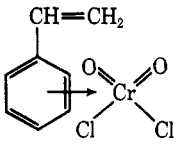
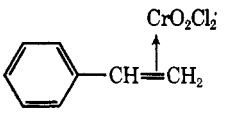


XIII

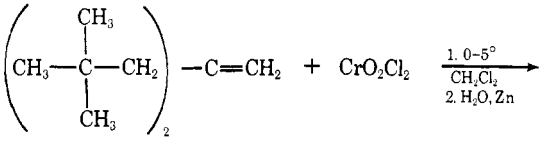


XIV

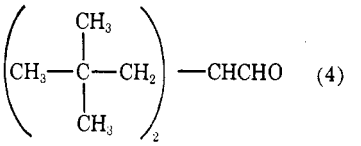
stituted styrenes with σ^+ gives a ρ value of -1.3[33] which is close to the observed value for the chromyl chloride oxidation. The activation parameters for the oxidation of V, $\Delta H^{\ddagger} = 8.4$ kcal/mole and $\Delta S^{\ddagger} = -23.8$ eu, are also consistent with the formulation of X, XI, or XII in the rate-limiting step since 1,3-dipolar cycloadditions and epoxidations require a high degree of order in the activated complex. In cycloadditions $\Delta S^{\ddagger}$ values of -25 to -35 eu are generally observed,[30,34] and in epoxidations $\Delta S^{\ddagger}$ values of -21 to -26 eu are obtained.[33-35]

The foregoing conclusions lend support to the suggestion that the mechanism of the chromyl chloride oxidation of V involves an electrophilic attack of chromyl chloride at the carbon–carbon double bond in the rate-determining step to give X, XI, or XII. Furthermore, it is possible that X could also be the activated complex of a rearrangement step to the postulated product-determining intermediate I or II, and that XI or XII could lead directly to the epoxide IV which isomerizes to the observed carbonyl products.

The activated complexes XI and XII also appear to be plausible for the chromyl chloride oxidation of alkenes.[6a] For example, 4,4-dimethyl-2-neopentyl-1-pentene (XV), on treatment with chromyl chloride (followed by reductive hydrolysis), gives an 81% yield of 4,4-dimethyl-2-neopentylpentanal (XVI), while it is inert to hot concentrated alkaline permanganate.[36] Presumably the bulky neopentyl groups preclude the typical *cis*-cycloaddition of permanganate to the carbon–carbon double bond.[37-40] In contrast to its inertness to permanganate, XV forms epoxides with chromyl



XV



XVI (4)

acetate[41] and perbenzoic acid.[36,40]

Acknowledgment. We express our deep appreciation for support of this work to the Research Corporation and to the donors of the Petroleum Research Fund administered by the American Chemical Society. Our thanks also go to Professor James L. Jensen for helpful discussions.

(33) Y. Ishii and Y. Inamoto, *Kogyo Kagaku Zasshi*, **63**, 705 (1960); *Chem. Abstr.*, **58**, 4393 (1963).
(34) P. Scheiner, J. H. Schomaker, S. Deming, W. V. Libbey, and G. P. Nowack, *J. Amer. Chem. Soc.*, **87**, 306 (1965).
(35) B. M. Lynch and K. H. Pausacker, *J. Chem. Soc.*, 1525 (1955).
(36) P. D. Bartlett, G. L. Fraser, and R. B. Woodward, *J. Amer. Chem. Soc.*, **63**, 495 (1941).
(37) XV is not readily attacked by chromic acid[38] or bromine.[32]
(38) See Table III, footnote *f*.
(39) F. C. Whitmore and J. D. Surmates, *J. Amer. Chem. Soc.*, **63**, 2200 (1941).
(40) M. S. Newman, N. Gill, and D. W. Thompson, *ibid.*, **89**, 2059 (1967).
(41) W. J. Hickinbottom and D. G. M. Wood, *J. Chem. Soc.*, 1600 (1951).

N-Phosphorylated Aziridines. The Reaction of 2-Iodoalkyl Azides with Phosphines and Phosphites[1]

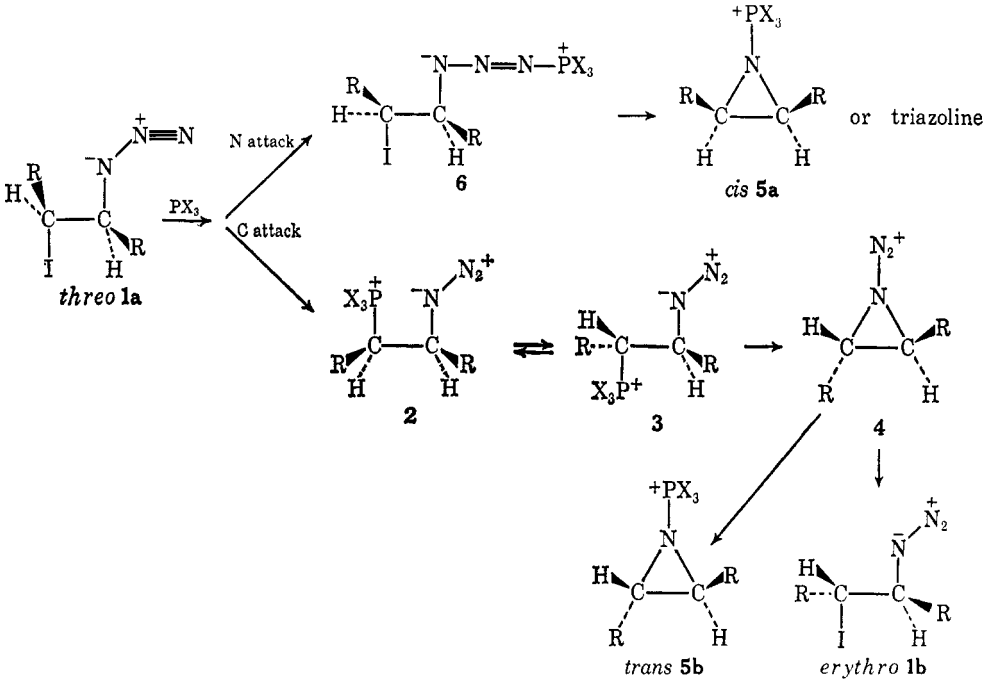
Alfred Hassner and James E. Galle

Contribution from the Department of Chemistry, University of Colorado, Boulder, Colorado 80302. *Received November 24, 1969*

Abstract: 2-Iodoalkyl azides react readily and stereospecifically with trivalent phosphorus nucleophiles by attack on azide to form N-phosphorylated aziridines. The use of triphenylphosphine gives aziridinyltriphenylphosphonium iodide salts **5**. When phosphites were used these salts underwent further transformations *in situ* leading to aziridinephosphonates **7**, **10**, or **11**. The structure of these compounds was proved by an independent synthesis. LAH reduction of **5** or **7** proceeded with P–N bond cleavage. This reaction sequence was shown to be a convenient method of aziridine synthesis in particular for cases where other methods failed. Dimethyl N-(2,2-diphenylaziridinyl)phosphonate **20** rearranges on standing to an enamine phosphonate **23**. The use of nmr in distinguishing between aziridinyl and open chain isomers is discussed.

We have previously reported the synthesis of 2-iodoalkyl azides[2] from olefins and their subsequent transformation among others into vinyl azides,[3] azirines,[4] and aziridines.[5] We now wish to report the reaction of 2-iodoalkyl azides with trivalent phosphorus compounds.

(1) Stereochemistry. L. For previous paper see A. Hassner, R. E. Wiederkehr, and A. J. Kascheres, *J. Org. Chem.*, **35**, 1962 (1970).
(2) F. W. Fowler, A. Hassner, and L. Levy, *J. Am. Chem. Soc.*, **89**, 2077 (1967).
(3) A. Hassner and F. W. Fowler, *J. Org. Chem.*, **33**, 2686 (1968).
(4) A. Hassner and F. W. Fowler, *J. Am. Chem. Soc.*, **90**, 2869 (1968).
(5) A. Hassner, G. J. Matthews, and F. W. Fowler, *ibid.*, **91**, 5046 (1969).

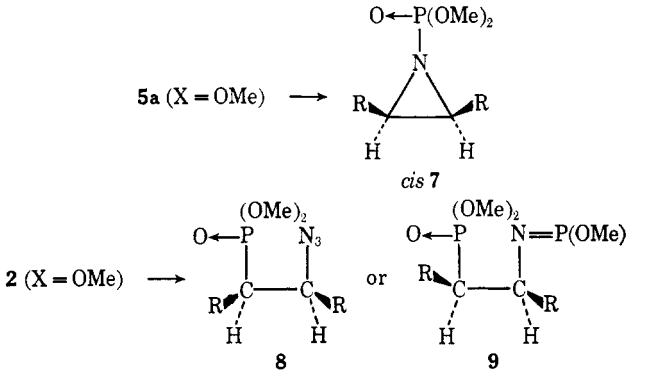


The reaction between phosphorus nucleophiles and azides (Staudinger reaction) giving phosphine imines is well known,[6-8] as are the subsequent reactions of these compounds with alkyl halides giving diakylaminophosphonium salts.[9] Furthermore, alkyl- or arylphosphines react with alkyl halides readily to produce phosphonium salts.[10] With very few exceptions,[11] no attention has been given to incorporating both the phosphine imine and the halide function into one molecule with the possibility of creating a cyclic product.

Halogenated alkyl azides of type **1** offer two sites of attack for trivalent phosphorus nucleophiles, namely on the azide function or on the halogen bearing carbon. If attack occurs on carbon in stereochemically pure *threo* iodo azide **1a**, and one assumes inversion in the formation of phosphonium salt **2**, then backside ring closure to an aziridine derivative **4** is possible, at least in acyclic compounds, after rotation to conformation **3**. The reaction pathways available for **4** include opening by I^- with formation of iodo azide **1b** the *erythro* diastereomer of **1a**. Interaction of **4** with R_3P can give rise to **5b**, the *trans* isomer of aziridine **5a**.

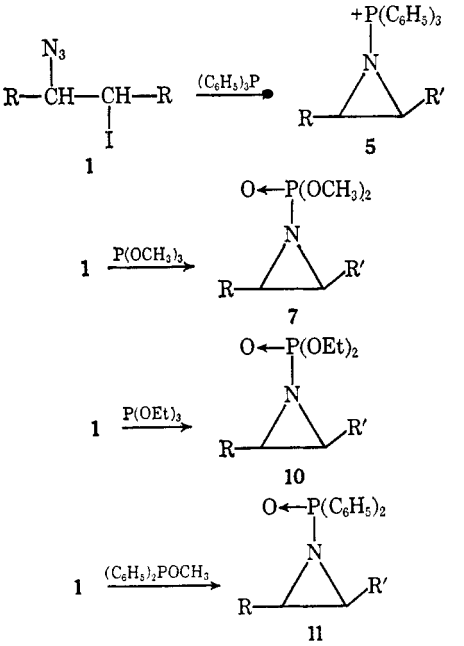
On the other hand, attack of R_3P on the nitrogen of **1a** is likely to produce *cis* aziridine **5a** or a phosphorylated triazoline. Thus, the stereochemistry of the products can provide an indication of the reaction pathway.

If phosphites, $(RO)_3P$, are used instead of phosphines, R_3P, then additional differentiation between attack on N or C becomes possible. Namely, phosphonium salt **5a** should give rise to *cis* aziridine **7**, while intermediate **2** could be converted to **8** or **9** instead of or in addition to the *trans* stereoisomer of **7**.



Results and Discussion

We found the reaction of 2-iodoalkyl azides with triphenylphosphine, trimethyl phosphite, triethyl phos-



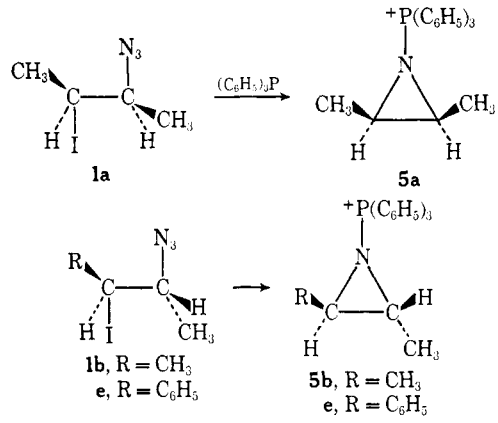
(6) For a general review on the reactions of azides with nucleophiles, see G. L'abbé, *Ind. Chim. Belge*, **34**, 519 (1968).
(7) H. Staudinger and M. Meyer, *Helv. Chem. Acta*, **2**, 635 (1919).
(8) J. E. Leffler and R. D. Temple, *J. Am. Chem. Soc.*, **89**, 5235 (1967), and references cited therein.
(9) H. Zimmer and G. Singh, *J. Org. Chem.*, **28**, 483 (1963).
(10) G. Wittig and V. Schöllkopf, *Chem. Ber.*, **87**, 1318 (1954).
(11) K. Ponsold and H. Groh [*Chem. Ber.*, **98**, 1009 (1965)] treated a β-azidoalkyl bromide with triphenylphosphine. The product was not characterized but gave on heating with hydrobromic acid a β-aminoalkyl bromide salt.

Table I. Conversion of 2-Iodoalkyl Azides **1** into Aziridinyltriphenylphosphonium Salts **5** and Dialkyl Aziridinylphosphonates **7** or **10**

Alkyl azide **1**	Yield, %		
1a (*threo*), R = R′ = CH_3	**5a** (*cis*) 91	**7a** (*cis*) 90[b]	**10a** (*cis*) 95[a]
1b (*erythro*), R = R′ = CH_3	**5b** (*trans*) 91	**7b** (*trans*) 89[b]	**10b** (*trans*) 100[a]
1c (*erythro*), R = R′ = C_6H_5		**7c** (*trans*) 93[c]	
1d (*erythro*), R = CH_3; R′ = CO_2CH_3		**7d** (*trans*) 80[b]	
1e (*erythro*), R = C_6H_5; R′ = CH_3	**5e** (*trans*) 86	**7e** (*trans*) 76[b]	
1f, R = C_6H_5; R′ = H	**5f** 95	**7f** 87[b]	
1g, R = *n*-C_4H_9; R′ = H		**7g** 94[b]	
1h, R = R′ = $(CH_2)_3$		**7h** 95[b]	
1i, R = R′ = $(CH_2)_4$	**5i** 100		**10i** 95[a]
1j, R = R′ = $(CH_2)_6$	**5j** 71		
1k, 2-azido-3-iodo-2-methylbutane		**7k** 76[b]	**10k** 90[a]

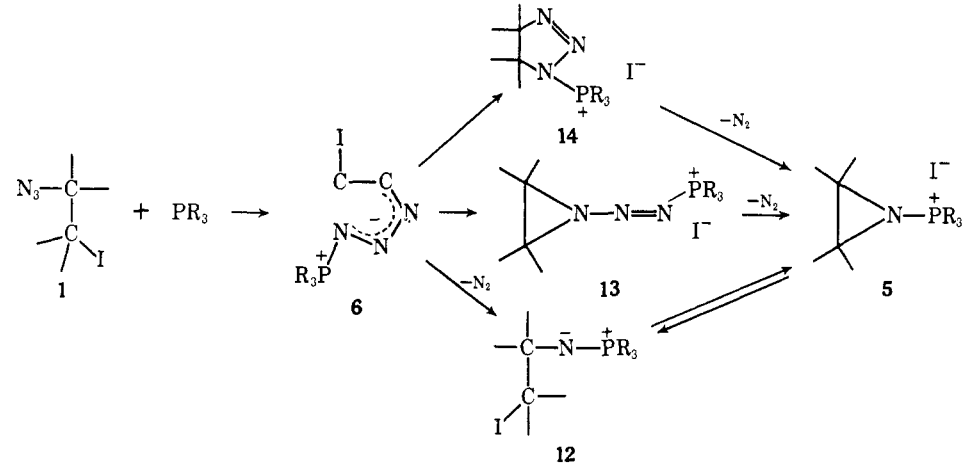
[a] Crude product. [b] After distillation. [c] Isolated only as the aziridine **15c** after LAH reduction.

phite, or methoxydiphenylphosphine to produce in good yield aziridine derivatives of type **5**, **7**, **10**, or **11**, respectively. Thus, the *threo* iodo azide **1a** derived from *cis*-butene reacted with triphenylphosphine to yield the *cis*-2,3-dimethyl-N-aziridinyltriphenylphosphonium iodide **5a**. Under the same conditions the *erythro* diastereomers **1b** and **1e** produced the *trans* aziridines **5b** and **5e**, respectively. The stereochemistry of the products was evident by conversion of **5a** to *cis*-2,3-dimethylaziridine (**15a**) and of **5e** to *trans*-2-methyl-3-phenylaziridine (**15e**) on LAH reduction.



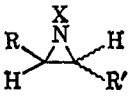
These clean stereochemical results indicate that 2-iodoalkyl azides react with trivalent phosphorus nucleophiles almost exclusively at the azide function. The reactions are thought to involve initial nucleophilic attack on the terminal azide nitrogen.[6] Intermediate **6** can undergo loss of nitrogen to ylide **12** which cyclizes to **5** with displacement of iodide anion. Alternately, cyclization to **13** or **14** may precede loss of N_2, although the rate of N_2 loss from azide–phosphine adducts of type **6** is generally believed to be faster than their rate of formation.[8]

That the aziridinyltriphenylphosphonium iodide salts **5** (see Table I) usually exist in the closed aziridine form **5** rather than in the open form **12** was shown by comparison of the nmr chemical shifts of the ring protons with those of other aziridine derivatives (see Table II). The nmr spectra of aziridine protons (CH) are shielded compared to CH's in open chain amines due to the magnetic current generated in three-membered rings.[12] Thus, alkylaziridines exhibit nmr absorption near τ 8.5 for CH_2 groups which occur at lower field if aromatic or electron withdrawing geminal substituents are present. Tertiary aziridinyl CH absorptions usually occur at τ 7.6–8.1 but these chemical shifts vary from 7.2 to 8.5 depending on the substituents and their stereochemistry. For comparison, the CH in isopropylamine is found at 6.9. This allows a differentiation between aziridines and other amines from chemical shift data of the ring protons. The same holds true if electron withdrawing N substituents are present in these systems, except that the ring protons absorb at lower field (see Table II). It can be seen from Table II that P(→O)(OR)$_2$ substituents on the nitrogen of aziridines cause a downfield shift of the ring protons by 0.5–0.8 ppm while C(=O)Ar, P(=O)Ar$_2$, C(=S)NHAr,



(12) S. J. Brois, *J. Org. Chem.*, 27, 3532 (1962).

Table II. Chemical Shifts of Ring Protons (τ) for Aziridines



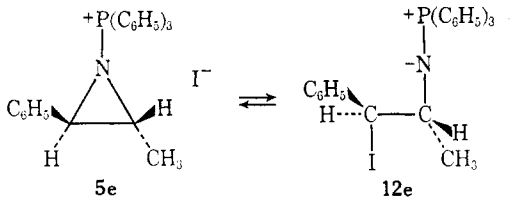
Aziridine R, R′	X = H (in CCl_4)	X = $P(=O)(OR)_2$ (in CCl_4)	X = $^+P(C_6H_5)_3I^-$ (in $CDCl_3$)	Others (solvent)
R = R′ = CH_3 (*cis*)	8.08	7.53	7.30	X = $C(=O)C_6H_5$ 7.3 ($CDCl_3$) X = $C(=S)NHC_6H_5$ 7.36 ($CDCl_3$)
R = R′ = CH_3 (*trans*)	8.53	7.75	6.75	X = $P(=O)(C_6H_5)_2$ 7.42 (CCl_4–$CDCl_3$)
R = R′ = $(CH_2)_3$	7.65	7.05		X = *p*-$C(=O)C_6H_4NO_2$ 6.70 ($CDCl_3$)
R = R′ = $(CH_2)_4$	7.93	7.43	7.17	X = $C(=O)C_6H_5$ 7.28 ($CDCl_3$) X = $P(=O)(C_6H_5)_2$ 7.13 ($CDCl_3$)
R = C_6H_5; R′ = H	7.25 8.08 8.45	6.57 7.40 7.94		
R = C_6H_5; R′ = CH_3 (*trans*)	7.56 8.17	6.97 7.48	5.0[a]	X = $P(=O)(C_6H_5)_2$ 6.38 ($CDCl_3$) 7.26
$(Me)_2CH—NH—X$	6.94	6.8		X = $C(=O)C_6H_5$ 5.72 ($CDCl_3$)

[a] Structure appears to be the ring opened **12e**.

and $^+PAr_3$ as N substituents effect an even greater (0.8–1.2 ppm) though less predictable downfield shift.

Considerable differences in chemical shifts were observed between the ring protons of *trans*-2,3-dimethylaziridine (**15b**) (τ 8.53) and *cis*-2,3-dialkylaziridines, specifically **15a** (8.08). The reasons for this difference and for the unusually low field absorption (6.75) of the phosphonium salt **5b** are still obscure. An open structure **12b** rather than the ring closed **5b** is unlikely since the former should show two CH_3 doublets while only one doublet, as in **15b**, was observed.

In the case of **5e**, the phosphonium salt appears to be present as a ring-opened form, presumably **12e** (or an isomer). This is indicated by the nmr absorption in $CDCl_3$ at τ 5.0 (multiplet, 2 H), which is too low for

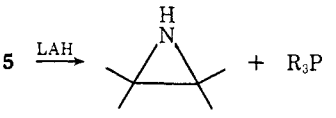


5e **12e**

aziridinyl protons but consistent with secondary protons geminal to iodine or N.

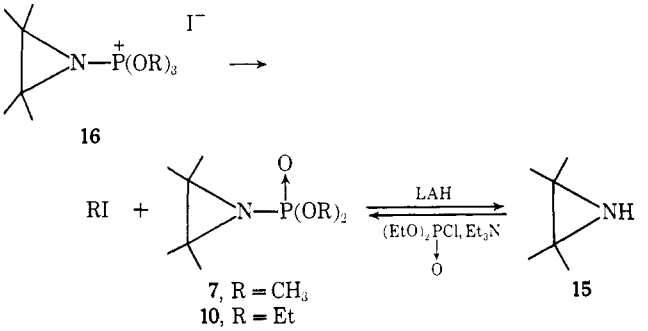
LAH reduction of **5** leads to formation of triphenylphosphine and the free aziridines **15**. This is in accord with the general principle that reduction or hydrolysis of phosphonium salts liberates the most electronegative group from the phosphorus. Similar results have been obtained in the LAH reduction of tetraalkylphosphonium salts.[13]

In spite of the ring-opened form, LAH reduction of **12e** leads to *trans*-2-methyl-3-phenylaziridine (**15e**) suggesting that the ring opening of **5e** by I^- is reversible and occurs with inversion. That the phenyl-substituted phosphonium salt **5e** is opened more readily by iodide ions than alkyl-substituted analogs is probably accountable by the fact that both SN2 and SN1 reactions are more favorable in benzylic systems. Further studies on this point are under way.



15

In the cases where alkyl phosphites were used the phosphonium salt intermediates **16** could not be isolated but presumably underwent further transformations (similar to the well-known Michaelis–Arbusov reaction)[14] giving aziridinephosphonates **7** or **10** and alkyl iodide (see Table I). The structure of these compounds was evident upon inspection of the crude nmr spectra which showed characteristic aziridine ring proton patterns, split also by phosphorus (J_{P-H} = 10–15 Hz). The structure of a number of these compounds was confirmed by synthesis from the free aziridine **15** and the corresponding dialkyl phosphorochloridate or by reductive cleavage of **7** with LAH to the free aziridine.



16

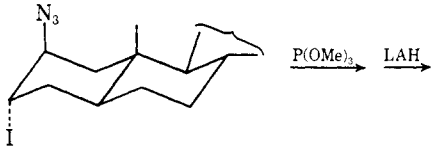
7, R = CH_3
10, R = Et

This reaction sequence constitutes an improved method of synthesis of certain aziridines *via* iodo azides. Lithium aluminum hydride reduction of iodo azides containing a primary or benzylic halide function give in addition to aziridines a large amount of product resulting from hydrogenolysis of the iodide function.[5] Similarly, compounds in which the iodo and azide functions are held rigidly in a *trans*-diaxial conformation (*i.e.*, **17**) give only reductive elimination with LAH.[5]

(13) W. J. Bailey and S. A. Buckler, *J. Am. Chem. Soc.*, 79, 3567 (1957).

(14) For a general review article, see R. G. Harvey and R. De sombre, "Topics in Phosphorus Chemistry," Vol. I, Interscience, New York, N. Y., 1964, p 59.

Neither of these difficulties were encountered using the phosphonate method. Thus, 1-azido-2-iodo-1-phenylethane (**1f**) and 2β-azido-3α-iodocholestane (**17**) could be converted in good yield into the corresponding aziridines.



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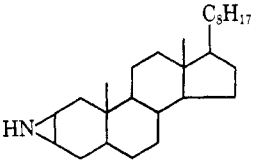
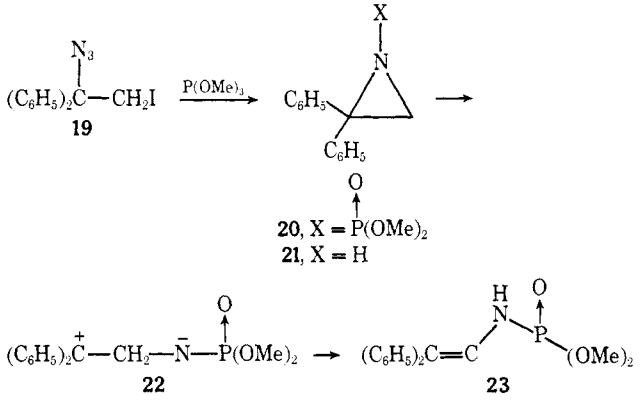


18

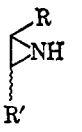
Although most of the aziridinylphosphonates are stable compounds and do not undergo ring opening readily, an interesting rearrangement was observed when the aziridine ring was substituted with two phenyl rings. 1-Azido-2-iodo-1,1-diphenylethane (**19**) gave an aziridine product **20** upon treatment with trimethyl phosphite. This was evident from inspection of the nmr spectrum of the crude product which showed a doublet integrating for two protons (J_{P-H} = 14 Hz) at τ 7.3. Using proper precautions this compound was reduced with LAH to give 2,2-diphenylaziridine (**21**) in good yield. However, upon standing for *ca.* 1 month at room temperature **20** had isomerized to **23**. The structure of **23** was evident from its ir spectrum which showed an NH band (3325 cm^{-1}) and a C=C band (1630 cm^{-1}). The enamine structure of **23** was confirmed by treatment with an acidified solution of 2,4-dinitrophenylhydrazine which produced the 2,4-dinitrophenylhydrazone of diphenylacetaldehyde in good yield.



A plausible mechanism involves opening of the aziridine to a zwitterionic species **22** in which the negative charge on N is stabilized by the electron-withdrawing phosphonate group and the positive charge by delocalization into the two phenyl substituents. Proton loss converts **22** into an olefin which reprotonates on N to form **13**. This pathway is analogous to the postulated ring opening of N-acylaziridines,[15] which, however, leads to allyl amides or isoxazole derivatives.

(15) H. W. Heine and M. S. Kaplan, *J. Org. Chem.*, 32, 3069 (1967).

Table III. Yield of Aziridines from LAH Reduction of **5**, **7**, or **10**



	Aziridine	Yield, %
15f	R = C_6H_5; R' = H	16[a,d]
		88[b]
15e	R = C_6H_5; R' = CH_3 (*trans*)	90[a]
		76[b]
15a	R = R' = CH_3 (*cis*)	46[a,e]
15j	R = R' = $(CH_2)_6$	50[a,d]
21	2,2-Diphenyl	93[b,c]
18	2β,3β-Iminocholestane	76[b,c]
15c	R = R' = C_6H_5 (*trans*)	93[b,c]

[a] Starting from phosphonium salt **5**. [b] Starting from dialkyl phosphonates **7** or **10**. [c] Based on starting iodo azide. [d] Isolated as the picrate. [e] Isolated as the chloro amine hydrochloride.

Experimental Section

General. All melting points were taken on a Fisher-Johns melting point block and are uncorrected. Infrared spectra were taken on a Perkin-Elmer Model 457 grating infrared spectrometer. Nmr spectra were taken on a Varian A-60A spectrometer in 10–25% solutions using tetramethylsilane as an internal standard. Elemental analyses were performed by Galbraith Labs, Knoxville, Tenn.

Materials. Solvents used were either reagent grade or distilled before use. Trimethyl phosphite (Columbia, practical grade) was distilled, the fraction boiling at 103–107° (630 mm) being used. Triethyl phosphite (Aldrich, technical grade) was distilled, the fraction boiling at 62–66° (20 mm) being used. Triphenylphosphine (Matheson Coleman and Bell), diethyl phosphorochloridate (Aldrich), and methoxydiphenylphosphine (kindly provided by Arapahoe Chemicals Co., Boulder, Colo.) were used without purification. The 2-iodoalkyl azides **1** were synthesized by previously published methods.[2]

General Method for the Synthesis of Aziridinyltriphenylphosphonium Iodide Salts. To triphenylphosphine (5 g) in 50–100 ml of solvent is added 1.0 equiv of the iodo azide **1**. A boiling chip is added to promote smooth nitrogen evolution, and the solution is kept near room temperature, using external cooling if necessary. Insoluble material soon begins to separate out (occasionally as an oil which later solidifies). After nitrogen evolution has ceased (2–5 hr) the solution is filtered with suction. The crude product is washed with benzene, then with pentane and briefly air dried.

N-(*trans*-2,3-Dimethylaziridinyl)triphenylphosphonium iodide (5b) was prepared from *erythro*-2-azido-3-iodobutane (**1b**) in benzene in 91% yield, mp 129–133° dec. An analytical sample from absolute ethanol had mp 136–140° dec. *Anal.* Calcd for $C_{22}H_{23}INP$: C, 57.52; H, 5.01. Found: C, 57.69; H, 5.01. Nmr ($CDCl_3$) showed τ 1.9–2.4 (m, 15), 6.5–7.1 (m, 2), and 8.75 (d, 6, J = 5 Hz).

N-(*cis*-2,3-Dimethylaziridinyl)triphenylphosphonium iodide (5a) was prepared from *threo*-2-azido-3-iodobutane (**1a**) in benzene in 91% yield, mp 146–148° dec. An analytical sample from absolute ethanol had mp 143–145° dec. *Anal.* Calcd for $C_{22}H_{23}INP$: C, 57.52; H, 5.10. Found: C, 57.27; H, 5.10. Nmr ($CDCl_3$) showed τ 1.8–2.4 (m, 15), 7.0–7.6 (m, 2), and 8.25–8.60 (m, 6).

N-(7-Azabicyclo[4.1.0]heptanyl)triphenylphosphonium iodide (5c) was prepared in benzene from *trans*-1-azido-2-iodocyclohexane (**1c**) in quantitative yield, mp 165–167° dec. An analytical sample from absolute ethanol had mp 164–169° dec. *Anal.* Calcd for $C_{24}H_{25}INP$: C, 59.38; H, 5.15. Found: C, 59.51; H, 5.18. Nmr ($CDCl_3$) showed τ 1.9–2.4 (m, 15), 7.17 (broad d, 2, J = 17 Hz), and 7.6–8.8 (m, 8).

N-(2-Phenylaziridinyl)triphenylphosphonium iodide (5d) was prepared from 1-azido-2-iodo-1-phenylethane in anhydrous ether. The crude product was washed with anhydrous ether and pentane giving a 95% yield of a light tan solid which decomposed upon heating to 120–150°. Attempts to characterize this material further failed.

N-(*trans*-2-Methyl-3-phenylaziridinyl)triphenylphosphonium iodide (5e) or open form **12e** was prepared from 1-azido-2-iodo-1-phenylpropane (**1e**) in 15% absolute ethanol–benzene in 86% yield, mp 145–150°. An analytical sample from absolute ethanol had mp 132–140° dec. Nmr ($CDCl_3$) showed τ 1.9–2.9 (m, 20), 5.6–6.4 (m, 2), and 8.53 (d, 3, J = 5.5 Hz). *Anal.* Calcd for $C_{27}H_{25}INP$: C, 62.19; H, 4.80. Found: C, 61.88; H, 4.90.

N-(9-Azabicyclo[6.1.0]nonanyl)triphenylphosphonium iodide (5f) was prepared from *trans*-1-azido-2-iodocyclooctane **1f** in benzene in 71% yield, mp 177–179° dec. An analytical sample from absolute ethanol had mp 184–186° dec. *Anal.* Calcd for $C_{26}H_{29}INP$: C, 60.82; H, 5.65. Found: C, 60.51; H, 5.76. Nmr ($CDCl_3$) showed τ 1.9–2.1 (m, 15) and 7.2–8.8 (m, 14).

General Procedure for the Synthesis of Dialkyl N-(Aziridinyl)-phosphonates. To 5 g of the alkyl phosphite in *ca.* 50 ml of pentane is added 1 equiv of the iodo azide **1**. A boiling chip is added to ensure smooth nitrogen evolution and the solution is allowed to stand at room temperature until N_2 evolution has ceased (generally 1–3 days). The remaining solvent is removed *in vacuo* and small amounts of the phosphite are added at 1-day intervals until the azide band at *ca.* 2100 cm^{-1} in the ir has completely disappeared. Products obtained in this manner were generally essentially pure as shown by nmr. If further purification is desired the products may be distilled at reduced pressure. Analytical samples were taken from the center cut of the distillation through a short path distillation apparatus. Deviations from this procedure are noted for specific compounds.

Diethyl N-(*trans*-2,3-dimethylaziridinyl)phosphonate (10b) was obtained from *erythro*-2-azido-3-iodobutane (**1b**) in 90% yield: bp 72–76° (0.1 mm); nmr (CCl_4) τ 5.7–6.3 (m, 4), 7.4–8.0 (m, 2), and 8.5–8.9 (m, 12). *Anal.* Calcd for $C_8H_{18}NO_3P$: C, 46.38; H, 8.70. Found: C, 46.10; H, 8.83.

Diethyl N-(*cis*-2,3-dimethylaziridinyl)phosphonate (10a) was prepared from *threo*-2-azido-3-iodobutane (**1a**) in 95% yield: bp 70–75° (0.1 mm); nmr (CCl_4) τ 5.7–6.3 (m, 4), 7.3–7.9 (m, 2), and 8.6–9.0 (m, 12). *Anal.* Calcd for $C_8H_{18}NO_3P$: C, 46.38; H, 8.70. Found: C, 46.25; H, 8.72.

Dimethyl N-(*trans*-2,3-dimethylaziridinyl)phosphonate (7b) was prepared from *erythro*-2-azido-3-iodobutane in 89% yield after distillation: bp 54–58° (0.1 mm); nmr (CCl_4) τ 6.26 (d, 3, J = 10.5 Hz), 6.30 (d, 3, J = 10.5 Hz), 7.4–8.1 (m, 2), and 8.69 (d, 2, J = 5.5 Hz). *Anal.* Calcd for $C_8H_{18}NO_3P$: C, 40.04; H, 7.37. Found: C, 39.94; H, 7.79.

Diethyl N-(7-azabicyclo[4.1.0]heptanyl)phosphonate (10i) was obtained from *trans*-1-azido-2-iodocyclohexane (**1i**) in 95% yield: bp 100–110° (0.1 mm); nmr (CCl_4) τ 5.7–6.3 (m,4), 7.43 (broad d 2, J = 17 Hz), 8.0–8.9 (m, 8), and 8.70 (t, 6, J = 7 Hz). *Anal.* Calcd for $C_{10}H_{20}NO_3P$: C, 51.50; H, 8.58. Found: C, 51.24; H, 8.65.

Diethyl N-(2,2,3-trimethylaziridinyl)phosphonate (10k) was obtained from 2-azido-3-iodo-2-methylbutane in 90% yield: bp 66–70° (0.1 mm); nmr (CCl_4) τ 5.6–6.3 (m, 4), 7.58 (dq, 1, $J_{P,H}$ = 16 Hz, $J_{CH_3,H}$ = 5 Hz), and 8.5–8.9 (m, 15). *Anal.* Calcd for $C_9H_{20}NO_3P$: C, 48.87; H, 9.05. Found: C, 48.51; H, 9.20.

Dimethyl N-(*cis*-2,3-dimethylaziridinyl)phosphonate (7a) was obtained from *threo*-2-azido-3-iodobutane (**1a**) in 90% yield after distillation: bp 53–60° (0.1 mm); nmr (CCl_4) τ 6.36 (d, 6, J = 11 Hz), 7.35–7.85 (m, 2), and 8.7–8.9 (m, 6). *Anal.* Calcd for $C_6H_{14}NO_3P$: C, 40.22; H, 7.82. Found: C, 40.04; H, 7.37.

Dimethyl N-(2,2,3-trimethylaziridinyl)phosphonate (7k) was prepared from 2-azido-3-iodo-2-methylbutane (**1k**) in 76% yield after distillation: bp 59–63° (0.1 mm); nmr (CCl_4) τ 6.38 (d, 3, J = 11 Hz), 6.40 (d, 3, J = 11 Hz), 7.60 (dq, 1, $J_{P,H}$ = 15 Hz, $J_{CH_3,H}$ = 6 Hz), and 8.5–8.9 (m, 9). *Anal.* Calcd for $C_7H_{16}NO_3P$: C, 43.52; H, 8.29. Found: C, 43.68; H, 8.39.

Dimethyl N-(*trans*-2-methyl-3-carbomethoxyaziridinyl)phosphonate (7d) was prepared from *erythro*-methyl 2-iodo-3-azidobutanoate (**1d**) in 80% yield after distillation: bp 109–111° (0.1 mm); nmr (CCl_4) τ 6.33 (d, 3, J = 11 Hz), 6.25 (s, 3), 6.37 (d, 3, J = 11 Hz), 6.9–7.5 (m, 2), and 8.53 (d, 3, J = 5 Hz). *Anal.* Calcd for $C_7H_{14}NO_5P$: C, 37.67; H, 6.28. Found: C, 37.61; H, 6.30.

Dimethyl N-(*trans*-2-methyl-3-phenylaziridinyl)phosphonate (7e) was prepared from *erythro*-1-azido-2-iodo-1-phenylpropane in 77% yield after distillation: bp 129–132° (0.1 mm); nmr (CCl_4) τ 2.74 (s, 5), 6.28 (d, 3, J = 11 Hz), 6.37 (d, 3, J = 11 Hz), 6.79 (dd, 1, $J_{P,H}$ = 12 Hz, $J_{CH_3,H}$ = 3 Hz), 7.8–7.3 (m, 1), and 8.43 (d, 3, J = 6 Hz). *Anal.* Calcd for $C_{11}H_{16}NO_3P$: C, 54.77; H, 6.64. Found: C, 54.64; H, 6.87.

Dimethyl N-(2-phenylaziridinyl)phosphonate (7f) was prepared from 1-azido-2-iodo-1-phenylethane (**1f**) in 87% yield after distillation: bp 125–128° (0.1 mm); nmr (CCl_4) showed τ 2.75 (s, 5), 6.24 (d, 3, J = 11 Hz), 6.29 (d, 3, J = 11 Hz), 6.57 (ddd, 1, $J_{P,H}$ = 15 Hz, J_{HH} = 3 Hz), 7.40 (ddd, 1, $J_{P,H}$ = 18, J_{H-C-H} = 2 Hz, $J_{H,H}$ = 6 Hz) and 7.94 (ddd, 1, $J_{P,H}$ = 15 Hz, 3 Hz, 2 Hz). *Anal.* Calcd for $C_{10}H_{14}NO_3P$: C, 52.86; H, 6.17. Found: C, 52.68; H, 6.24.

Dimethyl N-(2-*n*-butylaziridinyl)phosphonate (7g) was obtained from 2-azido-1-iodohexane (**1g**) in 94% yield after distillation: bp 94–98° (1.0 mm); nmr (CCl_4) showed τ 6.29 (d, 6, J = 10.5 Hz) and 7.2–9.3 (m, 12). *Anal.* Calcd for $C_8H_{18}NO_3P$: C, 45.93; H, 8.61. Found: C, 45.99; H, 8.71.

Dimethyl N-(6-azabicyclo[3.1.0]hexanyl)phosphonate (7h) was obtained from *trans*-1-azido-2-iodocyclopentane (**1h**) in 95% yield after distillation: bp 81–83° (0.1 mm); nmr (CCl_4) showed τ 6.33 (d, 6, J = 10 Hz), 7.05 (broad d, 2, J = 14 Hz), and 7.8–8.8 (m, 6). *Anal.* Calcd for $C_7H_{14}NO_3P$: C, 43.98; H, 7.33. Found: C, 44.06; H, 7.38.

N-(7-Azabicyclo[4.1.0]heptanyl)diphenylphosphine oxide (11i) was prepared from *trans*-1-azido-2-iodocyclohexane (**1i**) (1.16 g) and methoxydiphenylphosphine (1.0 g) in 25 ml of pentane. Upon concentration of the solution and cooling to *ca.* −30°, 1.38 g of crystals, mp 145–155°, was obtained. The analytical sample, mp 158–160°, was obtained by recrystallization from $CHCl_3$–hexane: nmr ($CDCl_3$) showed τ 1.8–2.3 (m, 4), 2.4–2.8 (m, 6), 7.13 (broad d, 2, J = 15.5 Hz), and 8.0–9.0 (m, 8). *Anal.* Calcd for $C_{18}H_{20}NOP$: C, 72.73; H, 6.73. Found: C, 72.62; H, 6.69.

(*trans*-2,3-Dimethylaziridinyl)diphenylphosphine oxide (11b) was obtained in 76% yield: mp 151–159°; nmr ($CDCl_3$) τ 8.69 (d, 6, J = 5 Hz), 7.42 (m, 2), and 1.7–2.8 (m, 10). The analytical sample (from cyclohexane) melted at 155–158°. *Anal.* Calcd for $C_{16}H_{18}NOP$: C, 70.85; H, 6.64. Found: C, 70.55; H, 6.80.

(*trans*-2-Methyl-3-phenylaziridinyl)diphenylphosphine oxide (11e) was isolated in 88% yield: mp 100–115°; nmr ($CDCl_3$–CCl_4) τ 8.44 (d, 3, J = 5.5 Hz), 7.26 (m, 1), 6.38 (dd, 1, J = 3 and 13 Hz), and 1.7–3.0 (m, 15). The analytical sample melted at 117–119°.

General Procedure for the Reduction of Dialkyl N-(Aziridinyl)-phosphonates. To a stirred solution of 2 g of LAH in 50 ml of anhydrous ether was added the phosphonate (0.02 mol) in 15 ml of ether at such a rate as to maintain reflux. The solution was allowed to stir at room temperature for 2 hr and the excess LAH was destroyed by the cautious addition of 8 ml of 20% NaOH solution. The solution was filtered through a medium porosity sintered glass filter, the aluminum salts were washed with ether, and the ether was removed *in vacuo* giving the crude aziridine.

Note! Owing to the evolution of evil smelling fumes during and after the reduction, the entire process should be conducted in a well ventilated hood.

***trans*-2-Methyl-3-phenylaziridine (15e)** was obtained from **7e** in 76% yield. The nmr and ir spectra of this material were identical with those of a sample prepared by previously published methods.[5] The phenylurea derivative melted at 145–147° (from acetone) (lit.[5] mp 144–146°).

Phenylaziridine (15f) was prepared from **7f** in 88% yield. The nmr spectrum was identical with that of an authentic sample.

2β,3β-Iminocholestane (18). To 0.5 g of trimethyl phosphite was added 1.0 g of 2β-azido-3α-iodocholestane (**17**) in 10 ml of benzene. This mixture was allowed to stand at room temperature until the azide band in the ir had completely disappeared. The solvent was removed *in vacuo* and much of the excess trimethyl phosphite was removed at 0.1 mm. The resulting product was reduced according to the general procedure to furnish 0.71 g of **18**, mp 101–103°. This material was further characterized as the N-acetyl derivative, mp 136.5–138.5° (lit.[16] mp 137–138°), and the iodoamine hydroiodide derivative, mp 190–195° (lit.[16] mp 197–198°).

2,2-Diphenylaziridine (21). 1-Azido-2-iodo-1,1-diphenylethane (**19**) (6.05 g) and 3 g of trimethyl phosphite were mixed in 30 ml of ether. After 3 days at room temperature the azide band had completely disappeared and the remaining solvent was removed *in vacuo*. Much of the remaining trimethyl phosphite was removed at 0.1 mm. This material was judged to be mostly dimethyl N-(2,2-diphenylaziridinyl)phosphonate (**20**) as shown by the nmr absorption at τ 7.30 (d, 2, $J_{P,H}$ = 14 Hz). LAH reduction gave 3.56 g (93%) of 2,2-diphenylaziridine (**21**) as a colorless oil: nmr (CCl_4) τ 2.75 (s, 10), 7.04 (s, 2), and 8.17 (broad s, 1) (83% pure by nmr integration of the ring and aromatic protons). Heating of this product for 15 min on a steam bath with an equal weight of phenyl isothiocyanate gave, after recrystallization from acetone, a phenylthiourea derivative, mp 213–215°, in 47% yield. The analytical

(16) A. Hassner and C. Heathcock, *J. Org. Chem.*, **30**, 1748 (1965).

sample was obtained by further recrystallization from acetone and melted at 213–214° (inserted on the block at 205°). *Anal.* Calcd for $C_{21}H_{18}N_2S$: C, 76.36; H, 5.46. Found: C, 76.10; H, 5.46.

Dimethyl N-(2,2-Diphenylethenyl)phosphoramidate (23). If the crude phosphonate (**20**) described above was allowed to stand on the shelf for *ca.* 1–2 months the entire product solidified to give the phosphoramidate (**25**), mp 89–90° after crystallization from Skellysolve B. The analytical sample was prepared by sublimation from the liquid melt at 130° (0.1 mm): mp 90–92°; ir (KBr) 3350 and 1640 cm^{-1}; nmr (CCl_4) τ 2.68–2.88 (m, 10), 3.35 (dd, 1, J = 6, 12 Hz) (collapses into a doublet, J = 6 Hz, upon exchange with D_2O), 4.85 (broad, 1, disappears with D_2O), and 6.31 (d, 6, J = 11 Hz). *Anal.* Calcd for $C_{16}H_{18}NO_3P$: C, 63.37; H, 5.94. Found: C, 63.12; H, 5.92.

When 0.4 g of this material was dissolved in a minimum amount of ethanol and added to an acidified solution of 0.4 g of 2,4-dinitrophenylhydrazine in ethanol, the 2,4 dinitrophenylhydrazone of 2,2-diphenylacetaldehyde, 0.45 g, mp 152–154° (from ethanol–ethyl acetate), precipitated after standing 12 hr. This material was identical by melting point, mixture melting point, and ir to a sample prepared in a similar manner from authentic 2,2-diphenylacetaldehyde.

***trans*-2,3-Diphenylaziridine (15c).** To 1.0 g of *erythro*-1-azido-2-iodo-1,2-diphenylethane (**1c**) dissolved in a minimum amount of THF was added 1.0 g of trimethyl phosphite. The mixture was kept at 0° for 1 day, the solvent removed *in vacuo*, and the remaining trimethyl phosphite removed at 0.1 mm. At this point there was a weak azide band in the ir. This material was reduced with LAH to give 0.52 g (93%) of **15c** as a semisolid, identical by ir and nmr with an authentic sample. Nmr integration showed this material to be approximately 90% pure.

LAH Reduction of Phosphonium Salt 5f. To a stirred solution of 4.0 g of **5f** in 50 ml of anhydrous ether was added in four portions 1.0 g of LAH at 10-min intervals. The mixture was stirred for 2 hr and the excess LAH destroyed by the cautious addition of 4.0 ml of 20% NaOH solution. The aluminum salts were filtered and washed with ether, and the ether was removed *in vacuo*. Chromatography on 75 g of basic alumina gave triphenylphosphine (eluted with 10% benzene–pentane) and phenylaziridine (0.54 g; eluted with 30% ether–benzene). Treatment of the aziridine fraction with an excess of saturated picric acid in ethanol gave the picrate, 0.44 g, 16% overall yield, mp 114–116°.

LAH Reduction of Phosphonium Salt 5a. Following the procedure described above, **5a** was reduced and the crude product was CO distilled with ether and cylohexane. Upon treatment of the distillate with HCl gas, *threo*-2-amino-3-chlorobutane hydrochloride, mp 151–154°, with sublimation (lit.[5] mp 141–147°), was isolated.

LAH Reduction of 5e. The reduction was carried out essentially as for **5f**. After chromatography there was obtained from 4.85 g of **5e** 0.79 g (90%) of *trans*-2-methyl-3-phenylaziridine (**12e**). This material was essentially pure and was identical with the material produced from **7e**.

LAH Reduction of Phosphonium Salt 5j. The reduction was carried out as for **5f**. From 10 g of **5j** there was obtained 7.4 g of a mixture of cyclooctenimine (**15j**) and triphenylphosphine. This material (3.75 g) was extracted with 25 ml of 95% ethanol, added to 25 ml of a saturated solution of picric acid in 95% ethanol, and cooled to −20°. The picrate of cyclooctenimine, 1.75 g (50%), mp 203–207° (lit.[5] mp 205–209°), was obtained after filtration.

General Procedure for the Conversion of Aziridines to Dialkyl N-(Aziridinyl)phosphonates. Using a modificaton of a procedure previously described,[17] 2.0 g of diethyl phosphorochloridate in 15–20 ml of dry benzene is mixed with 1.0 equiv each of the aziridine and triethylamine. The mixture is held just under the reflux temperature for 3 hr, then cooled to room temperature, diluted with 15 ml of pentane, cooled to −30°, and filtered. Removal of the solvent *in vacuo* gives the crude phosphonate. The crude products produced in this way were identical with those produced from the corresponding iodo azides and triethyl phosphite.

Diethyl N-(2,2,3-trimethylaziridinyl)phosphonate (10k) was obtained in 84% yield from 2,2,3-trimethylaziridine.

Diethyl N-(*cis*-2,3-dimethylaziridinyl)phosphonate (10a) was synthesized from *cis*-2,3-dimethylaziridine in quantitative yield.

Diethyl N-(7-azabicyclo[4.1.0]heptanyl)phosphonate (10i) was synthesized from 7-azabicyclo[4.1.0]heptane in quantitative yield.

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