Fluoromethanediphosphonic Acid (7). To 5.5 g (0.011 mol) of **5** in a 50-mL round-bottomed flask flushed with N_2 was added, with stirring, 20 mL of H_2O. After 30 min, the organic phase was separated, and the aqueous phase was extracted twice with 15-mL portions of Et_2O and then evaporated to dryness. Further drying over P_2O_5 at 0.001 mm gave 2.04 g (96%) of the pure acid as a deliquescent, waxy, white solid: mp 162–163 °C; ^{19}F NMR δ 225 (dt, J_{FH} = 46 Hz, J_{FP} = 63 Hz); ^{31}P NMR δ 10.5 (d, J_{PF} = 64 Hz); neutralization equivalent 195 (calcd for $CH_5O_6FP_2$ 194). It was further characterized as the dicyclohexylamine salt **9**: a solution of 0.194 g (0.001 mol) of **7** in 0.8 mL of MeOH was added to a solution of dicyclohexylamine (0.73 g, 0.004 mol) in a mixture of 0.5 mL of acetone and 0.8 mL of benzene. The resulting precipitate was collected by filtration, washed with cold benzene, and dried, giving 0.57 g (77%) of the derivative. Analysis was performed on a twice-recrystallized sample dried in vacuo at 120 °C; mp 223–224 °C dec.

Anal. Calcd for $C_{37}H_{74}O_6FN_3P_2$: C, 60.22; H, 10.11; N, 5.69. Found: C, 60.09; H, 10.06; N, 5.66.

Difluoromethanediphosphonic Acid (8). By use of the above procedure, 2.85 g (0.0057 mol) of **6** was hydrolyzed with 15 mL of H_2O to yield 1.20 g (99%) of **8** as a viscous liquid which solidified on prolonged drying (0.01 mm, over P_2O_5): mp 87–90 °C; ^1H NMR (no resonances in D_2O); ^{19}F NMR δ 121 (t, J_{FP} = 86 Hz); ^{31}P NMR δ 3.7 (t, J_{PF} = 86 Hz); neutralization equivalent 214 (calcd for $CH_4O_6F_2P_2$ 212). The dicyclohexylamine salt **10** had a melting point of 259–260 °C.

Anal. Calcd for $C_{37}H_{73}O_6F_2N_3P_2$: C, 58.79; H, 9.73; N, 5.56. Found: C, 58.55; H, 9.52; N, 5.47.

Acknowledgment. We thank Dr. S. Prakash for obtaining the FT80A NMR spectra and Mr. Brian Goldfine for preparing the starting phosphonate esters. This research was made possible by a grant from the H. F. Frasch Foundation (HFF-77).

Registry No. **1a**, 1660-94-2; **1b**, 1660-95-3; **2a**, 78715-56-7; **2b**, 78715-57-8; **3a**, 78715-58-9; **3b**, 78715-59-0; **4a**, 1478-53-1; **4b**, 681-80-1; **5**, 78715-60-3; **6**, 78715-61-4; **7**, 10595-93-4; **8**, 10596-32-4; **9**, 78715-62-5; **10**, 78715-63-6; perchloryl fluoride, 7616-94-6.

Papyriferic Acid: a Triterpenoid from Alaskan Paper Birch

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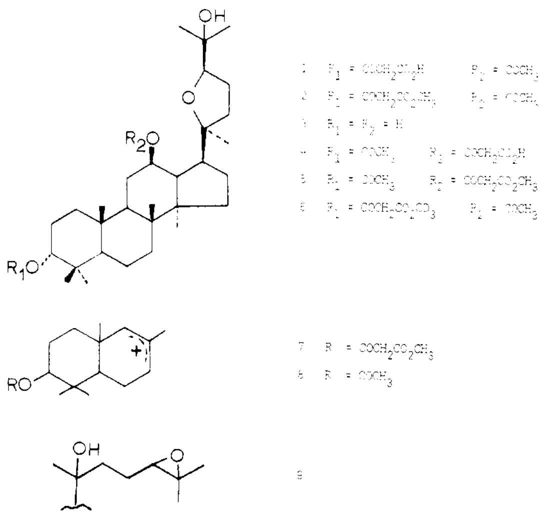
Chemical investigation of the herbivore-deterrent extract of Alaskan paper birch[1] (*Betula papyrifera* ssp. *humilis*) has led to the isolation and structure determination of papyriferic acid (**1**; see Chart I), a major triterpenoid of the juvenile stage of this species. Examination of the crude ether extract of juvenile twigs of *B. papyrifera* ssp. *humilis* by thin-layer chromatography (TLC) revealed a major component which could be eluted from silica gel with 20% methanol in diethyl ether. Trituration of the concentrated eluate with diethyl ether followed by recrystallization from acetone/cyclohexane afforded crystalline **1** ($C_{35}H_{56}O_8$). Infrared spectroscopy indicated the presence of ester (ν = 1752 cm^{-1}) and carboxylic acid (ν = 3570–2500, 1689 cm^{-1}) groups. The ^1H NMR spectrum (360 MHz) indicated a triterpene structure (eight methyl groups as 3H singlets in the δ 0.86–1.2 region), two acylated secondary alcohols [δ 4.72 (1 H, t, J = 2.2 Hz), 4.83 (1 H, dt, J = 5.2, 10.4 Hz)], one of which apparently occurred as an acetate [δ 2.02 (3 H, s)], and a secondary alcohol or ether [δ 3.67 (1 H, t, J = 7.0 Hz)]. An unusual 2H singlet at δ 3.48 was also evident. The ^{13}C NMR spectrum of **1** confirmed the presence of 35 carbons and indicated the presence of three secondary (75.6, 80.5, 83.3 ppm) and two tertiary (71.2, 85.8 ppm) carbons singly bonded to oxygen as well as three carbonyl groups (167.3, 169.1, 170.1 ppm).

Chart I



1 $R_1 = COCH_2CO_2H$ $R_2 = COCH_3$
2 $R_1 = COCH_2CO_2CH_3$ $R_2 = COCH_3$
3 $R_1 = R_2 = H$
4 $R_1 = COCH_3$ $R_2 = COCH_2CO_2H$
5 $R_1 = COCH_3$ $R_2 = COCH_2CO_2CH_3$
6 $R_1 = COCH_2CO_2CD_3$ $R_2 = COCH_3$
7 $R = COCH_2CO_2CH_3$
8 $R = COCH_3$
9

Treatment of **1** with diazomethane produced a methyl ester (**2**) which displayed an infrared spectrum in which hydroxyl (ν = 3580, 3400 cm^{-1}) and ester (ν = 1760, 1740 cm^{-1}) groups were evident.

The major structural features of **1** were elucidated by saponification to a triol having physical and spectral properties identical with those of betulafolientriol oxide I (**3**),[2] a constituent of two Japanese species of birch. The identity of **3** was confirmed by comparison of its infrared spectrum and chromatographic properties with those of an authentic sample of betulafolientriol oxide I.[3]

Consideration of the molecular compositions and ^1H NMR spectra of **1**–**3** led to assignments of the acylating groups in **1** as acetyl (δ 2.02 (3 H, s)] and malonyl [δ 3.48 (2 H, s)]. While the ^1H NMR spectrum of **1** required that it be a diacylated form of **3** in which the secondary hydroxyl groups of **3** (C-3 and C-12) were derivatized, the exact placement of acetate and malonate (i.e., **1** vs. **4**) was less straightforward. The tentative structural assignment of **1** was based upon the mass spectral data from methyl ester **2**. A low-intensity ion (ca. 3% of the base peak) was observed at *m/e* 307.194392 ($C_{18}H_{27}O_4$) and was assignable to ion **7** from the well-known AB ring fragment of dammaranes.[4] No such ion was seen at *m/e* 249, corresponding to the ion **8** expected from fragmentation of the alternative ester **5**.[5] This assignment was confirmed by

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[1] Bryant, J. P. In "Proceedings of the 1st International Logomorph Conference"; Meyeur, K., Ed.; Guelph University: Guelph, Ontario, Canada, in press.

(2) (a) Nagai, M.; Tanaka, N.; Tanaka, O.; Ichikawa, S. *Chem. Pharm. Bull.* **1973**, *21*, 2061. (b) Ohmoto, T.; Nikaido, T.; Ikuse, M. *Ibid.* **1978**, *26*, 1437.

(3) Both a sample and infrared spectrum of betulafolientriol oxide I were provided by Dr. T. Ohmoto of Toho University.

(4) Enzel, C. R.; Appleton, R. A.; Wahlberg, I. In "Biochemical Applications of Mass Spectrometry"; Waller, G. R., Ed.; Wiley: New York, 1979; p 370.

(5) This analysis was carried out with **2** instead of **1** because in the mass spectrum of **1** the only discernible oxygenated AB fragment was observed at *m/e* 249.187252 ($C_{16}H_{25}O_2$). This ion can, in retrospect, be assigned to the AB fragment in which decarboxylation of the malonic acid has already taken place but is equally consistent with placement of acetate at C-3 (i.e., **4**). The intensities of oxygenated AB fragment ions in these spectra are low due to facile ester pyrolysis leading to $C_{14}H_{21}$ (*m/e* 189).

mass spectral analysis of deuterated methyl ester 6[6] prepared (CH_2N_2/D_2O) by a modification of the method of Van der Merwe et al.[7] The ^{1}H NMR spectrum of 6 was identical with that of 2 with the exception that the esterifying methyl group in 6 appeared as a broadened singlet (δ 3.79) corresponding to about 1.7 H. The mass spectrum of 6 was that expected for deuteration in only the esterifying methyl group and, significantly, showed a marked reduction in the *m/e* 307 ion (0.59% of base peak) with corresponding increases at *m/e* 308–310. High-resolution data were consistent with the increased intensity of the *m/e* 308–310 ions resulting from deuterium incorporation; and statistical correction for ^{13}C and ^{18}O isotopic compositions[8] indicated the $d_0/d_1/d_2/d_3$ ratio of 6 to be 24:37:30:9, a result compatible with the deuterium content of 6 estimated from ^{1}H NMR. With placement of the malonate and acetate groups secure, the structure of papyriferic acid could then be assigned as 1.

Concern has been voiced[2] that the structural features of the side chain of 3 (and thus 1) may be artifactual, arising from rearrangement[9] of a 20-hydroxy-24,25-epoxy side chain (9). This point was investigated by examining the composition of resinous deposits on the exterior of juvenile shoots of *B. papyrifera* ssp. *humilis*. The white, semicrystalline deposits were scraped with a razor blade and dissolved in dichloromethane/acetone. TLC analysis revealed 1 as the major constituent of this extract, but suitable eluting solvents contained small amounts of organic acids and were thus potentially capable of causing the rearrangement in question. However, esterification of the extract (CH_2N_2) and TLC examination of the mixture in several systems containing no acidic solvents showed 2 to be the major component of the esterified extract. Furthermore, ^{1}H NMR examination of the esterification reaction mixture clearly revealed the presence of 2. Thus barring the possibility that rearrangement of the 20-hydroxy-24,25-epoxy side chain to that of 1 or 2 occurs upon mere contact with solvent, 1 is an authentic natural product of Alaskan paper birch.

Finally it is noted that although 1 is a major component of an extract which strongly deters browsing by snowshoe hares,[1] preliminary bioassay results indicate that pure 1 has at best only marginal deterrent properties.[10]

Experimental Section

Infrared (IR) spectra were recorded on a Perkin-Elmer Model 283B spetrophotometer; peak positions are reported in reciprocal centimeters. ^{1}H NMR spectra were recorded on Varian 360A and Nicolet NT-360 spectrometers, and the ^{13}C NMR spectrum was recorded on a Nicolet NT-150 spectrometer; chemical shifts are reported in parts per million (δ) downfield from tetramethylsilane as an internal standard. Mass spectra (EI, 70 eV) were obtained on an AEI MS-902; all spectra were run in the high-resolution mode, but exact masses are reported only for ions of particular importance. Polarimetry was carried out with a Rudolph DP-06 polarimeter. Thin-layer chromatography (TLC) was carried out on preprepared plates of Merck silica gel 60 and Kontes neutral aluminum oxide Q3F. Silica gel 62 (Davison) was used for column chromatography. Microanalysis was performed by Galbraith Laboratories. Melting points were determined on a Hoover Uni-Melt apparatus and are uncorrected.

Collection and Isolation of Papyriferic Acid (1). Juvenile shoots of *B. papyrifera* ssp. *humilis* were collected near Fairbanks, AK. Twigs (1.5 kg) were cut into 3–10-cm pieces and allowed to stand in diethyl ether (12 L) for 24 h at 25 °C. The ether solution was poured through cheesecloth, dried ($MgSO_4$), filtered, and evaporated to dryness under reduced pressure to a dark resinous mass (154 g).

A portion (70 g) of the extract was chromatographed on silica gel (1 kg). The column was eluted with an increasing gradient of ether in petroleum ether followed by methanol in ether. Trituration (ether) of the 20–50% methanol fractions afforded crude 1 (2.2 g).[11] Recrystallization from acetone/cyclohexane afforded pure 1: 1.8 g; mp 203–204 °C dec; $[\alpha]_D$ −18° (*c* 0.056, $CHCl_3$); ^{1}H NMR ($CDCl_3$, 360 MHz), 4.83 (1 H, dt, J = 5.2, 10.4 Hz), 4.72 (1 H, t, J = 2.2 Hz), 3.67 (1 H, t, J = 7.0 Hz), 3.48 (2 H, s), 2.02, 1.20, 1.18, 1.11, 0.99, 0.97, 0.89 (all 3 H, s), 0.86 (6 H, s); ^{13}C NMR ($CDCl_3$) 170.1 (s), 169.1 (s), 167.3 (s), 85.8 (s), 83.3 (d), 80.5 (d), 75.6 (d), 71.2 (s), 52.3 (s), 50.7 (d), 50.4 (d), 49.6 (d), 46.3 (d), 40.6 (t), 39.8 (s), 38.8 (t), 37.1 (s), 36.9 (s), 34.3 (t), 34.0 (t), 31.3 (t), 28.3 (t), 27.9 (q), 27.5 (q), 26.9 (t), 26.1 (t), 24.2 (q), 22.7 (t), 22.3 (q), 21.9 (q), 21.7 (q), 18.0 (t), 17.8 (q), 15.9 (q), 15.6 (q); IR (KBr) 3570–2500, 1752, 1689; mass spectrum, *m/e* (relative intensity) 501 (4), 381 (23), 249.187 252 (3), 189 (19), 143 (100). Anal. Calcd for $C_{35}H_{56}O_8$: C, 69.51; H, 9.33. Found: C, 69.65; H, 9.65.

Methyl Papyriferate (2). A solution of 1 (200 mg, 0.33 mmol) in 10 mL ether/methanol (3:1) was treated with an ethereal solution of diazomethane[12] (ca. 7 mmol), and the reaction mixture was allowed to evaporate (25 °C) overnight. Preparative TLC (silica gel, ether) of the residue afforded 2 (170 mg, 83%) as a white foam: ^{1}H NMR ($CDCl_3$, 60 MHz) 4.85 (1 H, m), 4.70 (1 H, br s, $w_{1/2}$ = 5 Hz), 3.79 (3 H, s), 3.66 (1 H, t, J = 7 Hz), 3.41 (2 H, s), 2.00 (3 H, s), 1.20 (6 H, s), 1.10 (3 H, s), 1.00 (3 H, s), 0.98 (3 H, s), 0.87 (9 H, s); IR ($CHCl_3$) 3580, 3500, 1760, 1740; mass spectrum, *m/e* (relative intensity) 559.368 136 (4, $M - C_2H_3O_2$), 501 (2), 500 (6), 381 (25), 307.194 392 (2.59), 308.193 753 (0.54), 309.199 136 (0.11), 189 (20), 143 (100).

Deuterated Methyl Papyriferate (6). A solution of 1 (60 mg, 0.10 mmol) in 10 mL of anhydrous dioxane containing 1.0 mL of D_2O was esterified with diazomethane as above. After being allowed to stand overnight, the reaction mixture was evaporated to dryness and treated with 15 mL of water. The aqueous suspension was extracted with three 10-mL portions of ether, and the combined organic extracts were dried ($MgSO_4$). Preparative TLC afforded 8 (30 mg, 49%) as a white foam. The chromatographic properties of 8 were identified with those of 2, and the ^{1}H NMR spectra of 2 and 8 were identical with the exception that the δ 3.79 signal in 8 was broadened and of reduced intensity (1.7 H): mass spectrum, *m/e* (relative intensity) 562 (0.5), 561 (2), 560 (2.5), 559 (0.5), 381 (30), 307.188 488 (0.59), 308.193 799 (0.93), 309.201 371 (0.81), 310.208 134 (0.26), 189 (20), 143 (100).

Betulafolientriol oxide I (3). A solution of 1 (60 mg, 0.10 mmol) in 5 mL 0.8 M potassium hydroxide in 95% ethanol was refluxed for 1 h. The cooled reaction mixture was diluted with water (10 mL) and extracted with three 5-mL portions of ether. The combined ether extracts were washed with brine, dried ($MgSO_4$), filtered, and evaporated to dryness. Recrystallization (acetone) of the residue afforded 3: 40 mg (84%); mp 235–236 °C (lit.[2b] 237–239 °C). The ^{1}H NMR (60 MHz) and IR (KBr) spectra of 3 were identical with those reported in the literature.[2b]

Larger quantities of 3 were more easily obtained by saponification of the original plant extract followed by column chromatography. Thus, 14.4 g of extract was saponified as above, and the nonsaponifiable lipids (6.1 g) were chromatographed on 200 g of silica gel. Elution with 20% acetone in ether gave crude 3 (2.1 g) which upon recrystallization (acetone) afforded pure 3 (1.5 g), identical in all respects with the saponification product of 1.

Analysis of 1 in Exterior Resin Deposits. The exterior of a juvenile twig of *B. papyrifera* ssp. *humilis* was scraped with

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(6) The use of CD_3 in 6 serves only to identify the position of deuterium. The actual deuterium content was less than d_3 (as discussed below).

(7) Van der Merwe, K. J.; Steyn, P. S.; Eggers, S. H. *Tetrahedron Lett.* **1964**, 3923.

(8) McLafferty, F. W. "Interpretation of Mass Spectra", 3rd ed.; University Science Books: Mill Valley, CA, 1980; Chapter 2.

(9) Warnhoff, E. W.; Halls, C. M. M. *Can. J. Chem.* **1965**, *43*, 3311. Biellman, J. F. *Tetrahedron Lett.* **1966**, 4803.

(10) Bryant, J. P., unpublished results.

(11) Substantial additional quantities of 1 were apparent (TLC with silica gel and acetic acid–ethyl acetate, 1:99) in the mother liquors and in related chromatography fractions, but the resinous nature of these mixtures thwarted attempts to crystallize additional quantities of 1.

(12) DeBoer, T. J.; Backer, J. H. "Organic Syntheses"; Wiley: New York, 1963; Collect. Vol. IV, p 250.

a razor blade to remove the semicrystalline resin deposits (112 mg). The scrapings were allowed to stand in 10 mL 1:1 dichloromethane/acetone for 2 h. The suspension was filtered and the filtrate reduced to ca. 0.5 mL under vacuum. TLC examination (silica gel; acetic acid/ethyl acetate, 1:99) showed 1 to be the major component.

A portion of this solution was evaporated to dryness (62 mg), dissolved in 5 mL ether containing a few drops of methanol, and esterified with diazomethane as above. Examination of this reaction mixture by TLC (silica gel developed with ether and with 1:1 dichloromethane/ethyl acetate; aluminum oxided developed with the same two solvent systems) showed 2 to be the major component. The ^{1}H NMR spectrum (60 MHz) of this mixture exhibited all the signals reported above for 2 in addition to those (principally in the δ 1–2 region) presumably ascribable to other uncharacterized constituents.

Acknowledgment. The author thanks Mr. J. P. Bryant for plant collection and identification and Dr. T. Ohmoto for an authentic sample and infrared spectrum of betulafolientriol oxide I. Mass spectra were provided by the Bioorganic, Biomedical Mass Spectrometry Resource (A. L. Burlingame, Director) supported by NIH Research Grant No. RR00719; ^{13}C NMR and 360-MHz ^{1}H NMR spectra were provided by the Colorado State University Regional NMR Center funded by NSF Grant No. CHE-78-18581. This work was supported by NSF Grant No. DEB 7823919.

Registry No. 1, 78782-15-7; 2, 78782-16-8; 3, 19942-05-3; 6, 78791-19-2.

Bimanes. 11. Random to Organized Rearrangements in Thin Films of *syn*-1,5-Diazabicyclo[3.3.0]octadienediones (9,10-Dioxa-*syn*-bimanes) Followed by Ultraviolet and Infrared Spectroscopy

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Received April 24, 1981

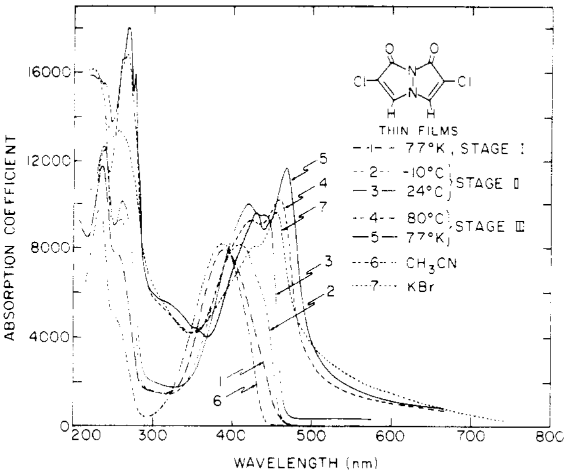
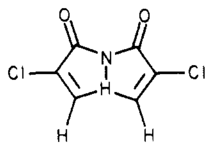
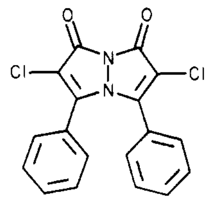


Figure 1. Spectra of 9,10-dioxa-*syn*-(hydrogen,chloro)bimane [*syn*-(H,Cl)B] in pure thin films, in a KBr window, and in CH_3CN solution. The bimane is distilled onto a sapphire optical window maintained at 77 K, producing a glassy (random) film (stage I; see curve 1). The similarity of the spectrum to that of the bimane in CH_3CN (curve 6) is evident. Annealing the film by warming it to between −10 and +24 °C leads to a shift in the longest wavelength absorption maxima (curves 2 and 3) to 416 and 440 nm and the change of a shoulder at 250 nm into an absorption band at 254 nm. Further annealing at temperatures between 75 and 85 °C leads to an additional shift of the long-wavelength maxima to 458 and 425 nm (curve 4), with a change to 468 and 430 nm (curve 5) on cooling to 77 K (stage III). The maximum at 254 nm becomes stronger and sharper in stage III. The spectrum of crystalline *syn*-(H,Cl)B dispersed in a KBr matrix resembles very much the spectrum of the stage III thin film (curve 7).

The facile synthesis, some crystal structures, and the interesting photophysical properties of the *syn*- and *anti*-9,10-dioxabimanes (1,5-diazabicyclo[3.3.0]octadienediones) have been reported.[2-7] A thin-film spectroscopy apparatus for distillable materials[8] allowed us to investigate a number of 9,10-dioxa-*syn*-bimanes. We can now report that the spectra of thin films of *syn*-(hydrogen,chloro)bimane (1) "plated" on an optical sapphire window at 77 K resemble those taken in CH_3CN (UV–vis) or $CHCl_3$ (IR) solution and that annealing the films leads to dramatic spectroscopic changes (UV–vis, IR, fluorescence) which appear to arise from the formation of ordered (crystallike) solids from random (liquidlike) glasses.



1 (*syn*-H,Cl)B)



2 (*syn*-(C_6H_5,Cl)B)

Plating [distillation at 155 °C (10^{-6} torr), condensation at 77 K] of *syn*-(H,Cl)B (1) (syntheses will be described elsewhere)[9] gave a thin film of bimane which exhibited the following spectroscopic characteristics: UV–vis λ_{max} 389 nm (ϵ 8100); fluorescence λ_{max} 485 nm ("normal" shape); IR 3135 (s), 3110, 3065 (C—H stretch), 1760, 1675, 1760/1675 cm^{-1} (intensity ratio ca. 10; C=O region). On annealing,[10] the spectra change strikingly in two distinct stages (initially stage I, succeeded by stages II and III).

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(1) (a) Tel-Aviv University. (b) State University of New York.

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(6) Part 6: Kosower, E. M.; Pazhenchevsky, B.; Dodiuk, H.; Kanety, H.; Faust, D. *J. Org. Chem.* **1981**, *46*, 1666.

(7) Part 7: Kosower, E. M.; Pazhenchevsky, B.; Dodiuk, H.; Kanety, H.; Ben-Shoshan, M. *J. Org. Chem.* **1981**, *46*, 1673.

(8) Hermolin, J.; Levin, M.; Kosower, E. M. *J. Am. Chem. Soc.* **1981**, *103*, 4801. A sapphire window (cooled to 77 K) is used to trap a jet of the material (e.g., pyridinyl radicals) under study. The amount deposited is measured interferometrically. The thin-film spectroscopy apparatus is small and may be easily transferred from instrument to instrument.

(9) Part 14: Kosower, E. M.; Faust, D.; Ben-Shoshan, M.; Goldberg, I., *J. Org. Chem.*, in press. The new bimane, *syn*-(H,Cl)B, had spectroscopic properties (UV, IR, NMR, mass) consistent with the assigned structure and gave a satisfactory elemental analysis.

(10) The film is warmed to a specified temperature and then cooled to 77 K. Spectra measured under these conditions are generally sharper. Cooling is particularly important in the case of the IR spectra since measurement of the spectra at scan speeds low enough to give well-defined spectra may be accompanied by IR heating of the sample and thus further annealing.

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