Convenient Preparations of Diethyl [(Acylamino)methyl]phosphonates, 2-Azabutadienes, and Isoquinolines from a 1,2-Monoazabisylide Equivalent

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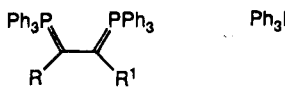
Diethyl [(triphenylphosphoranylidene)amino]methyl]phosphonate (**4**), prepared *in situ* by treatment of 1-[[(triphenylphosphoranylidene)amino]methyl]benzotriazole (betmip **6**) with diethyl phosphite anion, is converted by treatment with butyllithium into the corresponding carbanion **5**. Carbanion **5**, the first example of a 1,2-monoazabisylide equivalent, provides a versatile synthetic method to introduce the C=NC=C structural unit, as illustrated by convenient preparations of 1,4-diaryl-2-azabutadienes, 1,1,4,4-tetraaryl-2-azabutadienes, diethyl [(acylamino)methyl]phosphonates, and isoquinolines.

As mentioned in the preceding paper, bisylides and bisazabisylides are important in the preparation of cyclic olefins and heterocycles by bis-Wittig reactions.[2] Thus, 1,2-bisylides **1** and 1,2-bisazabisylide **2** were reported in the 1960's to form benzene[3] and pyridazine rings,[4] respectively.

However, 1,2-monoazabisylides **3** remained unknown. We now report the use of two novel and related intermediates, diethyl [(triphenylphosphoranylidene)amino]-methyl]phosphonate (**4**) and the corresponding carbanion **5**, which represents the first example of a 1,2-monoazabisylide equivalent.



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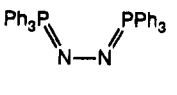

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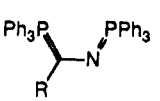

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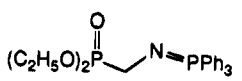

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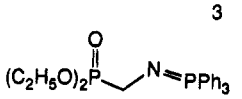

5

Olefin-forming Horner–Wittig reactions[1] were originally restricted to phosphonate carbanions carrying a stabilizing α-substituent (e.g., COO^-, COOMe, CN, SO_2R). Recently, aryl, vinyl, sulfide, amine, and ether functionalities have also been shown to stabilize the anion sufficiently for Horner–Wittig alkene formation to take place.[6] However, in the absence of such stabilization, the addition product of the phosphonate carbanion to an aldehyde or a ketone usually resists conversion to the olefin. The reactions now reported represent the first Horner–Wittig reactions of phosphonates with the strongly anion-destabilizing $-N=PR_3$ α-substituent.

Betmip, 1-[[(triphenylphosphoranylidene)amino]methyl]-benzotriazole (**6**), was previously demonstrated to be a useful synthetic auxiliary in a variety of interesting transformations.[7] By analogy to the reactions with other nucleophiles, we anticipated the displacement of the benzotriazole group from betmip by a phosphite anion. Thus, we have now been able to generate **4**, which converts to the nonstabilized phosphonate carbanion **5**, a 1,2-monoazabisylide equivalent, on further treatment with a base.

In our preliminary paper,[8] we described the reaction of **4** and **5** with araldehydes and phthalic dicarboxaldehyde giving 2-azabutadienes and isoquinoline, respectively. Both intermediates underwent novel bis-Wittig reactions in which both ends of the CHN group simultaneously reacted with aldehydes to form a C=C bond and C=N bond, respectively. We now report further details of those and of other reactions of **4** and **5** with carbonyl compounds.

Results and Discussion

Diethyl [[(triphenylphosphoranylidene)amino]methyl]-phosphonate (**4**) was prepared *in situ* in THF by stirring betmip and the lithium salt of diethyl phosphite [$(C_2H_5O)_2P(O)^-Li^+$ (**8**)] generated from diethyl phosphite with butyllithium at −78 °C. The reaction of betmip (**6**) with diethyl phosphite anion (**8**) is monitored by the formation of a white precipitate benzotriazolate. The resulting suspension containing **4** was either used directly for the reaction with an electrophile or treated with butyllithium at −78 °C to −30 °C to generate phosphonate carbanion **5**.

Reactions of 4 with Araldehydes and Acyl Chlorides: Preparation of 1,4-Diaryl-2-azabutadienes 11 and Diethyl [(Acylamino)methyl]phosphonates 12. We first examined aza-Wittig reactions of **4** with araldehydes, anticipating generation of [(N-arylideneamino)methyl]phosphonates **10**. However, we found that stirring the diethyl phosphite anion with betmip at room temperature followed by treatment with 1 molar equiv

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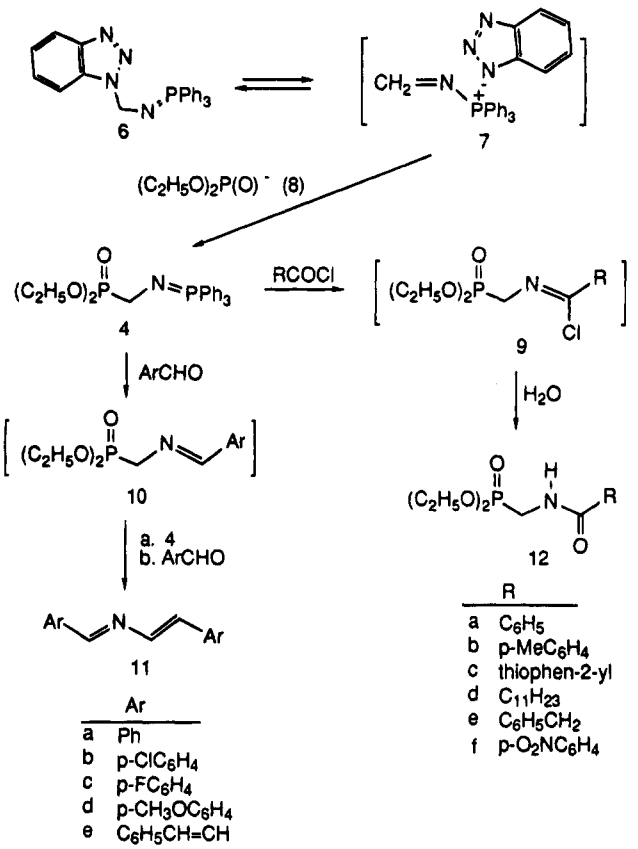
Scheme 1



of an araldehyde directly afforded 1,4-diaryl-2-azabutadienes (**11**) in good yields. No 2-azabutadienes were isolated from aliphatic aldehydes. Attempts at isolation of the intermediate **10** were unsuccessful, indicating they were deprotonated by the strong basic **4**, and a further Horner–Wittig reaction with another molecule of aldehyde followed to produce the 2-azabutadienes **11** (Scheme 1).

Diethyl [[(triphenylphosphoranylidene)amino]methyl]-phosphonate (**4**) was converted by 2 molar equiv of an acyl chloride into diethyl [(acylamino)methyl]phosphonates **12**; 1 equiv of the chloride was consumed by the lithium salt of benzotriazolate (formed in the reaction) to give acyl benzotriazolates (Scheme 1). The formation of the amides **12** probably occurs via intermediate **9**[9] with the oxygen atom of the carbonyl group derived from H_2O during aqueous workup. The results are summarized in Scheme 1 and Table 1. Aracyl, heteroacyl, and aliphatic acyl chlorides all gave the desired products. Compounds **12b-f** thus prepared are novel. The structures were established by ^1H and ^{13}C NMR spectra and confirmed by elemental analyses. In the ^1H NMR, the CH_2 group derived from betmip and those of the ethoxyl group were each split by phosphorus, and thus, two doublets at ca. 3.90 ppm and multiples at ca. 4.10 ppm, respectively, were observed. All the carbon signals except for those from the R group were coupled with the phosphorus, and an especially large splitting (more than 2 ppm) was observed for the CH_2 group adjacent to the NH group.

From the synthetic point of view, compound **4** is an analog of diethyl (aminomethyl)phosphonate, derivatives of which have found many applications in organic synthesis: as intermediates in the synthesis of β-lactam antibiotics;[10] as reagents for homologation of aldehydes and ketones via intermediate 2-aza dienes;[11] for the conversion of aldehydes and ketones to higher amines;[12] and for the asymmetric synthesis of aminophosphonic acids.[13] Diethyl (aminomethyl)phosphonate has previously been prepared from *N*-(hydroxymethyl)phthalimide in three steps in ca. 65% overall yield.[14] The present method has the advantages of mild reaction conditions, a simple one-pot procedure and readily available starting materials. The conversion of **4** with acyl chloride into [(acylamino)methyl]phosphonates **12** provides stable samples for convenient characterization as well as useful intermediates.

Reactions of Phosphonate Carbanion 5: Preparation of 1,2-Diaryl-2-azabutadienes 11 and 1,1,4,4-Tetraaryl-2-azabutadienes 14. As shown above, 2-azabutadienes are formed from **4** via the intermediate **10**. The deprotonation of **10** is facilitated by both the phosphonate and the imino group (Scheme 1). It was found that the methylene group in **4** can also be deprotonated by butyllithium to generate phosphonate carbanion **5** (a 1,2-monozabisylide equivalent) even though it is activated only by the phosphonate. However, complete lithiation required raising the temperature to −30 °C because the resulting carbanion **5** is destabilized by the formal negative charge on the N^-P^+ group; at −78 °C, byproducts from addition of butyllithium were formed.

As mentioned in the preliminary paper,[8] phosphonate carbanion **5** also reacted with araldehydes to give 1,4-diaryl-2-butadienes (Scheme 2) in good yields under conditions similar to those in Scheme 1. However, in Scheme 1, compound **4** reacted with a single molar equivalent of an aldehyde to give the 1:2 product **11** because one molecule of **4** is consumed as a base in the Horner–Wittig step. The overall reaction is an aza-Wittig reaction followed by a typical Horner–Wittig reaction.

In Scheme 2, intermediate **5** reacts with 2 equiv of aldehyde, and the formation of 2-azabutadiene **11d** is initiated by addition of the carbanion to the aldehyde followed by an aza-Wittig reaction to form the N=C bond. The C=C bond in the resulting 2-azabutadiene is then formed by elimination of the phosphate.

On the basis of this rationalization, the unsymmetrical 1,4-diaryl-2-azabutadiene **16** was prepared from two different aldehydes. Thus, when a solution of **5** was first reacted with *p*-chlorobenzaldehyde, followed by treatment with *p*-tolualdehyde, 1-tolyl-4-(chlorophenyl)-2-azabutadiene (**16**) was isolated in a 32% yield (Scheme 2).

Diethyl [[(triphenylphosphoranylidene)amino]methyl]-phosphonate (**4**) and phosphonate carbanion **5** both react readily with aldehydes at room temperature (Schemes 1 and 2). However, with benzophenone (Scheme 2), the intermediate **5** gave the desired 2-azabutadiene **14a** in 63% yield under reflux in THF, while most of the benzophenone was recovered under the same conditions when **4** was used. Ketones with either electron-withdrawing or electron-donating groups were also converted to 2-azabutadienes **14** by phosphonate carbanion **5**, although ketones with the electron-donating groups seem

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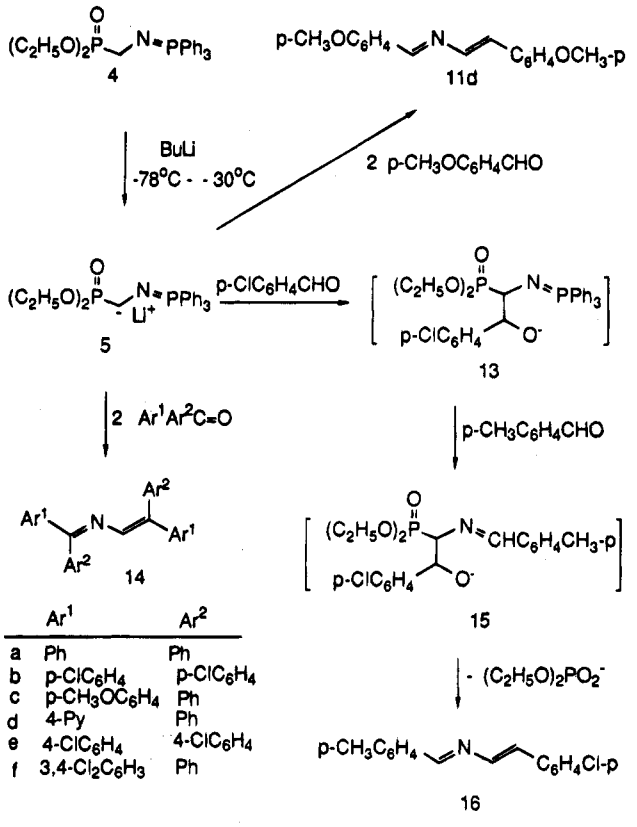
Table 1. Preparation of 2-Azabutadienes 11, 14, and 16, [(Acylamino)methyl]phosphonates 12, and Isoquinolines 18 and 20

compd	yield (%)	mp (°C) or bp (°C/mmHg)	formula	CHN analysis found (required)		
				C%	H%	N%
11a	76	53–55[a]	$C_{15}H_{13}N$			
11b	85	192–193	$C_{15}H_{11}NCl_2$	65.54 (65.24)	4.03 (4.01)	5.07 (5.07)
11c	86	123–124	$C_{15}H_{11}NF_2$	74.23 (74.06)	4.58 (4.56)	5.79 (5.76)
11d	65	178–179	$C_{17}H_{17}NO_2$	76.20 (76.38)	6.41 (6.41)	5.41 (5.24)
11e	70	143–145	$C_{19}H_{17}N$	87.30 (87.69)	6.57 (6.76)	5.31 (5.55)
12a[b]	58	oil	$C_{12}H_{18}NO_4P$			
12b	63	oil	$C_{13}H_{20}NO_4P$	54.66 (54.73)	7.40 (7.07)	4.58 (4.91)
12c	66	75–76	$C_{10}H_{16}NO_4PS$	43.26 (43.32)	5.98 (5.82)	4.72 (5.05)
12d	57	oil	$C_{17}H_{36}NO_4P$	58.29 (58.43)	10.52 (10.38)	4.00 (4.01)
12e	42	oil	$C_{13}H_{20}NO_4P$	54.36 (54.73)	7.01 (7.07)	5.01 (4.91)
12f	47	95–96	$C_{12}H_{17}N_2O_6P$	45.50 (45.56)	5.39 (5.42)	8.94 (8.86)
14a	63	177–178.5	$C_{27}H_{21}N$	90.09 (90.21)	5.87 (5.89)	3.81 (3.90)
14b	31	163–165	$C_{27}H_{19}NCl_2$	76.01 (75.71)	4.69 (4.47)	2.96 (3.27)
14c	38	95–96	$C_{29}H_{25}NO_2$	82.84 (83.03)	6.01 (6.01)	3.09 (3.34)
14d	34	234–235	$C_{25}H_{19}N_3$	82.88 (83.08)	5.31 (5.30)	11.49 (11.63)
14e	32	235–326	$C_{27}H_{17}NCl_4$	65.00 (65.22)	3.42 (3.45)	2.75 (2.82)
14f	29	163–164	$C_{27}H_{17}NCl_4$	64.96 (65.22)	3.50 (3.45)	2.72 (2.82)
16	32	179–181	$C_{16}H_{14}NCl$	75.07 (75.14)	5.44 (5.52)	5.46 (5.48)
18	55	82–85/1 mmHg[c]	C_9H_7N			
20	25	144–145	$C_{23}H_{19}N$	88.96 (89.28)	6.21 (6.19)	4.14 (4.53)

[a] Lit.[19] mp 51–53 °C. [b] NMR data identical to those reported.[22] [c] Lit.[24] bp 243 °C.

Scheme 2



	Ar^1	Ar^2
a	Ph	Ph
b	p-ClC$_6$H$_4$	p-ClC$_6$H$_4$
c	p-CH$_3$OC$_6$H$_4$	Ph
d	4-Py	Ph
e	4-ClC$_6$H$_4$	4-ClC$_6$H$_4$
f	3,4-Cl$_2$C$_6$H$_3$	Ph

to form less stable 2-azabutadienes. Thus, product **14c** (with the *p*-CH_3O group) partially decomposed on storage. 1,4-Diaryl-2-azabutadienes **11**, with the exception of 1,4-diphenyl-2-azabutadiene (**11a**), and all of the 1,1,4,4-tetraaryl-2-azabutadienes **14** thus prepared are novel. The structures were confirmed by ^1H and ^{13}C NMR spectra and by elemental analyses. When an unsymmetrical ketone (for **14d**, **14e**, or **14f** in Scheme 2) was used, a mixture of two isomers of 1,1,4,4,-tetraaryl-2-azabutadienes was isolated. In this case, all the carbon signals, including the C=N signals, appeared as doublets. With *p*-methoxybenzophenone, all four isomers of **14c** were observed. Attempts at the preparation of 2-azabutadienes from enolizable ketones failed, probably because of proton exchange with the phosphonate carbanion **5**.

2-Azabutadienes have recently received increasing attention due to their use in heterocycle synthesis. 2-Azabutadienes with electron-donating substituents,[15] with electron-withdrawing substituents,[16] and with alkyl or aryl substituents[17] have all been used in Diels–Alder cycloaddition reactions. Several methods for the preparation of 2-azabutadienes with alkyl or aryl substituents have been reported, but most of them are limited in scope and/or utilize starting materials that are difficult to obtain. They include (i) condensation of allylamine with an aldehyde followed by a base-catalyzed isomerization,[17c,18] (ii) Peterson reaction of *N,N*-bis(silyl)enamines,[17a,19] (iii) Horner–Wittig reaction of diethyl [(benzylideneamino)methyl]phosphonate with aldehydes,[11,20] and (iv) dimerization of enolizable imines.[17b] Our present work has encompassed the preparation of a series of 1,4-diaryl-substituted and 1,1,4,4-tetraaryl-substituted 2-azabutadienes of which classes only 1,4-diphenyl-2-azadienes have previously been reported.[11,17b]

Horner–Wittig/aza-Wittig Reactions of 1,2-Monoazabisylide Equivalent 5 with Dicarbonyl Compounds: Preparation of Isoquinolines. Intermolecular followed by intramolecular reaction (bis-Wittig) of phosphonate carbanion **5** with phthalic dicarboxaldehyde (**17**) and with diketone **19** afforded isoquinolines **18** and **20**, respectively. Isoquinoline **18** was prepared in 55% yield at room temperature (Scheme 3).[8] However, the

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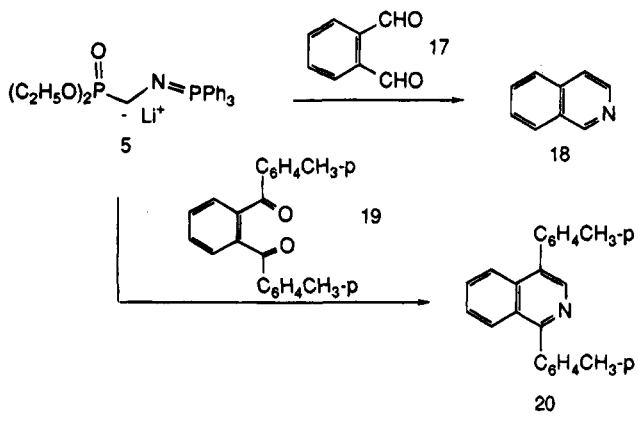
Scheme 3



preparation of 1,4-disubstituted isoquinoline **20** required reflux in THF probably due to the lower reactivity of the N=P group toward the ketone carbonyl. The annulation requires the formed C=CN=C to be the *ZZ* configuration which is usually thermodynamically unfavorable. Therefore, the formation of the isoquinoline ring is probably stepwise as shown in Scheme 2.

The chemistry of isoquinolines has been extensively studied. Methods for the formation of the isoquinoline ring were divided systematically into 15 types according to the bonding positions.[21] The formation of C(1)—N and C(3)—C(4) bonds was reported from (i) 1-aziridines and 1,3-diphenylisobenzofurans and (ii) cyanobenzocyclobutenes *via* two pericyclic steps. 1,2-Monoazabisylide equivalent **5** provides another route complementary to these types of annulation utilizing readily available starting materials.

Conclusions. We have developed two new reagents, diethyl [[(triphenylphosphoranylidene)amino]methyl]-phosphonate (**4**) and the corresponding carbanion **5** which both undergo Horner—Wittig/aza-Wittig reactions to build the C=NC=C structural unit in one-pot reactions. Compared with 1,2-bisylide[2] and 1,2-bisazabisylide[4] reactions, 1,2-monoazabisylide equivalent **5** possesses a more reactive carbanion and a less reactive iminophosphorane (azaylide) which can react selectively with electrophiles. The present method for the preparation of 1,4-diaryl-2-azabutadienes, 1,1,4,4-tetraaryl-2-azabutadienes, diethyl [(acylamino)methyl]phosphonates, and isoquinolines commences with easily available betmip and diethyl phosphite. The overall result is that betmip builds an N—C bridge between two carbonyl compounds.

Experimental Section

THF was freshly distilled from sodium benzophenone ketyl immediately before use. Column chromatography was conducted with silica gel grade 60—200 mesh. Elemental analyses were performed in house.

Preparation of 1,4-Diaryl-2-azabutadienes 11 from Diethyl [[(Triphenylphosphoranylidene)amino]methyl]-phosphonate 4. Representative Procedure for 1,4-Diphenyl-2-azabutadiene (11a). Butyllithium (6.0 mL, 15.0 mmol, 2.5 M solution in hexane) was added to a solution of diethyl phosphite (2.0 g, 14.0 mmol) in THF (40 mL) under argon at −78 °C. The cooling bath was removed, and the mixture was stirred for 15 min. Betmip (**6**) (5.9 g, 14.0 mmol) was added and stirred overnight until no more precipitate was formed. Aldehyde (for **11a**, benzaldehyde) (14.0 mmol) in THF (15 mL) was added and stirring continued for another 10 h. The solvent was removed under vacuum and the residue vigorously shaken with ethyl acetate (15 mL) and then diluted with ether (60 mL). The solid was filtered off and washed with ether (3 × 15 mL). The filtrate was dried ($MgSO_4$) and the solvent removed to give a solid residue which was purified by a short column chromatography (silica gel/Et_2O), followed by recrystallization from hexane: ^1H NMR ($CDCl_3$) δ 7.05 (d, J = 13.0 Hz, 1 H), 7.25—7.65 (m, 9 H), 7.85 (m, 2 H), 8.40 (s, 1 H); ^{13}C NMR ($CDCl_3$) δ 126.8, 127.9, 128.6, 128.7, 128.7, 131.1, 136.1, 136.2, 141.8, 161.3.

1,4-Bis(4-chlorophenyl)-2-azabutadiene (11b) was prepared from 4-chlorobenzaldehyde and recrystallized from acetone—ethyl acetate: ^1H NMR ($CDCl_3$) δ 6.93 (d, J = 14.0 Hz, 1H), 7.35 (m, 2 H), 7.50 (m, 4 H), 7.68 (d, J = 14.0 Hz, 1 H), 7.85 (d, J = 8.5 Hz, 2 H), 8.42 (s, 1 H); ^{13}C NMR ($CDCl_3$) δ 126.3, 126.9, 126.9, 127.2, 127.8, 127.9, 128.0, 133.0, 132.0, 140.6, 158.7.

1,4-Bis(4fluorophenyl)-2-azabutadiene (11c) was prepared from 4-fluorobenzaldehyde and recrystallized from ethyl acetate: ^1H NMR ($CDCl_3$) δ 6.90—7.20 (m, 5 H), 7.35—7.55 (m, 3 H), 7.75—7.90 (m, 2 H), 8.25 (s, 1 H); ^{13}C NMR ($CDCl_3$) δ 115.5, 115.6, 115.7, 115.8, 116.0, 128.2, 128.3, 129.9, 130.0, 130.3, 130.4, 130.5, 132.2, 132.3, 132.4, 132.4, 141.3, 159.6, 160.7, 162.8, 164.0, 166.2.

1,4-Bis(4-methoxyphenyl)-2-azabutadiene (11d) was prepared from *p*-anisaldehyde and recrystallized from hexane/ethyl acetate. This compound was also prepared from phosphonate carbanion **5** using the same procedure as shown later for the preparation of isoquinoline in 70% yield based on the aldehyde: ^1H NMR ($CDCl_3$) δ 3.80 (s, 3 H), 3.85 (s, 3 H), 6.85—7.0 (m, 5 H), 7.38—7.48 (m, 3 H), 7.75 (d, J = 9.5 Hz, 2 H), 8.25 (s, 1 H); ^{13}C NMR ($CDCl_3$) δ 55.3, 55.3, 114.1, 114.2, 127.8, 129.1, 129.2, 129.4, 130.1, 140.4, 159.2, 159.7, 161.9.

1,8-Diphenyl-4-azaoctatetrene (11e) was prepared from cinnamaldehyde and recrystallized from hexane/ethyl acetate: ^1H NMR ($CDCl_3$) δ 6.75—7.65 (m, 16 H), 8.05 (m, 1 H); ^{13}C NMR ($CDCl_3$) δ 126.4, 127.0, 127.4, 128.0, 128.5, 128.6, 128.9, 129.4, 131.8, 134.1, 135.9, 137.3, 142.8, 145.7, 162.0.

The Preparations of Diethyl [(Acylamino)methyl]-phosphonates (12). Representative Procedure for Diethyl (Benzamidomethyl)phosphonate (12a). Butyllithium (4.0 mL, 10 mmol, 2.5 M solution in hexane) was added to a solution of diethyl phosphite (1.38 g, 10 mmol) in THF (25 mL) under nitrogen at −78 °C and stirring continued at −78 °C for 2 h. Betmip (4.08 g, 10 mmol in THF) was then added at −78 °C and the mixture stirred at rt overnight to give a suspension of diethyl[[(triphenylphosphoranylidene)-amino]methyl]phosphonate (**4**). Acyl chloride (for **12a**, benzoyl chloride) (30 mmol) was added at −78 °C. The cooling bath was removed, and the reaction mixture was stirred at rt overnight. The reaction was quenched with water (10 mL) and washed with 1 N NaOH (2 × 25 mL) and H_2O (25 mL). The aqueous solution was extracted with ether. The combined organic layer was dried ($MgSO_4$) and the solvent removed. The product was isolated by column chromatography (hexane/Et_2O): ^1H NMR ($CDCl_3$) δ 1.31 (t, J = 7.1 Hz, 6 H), 3.94 (dd, J_1 = 11.6 Hz, J_2 = 6.1 Hz, 2 H), 4.14 (qv, $J_P = J_H$ = 7.5 Hz, 4 H), 7.37 (m, 2 H), 7.48 (m, 1 H), 7.62 (br, 1 H), 7.85 (m, 2 H); ^{13}C NMR ($CDCl_3$) 16.1, 16.2, 34.0, 36.0, 62.6, 62.7, 127.1, 128.3, 131.5, 133.5, 167.3, 167.4.

Diethyl [(4-methylbenzamido)methyl]phosphonate (12b) was prepared from *p*-toluoyl chloride and purified by column chromatography (hexane/Et_2O): ^1H NMR ($CDCl_3$) δ 1.29 (t, J = 7 Hz, 6 H), 2.34 (s, 3H), 3.93 (dd, J_1 = 11.6 Hz, J_2 = 6.1 Hz, 2 H), 4.15 (qv, $J_P = J_H$ = 7.5 Hz, 4 H), 7.14 (d, J = 8.2, 2 H), 7.80 (d, J = 8.2 Hz, 2 H), 8.18 (br, 1 H); ^{13}C NMR ($CDCl_3$) δ 15.8, 15.9, 20.8, 33.7, 35.8, 62.0, 62.1, 126.9, 128.4, 130.6, 141.2, 166.8, 166.9.

Diethyl [(2-thiophene-ylcarboxamido)methyl]phosphonate (12c) was prepared from 2-thiopheneylcarboxylic chloride and purified by column chromatography (hexane/

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Et_2O): ^1H NMR ($CDCl_3$) δ 1.33 (t, J = 7.1 Hz, 6 H), 3.91 (dd, J_1 = 11.6 Hz, J_2 = 6.1 Hz, 2 H), 4.17 (qv, $J_P = J_H$ = 7.5 Hz, 4 H), 7.02 (m, 1 H), 7.46 (d, J = 5.0 Hz, 1 H), 7.72 (d, J = 3.8 Hz, 1 H), 7.91 (br, 1 H); ^{13}C NMR ($CDCl_3$) δ 16.2, 16.2, 33.9, 36.0, 62.5, 62.6, 127.3, 128.4, 130.2, 131.8, 138.5, 161.7, 161.8.

Diethyl [(lauramido)methyl]phosphonate (12d) was prepared from lauroyl chloride and purified by column chromatography (hexane/Et_2O): ^1H NMR ($CDCl_3$) δ 0.88 (t, J = 6.9 Hz, 3 H), 1.25 (m, 16 H), 1.33 (t, J = 7.0 Hz, 6 H), 1.63 (m, 2 H), 2.25 (t, J = 7.3 Hz, 2 H), 3.72 (dd, J_1 = 11.6 Hz, J_2 = 6.1 Hz, 2 H), 4.13 (qv, $J_P = J_H$ = 7.5 Hz, 4 H), 7.20 (br, 1 H); ^{13}C NMR ($CDCl_3$) δ 13.8, 16.1, 16.2, 22.4, 25.5, 29.1, 29.2, 29.3, 29.4, 31.6, 33.1, 35.2, 35.9, 62.2, 62.3, 173.2, 173.2.

Diethyl [(Phenylacetamido)methyl]phosphonate (12e) was prepared from phenylacetyl chloride and purified by column chromatography (hexane/Et_2O): ^1H NMR ($CDCl_3$) δ 1.24 (t, J = 7.1 Hz, 6 H), 3.59 (s, 2 H), 3.69 (dd, J_1 = 11.6 Hz, J_2 = 6.1 Hz, 2 H), 4.05 (qv, $J_P = J_H$ = 7.5 Hz, 4 H), 7.30 (m, 6 H); ^{13}C NMR ($CDCl_3$) δ 16.1, 17.0, 33.4, 35.4, 42.8, 62.3, 62.4, 126.7, 128.4, 128.9, 134.9, 170.8, 170.9.

Diethyl [(4-nitrobenzamido)methyl]phosphonate (12f) was prepared from 4-nitrobenzoyl chloride and purified by column chromatography (hexane/Et_2O): ^1H NMR ($CDCl_3$) δ 1.35 (t, J = 7.1 Hz, 6 H), 3.78 (dd, J_1 = 11.6 Hz, J_2 = 6.1 Hz, 2 H), 4.17 (qv, $J_P = J_H$ = 7.5 Hz, 4 H), 8.07 (d, J = 9.0 Hz, 2 H), 8.22 (d, J = 9.0 Hz, 2 H), 8.36 (br, 1 H); ^{13}C NMR ($CDCl_3$) δ 16.3, 16.4, 34.3, 36.3, 62.8, 62.9, 123.4, 128.6, 139.1, 149.5, 165.2, 165.3.

The Preparations of 1,1,4,4-Tetraaryl-2-azabutadienes (14) from Phosphonate Carbanion 5. Representative Procedure for 1,1,4,4-Tetraphenyl-2-azabutadiene (14a). To a suspension of **4** obtained as above (see preparation of **12a**) was added butyllithium (6.0 mL, 15.0 mmol, 2.5 M solution in hexane) at −78 °C and stirring continued at −78 °C for 2 h and a further 0.5 h at rt to give a brown solution of phosphonate carbanion **5**. This was stirred with diaryl ketone (for **14a**, benzophenone) (12.0 mmol) overnight at rt and then at reflux for 3 h. The reaction was quenched with water (100 mL) and extracted with ether (3 × 40 mL). The combined organic layer was washed with 3 N NaOH (2 × 30 mL). The product was isolated by column chromatography (silica gel/Et_2O) and recrystallized from hexane: ^1H NMR ($CDCl_3$) δ 7.15−7.65 (m, 21 H); ^{13}C NMR ($CDCl_3$) δ 127.3, 127.4, 128.1, 128.1, 128.6, 128.6, 128.7, 129.0, 130.1, 130.8, 135.0, 136.2, 138.9, 139.5, 140.8, 141.9, 166.5.

1,4-Diphenyl-1,4-bis(4-chlorophenyl)-2-azabutadiene (14b). This (a mixture of two isomers) was prepared from 4-chlorobenzophenone and purified by column chromatography (hexane/Et_2O): ^1H NMR ($CDCl_3$) δ 7.63−7.61 (m, 19 H); ^{13}C NMR ($CDCl_3$) δ 127.6, 127.7, 127.8, 127.8, 128.3, 128.3, 128.4, 128.5, 128.6, 128.7, 129.0, 129.1, 129.7, 129.8, 129.9, 130.1, 130.2, 130.5, 130.6, 131.6, 133.0, 133.3, 134.4, 134.9, 134.9, 135.0, 135.2, 135.2, 135.6, 136.5, 137.2, 137.3, 137.9, 139.0, 140.1, 141.3, 165.6, 165.8.

1,4-Diphenyl-1,4-bis(4-methoxyphenyl)-2-azabutadiene (14c). This (a mixture of four isomers) was prepared from 4-methoxybenzophenone and purified by column chromatography (hexane/Et_2O). ^1H NMR ($CDCl_3$) δ 3.75−3.86 (eight singlets, 6 H), 7.70−6.61 (m, 18 H); ^{13}C NMR ($CDCl_3$) δ 55.1, 55.2, 112.7, 113.5, 113.5, 113.6, 113.7, 113.9, 127.2, 127.3, 128.0, 128.0, 128.3, 128.4, 128.5, 128.5, 128.6, 128.7, 128.8, 128.9, 129.1, 129.1, 129.4, 129.8, 129.8, 129.9, 130.0, 130.3, 130.4, 130.5, 130.6, 131.8, 131.8, 132.6, 133.1, 133.1, 134.1, 134.2, 134.3, 134.6, 136.6, 139.3, 140.1, 159.1, 159.5, 161.3, 165.3.

1,4-Diphenyl-1,4-di(4-pyridinyl)-2-azabutadiene (14d). This (a mixture of two isomers) was prepared from 4-benzoylpyridine and purified by column chromatography (hexane/Et_2O): ^1H NMR ($CDCl_3$) δ 7.21 (m, 3 H), 7.30 (m, 4 H), 7.42 (m, 5 H), 7.55 (m, 3 H), 8.60 (d, J = 5.9 Hz, 1 H), 8.67 (d, J = 5.9 Hz, 1 H), 8.68 (d, J = 5.9 Hz, 1 H), 8.81 (d, 1 H); ^{13}C NMR ($CDCl_3$) δ 122.5, 122.6, 123.1, 126.1, 126.1, 127.7, 128.3, 128.4, 128.5, 128.5, 128.7, 128.8, 128.9, 129.6, 131.2, 134.3, 135.5, 135.5, 136.0, 137.7, 139.6, 139.7, 140.6, 143.8, 145.9, 146.4, 146.5, 149.1, 149.1, 149.8, 150.0, 150.4, 164.6, 165.9.

1,1,4,4-Tetra(4-chlorophenyl)-2-azabutadiene (14e) was prepared from 4,4′-dichlorobenzophenone and purified by column chromatography (hexane/Et_2O): ^1H NMR ($CDCl_3$) δ 7.52 (m, 4 H), 7.38 (m, 4 H), 7.24 (m, 6 H), 7.12 (m, 3 H); ^{13}C NMR ($CDCl_3$) δ 127.8, 128.5, 128.6, 129.2, 129.9, 130.0, 130.1, 130.2, 132.9, 133.7, 133.8, 133.9, 134.9, 134.9, 135.3, 136.7, 136.9, 137.4, 139.4, 139.6, 164.9.

1,4-Diphenyl-1,4-bis(3,4-dichlorophenyl)-2-azabutadiene (14f). This (a mixture of two isomers) was prepared from 3,4-dichlorobenzophenone and purified by column chromatography (hexane/Et_2O): ^1H NMR ($CDCl_3$) δ 7.71 (m, 2 H), 7.61 (m, 1 H), 7.47 (m, 5 H), 7.26 (m, 9 H); ^{13}C NMR ($CDCl_3$) δ 128.0, 128.0, 128.2, 128.2, 128.4, 128.5, 128.6, 128.7, 128.8, 128.9, 129.4, 129.4, 130.2, 130.4, 130.7, 130.9, 131.0, 131.5, 131.6, 132.7, 133.6, 133.6, 134.7, 134.8, 135.0, 135.0, 135.4, 135.4, 138.7, 139.3, 139.7, 140.5, 165.1.

Procedure for the Preparation of 1-(4-Chlorophenyl)-4-(4-methylphenyl)-2-azabutadiene (16). To a solution of phosphonate carbanion **5** obtained as above (see preparation of **14a**) was added 4-methylbenzaldehyde (1.5 g, 12 mmol) in THF (40 mL) dropwise at −30 °C over 3 h and then the resulting mixture stirred at rt overnight. To this suspension was added 4-chlorobenzaldehyde (2.53 g, 18 mmol in 40 mL THF) and the mixture stirred at rt for another 10 h. The solvent was removed and the residue vigorously shaken with ethyl acetate (20 mL) and then diluted with ether (100 mL). The solid was filtered off and washed with ether (3 × 15 mL). The filtrate was dried ($MgSO_4$) and solvent removed to give a solid residue which was purified by a short column and recrystallized from hexane: ^1H NMR ($CDCl_3$) δ 2.39, 2.35 (s, 3 H), 6.98, 6.93 (d, J = 4.2 Hz, 1 H), 7.14 (d, J = 8.0 Hz, 1 H), 7.23 (d, J = 8.0 Hz, 1 H), 7.30 (d, J = 8.0 Hz, 1 H), 7.36−7.44 (m, 3 H), 7.48 and 7.52 (two doublets, $J_1 = J_2$ = 5.4 Hz, 1 H), 7.49 (d, J = 8.2 Hz, 1 H), 7.75 (d, J = 8.4 Hz, 1 H), 8.27 and 8.29 (two singlets, 1 H); ^{13}C NMR ($CDCl_3$) δ 21.3, 21.6, 126.6, 126.7, 127.9, 128.5, 128.9, 129.0, 129.1, 129.4, 129.5, 129.6, 129.7, 130.3, 130.5, 133.5, 133.5, 134.5, 137.2, 137.7, 141.2, 141.5, 141.9, 160.1, 160.8.

Representative Procedure for the Preparation of Isoquinolines 18 and 20. Preparation of Isoquinoline (18). The solution of phosphonate carbanion **5** prepared as described above (see preparation of **14a**) was stirred with a dicarbonyl compound (for **18**, phthalic dicarboxaldehyde) (13.0 mmol) for 2 h at −78 °C and then overnight at rt. The reaction was quenched with water (40 mL) and extracted with ether (3 × 40 mL). The combined organic layer was washed with 3 N NaOH (2 × 30 mL). The solvent was removed and the residue dissolved in $CHCl_3$ (40 mL) and extracted with 2 N HCl (2 × 30 mL). The aqueous solution was made basic with 3 N NaOH and extracted with $CHCl_3$ (2 × 25 mL). The organic layer was dried with $MgSO_4$ and the solvent removed to give *isoquinoline*: ^1H NMR ($CDCl_3$) δ 7.40−7.60 (m, 3 H), 7.75 (d, J = 8 Hz, 1 H), 7.80 (d, J = 8 Hz, 1 H), 8.50 (d, J = 6 Hz, 1 H), 9.20 (s, 1 H); ^{13}C NMR ($CDCl_3$) δ 119.7, 125.7, 126.4, 126.8, 127.9, 129.5, 134.9, 142.3, 151.8; identical in all respects with the spectra reported in the literature.[21]

1,4-Bis(*p*-methylphenyl)isoquinoline (20). This compound was prepared from 1,2-bis(4-methylbenzoyl)benzene (**19**). The reaction mixture of **5** and **19** required reflux for 2 h after being stirred at rt overnight. The product was purified by column chromatography (hexane/Et_2O): ^1H NMR ($CDCl_3$) δ 2.41 (s, 3 H), 2.42 (s, 3 H), 7.30 (m, 4 H), 7.42 (m, 3 H), 7.54 (m, 1 H), 7.60 (d, J = 7.8 Hz, 2 H), 7.95 (d, J = 8.5 Hz, 1 H), 8.16 (d, J = 8.5 Hz, 1 H), 8.56 (s, 1 H); ^{13}C NMR ($CDCl_3$) δ 21.1, 21.2, 125.0, 126.2, 126.5, 127.6, 128.8, 129.1, 129.7, 129.7, 129.8, 132.0, 134.1, 135.0, 136.6, 137.4, 138.1, 141.8, 159.7.