SRN1 Reactions of Vinyl Halides with Thiophenoxide and Acetone Enolate Ions[1]

Joseph F. Bunnett,* Xavier Creary, and John E. Sundberg

University of California, Santa Cruz, California 95064

Received October 21, 1975

Several vinyl halides undergo photostimulated reaction with acetone enolate ion or thiophenoxide ion in liquid ammonia to give substitution products. Although reactivity in some cases is fairly high, in general it is less than for aryl halides. Reactions with thiophenoxide ion are notably sluggish. β-Bromostyrene reacts with the enolate reagent with stimulation by potassium metal to form products of substitution and reduction. These reactions are believed to occur by the SRN1 mechanism.

Although aryl halides without strongly electron-attracting substituents are often thought to be unreactive with nucleophiles, they do react with several under stimulation by electrons or photons to form good yields of substitution products.[2] Prominent examples are the reactions of phenyl halides and similar substrates with amide ion[3,4] or acetone enolate ion,[5] provoked by solvated electrons in ammonia, and the photostimulated reactions of aryl iodides with arenethiolate,[6] dialkyl phosphite,[7] and ketone enolate ions.[8]

These reactions are believed to occur by the SRN1 mechanism. This is a radical chain mechanism, first formulated for certain nucleophilic substitutions at saturated carbon in 1966,[9,10] and recognized for substitutions at aromatic sites in 1970.[3] The propagation steps of the SRN1 mechanism are presented in Scheme I.

Scheme I

$$[RX]\cdot^- \rightarrow R\cdot + X^- \tag{1}$$

$$R\cdot + Y^- \rightarrow [RY]\cdot^- \tag{2}$$

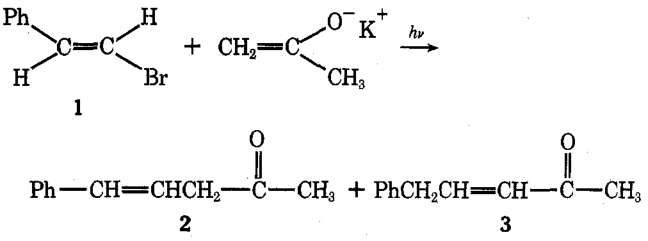
$$[RY]\cdot^- + RX \rightarrow RY + [RX]\cdot^- \tag{3}$$

Initiation may occur by RX accepting an electron (e.g., a solvated electron) to form its radical anion which then breaks up as in step 1. For photostimulated reactions, one possibility is photostimulated electron transfer from nucleophile Y^- to substrate RX, again to form $[RX]\cdot^-$ which enters the propagation cycle at step 1. Another is photolysis of a C–X bond to generate radical R· which enters the cycle at step 2. There must also be termination steps.

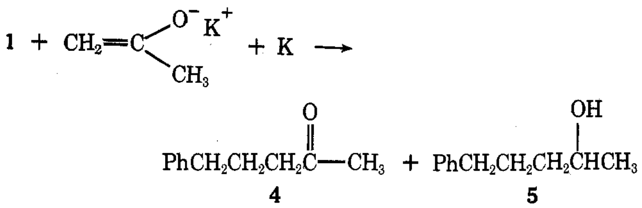
Vinyl halides resemble aryl halides in many respects. We now describe an inquiry into SRN1 reactions of vinyl halides.

Results

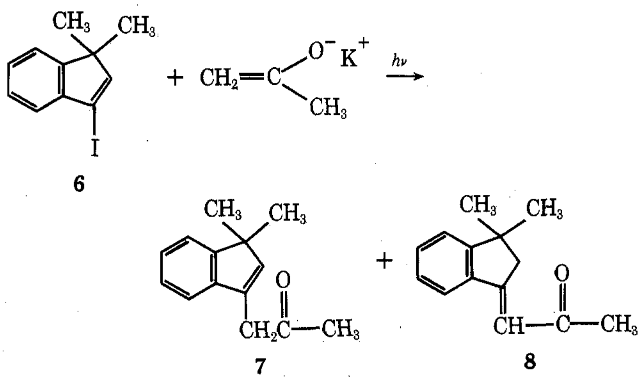
β-Bromostyrene with Acetone Enolate Ion. A solution of β-bromostyrene (1) and potassium acetone enolate in liquid ammonia in a Pyrex flask was exposed to "350-nm" radiation for 5 h. The main products were one of straightforward substitution, 2, in 48% yield, and a tautomer thereof, 3, in 34% yield. There was also 7% of styrene and 3% of unreacted 1.



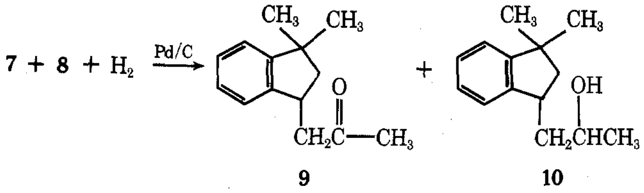
The same reactants were again combined in liquid ammonia and little bits of potassium metal were added one by one. The products obtained had the same carbon skeleton as from the photostimulated reaction but represent lower stages of oxidation. They are the saturated ketone, 4, in 63% yield and the corresponding secondary alcohol, 5, in 15% yield. Also formed was 6% of styrene.



Reactions of 3,3-Dimethyl-1-iodoindene (6). This substance reacted with acetone enolate ion in liquid ammonia under irradiation for 75 min to form mainly 7, representing forthright substitution, but also some of 8, a tautomer of 7; the total yield was 66%.

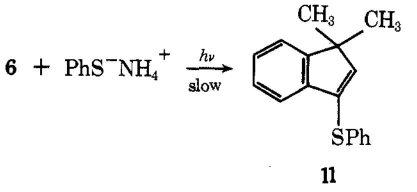


The mixture of 7 and 8 was subjected to catalytic hydrogenation, which afforded saturated ketone 9 and a little of the corresponding alcohol, 10.



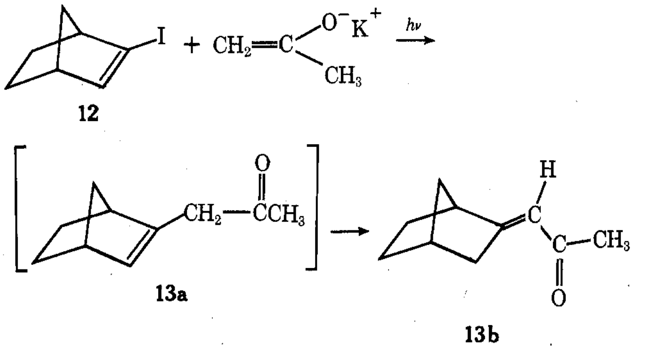
There was no detectable formation of 7 or 8 during 1 h exposure of 6 to excess potassium acetone enolate in liquid ammonia *in the dark*.

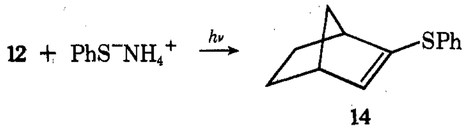
A solution of 6 with excess thiophenol in liquid ammonia was irradiated for 90 min. GLC analysis of the resulting mixture revealed a great deal of unreacted 6, some diphenyl disulfide, and a new substance, in ca. 20% yield, with mass and infrared spectra consistent with sulfide 11.



Reactions of 2-Iodo-2-norbornene (12). This compound[11] was synthesized by reaction of the hydrazone of 2-norbornanone with iodine and triethylamine,[12] and then with potassium *tert*-butoxide (*t*-BuOK) in *tert*-butyl alcohol (*t*-BuOH). The NMR spectrum indicated that it was free of 1-iodo-2-norbornene. In contrast, the reaction of camphor hydrazone with iodine and triethylamine forms 1-iodocamphene as the major product and only minor amounts of 2-iodo-2-bornene.[12,13] In our system, which lacks methyl substituents, Wagner–Meerwein rearrangement leading to the bridgehead iodide is not a complicating factor. The mechanism of the reaction of camphor hydrazone has been discussed by Pross and Sternhell.[12]

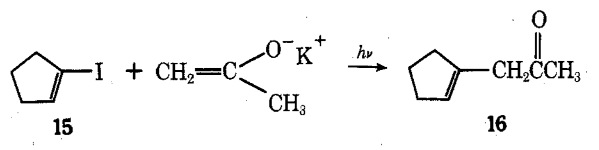
Vinyl iodide 12 reacted rather slowly with acetone enolate ion. In one experiment, only 57% of iodide ion was released during 75-min irradiation. From another, 54% of α,β-unsaturated ketone **13b** was isolated after irradiation for 150 min. This product was doubtless formed via isomer **13a**, probably by base-catalyzed prototropic rearrangement. The position of the double bond in **13b** was established by ozonolysis to 2-norbornanone. Catalytic hydrogenation of **13b** afforded 2-norbornylacetone.





During 2-h irradiation, 12 reacted with excess ammonium thiophenoxide in liquid ammonia to form 22% of substitution product **14**. Diphenyl disulfide was also produced, and much 12 was recovered.

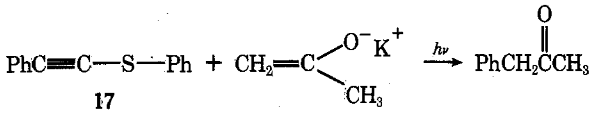
Reactions of 1-Iodocyclopentene (15). This vinyl iodide reacted with acetone enolate ion during 1-h irradiation to release 72% of iodide ion and to form a single product, namely **16**, representing straightforward substitution. In the course of chromatography on basic alumina, **16** was transformed in part to its α,β-unsaturated isomer.



There was no detectable reaction of 15 with acetone enolate ion in liquid ammonia during 1 h in the dark

Irradiation of a solution of 15 with a twofold excess of potassium diethyl phosphite in ammonia for 80 min caused the release of only 21% of iodide ion. Organic products were not sought.

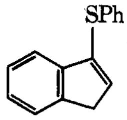
Reaction of Phenyl Phenylethynyl Sulfide (17) with Acetone Enolate Ion. This reaction, during 70 min of irradiation, furnished phenylacetone as the sole ketonic product, in 70% yield. About 15% of 17 remained unreacted. The formation of phenylacetone suggests that reaction occurred with rupture of the phenyl–sulfur bond, in resemblance to the reaction of diphenyl sulfide with acetone enolate ion.[8]



$$\underset{\mathbf{17}}{\mathrm{PhC{\equiv}C{-}S{-}Ph}} + \mathrm{CH_2{=}C}\begin{matrix}\mathrm{O^-K^+}\\ \mathrm{CH_3}\end{matrix} \xrightarrow{h\nu} \mathrm{PhCH_2\overset{O}{\overset{\|}{C}}CH_3}$$

Miscellaneous Experiments. During 90-min irradiation, phenyliodoacetylene reacted with ammonium thiophenoxide to form a small amount of **17** and a great deal of phenylacetylene and diphenyl disulfide, and to release iodide ion quantitatively. A dark reaction of the same duration produced 98% of iodide ion as well as high yields of phenylacetylene and diphenyl disulfide,[14] but no **17**. The formation of some **17** under the influence of light is therefore to be attributed to a photochemical reaction in competition with a "dark" reaction.

Treatment of the hydrazone of 1-indanone with iodine and triethylamine afforded a mixture of 1- and 3-iodoindenes, chiefly the latter. The mixture of these two isomers was combined with excess ammonium thiophenoxide in ammonia and submitted to irradiation for 1 h. 1-Indenyl phenyl sulfide (18) was produced in about 35% yield, about 15% of the starting iodoindenes was recovered, and much red, probably polymeric material was formed. Inasmuch as we saw indications that 1- and 3-iodoindene interconvert in basic systems (specifically, during chromatography on neutral alumina), and inasmuch as 3-iodoindene is an allylic halide, we cannot exclude the possibility that 18 resulted from an SN2 reaction of thiophenoxide ion with 3-iodoindene and subsequent isomerization of the allylic sulfide.



18

Discussion

Our experiments show that vinyl halides do react with nucleophiles, under stimulation by photons or electrons, in a fashion similar to aryl halides. Although in some cases reactivity approached that of aryl halides, e.g., in the reactions of 6 and 15 with acetone enolate ion, it was on the whole lower. The lower reactivity of vinyl halides was most pronounced in the reactions with thiophenoxide ion.

In two cases we have shown that reactions that occur under irradiation fail in the dark. Susceptibility to photostimulation is characteristic of many reactions believed to occur by the SRN1 mechanism but is not compelling evidence for it. Although we did not obtain other evidence to support this mechanism, we believe by analogy with reactions of aryl halides that it is also applicable to the vinyl halide reactions of the present study.

The SRN1 mechanism is a radical chain mechanism with many steps. For reactivity to be high, the initiation rate must be adequate and each of the propagation steps must be rapid in respect to termination steps. Our work does not indicate which component of the mechanism is frequently less satisfactory for vinyl halides or why some vinyl halide reactions go better than others.

Experimental Section

General Procedure. Reactions were conducted in liquid ammonia in Pyrex flasks with irradiation in a Rayonet Model RPR-100 photochemical reactor equipped with 16 RPR-3500A lamps rated to emit maximally at 350 nm. The method is described elsewhere.[6,15] Products were isolated and identified by standard procedures.

Preparation of Vinyl Iodides. The method of Pross and Sternhell,[12] involving treatment of a ketone hydrazone with iodine and triethylamine, was used in all cases. Often the initial product appeared to be a mixture of vinyl iodide and *gem*-diiodide, as they reported, and it was therefore treated with *t*-BuOK in refluxing *t*-BuOH to effect elimination of HI from the *gem*-diiodide. The preparation of

1-iodocyclopentene (**15**) required *t*-BuOK treatment; the product gave an NMR spectrum in agreement with that reported.[12]

The preparation of **3,3-dimethyl-1-iodoindene** (**6**) from the hydrazone of 3,3-dimethyl-1-indanone also required after-treatment with *t*-BuOK in *t*-BuOH. From 7.0 g of the hydrazone, 12.6 g of crude vinyl iodide was obtained and GLC indicated contamination by the ketone. Chromatography on alumina with elution by pentane, followed by distillation [bp 63–65 °C (0.08 Torr)], afforded 8.3 g of purified **6**: NMR (CCl_4) δ 1.28 (s, CH_3's), 6.65 (s, vinyl H), 7.17 (singlet with broad base, aryl H).

From 10.5 g of the hydrazone of 2-norbornanone, and with after-treatment with *t*-BuOK in *t*-BuOH, there was obtained similarly 7.29 g of **2-iodo-2-norbornene** (**12**): bp 53–55 °C (4 Torr); NMR (CCl_4) δ 0.83–1.28 (m), 1.28–1.83 (m), 2.66–2.86 (m, H-4), 2.86–3.02 (m, H-1), 6.30 (d, J = 3.0, H-3). The NMR resembles that reported[16] for 2-methoxy-2-norbornene, except that for **12** the signal for H-3 is much farther downfield.

Photostimulated Reaction of β-Bromostyrene (1) with Potassium Acetone Enolate. The enolate was in threefold excess, and irradiation was for 5 h. The ir and NMR spectra of **2** and **3**, isolated by preparative GLC, agreed within experimental error with those reported elsewhere.[17]

Potassium-Stimulated Reaction of β-Bromostyrene (1) with Potassium Acetone Enolate. The general procedure of Rossi and Bunnett[18] was followed, with the enolate in threefold excess over **1**; nearly as many moles of potassium metal as of enolate were used. Products **4** and **5** were recognized by ir and MS. The MS for **4** agrees with the published spectrum.[19]

Reaction of 3,3-Dimethyl-1-iodoindene (6) with Potassium Acetone Enolate. The enolate was in fivefold excess over **6**. The latter was at first an insoluble solid, but at termination of illumination the mixture was homogeneous and red. Products **7** (major) and **8** (minor) were substantially separated by distillation at reduced pressure, and pure samples were obtained by preparative GLC. They were characterized in part by MS: for both *m/e* 200 (M^+), 185, 157, 142, 129, 115, 43. Structures were assigned on the basis of ir: for **7**, $\nu_{C=O}$ 1713 cm^{-1}; for **8**, $\nu_{C=O}$ 1678, $\nu_{C=C}$ 1602 cm^{-1}. NMR (sample stored in glass one year and then redistilled, in CCl_4) δ 1.32 (s, CH_3's), 2.25 (s, CH_3CO), 3.19 (d, J = 2.6 Hz, CH_2), 6.79 (t, J = 2.6 Hz, vinyl H), 7.25–7.80 (m, aryl H).

Hydrogenation of a portion of the original mixture of **7** and **8** in CH_3OH over 10% palladium on charcoal at 65 psi for 4 h afforded a mixture of **9** (major product) and **10** (minor). Samples of each were isolated by preparative GLC. 1-(3′,3′-Dimethyl-1′-indanyl)-2-propanone (**9**): MS *m/e* 202 (M^+), 187, 165, 129, 43; ir $\nu_{C=O}$ 1720 cm^{-1}; NMR (CCl_4) δ 1.18 (s, CH_3), 1.32 (s, CH_3), 1.2–1.6 (m, ring CH_2), 2.10 (s, $COCH_3$), 2.15–2.85 (m, $-CH_2CO-$), 3.3–3.9 (m, H-1′), 7.02 (s, aryl H). 1-(3′,3′-Dimethyl-1′-indanyl)-2-propanol (**10**): MS *m/e* 204 (M^+), 186, 171, 145, 143, 131, 129; ir ν_{O-H} 3379 cm^{-1}.

Reaction of 6 with Ammonium Thiophenoxide. Thiophenol (2.1 g, 0.019 mol) and **6** (1.69 g, 0.00626 mol) in 150 ml of ammonia were irradiated for 90 min GLC analysis indicated much unreacted **6**, some diphenyl disulfide, and about 20% of phenyl 3,3-dimethyl-1-indenyl sulfide (**11**), isolated by preparative GLC: MS *m/e* 252 (M^+), 237, 221, 202, 143; ir 686, 740, 750, 1020, 1275, 1440, 1450, 1465, 1480, 1550, 1585, 1605, 2855, 2915, and 2958 cm^{-1}.

Reaction of 2-Iodo-2-norbornene (12) with Potassium Acetone Enolate. The enolate was in fourfold excess over **12**. 1-(2′-Norbornylidene)-2-propanone (**13b**) was isolated by distillation at reduced pressure and then preparative GLC on an SE-54 silicone column at 120 °C: MS *m/e* 150 (M^+), 135, 122, 107, 91, 79; ir $\nu_{C=O}$ and $\nu_{C=C}$ complex with absorption at 1623, 1663, and 1691 cm^{-1}; NMR (CCl_4) δ 1.0–1.8 (complex series), 2.07 (s, CH_3), 2.48 (broad singlet, 3′-CH_2), 2.68–2.85 (broad, H-1 and H-4), 6.17 (m, H-1). The stereoisomer of **13b** isolated is tentatively recognized as the *E* isomer, with acetyl trans to the 1′ bridgehead, on the basis of NMR spectral characteristics in comparison with those of related compounds currently under investigation.[20]

A sample (300 mg) of ketone **13b** was dissolved in 10 ml of methanol and ozone was passed through at −78 °C until a blue tint was evident in the solution. To the mixture, after it had warmed to room temperature, a solution of 2 g of NaI in water was added, and then diethyl ether. The ether layer was separated, washed with sodium thiosulfate solution, water, and saturated aqueous NaCl, and dried over anhydrous Na_2SO_4. The ether was removed and the residue distilled through a Vigreux column. The distillate (0.111 g, 50%) gave a single GLC peak; the GLC retention time and the infrared spectrum were identical with those of an authentic sample of 2-norbornanone.

Catalytic hydrogenation of **13** (in CH_3OH over 10% Pd/C) afforded 1-(2′-norbornyl)-2-propanone: MS *m/e* 152 (M^+), 137, 134, 109, 94, 67, 43; ir $\nu_{C=O}$ 1718 cm^{-1}; NMR ($CDCl_3$) δ 1.0–2.55 (m, peaking at 1.37), 2.18 (s, CH_3), 2.48 (broad singlet, $-CH_2CO-$). Which stereoisomer(s) was obtained is not defined.

Reaction of 12 with Ammonium Thiophenoxide. Thiophenol was provided in threefold excess over **12**. Phenyl 2-norbornenyl sulfide (**14**) was separated for the most part from unreacted **12** by distillation at reduced pressure, and an analytical sample was isolated by preparative GLC on an SE-54 silicone column: MS *m/e* 202 (M^+), 174 (there were also peaks at *m/e* 218, appropriate for the diphenyl disulfide molecule ion, as well as a very small one at *m/e* 312, appropriate for the molecule ion of an adduct of thiophenol to **14**); NMR (CCl_4) δ 1.02 (br), 1.17 (br), 1.40 (t, J = 2.0 Hz), 1.53 (d, J = 2.5 Hz), 1.69 (d, J = 2.0 Hz), 2.74 (br), 2.87 (br), 5.87 (d, J = 3.0 Hz), 7.20 (m), resembling those reported for 2-norbornene[21] and 2-methoxy-2-norbornene;[16] ir 685, 735, 1020, 1303, 1440, 1478, 1583, 2865, 2945, and 2960 cm^{-1}.

Reaction of 1-Iodocyclopentene (15) with Potassium Acetone Enolate. The enolate was in 4.5-fold excess over **15**. 1-(1′-Cyclopentenyl)-2-propanone (**16**) was isolated by preparative GLC on an SE-54 silicone column at 100 °C: ir $\nu_{C=O}$ 1712 cm^{-1}; MS *m/e* 124 (M^+), 109, 81, 67, 53, 43. Formed from **16** in the course of chromatography on alumina and isolated by GLC as above was 1-cyclopentylidene-2-propanone: ir[22] $\nu_{C=O}$ 1691, $\nu_{C=C}$ 1612 cm^{-1}; MS *m/e* 124 (M^+), 109, 81, 67, 66, 53, 43.

Reaction of Phenyl Phenylethynyl Sulfide (17) with Potassium Acetone Enolate. Authentic **17** was prepared by the method of Truce, Hill, and Boudakian.[23] The enolate ion was in fourfold excess over **17**. Phenylacetone was recognized by GLC retention time analysis and determined by GLC with naphthalene as internal standard.

Reactions Leading to 1-Indenyl Phenyl Sulfide (18). Reaction of 1-indanone hydrazone with iodine and triethylamine in tetrahydrofuran[12] afforded a product mixture purified by liquid chromatography on neutral alumina with pentane eluent. NMR showed the mixture to comprise mainly 3-iodoindene: δ 5.72 (m, H-3), 6.35 (d of d, J = 5.5, 2 Hz, H-2), 6.60 (d, J = 5.5 Hz, H-1). The minor component, of longer retention time, was 1-iodoindene: NMR δ 3.23 (d, J = 2 Hz, 2 H, H-1), 6.73 (t, J = 2 Hz, 1 H, H-2). Reaction of this mixture with ammonium thiophenoxide gave a product mixture from which **18** was isolated in ca. 35% yield by liquid chromatography on basic alumina with pentane eluent. For **18**: MS *m/e* 224 (M^+), 147, 115 (plus a small contaminant, maybe the sulfoxide, at *m/e* 240, 131); NMR (CCl_4) δ 3.30 (d, J = 2 Hz, 2 H, H-3), 6.37 (t, J = 2 Hz, 1 H, H-2), 7.16 (br m, 4 H, aromatic); ir (film) 683, 710, 735, 757, 1435, 1475, 1580, 2870, 3000, and 3050 cm^{-1}.

Registry No.—**1**, 103-64-0; **6**, 58426-10-1; **7**, 58426-11-2; **9**, 58426-12-3; **10**, 58426-13-4; **11**, 58426-14-5; **12**, 58426-15-6; **13b**, 56561-19-4; **14**, 58426-16-7; **15**, 17497-52-8; **16**, 823-91-6; **17**, 35460-31-2; **18**, 58426-17-8; potassium acetone enolate, 35648-48-7; ammonium thiophenoxide, 54043-02-6; 1-(2′-norbornyl)-2-propanone, 31683-73-5; 1-indanone hydrazone, 5736-44-7; 3 iodoindene, 58426-18-9; 1-iodoindene, 58426-19-0.

References and Notes

(1) Research supported in part by the National Science Foundation.
(2) J. F. Bunnett, *J. Chem. Educ.*, **51**, 312 (1974).
(3) J. K. Kim and J. F. Bunnett, *J. Am. Chem. Soc.*, **92**, 7463, 7464 (1970).
(4) R. A. Rossi and J. F. Bunnett, *J. Org. Chem.*, **37**, 3570 (1972).
(5) R. A. Rossi and J. F. Bunnett, *J. Am. Chem. Soc.*, **94**, 683 (1972).
(6) J. F. Bunnett and X. Creary, *J. Org. Chem.*, **39**, 3173 (1974).
(7) J. F. Bunnett and X. Creary, *J. Org. Chem.*, **39**, 3612 (1974).
(8) R. A. Rossi and J. F. Bunnett, *J. Org. Chem.*, **38**, 1407 (1973).
(9) N. Kornblum, R. E. Michel, and R. C. Kerber, *J. Am. Chem. Soc.*, **88**, 5662 (1966).
(10) G. A. Russell and W. C. Danen, *J. Am. Chem. Soc.*, **88**, 5663 (1966); **90**, 347 (1968).
(11) Cf. R. Keese and E.-P. Krebs, *Angew. Chem., Int. Ed. Engl.*, **10**, 262 (1971); **11**, 518 (1972).
(12) A. Pross and S. Sternhell, *Aust. J. Chem.*, **23**, 989 (1970).
(13) P. A. Hart and M. P. Tripp, *Chem. Commun.*, 174 (1969).
(14) This reaction, in methanol solution, has been described: M. C. Verploegh, L. Donk, H. J. T. Bos, and W. Drenth, *Recl. Trav. Chim. Pays-Bas*, **90**, 765 (1971).
(15) J. F. Bunnett and J. E. Sundberg, *Chem. Pharm. Bull.*, **23**, 2320 (1975).
(16) J. S. McConaghy, Jr., and J. J. Bloomfield, *J. Org. Chem.*, **33**, 3425 (1968).
(17) D. Chambenois and G. Mousset, *C. R. Acad. Sci.*, **275**, 1287 (1972); G. Dana, S. L. T. Thuan, and J. Gharbi-Benarous, *Bull. Soc. Chim. Fr.*, 1676 (1973).
(18) R. A. Rossi and J. F. Bunnett, *J. Org. Chem.*, **38**, 3020 (1973).
(19) J. K. MacLeod and C. Djerassi, *J. Org. Chem.*, **32**, 3485 (1967).
(20) X. Creary, work in progress at University of Notre Dame.
(21) P. Laszlo and P. v. R. Schleyer, *J. Am. Chem. Soc.*, **86**, 1171 (1964).
(22) G. Sturtz, *Bull. Soc. Chim. Fr.*, 2349 (1964).
(23) W. E. Truce, H. E. Hill, and M. M. Boudakian, *J. Am. Chem. Soc.*, **78**, 2760 (1956).