# Electrochemical Reduction of Substituted Isothiazole-3-thiones in Aprotic Media

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The title compounds are obtained in good yields from 1,2-dithiole-3-thiones. Using cyclic voltammetry in dimethylformamide, two kinds of behaviour are evidenced and discussed in terms of the aromaticity of the 5-substituent (Ar). With Ar = pyrazinyl or pyridazinyl, isothiazole-3-thiones undergo an electrochemical chemical electrochemical mechanism and the rate constant of the chemical step has been deduced from voltammetric measurements. When the aromaticity increases (Ar = pyridyl or phenyl) an apparent one-step irreversible two-electron addition occurs. Whatever the nature of Ar the resulting two-electron reduction product has been isolated after controlled-potential electrolysis (CPE). In addition, in acetonitrile, CPE affords a thiophene derivative as a secondary product.

In previous papers, we reported the chemical reactions of 1,2-dithiole-3-thiones with sodium ethanethiolate [1,2] and sodium cyanide,[3] in aprotic solvents or alcohols. Recently, we have
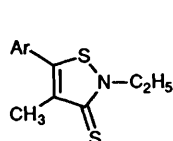
	Ar
1	Pyrazin-2-yl
2	Pyridazin-3-yl
3	Pyrimidin-5-yl
4	2-Pyridyl
5	Phenyl

turned our attention to the reaction of 1,2-dithiole-3-thiones with ethylamine to provide further information on the electrophilic character of the dithiole thione ring, and isothiazole-3-thiones have been isolated. These compounds, obtained in good yields, resulted from attack by ethylamine at the C-3 position of the 1,2-dithiole-3-thione ring. We examine in this paper the electrochemical reduction of isothiazole-3-thiones, in aprotic solvents, at a stationary platinum electrode.

Using cyclic voltammetry (CV), two kinds of behaviour are evidenced in the series studied, depending on the nature of Ar, while controlled-potential electrolysis (CPE) in N,N-dimethylformamide (DMF) or acetonitrile (ACN), followed by methylation of the intermediate, yields the thioamide **6** as the main product. Furthermore, in ACN, a thiophene derivative **8** has been obtained as the secondary product, in addition to the predominant thioamide.

Results and Discussion

The substituted isothiazole-3-thiones **1–5** were isolated after addition of an excess of ethylamine to a solution of the corresponding 1,2-dithiole-3-thione in dichloromethane (see Experimental), in markedly higher yields than those reported previously.[4,5] Our studies led us to the conclusion that 1,2-dithiole-3-thiones are transformed via attack at the C-3 position by ethylamine according to a mechanistic pathway in which the disulfide intermediate extrudes hydrogen sulfide (Scheme 1).

Scheme 1
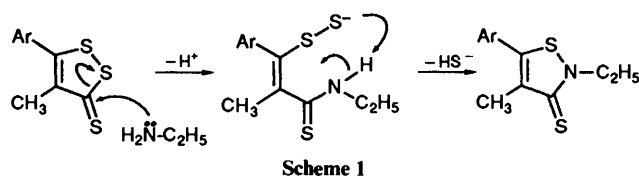
Cyclic Voltammetry in DMF at the Stationary Platinum Elec-

trode.—The voltammetric behaviour of isothiazole-3-thiones depends on the nature of the aryl substituent.

Ar = *Pyrazin-2-yl* (**1**) *or pyridazin-3-yl* (**2**).—When **1** is dissolved in DMF containing tetraethylammonium tetrafluoroborate (TEATFB) (0.05 mol dm^{-3}), two cathodic peaks, denoted P_{c1} and P_{c2}, are recorded at -1380 and -1900 mV vs. SCE, respectively [Fig. 1(a)]. At a given scan rate v, the heights of P_{c1} and P_{c2}, i_{Pc1} and i_{Pc2}, are proportional to c, where c is the concentration of **1**. With the height of the first cathodic peak of 9-fluorenone (under the same experimental conditions) being taken as a reference, it appears that P_{c1} and P_{c2} are due to monoelectronic processes.

When the potential scan is reversed after P_{c2}, two anodic peaks P_{a2} and P_{a1} appear in the reverse sweep of the cyclic voltammogram showing the reversibility of the monoelectronic transfer. The characteristics $E_{Pc1} - E_{Pc1}/2$ (difference between the peak potential and the potential at half-peak height), $E_{Pc1} - E_{Pa1}$, $i_{Pc1}/v^{\frac{1}{2}}$ and i_{Pa1}/i_{Pc1} are found to be as predicted theoretically for a reversible and diffusion-controlled one-electron transfer, at least when v is higher than 5 V s^{-1} (c 1 mmol dm^{-3}).

When v is lower than 5 V s^{-1}, the chemical reversibility decreases until no anodic peak is recorded when v is lower than 0.2 V s^{-1}. Accordingly, the observed increase in the ratio $i_{Pc}/v^{\frac{1}{2}}$ with decreasing v suggests the occurrence of an electrochemical chemical electrochemical (ECE) mechanism, in which the radical anion resulting from the first electron addition is involved in a chemical step yielding a species more reducible than **1**. These results can be compared with those given in the literature in the case of an ECE mechanism, when the chemical step consists of a first (or pseudo-first) order reaction.[6] For a system such as the ECE mechanism, there are several ways of determining the rate constant k for the chemical reaction.
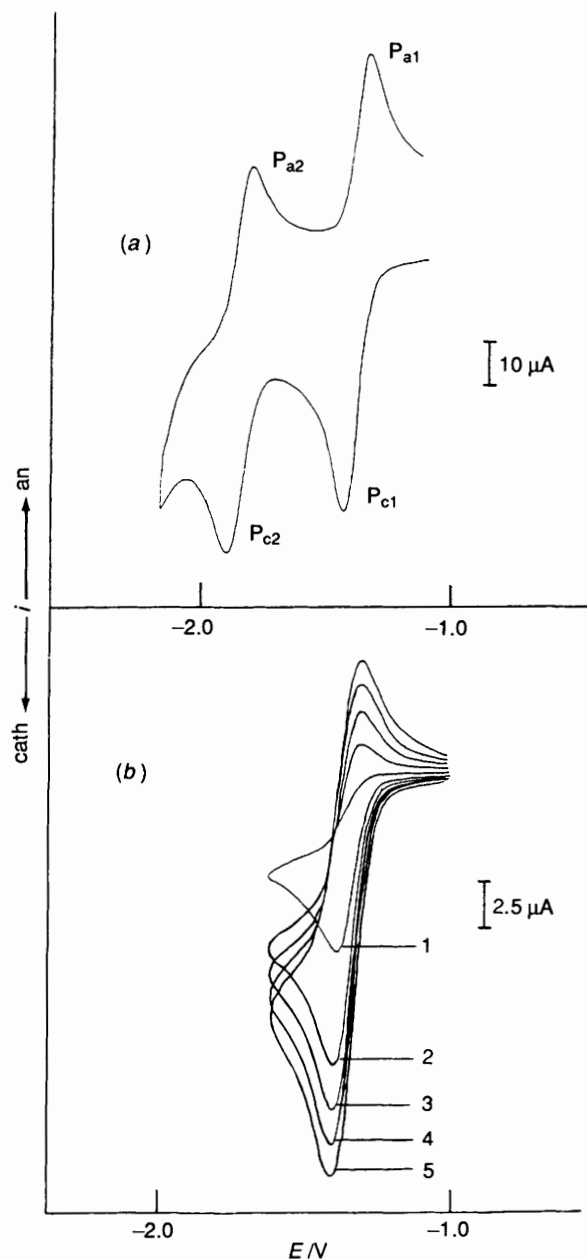
Firstly, the most convenient procedure is to use the cathodic peak P_{c1} alone. In this case, the empirical eqn. (1) can be used according to the method described in ref. 6.

$$i_k/i_d = (0.4 + k/a)/(0.396 + 0.469\,k/a) \qquad (1)$$

In this equation, i_k is the peak current measured at a scan rate such that kinetic effects are observed ($0.02 < v < 0.2$ V s^{-1}), and i_d is the diffusion-controlled peak current which would have been measured at the same scan rate in the absence of kinetic effects. The latter can be obtained from experimental data at high rates of voltage scan where the kinetic effects are small. If i_k and i_d are obtained at different scan rates, the data can be normalized by eqn. (2), where v_d is the rate of potential

Table 1 Measurements of i_{Pc1} and i_{Pc2} after addition of increasing quantities of acetic acid (or thiophenol) to a solution of **1** (c 1 mmol dm^{-3}), in DMF containing TEATFB 0.05 mol dm^{-3}; $v = 10$ V s^{-1}

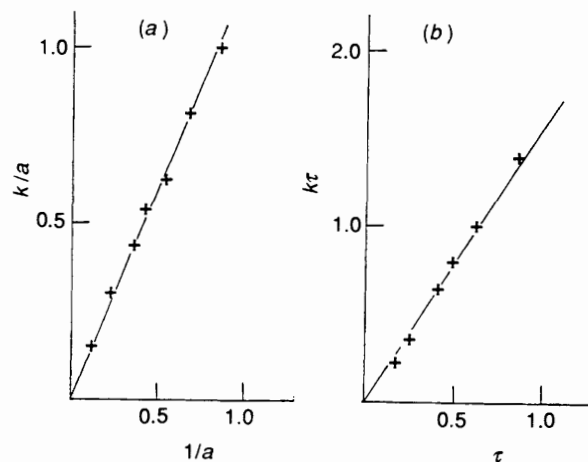| [Acetic acid]/mmol dm^{-3}	i_{Pc1}/μA	i_{Pc2}/μA
0.0	72	60
0.2	85	40
0.4	92	29
0.6	96	18
0.8	98	10
1.0	105	—

Fig. 2 Determination of k for the ECE reduction mechanism of **1**. (a) values of k/a, obtained from the current ratio i_k/i_d, $vs.$ $1/a$ ($a = nFv/RT$) at various values of v; (b) values of $k\tau$, obtained from the current ratio i_{Pa}/i_{Pc} using the cyclic voltammogramm of Fig. 1 (b), $vs.$ τ (τ is the time in seconds from E_1 to the switching potential) at various values of v.

Fig. 1 Cyclic voltammetry of **1** in DMF containing TEATFB 0.05 mol dm^{-3}; $c = 1$ mmol dm^{-3}: (a) $v = 5$ V s^{-1} and (b) $v = 0.2$ V s^{-1} (1); $v = 0.4$ V s^{-1}, (2); $v = 0.6$ V s^{-1}, (3) $v = 0.8$ V s^{-1}, (4); $v = 1$ V s^{-1} (5)

$$i_k/i_d = i_k v_k^{-\frac{1}{2}}/i_d \cdot v_d^{-\frac{1}{2}} \tag{2}$$

scan at which i_d, is measured. In this case, v_d could be any value larger than $ca.$ 5 V s^{-1}. Using eqn. (1), the values of k/a (where a is defined as nFv/RT) are deduced from the ratio i_k/i_d and

plotted $vs.$ $1/a$ [Fig. 2(a)]. The rate constant determined by the slope of the curve is 1.2 ± 0.2 s^{-1}.

Secondly, the observed increase in the ratio i_{Pa}/i_{Pc} of anodic to cathodic peak currents with increasing v [$v \geqslant 0.2$ V s^{-1}, Fig. 1(b)] can be used for a quick estimate of the rate constant. In ref. 6, it was found that for this type of ECE mechanism, the ratio i_a/i_c is a constant for a constant value of $k\tau$ (where τ is defined as the time in seconds from $E^{\ominus}$ to the switching potential) and furthermore, it was found that the working curve relating i_a/i_c and $k\tau$ was the same as the previously presented [7] for a system in which a reversible charge transfer is followed by a single irreversible chemical reaction. Using this working curve, values of $k\tau$ are obtained from the experimental ratio of i_a/i_c for different scan rates. These data are plotted $vs.$ τ [Fig. 2(b)] and the rate constant obtained from the slope of the curve is 1.5 ± 0.3 s^{-1}.

The same ECE mechanism is similarly followed using **2** as starting material; then we found $k = 6 \pm 1$ s^{-1}.

In addition, we can point out that: (a) there is no significant dependence of k upon the starting material concentration ($0.5 < c < 2$ mmol dm^{-3}), a result which confirms the assumption concerning the order of the chemical reaction; and (b) addition of a proton donor (acetic acid or thiophenol) to a solution of **1** results in significant dependence of i_{Pc1} and i_{Pc2} upon the proton donor concentration. Data listed in Table 1 prove that the chemical reaction involved is proton transfer interposed between two electron uptakes.

Ar = *Pyrimidin-5-yl* (**3**), *2-pyridyl* (**4**) *or phenyl* (**5**). The cyclic voltammetric behaviour of analogues **3–5** differs markedly from that of **1** and **2**: an apparent one-step irreversible two-electron reduction occurs, regardless of the potential sweep rate v. A cathodic peak P_c due to two-electron irreversible reduction is recorded at -1600 mV $vs.$ SCE, v being 5 V s^{-1}, while no anodic peak is observed in the reverse sweep of the cyclic voltammogram.

Controlled Potential Electrolysis.—In DMF. With the controlled potential of the platinum working electrode held more negative than E_{Pc1} (Table 2), a coulometric value of 2.0 ± 0.1 is found for the number of electrons n involved in the reduction of one molecule of **1**. From this result it seems reasonable to assume that the electrochemical pathway implies a major two-electron reduction process.

The progress of electrolysis was followed by UV–VIS absorption spectrometry. As the electrolysis proceeds, a decrease in absorption bands shown by the starting material at 290 and 404
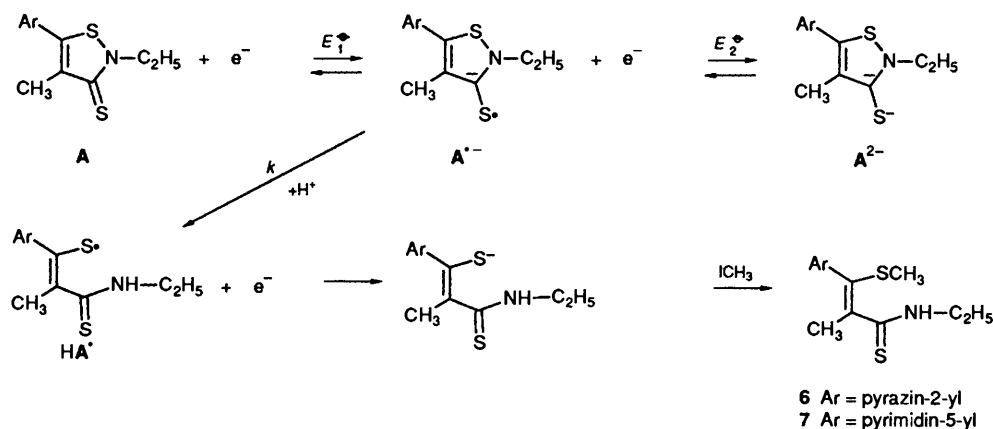
Table 2 The potential of the working platinum electrode (E); the number of electrons involved in the electrochemical reduction (n); and the products and yields of controlled potential electrolyses (DMF and ACN)

| Solvent	Starting material	n	E/mV vs. SCE	Product	Yield (%)
DMF	1	2.0	−1600	6	60
	3	1.9	−1650	7	61
ACN	1	1.2	−1600	6	45
				8	20
	3	1.5	−1650	7	55
				9	10
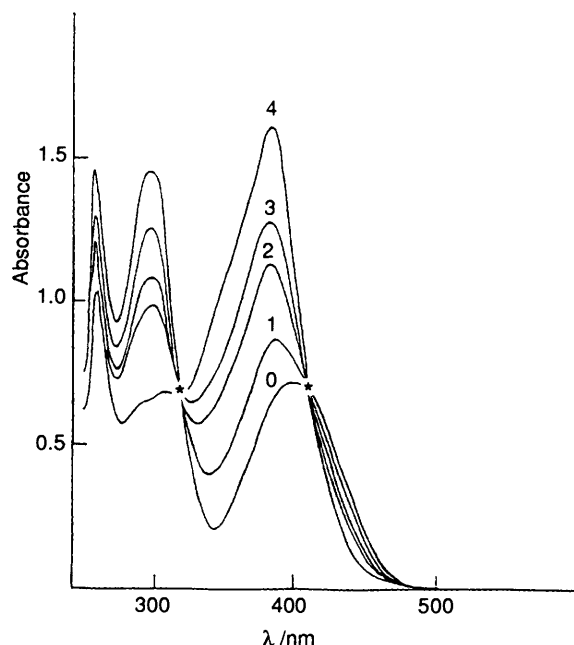
Fig. 3 Spectrophotometric changes accompanying the electrochemical reduction of **1** (1 mmol dm^{-3}) in DMF; cell thickness 0.1 cm; number of electrons: (0) 0 (before electrolysis); (1) 0.50; (2) 1.00; (3) 1.30; (4) 2.00. The asterisks mark the isosbestic points appearing during the electrochemical reduction.

nm is observed while a new band at 382 nm develops. The spectral changes show two isosbestic points at 318 and 412 nm, indicating that a simple reaction has taken place (Fig. 3).

After the addition of an excess of methyl iodide to the exhaustively reduced solution, the major product **6** was isolated in *ca.* 60% yield. The ^{1}H NMR, UV–VIS absorption spectrum and MS data are in agreement with the thioamide structure **6** (Scheme 2). With analogue **3**, a similar two-electron reduction process occurs yielding the corresponding thioamide **7** in good yield as indicated in Table 2.

In ACN. CPE of **1** carried out in ACN yields different results. A coulometric value of 1.2 ± 0.1 is found (Table 2). Compound **6** is obtained, but its extent corresponds to 45% of the amount of **1** existing before reduction, while a new product is isolated in 20% yield. The ^{1}H NMR, UV–VIS absorption spectrum and MS data are in agreement with the substituted thiophene structure **8** (Scheme 3).

1 Ar = pyrazin-2-yl
3 Ar = pyrimidin-5-yl

8 Ar = pyrazin-2-yl
9 Ar = pyrimidin-5-yl
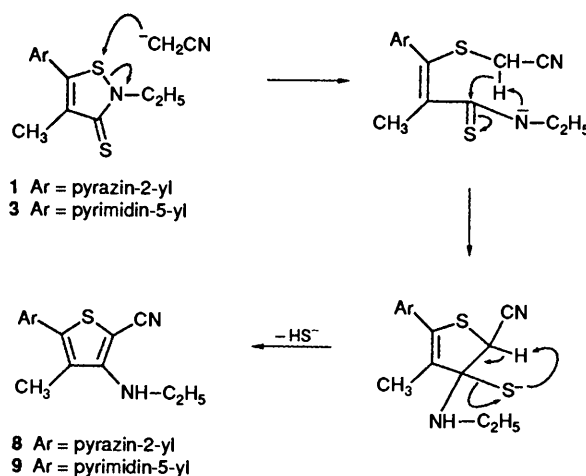
Scheme 3

Mechanistic Deductions.—In the electrochemical reduction of isothiazole-3-thiones, it is possible to distinguish two kinds of behaviour depending on the nature of the solvent.

In DMF. With Ar = pyrazin-2-yl (**1**) or pyridazin-3-yl (**2**), fast electrochemical techniques demonstrate the transient formation of the anion radical A$^{\cdot-}$ resulting from the reversible addition of one electron to the isothiazole-3-thione moiety. The standard potentials E_1° and E_2° of the redox couples A/A$^{\cdot-}$ and A$^{\cdot-}$/A^{2-} have been measured in DMF and are gathered in Table 3.

The data obtained by means of CV fit well with the diagnostic criteria for an ECE mechanism and the rate constant k of the


6 Ar = pyrazin-2-yl
7 Ar = pyrimidin-5-yl

Scheme 2

Table 3 Standard redox potentials, E°, and rate constants k for compounds **1** and **2** in DMF containing TEATFB, 0.05 mol dm^{-3} at 25 °C

Ar	$E_1^{\circ\,a}$/mV	$E_2^{\circ\,b}$/mV	k/s^{-1}
Pyrazin-2-yl	-1350 ± 5	-1870 ± 5	1.2 ± 0.2
Pyridazin-3-yl	-1420 ± 5	-1900 ± 5	6 ± 1

^{a} Redox couple A/A$^{\cdot-}$. ^{b} Redox couple A$^{\cdot-}$/A^{2-}.

chemical reaction has been calculated. This intermediate chemical reaction is certainly the ring-opening protonation of A$^{\cdot-}$, the proton donor probably being the residual water. That CPE afforded the N-protonated thioamide **6** may account for this hypothesis (Scheme 2).

With Ar = pyrimidin-5-yl (**3**), 2-pyridyl (**4**) or phenyl (**5**), the electrochemical reduction proceeds through an apparent one-step irreversible two-electron transfer. These differences in the electrochemical behaviour can be discussed in terms of aromaticity and/or the electron-withdrawing effect of the aryl substituent. The presence of an electron-withdrawing substituent at the C-5 position has an effect on total charge distribution on radical anion A$^{\cdot-}$. Therefore, when Ar is pyrazin-2-yl or pyridazin-3-yl, A$^{\cdot-}$ can undergo delocalization which involves the aryl substituent, resulting in a lower basicity of the isothiazole-3-thione moiety (Scheme 4).
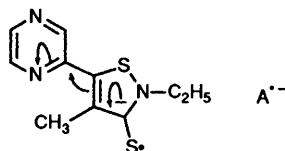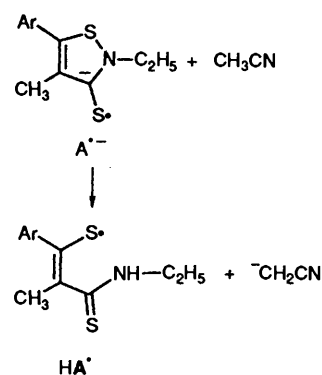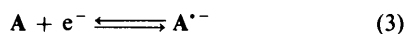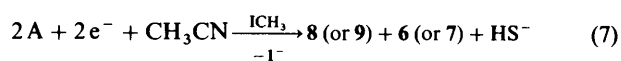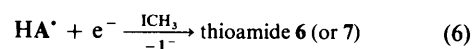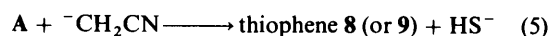
Scheme 4

If this explanation is true, the anion radical A$^{\cdot-}$ delocalization should decrease with increasing aromaticity of the Ar substituent (phenyl or 2-pyridyl), or when the ring nitrogen is not in a convenient position (pyrimidin-5-yl). A comparison of compounds **1–5** shows that this is indeed the case. With compounds **3–5**, the anion radical A$^{\cdot-}$ (electrochemically formed) would be more basic because of the lack of the electron-withdrawing tendency of the aryl substituent and, therefore, the rate constant of the intermediate chemical step (protonation) would be much higher so that an apparent one-step irreversible two-electron reduction occurs.

In ACN. Besides the major product **6** (or **7**), a thiophene derivative **8** (or **9**) was yielded as secondary product, whose production can be justified by the occurrence of an acid–base equilibrium yielding the acetonitrile anion $^-$CH$_2$CN. To prove that carbanion formed by proton abstraction from CH$_3$CN, a solution of **1** (or **3**), in ACN, was made alkaline by adding tetrabutylammonium hydroxide (TBAH) in a stoichiometric 1:1 ratio. As the thiophene derivative **8** (or **9**) was then chemically produced in good yield (63%), it can be concluded that TBAH is a sufficiently strong base in ACN to generate the acetonitrile anion $^-$CH$_2$CN, which undergoes condensation with **1** (or **3**) according to Scheme 3.

Similarly, in the course of the controlled-potential electrolysis, the radical anion A$^{\cdot-}$ would be a sufficiently strong base to generate the acetonitrile anion according to the acid–base reaction shown in Scheme 5.

If the two competitive pathways (Schemes 1 and 2) occurred equally, the value of n would be 1.0, according to eqns. 3–6.

$$A + e^- \rightleftharpoons A^{\cdot-} \tag{3}$$

$$A^{\cdot-} + CH_3CN \longrightarrow HA^\cdot + {}^-CH_2CN \tag{4}$$

Scheme 5

$$A + {}^-CH_2CN \longrightarrow \text{thiophene } 8 \text{ (or } 9) + HS^- \tag{5}$$

$$HA^\cdot + e^- \xrightarrow[-1^-]{ICH_3} \text{thioamide } 6 \text{ (or } 7) \tag{6}$$

$$2A + 2e^- + CH_3CN \xrightarrow[-1^-]{ICH_3} 8 \text{ (or } 9) + 6 \text{ (or } 7) + HS^- \tag{7}$$

[overall eqn. (7)]. In contrast, n would be 2.0 if Scheme 2 were the sole pathway. That thiophene **8** (or **9**) was afforded in 20% (or 10%) yield when performing CPE on a preparative scale, is consistent with the experimental values found for n and listed in Table 2. Thus, with **1**, n was found to be 1.2 and 2.0 in ACN and DMF, respectively, although ACN would be a better proton donor than DMF and hence the two-electron reduction would seem more preferred in ACN. However, a particular feature of the solvents, used as delivered, is their water content; found in the two cases to be *ca.* 10 mmol dm^{-3}. From these data, it appears safe to conclude that: (a) the most likely proton donor is the residual water, so that the proton donor abilities of DMF and ACN are, at first glance, of the same order of magnitude in the series studied (accordingly, the voltammograms recorded at slow scan rates are roughly identical in DMF and ACN); and (b) ACN exerts principally second-order effects through its ability to yield thiophene derivatives when CPE was performed in a preparative scale. Similar reactions have been investigated previously in the literature. They afford thiophene derivatives and involve selected carbanions, namely benzoyl acetate, diethyl benzylphosphonate,[8] sulfonium ylides or phenacylidene–dimethylsulfurane,[9] but electrochemical synthesis has not yet been reported to the best of our knowledge.

Experimental

Materials.—1,2-Dithiole-3-thiones were supplied by Rhone-Poulenc-Rorer. The solvents used for extraction and chromatography and acetic acid were obtained from SDS. N,N-Dimethylformamide (DMF), acetonitrile (ACN), methyl iodide, thiophenol and ethylamine were Merck products. Tetraethylammonium tetrafluoroborate (TEATFB) and tetrabutylammonium hydroxide (TBAH) were obtained from Fluka.

General.—M.p.s were determined on a Köfler block and were uncorrected. Elemental analysis was performed at the CNRS Centre of Microanalysis (Gif sur Yvette). UV–VIS spectra were recorded on a Varian DMS-90. ^{1}H NMR (300 MHz) spectra were obtained with a Bruker WM-300 spectrometer using CDCl$_3$ as the solvent. SiMe$_4$ was used as internal standard. Coupling constants are given in Hz. Chemical-ionization (CI; NH$_3$) mass spectrometry (MS) was carried out on a Riber R10-10C instrument.

Electrochemical measurements were made with a Tacussel PRG 5 multipurpose polarograph which was used simply as a rapid-response potentiostat. For cyclic voltammetry, triangular waveforms were supplied by a Tacussel GSTP 4 function generator. Current-potential curves were recorded on a Sefram SI 8312 instrument. The cell was a Tacussel CPRA water-jacketted cell, whose temperature was 25 °C. The reference electrode was a saturated calomel electrode (SCE) to which all potentials have been referred. The counter electrode was a platinum Tacussel Pt 11. The working electrode was a platinum disc (effective area 0.040 cm²) of a Tacussel EDI rotating electrode connected to a Tacussel Controvit servocontrol electronic amplifier and used without particular pre-treatment. CPEs were carried out using a three-compartment water-jacketed cell, whose counter and reference electrodes were filled with the background solution. A Tacussel PJT 120-1 potentiostat and a Tacussel IG5-N electronic integrator were included in the circuit. The reference electrode has been mentioned above. The counter electrode was a platinum foil. The solid working electrode was a platinum grid (6 cm diameter) and it was used without pre-treatment.

The water content of the solvent (DMF and ACN) was determined by means of a coulometric Karl Fischer titrator (Automate Bizot et Constant, Prolabo, Paris).

N-*Ethyl-4-methyl-5-pyrazin-2-ylisothiazole-3-thione* (1).—A solution of 4-methyl-5-pyrazin-2-yl-1,2-dithiole-3-thione (35972 RP) (452 mg, 2 mmol) in dichloromethane (50 cm³) was stirred and refluxed with ethylamine (25 mmol) at 40 °C for 12 h. The reaction mixture was then poured into water (100 cm³) and extracted with dichloromethane (200 cm³). The organic phase was dried over anhydrous sodium sulphate and the solvent removed under reduced pressure at 30 °C. Chromatography on silica gel with toluene–acetone (10:1) as eluent yielded an orange solid 1 (355 mg, 75%), m.p. 134–136 °C (CH₂Cl₂) (Found: C, 50.4; H, 4.5; N, 17.6; S, 27.1. $C_{10}H_{11}N_3S_2$ requires C, 50.6; H, 4.6; N, 17.7; S, 27.0%); λ_{max}(ACN)/nm 244 (ε/dm³ mol⁻¹ cm⁻¹ 16000), 292 (13300) and 396 (6800); δ_H 1.51 (3 H, t, NCH₂CH_3), 2.65 (3 H, s, 4-CH₃), 4.40 (2 H, q, NCH_2CH₃), 8.61 (1 H, d, 5-H or 6-H), 8.70 (1 H, d, 5-H or 6-H) and 9.13 (1 H, s, 3-H); m/z 238 (MH⁺).

N-*Ethyl-4-methyl-5-pyridazin-3-ylisothiazole-3-thione* (2).—Using the same method as for 1, 4-methyl-5-pyridazin-3-yl-1,2-dithiole-3-thione (36733 RP) yielded a yellow solid 2 (265 mg, 56%), m.p. 144–146 °C (CH₂Cl₂) (Found: C, 50.5; H, 4.7; N, 17.7; S, 27.2. $C_{10}H_{11}N_3S_2$ requires C, 50.6; H, 4.6; N, 17.7; S, 27.0%); λ_{max}(ACN)/nm 244 (ε/dm³ mol⁻¹ cm⁻¹ 20000), 292 sh (10000) and 400 (7000); δ_H 1.50 (3 H, t, NCH₂CH_3), 2.65 (3 H, s, 4-CH₃), 4.40 (2 H, q, NCH_2CH₃), 7.70 (1 H, dd, $J_{4.5}$ 5.0 and $J_{4.3}$ 8.7, 4-H), 8.02 (1 H, dd, $J_{3.4}$ 8.7 and $J_{3.5}$ 1.5, 3-H) and 9.25 (1 H, dd, $J_{5.4}$ 5.0 and $J_{5.3}$ 1.5, 5-H); m/z 238 (MH⁺).

N-*Ethyl-4-methyl-5-pyrimidin-5-ylisothiazole-3-thione* (3).—Using the previous method, 4-methyl-5-pyrimidin-5-yl-1,2-dithiole-3-thione (37069 RP) gave a pale yellow solid 3 (289 mg, 61%), m.p. 167–169 °C (CH₂Cl₂) (Found: C, 50.6; H, 4.7; N, 17.6; S, 27.1. $C_{10}H_{11}N_3S_2$ requires C, 50.6; H, 4.6; N, 17.7; S, 27.0%); λ_{max}(ACN)/nm 260 (ε/dm³ mol⁻¹ cm⁻¹ 14000) and 368 (8700); δ_H 1.50 (3 H, t, NCH₂CH_3), 2.35 (3 H, s, 4-CH₃), 4.40 (2 H, q, NCH_2CH₃), 8.90 (2 H, s, 6-H and 4-H) and 9.40 (1 H, s, 2-H); m/z 238 (MH⁺).

N-*Ethyl-4-methyl-5-(2-pyridyl)isothiazole-3-thione* (4).—Using the previous method, 4-methyl-5-(2-pyridyl)-1,2-dithiole-3-thione (36598 RP) afforded 4 as a yellow solid (245 mg, 52%), m.p. 125–127 °C (CH₂Cl₂) (Found: C, 55.7; H, 4.8; N, 12.0; S,

27.3. $C_{11}H_{12}N_2S_2$ requires C, 55.7; H, 5.1; N, 11.8; S, 27.1%); λ_{max}(ACN)/nm 244 (ε/dm³ mol⁻¹ cm⁻¹ 20000), 292 (17400) and 386 (9500); δ_H 1.50 (3 H, t, NCH₂CH_3), 2.65 (3 H, s, 4-CH₃), 4.40 (2 H, q, NCH_2CH₃), 7.37 (1 H, ddd, $J_{5.4}$ 8, $J_{5.6}$ 5 and $J_{5.3}$ 1, 5-H), 7.85 (2 H, m, 4-H and 3-H) and 8.32 (1 H, dd, $J_{6.5}$ 5 and $J_{6.3}$ 1, 6-H); m/z 237 (MH⁺).

N-*Ethyl-4-methyl-5-phenylisothiazole-3-thione* (5).—Using the previous method, 4-methyl-5-phenyl-1,2-dithiole-3-thione (37528 RP) yielded the pale yellow solid 5 (372 mg, 75%) m.p. 85–87 °C (CH₂Cl₂) (Found: C, 61.0; H, 5.3; N, 6.1; S, 27.5. $C_{12}H_{13}NS_2$ requires C, 61.1; H, 5.5; N, 5.95; S, 27.2%); λ_{max}(ACN)/nm 260 (ε/dm³ mol⁻¹ cm⁻¹ 14000), 278 sh (10000) and 360 (8700); δ_H 1.50 (3 H, t, NCH₂CH_3), 2.35 (3 H, s, 4-CH₃), 4.40 (2 H, q, NCH_2CH₃), and 7.50 (5 H, m, 5-Ph); m/z 236 (MH⁺).

N-*Ethyl-2-methyl-3-methylthio-3-pyrazin-2-ylpropenethio-amide* (6) *and* N-*ethyl-2-methyl-3-methylthio-3-pyrimidin-5-yl-propenethioamide* (7).—Compound 1 (0.2 mmol) was dissolved in DMF (200 cm³) containing 0.05 mol dm⁻³ TEATFB. The resulting solution was reduced under nitrogen at a platinum electrode ($E = -1600$ mV vs. SCE) at 25 °C. After exhaustive electrolysis, i.e. when a steady state minimum value of the current was recorded, the reduced solution was methylated with an excess of methyl iodide (10 mmol). The resulting solution was extracted with ethyl acetate (200 cm³) after the addition of water (200 cm³). The organic phase was washed vigorously with water, dried over anhydrous sodium sulphate, and the solvent removed under reduced pressure at 30 °C. Preparative TLC with toluene–acetone (10:2) resulted in a brown solid 6 (31 mg, 60%) m.p. 143–145 °C (CH₂Cl₂) (Found: C, 52.5; H, 6.0; N, 16.6; S, 25.0. $C_{11}H_{15}N_3S_2$ requires C, 52.15; H, 5.9; N, 16.6; S, 25.3%); λ_{max}(ACN)/nm 244 (ε/dm³ mol⁻¹ cm⁻¹ 18000) and 330 sh (4000); δ_H 1.40 (3 H, t, 1-NHCH₂CH_3), 1.90 (3 H, s, 2-CH₃ or 3-SCH₃), 2.05 (3 H, s, 2-CH₃ or 3-SCH₃), 3.80 (2 H, qd, J 2, 1-NHCH_2CH₃), 7.60 (1 H, br s, 1-NHCH₂CH₃), 8.55 (1 H, d, $J_{6.5}$ 2.5, 6-H), 8.65 (1 H, dd, $J_{5.6}$ 2.5 and $J_{5.3}$ 1.5, 5-H) and 8.75 (1 H, d, $J_{3.5}$ 1.5, 3-H); m/z 254 (MH⁺).

Using the previous method, 3 afforded 7 as a colourless oil (31 mg, 61%) (Found: C, 52.4; H, 6.2; N, 17.0; S, 24.8. $C_{11}H_{15}N_3S_2$ requires C, 52.2; H, 5.9; N, 16.6; S, 25.3%); λ_{max}(ACN)/nm (ε dm³ mol⁻¹ cm⁻¹ 7000) and 274 (8000); δ_H 1.40 (3 H, t, 1-NHCH₂CH_3), 1.90 (3 H, s, 2-CH₃ or 3-SCH₃), 2.00 (3 H, s, 2-CH₃ or 3-SCH₃), 3.80 (2 H, qd, J 5, 1-NHCH_2CH₃), 7.80 (1 H, br s, 1-NHCH₂CH₃), 8.75 (2 H, s, 4-H and 6-H) and 9.20 (1 H, s, 2-H); m/z 254 (MH⁺).

2-*Cyano-3-ethylamino-4-methyl-5-pyrazin-2-ylthiophene* (8) *and* 2-*Cyano-3-ethylamino-4-methyl-5-pyrimidin-5-ylthiophene* (9).—*Method A*. Compound 1 (0.2 mmol) was dissolved in ACN (200 cm³) containing 0.05 mol dm⁻³ TEATFB. The resulting solution was reduced under nitrogen at a platinum electrode ($E = -1600$ mV vs. SCE) at 25 °C. When 90% of the starting material 1 was consumed, electrolysis was stopped and the reduced solution was methylated with an excess of methyl iodide (10 mmol). The resulting solution was evaporated to dryness *in vacuo* at 30 °C. The residue was taken up in ethyl acetate (150 cm³) in which the solubility of TEATFB is low. TEATFB was removed by filtration and the resulting organic phase was washed with water (200 cm³), dried over anhydrous sodium sulphate and the solvent removed under reduced pressure at 30 °C. Preparative TLC with toluene–acetone (10:2) afforded 6 as the major product (23 mg, 45%) and a pale yellow solid 8 as the secondary product (9 mg, 20%) m.p. 93–95 °C (CH₂Cl₂) (Found: C, 59.2; H, 5.1; N, 23.2; S, 12.9. $C_{12}H_{12}N_4S$ requires C, 59.0; H, 4.9; N, 22.95; S, 13.1%); λ_{max}(ACN)/nm 242 (ε/dm³ mol⁻¹ cm⁻¹ 9600), 294 (11000), 330 sh (6500) and 380 sh

(3000); δ_H 1.40 (3 H, t, 3-NHCH$_2$CH_3), 2.30 (3 H, s, 4-CH$_3$), 3.75 (2 H, qd, J 5, 3-NHCH_2CH$_3$), 4.20 (1 H, br s, 3-NHCH$_2$-CH$_3$), 8.48 (1 H, d, $J_{6.5}$ 2.5, 6-H), 8.58 (1 H, dd, $J_{6.5}$ 2.5 and $J_{5.3}$ 1.5, 5-H) and 8.75 (1 H, d, $J_{3.5}$ 1.5, 3-H); m/z 262 (MNH$_4$$^+$) and 245 (MH$^+$).

Using method A, compound **3** provided **7** as the major product (28 mg, 55%) and a pale yellow solid **9** as the secondary product (5 mg), 10%), m.p. 128–126 °C (CH$_2$Cl$_2$) (Found: C, 59.1; H, 5.3; N, 23.2; S, 12.8. C$_{12}$H$_{12}$N$_4$S requires C, 59.0; H, 4.9; N, 22.95; S, 13.1%); λ_{max}(ACN) 268 (ε/dm^3 mol^{-1} cm^{-1} 12 000) and 340 sh (4800); δ_H 1.36 (3 H, t, 3-NH-CH$_2$CH_3), 2.05 (3 H, s, 4-CH$_3$), 3.72 (2 H, qd, J 5.5, 3-NH-CH_2CH$_3$), 4.18 (1 H, t, J 5.5, 3-NHCH$_2$CH$_3$), 8.80 (2 H, s, 4-H and 6-H) and 9.25 (1 H, s, 2-H); m/z 245 (MH$^+$).

Method B. Tetrabutylammonium hydroxide (0.6 mmol) was added to a solution of **1** (0.4 mmol) in ACN (100 cm^3) at 25 °C. The reaction was allowed to go to completion and the resulting mixture was evaporated to dryness *in vacuo* at 30 °C. The residue was poured into water (200 cm^3) and then extracted with ethyl acetate (200 cm^3). The organic phase was dried over anhydrous sodium sulphate and the solvent removed under reduced pressure at 30 °C. Chromatography on silica gel with toluene–acetone (10:2) as eluent yielded **8** (62 mg, 63%). Using method B, compound **3** gave **9** as the major product (60 mg, 61%).

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