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Polyphosphoric Acid Catalyzed Cyclization of Aralkenyl-Substituted Quaternary Ammonium Salts

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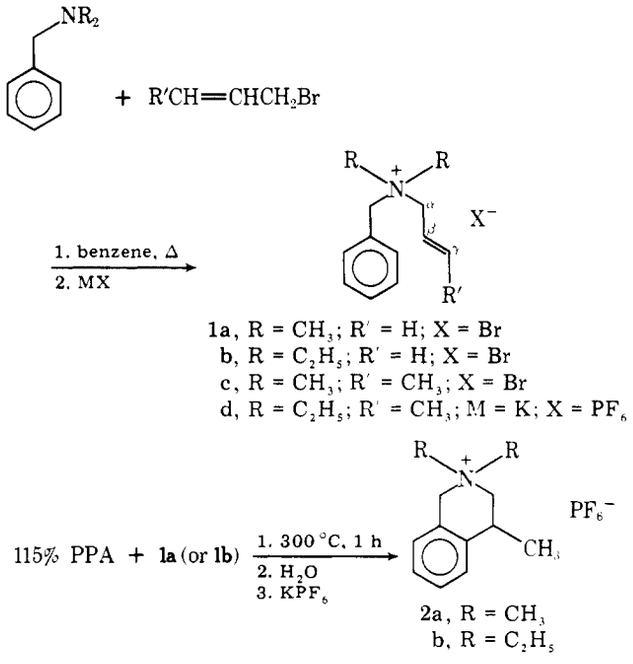
A simple method of wide scope for the synthesis of substituted indolium, quinolinium, isoquinolinium, and benzoazepinium salts has been developed from readily available starting materials. Quaternary ammonium compounds possessing a β-alkenyl substituent and an arylmethyl group readily cyclized in the presence of 115% polyphosphoric acid (PPA) at 300 °C for 1 h to furnish the substituted isoquinolinium and benzoazepinium salts in respectable yields (55–67%). On the other hand, alkenylanilinium salts cyclized at 130–140 °C for 1 h to give indolium and quinolinium salts in modest yields (18–38%). However, workup simply involved addition of the reaction mixture to ice–water to produce a homogeneous solution followed by the treatment with saturated aqueous KPF_6 and extraction of the salt formed with $HCCl_3$ or CH_2Cl_2. Spectral and elemental analyses supported the structures of the heterocyclic derivatives. A plausible mechanism involving the alkylation of a cation intermediate by the arene in a typical electrophilic substitution process is suggested for the salts carrying an arylmethyl group. In the case of the alkenylanilinium salts, the mechanism is not clear but rearrangements of the Claisen type appear to be operative.

Recently we reported[2] a facile ring closure of alkenylphosphonium salts containing an aryl or an arylmethyl group in the presence of 115% polyphosphoric acid (PPA) to furnish certain rare, difficultly accessible carbon–phosphorus heterocycles[3] in modest to good yields (24–82%). Likewise, treatment of arylmethylphosphonium salts having a β-carboxyl group produced functionalized C–P heterocycles in respectable yields.[4] The method appeared synthetically attractive from simplicity of experimental procedure alone which involved addition of the reaction mixture to ice–water followed by the treatment with aqueous saturated KPF_6 to precipitate the cyclic phosphonium salts often in a high state of purity.[2,4] Despite the widespread use of PPA as a cyclizing agent in organic synthesis for the obtention of a variety of ring systems,[5-7] quarternary ammonium compounds, via reaction with PPA, have not been fully explored as precursors to heterocyclic derivatives. However, related species may be expected to form from precursors containing heteroatoms in the cyclization reactions with PPA.[7] These considerations coupled with the observation[8,9] that arylphosphine oxides, with an appropriately oriented functionality, also cyclized smoothly in the presence of commercial 115% PPA[10] to give cyclic products, prompted us to extend the study to a few alkenyl substituted ammonium salts. We herein report the successful application of the technique to the synthesis of derivatives of indole, quinoline, isoquinoline, and benzoazepine from readily available, inexpensive reagents.

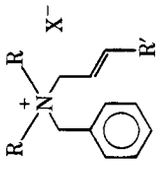
Allylbenzyldimethylammonium bromide (**1a**), the starting synthon, was prepared in near-quantitative yield by the quaternization of benzyldimethylamine with allyl bromide in benzene (Table I).[11] In the presence of 115% PPA at 300 °C for 1 h (Scheme I), salt **1a** cyclized to afford, after workup, the

Scheme I



crystalline 1,2,3,4-tetrahydro-2,2,4-trimethylisoquinolinium hexafluorophosphate (**2a**), mp 114.5–116.5 °C, in moderate yield (56%). ^1H NMR spectral analysis of the product **2a**, which contained the characteristic doublet for the *C*-methyl group at δ 1.41 (J_{HCCH} = 6 Hz), anchored the site of cyclization in **1a** at the β position (in relation to $>N^+<$ group). A gas, presumably HBr,[12] was evolved during the addition of the salt

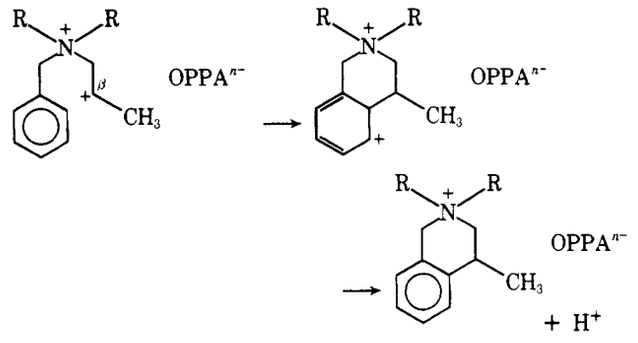
Table I



Compd	R	R′	X⁻	Mp, °C	Quaternizing solvent (reaction time, h)	Equiv of halide[a]	Yield, %[b]	Molecular formula		Anal., % C	H	N	P
1a[c]	CH_3	H	Br	99–100	Benzene (24)	1.16	97.7	$C_{12}H_{18}BrN$	Calcd	59.10	7.74	4.93	
1b	C_2H_5	H	Br	120–122	Benzene (24)	1.16	90.8	$C_{14}H_{22}BrN$	Found	58.87	8.07	5.00	
									Calcd	57.73	7.40	5.18	
1c	CH_3	CH_3	Br	128–129.5	Benzene (24)	1.10	93.3	$C_{13}H_{20}BrN$	Found	57.71	7.48	5.23	
									Calcd	49.59	6.61	3.86	8.54
1d[d]	C_2H_5	CH_3	PF_6	101–102	Benzene (26)	1.00	67	$C_{15}H_{24}F_6NP$	Found	49.39	6.63	3.80	8.51

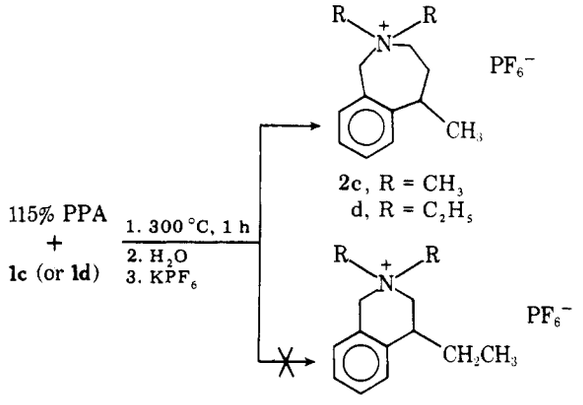
[a] Based on 1 equiv of amine. [b] Yield based on starting amine. [c] Previously reported in ref 11. [d] Isolated as the bromide and converted to the hexafluorophosphate derivative.

1a to PPA. Conceivably, the explusion of Br^- by PPA occurred during the reaction with simultaneous protonation of the olefinic bond in a preferred manner so as to produce a



cation at the β position.[2] Alkylation of the cation by the arene in a manner typical of an electrophilic substitution process followed by rearomatization would account for the observed product. Likewise, **1b** gave **2b** in good yield (67.6%). Interestingly, a seven-membered heterocyclic compound was *not* formed as judged from ^1H NMR analysis of the crude cyclized product obtained from **1a** or **1b.** In contrast, ammonium salts **1c** and **1d** possessing a crotyl chain, prepared by standard techniques (Table I) under identical reaction conditions, furnished the seven-membered cyclic salts **2c** and **2d,** respectively (Scheme II). No six-membered ring system was

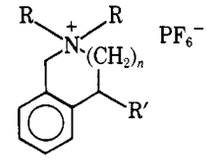
Scheme II



found. Here again, the position at which cyclization occurred was determined via ^1H NMR spectroscopy. Apparently, protonation of the olefinic bond must have occurred so as to produce a cation at the γ carbon (in relation to $>N^+<$) rather than a cation at the alternate β position. The results imply that (1) a cation intermediate is probably more stable at the γ position than a cation at the β position (hyperconjugative effect[2]); or (2) protonation is favored at the γ position in order to place the positive centers at the most remote positions. Unfortunately, lack of kinetic data with such ammonium salts or with related systems containing sulfur or phosphorus makes predictions extremely difficult.[13] An additional consideration must include the $>N^+<$ group which, although insulated from the aryl ring by the adjacent methylene, has been reported to deactivate the aromatic ring in electrophilic substitution reactions.[14] Nevertheless, the ring closure occurs in our systems.

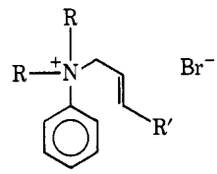
Very surprisingly the process was also found adaptable (although in low yields) for cyclization of anilinium salts possessing an alkenyl substituent. For example, treatment of allyldimethylanilinium bromide (**3a**)[15] in the presence of 115% PPA at 130–140 °C (Scheme III) gave the indolinium salt **4a** (after separation from a dark, viscous reaction mixture by column chromatography) only in low yield (18%). ^1H NMR analysis strongly suggested several components in the residual

Table II



Compd	R	R′	n	Mp, °C	Yield, %	Molecular formula	Anal., %	C	H	N	P
2a	CH_3	CH_3	1	114.5–116.5	56	$C_{12}H_{18}F_6NP$	Calcd	44.87	5.65	4.36	9.64
							Found	45.02	5.71	4.40	9.46
2b	C_2H_5	CH_3	1	131–132	67.6	$C_{14}H_{22}F_6NP$	Calcd	48.14	6.30	4.01	8.88
							Found	48.41	6.31	4.01	8.76
2c	CH_3	CH_3	2	122–123	62.5	$C_{13}H_{20}F_6NP$	Calcd	46.61	5.97	4.18	9.25
							Found	46.26	6.05	3.96	9.18
2d	C_2H_5	CH_3	2	128–129	55	$C_{15}H_{24}F_6NP$	Calcd	49.59	6.61	3.86	8.54
							Found	49.32	6.72	3.60	8.22

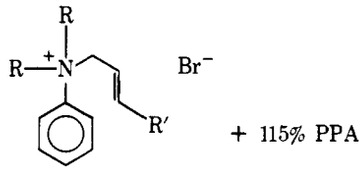
Table III



Compd	R	R′	Mp, °C	Quaternizing solvent (reaction time, h)	Equiv of halide[a]	Yield, %[b]
3a[c]	CH_3	H	123–124	Benzene (24)	1.32	96
3b[d]	C_2H_5	H	148–150	Neat (5 days)	1.24	75
3c[e]	CH_3	CH_3	123–125	Benzene (24)	1.00	54
3d	C_2H_5	CH_3	105–107	Neat (5 days)	1.26	90

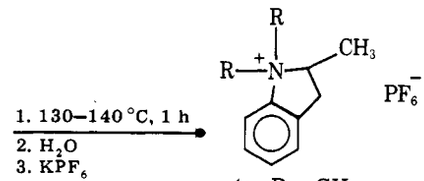
[a] Based on 1 equiv of amine. [b] Yield based on starting amine. [c] Previously reported in ref 15 and 25. [The I^- and $(C_6H_5)_4B^-$ salts are reported in ref 19.] [d] Reported in ref 26 but no physical data were included. [e] Previously reported in ref 19 and 25 as the trans isomer, mp 143–144 °C. Our material is a mixture of cis and trans isomers in the ratio of 1:3.

Scheme III



+ 115% PPA

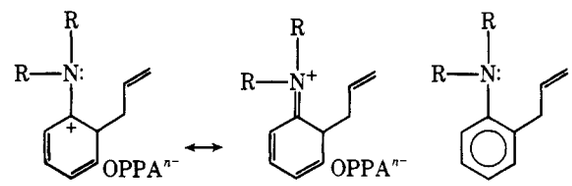
3a, R = CH_3; R′ = H
b, R = C_2H_5; R′ = H
c, R = CH_3; R′ = CH_3
d, R = C_2H_5; R′ = CH_3



1. 130–140 °C, 1 h
2. H_2O
3. KPF_6

4a, R = CH_3
b, R = C_2H_5

mixture which, however, could not be readily separated. Repeated experiments aimed at improving the yield of the indolium salts utilizing the more abundant salt **3b** in the temperature range 150–300 °C gave only tarry material. At 100 °C, however, the starting material was recovered as the PF_6 salt, anion metathesis having occurred during the workup. Isolation of the cyclic products **4a** and **4b**, though in a low yield, is reasonable since the formation of the suspected intermediate **5** is like that found from an acid-catalyzed sigmatropic shift (Claisen type rearrangement) of allylaniline observed previously.[7] No such rearrangement has been reported from a quaternary salt, however. Solubility of the entire PPA reaction mixture in water and formation of the PF_6 salts upon addition of saturated aqueous KPF_6 to the resulting homogeneous solution is suggestive of stabilization of a cation intermediate by PPA anion ($OPPA^{n-}$). Recent mechanistic studies carried out in our laboratory[16] with structurally similar phosphonium salts via ^{31}P NMR spectroscopy support this hypothesis for the phosphorus system. In the present cases, the driving force for the reaction is probably the rapid loss of hydrogen from intermediate **5** (facilitated by the presence of the electron-deficient >N⁺< group)[14,17] to give **6** which cyclizes to **4a** or **4b**. Since salt **4a** was previously unreported, it was converted to the iodide, the properties of which were identical with those of that prepared by an alternative route (see Experimental Section).



5 6

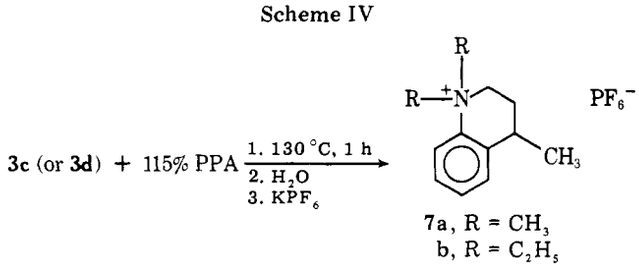
Anilinium salts **3c** and **3d** with a crotyl substituent also cyclized at 130 °C for 1 h in the presence of 115% PPA (Scheme IV) to give, surprisingly, the corresponding 4-alkylquinoline derivatives **7a** and **7b** as crystalline solids in low yields (21 and 29%). The position of the methyl group at C-4 rather than at C-2 in **7a** was confirmed by IR, ^1H NMR, elemental analysis, and by conversion to the iodide. The 4-isomeric iodide melted at 172–174 °C while the 2 isomer, which might result from **3c** by fragmentation and recombination of

Table IV. Physical Data for Indolium and Quinolinium Salts

Compd	R	Mp, °C	Yield, %	Molecular formula	Anal., %	C	H	N	P
4a[a]	CH_3	140–141	18	$C_{11}H_{16}F_6NP$	Calcd	43.01	5.21	4.56	10.08
					Found	43.39	5.32	4.66	9.97
4b	C_2H_5	85–86	38	$C_{13}H_{20}F_6NP$	Calcd	46.61	5.97	4.18	9.25
					Found	46.67	6.10	4.16	8.98
7a[b]	CH_3	108–109	21	$C_{12}H_{18}F_6NP$	Calcd	44.87	5.65	4.36	9.64
					Found	44.68	5.68	4.29	9.73
7b	C_2H_5	150–152	29	$C_{14}H_{22}F_6NP$	Calcd	48.14	6.30	4.01	8.88
					Found	48.10	6.39	4.04	8.80

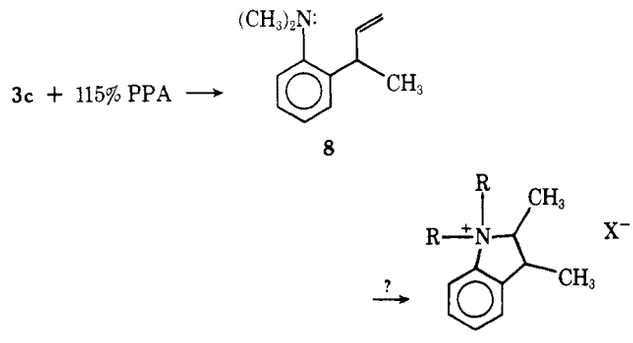
[a] Iodide; mp 208–210 °C. Anal. Calcd for $C_{11}H_{16}NI$: C, 45.71; H, 5.54; N, 4.84. Found: C, 45.65; H, 5.72; N, 4.90. [b] Iodide; mp 172–174 °C. Anal. Calcd for $C_{12}H_{18}NI$: C, 47.56; H, 5.94; N, 4.62. Found: C, 47.50; H, 6.12; N, 4.56.

Scheme IV

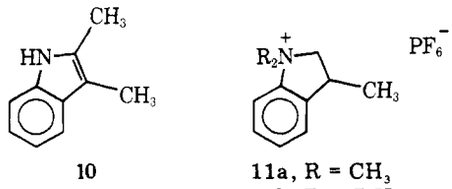


7a, R = CH_3
b, R = C_2H_5

the crotyl group, was reported to melt at 204 °C[18] and to have an ^1H NMR spectrum different from that of our isomer. Isolation and identification of **7a** was surprising in view of the predicted acid-catalyzed Claisen rearrangement of crotylaniline,[7,19] although admittedly the protonated form of the latter is not a quaternary salt. Since a complex mixture was formed from the PPA-catalyzed cyclizations leading to **7a** and **7b**, we cannot exclude the possibility that a Claisen-type intermediate (such as 8) and product (such as 9) are present in



low yields in the mixture. In fact, heating the $B(C_6H_5)_4$ salt of **3c** to 105 °C in HMPA has reportedly given **8**,[19] and heating crotylaniline in concentrated HCl reportedly gave the related product **10**.[7,19] In similar fashion, we cannot eliminate potential products **11a** or **11b** which, if present, are certainly in low yield in the mixture obtained from **3a** or **3b**, respectively.



11a, R = CH_3
b, R = C_2H_5

In summary, the cyclization of allyl type, benzyl-substituted amines **1** proceeds well to give tetrahydroisoquinolines in modest yield but from stable, readily prepared synthons and under simple conditions. Although our approach does not supersede such methods as the classic Bischler–Napieralski,[20] Pictet–Spengler,[21] and Pomeranz–Fritsch[22] reactions, the use of quaternary salts does have the advantage that the immediate precursor can be made in large quantity and safely stored for long periods. On the other hand, the related quaternary anilinium salts **3** suffer some skeletal rearrangements during cyclization.

Experimental Section

General Data. Melting points were obtained with a Thomas-Hoover melting point apparatus and are uncorrected. Infrared spectra were recorded on a Beckman IR-5A unit as KBr pellets. ^1H NMR spectra were recorded on a XL-100(15) Varian spectrometer equipped with a Nicolet TT-100 FT accessory and obtained with tetramethylsilane as the internal standard. Elemental analyses were carried out by Galbraith Laboratories, Knoxville, Tenn. Anhydrous solvents such as ether, petroleum ether (bp 40–60 °C), and benzene were dried over sodium and filtered prior to use. Neutral alumina (Brinkmann, activity I) supplied by Merck was employed for column chromatography.

Starting Materials. Allyl bromide, crotyl bromide, and the tertiary amines were all purchased from commercial sources and were purified by distillation prior to use. 2-Methylindole was purchased from Aldrich Chemical Co. The 115% PPA was obtained from FMC Corp.[10]

Allylbenzyldimethylammonium bromide (**1a**) was prepared from benzyldimethylamine and allyl bromide in benzene by the literature method.[11] Salt **1b** was prepared by a similar procedure. Anilinium salts **3a**[15] and **3c**[19,25] were prepared by known methods while the preparations of salts **3b** and **3d** followed a similar procedure and are reported in Table III.

Benzyl-2-butenyldimethylammonium Bromide (1c). A solution of benzyldimethylamine (13.5 g, 0.10 mol) and crotyl bromide (15.0 g, 0.11 mol) in dry benzene (175 mL) was boiled for 24 h (N_2). Rotoevaporation of the solvent left a viscous, brown oil which was boiled with ether (ca. 100 mL) for 3 h. The precipitated solid was filtered, washed with ether, and dried over P_2O_5 in vacuo (65 °C, 48 h) to give 25.2 g (93.3%) of **1c**, mp 128–129.5 °C. Infrared, ^1H NMR, and analytical data are given in Tables I and V.

Benzyl-2-butenyldiethylammonium Hexafluorophosphate (1d). A solution of benzyldiethylamine (8.0 g, 0.05 mol) and crotyl bromide (7 g, 0.05 mol) in dry benzene (150 mL) was boiled for 24 h (N_2) with the formation of a light brown oil. Benzene was removed in vacuo and the residual oil was boiled with ether (12 h) without solidification. The ether layer was decanted, the oil was dissolved in water (50 mL) and extracted with ether (2 × 100 mL), and the aqueous layer was treated with cold saturated solution of KPF_6 (50 mL). The cloudy solution was extracted with chloroform (4 × 200 mL), and the combined organic layers dried ($MgSO_4$). Evaporation of the solvent left an oil which, upon trituration with ether (200 mL), crystallized on standing. The filtered solid was dried over P_2O_5 in vacuo (70 °C, 72 h) to give 12.2 g (67%) of salt **1d**, mp 101–102 °C. Infrared, ^1H NMR, and analytical data are given in Table I and V.

Ring Closures to Produce the Isoquinolinium and Benzoazepinium Salts. The general procedure will be illustrated with the preparation of **2a**.

1,2,3,4-Tetrahydro-2,2,4-trimethylisoquinolinium Hexafluorophosphate (2a). In a 100-mL beaker was placed 60 mL of 115% PPA which was stirred with a mechanical stirrer and heated to 300 °C. Compound **1a** (2.0 g, 7.8 mmol) was added to the PPA in small

Table V. Spectral Data for the Starting Ammonium Salts and Reaction Products

Compd	IR absorption spectra in KBr,[a] selected bands, cm^{-1}	^1H NMR spectral assignments, chemical shifts, δ[b]
1a	1482 (m), 952 (m), 868 (vs), 782 (vs), 742 (vs), 703 (vs)	3.26 [s, $(CH_3)_2N^+<$, 6 H], 4.48 [d (J_{HCCH} = 6 Hz), $>N^+CH_2CH=$, 2 H], 5.12 (s, $ArCH_2N^+<$, 2 H), 5.56–6.40 (m, $-CH=CH_2$, 3 H), 7.30–7.90 (m, ArH, 5 H)
1b	1460 (m), 972 (m), 760 (vs), 722 (m), 708 (s)	1.47 [(J_{HCCH} = 7 Hz), $(CH_3CH_2)_2N^+<$, 6 H], 3.34–3.58 [q (J_{HCCH} = 7 Hz), $(CH_3CH_2)_2N^+<$, 4 H], 4.18 [d (J_{HCCH} = 6 Hz), $>^+NCH_2CH=$, 2 H], 4.84 (s, $ArCH_2N^+<$, 2 H), 5.48–6.38 (m, $-CH=CH_2$, 3 H), 7.22–7.82 (m, ArH, 5 H)
1c	1478 (m), 978 (m), 858 (s), 768 (m), 732 (m)	1.82 (d, $CH_3CH=$, 3 H), 3.22 [s, $(CH_3)_2N^+<$, 6 H], 4.42 (d, $>^+NCH_2CH=$, 2 H), 5.06 (s, $ArCH_2N^+<$, 2 H), 5.52–5.92 (m, $-CH=$, 1 H), 6.06–6.52 (m, $-CH=$, 1 H), 7.26–7.58 (m, ArH, 3 H), 7.60–7.88 (m, ArH, 2 H)
1d[c]	1460 (m), 982 (m), 835 (vs), 764 (s), 712 (s)	1.40 [t (J_{HCCH} = 7 Hz), $(CH_3CH_2)_2N^+<$, 6 H], 1.83 [d (J_{HCCH} = 6 Hz), $CH_3CH=$, 3 H], 3.06–3.28 [q (J_{HCCH} = 7 Hz), $(CH_3CH_2)_2N^+<$, 4 H], 3.68 [d (J_{HCCH} = 6 Hz), $>^+NCH_2CH$, 2 H], 4.28 (s, $ArCH_2N^+<$, 2 H), 5.38–5.80 (m, $-CH=$, 1 H), 5.80–6.36 (m, $-CH=$, 1 H), 7.22–7.60 (m, ArH, 5H)
2a	1490 (s), 835 (vs), 768 (s), 736 (m)	1.41 [d (J_{HCCH} = 6 Hz), CH_3CH, 3 H], 3.06 and 3.29 [s, $(CH_3)_2N^+<$, 6 H], 3.12–3.54 (m, $>N^+CH_2CH$, 2 H), 3.60–3.84 (m, $ArCH<$, 1 H), 4.24–4.68 (m, $ArCH_2N^+<$, 2 H), 7.02–7.50 (m, ArH, 4 H)
2b[c]	1485 (s), 838 (vs), 768 (s)	1.24–1.56 [m, $(CH_3CH_2)_2N^+<$ and $>CHCH_3$, 9 H], 2.90–3.58 [m, $(CH_2)_3N^+<$, 6 H], 3.58–3.84 (m, $ArCHCH_3$, 1 H), 4.20 (m, $ArCH_2N^+<$, 2 H), 7.00–7.46 (m, ArH, 4 H)
2c[c]	1482 (s), 838 (vs), 764 (s)	1.40 [d (J_{HCCH} = 6 Hz), CH_3CH, 3 H], 1.60–2.32 (m, $>CHCH_2$, 2 H), 2.82 and 3.17 [s, $(CH_3)_2N^+<$, 6 H], 2.50–3.80 (m, $>CHCH_3$ and $>^+NCH_2$, 3 H), 4.10–4.80 (m, $ArCH_2N^+<$, 2 H), 6.98–7.56 (m, ArH, 4 H)
2d[c]	1475 (m), 836 (vs), 768 (m)	1.06–1.56 [m, $(CH_3CH_2)_2N^+<$, 6 H], 1.43 [d (J_{HCCH} = 7 Hz), CH_3CH, 3 H], 1.62–2.36 (m, ring CH_2, 2 H), 2.80–3.66 [m, $(CH_2)_3N^+<$ and $ArCH<$, 7 H], 4.20–4.70 (m, $ArCH_2N^+<$, 2 H), 7.10–7.60 (m, ArH, 4 H)
3a[d]	1464 (m), 962 (m), 766 (s), 694 (s)	4.0 [s, $(CH_3)_2N^+<$, 6 H], 5.18 (m, $>N^+CH_2-$, 2 H), 5.36–5.96 (m, $-CH=CH_2$, 3 H), 7.40–7.78 (m, ArH, 3 H), 8.04–8.24 (m, ArH, 2 H)
3b	1485 (s), 1460 (s), 960 (s), 768 (s), 710 (s), 692 (s)	1.26 [t (J_{HCCH} = 7 Hz), $(CH_3CH_2)_2N^+<$, 6 H], 4.00–4.44 [m, $(CH_3CH_2)_2N^+<$, 4 H], 4.82 (m, $>N^+CH_2-$, 2 H), 5.48–5.94 (m, $-CH=CH_2$, 3 H), 7.40–7.82 (m, ArH, 3 H), 8.10–8.36 (m, ArH, 2 H)
3c[d]	1486 (s), 965 (m), 850 (m), 760 (m), 692 (s)	1.62 [d (J_{HCCH} = 6 Hz), trans CH_3], 1.80 [d (J_{HCCH} = 7 Hz), cis CH_3] (trans 66.7% and cis 33.3%), 3.94, 4.07 [s, $(CH_3)_2N^+<$, 6 H], 5.11 (m, $>N^+CH_2-$ and $-CH=$, 3 H), 6.22 (m, $-CH=$, 1 H), 7.38–7.76 (m, ArH, 3 H), 7.98–8.20 (m, ArH, 2 H)
3d	1482 (s), 972 (m), 895 (m), 848 (m), 780 (s), 772 (s), 696 (s)	1.22 [t (J_{HCCH} = 7 Hz), $(CH_3CH_2)_2N^+<$, 6 H], 1.74 [d (J_{HCCH} = 6 Hz), $CH_3CH=$, 3 H], 3.94–4.46 [m, $(CH_3CH_2)_2N^+<$, 4 H], 4.56–4.86 (m, $>N^+CH_2-$, 2 H), 5.20–5.60 (m, $CH=$, 1 H), 6.04–6.46 (m, $CH=$, 1 H), 7.34–7.80 (m, ArH, 3 H), 8.04–8.36 (m, ArH, 2 H)
4a[c]	1465 (s), 838 (vs), 765 (m), 724 (m)	1.70 [d (J_{HCCH} = 7 Hz), $>CHCH_3$, 3 H], 3.12 and 3.48 [s, $(CH_3)_2N^+<$, 6 H], 2.94–3.62 (m, benzylic CH_2, 2 H), 4.14–4.40 (m, CH_3CH, 1 H), 7.40–7.62 (m, ArH, 4 H)
4b[c]	1476 (s), 840 (vs), 770 (m), 722 (m)	1.10–1.30 [t of t (J_{HCCH} = 7 Hz), $(CH_3CH_2)_2N^+<$, 6 H], 1.70 [d (J_{HCCH} = 6 Hz), $>CHCH_3$, 3 H], 2.94–4.04 [m, $(CH_3CH_2)_2N^+<$ and benzylic CH_2, 6 H], 4.30–4.60 (m, $CHCH_3$, 1 H), 7.32–7.58 (m, ArH, 4 H)
7a[c]	1474 (s), 840 (vs), 766 (s), 764 (m)	1.40 [d (J_{HCCH} = 8 Hz), CH_3CH, 3 H], 1.78–2.62 (broad m, ring CH_2, 2 H), 3.04–3.30 (m, $>CHCH_3$, 1 H), 3.52 and 3.58 (s, $(CH_3)_2N^+<$, 6 H), 3.76–3.92 (m, $>N^+CH_2-$, 2 H), 7.36–7.66 (m, ArH, 4 H)
7b[c]	1462 (m), 842 (vs), 762 (s)	1.25–1.48 [m, $(CH_3CH_2)_2N^+<$ and CH_3CH, 9 H], 1.80–2.66 (m, ring CH_2, 2 H), 3.06–3.30 (m, $>CHCH_3$, 1 H), 3.56–4.04 [m, $(CH_3CH_2)_2N^+<$ and benzylic CH_2, 6 H], 7.30–7.54 (m, ArH, 4 H)

[a] The spectra were obtained on samples (2–4 mg) with KBr (400 mg) pellets. All the PF_6 salts showed very strong absorption in the region 830–840 cm^{-1}; see L. C. Thomas, "Interpretation of the Infrared Spectra of Organophosphorus Compounds", Heyden, London, 1974, Chapter 7. [b] Spectra obtained on $DCCl_3$ solution of each compound with Me_4Si as internal standard; peak positions quoted in the case of doublets are measured from the approximate center, and relative peak areas are given as whole numbers. [c] ^1H NMR spectra obtained in $DCCl_3$ with added trifluoroacetic acid to give a clear solution. [d] IR and ^1H NMR of $(C_6H_5)_4B$ salt reported in ref 19.

portions over a 10-min period followed by additional heating and stirring for 1 h. During the addition, a gas (presumably HBr[12]) was evolved. The dark brown solution was cooled to 90–100 °C and slowly poured onto 300 mL of ice–water with swirling, a process which resulted in formation of a *homogeneous solution* upon stirring for 15 min. The solution was filtered to remove black particles and the brown filtrate was treated with saturated KPF_6 (75 mL) in the cold to the formation of cloudiness. This mixture was concentrated in a rotary evaporator to about 200 mL until excess KPF_6 precipitated and repeatedly extracted with chloroform (6 × 200 mL). The organic layer was dried ($MgSO_4$), filtered, and treated with carbon black which, when filtered hot, left a colorless filtrate. Evaporation of the solvent

gave a brown oil which, when triturated with ether (100 mL), solidified. The solid was collected and recrystallized twice from CH_2Cl_2–ether to afford 1.4 g (56%) of salt **2a**, mp 114.5–116.5 °C. Infrared, ^1H NMR, and analytical data are given in Tables II and V.

Ring Closures to Produce the Indolium Salts. The general procedure will be illustrated with the preparation of **4a**.

2,3-Dihydro-1,1,2-trimethylindolium Hexafluorophosphate (4a). To 60 mL of 115% PPA mechanically stirred and heated to 140 °C, salt **3a** (2.0 g, 7.41 mmol) was added during a 10-min period, followed by an additional period of heating for 1 h. Workup was as described for **2a** to afford a dark brown oil (1.9 g). The oil was dissolved in a minimum amount of CH_2Cl_2 and eluted through an alumina column (60 g) with CH_2Cl_2. Evaporation of the solvent to a small volume, followed by the dropwise addition of ether to produce turbidity, afforded, upon standing in the refrigerator, salt **4a**. Crystallization (twice) from CH_2Cl_2–ether afforded pure **4a** (430 mg, 18%) as a white, crystalline solid, mp 140–141 °C. The identity of **4a** was established by conversion to the known iodide, mp 208–210 °C (methanol–ethyl acetate, lit.[23] 208–210 °C), by metathesis of the anion of **4a** with potassium iodide in CH_3CN/H_2O. A more direct proof that the product isolated in the above reaction was the 2-methylindolium salt rather than the 3-methylindolium hexafluorophosphate was obtained as follows.

2-Methylindole was reduced by the known method[24] to 2,3-dihydro-2-methylindoline which gave the following spectral data: IR (film) ν 3330, 1640, 1448, 1435, 1250, 752 cm^{-1}; ^1H NMR ($DCCl_3$) δ 1.14 [d (J_{HCCH} = 6 Hz), CH_3CH, 3 H], 2.38–3.13 (pair of quartets, benzylic CH_2, 2 H), 3.62 (s, >NH, 1 H, which disappeared on shaking with D_2O), 3.66–3.88 (m, –CH, 1 H), and 6.45–7.04 (m, ArH, 4 H). Alkylation with methyl iodide by the reported procedure[23] gave the methiodide as a white, crystalline solid, mp 208–210 °C (methanol–ethyl acetate, lit.[23] 208–210 °C), with the following spectral properties: IR (KBr) ν 1475, 1450, 1230, 1024, 982, 762, 718 cm^{-1}; ^1H NMR (F_3CCO_2D) δ 1.81 [d (J_{HCCH} = 7 Hz), >CHCH_3, 3 H], 3.28 and 3.64 [s, $>N^+(CH_3)_2$, 6 H], 3.00–3.70 (m, benzylic CH_2, 2 H), 4.34–4.60 (m, >CHCH_3, 1 H), and 7.55–7.76 (m, ArH, 4 H). The iodide was transformed to the PF_6 salt, mp 140–141 °C (CH_2Cl_2–ether), by the same procedure in CH_3OH/H_2O with KPF_6. The melting points of the PF_6 salt and the iodide from the PPA cyclization reaction were not depressed on admixture with authentic samples of the PF_6 salt and the iodide, respectively. Furthermore, infrared and ^1H NMR of both the PF_6 salt and the iodide were identical with those of authentic samples. Infrared, ^1H NMR, and analytical data are given in Tables II and V.

Ring Closures to Produce Quinolinium Salts. The general procedure will be illustrated with the preparation of **7a**.

1,2,3,4-Tetrahydro-1,1,4-trimethylquinolinium Hexafluorophosphate (7a). To a well-stirred sample of 115% PPA maintained at 130 °C salt **3c** (2 g, 7.80 mmol) was added during a 10-min period and heating was continued for 1 h. Workup of the reaction mixture was carried out as described previously for **2a**. The resulting dark-colored gum (1.65 g) was chromatographed over neutral alumina (45 g). Elution with hexane and subsequent purification by short-path distillation afforded a light brown oil (0.49 g), bp 85 °C (0.25 mm), which appeared to be a mixture of several products on analysis by ^1H NMR. Further elution with $HCCl_3$ and CH_2Cl_2 afforded a white solid, after solvent evaporation, which was crystallized twice from CH_2Cl_2–ether to afford the crystalline salt **7a** (0.53 g, 21%), mp 108–109 °C. Infrared, ^1H NMR, and analytical data are given in Tables II and V. The corresponding iodide, prepared by the general metathesis reaction, melted at 172–174 °C (CH_2Cl_2–ether), and had the following spectral data: IR (KBr) ν 1495, 1440, 1052, 948, 850, 772 cm^{-1}. ^1H NMR (F_3CCO_2D) δ 1.50 [d (J_{HCCH} = 7 Hz, >CHCH_3, 3 H], 1.86–2.72 (broad m, ring CH_2, 2 H), 3.10–3.32 (m, benzylic >CH–, 1 H), 3.62 and 3.66 [s, $>N^+(CH_3)_2$, 6 H], 3.88–4.10 (m, $>N^+CH_2$, 2 H), and 7.48–7.74 (m, ArH, 4 H). A report[18] of the 2 isomer gives a mp of 204 °C along with an ^1H NMR spectrum different from that of our product.

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Registry No.—**1a,** 22100-10-3; **1b,** 62076-98-6; **1c,** 62058-78-0; **1d,** 62058-80-4; **2a,** 62058-82-6; **2b,** 62058-84-8; **2c,** 62058-86-0; **2d,** 62077-00-3; **3a,** 16370-22-2; **3b,** 62058-87-1; *cis*-**3c,** 62058-88-2; *trans*-**3c,** 62058-89-3; **3d,** 62058-90-6; **4a,** 62058-92-8; **4a** iodide, 62058-93-9; **4b,** 62058-95-1; **7a,** 62058-97-3; **7a** iodide, 62058-98-4; **7b,** 62059-00-1; benzyldimethylamine, 103-83-3; crotoyl bromide, 4784-77-4; benzyldiethylamine, 772-54-3; methylindole-2, 95-20-5; 2,3-dihydro-2-methylindoline, 6872-06-6; methyl iodide, 74-88-4.

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