corresponding phosphonium salt in alcohol in the presence of sodium alkoxide, the reaction occurred at the nitrile groups in DDQ, yielding the aza-derivative **233** and the bisimino adduct **234** respectively.[156] It is assumed that the basic medium stimulates the course of the reaction at the nitrogen function.



SCHEME 51

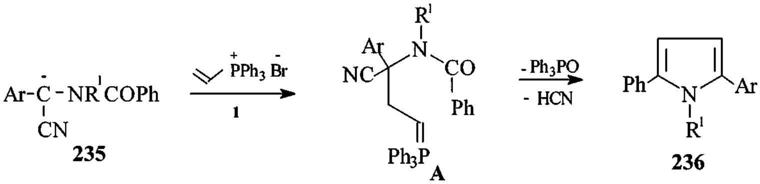


233



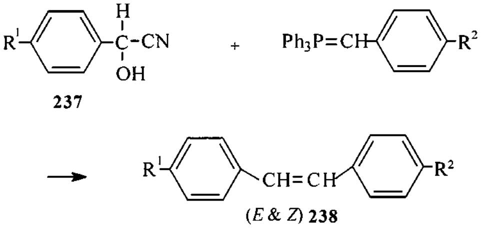
234

Another reaction route for nitriles with phosphonium ylides is a replacement reaction.[42,157,158] Cyanocarbanions **235**, for example, were reported to react with vinylphosphonium bromide 1 to give the substituted pyrroles **236** via an intramolecular Wittig reaction and the elimination of HCN from the initially formed Michael-addition products A (Scheme 52).[44]



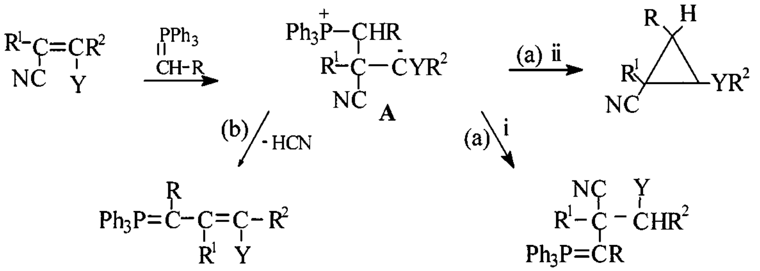
SCHEME 52

Similarly, substituted mandelonitriles **237** reacted, in the presence of sodium *tert*-butoxide-like the corresponding aldehyde with substituted benzylidene phosphoranes-via the internal Wittig reaction and the elimination of HCN to yield mixtures of diastereomeric 4,4′-disubstituted stilbenes **238** (Scheme 53).[158]



SCHEME 53

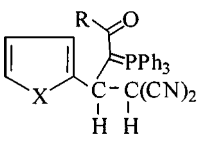
If a nitrile compound is activated with a normal carbon-carbon double bond, the reaction occurs at that site in preference to the cyano group. The mechanism of the reactions can be explained in terms of an initial Michael addition by an ylide followed by two separate routes to completion: (a) without involving the nitrile group in the second step whereupon the zwitterion intermediate **A** either undergoes a 1,3-proton transfer to form a new stable ylide (path a-i),[159–161] or eliminates the phosphine to form a cyclopropane derivative (path a-ii),[162,163] (b) the nitrile function is acting as a good leaving group and the zwitterion intermediate **A** eliminates HCN to form a more stable phosphorane (Scheme 54, b).[162,164]



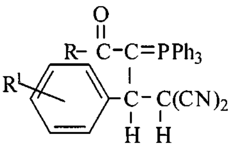
SCHEME 54

Reaction of 10-dicyanomethylene 9(*10H*)phenanthrenone **239** with ester-**31a**,**b** and ketoylides **31c** was reported to follow Scheme 54, affording high yields of new ylides **240**. Subjecting the Michael product **240** to pyrolysis yielded the fused pyran **241**; while treating it with aldehydes yielded the respective olefin **242** (Scheme 55).[159]

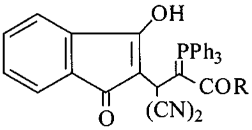
Reactions of furfurylidene-,[160] thienylidene-,[160] arylidene-,[165] and 1,3-dioxo-$\Delta^{2-\alpha}$-indan-[166] malonitriles with stabilized ylides to give the corresponding phosphoranylidenes **243a**,**b**, **244**, and **245**, respectively, were also reported.



243a, X = O
243 b, X = S



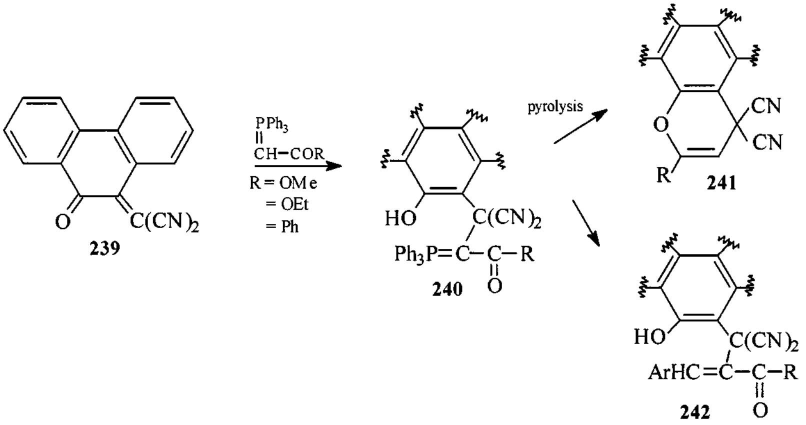
244



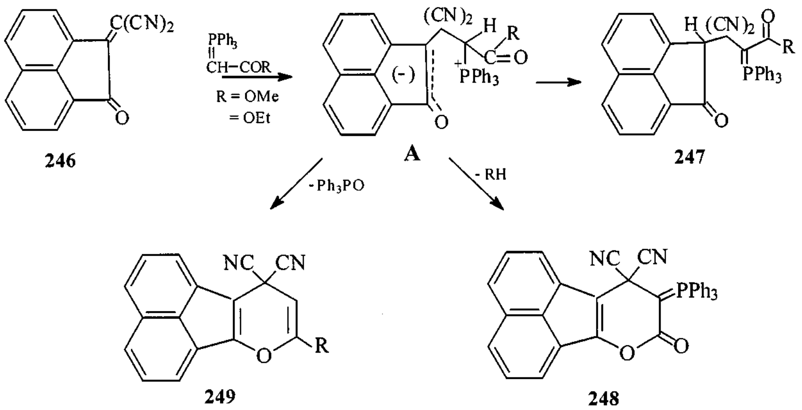
245

A similar pattern occurred in the reaction of α,β-unsaturated nitrile, 1-dicyanomethyleneacenaphthen-2-one (**246**) with ylides **31a**,**b** to give the fused pyranylidene **248** as a major product (35% yield) along with the ylides **247** and the pyrans **249** in equal yields. It was assumed that the three products were derived from the initially formed Michael addition betaine A according to Scheme 56.[167]

Reaction of tetracyanoethylene (**250**) with ester ylides **31a**,**b** was reported to give the cyclopropane **251** in addition to the conjugated

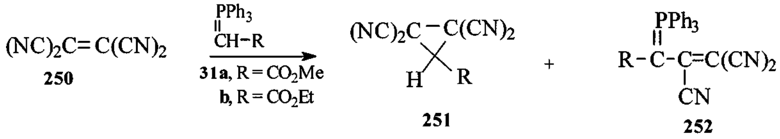


SCHEME 55



SCHEME 56

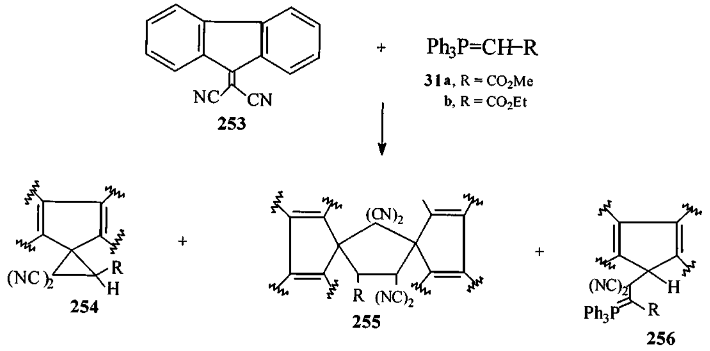
ylide **252** (Scheme 57).[162] In an earlier report, Trippett[168] also prepared the ylide **252** (R=CN) from the reaction of **250** and cyanophosphorane **31f**.



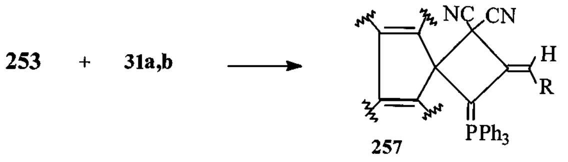
SCHEME 57

Reaction of fluoren-9-ylidenemalonitrile (**253**) with ester ylides **31a**,**b** was indicated in one report[163] to give three products **254–256**

(Eq. 29); while in a recent report,[169] the reaction product was claimed to be the corresponding phosphoranylidenecyclobutylidene **257** (Eq. 30). The dicyanomethylene derivative of thiaxanthone was, however, reported to be inactive toward the same ester ylides.[169]

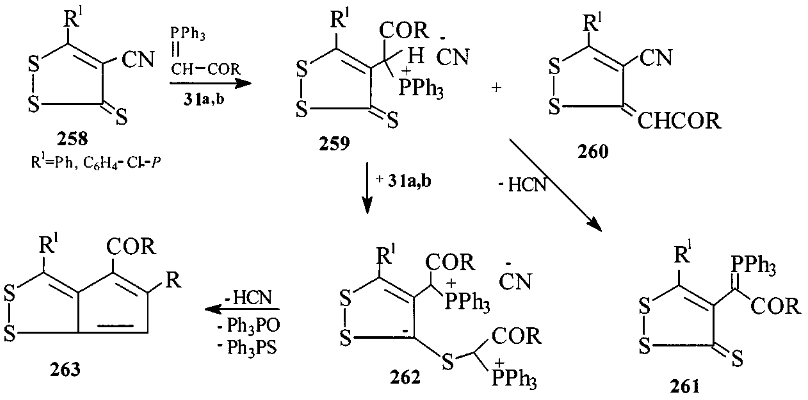


(29)



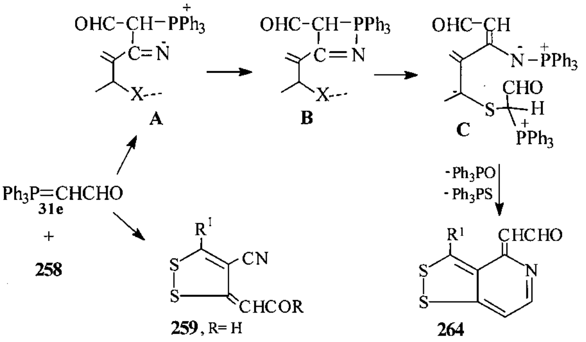
(30)

Phosphonium ylides **31a**,**b** were reported to attack both thiono- and nitrile groups in 4-cyano-1,2-dithioles **258** giving a mixture of compounds **260**,**261**, and **263** (Scheme 58).[164] Nevertheless, a different pathway was reported[164] for the reaction of formyl phosphorane **31e**



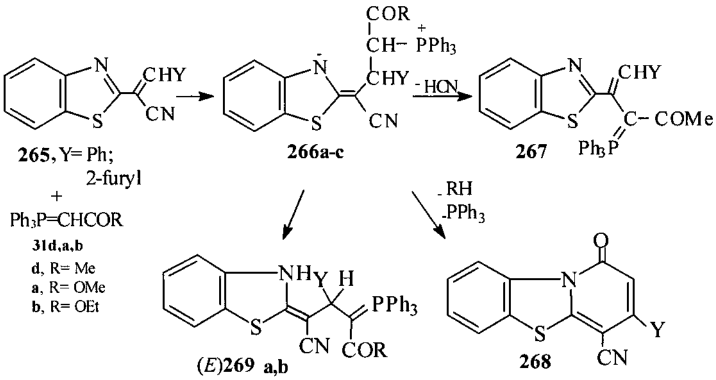
SCHEME 58

with the above dithioles **258** giving the pyridinylidene derivatives **264** along with the parallel thio-olefinated products **260** (R=H) according to the mechanism presented in Scheme 59. It was pointed out that the presence of the electron-withdrawing group (CN) substituent α- to thiocarbonyl group is responsible for stabilizing the dithiole ring through the reactions in Schemes 58 and 59.



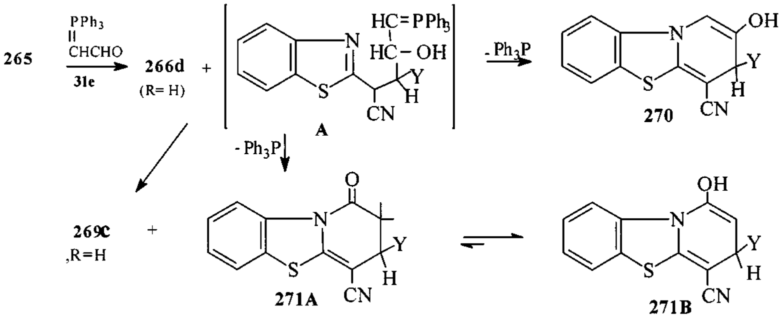
SCHEME 59

Recently, the reaction of the acrylonitrile **265** with phosphorus ylides was reported to undergo also different routes, leading to unexpected products, depending only on the type of the ylide used.[170] Thus, whereas the nitrile **265** reacted with keto ylide **31d** (R=CH_3) and yielded, exclusively, the new ylide **267** via the elimination of HCN from the initially formed betaine **266a**, with ester ylides **31a**,**b** the pyridinone derivatives **268** and the ylides **269** were obtained (Scheme 60).[170,171] It was assumed that the formation of the cyclic **268** and acyclic **269** products in the latter reaction was dependent on the spatial rearrangement (*E* and *Z* isomers) of the reactive groups in the intermediates **266b**,**c**.



SCHEME 60

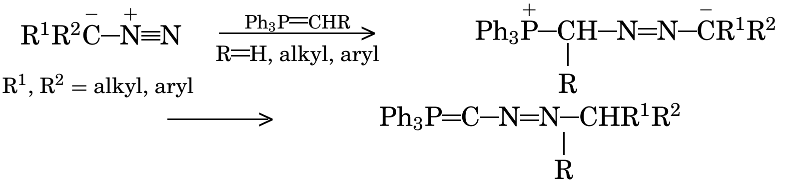
When **265** was allowed to react with keto-ylide **31e** (R=H), prepared in situ from its chloride salt, in boiling ethyl alcohol containing TEA, the pyridine derivatives **270** and **271** were obtained in addition to the parallel ylide analog **269c** (R=H) (Scheme 61).[170] It was indicated that ylide **31e** attacks **265** on the benzylidene double bond in two forms: (a) the ylidic form to produce **266d** (Scheme 60, R=H) followed by proton migration, yielding **269c** (R=H) or it undergoes an intramolecular cyclization through the elimination of Ph_3P to give the pyridine derivative **271**, which may be present in equilibrium **271A** ⇌ **271B**; (b) the reduced form of the aldehydic function, invoked by the basic medium to give the pyridine derivative **270**.



SCHEME 61

Reactions with Diazo Compounds and Diazonium Salts

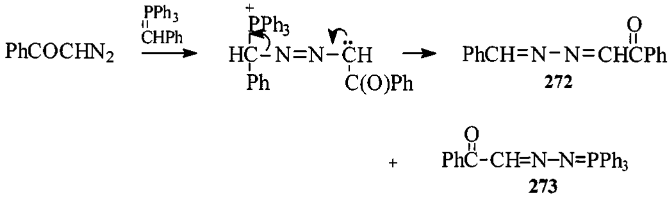
Diazo function is generally less reactive toward phosphonium ylides than the carbon-carbon double bond. In their early work, however, alkylidene phosphoranes were known to form *N*-alkylated phosphonium ylides when treated with diazo compound according to Equation 31.[172,173]



$$R^1R^2\overset{-}{C}-\overset{+}{N}\equiv N \xrightarrow[R=H,\ \text{alkyl, aryl}]{Ph_3P=CHR} Ph_3\overset{+}{P}-\underset{R}{\underset{|}{C}}H-N=N-\overset{-}{C}R^1R^2$$

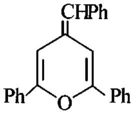
$$R^1, R^2 = \text{alkyl, aryl} \qquad \longrightarrow \qquad Ph_3P=\underset{R}{\underset{|}{C}}-N=N-CHR^1R^2 \qquad (31)$$

Diazoacetophenone was reported to react with benzyl ylide **31g** yielding a mixture of azine **272** and phosphazine **273** (Eq. 32).[173] The latter was assumed to be formed from the subsequent reaction of the eliminated Ph_3P with the unreacted diazo-compound.



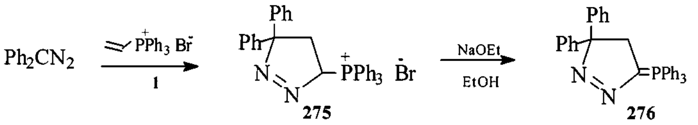
(32)

Conversely, the nitrogen completely disappeared when diazoacetophenone was treated with benzoyl ylide **31c** whereby 2,6-diphenyl-4-benzylidene pyran (**274**) was the reported product.[174]



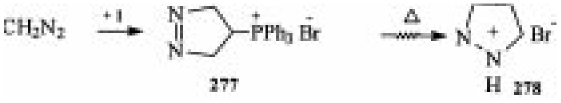
274

Diphenyldiazomethane and diazomethane were reported to undergo 1,3-dipolar addition with vinyl phosphonium salt **1** in CH_2Cl_2 yielding pyrazoline phosphonium salts **275** and **277** respectively. A series of secondary steps such as Wittig reaction, alkali hydrolysis or pyrolysis of the initial 1,3-dipolar product would lead to further products (Eqs. 33 and 34).[175]



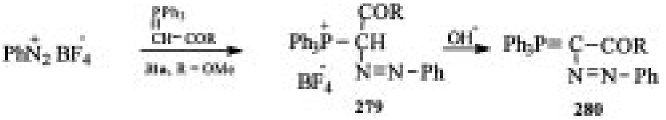
(33)

In effect, pyrazoline synthesis from the reactions of diazo compounds with nonstabilized ylides was early applied in several publications.[175–177] Furthermore, the possibility of exploiting the resulting pyrazolinyltriphenylphosphonium bromides, as synthones was of great significance in several applications.



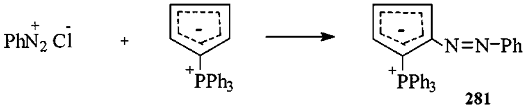
(34)

Diazonium salts, on the other hand, are more reactive than the diazo-compound counterparts; that enabled them to couple directly with stabilized ylides and yield the respective phosphonium salts, from which a proton is easily removed to produce diazo-substituted ylides. For example, the reaction of benzenediazoniumtetrafluoroborate with ester ylide **31a** was reported to give the phosphonium salt **279** which could be converted to a new ylide **280** upon treatment with aqueous base (Eq. 35).[178]



(35)

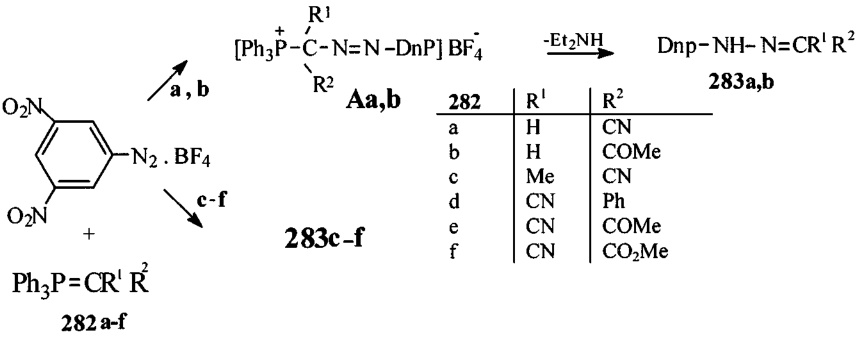
Cyclopentadienetriphenylphosphorane also reacted with benzenediazonium chloride, but underwent electrophilic aromatic substitution on the cyclopentadienyl ring to give the ylide **281** (Eq. 36).[179]



281

(36)

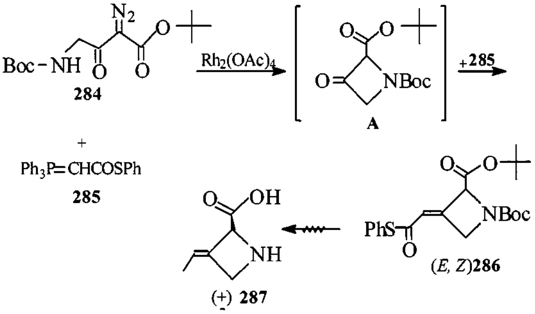
A few additional reports on reactions of diazo-compounds with ylides have been added since 1980. In 1992, Froeyen[180] described the reaction of 2,4-dinitrobenzene-diazonium tetrafluoroborate with a series of stabilized ylides **282**. The reaction courses led to the formation of either azo-phosphonium salts **A** (with **282a**,**b**) or the hydrazones **283** (with **282c–f**). The salts **Aa**,**b** were further converted to the corresponding hydrazones by hydrolytic decomposition (Et_2NH) (Scheme 62).



282	R^1	R^2
a	H	CN
b	H	COMe
c	Me	CN
d	CN	Ph
e	CN	COMe
f	CN	CO_2Me

SCHEME 62

The reaction of α-diazo-β-keto ester **284**-initially treated with a catalytic amount of rhodium (*II*) acetate-with thio-ester ylide **285** was reported to give the isomeric phenylthioester derivatives **286**, which could be used to produce (2RS,E)-3-ethylidene-azetdine-2-carboxlic acid (racemic polyoximic acid) **287** after going through several steps (Scheme 63).[181]



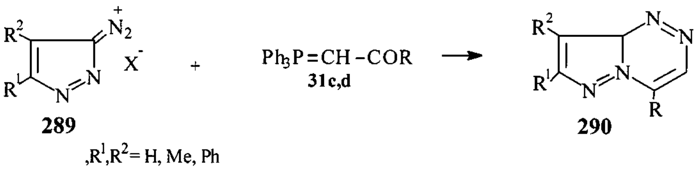
SCHEME 63

An olefinic bond formation was reported to take place by a one pot-reaction of an aldehyde, diazoacetate and Ph_3P in the presence of a catalytic amount of molybdenum complex. Thus, a mixture of *p*-methoxybenzaldehyde, ethyl diazomethylacetate, Ph_3P, and the catalyst was refluxed for 5 h to give *trans* isomer of the unsaturated ester **288** in 85% yield (Eq. 37).[182]

$$\mathrm{EtOOC{-}CHN_2 + (Ar{-}CHO + PPh_3)} \xrightarrow{\mathrm{MoO_2(S_2CNEt_2)_2}} \mathrm{EtO_2C{-}CH{=}CHAr}$$

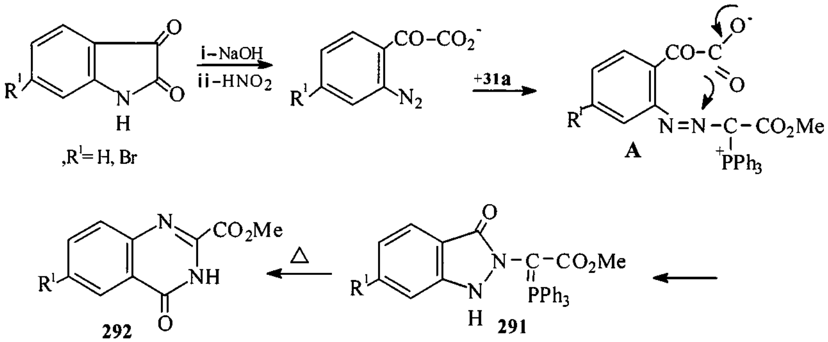
$$,\mathrm{Ar} = p\text{-}\mathrm{MeOC_6H_4} \qquad E\text{-}\mathbf{288} \qquad (37)$$

Several azolotriazines **290** were prepared in 40–73% yields by cyclocondensation reaction between the azolodiazonium salts **289** and the keto ylides **31c,d** (Scheme 64).[183]



SCHEME 64

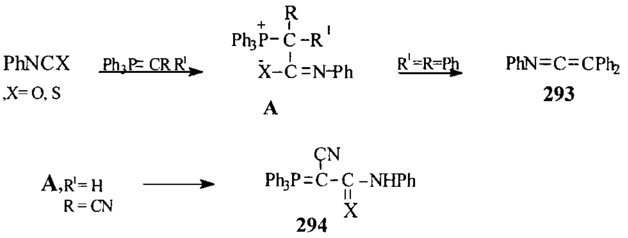
Coupling diazonium salts, from isatic acids, with ester ylide **31a** in alcoholic solution and treating the product mixture, further, with dilute NaOH was reported to directly give 3-oxoindazolin-2-yl(methoxycarbonylmethylenetriphenylphosphoranes) (**291**). Upon heating the compounds **291** in toluene, 4-oxoquinazolines **292** were afforded (Scheme 65).[184]



SCHEME 65

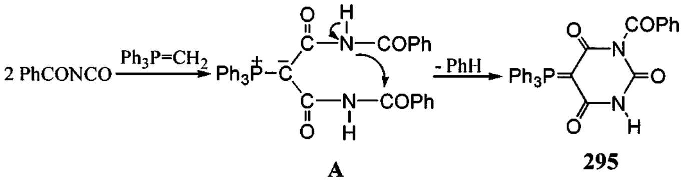
Reactions with Isocyanates and Isothiocyanates

It has been established that phosphorus-stabilized carbanions react with isocyanates and isothiocyanates according to Wittig reaction scheme, producing keteneimines **293**.[185,186] If an α-proton is available on the intermediate betaine **A**, the preferred reaction would be the migration of a proton to the nitrogen atom to form a new acylated ylide **294** particularly, if R exhibits an electron-withdrawing effect (Scheme 66).[185,187]



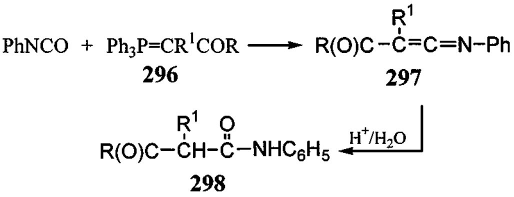
SCHEME 66

Activated isocyanates, benzoyl isocyanate for example, would react with nonstabilized ylide, in 2:1 molar ratio, to afford heterocycle ylide **295**. It is assumed that a prototropic shift occurred to form the betaine stage **A** followed by immediate cyclization to form the final product (Scheme 67).[188]



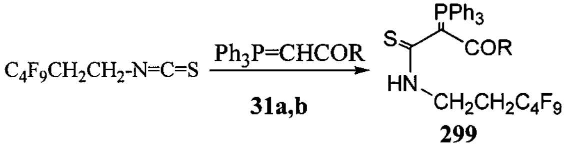
SCHEME 67

Bestmann and Kumar[189] reported additional examples of keteneimine formation by the reaction of isocyanates with stabilized ylides. Thus, α-acylphosphonium ylides **296** react with phenylisocyanate to form α-acylketeneimines **297**, which can be hydrolyzed to α-branched β-ketocarboxylic acid anilides **298** (Eq. 38).[189]



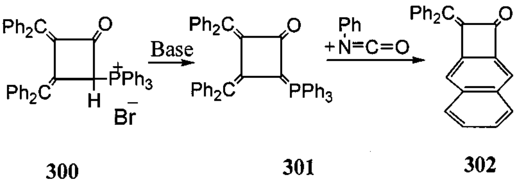
(38)

In the same manner, the reaction of 2-fluoroalkylethyl thiocyanates with ester ylides **31a**,**b** was reported to produce a perfluoroalkyl chain into the structure of stabilized ylides to give α-thioamide ylides **299** via proton transfer (Eq. 39).[190] The method was extended with thiocyanates to allow the introduction of an alkyl or alkylaryl chain into such a structure.[190]



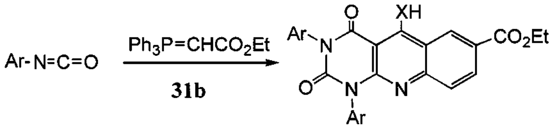
(39)

Cycle phosphonium ylide **301**, derived from its bromide salt **300**, was reported to react with phenyl isocyanate yielding **302** (Eq. 40).[191]



(40)

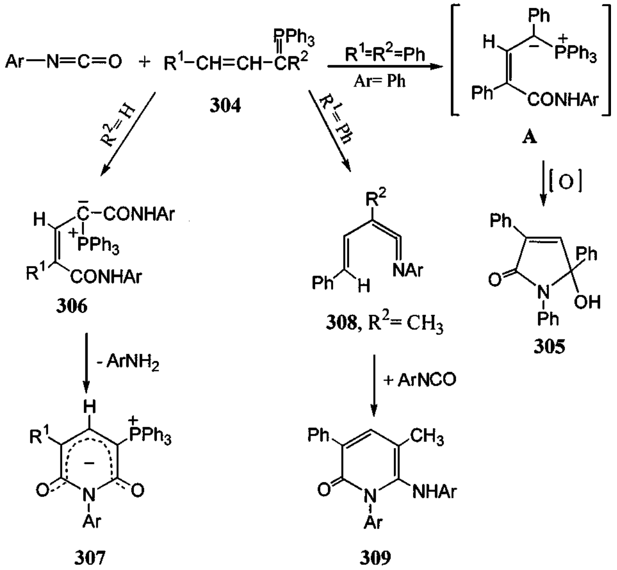
Reaction of aryl isocyanates with ester-stabilized ylide **31b** introduced a simple approach to the synthesis of 1,3,9-triazoanthracene derivatives **303** (Eq. 41).[192]



(41)

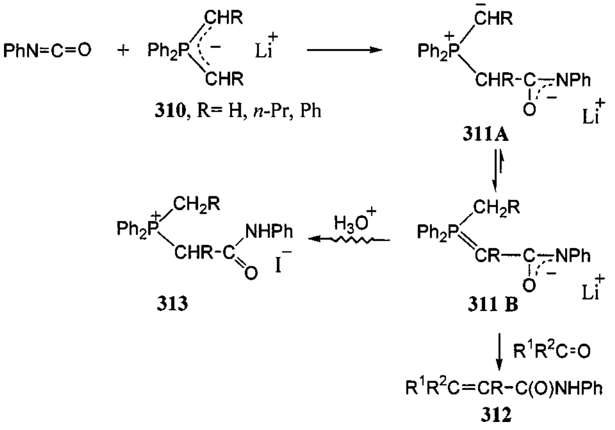
303, X= NAr or O

Conversely, aryl isocyanates were reported to convert allylidene phosphoranes **304**, according to their α-substituent, either into the hitherto little known vinylketeneimines **308** via Wittig reaction, or into the pyrrolone **305** by carbamoylation and ring closure, or into the 3-pyridylidene phosphoranes **307**. A new stable ylide series **308** (R^2=CH_3) reacted, further, with electron deficient dienophiles (e.g. ArNCO) in a [4+2] cycloaddition to yield **309** (Scheme 68).[193]



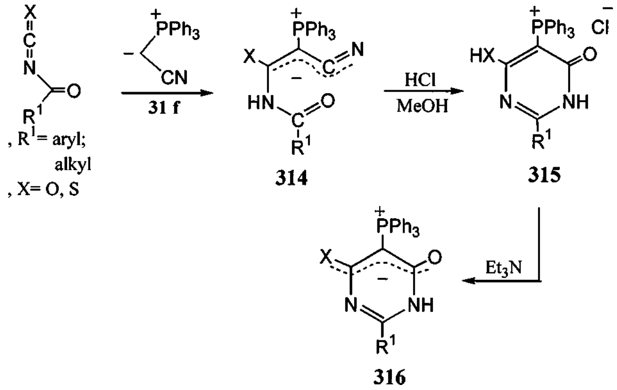
SCHEME 68

Phenylisocyanate was also reported to react with lithium diphenylphosphonium diylides **310** yielding semi-stabilized ylides **311** bear a metallated amide function; that could, further, be used in situ, as Wittig reagents toward aldehydes and ketones. The approach has shown to be a new one-pot, *E*-stereoselective synthesis for α,β-unsaturated anilides **312**. Moreover, the corresponding phosphonium salts **313** were successfully isolated (Scheme 69).[194]



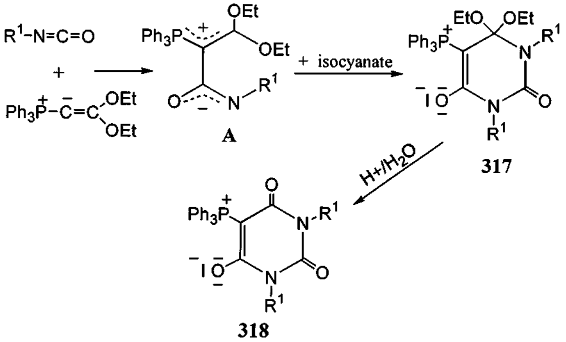
SCHEME 69

Recently, Meervelt et al.[195] reported that the adducts **314** of the available ylide **31f** with aroyl- or acylisocyanates and their thio analogues undergo facile cyclization, promoted by hydrogen chloride in methanol, to give high yields of 2-alkyl (aryl)-4-hydroxy(mercapto)-6-oxo-1,6-dihydropyrimidin-5-yltriphenylphosphonium chlorides **315**, suitable for preparing several types of phosphonium ylide-betaines of the pyrimidine series (e.g., **316**) (Scheme 70).



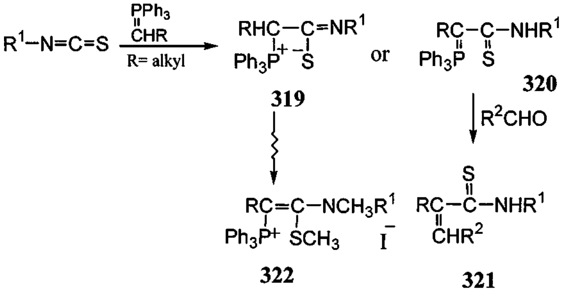
SCHEME 70

The reaction of two equivalents of isocyanates with (2,2′-diethoxyvinylidene)-triphenylphosphorane was reported to yield 1,3-disubstituted 6,6-diethoxy-5,6-dihydro-5-(triphenylphosphoranylidene)-2,4-(1*H*,3*H*)-pyrimidinediones **317** through the intermediate betaine **A**. By boiling **317** in acetic acid, the acetal group is cleaved with the formation of the corresponding 6-oxo-derivative **318** (Scheme 71).[196,197]



SCHEME 71

Isothiocyanates were reported to give alkylidene phosphoranes either as stable betaine **319** (if R exhibits an (+) I-effect)[198] or as the ylide **320** (for groups with an (−) I-effect).[185c,d] Subsequent reactions of **319** or **320** make possible the synthesis of thiocarboxylic acid amides **321**, as well as substituted vinylphosphonium salts **322** (Scheme 72).[185d,198]



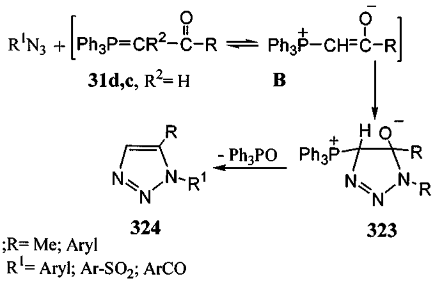
SCHEME 72

Reactions with Azides

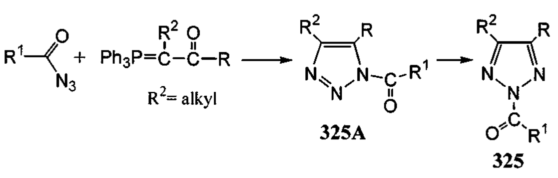
The reactions of phosphorus ylides with organic azides would be expected to parallel the reactions of phosphines, Grignard reagents and carbanions with azides. In these three cases, nucleophilic attack occurs on the azide terminus to give initially a triazo intermediate **A** which either remains stable or decomposes into other products (Eq. 42). In effect, adducts from stabilized ylides and organic azides fall within this latter group and

$$R^1N_3 + \bar{Y} \longrightarrow \underset{\mathbf{A}}{\overset{+}{Y}-N{=}N-\bar{N}-R} \rightsquigarrow \text{Products} \qquad (42)$$

their mode of decomposition depends upon the electrophilicity of the carbonyl group of the ylide. Thus, 2-oxoalkylidenephosphoranes **31d**,**c** reacted with azido compounds and afforded a versatile general synthesis of vicinal triazoles **324** (Scheme 73). The reaction could be visualized as a 1,3-dipolar cycloaddition of the azido group to the enol betaine form **B**. Originally, the method was described for phosphoranes **31d**,**c** in which R^2=H,[199] and later was broadened in scope[200–204] to include phosphoranes in which R^2 = alkyl. Thus, it has been shown that applying the reaction to carboxylic acid azides yields primary products **325A** in which the acyl group is attached to N-1 of the produced triazoles; however, migration to N-2, **325**, could occasionally occur (Scheme 74).[200–204]

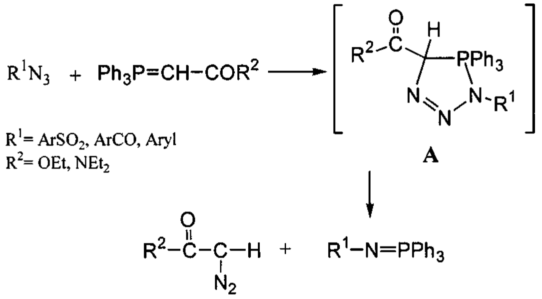


SCHEME 73



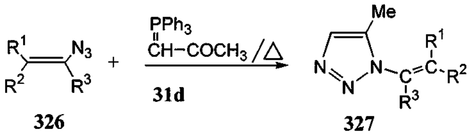
SCHEME 74

In some instances, the azido group is found to undergo a 1:3-dipolar cycloaddition to the P=C (double bond) of the phosphorane **31d**,**c** as shown in Scheme 75.[199,203–206]



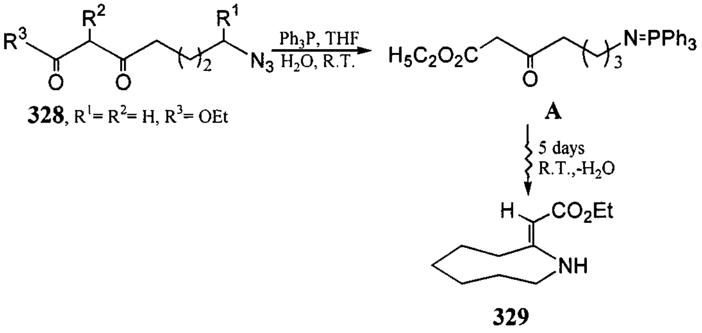
SCHEME 75

The reaction formulated in Scheme 73 was also applied to vinyl azides **326** and gave the triazoles **327** (Scheme 76),[207] although extremely long reaction times are necessary.



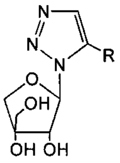
SCHEME 76

Even though the scope of the reaction of phosphonium ylides with azides has been early explored[208] and flourished in the 1960s and 70s, relatively little has been added after that. Old Staudinger reaction followed by an aza-Wittig cyclization to build unsaturated nitrogen heterocycles and the versatility of the azide group, as well, was reported in several publications.[209–213] For example, the treatment of ω-azido-β-dicarbonyl derivatives **328** with one equivalent of Ph_3P led to a transient phosphineimine **A** (Staudinger reaction), which cyclized into vinylogous urethanes **329** and amides via an intramolecular aza-Wittig reaction in excellent yields (Eq. 43).[209]



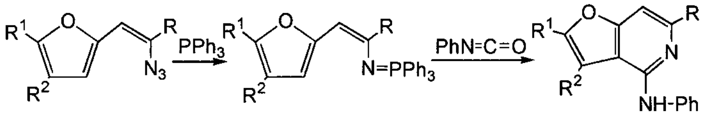
(43)

Preparation of 1,2,3-triazole nucleosides **330** from the reaction of apiofuranose azide with keto ylides ($Ph_3P{=}CHC(O)R$) in four steps was also reported.[214] A number of lipids were similarly prepared by the reaction of the corresponding azido derivative with keto ylides or by the reduction of the azido group to an amino group followed by the Wittig reaction.[215]



330

In the same manner, a number of furo[3,2-*c*]pyridines **333a–d** and benzo[*b*]derivative **333e** were prepared by the reaction of the corresponding iminophosphoranes **332**, available from ethyl azidoheteroacrylates **331** and triphenylphosphine, with phenyl isocyanates (Eq. 44).[216]

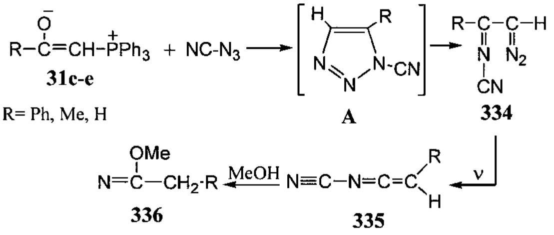


331 **332** **333a-e**

, R= CO_2Et (44)

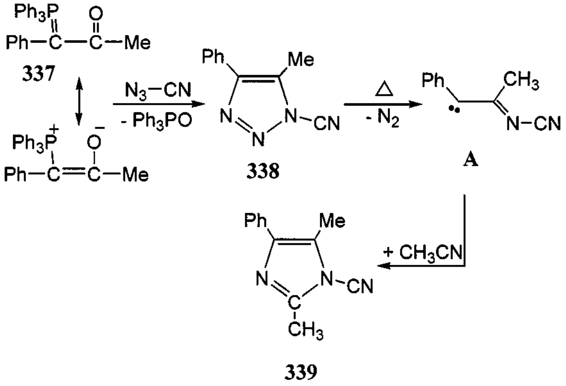
	R^1	R^2		R^1	R^2
a	Me	Me	**d**	4-Me-C_6H_4	H
b	Me	H	**e**	R^1–R^2=	CH=CH-CH=CH
c	Ph	H			

Cyanazide was reported to react with acylmethylenephosphoranes **31c–e** to give *N*-cyano-*α*-diazoimines **334** and Ph_3PO. Photolytically, the diazo products **334** were transformed into the *N*-cyanoketeneimines **335**, which had been trapped as imidoesters **336** by the addition of methanol (Scheme 77).[217]



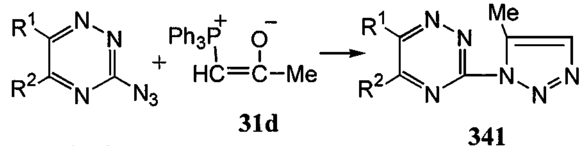
SCHEME 77

Conversely, triazole-1-carbonitrile **338** was obtained in 90% yield by reaction of the methylenephosphorane **337** with cyanoazide in dichloromethane/acetonitrile with concomitant formation of Ph_3PO. When a solution of **338** in acetonitrile was heated 2,5-dimethyl-4-phenylimidazole-1-carbonitrile (**339**) was formed by [3+2]-cycloaddition of α-cyanoiminocarbene (**A**) to the solvent (Scheme 78).[218]



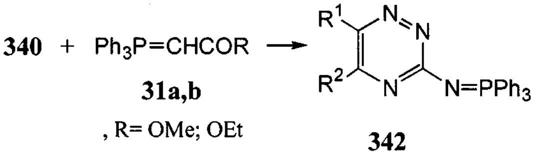
SCHEME 78

3-Azidotriazines **340** has been recently reported to react with keto ylide **31d** yielding 1-triazino-5-substituted-1,2,3-triazoles **341**, whereas with ester ylides **31a**,**b** the corresponding iminophosphoranes **342** were formed (Eqs. 45 and 46).[219]



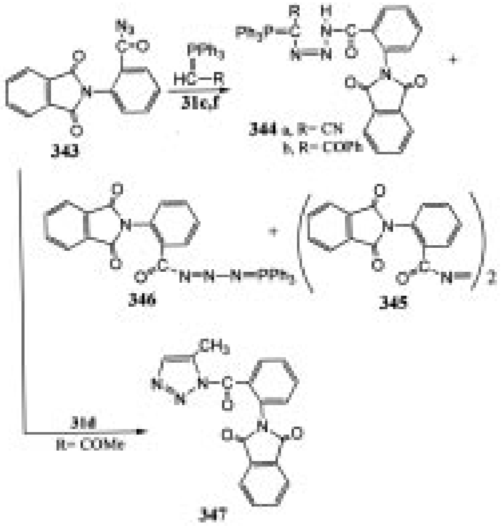
(45)

340, R^1, R^2= Phenanthrene
$R^1 = R^2$= Ph



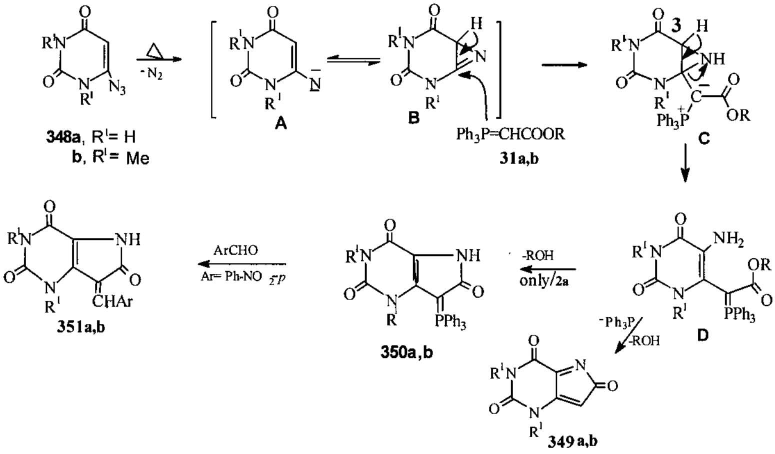
(46)

The reaction of *o*-phthalimidobenzoic acid azide **343** with stabilized ylides has been recently reported in some details.[220] With cyano ylide **31f**, **343** afforded three products **344–346**; whereas with keto ylides **31c** and **31d**, it yielded **344b** and **347** respectively (Scheme 79).[220]



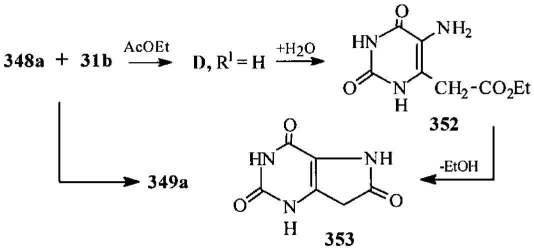
SCHEME 79

More recently, a series of 9-deazaxanthines was regioselectively prepared in reasonable yields as major products from the reactions of 6-azidouracils with stabilized ester-, keto-**2c** and moderate allyl ylide phosphoranes, instead of the expected triazoles.[221] Thus, azide **348a** reacted thermally with ester ylide **31a** and afforded pyrrolo[3,2]pyrimidines **349a** and **350a** (Scheme 80).

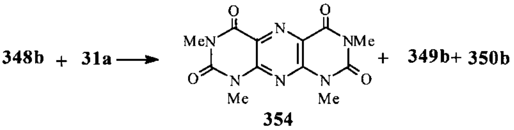


SCHEME 80

On the other hand, treatment of **348a** with **31b** yielded **349a** along with (*o*-amino-pyrimidino)ethyl acetate **352**. The latter compound was further heated in a mixture of acetic anhydride and pyridine to give the fused pyrrolone **353** (Eq. 47). Pyrimido[5,4-*g*]pteridine-2,4,5,7-tetrone **354** along with **349b** and **350b** were obtained when the azide **348b** was treated with either **31a** or **31b** (Eq. 48). The treatment of cyclic ylides

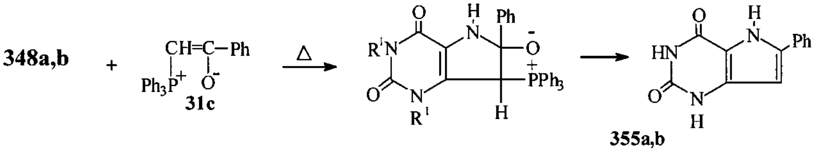


(47)



(48)

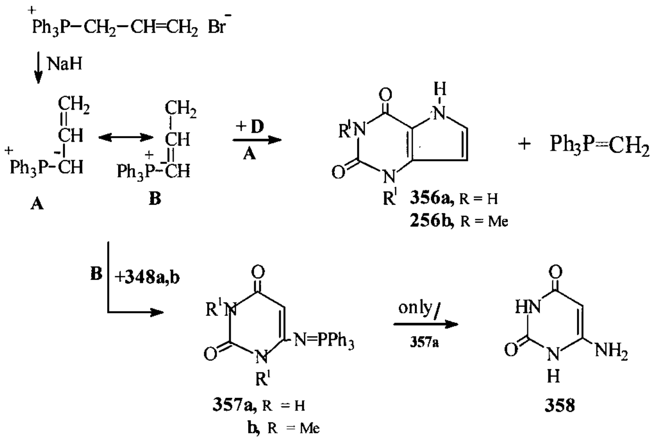
350a,b with aromatic aldehydes afforded the corresponding Wittig products **351a,b**. Furthermore, by treating the azides **348a,b** with keto ylide **31c**, pyrroles **355a,b** and pteridine **352** (with **348b**) were obtained (Scheme 81). With allyl ylide-prepared in situ from its bromide salt by using NaH-the reaction products consisted of the respective pyrrolo fused-pyrimidines **356a,b** along with 6-aminouracil **358** or the iminophosphorane **357b** are the reaction products (Scheme 82).[221]



SCHEME 81

CONCLUSIONS AND PROSPECTS

This brief review of chemical reactivity of alkylidene phosphoranes toward carbon-nitrogen systems is by no means exhaustive. By using some selected, but not typical examples, the value of phosphonium ylides as synthons for organic synthesis, in particular for their ability to



SCHEME 82

react with poor electrophiles, has been illustrated. In most cases, a few easy reaction steps enable the synthesis of novel and highly interesting types of condensed heterocycles that are difficult to obtain by other synthetic means. There are reasons to believe that the chemoselectivity and regioselectivity of some of the reactions reported need further refinement.

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REFERENCES

[1] a) A. W. Johnson, *Ylides and Imines of Phosphorus*, with special contributions by, W. C. Kaska', K. A. Ostoja Starzewsk and D. A Dixon, Wiley: New York (1993). b) D. A. Dixon, chapter 2. c) chapters 6 and 7. d) A. W. Johnson, *Ylide Chemistry* (Academic Press: New York, 1966).

[2] B. E. Maryanoff and A. B. Reitz, *Chem. Rev.*, **89,** 863 (1989).

[3] E. W. Vedejs and G. Frederick, *Chem. Rev.*, **86,** 941 (1986).

[4] a) O. I. Kolodiazhnyi, *Phosphorus Ylides: Chemistry and Application in Organic Synthesis* (Wiley, VCH: Weinheim, Germany, 1994). b) O. I. Kolodiazhnyi and V. P. Kukhar, *Russ. Chem. Revs.*, **52,** 1096 (1983).

[5] P. J. Murphy and J. Brennan, *Chem. Soc. Revs.*, **17,** 1 (1988).

[6] a) H. J. Cristau, *Chem. Rev.*, **94,** 1299 (1994). b) S. Trippett, *Organophosphorus Chemistry*, The Chemical Society, Burlington House, London (1975–1983).

[7] a) J. I. G. Cadogan, *Organophosphorus Reagents in Organic Synthesis* (Academic Press: London, 1979). b) ibid. pp. 219–220. c) J. Emsley and D. Hall, *The Chemistry of Phosphorus* (Wiley, New York, 1976). d) H. J. Bestmann and R. Zimmermann, *Organic Phosphorus Compounds* (Wiley, Chichester, 1972), vol. 3, chapter 5. e) S. Trippett, *Quart. Revs.*, **17,** 406 (1963).

[8] W. J. Hehre, L. Radom, P. von R. Schleyer, and J. Pople, *Ab Initio Molecular Orbital Theory* (Wiley, New York, 1986).

[9] D. M. Hirsl, *A Computational Approach to Chemistry* (Blackwell Scientific, Oxford, Great Britain, 1990).

[10] H. Schmidbaur, J. Jeong, A. Schier, W. V. D. L. Wilkinson, and G. Müller, *New J. Chem.*, **13,** 34 (1989).

[11] a) D. G. Gilheany, *Chem. Rev.*, **94,** 1339 (1994). b) A. E. Reed and P. von P. Schleyer, *J. Am. Chem. Soc.*, **112,** 1434 (1990). b) D. G. Morris, *Recent Advances in the Chemistry of Ylides in Survey of Progress in Chemistry* (Butterworth Scientific, Oxford, Great Britain, 1983). b) W. Kutzelnigg, *Angew. Chem. Int. Ed. Engl.*, **23,** 272 (1984). c) *Angrew. Chem.*, **96,** 262 (1984). d) E. Magnusson, *J. Am. Chem. Soc.*, **112,** 7940 (1990). e) A. E. Reed and F. Weinhold, *J. Am. Chem. Soc.*, **108,** 3586 (1986).

[12] J. E. Huheey, E. A. Keiter, and R. L. Keiter, *Inorganic Chemistry* (Harper Collins, New York, 1993), 4th ed.

[13] G. Pacchioni and P. S. Bagus, *Inorg. Chem.*, **31,** 4391 (1992).

[14] D. E. Evans, S. W. Kaldov, T. K. Johnes, J. Clardy, and T. J. Stout, *J. Am. Chem. Soc.*, **112,** 7001 (1990).

[15] a) T. B. Attra, Y. Le Bigot, R. El-Gharbi, M. Delmas, and A. Gaset, *Synth. Commun.*, **22,** 1421 (1992). b) L. I. Mizrakh and L. Y. Polonskaya, *J. Gen. Chem.*, **59,** 1299 (1990).

[16] M. Le Corre, *Bull. Soc. Chim. Fr.*, 1951 (1974).

[17] H. J. Bestmann, H. Hortung, and I. Pils, *Angew. Chem.*, **77,** 1011 (1965).

[18] A. Padwa and S. F. Hornbuckle, *Chem. Rev.*, **91,** 263 (1991).

[19] A. J. Speziale, G. T. Marco, and K. W. Ratts, *J. Am. Chem. Soc.*, **84,** 854 (1962).

[20] G. Wittig and M. Schlosser, *Chem. Ber.*, **94,** 1373 (1961).

[21] E. Hedaya and S. Theodoropulos, *Tetrahedron*, **24,** 2241 (1968).

[22] F. Ramirez, O. P. Madan, and C. P. Smith, *Tetrahedron Lett.*, 201 (1965).

[23] R. F. Hudson and P. A. Chopard, *Helv. Chim. Acta.*, **46,** 2178 (1963).

[24] M. A. Shaw, J. C. Tebby, R. S. Ward, and H. Williams, *J. Chem. Soc.* (*C*), 2442 (1967).

[25] M. A. Shaw and J. C. Tebby, *J. Chem. Soc.*, 5 (1970).

[26] R. J. Linderman and A. I. Meyers, *Tetrahedron Lett.*, 3043 (1983).

[27] A. G. Cameron and A. T. Hewson, *J. Chem. Soc. Perkin Trans.*, **1,** 2979 (1983).

[28] a) D. Cavella and S. Warren, *Tetrahedron Lett.*, 4505 (1982). b) 295 (1983).

[29] E. Cereda, M. Attolini, E. Bellora, and A. Donetti, *Tetrahedron Lett.*, 2219 (1982).

[30] N. A. Nesmeyanov, V. V. Mikul'shina, V. G. Kharitonov, P. V. Petrovskii, and O. A. Reutov, *Iszv. Akad. Nauk SSSR, ser. Kim*, **5,** 1182 (1989); C. A. **112,** 56086 (1990).

[31] a) R. Apple, W. Buchner, and E. Guth, *Leibigs Ann. Chem.*, **618,** 53 (1958). b) L. H. Horner and H. Oediger, ibid. **627,** 142 (1959). c) L. N. Markouskii, V. Yu. Abramov, and Yu. G. Shermoluich, *Ukr. Khim. Zh.*, **57,** 2191 (1991); C. A. **117,** 111664 (1992).

[32] H. J. Cristau and C. Garcia, *Synthesis*, 315 (1990).

[33] E. E. Schweizer, C. S. Kim, C. S. Labaw, and W. P. Murray, *J. Chem. Soc. Chem. Commun.*, **7** (1973).

[34] T. S. Hafez, M. M. Henry, and M. R. Mahran, Proceeding 7th Ibn Sina International Conference, pp. 142 (2000).

[35] F. Palacios, D. Aparicio, and J. M. de los Santos, *Tetrahedron Lett.*, **34,** 3481 (1993).

[36] J. Hajicek, J. Hrbata, P. Pihera, B. Brunova, M. Ferenc, J. Krepelka, L. Kvapil, and J. Pospisil, *Czeeh. CS Pospisil*, **272,** 574 (1991); C. A. **117,** 796 (1992).

[37] K. Okuma, Y. Komiya, and H. Ohta, *Chem. Lett.*, 1145 (1988); C. A. **109,** 189813 (1988).

[38] H. J. Bestmann, G. Shmid, H. Oechsner, and P. Ermann, *Chem. Ber.*, **117,** 1561 (1984).

[39] M. von Strandtmann, M. P. Cohen, C. Puchalski, and J. Shavel, *J. Org. Chem.*, **33,** 4306 (1968).

[40] R. Gompper and K. P. Bichimayer, *Tetrahedron Lett.*, **21,** 2879 (1980).

[41] F. M. Soliman, K. M. Khalil, A. A. El-Kateb, R. Shabana, and G. Abdel-Naim, *Chemistry and Industry*, 554 (1985).

[42] J. P. Bégué, D. Bonnet-Delpon, D. Mesureur, G. Née, and S. W. Wu, *J. Org. Chem.*, **57,** 3807 (1992).

[43] M. Le Corre, A. Hercouet, and H. Le Baron, *J. Chem. Soc. Chem. Commun.*, 14 (1981).

[44] J. V. Cooney and W. E. McEwen, *J. Org. Chem.*, **46,** 2570 (1981).

[45] M. L. Gilpin, J. B. Harbridge, T. T. Howarth, and T. J. King, *J. Chem. Soc. Chem. Commun.*, 929 (1981).

[46] J. P. Bazureau and M. Le Corre, *Tetrahedron Lett.*, 1919 (1990).

[47] M. J. O'Donnell, A. Arasappan, W. J. Hornback, and J. C. Hufmann, *Tetrahedron Lett.*, **31,** 157 (1990).

[48] D. Scholz, S. Weber-Roth, E. Macoratti, and E. Francotte, *Synth. Commun.*, **29,** 1143 (1999).

[49] H. T. Reetz, N. Grebenow, and R. Goddard, *J. Chem. Soc. Chem. Commun.*, **16,** 1605 (1995).

[50] R. A. Aitken, H. R. Cooper, and A. P. Mehrotra, *J. Chem. Soc. Perkin Trans.*, **1,** 479 (1995).

[51] M. P. Sibi and P. A. Renhowe, *Tetrahedron Lett.*, **31,** 7407 (1990).

[52] T. Henk, A. Giannis, and K. Sandhoff, *Leibigs Ann. Chem.*, 167 (1992).

[53] A. G. M. Barrett, H. B. Broughton, S. V. Attwood, and A. A. L. Guna-tilaka, *J. Org. Chem.*, **51,** 1986 (1986).

[54] a) G. Sabitha, M. M. Reddy, D. Srinivas, and J. S. Yadov, *Tetrahedron Lett.*, 165 (1999). b) M. C. A. van Vliet, G. J. Meuzelaar, J. Bras, L. Maat, and R. A. Sheldon, *Leibigs Ann./Recl.*, 1989 (1997).

[55] C. Cativiela, M. D. Diaz-de Billegas, and A. T. Timenez, *Tetrahedron*, **52,** 5881 (1996).

[56] S. Kalka, M. Kovar, A. Klasek, and T. Kappe, *Heterocycl. Chem.*, **33,** 1977 (1996).

[57] E. J. Latham, S. M. Murphy, and S. P. Stanforth, *Tetrahedron*, **51,** 10385 (1995).

[58] F. M. Soliman, E. S. Yakout, and M. M. Said, *Bull. Chem. Soc. Jpn.*, **67,** 1 (1994).

[59] Z. Y. Wei and E. E. Knaus, *Synlett*, **5,** 345 (1994); C. A. **121,** 205156 (1994).

[60] T. Kawasaki, Y. Nonaka, M. Uemura, and M. Sakamoto, *Synthesis*, 701 (1991).

[61] F. M. Soliman and M. M. Said, *Sulfur Lett.*, **13,** 213 (1991).

[62] a) M. H. N. Arsanious, *Monatsh*, **130,** 921 (1999); D. Person and M. Le Corre, *Bull. Soc. Chim. Fr.*, 673 (1989); C. A. **113,** 6790 (1990).

[63] M. L. Gilpin, J. B. Harbridge, and T. T. Howarth, *J. Chem. Soc. Perkin Trans.*, **1,** 1369 (1987).

[64] T. Kaneko, H. Wong, T. W. Ddye, W. C. Rose, and W. T. Brandner, *J. Med. Chem.*, **28,** 388 (1985).

[65] G. G. Triyo and F. F. Liama, *Heterocycles*, **23,** 2999 (1985).

[66] K. Faber, H. Stueckler, and T. Kappe, *Heterocyclic Chem.*, **21,** 177 (1984).

[67] G. Tacconi, L. A. Gambe, P. P. Righetti, and G. J. Desimoni, *Prakt. Chem.*, **322,** 711 (1980).

[68] T. Shono, Y. Matsumara, T. Kanazawa, M. Habuka, K. Unchida, and K. Toyeda, *J. Chem. Research* (*S*), 320 (1984); C. A. **102,** 184938 (1985).

[69] M. M. Campbell and B. P. Connarty, *Heterocycles*, **19,** 1853 (1982).

[70] H. Cristau and Y. Ribeilly, *J. Organomet. Chem.*, **352,** C51 (1988); C. A. **111,** 78125 (1989).

[71] H. J. Bestmann, N. Sommer, and H. A. Staab, *Angew. Chem.*, **74,** 270 (1962).

[72] H. A. Staab and N. Sommer, *Angew. Chem.*, **74,** 294 (1962).

[73] S. Boulard, P. Gordon, and S. P. Stanforth, *J. Chem. Res.* (*S*), 728 (1998) and (*M*) 3201 (1998).

[74] T. Okawa, M. Toda, S. Eguchi, and A. Kakehi, *Synthesis*, 1467 (1998).

[75] U. Wolf, *Z. Naturforsch.*, **36,** 383 (1981); C. A. **95,** 7155 (1981).

[76] G. Lindgren, *Chemica Scripta*, **24,** 38 (1984); C. A. **102,** 6307 (1985).

[77] H. S. Lee and K. Kim, *Tetrahedron Lett.*, **37,** 869 (1996).

[78] L. Calabi, B. Daniel, G. Lesma, and G. Palmisano, *Tetrahedron Lett.*, **23,** 2139 (1982).

[79] M. Eitel and U. Pindur, *Synthesis*, 364 (1989).

[80] M. Le Corre, A. Hercouet, Y. Le Stanc, and H. Le Baron, *Tetrahedron*, **41,** 5313 (1985).

[81] I. Ernest, C. W. Greengrass, W. Holick, D. E. Jackman, H. R. Pfaendler, and R. B. Woodward, *J. Am. Chem. Soc.*, **100,** 8214 (1978).

[82] H. R. Pfaendler, J. Gosteli, and R. B. Woodward, *J. Am. Chem. Soc.*, **101,** 6306 (1979).

[83] Y. Hamashima, S. Yamamoto, T. Kubota, K. Tokura, K. Ishikura, K. Minami, F. Matsubara, M. Yamaguchi, I. Kikkawa, and W. Nagata, *Tetrahedron Lett.*, 4947 (1979).

[84] R. J. Ponsford, P. M. Roberts, and R. Southgate, *J. Chem. Soc. Chem. Commun.*, 847 (1979).

[85] M. Lang, K. Parasad, W. Holick, J. Gosteli, I. Ernest, and R. B. Woodward, *J. Am. Chem. Soc.*, **101,** 6296 (1979).

[86] Y. Katsura and M. Aratani, *Tetrahedron Lett.*, **35,** 9601 (1994).

[87] T. Kametani, K. Fukomoto, and M. Ihara, *Heterocycles*, **17,** 463 (1982).

[88] H. Iwagami, S. R. Woulfe, and M. I. Miller, *Tetrahedron Lett.*, **27,** 3095 (1986).

[89] A. Yoshida, Y. Tajima, N. Takeda, and S. Oida, *Tetrahedron Lett.*, 2793 (1984).

[90] A. J. G. Baxter, R. J. Ponsford, and R. Southgate, *J. Chem. Soc. Chem. Commun.*, 429 (1980).

[91] C. N. Hsiao and T. Kolasa, *Tetrahedron Lett.*, **33,** 2629 (1992).

[92] J. Bourguignon, M. Lemarchand, and G. J. Quequiner, *Heterocycl. Chem.*, **17,** 257 (1980).

[93] H. J. Bestmann and D. Roth, *Angew. Chem.*, **29,** 99 (1990).

[94] L. S. Boulos and M. H. N. Arsanious, *Tetrahedron*, **53,** 3649 (1997).

[95] I. T. Hennawy, *Egypt. J. Appl. Sci.*, **9,** 864 (1994).

[96] H. J. Bestmann and H. J. Lang, *Tetrahedron Lett.*, **25,** 2101 (1969).

[97] M. M. Sidky, M. R. Mahran, A. A. El-Kateb, I. T. Hennawy, and H. A. Abd El-Malek, *Phosphorus and Sulfur*, **29,** 227 (1987).

[98] M. L. Fi Clerici, D. Gelmi, and R. Rondena, *Tetrahedron*, **51,** 9985 (1995).

[99] W. M. Abdou, E. M. A. Yakout, and M. M. Said, *Sulfur Lett.*, **17,** 33 (1993).

[100] a) J. E. Bishop, J. E. O'Connell, and H. Rapoport, *J. Org. Chem.* **56,** 5079 (1991).
b) D. N. Harpp and J. G. Gleason, *J. Am. Chem. Soc.*, **94,** 2514 (1972).

[101] R. Galli, *J. Org. Chem.*, **52,** 5349 (1987).

[102] W. M. Abdou and I. T. Hennawy, *Phosphorus, Sulfur and Silicon*, **89,** 105 (1994).

[103] W. M. Abdou, *Phosphorus, Sulfur and Silicon*, **144,** 393 (1999).

[104] W. M. Abdou and E. M. A. Yakout, *Tetrahedron*, **49,** 6411 (1993).

[105] L. S. Boulos and I. T. Hennawy, *Phosphorus, Sulfur and Silicon*, **56,** 65 (1991).

[106] A. A. Fahmy, T. S. Hafez, and L. S. Boulos, *Phosphorus, Sulfur and Silicon*, **56,** 219 (1991).

[107] A. Gossauer, F. Roessler, and H. Zilch, *Leibigs Ann. Chem.*, 1309 (1979).

[108] W. Flitsch and H. Peters, *Tetrahedron Lett.*, 1161 (1969).

[109] M. Natsune, M. Takhashi, K. Kiuchi, and H. Sugaya, *Chem. Pharm. Bull.*, **19,** 2648 (1971).

[110] W. Flitsch and S. R. Schindler, *Synthesis*, 685 (1975).

[111] A. I. Meyers, J. P. Lawson, and D. R. Carver, *J. Org. Chem.*, **46,** 3119 (1981).

[112] L. S. Boulos, N. Khir-Eldin, and M. F. Zayed, *Phosphorus, Sulfur and Silicon*, **61,** 131 (1991).

[113] M. Augustin and P. Jeschke, *J. Prakt. Chem.*, **329,** 637 (1987).

[114] F. M. Soliman, M. M. Said, and S. S. Maigali, *Heteroatom Chem.*, **8,** 157 (1997).

[115] H. Z. Alkathlan, *Synthetic Commun.*, **22,** 2659 (1992); C. A. **118,** 22130 (1993).

[116] a) A. Gossauer, R. P. Hinze, and H. Zilch, *Angew. Chem.*, **16,** 418 (1977). b) A. Gossauer and R. P. Hinze, *J. Org. Chem.*, **43,** 283 (1987).

[117] M. Slopianka and A. Gossauer, *Leibigs Ann. Chem.*, 2258 (1981).

[118] W. M. Abdou, E. M. A. Yakout, and N. A. F. Ganoub, *Tetrahedron*, **51,** 11411 (1995).

[119] L. S. Boulos and M. H. N. Arsanious, *Heteroatom Chem.*, **10,** 337 (1999).

[120] E. S. M. A. Yakout, D. B. Giurgius, and L. S. Boulos, *Phosphorus, Sulfur and Silicon*, **148,** 177 (2000).

[121] H. J. Bestmann and F. Seng, *Angew. Chem.*, **75,** 475 (1963).

[122] E. Zbiral, *Tetrahedron Lett.*, 3963 (1964).

[123] O. Arjona, R. Perez-Ossorio, J. Plumet, and M. J. Santesmases, *An. Quim. Ser. C.*, **82,** 272 (1986); C. A. **107,** 197723 (1987).

[124] L. S. Boulos, R. Shabana, and Y. M. Shaker, *Heteroatom Chem.*, **11,** 57 (2000).

[125] F. M. Soliman, M. M. Said, S. S. Maigali, and T. S. Hafez, Proc. 6th Ibn Sina. Int. Conf., pp. 291 (1997).

[126] M. D. Khidre, H. M. Abo-Yousef, and M. R. Mahran, *Phosphorus, Sulfur and Silicon*, **140,** 147 (1998).

[127] L. S. Boulos and M. H. N. Arsanious, *Phosphorus and Sulfur*, **36,** 23 (1988).

[128] L. S. Boulos, I. I. Hennawy, and M. H. N. Arsanious, *Heteroatom Chem.*, **5,** 447 (1994).

[129] L. S. Boulos, M. F. Zayed, and Y. O. El-Khoshnieh, *Phosphorus, Sulfur and Silicon*, **62,** 231 (1991).

[130] L. S. Boulos, Y. O. El-Khoshnieh, and M. H. N. Arsanious, *Phosphorus, Sulfur and Silicon*, **47,** 19 (1990).

[131] L. S. Boulos and M. H. N. Arsanious, *Phosphorus, Sulfur and Silicon*, **42,** 47 (1989).

[132] H. J. Bestmann, *Angew. Chem.*, **77,** 850 (1965).

[133] E. E. Schweizer and C. M. Kopay, *J. Org. Chem.*, **37,** 1561 (1972).

[134] A. A. El-Kateb and H. A. Abdel-Malek, *Phosphorus, Sulfur and Silicon*, **112,** 41 (1996).

[135] E. S. H. El-Ashry, A. Amer, G. H. Labib, M. M. A. Rahman, and A. M. El-Massry, *J. Heterocycl. Chem.*, **24,** 63 (1987).

[136] W. M. Abdou, N. A. F. Ganoub, and A. A. M. Shaddy, *Phosphorus, Sulfur and Silicon*, **165,** 171 (2000).

[137] M. D. Khidre, *Egypt. J. Chem.*, **40,** 327 (1997).

[138] G. K. Papageorgiou, D. Nicolaides, and J. Stephanidou-Stephanatou, *Leibigs Ann. Chem.*, 397 (1989).

[139] M. R. Mahran, W. M. Abdou, and N. A. F. Ganoub, *Phosphorus, Sulfur and Silicon* **39,** 51 (1988).

[140] W. M. Abdou, N. A. F. Ganoub, and A. A. M. Shaddy, *Heterocycl. Commun.*, **3,** 57 (1997).

[141] D. N. Nicolaides, K. E. Litinas, G. K. Papageorgiou, and J. Stephanidou-Stephanatou, *J. Heterocycl. Chem.*, **28,** 139 (1991).

[142] D. N. Nicolaides, R. W. Awad, G. K. Papageorgiou, and J. Stephanidou-Stephanatou, *J. Org. Chem.*, **59,** 1083 (1994).

[143] D. N. Nicolaides, R. W. Awad, G. K. Papageorgiou, and J. Stephanidou-Stephanatou, *Tetrahedron Lett.*, **37,** 1097 (1996).

[144] C. Bezergiannidou-Balouctsi, K. E. Litinas, E. Malamidou-Xenikaki, and D. N. Nicolaides, *Leibigs Ann. Chem.*, 1175 (1993).

[145] D. N. Nicolaides, G. K. Papageorgiou, and J. Stephanidou-Stephanatou, *Tetrahedron*, **45,** 4585 (1989).

[146] W. M. Abdou, *Synth. Commun.*, **27,** 3599 (1997).

[147] a) A. A. Nada, A. W. Erian, N. R. Mohamed, and A. M. Mahran, *J. Chem. Research* (*S*) 236 (1997). b) (*M*) 1576 (1997).

[148] H. Behbehani, M. M. Abdel-Khalik, and M. H. Elnagdi, *Org. Prep. and Proc. Int.*, **31,** 551 (1999).

[149] A. W. Erian, N. R. Mohamed, and H. M. Hassaneen, *Synth. Commun.*, **29,** 1527 (1999).

[150] N. R. Mohamed, *Heterocyclic Commun.*, **5,** 433 (1999).

[151] a) R. G. Barnhardt, Jr. and W. E. McEwen, *J. Am. Chem. Soc.*, **89,** 7009 (1967). b) A. Bladè-Font, W. E. McEwen, and C. A. Vander-Werf, ibid. **83,** 3646 (1960).

[152] A. Bladè-Font and H. J. Bestmann, *Angew. Chem.*, **77,** 850 (1965).

[153] E. Ciganek, *J. Org. Chem.*, **35,** 3631 (1970).

[154] J. Vicente, M. T. Chicote, J. Fernandez-Baeza, F. J. Lahoz, and J. A. Lopez, *Inorg. Chem.*, **30,** 3617 (1991).

[155] H. Trabelsi, E. Bolen, and A. Cambon, *Synthesis*, 623 (1990).

[156] W. M. Abdou, M. A. E. Salem, and A. A. Sediek, *Tetrahedron*, **53,** 13945 (1997).

[157] M. Schwarz and M. Casutt, *Eur. Pat. Appl. EP*. 513, 700 (Cl. Co 7D 513/04), (1992).

[158] G. Kossmehl and R. Nuck, *Chem. Ber.*, **114,** 2920 (1981).

[159] W. M. Abdou and N. A. Ganoub, *Chem. and Indust.*, (London), **217,** 1029 (1991).

[160] M. R. Mahran, W. M. Abdou, N. M. Abd El-Rahman, and M. D. Khidre, *Heteroatom Chem.*, **3,** 93 (1992).

[161] W. Flitsch and E. R. F. Gesing, *Chem. Ber.*, **114,** 3146 (1981).

[162] W. M. Abdou and N. A. F. Ganoub, *Heterocycl. Commun.*, **1,** 387 (1995).

[163] N. A. F. Ganoub, *Phosphorus, Sulfur and Silicon*, **81,** 125 (1993).

[164] W. M. Abdou and N. A. F. Ganoub, *Phosphorus, Sulfur and Silicon*, **105,** 63 (1995).

[165] T. S. Hafez, N. A. Ismail, A. A. Fahmy, and S. M. Sh. Atta, *Phosphorus, Sulfur and Silicon*, **84,** 165 (1993).

[166] F. M. Soliman and M. M. Said, *Phosphorus, Sulfur and Silicon*, **61,** 335 (1991).

[167] W. M. Abdou and N. A. Ganoub, *Heteroatom Chem.*, **3,** 133 (1992).

[168] S. Trippett, *J. Chem. Soc.*, 4733 (1962).

[169] L. S. Boulos and H. A. Abd El-Malek, *Heteroatom Chem.*, **10,** 263 (1999).

[170] W. M. Abdou, N. A. F. Ganoub, and A. A. M. Shaddy, *Tetrachedron*, **54,** 9079 (1998).

[171] N. A. F. Ganoub, *Phosphorus, Sulfur and Silicon*, **141,** 43 (1999).

[172] a) G. Wittig and M. Schlosser, *Tetrahedron*, **18,** 1023 (1962). b) G. Ege and K. Gilbert, *Tetrahedron Lett.*, 1567 (1979).

[173] G. Markl, *Tetrahedron Lett.*, 811 (1961).

[174] a) H. C. R. Strzelecka, M. S. Siemiatycki, and C. Prevost, *Compt. Rend.*, **254,** 696 (1962). b) P. Froeyen and P. Juvvik, *Phosphorus, Sulfur and Silicon*, **69,** 83 (1992).

[175] a) E. E. Schweizer, C. S. Kim, and R. A. Johnes, *Chem. Commun.*, 39 (1970). b) E. E. Schweizer and C. S. Kim, *J. Org. Chem.*, **36,** 4033 (1971). c) E. E. Schweizer and C. S. Labaw, **38,** 3069 (1973).

[176] E. Zbiral and E. Bauer, *Tetrahedron*, ibid. **28,** 4189 (1972).

[177] E. E. Schweizer and C. S. Kim, *J. Org. Chem.*, **36,** 4041 (1971).

[178] G. Markl, *Tetrahedron Lett.*, 807 (1961).

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

[180] P. Froeyen and P. Juvvik, *Phosphorus, Sulfur and Silicon*, **69,** 83 (1992).

[181] G. Emmer, *Tetrahedron*, **48,** 7165 (1992).

[182] X. Lu, H. Fang, and Z. Ni, *J. Organomet. Chem.*, **373,** 77 (1989); C. A. **113,** 77838 (1990).

[183] G. Ege and K. Gilbert, *J. Heterocycl. Chem.*, **18,** 675 (1981).

[184] A. Alemagna, P. D. Buttero, E. Licandro, S. Maiorana, and J. C. Guastini, *J. Chem. Soc. Chem. Commun.*, 337 (1983).

[185] a) S. Trippett and D. M. Walker, *J. Chem. Soc.* 3874 (1959). b) G. H. Birum and C. N. Matthews, *Chem. Ind.* 653 (1968). c) H. Saikachi and K. Takai, *Yakugaku Zassli*, **89,** 1401 (1969); C. A. **72,** 124524 (1970); H. J. Bestmann and S. Pfohl, *Angew. Chem.*, **81,** 750 (1969).

[186] T. Saito, M. Nakane, T. Miyazaki, and S. Motoki, *J. Chem. Soc. Perkin Trans.*, **1,** 2140 (1984).

[187] G. Himbert, K. Diehl, and G. Maas, *J. Chem. Soc. Chem. Commun.*, 900 (1984).

[188] Y. Ohshiro, Y. Mori, M. Komatsu, and T. Agawa, *J. Org. Chem.*, **36,** 2029 (1971).

[189] H. J. Bestmann and K. Kumar, *Chem. Ber.*, **116,** 2708 (1983).

[190] E. Bollens, F. Szoenyi, H. Trabelsi, and A. Cambon, *J. Fluorine Chem.*, **67,** 117 (1994); C. A. **121,** 83490 (1994).

[191] F. Toda and K. Tanaka, *Tetrahedron Lett.*, **21**, 4869 (1980).

[192] L. Capuano, M. Bronder, K. Djoka, and I. Müller, *Chem. Ber.*, **113,** 395 (1980).

[193] L. Capuano and A. Willmes, *Leibigs Ann. Chem.*, 80 (1982).

[194] H. J. Cristau, A. Ribeill, and Y. Perraud-Darcy, *Tetrahedron Lett.*, **33,** 2693 (1992).

[195] L. Van Meervelt, O. B. Smolii, N. L. Mishchenko, D. B. Shakhnin, E. A. Romanenko, and B. S. Drach, *Tetrahedron*, **52,** 8835 (1996).

[196] H. J. Bestmann and K. Roth, *Angew. Chem.*, **94,** 635 (1982); *Angew. Chem. Internal. Ed.*, **21,** 621 (1982).

[197] H. J. Bestmann and R. W. Saalfrank, *Chem. Ber.*, **114,** 2661 (1981).

[198] H. J. Bestmann, B. Siegel, and G. Schmid, *Chemistry Lett.*, 1529 (1986).

[199] G. A. Harvey, *J. Org. Chem.*, **31,** 1587 (1966).

[200] G. L'abbé and H. J. Bestmann, *Tetrahedron Lett.*, 63 (1969).

[201] G. L'abbé, P. Ykman, and G. Smets, *Bull. Soc. Chim. Belg.*, **78,** 147 (1969).

[202] P. Ykman, G. L'abbé, and G. Smets, *Tetrahedron Lett.*, 5225 (1970).

[203] G. L'abbé, P. Ykman, and G. Smets, *Tetrahedron*, **25,** 5421 (1969).

[204] P. Ykman, G. L'abbé, and G. Smets, *Tetrahedron*, **27,** 5623 (1971).

[205] E. Zbiral and J. Stroh, *Manatsh. Chem.*, **100,** 1438 (1969).

[206] P. Ykman, G. L'abbé, and G. Smets, *Tetrahedron*, **27,** 845 (1971) and **29,** 195 (1973).

[207] P. Ykman, G. Mathys, and G. L'abbé, *J. Org. Chem.* **37,** 3213 (1973).

[208] H. Hofmann, *Chem. Ber.*, **95,** 2563 (1962).

[209] P. H. Lambert, M. Vaultier, and R. Carrié, *J. Org. Chem.* **50,** 5352 (1985).

[210] P. M. Fresneda and S. Garcia-Zafra, *Tetrahedron Lett.*, **52,** 9353 (1996).

[211] F. Palacios and G. Rubiales, *Tetrahedron Lett.*, **37**(35), 6379 (1996).

[212] J. Kovacs, I. Pinter, F. Szego, G. Toth, and A. Messmer, *Magy. Kem. Foly*, **87,** 49 (1981); C. A. **95,** 81359 (1981).

[213] J. M. G. Fernandez, C. Qrtiz-Mellet, V. M. Diaz-Perez, J. Fuentes, J. Kovacs, and I. Pinter, *Tetrahedron Lett.*, **38,** 4161 (1997).

[214] F. Hammerschmidt, J. P. Polsterer, and E. Zbiral, *Synthesis*, 415 (1995).

[215] H. Shibuya, K. Kawashima, N. Narita, M. Ikeda, and I. Kitagava, *Chem. Pharm. Bull.*, **40,** 1154 (1992).

[216] A. Krutosikova, M. Dandarova, J. Chylova, and D. Vegh, *Monatsh. Chem.*, **123,** 807 (1992).

[217] B. Arnold and M. Regitz, *Tetrahedron Lett.*, **21,** 909 (1980).

[218] D. Danion, B. Arnold, and M. Regitz, *Angew. Chem.*, **93,** 118 (1981).

[219] Y. O. El-Khoshnieh, *Heterocycl. Commun.*, **5,** 77 (1999).

[220] L. S. Boulos and N. Khir-Eldin, *Tetrahedron*, **49,** 3871 (1993).

[221] W. M. Abdou, A. F. M. Fahmy, and A. A. Kamel, *Heteroatom Chem.*, in press (2001).