Reactions of 1,2,3-dithiazoles with halogenated malononitriles

Irene C. Christoforou,[a] Panayiotis A. Koutentis[a] and Charles W. Rees[b]

[a] *Department of Chemistry, University of Cyprus, P.O. Box 20537, 1678 Nicosia, Cyprus. E-mail: koutenti@ucy.ac.cy*
[b] *Department of Chemistry, Imperial College of Science, Technology and Medicine, London, UK SW7 2AY. E-mail: c.rees@ic.ac.uk*

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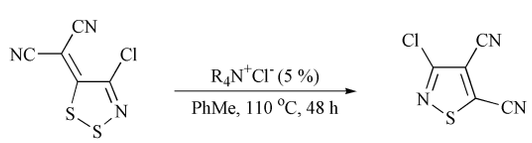
Dibromomalononitrile **3a** reacts with 4-chloro-1,2,3-dithiazole-5-thione **9** and monobromomalononitrile **3c** reacts with 4,5-dichloro-1,2,3-dithiazolium chloride **4** (Appel salt) to give 4-chloro-5*H*-1,2,3-dithiazole-5-ylidenemalononitrile **1** in 76 and 73% yields, respectively, thus providing the best available synthesis of this key intermediate. The reactions were accompanied by the formation of 1-(4-chloro-5*H*-1,2,3-dithiazol-5-ylideneamino)-1,2-dihaloethene-2-carbonitriles **5**, the yields of which increased with reaction temperature. In refluxing toluene, dibromomalononitrile **3a** and dithiazolethione **9** give directly 3-bromoisothiazole-4,5-dicarbonitrile **12** (59%); the probable intermediate (dicyanomethylene)dithiazole **1** is readily converted into bromoisothiazole **12** on treatment with anhydrous gaseous HBr at *ca.* 20 °C (83%). The addition of bromine to dithiazolethione **9** gives 5-bromosulfanyl-4-chloro-1,2,3-dithiazolium bromide **11** almost quantitatively. Mechanisms are proposed for all these reactions.

The (dicyanomethylene)dithiazole **1** can be readily converted into the fully functionalised isothiazole **2** in quantitative yield.[1,2] The isothiazole is an important building block for a variety of potent biocides;[3] however, access to isothiazole **2** is limited by the availability of ylidene **1**. The preparation of ylidene **1** from malononitrile and Appel salt gave the ylidene in only 40% yield and required chromatography[1] whilst alternative higher yielding (60 to 70%) preparations from either Appel salt **4** or dithiazolethione **9** used the expensive reagent tetracyanoethylene oxide (TCNEO), and both reactions gave unexpected by-products.[1,2]

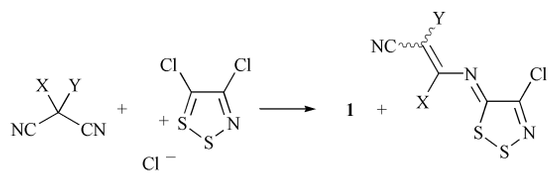


1 **2**

In an attempt to overcome these limitations we sought new routes to ylidene **1** from Appel salt **4** or thione **9** by reaction with malononitrile derivatives which are mechanistically equivalent to TCNEO, but are simpler and cheaper. Since TCNEO appears to react through its ring opened stabilized ylide form, $(NC)_2C{=}O^+{-}C^-(CN)_2$, [1,2,4] we need to generate a dicyanomethyl carbanion with a leaving group on the central carbon atom. In the ylide form of TCNEO the leaving group, $-O^+{=}C(CN)_2$, could possibly be replaced by halogen. Bromo-, dibromo- and dichloromalononitrile, which are all readily prepared from malononitrile in one step, were therefore investigated as TCNEO substitutes.

Reaction of Appel salt 4 with halogenated malononitriles 3a–c

Treatment of Appel salt **4** with dibromo-, dichloro- and bromomalononitriles **3a**–**c** did indeed give the desired ylidene **1** together with the dithiazolimines **5a**–**c** (Scheme 1) in moderate yields (Table 1). The reactions gave only traces of the dithiazolethione **9** and the corresponding dithiazolone (by TLC). Monobromomalononitrile **3c** was by far the most reactive of the malononitriles **3a**–**c** followed by the dibromo- and finally the dichloromalononitrile. Higher reaction temperatures gave better yields of the dithiazolimines **5** and an excess of the halogenated malononitriles improved the yields of both ylidene



3a X = Y = Br
3b X = Y = Cl
3c X = H, Y = Br

4

5a X = Y =Br
5b X = Br, Y = Cl
5c X = Y = Cl

Scheme 1

Table 1 Reaction of halogenated malononitriles **3** with Appel salt **4** (0.50 mmol)

3 (equiv.)	Solvent (3 ml)	*T*/°C	*t*/h	Yields (%) **5a**,**b**[c]	**5c**	**1**
3a (1)	DCM	20	24	Trace	–	Trace
3a (1)	DCM	40	24	Trace	–	7
3a (1)	PhH	80	24	4	–	13
3a (2)	PhH	80	24	11	–	35
3a (2)	PhMe	110	24	2	–	38
3a (2)	PhCl	132	24	13	–	56
3a (3)	PhH	80	24	16	–	46
3a (4)	PhH	80	24	13	–	51
3b (2)	DCM	40	24	–	0	0
3b (2)	PhH	80	24	–	5	4
3b (2)	PhMe	110	24	–	21	11
3b (2)	PhMe	110	48	–	17	5
3b (2)	PhCl	132	24	–	17	15
3c (1)[a]	DCM	20	12	Trace	–	57
3c (2)[b]	DCM	20	12	2	–	73
3c (1)	DCM	40	24	12	–	32
3c (2)	DCM	40	24	22	–	62
3c (1)	PhH	80	2.5	33	–	45
3c (2)	PhH	80	1.5	39	–	54
3c (2)	PhCl	132	0.5	34	–	51

[a] With pyridine (1 equiv.). [b] With pyridine (2 equiv.). [c] Predominantly **5b**.

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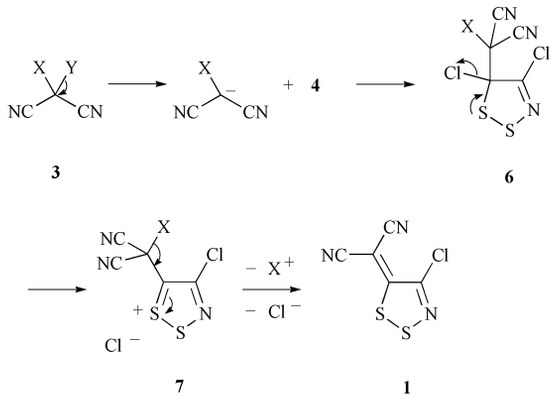
1 and imines **5**. The dithiazolimines **5** were mixtures of *E*/*Z* isomers and, because of difficulties in their chromatographic separation, they were isolated and characterized as mixtures. In the dibromomalononitrile reactions, mixtures of dithiazolimines **5a** and **5b** were obtained. The ylidene obtained from the reaction of dihalomalononitriles **3a** and **3b** was dark brown in colour even after chromatography, which indicated some unidentified contamination. Using bromomalonitrile **3c** the ylidene was obtained as a bright orange material. The best conditions for the preparation of pure ylidene **1** (73%) involved the use of two equivalents of bromomalononitrile **3c** with pyridine (2 equiv.) in DCM at *ca.* 20 °C and these conditions gave only traces of dithiazolimines **5**.

With bromomalononitrile **3c** and pyridine, deviation from an equimolar ratio dramatically reduced the yields of dithiazolimines **5**. The imines, however, were stable to pyridine in DCM at *ca.* 20 °C. At reflux in DCM or in PhH no pyridine was necessary and the yields of dithiazolimine **5** were improved. With or without pyridine, 3 or 4 equivalents of bromomalononitrile **3c** resulted in significant contamination of ylidene **1** with malononitrile, even after chromatographic work-up; however, this contamination was less apparent (by ^{1}H NMR) when pyridine was used. The malononitrile could be washed out with cold diethyl ether or ethanol. The identification of malononitrile (by ^{1}H NMR) suggested disproportionation; however, whilst dibromomalononitrile **3a** and malononitrile disproportionate to give bromomalononitrile in the presence of BF_3 in refluxing EtOH,[5] bromomalononitrile **3c** did not disproportionate in refluxing DCM or PhH after 48 h. In refluxing PhMe or PhCl, however, bromomalononitrile **3c** did give some malononitrile and other products. Bromomalononitrile **3c** is known to react with bases to give pentacyanopropenide anions and bromomalononitrile anions.[6] The addition of pyridine at *ca.* 20 °C to a DCM solution of bromomalononitrile **3c** gave a complex mixture.

The *E*- and *Z*-dithiazolimines **5c** obtained from the dichloromalononitrile **3b** reaction, were identical with the dithiazolimines obtained from the reaction of Appel salt with TCNEO.[2] The imines obtained from the reactions of monobromo- and dibromomalononitrile **3c** and **3a** were deeper red in colour and less soluble than dithiazolimines **5c**; but they all co-run on silica TLC. Mass spectrometry of the dithiazolimines obtained from the dibromomalononitrile reaction indicated the imines were a mixture of bromochloroethene and dibromoethene substituted materials (*m*/*z* 317 and 361). A clean ^{13}C NMR spectrum was not obtainable from this mixture, but elemental analysis and MS suggested that the mixture was predominantly dithiazolimines **5b**. We were unable to separate the mixture of imines **5a** and **5b** using standard chromatography techniques. In contrast the dithiazolimines obtained from monobromomalononitrile **3c** and Appel salt gave a very clean spectrum of only 10 carbon signals in the range 162–80 ppm, tentatively assigned to the two *E*/*Z* isomers of the dithiazolimines **5b**. This was supported by elemental analysis which gave a formula of $C_5BrCl_2N_3S_2$ and MS which showed no parent ion corresponding to imines **5a**. The 10 ^{13}C NMR peaks were also identifiable in the complex ^{13}C NMR spectrum of the imines from the dibromomalononitrile reactions. The two peaks (115.7 and 114.5 ppm), probably derive from the nitrile groups. In a direct comparison with the data obtained for the dithiazolimines **5c** the spectra were remarkably similar, and the most significant differences between these ^{13}C NMR signals and those of the dithiazolimines **5c** was the upfield shift of the ethylene carbon attached to the nitrile (87.5 and 81.8 ppm in **5b** *vs.* 100.3 and 96.0 ppm in **5c**). This upfield shift tentatively supports the presence of bromine rather than chlorine in this position, which is also reasonable mechanistically.

The mechanism for the formation of ylidene **1** (Scheme 2) probably involves ionization of the halogenated malononitrile to the anion. Such a possibility is supported by the strong

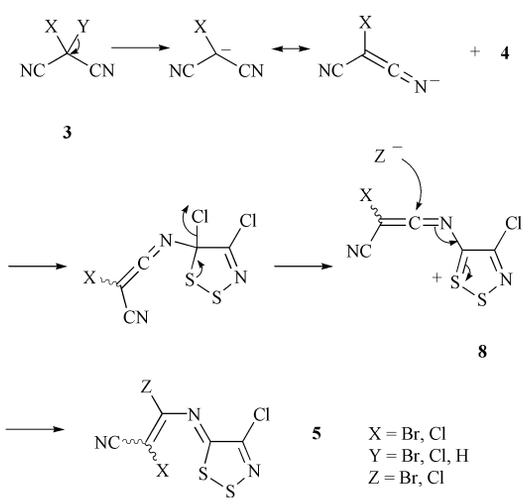


Scheme 2

brominating capabilities of dibromomalononitrile.[5] With monobromomalononitrile **3c** the hydrogen is more labile than the bromine and this could account for the improved yields in the presence of base.

The reaction proceeds either by a concerted or stepwise thermal loss of dihalogen from adduct **6** and whilst no evidence is available to differentiate between the possible dehalogenation pathways, the stepwise process which utilizes the aromatic dithiazolium intermediate **7** is preferred.

Formation of dithiazolimines **5** can be similarly explained from the reaction of malononitrile anion now acting as a nucleophile through nitrogen (Scheme 3). The halogen on the ethene

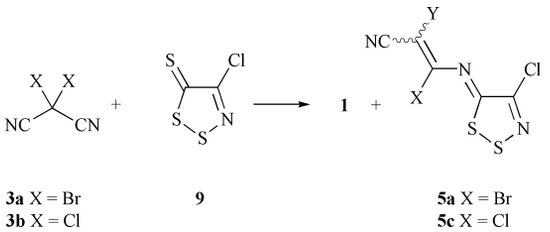


Scheme 3

carbon β to the nitrile group in dithiazolimine **5** could be introduced by addition to the keteneimine **8**, a highly reactive Michael acceptor. The ratio of imines **5** to ylidene **1** tends to increase at higher reaction temperatures (Table 1).

Reaction of dithiazolethione 9 with halogenated malononitriles 3

Malononitrile does not react with 4-chloro-1,2,3-dithiazole-5-thione **9** even under reflux (DCM, PhH, PhCl) or with the addition of bases such as pyridine. Analogous conditions but using bromomalononitrile **3c** gave mainly unreacted starting thione **9** (85–97%) and traces of the ylidene **1** (1–7%). Dithiazolethione **9**, however, reacts with dihalomalononitriles **3a** and **3b** to give ylidene **1**, dithiazolimines **5a** and **c**, and elemental sulfur (Scheme 4). By using a three- or fourfold excess of dibromomalononitrile **3a**, the reaction could be driven to completion in refluxing DCM to afford good yields of ylidene (70–76%) with only minor by-products. Higher temperatures resulted in the formation of small quantities of dithiazolimines **5**. Dichloromalononitrile **3b** was significantly less reactive than dibromomalononitrile and the reaction could not readily be



3a X = Br
3b X = Cl

9

5a X = Br
5c X = Cl

Scheme 4

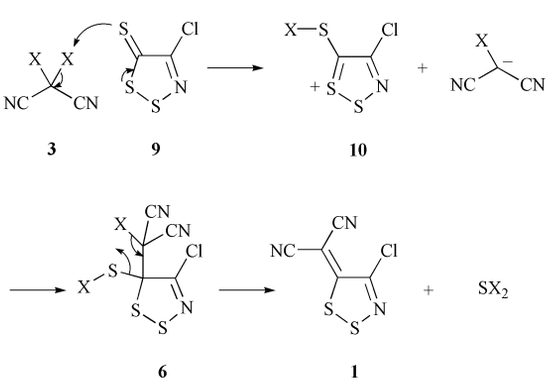
Table 2 Reaction of dihalomalononitriles **3a** and **3b** with dithiazolethione **9** (0.60 mmol) at reflux

3 (equiv.)	Solvent (3 ml)	*t*/h	Yields (%) **9**	**5a**[a]	**5c**[a]	**1**[a]
3a (1)	DCM	24	66	0	–	54
3a (2)	DCM	24	23	0	–	60
3a (3)	DCM	16	Trace	0	–	76
3a (1)	PhH	4	Trace	19	–	76
3b (2)	DCM	24	100	–	0	0
3b (2)	PhH	24	86	–	Trace	85
3b (2)	PhMe	24	31	–	10	64
3b (2)	PhMe	48	7	–	6	63
3b (2)	PhCl	24	3	–	24	45

[a] Based on consumed thione **9**.

driven to completion. Generally both dihalomalononitriles afforded minor quantities of the dithiazolimines **5** (Table 2).

As expected, the electron-rich dithiazolethione **9** was not susceptible to nucleophilic attack by either malononitrile or bromomalononitrile anions. Pure bromomalononitrile **3c** was stable in refluxing PhH and showed no signs of disproportionation to dibromomalononitrile **3a** and malononitrile (by NMR), but it was consumed during the reaction with dithiazolethione **9**. Reasonable mechanisms to explain the formation of the products are proposed in Schemes 5 and 6. The halophilic[7]



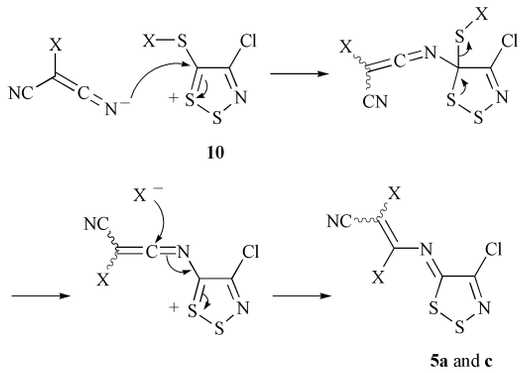
3 **9** **10**

6 **1**

Scheme 5

dithiazolethione **9** could first abstract halogen from the halogenated malononitriles **3** to form the sulfenyl halide **10** and the malononitrile anion. These two species could combine to give dithiazole **6** proposed above (Scheme 2), which subsequently collapses to ylidene **1** and possibly sulfur dihalide. Both monobromo-[8] and dibromomalononitrile are known brominating agents,[5] but the lack of reaction with bromomalononitrile suggests that the latter is less susceptible to nucleophilic attack on bromine. The alternative S_N2 attack of the thione at carbon seems less likely.[9]

The dithiazolimines **5a** and **5c** were observed depending on the starting dihalomalononitrile; a mechanism for their formation is proposed in Scheme 6. ^{13}C NMR spectroscopy of the dibromoethene dithiazolimine **5a** (X=Br) showed a strong set of five carbon resonances together with a weaker set, suggesting that one of the *E*/*Z* isomers was much preferred; for steric reasons the major isomer is likely to be the *trans*



10

5a and **c**

Scheme 6

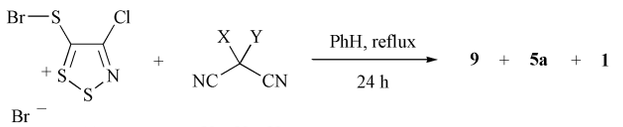
1,2-dibromoethene. In contrast with the Appel salt reaction (Scheme 1), the bromo(chloro)ethene **5b** is not expected here since there is no source of chloride except from the starting thione **9**. This was supported by elemental analysis which gave a formula of $C_5Br_2ClN_3S_2$ and by MS which showed no parent ion for dithiazolimines **5b**. As proposed in Scheme 3, the bromomalononitrile anion is an ambident anion which starts to attack through nitrogen as the temperature is raised.

To gain support for the mechanisms of Scheme 5 and 6, we prepared the sulfenyl bromide **10** (X=Br) independently and treated this with the halomalononitriles **3**. The dithiazolethione **9** on treatment with bromine in DCM or in MeCN gave a yellow–orange crystalline precipitate believed to be 5-bromosulfanyl-4-chloro-1,2,3-dithiazolium bromide **11**, mp 162–164 °C. Mass spectroscopic analysis (EI) did not identify the parent ion but indicated a strong ion for the thione (*m*/*z* 169, 100%) and dibromine (*m*/*z* 160, 47%); however, the milder chemical ionization techniques using methane as a proton source (CI/CH_4) did give an ion for the cation (M^+, 250, 1%) which was supported by elemental analysis, giving the formula $C_2Br_2ClNS_3$.

The dithiazolium bromide **11** was relatively stable, but on standing in the atmosphere or on treatment with pyridine it reverted predominantly to the dithiazolethione **9**. The salt was not sufficiently soluble for the acquisition of its ^{13}C NMR spectrum. Similar salt formations involving the addition of molecular bromine to 1,2-dithiole-3-thiones[10,11] and 1,3-dithiole-2-thiones[12] are known.

Bromosulfanyl salt **11** was then treated with malononitrile, bromomalononitrile **3c**, or dibromomalononitrile **3a** in refluxing benzene for 24 h to give thione **9**, dithiazolimines **5** and dithiazole ylidene **1** in the yields shown in Table 3. These reactions of dithiazolium salt **11** with the malononitriles were sluggish but this was not unexpected since single crystal X-ray diffraction studies of closely related 4-chloro-5-methylsulfanyl dithiazolium perchlorate[13] indicate that the cationic charge is evenly distributed between the sulfenyl sulfur and the dithiazole ring sulfur S-1, making C-5 less electrophilic.

Table 3 Reaction of the sulfenyl bromide **11** (0.30 mmol) with malononitriles in PhH at 80 °C for 24 h



11

X = Y = H
X = H, Y = Br
X = Y = Br

PhH, reflux
24 h

9 + **5a** + **1**

3 (2 equiv.)	Yields (%) **9**	**5a**	**1**
$CH_2(CN)_2$	25	Trace	36
$CHBr(CN)_2$	0	6	54
$CBr_2(CN)_2$	0	22	49

Table 4 Preparation of bromoisothiazole **12** from dibromomalononitrile **3a** and dithiazolethione **9** (0.60 mmol)

3a (equiv.)	Solvent (3 ml)	*T*/°C	*t*/h	Yields (%) BnBr	**12**	**1**	**5**
1	PhH	80	2	0	0	76	11
1	PhMe	110	2	Nd	37	54	5
1	PhMe	110	24	78	20	40	0
2	PhMe	110	2	85	59	Trace	Trace
2	PhCl	120	2	0	Trace	56	10
2	PhCl	120	24	0	10	60	2
3	PhCl	120	2	0	7	76	7

Presumably as thione **9** dehalogenates the malononitriles to generate the dithiazolium salt and the malononitrile anion, the close proximity of the paired ions will strongly facilitate the further reaction.

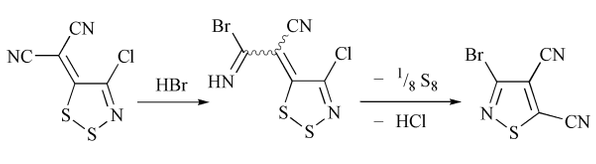
Preparation of 3-bromoisothiazole-4,5-dicarbonitrile 12

Somewhat unexpectedly, in PhMe at *ca.* 110 °C dibromomalononitrile **3a** and dithiazolethione **9** gave 3-bromo-4,5-dicyanoisothiazole **12**, and benzyl bromide **13**. In PhCl at 120 °C some isothiazole **12** was formed but the reaction was significantly slower suggesting that the methyl substituent of the toluene may be involved in the reaction. Prolonged reaction times diminish the product yields. The analogous reaction with Appel salt **4** in place of dithiazolethione **9** did not yield isothiazole **12**, in refluxing PhH, PhMe or PhCl, although bromination of toluene to give benzyl bromide was observed.

The assignment of structure **12** to the isothiazole product was initially based on the very close similarity of its ^{13}C NMR, UV–VIS, MS and IR spectroscopic data with that of known 3-chloroisothiazole-4,5-dicarbonitrile **2**.[1] The structure was confirmed by its smooth conversion (75%) into the known 3-morpholinoisothiazole-4,5-dicarbonitrile **14**[1] by heating under reflux with morpholine in toluene.

Presumably ylidene **1**, which is formed in the reaction between dibromomalononitrile **3a** and the thione **9**, is converted into isothiazole **12** and the reaction is assisted by toluene in some manner (see Table 4). In the absence of dithiazolethione **9** under analogous reaction conditions, (24 h at 110 °C) dibromomalononitrile **3a** did not react with toluene to give benzyl bromide. Bromination of benzylic positions occurs readily with dibromine and it is possible that a little dibromine could have been formed either by disproportionation of the postulated sulfur dibromide (Scheme 5) or from some decomposition of dibromomalononitrile by dithiazolethione **9**.

The formation of benzyl bromide will be accompanied by the release of HBr which could react with either nitrile group of ylidene **1** to generate an *E*/*Z* isomeric mixture of imidoyl bromides **15**. Closure of the imine N adjacent to the dithiazole ring onto sulfur S-1 is known to lead to the formation of isothiazoles.[14] Ready rotation about the ethene bond in **15** will result from the push–pull contribution from the dithiazole ring sulfurs to the cyano and imine bonds.



1 **15** **12**

Treatment of ylidene **1** with anhydrous gaseous HBr for 5 min in either PhMe or PhCl at *ca.* 20 °C followed by continuous stirring for 24 h gave bromoisothiazole **12** in 82 and 83% yields, respectively. This supports the conversion of ylidene **1** into bromoisothiazole **12** by HBr generated during the bromination of the toluene methyl group, as proposed above. Treatment of ylidene **1** with dibromine (2 equiv.) at *ca.* 20 °C, in PhMe gave bromoisothiazole **12** in good yield. However, the reaction was complex and the product required repeated recrystallisation to remove impurities. In general agreement with these mechanistic proposals, we would expect dibromine to convert ylidene **1** into isothiazole **12** in PhMe, but not in PhCl, and this proved to be the case.

In contrast, it should be noted that the reaction of dithiazolethione **9** with dichloromalononitrile **3b** (4 equiv.) in PhMe at 110 °C after 24 h gave neither chloroisothiazole **2** nor benzyl chloride, and treatment of ylidene **1** with anhydrous gaseous HCl at *ca.* 20 °C gave only a trace of the chloroisothiazole **2** and almost all of the starting ylidene **1** was recovered. This parallels the much slower addition of HCl to malononitrile itself compared to that of HBr.[15]

The conversion of ylidene **1** into isothiazole **12** on treatment with HBr at *ca.* 20 °C provides a simple, alternative route to isothiazoles under mild conditions.

In conclusion we have shown that dihalomalononitriles **3** reacted with both 4,5-dichloro-1,2,3-dithiazolium chloride **4** (Appel salt) and 4-chloro-1,2,3-dithiazole-5-thione **9** to give 4-chloro-5*H*-1,2,3-dithiazole-5-ylidenemalononitrile **1** and various dithiazolimines **5a**–**c**. Convenient conditions have been determined for the preparation of ylidene **1** in high yield starting from the readily prepared monobromomalononitrile **3c**. A one-pot preparation of 3-bromoisothiazole-4,5-dicarbonitrile **12** from dibromomalononitrile **3a** and dithiazolethione **9** in refluxing toluene has been discovered and an investigation of the reaction led to isothiazole formation under mild conditions by treatment of ylidene **1** with anhydrous HBr.

Experimental

Solvents DCM, PhH, PhMe and PhCl were freshly distilled from CaH_2 under argon. Reactions were protected by $CaCl_2$ drying tubes. Anhydrous sodium sulfate was used for drying organic extracts, and all volatiles were removed under reduced pressure. All reaction mixtures and column eluents were monitored by TLC using commercial glass backed thin-layer chromatography (TLC) plates (Merck Kieselgel 60 F_{254}). The plates were observed under UV light at 254 and 365 nm. The technique of dry flash chromatography was used throughout for all non-TLC scale chromatographic separations using Merck Silica Gel 60 (less than 0.063 mm). Melting points were determined using a Stuart Scientific SMP 1 apparatus. Solvents used for recrystallisation are indicated after the melting point. UV spectra were obtained using a Shimadzu UV-1601 spectrometer and inflections are identified by the abbreviation "inf". IR spectra were recorded on a Jasco FT/IR-460 plus spectrometer and strong, medium and weak peaks are represented by s, m and w respectively. ^1H and ^{13}C NMR spectra were recorded on Bruker Avance 300 machine (at 300 and 75 MHz respecively). Deuteriated solvents were used for homonuclear locks and the signals are referenced to the deuteriated solvent peaks. Mass spectra were recorded on a VG Autospec "Q" mass spectrometer. Microanalyses were performed at the University of North London. Petrol refers to light petroleum, bp 40–60 °C. Appel salt **4**,[16] dithiazolethione **9**,[16] bromo-

malononitrile **3c**,[6] dibromomalononitrile **3a**,[17] and dichloromalononitrile **3b**[18] were prepared according to literature procedures.

Reaction of Appel salt 4 with dibromomalononitrile 3a: typical procedure

To a stirred suspension of 4,5-dichloro-1,2,3-dithiazolium chloride **4** (104 mg, 0.50 mmol) in PhCl (3 ml) at *ca.* 20 °C, dibromomalononitrile **3a** (225 mg, 1.00 mmol) was added and the mixture was heated to *ca.* 132 °C. After 24 h TLC indicated two orange products and chromatography (petrol–DCM 1 : 1) gave an inseparable mixture of the *E*/*Z* isomers of 1-(4-chloro-5*H*-1,2,3-dithiazol-5-ylideneamino)-1,2-dibromoethene-2-carbonitrile **5a** (minor) and 1-(4-chloro-5*H*-1,2,3-dithiazol-5-ylideneamino)-2-bromo-1-chloroethene-2-carbonitrile **5b** (major) (21 mg, 13% based on **5b** *m*/*z* 317) as orange–red crystals, mp 142–145 °C (from cyclohexane) (Found: C, 18.6; N, 12.4. $C_5BrCl_2N_3S_2$ requires C, 18.9; N, 13.2 %) ν_{max}(Nujol)/cm^{-1} 2213s (CN), 2174m (CN), 1629w, 1541s, 1456s, 1309m, 1205s, 1152w, 1136m, 1118m, 1093s, 1060m, 883s, 844m, 814s, 803s, 770s, 699s, 660s; *m*/*z* (EI) 361 (M^+, 5%), 317 (M^+, 35%), 282 [M^+(361) − Br, & M^+(317) − Cl, 20], 256 [M^+(317) − S_2, 5], 236 [M^+(361) − Br_2, & M^+(317) − BrCl, 45], 201 (7), 175 (7), 163 (5), 140 (3), 125 (15), 117 (7), 108 (12), 102 (13), 93 (17), 70 (28), 64 (S_2^+, 100). Further elution (DCM) gave 2-(4-chloro-5*H*-1,2,3-dithiazol-5-ylidene)propanedinitrile **1** (56 mg, 56%) as brown crystals, mp 181–182 °C (from 1,2-dichloroethane) identical with that reported.[1]

Reaction of Appel salt 4 with dichloromalononitrile 3b

Similar treatment of 4,5-dichloro-1,2,3-dithiazolium chloride **4** with dichloro-malononitrile **3b** gave the *E*/*Z* isomeric mixture of 1-(4-chloro-5*H*-1,2,3-dithiazol-5-ylideneamino)-1,2-dichloroethene-2-carbonitrile **5c** (23 mg, 17%) as orange–red crystals, mp 144–154 °C (from cyclohexane); λ_{max}(DCM)/nm 226 (log ε 3.89), 261inf (3.76), 270 (3.79), 415inf (4.13), 425 (4.15), 445inf (4.03), 473inf (3.66); ν_{max}(Nujol)/cm^{-1} 2216m (CN), 2201m (CN), 1560s, 1530w, 1519m, 1214m, 1157m, 1091m, 892s, 863w, 811m, 785m, 682s; δ_C(75 MHz; $CDCl_3$) 161.8 (C-5), 159.8 (C-5), 150.2 (C-4), 150.1 (C-4), 147.2 (*C*=CCN), 142.1 (*C*=CCN), 115.1 (CN), 113.7 (CN), 100.3 (=*C*CN), 96.0 (=*C*CN), identical with that reported.[2] Further elution (DCM) gave 2-(4-chloro-5*H*-1,2,3-dithiazol-5-ylidene)-propanedinitrile **1** (15 mg, 15%) as orange–brown crystals, mp 181–182 °C identical with that reported above.

Reaction of Appel salt 4 with bromomalononitrile 3c (without base)

Similar treatment of 4,5-dichloro-1,2,3-dithiazolium chloride **4** with bromomalononitrile **3c** gave an *E*/*Z* isomeric mixture of 1-(4-chloro-5*H*-1,2,3-dithiazol-5-ylideneamino)-2-bromo-1-chloroethene-2-carbonitrile **5b** (54 mg, 34%) as orange–red crystals, mp 139–141 °C (from cyclohexane) (Found: C, 19.0; N, 13.2. $C_5BrCl_2N_3S_2$ requires C, 18.9; N, 13.2%); λ_{max}(DCM)/nm 227 (log ε 3.84), 272 (3.92), 356inf (3.50), 434 (4.26), 467inf (4.07), 493inf (3.67); ν_{max}(Nujol)/cm^{-1} 2213s (CN), 2174m (CN), 1629w, 1541s, 1456s, 1309m, 1205s, 1152w, 1136m, 1118m, 1093s, 1060m, 883s, 844m, 814s, 803s, 770s, 699s, 660s; δ_C(75 MHz; $CDCl_3$) 161.9 (C-5), 159.4 (C-5), 150.3 (C-4), 150.2 (C-4), 149.0 (*C*=CCN), 141.9, (*C*=CCN), 115.7 (CN), 114.5 (CN), 87.5 (=*C*CN), 81.8 (=*C*CN); *m*/*z* (EI) 315 (M^+, 25%), 282 (M^+ − Cl, 10), 256 (M^+ − S_2, 5), 236 (M^+ − BrCl, 53), 201 (5), 175 (10), 163 (5), 125 (15), 108 (8), 102 (13), 93 (17), 70 (25), 64 (S_2^+, 100); (Found: M^+, 314.8082. $C_5BrCl_2N_3S_2$ requires *M*, 314.8094). Further elution (DCM) gave 2-(4-chloro-5*H*-1,2,3-dithiazol-5-ylidene)propanedinitrile **1** (51 mg, 51%) as orange crystals, mp 181–182 °C identical with that reported above.

Reaction of Appel salt 4 with bromomalononitrile 3c with base: typical procedure

To a stirred suspension of 4,5-dichloro-1,2,3-dithiazolium chloride **4** (104 mg, 0.50 mmol) in DCM (3 ml) at *ca.* 20 °C, bromomalononitrile (145 mg, 1.00 mmol) was added. After 10 h pyridine (79 µl, 2 mmol) was added and the mixture was left to stir for a further 2 h. TLC indicated only one main orange product and chromatography (petrol–DCM 1 : 1) gave a trace of an inseparable *E*/*Z* isomeric mixture of 1-(4-chloro-5*H*-1,2,3-dithiazol-5-ylideneamino)-2-bromo-1-chloroethene-2-carbonitriles **5b** (3 mg, 2%) as orange–red crystals, mp 139–141 °C identical with that described above. Further elution (DCM) gave 2-(4-chloro-5*H*-1,2,3-dithiazol-5-ylidene)propanedinitrile **1** (73 mg, 73%) as orange crystals, mp 181–182 °C identical with that reported above.

Reaction of dithiazolethione 9 with halogenated malononitriles 3a–c: typical procedure

To a stirred suspension of 4-chloro-1,2,3-dithiazole-5-thione **9** (102 mg, 0.60 mmol) in PhH (3 ml) at *ca.* 20 °C, dibromomalononitrile (134 mg, 0.60 mmol) was added and the reaction was heated to reflux. After 4 h TLC indicated two main orange products and chromatography (petrol–DCM 1 : 1) gave an *E*/*Z* isomeric mixture of 1-(4-chloro-5*H*-1,2,3-dithiazol-5-ylideneamino)-1,2-dibromoethene-2-carbonitriles **5a** (41 mg, 19%) as red crystals, mp 145–147 °C (from cyclohexane) (Found: C, 16.8; N, 11.6. $C_5Br_2ClN_3S_2$ requires C, 16.6; N, 11.6%); λ_{max}(DCM)/nm 226 (log ε 4.01), 248inf (3.93), 274 (3.95), 367inf (3.70), 431inf (4.27), 440 (4.28), 467inf (4.13), 499inf (3.68); ν_{max}(Nujol)/cm^{-1} 2208s (CN), 1620w, 1544s, 1456s, 1307w, 1202s, 1135m, 1094m, 1078s, 1051m, 1017w, 878s, 812s, 727s, 693s, 657m, 586w; δ_C(75 MHz; $CDCl_3$) 162.3 (C-5), 159.7 (C-5), 150.3 (C-4), 150.3 (C-4), 143.5 (*C*=CCN), 133.0 (*C*=CCN), 116.7 (CN), 114.8 (CN), 90.7 (=*C*CN), 82.4 (=*C*CN); *m*/*z* (EI) 361 (M^+, 40%), 282 (M^+ − Br, 100), 236 (M^+ − Br_2, 10), 201 (18), 175 (3), 163 (7), 140 (7), 125 (12), 108 (12), 102 (30), 93 (23), 70 (45), 64 (S_2^+, 95); (Found: M^+, 358.7586. $C_5Br_2ClN_3S_2$ requires *M*, 358.7589). Further elution (DCM) gave 2-(4-chloro-5*H*-1,2,3-dithiazol-5-ylidene)propanedinitrile **1** (92 mg, 76%) as brown crystals, mp 181–182 °C identical with that reported above.

5-Bromosulfanyl-4-chloro-1,2,3-dithiazolium bromide 11

To a stirred solution of 4-chloro-1,2,3-dithiazole-5-thione **9** (500 mg, 2.95 mmol) in DCM (25 ml) at *ca.* 20 °C, was added a solution of bromine (470 mg, 2.95 mmol) in DCM (5 ml). An immediate yellow–orange precipitate was formed and the mixture was left to stir for 10 min. The precipitate was filtered off, washed (DCM) and dried under vacuum at *ca.* 20 °C to afford the *title compound* **11** (923 mg, 95%) as a yellow–orange powder, mp 162–164 °C (decomp.) (Found: C, 7.3; N, 3.9. $C_2Br_2ClNS_3$ requires C, 7.3; N, 4.2%); λ_{max}(CH_3CN)/nm 235 (log ε 3.78), 269 (4.30), 317inf (3.51), 427 (3.79); ν_{max}(Nujol)/cm^{-1} 1632w, 1426s, 1411m, 1267m, 1241s, 1210s, 1089s, 1052m, 904s, 890w, 818s, 722w, 620m, 594m; *m*/*z* (CI/CH_4) 250 [(MH − Br)$^+$, 1%], 170 [(MH − Br)$^+$, 100], 134 (5), 118 (5), 108 (15), 93 (12), 81 (HBr, 15), 76 (7), 70 (10), 64 (9).

Reaction of 5-bromosulfanyl-4-chloro-1,2,3-dithiazolium bromide 11 with malononitrile, bromomalononitrile 3c and dibromomalononitrile 3a: typical procedure

To a stirred suspension of 5-bromosulfanyl-4-chloro-1,2,3-dithiazolium bromide **11** (100 mg, 0.30 mmol) in PhH (3 ml) at *ca.* 20 °C, dibromomalononitrile (134 mg, 0.60 mmol) was added and the reaction mixture was heated to reflux. After 24 h TLC indicated two main orange products and chromatography (petrol–DCM 1 : 1) gave an *E*/*Z* isomeric mixture of 1-(4-chloro-5*H*-1,2,3-dithiazol-5-ylideneamino)-1,2-

dibromoethene-2-carbonitriles **5a** (24 mg, 22%) identical with that described above. Further elution (DCM) gave 2-(4-chloro-5*H*-1,2,3-dithiazol-5-ylidene)propanedinitrile **1** (30 mg, 49%) as orange–brown crystals, mp 181–182 °C, identical with that reported above.

3-Bromoisothiazole-4,5-dicarbonitrile 12

(i) From dithiazolethione 9 and dibromomalononitrile 3a in toluene. To a stirred solution of dibromomalononitrile **3a** (220 mg, 2.40 mmol) in PhMe (3 ml) at *ca.* 20 °C, 4-chloro-1,2,3-dithiazole-5-thione **9** (102 mg, 0.60 mmol) was added and the mixture was heated to reflux. After 2 h TLC indicated the presence of sulfur, two colourless products, trace amounts of dithiazole ylidene **1**, dithiazolimines **5**, and unidentified products. The reaction mixture was cooled to *ca.* 20 °C and chromatography (petrol–DCM 4 : 1) gave benzyl bromide **13** (349 mg, 85%) as a colourless oil, (lachrymator) identical with an authentic sample. Further elution (petrol–DCM 4 : 1) gave the *title compound* **12** (76 mg, 59%) as colourless plates, mp 140–141 °C (from cyclohexane) (Found: C, 28.1; N, 19.6. C_5BrN_3S requires C, 28.0; N, 19.6%); λ_{max}(DCM)/nm 247 (log ε 3.81), 256inf (3.73), 295 (3.86), 298inf (3.85); ν_{max}(Nujol)/cm^{-1} 2243s (CN), 2236s (CN), 1641w, 1592w, 1502s, 1360m, 1342s, 1257w, 1186s, 1166s, 1136m, 1006s, 977m, 843s, 800s, 627s, 567s; δ_C(75 MHz; $CDCl_3$) 142.4, 139.8, 119.3 (CN), 109.0 (CN), 106.7; *m*/*z* (EI) 213 (M^+, 100%), 137 ($CBrNS^+$, 43), 134 ($MH^+ - Br$, 8), 108 (27), 82 (10), 76 (10), 70 (35), 58 (15) (Found: M^+, 212.8996 C_5BrN_3S requires *M*, 212.9001).

(ii) From ylidene 1 with anhydrous hydrogen bromide. A stirred solution of 2-(4-chloro-5*H*-1,2,3-dithiazol-5-ylidene)propanedinitrile **1** (100 mg, 0.50 mmol) in PhMe (3 ml) at *ca.* 20 °C, was vigorously purged for 5 min with anhydrous gaseous HBr. TLC indicated the presence of sulfur, bromoisothiazoledicarbonitrile **12**, and unreacted ylidene. After 24 h no starting material **1** was observed (by TLC) and chromatography gave the title compound **12** (89 mg, 83%) as colourless plates, mp 140–141 °C identical with that described above.

(iii) From ylidene 1 with dibromine in toluene. To a stirred solution of 2-(4-chloro-5*H*-1,2,3-dithiazol-5-ylidene)propanedinitrile **1** (100 mg, 0.50 mmol) in PhMe (3 ml) at *ca.* 20 °C, dibromine (80 mg, 0.50 mmol) was added. After 24 h TLC indicated the presence of sulfur, benzyl bromide, benzyl alcohol, benzaldehyde, bromoisothiazole-dicarbonitrile **12** and unreacted ylidene **1**. More dibromine (80 mg, 0.50 mmol) was added and after an additional 24 h of stirring, chromatography of the mixture gave the title compound **12** (70 mg, 65%) as colourless plates, mp 140–141 °C identical with that described above.

3-Morpholinoisothiazole-4,5-dicarbonitrile 14

To a stirred solution of 3-bromoisothiazole-4,5-dicarbonitrile **12** (100 mg, 0.47 mmol) in toluene (4 ml) at *ca.* 20 °C, was added morpholine (327 μl, 3.76 mmol). The reaction mixture was heated to *ca.* 110 °C for 2 h until no starting material **1** remained (TLC). The mixture was allowed to cool to *ca.* 20 °C and chromatography (DCM) gave the title compound **14** (78 mg, 75%) as yellow prisms, mp 185–187 °C (cyclohexane); δ_H(300 MHz; $CDCl_3$) 3.82 (4H, t, CH_2O) and 3.67 (4H, t, CH_2N); δ_C(75 MHz; $CDCl_3$) 165.3, 142.6, 111.4, 108.3, 102.9, 66.0 and 47.9; identical with an authentic sample.[1]

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