calcd for $C_{11}H_{12}O_3S_2$ m/e 256.0229, obsd m/e 256.0255.

25. The metalation of **21b** (100 mg, 0.39 mmol) was conducted in THF (4 mL) at −70 °C, using *n*-BuLi (0.39 mmol) over 10 min. Dimethyl disulfide (0.04 mL, 0.44 mmol) was added, the solution was stirred for 15 min at −70 °C, and the reaction was quenched with aqueous Na_2CO_3. Workup followed by filtration of the crude product through neutral alumina (activity III, 1.5 × 6 cm column, 10% Et_2O/PE as eluant) gave 92 mg of **25** as a pale yellow oil: IR (neat) 2950 (s), 2845 (s), 1470, 1462, 1450, 1438 (all s, overlapping), 1380 (s), 1305 (s), 1275 (s), 1248 (s), 1210 (s), 1164 (s), 1137 (s), 1080 (s), 980, 962 (overalapping, s) cm^{-1}; ^1H NMR (CCl_4) δ 6.90 (s, 1 H), 6.05 (s, 2 H), 3.20 (s, 6 H), 3.15 (s, 6 H), 2.47 (s, 3 H); exact mass calcd for $C_{13}H_{18}O_4S_2$ m/e 302.0646, obsd m/e 302.0654.

28 and 29. A heterogeneous mixture of **27** (1.0 g, 3.05 mmol), THF (40 mL), and zinc–copper couple (0.62 g, 9.15 mmol) was heated to reflux, and 25% HOAc (12 mL) was added through the condenser. After heating for 1 h, the solution was cooled and filtered, and the filtrate was concentrated. Workup as usual gave the air-sensitive phenol, which was immediately dissolved in CH_2Cl_2 (100 mL). Pyridinium bromide perbromide (0.98 g, 3.05 mmol) was added to the solution, and the reaction mixture was stirred for 30 min (solution color changed from red to yellow). After quenching with saturated $NaHCO_3$ (20 mL), workup gave an air-sensitive oil, which was immediately dissolved in acetone (100 mL). After addition of K_2CO_3 (0.84 g, 6.1 mmol) and dimethyl sulfate (0.43 mL, 4.5 mmol), the mixture was heated to reflux for 5 h, cooled, and filtered. Workup gave a light yellow oil, which was chromatographed on silica gel (12.5 × 25 cm column, 3% Et_2O/PE as eluant). The elution proceeded as follows: 120 mL, nil; 100 mL, 607 mg (51%) of **28** as a colorless oil [^1H NMR (CCl_4) δ 7.31 (s, 12 H), 3.92 (s, 3 H), 3.88 (s, 3 H), 2.35 (s, 3 H), 0.38 (s, 9 H)]. The analytical sample was prepared by molecular distillation (80 °C, 0.1 mmHg). Anal. Calcd for $C_{14}H_{19}O_2S_2SiBr$: C, 42.96; H, 4.89. Found: C, 43.04; H, 4.86.

Continued elution gave 20 mL of an unweighed mixed fraction and 150 mL (250 mg, 24%) of **29** as a clear oil identified by its ^1H NMR [(CCl_4) δ 7.35 (s, 2 H), 3.90 (s, 6 H), 2.35 (s, 3 H); exact mass calcd for $C_{11}H_{11}O_2SBr$ m/e 317.384, obsd m/e 317.389].

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Registry No. **1**, 63693-26-5; **6a**, 63693-33-4; **9**, 73630-87-2; **14**, 13414-95-4; **15**, 25074-27-5; **17a**, 3781-90-6; **17b**, 73630-81-6; **17c**, 73630-82-7; **17d**, 87279-67-2; **18**, 1468-84-4; **19**, 87279-68-3; **20a**, 68452-01-7; **20c**, 87279-69-4; **21a**, 73630-83-8; **21b**, 73630-84-9; **21c**, 73630-85-0; **21d**, 87279-70-7; **22**, 73630-86-1; **23b**, 73630-88-3; **23c**, 73630-89-4; **24e**, 87279-71-8; **25**, 87279-72-9; **26**, 87279-73-0; **27**, 87279-74-1; **28**, 87279-75-2; **29**, 87279-76-3; **30**, 87279-77-4; **31**, 87279-78-5; **32**, 87279-79-6; **33a**, 87279-80-9; **33b**, 87279-81-0; **34a**, 87279-82-1; **34b**, 87279-83-2; 5-bromobenzo[*b*]thiophen-4-ol, 34576-98-2; 4-oxo-5-methyl-4,5,6,7-tetrahydrobenzo[*b*]thiophene, 19995-43-8; 4-oxo-5,5-dimethyl-4,5,6,7-tetrahydrobenzo[*b*]-thiophene, 87279-84-3; 6-bromo-7-hydroxybenzo[*b*]thiophene, 87279-85-4; 4,7-dihydro-4,4-dimethoxy-5-methylbenzo[*b*]thiophen-7-ol, 87279-86-5; 5-bromobenzo[*b*]thiophene-4,7-quinone, 63693-34-5; 5-bromo-4,7-dihydro-4,4-dimethoxy-7-methylbenzo-[*b*]thiophen-7-ol, 87279-87-6; phytol, 7541-49-3; 5-bromo-6-butylbenzo[*b*]thiophene-4,7-quinone, 87279-88-7.

Supplementary Material Available: Experimental procedures and spectroscopic data for benzo[*b*]thiophene-4,7-quinone, 5-bromobenzo[*b*]thiophene-4,7-quinone, 5-methylbenzo[*b*]-thiophene-4,7-quinone, 5-bromo-6-butylbenzo[*b*]thiophene-4,7-quinone, **31**, **32**, **33a**, **33b**, **34b** are given (5 pages). Ordering information is given on any current masthead page.

Synthesis of α-Thiophene Oligomers via 1,3-Butadiynes

Jacques Kagan* and Sudershan K. Arora

Department of Chemistry, University of Illinois at Chicago, Chicago, Illinois 60680

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Individual oligomers possessing thiophenes linked by their 2- and 5-positions are conveniently prepared via 1,3-butadiynes. These can be prepared in good yield by the Glaser symmetrical coupling of thienylacetylenes. Following the cyclization of the 1,3-butadiyne unit into a thiophene with sodium sulfide, an oligomer possessing an odd number of thiophene rings is obtained. Oligomers with an even number of rings are accessible from unsymmetrical butadiynes obtained either by the Cadiot–Chodkiewicz procedure, utilizing an odd and an even precursor, or by an organoborane coupling procedure.

Many bithiophene and terthiophene derivatives display interesting biological properties. Most notably, they are toxic to nematodes, and this effect can be greatly enhanced by the presence of ultraviolet light.[1] The most carefully scrutinized of these compounds is α-terthienyl (**3**, n = 1), which has shown photoenhanced activity against nematodes,[1] microorganisms,[2-5] algae,[6] human erythrocytes,[7] insect larvae[8-10] and eggs,[11] in addition to generating skin pigmentation,[12] acting as herbicide,[13] and acting as a seed germination inhibitor.[14] A study of the structure–activity relationship in this type of molecule required significant

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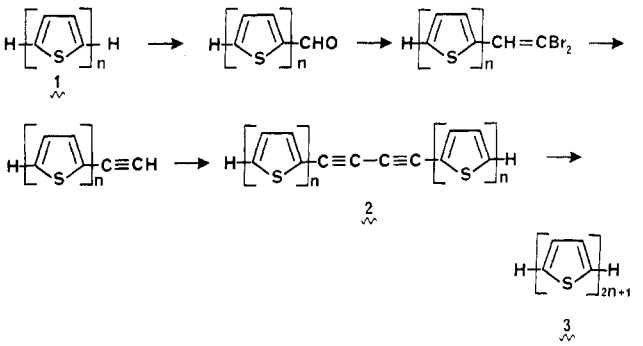
0022-3263/83/1948-4317$01.50/0

Scheme I



amounts of the higher 2,5-thiophene oligomers. A search of the literature revealed that although such oligomers with four to seven thiophene groups had been previously prepared,[15] the yields were often minuscule, and more practical syntheses were needed, except in the case of α-terthienyl.

The standard reaction of 2-iodothiophene with copper does not yield pure 2,2′-bithiophene.[15] Rather, significant amounts of α-terthienyl and higher oligomers are produced, and the purification of the individual oligomers required repeated sublimations and crystallizations[15] or extensive chromatography.[16]

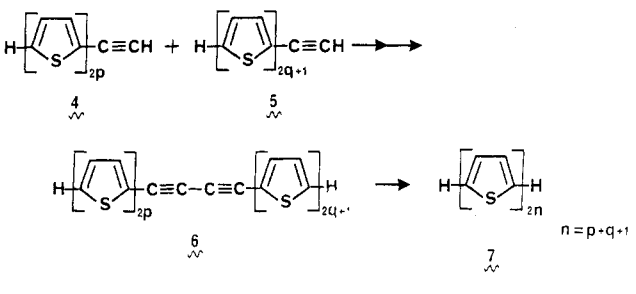
Similarly, the mixed coupling of 2-iodothiophene with the corresponding iodo derivative of 2,2′-bithiophene in the presence of copper was not specific.[17] This approach is not likely to be improved to produce selected oligomers without contamination by other congeners. Consequently, the design of other approaches was desirable.

Discussion

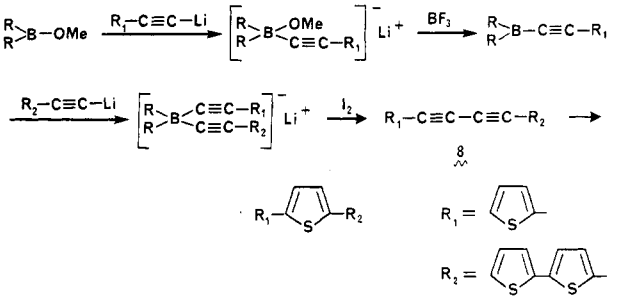
Our recent success in synthesizing a number of terthiophenes via the hydrogen sulfide cyclization of a 1,4-dithienyl-1,3-butadiyne[18,19] encouraged us to extend the procedure to higher oligomers.

The symmetrical coupling of terminal acetylenic molecules can be performed in good yield by the Glaser procedure,[20] with cuprous chloride and air, and provides a convenient method for preparing oligomers with an odd number of thiophene rings as shown in Scheme I. In each case the desired terminal acetylene was synthesized from a simpler thiophene precursor, which was formylated with *N*-methyl-*N*-phenylformamide in the presence of $POCl_3$. The aldehyde was treated with carbon tetrabromide and triphenylphosphine, followed by *n*-butyllithium.[21] After the workup the desired acetylene **1** was obtained in good yield, and it was immediately coupled to **2**. These 1,3-butadiyne derivatives have interesting phototoxic properties, and they readily give the polythiophenes **3** upon treatment with sodium sulfide in methanol or dioxane. Oligomers possessing three, five, and seven thiophene rings were prepared in this manner. The overall yields for the four steps starting with the aldehyde were 66%, 45% and 88.5%, respectively. Unlike the oligomerization reactions

Scheme II



Scheme III



starting with 2-iodothiophene, which require the separation of products with increasingly similar physical properties, the directed syntheses reported here lead to mixtures containing components of widely different molecular weights and physical properties.

Obviously, oligomers containing an even number of thiophene rings cannot be obtained by the Glaser coupling of terminal acetylenes. However, these compounds can be obtained by the coupling of odd-numbered with even-numbered ethynylthiophenes, as shown in Scheme II. The feasibility of this approach was demonstrated by utilizing the Cadiot–Chodkiewitz coupling procedure for the unsymmetrical coupling of acetylenes.[22] In the case of the α-quaterthienyl, the more readily available 2-ethynylthiophene (**5**, $q = 0$) was converted into the bromoacetylene with sodium hypobromide, and the coupling of this with 5-ethynyl-2,2′-bithiophene (**4**, $p = 1$) took place in 95.6% yield. The cyclization to **7** ($n = 2$) with sodium sulfide was quantitative.

Sinclair and Brown demonstrated for the unsymmetrical coupling of acetylenes could be advantageously replaced by an organoborane-mediated approach where the lithium salts of each of the acetylenic reagents were introduced successively onto a boron compound to form an ate complex. Iodine oxidation produced the diacetylene cleanly.[22] This procedure should be applicable to the synthesis of all the thiophene oligomers **3** and **7**, since it allows flexibility in the choice of the polythiophene moieties expressed in R_1 and R_2 (Scheme III). Because the Glaser procedure for the symmetrical coupling of terminal acetylenes uses a single step and does not require the formation of the lithium salts, it is more attractive than the organoborane approach for preparing symmetrical butadiynes **2**. A notable exception might be where one thiophene ring, for example one carrying a label, must be introduced selectively into a polythiophene molecule containing an odd number of units. We demonstrated the application of Scheme III to the synthesis of α-quaterthienyl (**7**, $n = 2$) utilizing 9-BBN and the acetylene reagents corresponding to thiophene and dithiophene (R_1 = 2-thienyl, R_2 = 2,2′-diethienyl-5-yl in Scheme III). As expected, the reaction

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was very clean and produced the butadiyne 8 in 69% yield based on 9-BBN.

Conclusion

Individual α-thiophene oligomers can be synthesized in greatly improved yields over the traditional method by constructing a 1,3-butadiyne properly substituted with thiophene groups and treating it with sodium sulfide. The procedure is versatile enough to allow the synthesis of oligomers having either an odd or an even number of repeating units, but the generality of the reactions herein described is severely limited by practical considerations of solubility, which decreases rapidly as the molecular weight of the oligomers increases.

Experimental Section

The NMR spectra were obtained with a Varian T-60 and the mass spectra with a Hewlett-Packard 5985. The elemental analyses were performed by Micro-Tech, Skokie, IL. The purifications by flash chromatography were performed by using silica gel (60–200 mesh) according to Stille.[24]

1,4-Bis(2,2′-bithienyl-5-yl)-1,3-butadiyne (2, *n* = 2). 5-Ethynyl-2,2′-bithiophene[25] (1.660 g, 8.7 mmol) was added to a stirred mixture of Cu_2Cl_2 (198 mg, 1 mmol) and *N,N,N′,N′*-tetramethylethylenediamine (0.56 ml, 3 mmol) in dimethoxyethane (10 mL). Air was bubbled for 1 h through the mixture which was kept at 30–35 °C. The mixture was then poured into cold water and extracted with ether which was later dried over $MgSO_4$ and concentrated under vacuum. The residue was flash chromatographed (hexane–$CHCl_3$, 7:3) to give a semisolid which was crystallized from benzene–hexane to yield 1.200 g (3.17 mmol, 72.7% yield) of the title compound as yellow crystals: mp 167 °C dec (lit.[26] mp 168 °C dec); NMR (C_6D_6) 6.60–6.97 ppm (m); mass spectrum, *m/e* (relative intensity) 378 (M^+, 100).

α-Quinquethienyl (3, *n* = 2). A mixture of **2** (*n* = 2; 25 mg, 0.066 mmol), $Na_2S{\cdot}9H_2O$ (64 mg, 0.264 mmol), and dioxane (50 mL) was refluxed for 10 h, cooled, and concentrated to dryness. The residue was washed with water, filtered, and crystallized from dioxane–water to give 20 mg (0.048 mmol, 73.5% yield) of the title compound mp 256–258 °C (lit.[15] mp 256–257 °C); single spot on TLC (MeOH–CS_2, 95:5); mass spectrum, *m/e* (relative intensity) 412 (M^+, 100).

1,1-Dibromo-2-(2,2′:5′,2″-terthienyl-5-yl)ethylene. 2,2′:5′,2″-Terthiophene-5-carboxaldehyde (820 mg, 2.9 mmol) in CH_2Cl_2 (10 ml) was added at 0 °C under N_2 to a stirred mixture of triphenylphosphine (1.950 g, 7.4 mmol) and CBr_4 (1.230 g, 3.7 mmol) in 40 mL of CH_2Cl_2. After the mixture was stirred for 1 h at room temperature, enough hexane (ca. 10 mL) was added to the homogeneous mixture to precipitate triphenylphosphine oxide, which was filtered off. Further addition of hexane (100 mL) to the filtrate produced a yellow solid, which was flash chromatographed (hexane–acetone, 8:2). After recrystallization from EtOH, the title compound gave the following: 1.200 g (2.78 mmol, 96% yield); mp 158–160 °C; NMR ($CDCl_3$) 7.0–8.0 ppm (m); mass spectrum, *m/e* (relative intensity) 432 (M^+, 100). Anal. Calcd for $C_{14}H_8Br_2S_3$: C, 38.98; H, 1.86; S, 22.27. Found: C, 38.72; H, 2.04; S, 21.96.

5-Ethynyl-2,2′:5′,2″-terthiophene. *n*-Butyllithium (325 mg, 5 mmol) was added dropwise under N_2 to a solution of the above compound (1.000 g, 2.3 mmol) in dry THF (30 mL) at −78 °C. After being stirred for 2 h at this temperature, the mixture was allowed to warm to room temperature, and stirring was continued for 1 h. The mixture was poured into ice–water and extracted with CH_2Cl_2 (3 × 30 mL), and the extract was dried over $MgSO_4$ and concentrated. The residue was flash chromatographed with acetone–hexane (1:4). After recrystallization from EtOH, the title product was obtained: 0.600 g (2.21 mmol, 95.9% yield); mp 118–119 °C; NMR ($CDCl_3$) 3.4 (s, 1 H), 6.9–7.9 ppm (m, 7 H); mass spectrum, *m/e* (relative intensity) 272 (M^+, 100).

1,4-Bis(2,2′:5′,2″-terthienyl-5-yl)-1,3-butadiyne (2, *n* = 3). The above product (500 mg, 1.84 mmol) was added to a stirred mixture of Cu_2Cl_2 (36 mg, 0.18 mmol) and *N,N,N′,N′*-tetramethylethylenediamine (0.1 mL) in dimethoxyethane (10 mL). Air was bubbled for 2 h through the mixture which was kept at 30–35 °C. The mixture was then poured into water. The precipitate was filtered off, washed with water, dried, and recrystallized from dioxane to yield the title compound: 491 mg (0.91 mmol, 98.5% yield); mp 253–254 °C; NMR (Me_2SO-d_6) 7.0–7.45 ppm (m); mass spectrum, *m/e* (relative intensity) 542 (M^+, 100).

α-Septithienyl (3, *n* = 3). A mixture of the above compound (400 mg, 0.73 mmol) and $Na_2S{\cdot}9H_2O$ (708 mg, 2.92 mmol) in dioxane (50 ml) was refluxed for 20 h, cooled, and filtered. The filtrate was thoroughly washed with water, dried, and sublimed to yield the title product: 410 mg (0.71 mmol, 97.5% yield); mp 327–328 °C (lit.[15] mp 326–328 °C); mass spectrum, *m/e* (relative intensity) 576 (M^+, 100).

1-(2-Thienyl)-4-(2,2′-bithienyl-5-yl)-1,3-butadiyne (6, *p* = 1, *q* = 0). Procedure A. A solution of bromo(2-thienyl)acetylene (380 mg, 2 mmol) in MeOH (10 mL) was added at room temperature to a well-stirred mixture of Cu_2Cl_2 (11.1 mg), a small crystal of $NH_2OH{\cdot}HCl$, 70% aqueous ethylamine (0.277 mmol), and **4** (*p* = 1, 380 mg, 2 mmol) with 5 mL of MeOH and 5 mL of ether. After the mixture was stirred for 1 h, NaCN (4.5 mg) in water (5 ml) was added, and the mixture was extracted with CH_2Cl_2 (4 × 15 mL). The extract was washed with water (3 × 10 mL), dried over $MgSO_4$, and concentrated under vacuum. The residue was recrystallized from THF– water to yield 566 mg of the title compound: 1.91 mmol (95.6% yield); mp 120–121 °C; NMR (Me_2SO-d_6) 7.0–7.65 ppm (m); mass spectrum, *m/e* (relative intensity) 296 (M^+, 100).

Procedure B. 9-BBN (0.244 g, 2 mmol) and dry, freshly distilled THF (5 mL) were placed in a dry three-necked, 250-mL flask fitted with a gas inlet tube and a septum inlet. Under nitrogen and with magnetic stirring, dry MeOH (0.064 g, 2 mmol) was added dropwise at room temperature, and the solution was stirred for 1 h longer. To a separate 100-mL flask containing 5-ethynyl-2,2′-bithienyl (0.380 g, 2 mmol) in dry THF (10 mL) kept at −78 °C was added *n*-BuLi (0.128 g, 2 mmol) dropwise, and the solution was stirred at that temperature for 1 h. The first flask was then cooled to −78 °C, and the content of the second flask was transferred via a canula. An additional 5 mL of THF was used for washing the flask and was transferred too. The mixture was stirred at −78 °C for 30 min, and freshly distilled boron trifluoride etherate (0.376 g, 3.3 mmol) was added with a syringe. The mixture was stirred for 20 min at −78 °C and then warmed to room temperature. The flask was cooled again to −78 °C, and 2-(lithioethynyl)thiophene prepared by reacting *n*-BuLi (0.128 g, 2 mmol) with 2-ethynylthiophene (0.216 g, 2 mmol) in 10 mL of THF was added. The mixture was stirred for 30 min at −78 °C, iodine (0.508 g, 2 mmol) dissolved in 5 mL of THF was added dropwise, and stirring was continued for 30 min at −78 °C. After returning to room temperature, the solution was washed twice with 0.6 mL of 3 M NaOH, and 0.8 mL of 3 M NaOH was added, followed by 0.8 mL of 30% H_2O_2 at such a rate that the temperature remained below 50 °C. After saturation with K_2CO_3, the organic layer was removed. The aqueous phase was extracted with CH_2Cl_2 (2 × 10 mL), and the combined organic extracts were dried over anhydrous K_2CO_3 and concentrated. The solid residue was recrystallized from THF–water to yield 0.410 g (69%) of the title compund: mp 120–121 °C; identical (NMR and mass spectra, mixture melting point) with the product obtained by procedure A.

α-Quaterthienyl (7, *n* = 2). A mixture of the butadiyne **6** (*p* = 1, *q* = 0; 200 mg, 0.6 mmol) and $Na_2S{\cdot}9H_2O$ (2.4 mmol) in THF (40 mL) was refluxed overnight. After the mixture was cooled and concentrated to dryness under vacuum, the residue was washed with water and recrystallized from 95% EtOH to give the title compound: 200 mg (0.6 mmol, 100% yield); mp 211–212 °C (lit.[15] mp 210–212 °C); NMR (Me_2SO-d_6) 6.95–7.60 ppm; mass spectrum, *m/e* (relative intensity) 330 (M^+, 100).

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thienyl.

Registry No. **2** (n = 2), 87350-64-9; **2** (n = 3), 87337-90-4; **3** (n = 2), 5660-45-7; **3** (n = 3), 86100-63-2; **4** (p = 2), 4743-21-9; **6** (p = 1, q = 0), 87337-91-5; **7** (n = 2), 5632-29-1; poly(2,5-thiophenediyl) (SRU), 51325-05-4; 1,1-dibromo-2-(2,2′:5′,2″-terthienyl-5-yl)ethylene, 87350-66-1; 2,2′:5′,2″-terthiophene-5-carboxaldehyde, 7342-41-8; 5-ethynyl-2,2′:5′,2″-terthiophene, 87337-92-6; bromo(2-thienyl)acetylene, 33675-51-3; 1-lithio-2-ethynylthiophene, 62439-93-4.

Formation of α-Cyanoaziridines and 1-(Alkylamino)cyclopropanecarbonitriles by Cyanation of α-Halo Ketimines[1]

Norbert De Kimpe,*[2] Paul Sulmon, Roland Verhé, Laurent De Buyck, and Niceas Schamp

Laboratory of Organic Chemistry, Faculty of Agricultural Sciences, State University of Gent, Coupure Links 653, B-9000 Gent, Belgium

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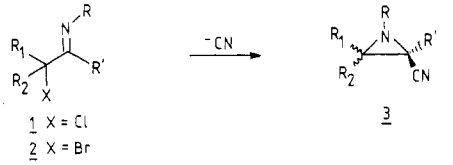
A new convenient synthesis of α-cyanoaziridines was developed by reaction of α-halo ketimines with cyanide in methanol or acetonitrile. Tertiary α-chloro ketimines with cyanide in methanol gave rise to a competitive reaction between α-cyanoaziridine formation and production of 1-(alkylamino)cyclopropanecarbonitriles, the latter being classified as a Favorskii rearrangement-type product. The scope and limitations of this reaction have been determined by investigation of reaction parameters such as the nitrogen substituent, the solvent, the inorganic cyanide, the carbon skeleton, and the nature of the α-halogen.

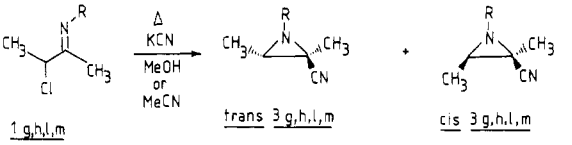
In a preliminary communication, we described a novel synthesis of α-cyanoaziridines **3** by reaction of α-chloro ketimines **1** with potassium cyanide in methanol (Scheme I).[3] Such α-cyanoaziridines are an important class of organic compounds, and much attention has been devoted to them because they are able to undergo 1,3-cycloadditions to, for example, olefins or alkynes via azomethine ylides.[4-6]

These functionalized aziridines have been previously prepared by various methodologies, including reaction of primary amines with α-halogeno-α,β-unsaturated nitriles[7-10] or condensation of α,β-unsaturated nitriles with nitrenes,[11] N-unsubstituted oxaziridines,[12] and organic azides.[13] Alternative methods of preparation involved substitution by cyanide of α-chloroaziridines,[14] reaction of α-chloro nitriles with aromatic aldimines in alkaline medium (i.e., the analogue of the Darzen reaction),[15] addition of diazoacetonitrile to certain aldimines,[16] or reaction of Δ^1-pyrroline N-oxides with the anion derived from diethyl cyanomethylphosphonate.[17] The principle interest

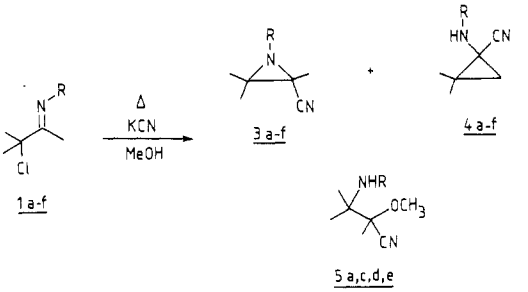
Scheme I



Scheme II



Scheme III



(1) This is part 31 of our series dealing with the chemistry of α-halogenated imines. For part 30, see: De Kimpe, N.; Sulmon, P.; Verhé, R.; De Buyck, N.; Schamp, N. *Tetrahedron Lett.* **1983**, *24*, 2885.
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