SYNTHESIS OF MIXED THIOPHENE-PYRROLE HETEROCYCLES

Renée E. Niziurski-Mann and Michael P. Cava*
Department of Chemistry, The University of Alabama, Box 870336, Tuscaloosa, AL 35487-0336, U.S.A.

Abstract - The synthesis of mixed thiophene-pyrrole heterocycles has been reviewed. The systems under consideration are various isomeric thienylpyrroles as well as tricyclic analogs containing non-condensed combinations of two or three pyrrole and thiophene units.

INTRODUCTION

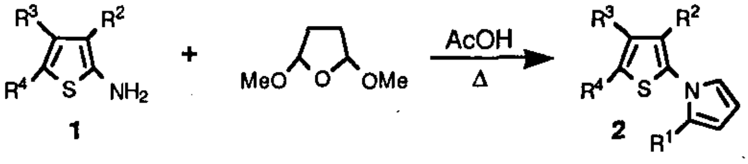
A number of heterocyclic ring systems have been described which contain non-condensed combinations of two or three pyrrole and thiophene units. The majority of the literature on thienylpyrroles is devoted to derivatives of the biheterocyclic ring systems as compounds of potential pharmaceutical interest. More recently, combinations of α,α'-linked thienylpyrrole oligomers are being explored for their application as conducting polymers and in nonlinear optics.

This review will consider the chemistry of the bicyclic thienylpyrroles as well as their triheterocyclic analogs. The literature cited through April 1992 has been covered rather thoroughly with the exception of the patent literature. Patent references (CA) are listed in brief at the end of the reference section.

1. Synthesis of Thienylpyrroles

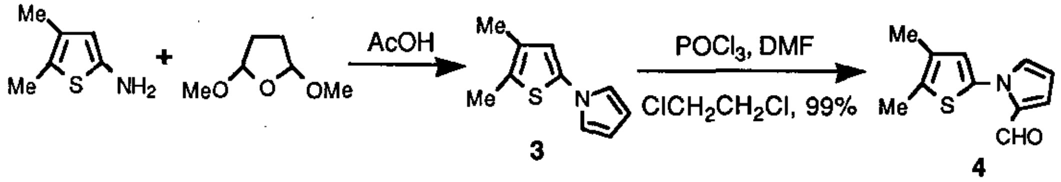
1.1 1-Thienylpyrroles

The first examples of 1-thienylpyrroles appeared in 1969 and were prepared by Shvedov, Kharizomenova and Grinev at the All-Union Scientific-Research Chemical-Pharmaceutical Institute in the U.S.S.R.[1,2] The 1-substituted 2-thienylpyrrole derivatives were synthesized in good yield by condensing substituted 2-aminothiophenes (**1**) with 2,5-dimethoxytetrahydrofuran in AcOH to afford **2**. Additional derivatives were obtained by decarboxylation and Mannich reactions.[1] The same group of workers also obtained a patent, following the above procedure, on 1-(3-ethoxycarbonyl-2-thienyl)pyrrole derivatives in 1969.[2]

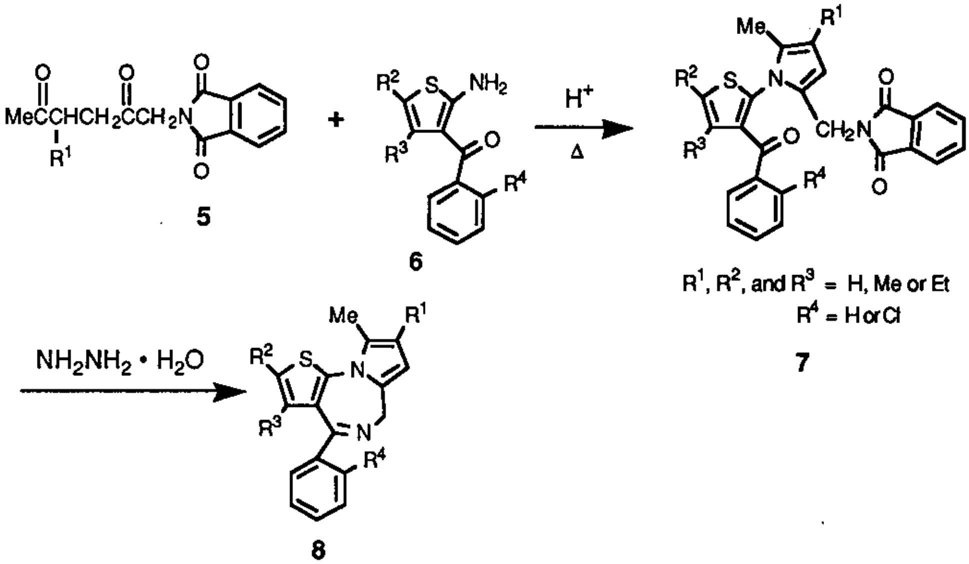


2	R^1	R^2	R^3	R^4
a	H	CO_2Et	Me	Me
b	H	CO_2Et	H	H
c	H	CO_2H	Me	Me
d	H	CO_2H	H	Et
e	H	H	Me	Me
f	CH_2NMe_2	CO_2Et	Me	Me
g	CH_2NMe_2	H	Me	Me

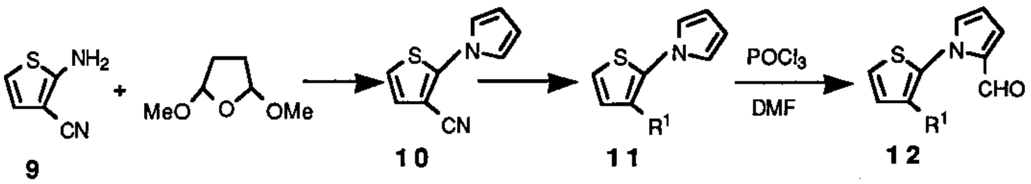
Kusharov and his coworkers[3] were interested in studying the conformation and properties of 1-substituted pyrrole-2-carboxaldehydes and they synthesized 1-(4,5-dimethyl-2-thienyl)pyrrole-2-carboxaldehyde (4) as part of their investigation. Treatment of 2-amino-4,5-dimethylthiophene with 2,5-dimethoxytetrahydrofuran in glacial acetic acid gave 3, which was formylated by Vilsmeier reaction to give the corresponding aldehyde (4) in high yield. Experimental and calculated values of the dipole moment and Kerr constants were compared to determine the preferred conformation, based on steric interactions, of the carbonyl oxygen with respect to the N-atom of 4 and other substituted pyrrole-2-carboxaldehydes.



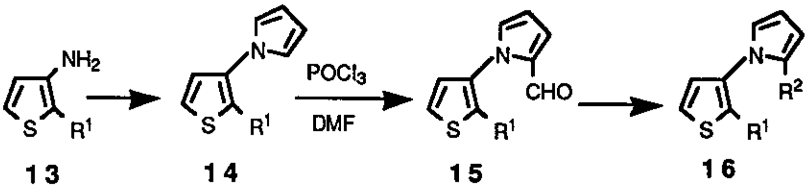
By far the largest number of 1-thienylpyrrole derivatives have been prepared as intermediates in the synthesis of tricyclic systems, having potential application in medicinal chemistry. Tricyclic diazepine compounds containing pyrrole and thiophene are of interest due to their structural relationship to anthramycin,[4] as well as to the benzodiazepines. The first synthesis of heterocyclic diazepines containing a thiophene unit was reported in 1977.[5] The 1,4-diketones (5) were heated with various 2-amino-3-benzoylthiophenes (6) in benzene and *p*-toluenesulfonic acid to give a number of new 3-benzoyl-2-pyrrolylthiophenes (7) in good yield (80-86%). These compounds were then converted to the corresponding pyrrolothienodiazepines (**8**) by refluxing **7** in ethanol and DMF with hydrazine hydrate.



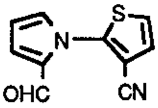
Reaction of the readily available 2-amino-3-cyanothiophene[6] (**9**) with 2,5-dimethoxytetrahydrofuran afforded *N*-(3-cyano-2-thienyl)pyrrole (**10**). In a series of papers by Robba[7,8] and Vega,[9] compound (**10**) has been used as the starting material for a large number of derivatives of the type **11**, where R^1 is equal to a wide variety of functional groups. A formyl group was introduced into the 2-position of the pyrrole ring by means of the Vilsmeier-Haack reaction and this led to an additional series of derivatives of structure **12**. The derivatives of series **11** and **12** were then intramolecularly cyclized to give a variety of 1,4-diazepines,[7-9] thienopyrrolizines,[10] and pyrrolothienopyrazines[11] which were tested for biological activity.



In continuation of the study of tricyclic systems containing thiophene and pyrrole for potential medicinal applications, a series of derivatives of the *N*-(3-thienyl)pyrrole system (**16**) were synthesized. Starting with 3-aminothiophenes of the type **13**,[12] a variety of derivatives were synthesized resembling **14**. The Vilsmeier-Haack reaction afforded the corresponding aldehydes (**15**) which could be further reacted to give additional derivatives of the type **16**. Derivatives of structures **11**, **12**, **14**, **15**, and **16** provided unique routes, by intramolecular cyclization, to a new series of 1,4-diazepines,[9] condensed pyrimidines,[13] pyrrolizines,[14] and pyrazines[15] containing both thiophene and pyrrole rings.



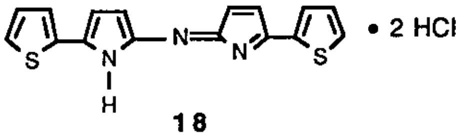
The crystal structure of *N*-(3-cyano-2-thienyl)pyrrole-2-carboxaldehyde (**17**)[7] has recently been reported.[16] Quite surprisingly, the compound was found to exist preferentially in the most sterically hindered conformation with the formyl and nitrile groups residing on the same side of the molecule.



17

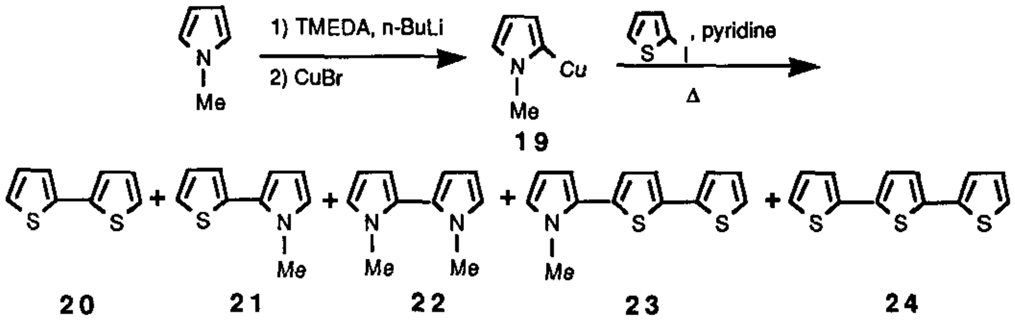
1.2 2-Thienylpyrroles

The first 2-thienylpyrrole derivative was reported in 1947 by Edward Knott at Kodak, Ltd.[17] as a dihydrochloride salt dye. The azamethine salt was prepared by refluxing β-2-thenoylpropionitrile and hydroxylamine hydrochloride in methanol to give bis-2-[5-(2-thienyl)pyrrole]azamethine dihydrochloride. The resulting compound was given structure **18** (shown below) and, when recrystallized from acetic acid, formed short green needles. In 1949, Eastman Kodak Co. was granted a patent for the thienyl and several other substituted 2-pyrrole-azamethine dyes.[18]

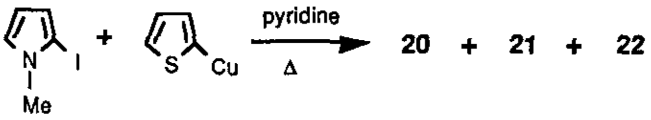


18

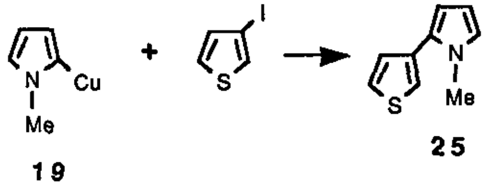
2-Thienylpyrrole and its N-methyl derivative have been prepared in a variety of ways. Gronowitz investigated the synthesis of *N*-methyl-2-(2-thienyl)pyrrole by copper coupling of aryl halides.[19] Reaction of *N*-methyl-2-pyrrolylcopper (**19**) with 2-iodothiophene gave a mixture of products (**20**), (**21**), (**22**), and (**23**) in the relative



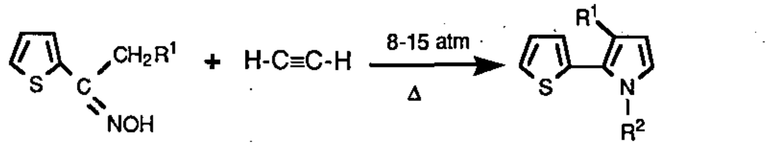
proportions of 7:53:24:14, as well as a trace amount of terthiophene (**24**). Following purification, **21** was obtained in <50% yield. When the coupling reaction was performed between 2-iodo-1-methylpyrrole and 2-thienylcopper, **20**, **21**, and **22** were formed in the ratio of 54:42:1 with small amounts of 2-bromo-1-methylpyrrole being detected.



The reaction of 3-iodothiophene with 1-methyl-2-pyrrolylcopper (**19**) was reported to give a complex mixture of 16 different components, one of which was the desired 1-methyl-2-(3-thienyl)pyrrole (**25**).[19] Kumada and coworkers[20] found that the yield of **25** could be significantly improved by coupling 1-methyl-2-pyrrolyl-magnesium bromide and 3-bromothiophene with $PdCl_2$(dppb).



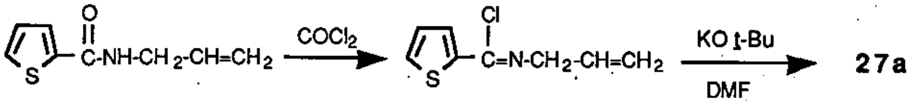
Methyl 2-thienyl ketoxime (**26a**) reacts with acetylene and potassium hydroxide under high pressure to give 2-(2-thienyl)pyrrole (**27a**) in 60% yield.[21] The use of excess acetylene produces the *N*-vinyl derivative (**28a**). Likewise, 2-(2-thienyl)-3-alkylpyrrole derivatives (**27b**) and (**28b**) may be prepared by starting with the appropriate alkyl 2-thienyl ketoxime (**26b**).[22] Several additional derivatives of the 2-(2-thienyl)pyrroles prepared by this route have been synthesized,[23] and the monomer unit (**28a**) has been polymerized and studied for photosensitizing applications.[24]



26a R^1 = H
26b R^1 = alkyl

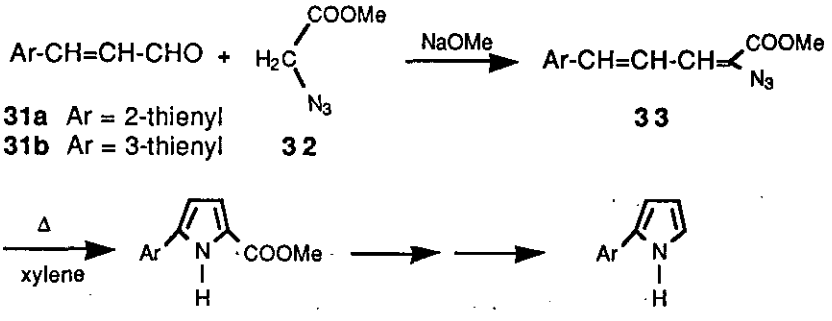
27a R^1, R^2 = H
27b R^1 = alkyl, R^2 = H
28a R^1 = H, R^2= CH=CH$_2$
28b R^1 = alkyl, R^2 = CH=CH$_2$

Steglich[25] found that **27a** could be synthesized in high yield from *N*-allyl-2-thienylcarboxamide (**29**). Formation of the imidoyl chloride (**30**) followed by cyclization with potassium tert-butoxide gave **27a** in 86% yield.



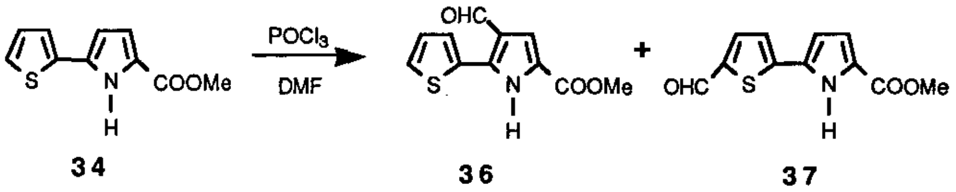
29 **30**

Following a synthetic strategy employed by Hemetsberger to prepare condensed pyrrole systems,[26] Guilard[27] synthesized **27a** and 2-(3-thienyl)pyrrole (**35**) from β-arylacroleins (**31**) and methyl azidoacetate (**32**). The azide (**33**), prepared by condensing **31** and **32** in the presence of base, was cyclized to the pyrrole ester (**34**). After heating, hydrolysis, and decarboxylation, **27a** or **35** were obtained in overall yields of 22% and 34%, respectively.

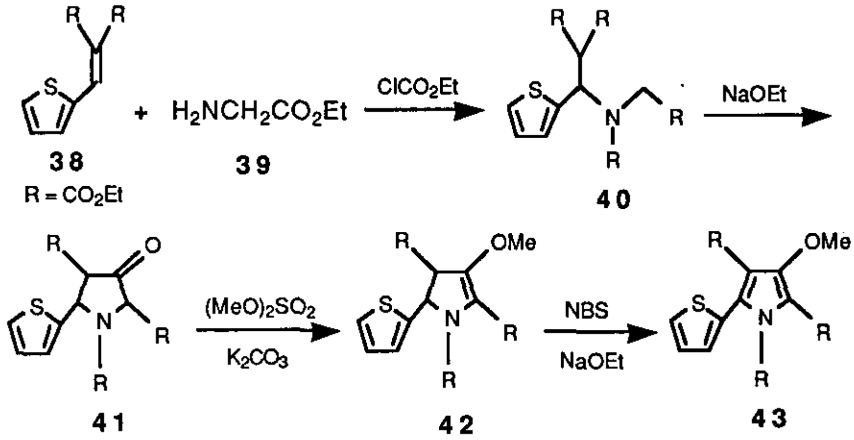


31a Ar = 2-thienyl
31b Ar = 3-thienyl
32
33
34
27a Ar = 2-thienyl
35 Ar = 3-thienyl

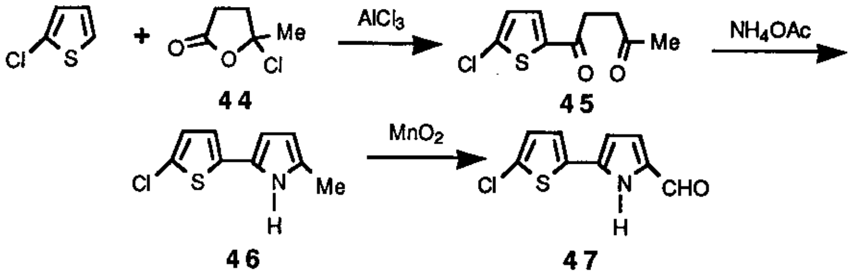
Electrophilic substitution reactions of thienylpyrroles were found to be very selective. The reactivity of these systems has been demonstrated with the use of formylation[27,28] and trifluoroacetylation[29] reactions producing derivatives with the electrophile substituted primarily on the pyrrole ring. It appears that the pyrrole ring is much more reactive and capable of delocalizing the positive charge than is the thiophene unit so that, even when both α-positions of the pyrrole ring are occupied, electrophilic substitution will preferentially occur in the β-position of the pyrrole ring versus the α-position of the thiophene ring. For example, in the Vilsmeier-Haack reaction shown below, **36** was formed preferentially over **37** in a ratio of 95:5.[28]



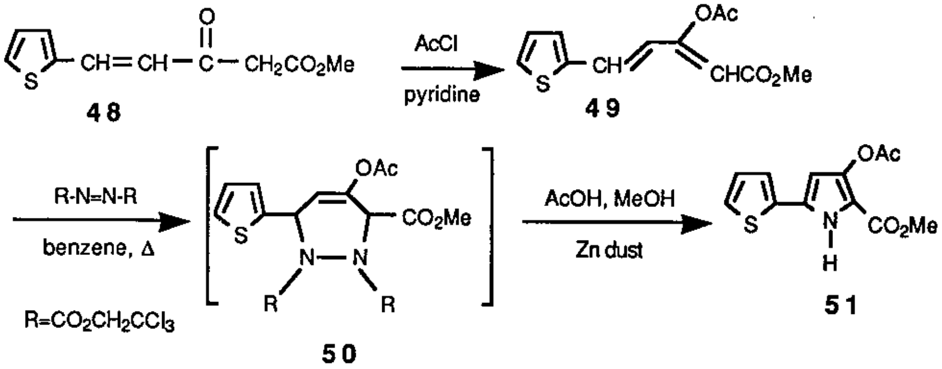
A series of procedures describe the syntheses of prodigiosin analogs containing thienylpyrrole units. The first to appear was by Campaigne and Shutske who prepared the thienylpyrrole unit starting with a Michael reaction between ethyl glycinate (**39**) and the arylidenemalonate (**38**).[30] The adduct (**40**) was cyclized to the thienylpyrrolidine (**41**) with sodium ethoxide, treated with dimethyl sulfate and potassium carbonate to give the methoxypyrroline (**42**), and aromatized in the presence of base with NBS to obtain **43**. The product (**43**) was subjected to further reaction to give the desired prodigiosin analog.



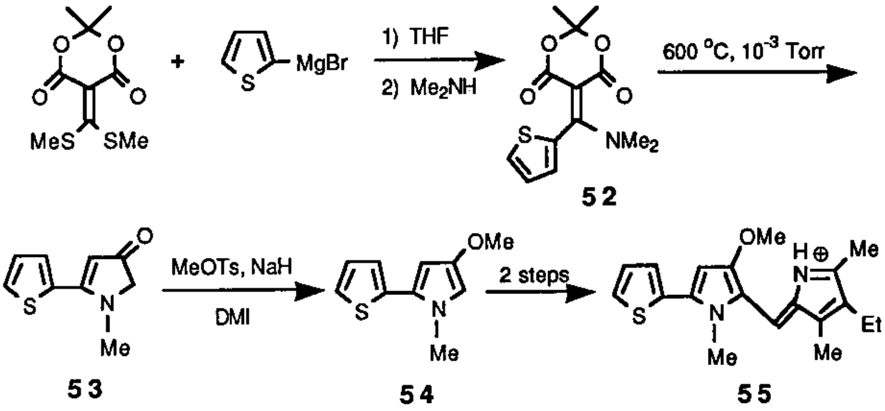
One of the simplest methods for preparing pyrroles, due to the ready availability of γ-diketones, is by way of the Paal-Knorr synthesis. Reaction of γ-diketones with ammonium acetate or primary amines, usually under acidic conditions and with the elimination of water, leads to the formation of 2,5-disubstituted or 1,2,5-trisubstituted pyrroles.[31] 2-(5-Chloro-2-thienyl)pyrrole-5-carboxaldehyde (**47**) was prepared by this procedure as an intermediate in the synthesis of structurally related analogs of metacycloprodigiosin.[32] The 1,4-diketone (**45**) was prepared in low yield by Friedel-Crafts reaction between 2-chlorothiophene and levulinic acid ψ-chloride (**44**) followed by reaction with ammonium acetate to obtain **46**. The methyl substituent was subsequently converted to a formyl group by oxidation with manganese dioxide to afford **47**.[32]



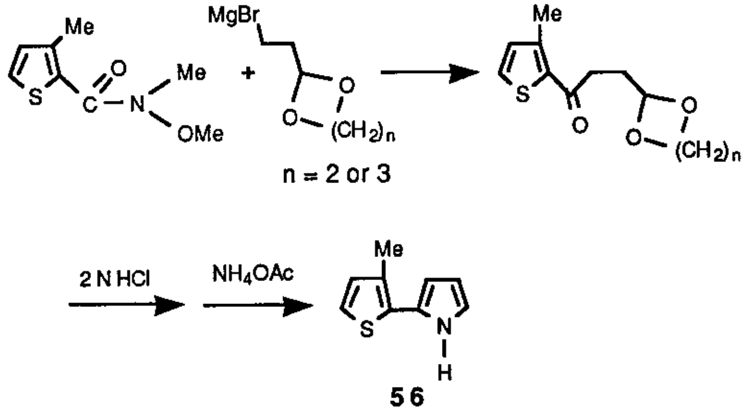
Another procedure for the intermediate in the synthesis of prodigiosin analogs employed the Diels-Alder reaction for the synthesis of the pyrrole unit.[33] Acetylation of the keto ester (**48**) gave the diene (**49**) which was refluxed in benzene with the azodicarboxylate to obtain the Diels-Alder adduct (**50**). Formation of the pyrrole ring occurred by treatment of **50** with zinc dust in acetic acid to give **51** in low yield.



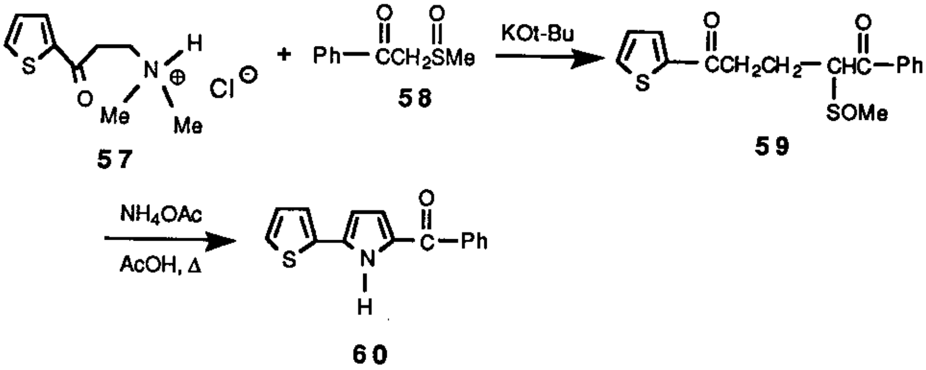
Finally, a "short synthesis" of the prodigiosin analog intermediate involved the pyrolysis of a dimethylaminomethylene derivative (**52**) to form the pyrrolone (**53**) which was treated with base to give the thienylpyrrole unit (**54**).[34] Two additional steps of formylation and a coupling reaction provided the desired analog **55** in 17% overall yield.



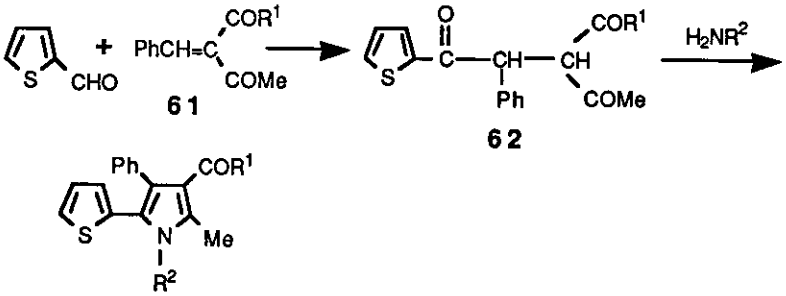
A new general procedure for the synthesis of 2-arylpyrroles has been described which involves the Paal-Knorr synthesis in the final step. The reaction was applied to the synthesis of the thiophene derivative (**56**) from the methoxyamide.[35]



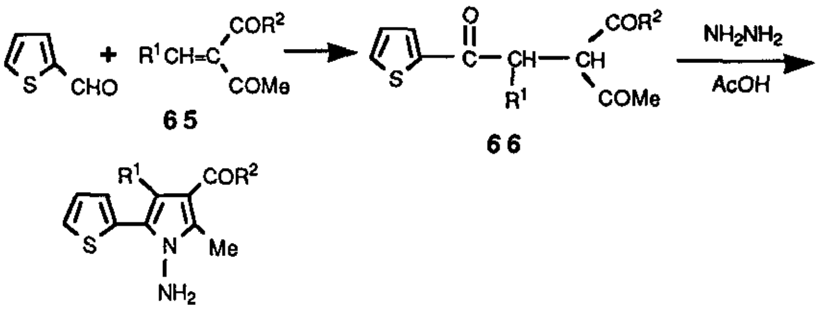
1,5-Pentanediones (**59**), formed as the Michael adduct from **57** and **58**, can be condensed with NH_4OAc to obtain aroyl-substituted thienylpyrroles (**60**).[36] The cycloaddition reaction of **59** with NH_4OAc is carried out in boiling acetic acid for 10 min and gives **60** as a crystalline product in low yield.



Highly substituted 2-(2-thienyl)pyrrole derivatives have been synthesized, by way of the Paal-Knorr reaction, with branched tricarbonyl compounds.[37] The 1,3-dicarbonyl Knoevenagel reaction products (**61**) and (**65**) were condensed with 2-thiophenecarboxaldehyde, in the presence of a thiazolium salt catalyst, to obtain the tricarbonyl compounds (**62**) and (**66**). Cyclization with primary amines afforded **63** and **64** in higher yields than the reactions employing hydrazine hydrate which gave **67** and **68**.[37]



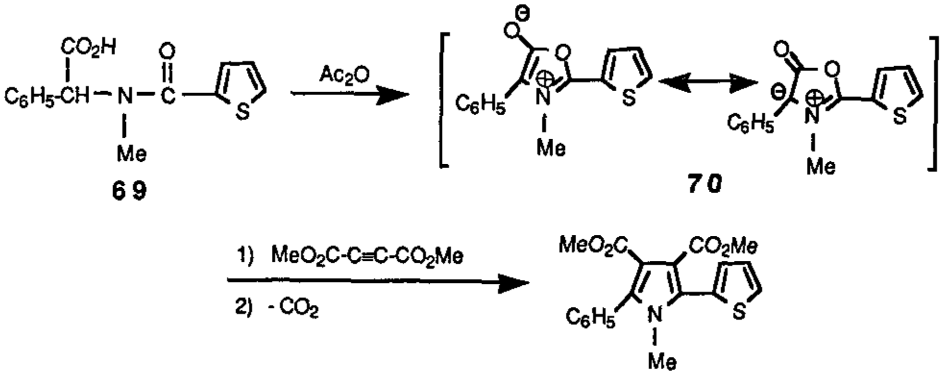
	R^1	R^2
63	Me	C_6H_5
64	OMe	4-$MeOC_6H_4$



65 66

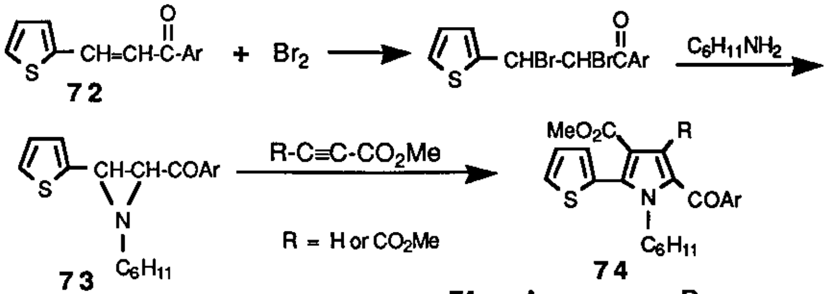
	R^1	R^2
67	2-thienyl	OMe
68	2-furyl	OEt

Substituted 2-(2-thienyl)pyrroles may also be obtained as products of 1,3-dipolar cycloadditions. *N*-Methyl-*N*-(2-thenoyl)phenylglycine (**69**) was cyclized to the oxazolium 5-oxide (**70**) giving bright red crystals which were then reacted with dimethyl acetylenedicarboxylate to give the cycloaddition product (**71**).[38]



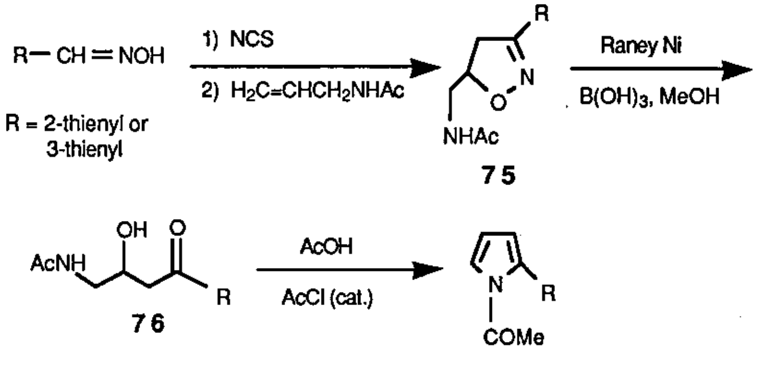
69 70 71

Another type of 1,3-dipolar cycloaddition reaction involved the use of 2-(2-thienyl)aziridines as intermediates in the synthesis of 2-(2-thienyl)pyrrole derivatives.[39] The 2-thienyl-3-aroylaziridines (**73**) were obtained by bromination of **72**, a Claisen-Schmidt reaction product, followed by reaction with cyclohexylamine. The cis and trans aziridines (**73**) were subsequently condensed with either dimethyl acetylenedicarboxylate or methyl propiolate to obtain the [2+3] cycloaddition products (**74**) in moderate yields.[39]



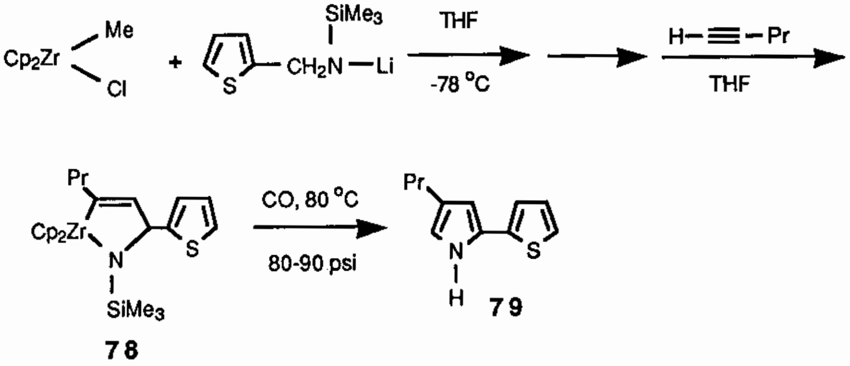
74	Ar	R
a	C_6H_5	CO_2Me
b	m-$NO_2C_6H_4$	CO_2Me
c	p-MeC_6H_4	CO_2Me
d	p-MeC_6H_4	CO_2Me
e	C_6H_5	H
f	m-$NO_2C_6H_4$	H
g	p-MeC_6H_4	H
h	p-$MeOC_6H_4$	H
i	2-naphthyl	H

Isoxazolines (**75**), formed by the reaction of chlorinated thiophene aldoximes with allyl acetamides, can be further reacted to give *N*-substituted thienylpyrroles (**77**).[40] Treatment of the isoxazoline (**75**) with Raney Ni in the presence of boric acid (to suppress over-reduction) results in the formation of compounds (**76**) which are recyclized in acetic acid to obtain the biheterocyclic compounds (**77**).

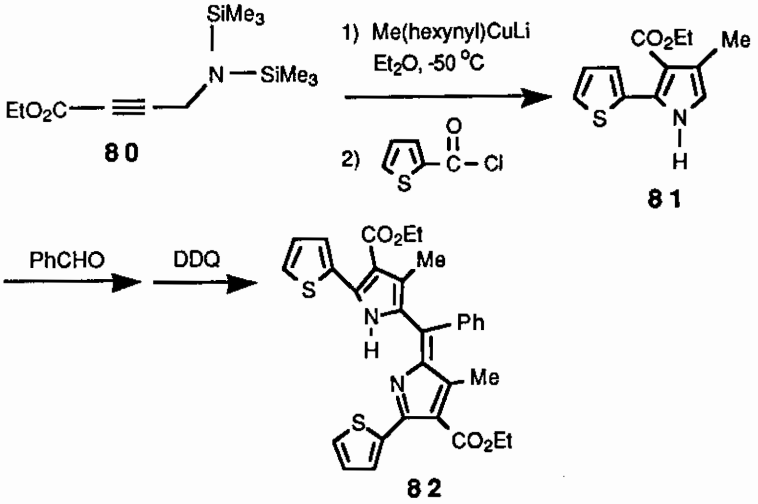


77

Pyrrole substituted biheterocycles have been synthesized *via* a transition-metal intermediate.[41] To obtain the thienylpyrrole derivative (**79**), the zirconocene complex (**78**) was synthesized in several steps and then reacted under high pressure with CO to give the substituted pyrrole (**79**) in 41% yield.



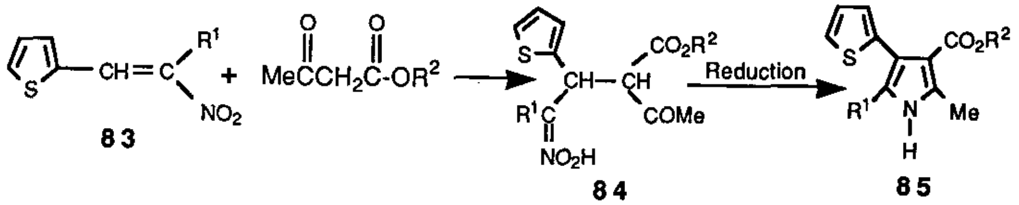
The aminosilane (**80**) was reacted with an organocuprate reagent and 2-thiophenecarbonyl chloride to give the thienylpyrrole (**81**) in moderate yield.[42] Subsequent treatment of **81** with benzaldehyde in acetic acid followed by oxidation with DDQ gave the highly conjugated red compound (**82**) in high yields.



The conformation and electronic structures of 2-(2-thienyl)pyrroles and a few of the simple derivatives have received much interest and have been studied by several groups using quantum chemical calculations,[43] photoelectron spectroscopy,[44] fluorescence spectroscopy,[45] nmr spectroscopy,[46] and dipole moments.[47]

1.3 3-Thienylpyrroles

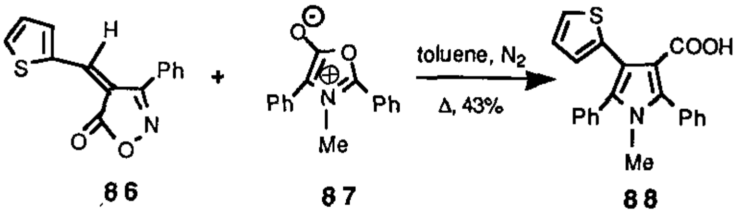
3-(2-Thienyl)pyrroles were synthesized from α-nitroolefins in low yields. The reaction of **83** with a β-keto ester results in the formation of nitronic acid (**84**) which, following reduction, affords the substituted pyrrole unit (**85**).[48]



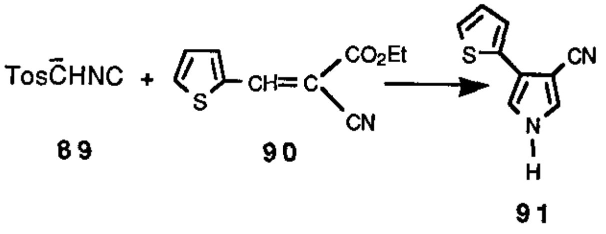
85	R^1	R^2	Reducing Agent[a]
a	Me	Et	A
b	Et	Et	A
c	C_6H_5	Et	B
d	Me	t-Bu	A

[a] A: Na_2S in NH_3(aq) and NH_4Cl
B: Zn/HCl

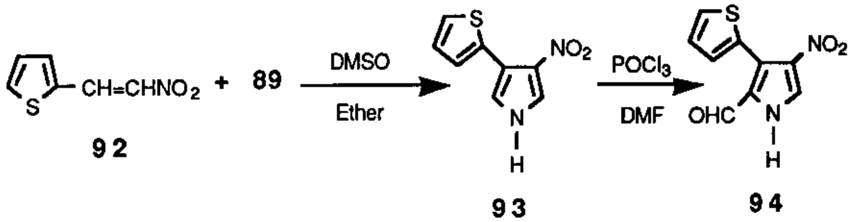
Highly substituted 3-(2-thienyl)pyrroles can also be formed by a 1,3-dipolar cycloaddition reaction of oxazolium-5-olates (**87**) with 4-arylidene-5(4H)-isoxazolones (**86**).[49] Reaction of 3-phenylisoxazol-5-one with 2-thiophene-carboxaldehyde gave **86** which was refluxed in toluene with a slight excess of dipole (**87**) to give a pyrrole-3-carboxylic acid (**88**). Details of the reaction paths and regiochemistry are discussed within.



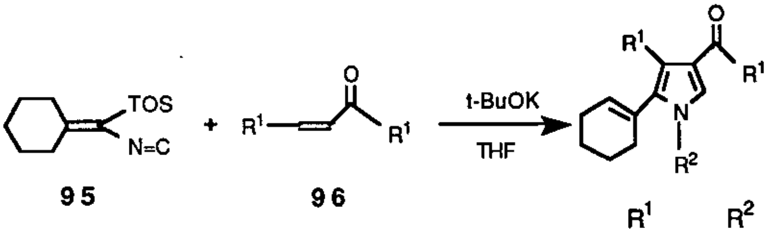
In a chapter on the synthesis of 1-H-pyrroles, Bean cites a Japanese patent referring to the synthesis of 3-(2-thienyl)-4-cyanopyrrole (**91**) from p-toluenesulfonylmethyl isocyanide and an alkene.[24] Formation of **91** occurs by the reaction of anion (**89**) with **90** in a Michael-type addition followed by the loss of a sulfinate anion and decarboxylation. Compound (**91**) was prepared for its potential use as an intermediate in the synthesis of pharmaceuticals and agrochemicals.[50]



Recently the isocyanide strategy was also employed in the synthesis of 3-(2-thienyl)-4-nitropyrrole (**93**).[51] In this case, a nitroalkene (**92**) was reacted with **89**, generated from NaH in DMSO, to give **93** in moderate yield. This compound (**93**) was then formylated in the 2-position by Vilsmeier reaction to give **94**.



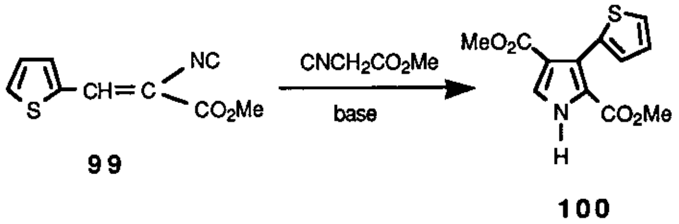
2-Alk-1′-enyl-3-arylpyrroles, of type(**97**)and(**98**) can be synthesized in high yield by Michael addition of a 1-tosylalk-1-enyl isocyanide (**95**) to **96** in the presence of base.[52] These novel alk-1-enylpyrroles can then be photochemically cyclized to give fused indole derivatives.



	R^1	R^2
97	2-thienyl	H
98[a]	2-thienyl	Me

[a] Formed in a second reaction step with MeI.

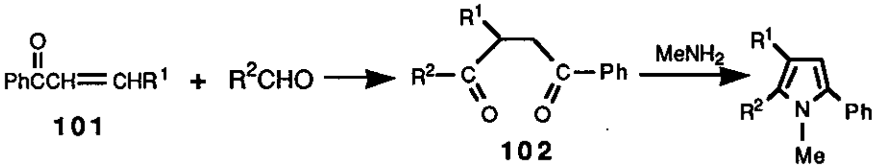
In yet another isocyanide based procedure, diester (**100**) was obtained by the reaction of methyl isocyanoacetate with the α-isocyanoacrylate (**99**) in the presence of base.[53]



2. Synthesis of Tricyclic Thienylpyrroles

2.1 2,3-Bis-(thienyl)pyrroles

Several 2,3-bis-(thienyl)pyrroles have been synthesized for study in oxidative photocyclization reactions.[54] The γ-diketone intermediate (**102**) was synthesized under Stetter reaction conditions[55] by reaction of a thiophene aldehyde with an α-β-unsaturated ketone (**101**). Treatment of the γ-diketone with aqueous methylamine gave **103** in good yield.[54]

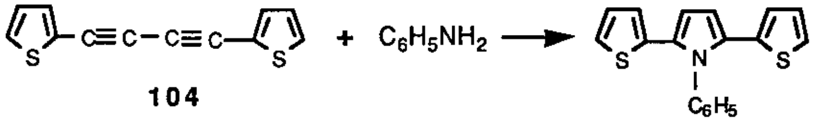


101 **102** **103**

103	R¹	R²
a	2-thienyl	2-thienyl
b	2-thienyl	3-thienyl
c	3-thienyl	2-thienyl
d	3-thienyl	3-thienyl

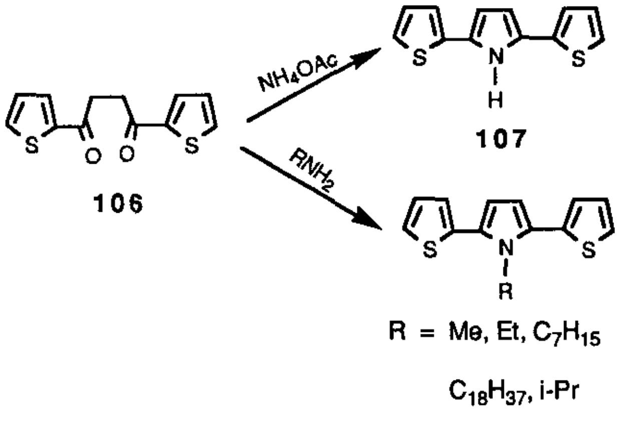
2.2 2,5-Bis-(2-thienyl)pyrrole derivatives

The triheterocyclic thienylpyrrole system which has been studied the most is 2,5-bis-(2-thienyl)pyrrole. *N*-Phenyl-2,5-bis-(2-thienyl)pyrrole (**105**) was the first compound to be synthesized in this series. It was prepared from 1,4-bis-(2-thienyl)diacetylene (**104**) and aniline in 68% yield.[56]



104 **105**

In recent years, a simple and convenient entry into the 2,5-bis-(2-thienyl)pyrrole system has been realized through the readily available 1,4-diketone (**106**)[57] which can be converted into the desired compound, in the presence of acid, with ammonium acetate[58] or primary amines.[59] The interest in this series, as monomers for conducting polymeric systems, will be further discussed in section 3.2.



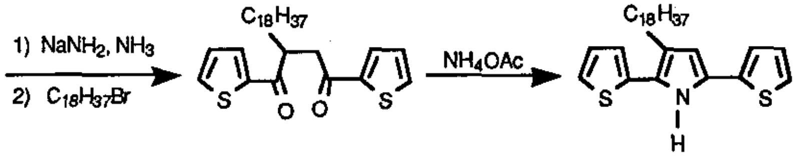
106 **107**

R = Me, Et, C_7H_{15}
$C_{18}H_{37}$, i-Pr

108

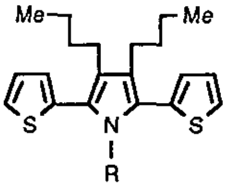
Compounds of the type (**107**) which are substituted other than on the pyrrole nitrogen, are rare and only a few have been reported.[60,61] Compound (**109**) was synthesized in moderate yield by alkylation of **106** with octadecyl bromide, followed by cyclization of the resulting diketone with ammonium acetate.[60]

106

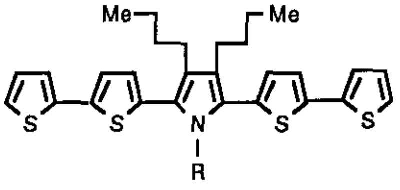


109

Compounds of the type (**110**) and (**111**) have been mentioned in a recent meeting abstract although details of the synthesis have not yet been published.[61]



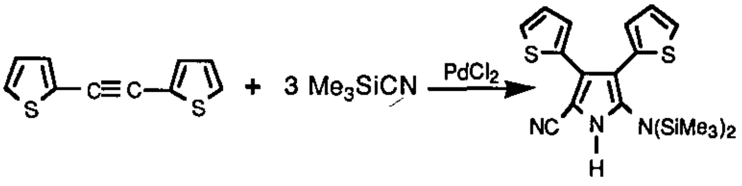
110



111

2.3 3,4-Bis-(thienyl)pyrroles

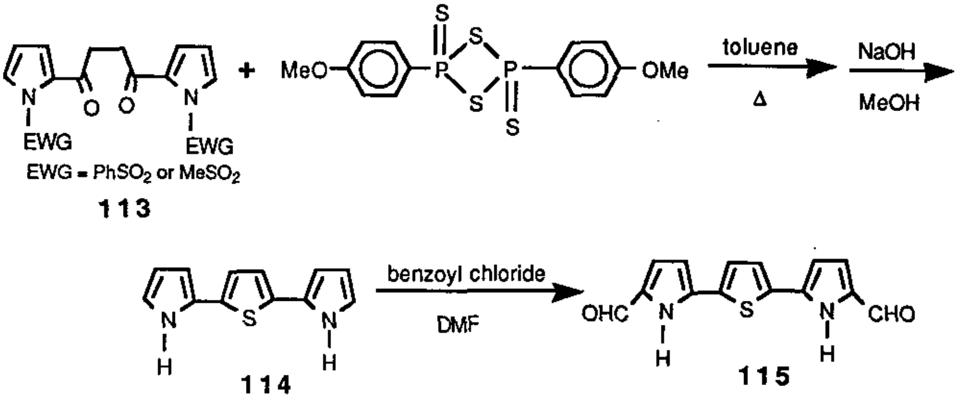
A palladium-catalyzed reaction between bis-(2-thienyl)acetylene and trimethylsilyl cyanide gave 5-amino-3,4-bis-(2-thienyl)pyrrole-2-carbonitrile (**112**) in good yield.[62]



112

2.4 2,5-Bis-(2-pyrryl)thiophenes

LeGoff developed a modified Stetter procedure for synthesizing 2,5-bis-(2-pyrryl)thiophene (**114**).[63] The low reactivity of the carbonyl group in pyrrole aldehydes and ketones required the use of electron-withdrawing groups on the pyrrole nitrogens to allow the formation of diketone (**113**). Treatment of **113** with Lawesson's reagent[64] followed by base hydrolysis afforded **114** in high yields. Formylation of the pyrrole rings could be carried out using a Clezy modified Vilsmeier reaction[65] to give **115**.

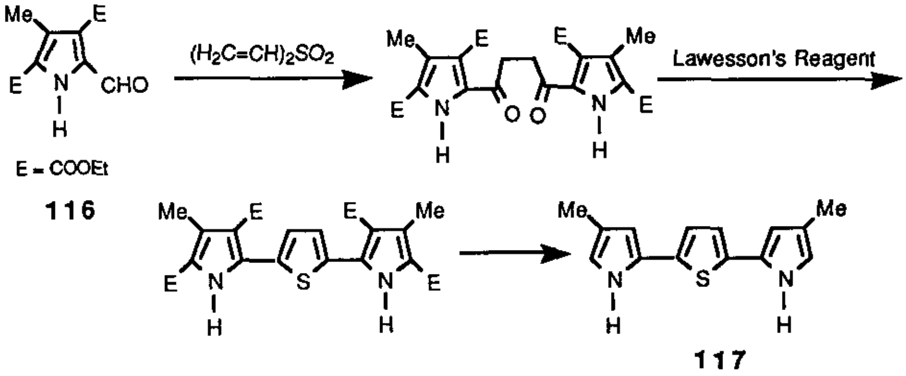


113

114

115

The closely related compound (**117**) was prepared by a different modification, as shown below, using the divinylsulfone methodology.[63] The key point of interest in this sequence is that the two ester substituents of the starting aldehyde (**116**) activate the aldehyde group sufficiently so that *N*-substitution by an electron-withdrawing group was not necessary.



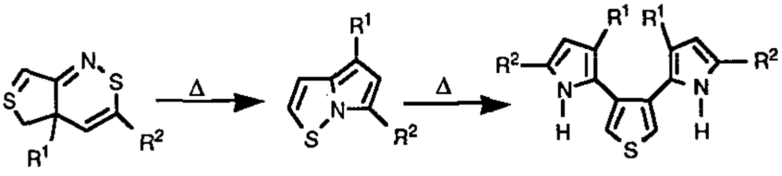
E = COOEt

116

117

2.5 3,4-Bis(2-pyrryl)thiophenes

3,4-Bis(5-ethoxycarbonyl-3-phenylpyrrol-2-yl)thiophene (**120**) was obtained in 49% yield as the thermal rearrangement product of the pyrroloisothiazole (**119**) or directly from **118** in 28% yield by using higher reflux temperatures.[66]



118

119

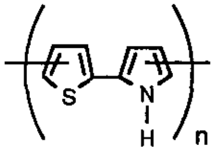
120

R^1 = Ph, R^2 = CO_2Et

3. Polymers Derived from Thienylpyrroles

3.1 Poly(thienylpyrrole)

2-(2-Thienyl)pyrrole has been electrochemically polymerized to produce bisulfate doped violet films on indium tin oxide (ITO) conducting glass.[67] The poly(thienylpyrrole) film was reported by Naitoh and coworkers to have a conductivity of up to 3.3 S/cm, which is higher by at least one order of magnitude than the conductivities of polypyrrole[68] and polythiophene[69] doped with the same anion. Aldissi and Nyitray also studied the effect that temperature variations have on the conductivity of poly(thienylpyrrole).[70] As pointed out by Pelter, the polymer obtained from 2-(2-thienyl)pyrrole "...can only be expressed by **121**, in which the order of the units is unknown, as well as the positions of linkage, the degree of branching, and the extent of crosslinking."[71]

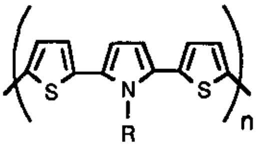


121

3.2 Poly(2,5-bis-(2-thienyl)pyrrole) and its *N*-alkyl derivatives

Unlike the case of poly(thienylpyrrole), the repeat unit of the polymers obtained from **107** and **108** must consist of alternating units of bithiophene and *N*-R-pyrrole, as represented by **122**, assuming that only α-thienyl propagation is taking place. However, it is possible that some non-α,α′-linkages may occur, and that some propagation may also take place through the β-positions of the pyrrole ring.

Most of the reported research on the polymers derived from this series has been devoted to the optical and electrochemical properties of the monomers and polymers.[58b-60,72] Some electrical conductivities have been reported in this series and they vary from 10^{-3} to 280 S/cm depending on the dopant and the method of preparation.[58b,59a,72a]



122

3.3 Copolymers of pyrrole and thiophene

Several copolymeric systems have been electrochemically prepared from pyrrole and thiophene,[73] bithiophene,[74] and terthiophene[74d,75] with the intent of modifying the physical properties of the homopolymers. In addition to studying the electrochemical behavior of the resulting copolymers, several groups have tried to establish a relationship between the stoichiometry of the copolymer and the applied potential of electropolymerization. Conductivities were reported for copolymers of pyrrole and thiophene[73] and pyrrole and terthiophene[75] ranging from 0.15 - 44 S/cm and 1 S/cm, respectively.

ACKNOWLEDGEMENTS

We thank the National Science Foundation (Grant CHE 9001714) and JVC (Japan) for support of this project.

REFERENCES

1. V. I. Shvedov, I. A. Kharizomenova, and A. N. Grinev, Khim.-Farm. Zh., 1969, 3(12), 12.
2. V. I. Shvedov, I. A. Kharizomenova, and A. N. Grinev, U.S.S.R. 251,581 (Chem. Abstr., 1970, 72, 43434y).
3. A. S. Kuzharov, V. N. Sheinker, I. A. Kharizomenova, V. I. Shvedov, O. A. Osipov, and A. N. Grinev, Zh. Obshch. Khim., 1976, 46, 2570.
4. W. Leimgruber, A. D. Batcho, and F. Schenker, J. Amer. Chem. Soc., 1965, 87, 5793.
5. H. Fujimori, Y. Kayama, T. Hara, K. Itoh, and T. Sunami, J. Heterocycl. Chem., 1977, 14, 235.
6. K. Gewald, Chem. Ber., 1965, 98, 3571.
7. S. Rault, M. Cugnon de Sevricourt, and M. Robba, C. R. Hebd. Seances Acad. Sci. Ser. C., 1978, 287, 117.
8. a) S. Rault, M. Cugnon de Sevricourt, and M. Robba, C. R. Hebd. Seances Acad. Sci. Ser. C., 1977, 284, 533; ibid., 1977, 285, 381; b) S. Rault, M. Cugnon de Sevricourt, and M. Robba, Heterocycles, 1979, 12, 1009; c) S. Rault, M. Cugnon de Sevricourt, M. Robba, and Nguyen-Huy Dung, Tetrahedron Lett., 1979, 643; d) S. Rault, M. Cugnon de Sevricourt, H. El Khashef, and M. Robba, C. R. Hebd. Seances Acad. Sci. Ser. C., 1980, 290, 169.
9. S. Vega and M. S. Gil, J. Heterocycl. Chem., 1991, 28, 945.
10. C. Laporte-Wojcik, A. Godard, S. Rault, and M. Robba, Heterocycles, 1985, 23, 1471.
11. J.-P. Rioult, M. Cugnon de Sevricourt, S. Rault, and M. Robba, J. Heterocycl. Chem., 1984, 21, 1449.
12. S. Rault, M. Cugnon de Sevricourt, and M. Robba, Rec. Trav. Chim., 1982, 101, 205.
13. a) Y. Effi, M. Cugnon de Sevricourt, S. Rault, and M. Robba, Heterocycles, 1981, 16, 1519; b) S. Rault, Y. Effi, J.-C. Lancelot, and M. Robba, Heterocycles, 1986, 24, 575.
14. S. Rault, J. C. Lancelot, Y. Effi, and M. Robba, Heterocycles, 1983, 20, 477.
15. a) S. Rault, M. Cugnon de Sevricourt, and M. Robba, Heterocycles, 1980, 14, 651; b) S. Rault, M. Cugnon de Sevricourt, Nguyen-Huy Dung, and M. Robba, J. Heterocycl. Chem., 1981, 18, 739; c) S. Rault, Y. Effi, M. Cugnon de Sevricourt, J. C. Lancelot, and M. Robba, J. Heterocycl. Chem., 1983, 20, 17; d) Y. Effi, J.-C. Lancelot, S. Rault, and M. Robba, J. Heterocycl. Chem., 1986, 23, 17; e) Y. Effi, S. Rault, J.-C. Lancelot, and M. Robba, J. Heterocycl. Chem., 1987, 24, 431.
16. A. Tomas, Nguyen-Huy Dung, and B. Viossat, Acta Cryst., 1991, C47, 2222.
17. E. B. Knott, J. Chem. Soc., 1947, 1196.
18. E. B. Knott, U.S. 2,469,830 (Chem. Abstr., 1949, 43, 7848b).
19. N. Gjøs and S. Gronwitz, Acta. Chem. Scand., 1971, 25, 2596.
20. A. Minato, K. Tamao, T. Hayashi, K. Suzuki, and M. Kumada, Tetrahedron Lett., 1981, 22, 5319.

21. B. A. Trofimov, A. I. Mikhaleva, R. N. Nesterenko, A. N. Vasil'ev, A. S. Nakhmanovich, and M. G. Voronkov, Khim. Geterotsikl. Soedin., 1977, 1136.

22. S. E. Korostova, A. I. Mikhaleva, R. N. Nesterenko, N. V. Maznaya, V. K. Voronov, and N. M. Borodina, Zh. Org. Khim., 1985, 21, 406.

23. a) L. I. Kopylova, S. E. Korostova, L. N. Sobenina, R. N. Nesterenko, M. V. Sigalov, A. I. Mikhaleva, B. A. Trofimov, and M. G. Voronkov, Zh. Obshch. Khim., 1981, 51, 1778; b) S. E. Korostova, A. I. Mikhaleva, S. G. Shevchenko, V. V. Shcherbakov, R. N. Nesterenko, M. V. Sigalov, and B. A. Trofimov, Zh. Org. Khim., 1986, 22, 2489; c) L. N. Sobenina, M. P. Sergeeva, A. I. Mikhaleva, M. V. Sigalov, S. E. Korostova, N. I. Golovanova, V. N. Salaurov, E. V. Bakhareva, and N. N. Vasil'eva, Khim. Geterotsikl. Soedin., 1990, 612.

24. L. V. Morozova, A. I. Mikhaleva, S. E. Korostova, and I. L. Filimonova In Elektron. Org. Mater., ed. by A. A. Ovchinnikov, Nauka, Moscow, 1985; pp. 305-307.

25. N. Engel and W. Steglich, Angew. Chem. Int. Ed., 1978, 17, 676.

26. a) H. Hemetsburger, D. Knittel, and H. Weidmann, Monatsh. Chem., 1969, 100, 1599; b) H. Hemetsberger and D. Knittel, Monatsh. Chem., 1972, 103, 194.

27. J. P. Boukou-Poba, M. Farnier, and R. Guilard, Tetrahedron Lett., 1979, 1717.

28. J. P. Boukou-Poba, M. Farnier, and R. Guilard, Can. J. Chem., 1981, 59, 2962.

29. a) B. A. Trofimov, S. E. Korostova, A. I. Mikhaleva, R. N. Nesterenko, M. V. Sigalov, V. K. Voronov, and R. I. Polovnikova, Zh. Org. Khim., 1982, 18, 894; b) S. E. Korostova, R. N. Nesterenko, A. I. Mikhaleva, S. G. Shevchenko, G. A. Kalabin, and R. I. Polovnikova, Khim. Geterotsikl. Soedin., 1990, 273; ibid., 1991, 337.

30. E. Campaigne and G. M. Shutske, J. Heterocycl. Chem., 1976, 13, 497.

31. G. P. Bean In The Synthesis of 1-*H*-Pyrroles, ed. by R. A. Jones, The Chemistry of Heterocyclic Compounds: Pyrroles, Part 1, John Wiley & Sons, New York, 1990, 48, p. 206.

32. H. Berner, G. Schulz, and H. Reinshagen, Monatsh. Chem., 1977, 108, 285.

33. G. Kresze, M. Morper, and A. Bijev, Tetrahedron Lett., 1977, 2259.

34. A. J. Blake, G. A. Hunter, H. McNab, J. Chem. Soc., Chem. Commun., 1990, 734.

35. C. G. Kruse, J. P. Bouw, R. van Hes, A. van de Kuilen, and J. A. J. den Hartog, Heterocycles, 1987, 26, 3141.

36. P. Messinger and C. Kunick, Synthesis, 1986, 213.

37. H. Stetter and F. Jonas, Chem. Ber., 1981, 114, 564.

38. R. Huisgen, H. Gotthardt, H. O. Bayer, and F. C. Schaefer, Chem. Ber., 1970, 103, 2611.

39. a) J. W. Lown and K. Matsumoto, Can. J. Chem., 1970, 48, 2215; ibid., 1970, 48, 3399.

40. S. S. Ghabrial, I. Thomsen, and K. B .G. Torssell, Acta Chem. Scand., Ser. B, 1987, 41, 426.

41. S. L. Buchwald, M. W. Wannamaker, and B. T. Watson, J. Am. Chem. Soc., 1989, 111, 776.

42. R. J. P. Corriu, G. Bolin, J. J. E. Moreau, and C. Vernhet, J. Chem. Soc., Chem. Commun., 1991, 211.

43. V. Galasso, M. Milun, and N. Trinajstic´, Z. Naturforsch., 1973, 28, 464.

44. a) Galasso, L. Klasinc, A. Sabljic´, N. Trinajstic´, G. C. Pappalardo, and W. Steglich, J. Chem. Soc., Perkin Trans. 2, 1981, 127; b) V. K. Turchaninov, K. B. Petrushenko, A. F. Ermikov, and A. I. Vokin, Khim. Geterotsikl. Soedin., 1989, 9, 1213; c) V. K. Turchaninov, A. F. Ermikov, S. E. Korostova, and V. A. Shagun, Zh. Obshch. Khim., 1989, 59, 791.

45. D. Birnbaum and B. E. Kohler, J. Chem. Phys., 1991, 95, 4783.

46. A. V. Afonin, V. K. Voronov, A. I. Mikhaleva, R. N. Nesterenko, R. I. Polovikova, N. O. Saldabol, and B. A. Trofimov, Izv. Akad. Nauk SSSR, Ser. Khim., 1987, 184.

47. a) A. S. Kuzharov, V. N. Sheinker, I. A. Kharizomenova, V. I. Shvedov, O. A. Osipov, and A. N. Grinev, Zh. Obshch. Khim., 1976, 46, 2570; b) B. A. Trofimov, V. B. Modonov, T. N. Aksamentova, A. I. Mikhaleva, S. E. Korostova, L. N. Sobenina, R. N. Nesterenko, and R. I. Polovnikova, Izv. Akad. Nauk SSSR, Ser. Khim., 1987, 1322.

48. a) F. Boberg, K.-H. Garburg, K. J. Görlich, E. Pipereit, and M. Ruhr, Liebigs Ann. Chem., 1985, 239; b) F. Boberg, M. Ruhr, K. -H. Garburg, and A. Garming, J. Heterocycl. Chem., 1986, 23, 759.

49. F. Clerici, E. Erba, P. Mornatti, and P. Trimarco, Chem. Ber., 1989, 122, 295.

50. G. Genda and S. Nakayama, Jpn. Pat. 86,200,984 (Chem. Abstr., 1987, 106, 119691y).

51. N. Ono, E. Muratani, and T. Ogawa, J. Heterocycl. Chem., 1991, 28, 2053.

52. J. Moskal and A. M. van Leusen, J. Org. Chem., 1986, 51, 4131.

53. K. Matsumoto, M. Suzuki, Y. Ozaki, and M. Miyoshi, Agric. Biol. Chem., 1976, 40, 2271.

54. D. M. Perrine, J. Kagan, D.-B. Huang, K. Zeng, and B.-K. Teo, J. Org. Chem., 1987, 52, 2213.

55. H. Stetter, Chem. Ber., 1985, 118, 3172.

56. K. E. Schulte, J. Reisch, and H. Walker, Chem. Ber., 1965, 98, 98.

57. H. Stetter, Angew. Chem., Int. Ed., 1976, 15, 639.

58. a) H. Wynberg and J. Metselaar, Synth. Commun., 1984, 14, 1; b) G. G. McLeod, M. G. B. Mahboubian-Jones, R. A. Pethrick, S. D. Watson, N. D. Truong, J. C. Galin, and J. Francois, Polymer, 1986, 27, 455.

59. a) J. P. Ferraris and G. D. Skiles, Polymer, 1987, 28, 179; b) J. P. Ferraris, R. G. Andrus, and D. C. Hrncir, J. Chem. Soc., Chem. Commun., 1989, 1318.

60. J. P. Ferraris and M. D. Newton, Polymer, 1992, 33, 391.

61. M. E. Benz and E. LeGoff, Abstracts of Papers, Thirteenth International Congress of Heterocyclic Chemistry, Corvallis, OR, Cascade Printing, Corvallis, OR, 1991, Abstract P02-77.

62. N. Chatani and T. Hanafusa, Tetrahedron Lett., 1986, 27, 4201.

63. B. A. Merrill and E. LeGoff, J. Org. Chem., 1990, 55, 2904.

64. B. S. Pederson, S. Scheibye, N. H. Nilsson, and S.-O. Lawesson, Bull. Soc. Chim. Belg., 1978, 87, 223.

65. R. Chong, P. S. Clezy, A. J. Liepa, and A. W. Nichol, Aust. J. Chem., 1969, 22, 229.

66. R. S. Gairns, R. D. Grant, C. J. Moody, C. W. Rees, and S. C. Tsoi, J. Chem. Soc., Perkin Trans. 1, 1986, 491.

67. a) S. Naitoh, K. Sanui, and N. Ogata, J. Chem. Soc., Chem. Commun., 1986, 1348; b) S. Naitoh, Synth. Met., 1987, 18, 237.

68. M. Salmon, A. F. Diaz, A. J. Logan, M. Krounbi, and J. Bargon, Mol. Cryst. Liq. Cryst., 1982, 83, 26.

69. R. J. Waltman, J. Bargon, and A. F. Diaz, J. Phys. Chem., 1983, 87, 1459.

70. M. Aldissi and A. M. Nyitray In Electrochemical Synthesis and Characterization of New Polyheterocycles, ed. by M. J. Comstock, ACS Symposium Series, 346, American Chemical Society, Washington, DC, 1987, pp. 559-567.

71. A. Pelter, M. Rowlands, and I. H. Jenkins, Tetrahedron Lett., 1987, 28, 5213.

72. a) J. P. Ferraris and T. R. Hanlon, Polymer, 1989, 30, 1319; b) M. T. Zhao, M. Samoc, B. P. Singh, and P. N. Prasad, J. Phys. Chem., 1989, 93, 7916; c) J. P. Ferraris, R. G. Andrus, R. Wiser-Halladay, and D. C. Hrncir, New Polymeric Mater., 1990, 2, 41.

73. S. Kuwabata, S. Ito, and H. Yoneyama, J. Electrochem. Soc., 1988, 135, 1691.

74. a) B. L. Funt, E. M. Peters, and J. D. Van Dyke, J. Polym. Sci., Part A: Polym. Chem. Ed., 1986, 24, 1529; b) D. Gningue, G. Horowitz, and F. Garnier, J. Electrochem. Soc., 1988, 135, 1695; c) E. M. Peters and J. D. Van Dyke, J. Polym. Sci., Part A: Polym. Chem. Ed., 1991, 29, 1379; d) W. Torres and M. A. Fox, Chem. Mater., 1992, 4, 146. For a closely related study, see also other references cited therein.

75. O. Inganäs, B. Liedberg, W. Chang-Ru, and H. Wynberg, Synth. Met., 1985, 11, 239.

PATENTS

1. 4*H*-Pyrrolo[1,2-*a*]thieno[3,2-*f*][1,4]diazepines; Chem. Abstr., 1978, **88**, 50934v.

2. Phthalimidomethylpyrrolylthiophenes; Chem. Abstr. 1978, **88**, 22621x.

3. Antiinflammatory 4,5-diaryl-2-(substituted thio)pyrroles and their corresponding sulfoxides and sulfones; Chem. Abstr., 1981, **95**, 61982e.

4. Conductive polymers; Chem. Abstr., 1986, **105**, 98165s.

5. Conductive polymers; Chem. Abstr., 1986, **105**, 98166t.

6. 1-Alkylpyrrole derivatives; Chem. Abstr., 1983, **99**, 139759s.

7. 1-Alkylpyrroles; Chem. Abstr., 1983, **99**, 175585r.

8. Sulfenylpyrroles as fungicides; Chem. Abstr., 1984, **100**, 6324p.

9. Use of pyrroles as biocides for the protection of materials; Chem. Abstr., 1984, **101**, 124892r.

10. Pyrrolecarbonitrile derivatives; Chem. Abstr., 1987, **106**, 119691y.

11. Polymerization of five-membered heterocyclic compounds; Chem. Abstr., 1988, **108**, 6634e.

12. Composite organic electrophotographic photoconductors; Chem. Abstr., 1988, **108**, 195892w.

13. A conductive polymer composite containing manganese dioxide and its manufacturing; Chem. Abstr., 1989, **110**, 162517r.

14. Electrochemical synthesis of electrically conductive alternating copolymers; Chem. Abstr., 1989, **111**, 165457c.

15. Phthalocyanine derivatives as photochromic substances; Chem. Abstr., 1989, **111**, 184251x.

16. Conductive polymers, their preparation and conjugation to analyte probes, and their use in diagnostic devices; Chem. Abstr., 1990, **112**, 51794a.

17. Preparation of bithiophene compounds as herbicides; Chem. Abstr., 1990, **113**, 97444k.

18. Preparation of 2,5-dithienylpyrrole monomers for semi-conducting oligomers; Chem. Abstr., 1991, **114**, 207015b.

19. Manufacture of solid electrolytic capacitor using polymer of thiophene derivative as electrolyte; Chem. Abstr., 1991, **115**, 83680p.

20. Preparation of 4*H*-pyrrolo[1,2-*a*]thieno[3,2-*f*][1,4]diazepines and analogs as cholecystokinin antagonists; Chem. Abstr., 1991, **115**, 256242c.

21. Preparation of pyrrolo[1,2-*a*]thieno[3,2-*f*][1,4]diazepines as drugs; Chem. Abstr., 1992, **116**, 41491t.

22. Preparation of 2-aryl- and 2,5-diarylthiophenes as photosensitizers; Chem. Abstr., 1992, **116**, 59201h.

Received, 18th May, 1992