# One-step synthesis of 5-acylisothiazoles from furans

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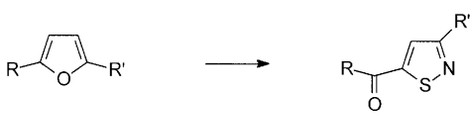
***Received (in Cambridge, UK) 5th February 2001, Accepted 12th April 2001***
***First published as an Advance Article on the web 15th May 2001***



Premixed ethyl carbamate, thionyl chloride and pyridine (which generate thiazyl chloride, N≡SCl) in boiling benzene or toluene convert 2,5- and 2,3,5-substituted furans into 5-acylisothiazoles regiospecifically. The reactions are much faster and generally higher yielding in boiling chlorobenzene with more thionyl chloride and with pyridine or isoquinoline as base. Under the more vigorous conditions, even fully substituted 3-bromofurans give isothiazoles, with the displacement of bromine. Deactivated furans, with electron-withdrawing groups such as ester, cyano, benzoyl and phenylsulfonyl in the α-position, react under the more vigorous conditions to give 5-acylisothiazoles with the electronegative group in the 3-position. The 'activated' 2-methyl-5-phenyl- and 5-phenyl-2-phenylthio-furans react analogously, with the more electron-releasing group becoming part of the 5-acyl substituent, exclusively or predominantly. These results are explained by initial electrophilic attack of the furan ring to give a β-thiazyl derivative which spontaneously ring-opens and closes to the isothiazole. The X-ray structures of five of the differently substituted isothiazole compounds are reported. All have very similar patterns of bonding within their isothiazole rings that appear to be independent of the electron-withdrawing or -donating nature of the substituents. Three of the compounds (**8a**, **8g** and **13**) have loosely linked chain structures in the solid state, adjacent molecules being connected by combinations of hydrogen bonding and π–π stacking interactions.

## Introduction

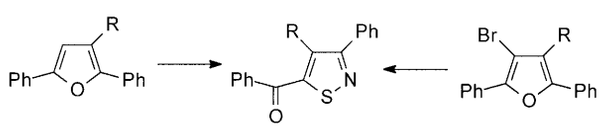
We have recently shown that the one-step conversion of 2,5-disubstituted furans into 5-acyl-3-substituted furans by trithiazyl trichloride, $(NSCl)_3$,[1] can be achieved much more conveniently by replacing the inorganic reagent by a mixture of ethyl carbamate, thionyl chloride and pyridine.[2] This and other closely related mixtures were shown by Katz and co-workers to be the equivalent of $(NSCl)_3$ in the conversion of quinones into their fused 1,2,5-thiadiazole derivatives.[3] This mixture, the Katz reagent, probably generates thiazyl chloride, N≡SCl, which is in equilibrium with its trimer. We found that the Katz reagent behaved exactly like $(NSCl)_3$ in transforming 2,5-diaryl- and 2,5-di-*tert*-butyl-furans into the 5-acyl-3-substituted isothiazoles, though in even higher yield.[2] Thus, following earlier work,[3] a solution of ethyl carbamate (4.3 mmol), thionyl chloride (4.3 mmol) and pyridine (2 ml) in benzene (20 ml) was stirred at room temperature for 30 min (Method A). The furan **1a–d** (1 mmol) was then added and the mixture heated at reflux until the furan was consumed, to give the isothiazoles **2a–d** in 98, 94, 66 and 76% yield, respectively. The trisubstituted furans **3a,b** gave the analogous isothiazoles **4a,b** similarly in 56 and 99% yield respectively.[2]



**1** **2**

**a**, R = R' = Ph; **b**, R = R' = *p*-tolyl; **c**, R = R' = $Bu^t$
**d**, R = 4-$MeOC_6H_4$, R' = 4-$O_2NC_6H_4$;
**e**, R = R' = $Me_2CHCMe_2SiMe_2$

The reactions are regiospecific giving only the 5-acyl, and none of the 3-acyl isomer. The similarity of the results with



**3a**, R = Ph **4a**, R = Ph **6**, R = Ph
**3b**, R = Br **4b**, R = Br **5**, R = Br

$(NSCl)_3$ and with the Katz reagent, especially with the polarised furan **1d**, suggested that the reactions had a common intermediate, most reasonably thiazyl chloride, NSCl.[1,2] This electrophilic species probably substitutes the furan to give a β-thiazyl derivative which spontaneously rearranges to the isothiazole.[1]

Since this new reaction provides an attractive one-step route from readily available furans to isothiazoles, we have now explored the reagents and reaction conditions in more detail and extended the furan substrates to include electron-withdrawing and electron-releasing functional groups.

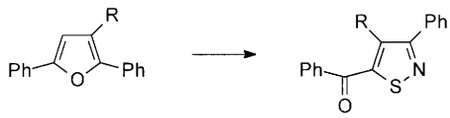
## Results and discussion

### Reagent variation

With the aim of reducing reaction times and, where necessary, increasing yields, we examined the conversion of 2,5-diphenylfuran **1a** and 2,3,5-triphenylfuran **3a** into the isothiazoles **2a** and **4a**, respectively, under more vigorous conditions (Table 1). Replacing the solvent benzene by toluene (Method B) decreased the reaction time from 24 to 6 h for **1a** though with a drop in yield, and from 18 to 1 h for **3a**, with a large increase in yield. This trend continued with chlorobenzene as solvent and with pyridine optionally replaced by isoquinoline as the base, the amount of thionyl chloride being doubled to take account of its volatility (Method C); both **1a** and **3a** gave high

 DOI: 10.1039/b101157j

**Table 1** Treatment of furans **1a** and **3a** with ethyl carbamate, thionyl chloride and a base in a boiling solvent



**1a**, R = H
**3a**, R = Ph

**2a**, R = H
**4a**, R = Ph

| Furan | Urethane/ mmol | $SOCl_2$/ mmol | Base | Solvent | Reaction time/h | Yield of **2a/4a** (%) |
|---|---|---|---|---|---|---|
| **1a** | 4.3 | 4.3 | Pyridine | Benzene | 24 | **2a** (98) |
| **3a** | 4.3 | 4.3 | Pyridine | Benzene | 18 | **4a** (56) |
| **3a** | 4.3 | 4.3 | Pyridine | None | 1 | **4a** (77) |
| **3a** | 4.3 | 4.3 | 4 Å mol. sieves | Benzene | 7 | **4a** (5) |
| **1a** | 4.3 | 4.3 | Pyridine | Toluene | 6 | **2a** (70) |
| **3a** | 4.3 | 4.3 | Pyridine | Toluene | 1 | **4a** (85) |
| **3a** | 2.15 | 4.3 | Pyridine | Toluene | 3.5 | **4a** (71) |
| **1a** | 4.3 | 8.6 | Pyridine | PhCl | 0.5 | **2a** (77) |
| **3a** | 4.3 | 8.6 | Pyridine | PhCl | 0.5 | **4a** (88) |
| **3a** | 4.3 | 8.6 | None | PhCl | | No reaction |
| **3a** | 4.3 | 8.6 | Quinoline | PhCl | 48 | **4a** (26) |
| **3a** | 4.3 | 8.6 | 2,6-Lutidine | PhCl | 12 | **4a** (56) |
| **3a** | 4.3 | 8.6 | DMAP | PhCl | 0.5 | **4a** (82) |
| **1a** | 4.3 | 8.6 | Isoquinoline | PhCl | 0.5 | **2a** (80) |
| **1a** | 4.3 | 8.6 | Isoquinoline | PhCl | 0.5 | **2a** (95) |



yields of the respective isothiazoles (80 and 95%) in a mere 30 min of heating under reflux. These hotter reactions in toluene and in chlorobenzene, with premixing of the carbamate, thionyl chloride and base at room temperature before the addition of the furan, became our standard procedures for most of the later reactions. Quinoline and 2,6-lutidine were less efficient than isoquinoline in chlorobenzene reactions, though the more expensive DMAP was equally good. There was no reaction in the absence of added base though 4 Å molecular sieves, which absorb hydrogen chloride, did give very slow reaction in boiling benzene. Replacement of thionyl chloride by thionyl bromide gave much lower yields. No advantage was gained by using methyl, allyl or phenyl carbamate in place of urethane.

These higher temperature conditions were then tested on 3-bromo-2,5-diphenylfuran **3b**, 3,4-dibromo-2,5-diphenylfuran **5** and 3-bromo-2,4,5-triphenylfuran **6** readily made by bromination of **1a** and **3a**. With pyridine in benzene, the trisubstituted furan **3b** gave the isothiazole **4b** in virtually quantitative yield, though in a relatively long time (16 h); with isoquinoline in chlorobenzene it gave **4b** in 80% yield in 10 min.

The tetrasubstituted furans **5** and **6** were not expected to react with the Katz reagent since they had been found not to react with $(NSCl)_3$.[1b] This seemed reasonable since the reaction stoichiometry involved the loss of hydrogen chloride, with the hydrogen being displaced from the furan ring.[1b] These compounds were reported not to react in boiling benzene,[2] though a reinvestigation has shown that **5** does react very slowly, giving, after 48 h, 13% of the same isothiazole **4b** as from the monobromo furan **3b**. When this reaction was repeated with isoquinoline in chlorobenzene, **4b** was isolated in 68% yield after 1 h. Furan **6** also reacted with the Katz reagent to give low yields of the same isothiazole **4a** as from triphenylfuran **3a**; with pyridine in toluene consumption of **6** was slow giving 15% of **4a** in 24 h, with starting material remaining, and with isoquinoline in chlorobenzene it was fast but complex, giving 12% of **4a** in 45 min.

In this unexpected conversion of bromofurans **5** and **6** into isothiazoles with one fewer bromine atom, bromine is lost presumably as $Br^+$ by electrophilic displacement *e.g.* by acid or NSCl. However, a brief attempt to intercept $Br^+$, or BrCl, with anisole added to the reaction mixture was unsuccessful.

The lack of reaction of **5** and **6** with $(NSCl)_3$ in boiling tetrachloromethane[1b] may result from the lower temperature and/or the absence of acid, which is generated in the ethyl carbamate–thionyl chloride reaction.

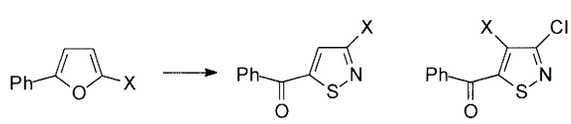
2,5-Di-*tert*-butylfuran **1c** gave the isothiazole **2c** in moderately good yield (66%) with pyridine in benzene, but much more slowly (6 days) than the diaryl compounds. With isoquinoline in chlorobenzene the reaction time was reduced to 12 h but with some decomposition and a lower yield (40%).

All of these results indicate the much enhanced reactivity of the isoquinoline–chlorobenzene modification of the Katz reagent.

### Deactivated furans

We next examined a series of 5-phenylfurans **7** bearing an electron-withdrawing group, X, at the 2-position (X = $CO_2H$, $CO_2Et$, CH=NOH, CH=NOMe, CN, COMe, COPh and $SO_2Ph$) to see if these deactivated rings would undergo the same reaction.

With the exception of the oxime none of these compounds reacted significantly with the benzene–pyridine reagent, but they did react under the more vigorous conditions. 5- Phenylfuran-2-carboxylic acid **7a** decomposed but its ethyl ester **7b** gave the ethyl 5-benzoylisothiazole-3-carboxylate **8b** in 25% yield with pyridine in toluene after 3 days and in 52% yield in chlorobenzene after 48 h.



**7** **8** **9**

**a**, X = $CO_2H$; **b**, X = $CO_2Et$; **c**, X = CN; **d**, X = CH=NOMe; **e**, X = COMe; **f**, X = COPh; **g**, X = $SO_2Ph$; **h**, X = $SiMe_3$; **i**, X = $SiMe_2hex^t$; **j**, X = $Si(Pr^i)_3$, **k**, X = Cl; **m**, X = H.

Similar furan to isothiazole conversions were obtained in chlorobenzene with X = CN (24%, 2 days), X = CH=NOMe (27%, 2 days), X = COPh (51%, 2.5 h) and X = $SO_2Ph$ (60%, 6 h and 55% with pyridine in toluene for 48 h) to give **8c, d, f** and **g** respectively. With X = Ac however, rapid decomposition ensued in toluene and chlorobenzene, possibly involving the enol tautomer. Treatment of the isomeric oximes **7**, X = CH=NOH,

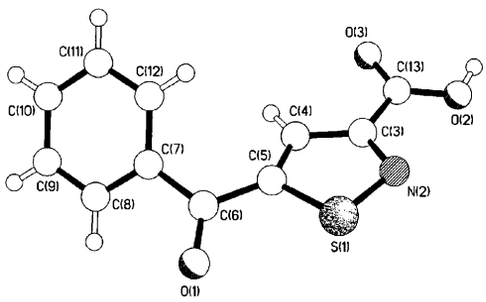
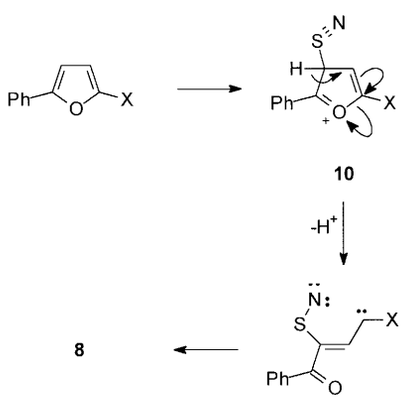



**Fig. 1** The molecular structure of **8a**.

with the thionyl chloride reagent in boiling benzene, or better, toluene not surprisingly gave the cyanide **7c** very efficiently (92%), but the isomeric oxime ethers **7d** resulted in the isothiazole **8d**, presumably as the more stable *anti*-isomer. The structures of the isothiazoles **8** followed from their spectroscopic properties, compared with other 5-benzoylisothiazoles made in the same way, and were confirmed by X-ray crystallography for the carboxylic acid **8a**, prepared by hydrolysis of its ethyl ester **8b**, and for the sulfone **8g**. Thus the regiochemistry of these reactions is as expected for the initial substitution of the polarised furan ring at the more nucleophilic β-position, *via* **10** which is thought to rearrange by ring-opening and ring-closing (Scheme 1) to give the 5-benzoylisothiazole exclusively.[1a]




**Scheme 1**

The structure of the carboxylic acid **8a** (Fig. 1) shows the carboxylic acid group to lie almost coplanar with the isothiazole ring, the torsional twist about the C(3)–C(13) bond being only *ca.* 6°. The phenyl ring is fairly steeply inclined, by *ca.* 49°, to the isothiazole ring plane, the inclination being produced by torsional twists of 22 and 33° about the C(5)–C(6) and C(6)–C(7) bonds respectively. The O(1) carbonyl group is oriented *syn* to the isothiazole ring sulfur atom. The isothiazole ring is almost perfectly planar (maximum deviation of <0.001 Å), but C(6) lies 0.106 Å out of this plane whereas C(13) deviates by only 0.043 Å in the opposite sense. The bonding within the isothiazole ring is fairly typical of that reported previously for this ring system, there being a distinct pattern of bond ordering with the C(3)–N(2) and C(4)–C(5) bonds each displaying significant double bond character (Table 2). Adjacent centrosymmetrically related pairs of molecules pack with their isothiazole rings overlying each other, this stacking interaction (**a** in Fig. 2) being supplemented by a pair of carbonyl···carboxylic $O^{\delta-}\cdots C^{\delta+}$ interactions (**b** in Fig. 2). These "dimer pairs" are then linked *via* carboxylic···carboxylic hydrogen bonds (**c** in Fig. 2) to form continuous chains. Neighbouring chains are weakly cross-linked by π–π interactions between the phenyl rings in one chain and the opposite face of the carboxylic group involved in the $\delta^+\cdots\delta^-$ interaction (**b**) in the next and *vice versa*; the $Ph_{(ring\ centroid)}\cdots C(13)$ distance is 3.48 Å. There are no short intermolecular S···N contacts.

**Table 2** Isothiazole bond lengths (Å) for structures **8a**, **8g**, **8j**, **9j** and **13**

| | **8a** | **8g** | **8j** | **9j** | **13** |
|---|---|---|---|---|---|
| S(1)–N(2) | 1.635(2) | 1.642(2) | 1.644(2) | 1.635(3) | 1.639(2) |
| N(2)–C(3) | 1.327(2) | 1.311(3) | 1.335(3) | 1.298(3) | 1.323(3) |
| C(3)–C(4) | 1.404(3) | 1.410(3) | 1.424(3) | 1.432(3) | 1.422(3) |
| C(4)–C(5) | 1.368(3) | 1.368(3) | 1.364(3) | 1.381(3) | 1.365(3) |
| C(5)–S(1) | 1.707(2) | 1.714(2) | 1.701(2) | 1.704(3) | 1.708(2) |

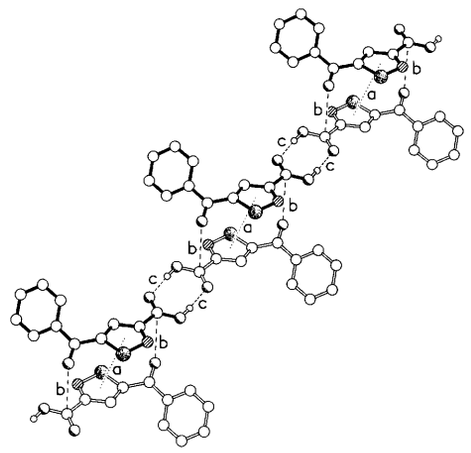



**Fig. 2** Part of one of the continuous chains of molecules present in the structure of **8a**. The respective mean interplanar and ring centroid···ring centroid separations are (**a**) 3.59, 3.84 Å. The O···C separation (**b**) is 3.15 Å. The O–H···O hydrogen bond (**c**) has O···O, H···O distances 2.65, 1.75 Å, and O–H···O angle 175°.

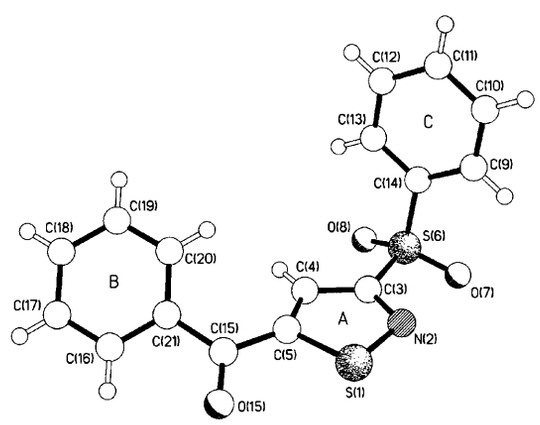



**Fig. 3** The molecular structure of **8g**.

The solid state structure of the sulfone **8g** is illustrated in Fig. 3. The isothiazole phenyl sulfone adopts an open-book conformation analogous to that invariably observed for unstrained diphenyl sulfones,[4] the torsional twists about the C(3)–S(6) and S(6)–C(14) linkages being *ca.* 89 and 85° respectively. The terminal phenyl ring **B** is less steeply inclined to the isothiazole ring than in **8a**, the 40° inclination being comprised of torsional twists of 18 and 25° about C(5)–C(15) and C(15)–C(21) respectively. As observed in **8a**, the carbonyl oxygen is oriented *syn* to the isothiazole sulfur. The pattern of bonding in the isothiazole ring does not differ markedly from that observed in **8a**. Unlike in **8a**, the C(15) and S(6) substituents lie only 0.056 and 0.008 Å respectively above and below the isothiazole ring plane (which is planar to within 0.007 Å). $C_2$ related molecules stack with the isothiazole ring **A** of one molecule overlaying the phenyl ring **B** of the next and *vice versa* (**a** in Fig. 4). This stacking interaction is supplemented by a pair of C–H···π interactions between one of the *meta* C–H hydrogen atoms of ring **B** in one molecule and the phenyl sulfone ring **C** in the next (**b** in Fig. 4). These "dimer pairs" are linked by C–H···O hydrogen bonds between

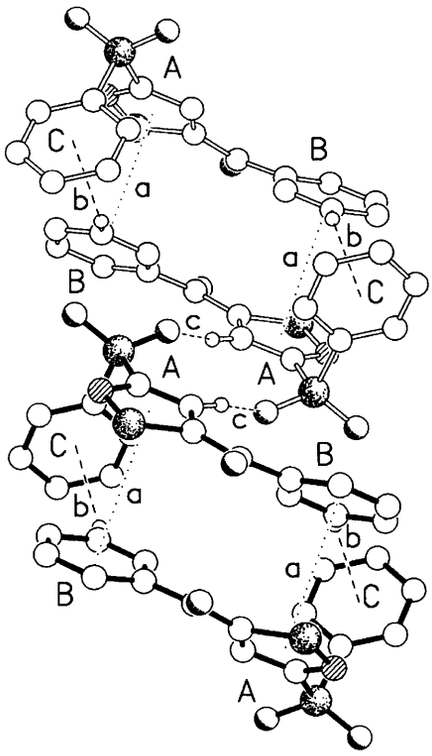
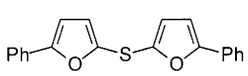



**Fig. 4** Part of one of the continuous chains of linked "dimers" present in the structure of **8g**. The respective mean interplanar and ring centroid · · · ring centroid separations are (**a**) 3.68, 3.91 Å. The C–H · · · π interaction (**b**) has H · · · π 2.82 Å and C–H · · · π 147 °. The C–H · · · O hydrogen bond (**c**) has C · · · O, H · · · O distances 3.31, 2.40 Å, and C–H · · · O angle 157°.

the isothiazole methine hydrogen in one molecule and one of the sulfone oxygen atoms O(8) in the next (**c** in Fig. 4). These interactions combine to form continuous chains of molecules, though here there are no obvious interchain interactions of note.

As with the 5-phenyl derivatives, 5-*tert*-butylfuran-2-carboxylic acid also decomposed under the standard conditions, but its ethyl ester reacted cleanly to give ethyl 5-pivaloylisothiazole-3-carboxylate in 57 and 80% yield respectively in pyridine–toluene and in isoquinoline–chlorobenzene. A limited range of activated 2-phenylfurans was also examined. 2-Phenylfuran itself did not give any isothiazole with the Katz reagent in toluene, but instead a low yield (15%) of bis(5-phenylfuran-2-yl) sulfide **11** together with much decomposition. The structure of




**11**

**11** was confirmed by a more obvious synthesis from 2-phenylfuran and sulfur dichloride in the presence of pyridine. The formation of **11** with the Katz reagent is not too surprising since the free α-position of 2-phenylfuran is highly susceptible to electrophilic attack, for example by thionyl chloride to give the furansulfinyl chloride which can react again with starting furan to give the bis-furanyl sulfoxide;[5] this could be reduced by more thionyl chloride, a known process,[6] or by a related intermediate species, to the sulfide **11**. Substitution of the free α-position of the 2-phenylfuran by thiazyl chloride, NSCl, is also possible but this does not lead to a reasonably low energy ring-opening and ring-closing sequence to give an isothiazole, as the β-thiazyl derivatives do. With both α-positions blocked, 2-methyl-5-phenylfuran did give the expected 5-benzoyl-3-methylisothiazole **8**, X = Me in 40 and 50% yield in toluene and chlorobenzene respectively.

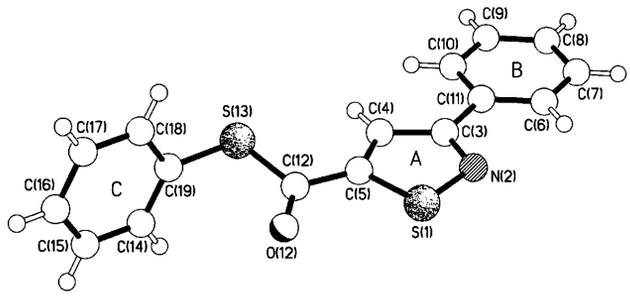



**Fig. 5** The molecular structure of **13**.

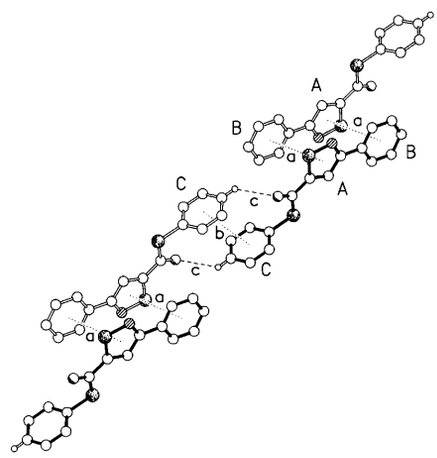
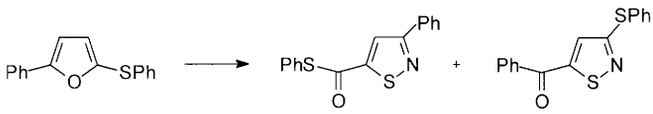



**Fig. 6** Part of one of the continuous chains of molecules in the structure of **13**. The mean interplanar and centroid · · · centroid separations are (**a**) 3.60, 3.93 Å and (**b**) 3.58, 3.98 Å respectively. The C–H · · · O hydrogen bond (**c**) has C · · · O, H · · · O distances 3.30, 2.56 Å, and C–H · · · O angle 135°.

Finally and more interestingly, 5-phenyl-2-phenylthiofuran **12** reacted with the Katz reagent in toluene (8 h) and in chlorobenzene (30 min) to give both possible isomeric 5-acylisothiazoles **13** and **14** in the yields shown (Table 3). The structures of **13** and **14** followed from the spectroscopic data, and structure **13** was confirmed by X-ray crystallography. In the starting furan **12** the β-position adjacent to the phenylthio group is the more nucleophilic and preferential attack here leads to the major isothiazole **13**. This result should be contrasted with the same reaction of the corresponding sulfone **7g** which gave exclusively the isothiazole **8g** resulting from attack at the β-position non-adjacent to the phenylsulfonyl group, as expected. This illustrates, once more, that the more electron-withdrawing α-substituent of the furan becomes the isothiazole 3-substituent and the more electron-releasing one becomes part of the isothiazole 5-acyl substituent.

The X-ray analysis of **13** (Fig. 5) shows the isothiazole and its adjacent phenyl ring (**B**) to be in almost perfect conjugation with each other, the torsional twist about the C(3)–C(11) linkage being only *ca.* 2°. The carbonyl oxygen is again oriented *syn* to the ring sulfur atom, though the group lies much closer to the isothiazole ring plane [torsional twist of *ca.* 8° about C(15)–C(12)]. The terminal phenyl ring **C** is oriented almost orthogonally to the remainder of the molecule, there being a *ca.* 80° rotation about the S(13)–C(19) bond. Within the isothiazole ring, the bond lengths show only minor variations compared with those in **8a** and **8g** (Table 2). The molecules are linked by π–π stacking interactions to form continuous chains (Fig. 6). There is (i) a centrosymmetric reverse-stacking of the phenylisothiazole ring systems, ring **A** overlaying ring **B** and *vice versa* (**a** in Fig. 6) and (ii) a parallel stacking of rings **C** about an independent inversion centre (**b** in Fig. 6). This latter interaction is supplemented by a pair of possible weak C–H · · · O hydrogen bonding interactions across the same inversion centre between the *para* hydrogen on ring **C** in one molecule and the

**Table 3** Treatment of 5-phenyl-2-phenylthiofuran **12** with ethyl carbamate, thionyl chloride and a base in a boiling solvent




**12** **13** **14**

| Base | Solvent | Reaction time/h | Yield (%) **13** | Yield (%) **14** |
|---|---|---|---|---|
| Pyridine | Toluene | 8 | 34 | 17 |
| Isoquinoline | Chlorobenzene | 0.5 | 30 | 12 |

**Table 4** Conversion of furans into 5-acylisothiazoles

| | | Method A | | Method B | | Method C | |
|---|---|---|---|---|---|---|---|
| Furan | Isothiazole | Time/h | Yield (%) | Time/h | Yield (%) | Time/h | Yield (%) |
| **1a** | **2a** | 24 | 98 | 6 | 70 | 0.5[a] | 80 |
| **1c** | **2c** | 6 | 66 | | — | 12[a] | 40 |
| **3a** | **4a** | 18 | 56 | 1 | 85 | 0.5[a] | 95 |
| **3b** | **4b** | 16 | 99 | | — | 10 min[a] | 80 |
| **5** | **4b** | 48 | 13 | | — | 1[a] | 68 |
| **6** | **4a** | | — | 24 | 15 | 0.75[a] | 12 |
| **7b** | **8b** | | — | 3 | 25 | 48[a] | 52 |
| **7c** | **8c** | | — | 2 | 14 | 2[a] | 24 |
| **7d** | **8d** | | — | 5 | 20 | 2[a] | 27 |
| **7f** | **8f** | | — | 12 | 2 | 2.5[a] | 51 |
| **7g** | **8g** | | — | 48 | 55 | 6[a] | 60 |
| **7h** | **8h/9m** | | — | 24 | **8h**: 38 | 1.5[b] | **9m**: 35 |
| **7i** | **8i/9i** | | — | 48 | **8i**: 47 | 2[b] | **8i**: 6; **9i**: 25 |
| **7i** | **8i/9i** | | — | | — | 2[b,c] | **8i**: 38; **9i**: 11 |
| **7j** | **8j/9j** | | — | 24 | **8j**: 35 | 6[a] | **8j**: 12; **9j**: 41 |
| **7j** | **8j/9j** | | — | | — | 6[a] | **8j**: 31; **9j**: 47 |
| **7j** | **8j/9j** | | — | | — | 6[a,d] | **8j**: 24; **9j**: 36 |
| **7j** | **8j/9j** | | — | | — | 6[a,e] | **8j**: 80; **9j**: 13 |
| **12** | **13** | | — | 8 | 34 | 0.5[a] | 30 |
| | +**14** | | — | 8 | 17 | 0.5[a] | 12 |
| 2-Me-5-Ph | 5-PhCO-3-Me | | — | 5 | 40 | 72[a] | 50 |
| 5-Bu$^t$-2-$CO_2$Et | 3-Et$O_2$C-5-COBu$^t$ | | — | 24 | 57 | 24[a] | 80 |

[a] Isoquinoline used as base. [b] Pyridine used as base. [c] Half of the thionyl chloride added at the start of reaction and the other half added after half reaction time. [d] Only 4.3 mmol thionyl chloride used. [e] Thionyl chloride added dropwise throughout the reaction.



carbonyl oxygen O(12) of the next (**c** in Fig. 6). Adjacent chains are loosely linked by aromatic edge-to-face interactions between the edges of rings **C** in one chain and the faces of rings **A** in the next (the centroid · · · centroid separations are 5.14 Å).

### Silylated furans

Because of the well known replaceability of a silyl group by a wide range of other substituents, we finally investigated the transformation of silylated furans into the corresponding silylated isothiazoles. This would be of particular value in that, for example, simple acylisothiazoles are hardly known, and could be made by appropriate protodesilylation.

Both 5-silylated-2-phenylfurans **7h–7j** and 2,5-di-silylated furans were readily synthesised by reaction of the corresponding organolithium derivative with a trialkylsilyl chloride. The silyl groups investigated were trimethylsilyl, dimethyl-*tert*-hexylsilyl, and triisopropylsilyl.

Reaction of the 5-silylated-2-phenylfurans **7h–7j** with the Katz reagent in refluxing toluene with pyridine as the base, generated the expected 5-benzoyl-3-silylated isothiazoles **8h–8j** in 38, 47 and 35% respectively (Table 4). However, in boiling chlorobenzene with pyridine or isoquinoline as the base the trimethylsilylfuran **7h** gave instead the chlorodesilylated product, **9m** (38%). The more heavily substituted silylfuran derivatives **7i** and **7j** in hot chlorobenzene gave the expected products **8i** and **8j** in slightly lower yields, together with an analogous isothiazole bearing an extra chlorine substituent in place of the isothiazole ring hydrogen. Comparative spectral data together with X-ray crystallography on both of the isothiazoles derived from **7j**, revealed, surprisingly, that the chlorinated product was the rearranged 3-chloro-4-silylated-5-benzoylisothiazole **9j**. Furthermore, the isolated isothiazole **8j** was not transformed, as expected, into the rearranged product by further Katz treatment in chlorobenzene! The starting furans were also not chlorinated by treatment with thionyl chloride in refluxing chlorobenzene, or by pyridine hydrochloride in the same solvent. The yield of the rearranged products is greatest when technical grade thionyl chloride is utilised, suggesting possibly that sulfur chlorides are the key chlorinating agents bringing about the rearrangement. Thus with technical grade thionyl chloride using pyridine in chlorobenzene, after 6 h reflux the yields of **8j** and **9j** were 58 and 31% respectively; using purified thionyl chloride under the same conditions, the same products were isolated in 70 and 21% yields.

At present we have no evidence for the mechanism of this novel silyl rearrangement and chlorination process. Optimisation of the conditions allowed the triisopropylsilylfuran **7j** to give 80% of the unrearranged isothiazole **8j** together with 13% rearranged product **9j** by addition of thionyl chloride dropwise during the 6 h reflux in chlorobenzene with pyridine as base. Alternatively, using the standard mode of reaction 31% unrearranged together with 47% rearranged isothiazole were isolated.

These silylated isothiazoles have so far proved impervious to the action of a variety of electrophiles including mineral

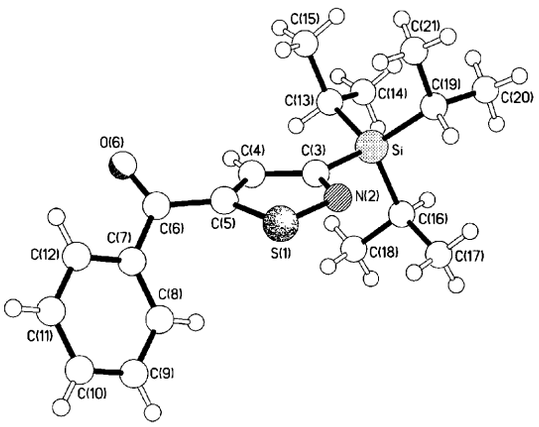



**Fig. 7** The molecular structure of **8j**.

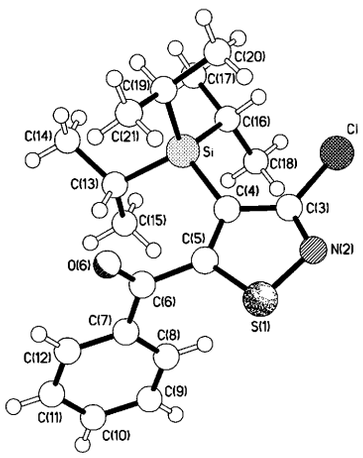



**Fig. 8** The molecular structure of **9j**.

acid, bromine or NBS and iodine and silver trifluoroacetate. Tetrabutylammonium fluoride in refluxing THF caused decomposition of the substrates.

In the structure of **8j**, the replacement of the carboxylic acid in **8a** by a triisopropylsilyl unit is accompanied by a dramatic change in the orientation of the Ph–C=O substituent with respect to the isothiazole ring. As in **8a**, the phenyl and isothiazole ring planes are fairly steeply inclined (by *ca.* 60°), the inclination being a result of torsional twists of *ca.* 34 and 32° about C(5)–C(6) and C(6)–C(7) respectively. However, here in **8j** the carbonyl oxygen is *anti* to the ring sulfur atom (Fig. 7) *cf. syn* orientations in **8a, 8g** and **13**. The bond length within the isothiazole ring are again little changed compared with those in the preceding structures (Table 2). The only intermolecular packing interaction of note is a parallel π–π stacking of centrosymmetrically related pairs of phenyl rings for which the mean interplanar and centroid···centroid separations are 3.54 and 3.87 Å respectively. The formation of linked chains is here prevented by the steric bulk and hydrophobic exterior of the triisopropylsilyl substituent.

The X-ray structure of **9j** is shown in Fig. 8. Here, the presence of the bulky triisopropylsilyl group on the 4-position forces the Ph–C=O unit to adopt an orientation nearly orthogonal to the isothiazole ring plane; the torsional twists about the C(5)–C(6) and C(6)–C(7) bonds are 82 and 5° respectively. Again there are only small differences in the pattern of bonding within the isothiazole ring compared with those in the other four structures (Table 2). There are no intermolecular packing interactions of note, again presumably because of the congested environment of the ring systems.

Although the differences in the patterns of bonding within the isothiazole rings throughout the five structures investigated are small, there are, over the range, noticeable differences in the relative values for the N(2)–C(3) and C(3)–C(4) distances; within statistical significance, those for C(4)–C(5), C(5)–S(1) and S(1)–N(2) are unchanged (Table 2). There are, however, no obvious correlations between the small changes in the N(2)–C(3) and C(3)–C(4) bond lengths and the electron-withdrawing or -donating nature of the substituents on C(3) and C(4). The marginally longer value for C(4)–C(5) in **9j** is probably due to the absence of any possible conjugation with the Ph–C=O group attached to C(5), *vide supra*.

The transformation of furans reported in this paper provides a novel and very simple route to a new range of functionalised isothiazoles of considerable interest as components of natural products and as pharmaceutical and agrochemical compounds.

## Experimental

### General details

Melting points were taken on a Reichert hot-stage apparatus. Infrared spectra were recorded on a Unicam Research Series 1 FTIR instrument as liquid films (for oils) or KBr discs. NMR spectra were recorded on a JEOL 270 spectrometer. Chemical shifts are given in ppm and are referenced to the residual peak of the solvent or tetramethylsilane. Coupling constants are given in hertz. Low resolution mass spectra were recorded on a Kratos MS8ORF and accurate mass measurements on a VG Autospec mass spectrometer using chemical ionisation employing ammonia. TLC was performed using Merck silica 60F254 plates and flash chromatography with Fluka silica gel 60. Light petroleum refers to the fraction boiling between 60 and 80 °C. Organic layers were dried over $Na_2SO_4$.

The following compounds were prepared by literature methods: 2,5-diphenylfuran **1a**,[1a] 2,5-di-*tert*-butylfuran **1c**,[7] 3-bromo-2,4,5-triphenylfuran **6**,[1a] 3,4-dibromo-2,5-diphenylfuran **5**,[1a] 2-phenylfuran,[8,9] 2-methyl-5-phenylfuran[1c,8] and 5-*tert*-butylfuran-2-carboxylic acid.[7] 5-Phenylfuran-2-carbaldehyde was prepared[9,10] by the formylation of 2-phenylfuran to give an oil (84%), $\nu_{max}$ (neat)/cm$^{-1}$ 3114, 2815, 1673, 1523, 1475, 1390, 1257, 1029; $\delta_H$ ($CDCl_3$) 6.83 (1H, d, *J* 3.62), 7.31 (1H, d, *J* 3.62), 7.36–7.48 (3H, m), 7.77–7.85 (2H, m), 9.64 (1H, s, CHO); *m*/*z* 173 (M + 1, 100%).

Oxidation[9] of this aldehyde gave 5-phenylfuran-2-carboxylic acid **7a** (65%), mp 147 °C (methanol) (lit.[9] 146–148 °C), $\nu_{max}$ (KBr)/cm$^{-1}$ 3143–2800, 1677, 1523, 1475, 1265, 1164, 1027; $\delta_H$ (DMSO-$d_6$) 7.12 (1H, d, *J* 3.63), 7.26 (1H, d, *J* 3.63), 7.35–7.43 (1H, m), 7.44–7.52 (2H, m), 7.76–7.83 (2H, m); *m*/*z* 189 (M + 1, 100%), 171 (7). Ethyl 5-phenylfuran-2-carboxylate **7b** was prepared from the above acid **7a** and catalytic sulfuric acid in ethanol under reflux for 12 h to give a colourless oil (70%), $\nu_{max}$ (neat)/cm$^{-1}$ 2983, 1714, 1481, 1335, 1301, 1141, 1018; $\delta_H$ ($CDCl_3$) 1.39 (2H, t, *J* 7.1), 4.38 (2H, q, *J* 7.1), 6.72 (1H, d, *J* 3.3), 7.22 (1H, d, *J* 3.3), 7.25–7.45 (m, 3H), 7.72–7.85 (2H, m); *m*/*z* 217 (M + 1, 100%), 189 (M − $C_2H_5$, 48), 171, 149.

5-Phenylfuran-2-carbaldehyde oxime was prepared from the aldehyde and aqueous hydroxylamine in ethanol to give a mixture of the isomeric oximes as yellow crystals (99%), mp 193–194 °C (lit.[10] 194–195 °C), $\nu_{max}$ (KBr)/cm$^{-1}$ 3218, 2923, 1633, 1484, 1448, 1297, 987, 908; $\delta_H$ ($CDCl_3$ + $D_2O$) (signals for two geometrical isomers, a and b) 6.70 (2H, s, $H_{furan\text{-}a}$), 6.77 (1H, d, *J* 3.85, $H_{furan\text{-}b}$), 7.23–7.45 (7H, m, $H_{a,b}$), 7.60 (1H, s, -$CH_b$=N-), 7.68–7.79 (4H, m, $H_{a,b}$), 8.04 (1H, s, -$CH_a$=N-); *m*/*z* 188 (M + 1, 40%), 170 (M + 1 − $H_2O$, 75), 85 (100).

### 5-Phenylfuran-2-carbaldehyde *O*-methyloxime 7d

A solution of 5-phenylfuran-2-carbaldehyde (500 mg, 2.89 mmol) and methoxylamine hydrochloride (241 mg, 2.89 mmol) in pyridine (5 ml) was stirred under nitrogen for 2 h. The reaction mixture was poured into a mixture of ice–water and $Na_2CO_3$ and the aqueous layer was extracted with dichloromethane (3 × 30 ml). The organic layer was washed with water,

dried and the solvent removed under reduced pressure. The residue was purified by flash chromatography (1% ethyl acetate–light petroleum) to give the title compound as a brown oil (500 mg, 86%). Found *m/z* $[M]^+$, 201.0789. $C_{12}H_{11}NO_2$ requires *m/z* $[M]^+$, 201.0790; $\nu_{max}$ (neat)/$cm^{-1}$ 2937, 2819, 1616, 1519, 1481, 1448, 1054, 890; $\delta_H$ ($CDCl_3$) (signals for two geometrical isomers, a and b) 3.99 (1H, s, $CH_{3a}$), 4.05 (1H, s, $CH_{3b}$), 6.67 (2H, s, $H_{furan\text{-}a}$), 6.73 (1H, d, *J* 3.63, $H_{furan\text{-}b}$), 7.20–7.42 (7H, m, $H_{a,b}$), 7.47 (1H, s, -$CH_b$=N-), 7.65–7.74 (4H, m, $H_{a,b}$), 7.95 (1H, s, –$CH_a$=N–); $\delta_C$ ($CDCl_3$) (signals for two geometrical isomers) 62.2, 62.7, 106.9, 107.6, 114.5, 119.75, 124.3, 124.3, 128.1, 128.2, 128.63, 128.75, 129.9, 135.8, 138.9, 138.95, 144.6, 146.5, 154.3, 155.5; *m/z* 202 (M + 1, 13%), 170 (M − $OCH_3$, 55), 85 (80), 57 (C=N–$OCH_3$, 100).

### 5-Phenylfuran-2-carbonitrile 7c

A solution of ethyl carbamate (2.46 g, 27.74 mmol), pyridine (10 ml) and thionyl chloride (2.17 ml, 27.74 mmol) in toluene (30 ml) was stirred under a nitrogen atmosphere at ambient temperature for 30 min. To the yellow suspension was added 5-phenylfuran-2-carbaldehyde oxime (1.20 g, 6.45 mmol) and the reaction mixture was heated at reflux for 2 h. The solvent was evaporated under reduced pressure and the resulting residue was dissolved in dichloromethane (20 ml), washed with aqueous hydrochloric acid (2 M, 2 × 10 ml) and $H_2O$ (2 × 10 ml). The organic layer was dried and evaporated under reduced pressure. The crude product was purified by flash chromatography (5% ethyl acetate–light petroleum) to give **7c** as pale yellow crystals (1.00 g, 92%), mp 70 °C (ethanol) (lit.[11] 72 °C), $\nu_{max}$ (KBr)/$cm^{-1}$ 3118, 2923, 2229, 1450, 1035; $\delta_H$ ($CDCl_3$) 6.72 (1H, d, *J* 3.63), 7.17 (1H, d, *J* 3.62), 7.35–7.44 (3H, m), 7.67–7.76 (2H, m); *m/z* 170 (M + 1, 100%), 85 (91).

The nitrile **7c** was identical to that prepared from the aldehyde, hydroxylamine and formic acid[12] in low yield (20%).

### 2-Acetyl-5-phenylfuran 7e

To a solution of 2-phenylfuran (200 mg, 1.39 mmol) in benzene (5 ml) were added acetic acid (0.8 ml, 13.90 mmol) and phosphorus pentaoxide (986 mg, 6.96 mmol).[12] The solution was stirred and heated under reflux for 2 h. The reaction mixture was cooled to 0 °C, hydrolysed with a saturated solution of $NaHCO_3$ and the aqueous layer extracted with ethyl acetate (3 × 20 ml). The organic layer was dried and the solvent evaporated under reduced pressure. The residue was purified by flash chromatography (5% ethyl acetate–light petroleum) to give **7e** as a pale red oil (155 mg, 60%). Found *m/z* $[M + 1]^+$, 187.0759. $C_{12}H_{10}O_2$ requires *m/z* $[M + 1]^+$, 187.0759; $\nu_{max}$ (neat)/$cm^{-1}$ 3118, 3064, 2925, 1671, 1519, 1475, 1272; $\delta_H$ ($CDCl_3$) 2.5 (3H, s, OMe), 6.77 (1H, d, *J* 3.79), 7.26 (1H, d, *J* 3.79), 7.34–7.50 (3H, m), 7.76–7.85 (2H, m); $\delta_C$ ($CDCl_3$) 25.5, 107.1, 119.2, 124.6, 128.55, 128.9, 129.0, 151.5, 157.3, 185.9; *m/z* 187 (M + 1, 100%), 171 (M − Me, 5).

### 2-Benzoyl-5-phenylfuran 7f

To a solution of 2-phenylfuran (1.0 g, 6.95 mmol) in benzene (10 ml) were added benzoic acid (8.5 g, 69.5 mmol) and phosphorus pentaoxide (4.94 g, 34.7 mmol). The solution was stirred and heated under reflux for 24 h. The reaction mixture was cooled to 0 °C, hydrolysed with a saturated solution of $NaHCO_3$ and the aqueous layer extracted with ethyl acetate (3 × 30 ml). The organic layer was dried and the solvent evaporated under reduced pressure. The residue was purified by flash chromatography (5% ethyl acetate–light petroleum) to give **7f** as pale yellow crystals (1.37 g, 80%), mp 86–87 °C (ethanol) (lit.[11] 95–96 °C) (Found C, 82.1; H, 4.9; $C_{17}H_{12}O_2$ requires C, 82.25; H, 4.8%); $\nu_{max}$ (KBr)/$cm^{-1}$ 3062, 1637, 1515, 1471, 1319, 1270, 1072, 881; $\delta_H$ ($CDCl_3$) 6.83 (1H, d, *J* 3.63), 7.32 (1H, d, *J* 3.63), 7.33–7.65 (6H, m), 7.77–7.87 (2H, m), 7.96–8.05 (2H, m); $\delta_C$ ($CDCl_3$) 107.4, 122.8, 125.1, 128.4, 128.9, 129.3, 132.4, 137.6, 151.5, 158.40, 182.1; *m/z* 249 (M + 1, 57%), 171 (M − Ph, 8), 105 (PhCO, 13), 29 (100).

### 5-Phenyl-2-phenylthiofuran 12

This compound was prepared by the literature method[13] from 2-phenylfuran by treatment of its 5-lithio derivative with diphenyl disulfide as colourless crystals (94%), mp 84 °C (ethanol) (lit.[14] 84–86 °C); $\nu_{max}$ (KBr)/$cm^{-1}$ 3040, 2918, 1581, 1471, 1440, 1018; $\delta_H$ ($CDCl_3$) 6.71 (1H, d, *J* 3.3), 6.82 (1H, d, *J* 3.3), 7.10–7.32 (6H, m), 7.34–7.41 (2H, m), 7.65–7.75 (2H, m).

### 5-Phenyl-2-phenylsulfonylfuran 7g

To a solution of 5-phenyl-2-phenylthiofuran (1.0 g, 3.96 mmol) in acetic acid (10 ml) was added a 35% solution of hydrogen peroxide (6 ml). After 12 h, the solution was quenched with a saturated solution of $NaHCO_3$ and the aqueous layer was extracted with ethyl acetate (3 × 30 ml). The organic layer was dried and evaporated under reduced pressure. The residue was purified by flash chromatography (5% ethyl acetate–light petroleum) to give **7g** as pale yellow crystals (789 mg, 70%), mp 86–88 °C (ethanol) (Found C, 67.4; H, 4.35. $C_{16}H_{12}O_3S$ requires C, 67.6; H, 4.2%); $\nu_{max}$ (KBr)/$cm^{-1}$ 3129, 3066, 1473, 1446, 1330, 1184, 1147; $\delta_H$ ($CDCl_3$) 6.70 (1H, d, *J* 3.7), 7.26 (1H, d, *J* 3.7), 7.32–7.44 (3H, m), 7.47–7.70 (5H, m), 8.0–8.08 (2H, m); $\delta_C$ ($CDCl_3$) 106.3, 119.5, 124.8, 127.8, 128.9, 129.4, 133.7, 140.20, 148.5, 159.0; *m/z* 285 (M + 1, 100%), 207 (M − Ph, 5), 184, 144.

### Ethyl 5-*tert*-butylfuran-2-carboxylate

A solution of 5-*tert*-butylfuran-2-carboxylic acid (5.0 g, 29.76 mmol) and sulfuric acid (catalytic amount) in ethanol (50 ml) was stirred under reflux for 12 h. The reaction mixture was then cooled and concentrated under reduced pressure. The residue was poured into water and neutralised with saturated aqueous $NaHCO_3$ and the aqueous layer was extracted with dichloromethane (3 × 50 ml). The organic layer was washed with water and brine, and dried. The solvent was evaporated under reduced pressure and the residue was purified by flash chromatography (5% ethyl acetate–light petroleum) to give the title compound as a colourless oil (1.17 g, 85%) (Found $[M + 1]^+$, 197.1176. $C_{11}H_{16}O_3$ requires $[M + 1]^+$, 197.1178); $\nu_{max}$ (neat)/$cm^{-1}$ 2969, 1727, 1521, 1365, 1303, 1201, 1139, 1014; $\delta_H$ ($CDCl_3$) 1.31 (9H, s, $CH_3$), 1.36 (3H, t, *J* 6.93, $CH_3$), 4.34 (2H, q, *J* 6.93, $CH_2$), 6.08 (1H, d, *J* 3.30), 7.05 (1H, d, *J* 3.30); $\delta_C$ ($CDCl_3$) 14.7, 29.2, 33.4, 60.8, 104.9, 118.9, 143.5, 159.3, 169.1; *m/z* 197 (M + 1, 100%), 181 (M − $CH_3$, 12), 169 (21), 187 (33), 151 (27).

### General procedure for the preparation of the silylated derivatives of 2-phenylfuran

To a solution of 2-phenylfuran (2.0 g, 13.80 mmol) in dry tetrahydrofuran (20 ml) at −10 °C was added *n*-butyllithium (6.6 ml of a 2.5 M solution in hexanes, 16.7 mmol). The mixture was stirred for 2 h and then allowed to warm to 0 °C. The trialkylchlorosilane (1.2 equiv.) was then added dropwise and the solution stirred overnight, after which it was hydrolysed with aqueous ammonium chloride (10%, 30 ml) and the aqueous layer extracted with ethyl acetate (3 × 50 ml). The organic layer was dried and concentrated under reduced pressure and the residue purified by flash chromatography (5% ethyl acetate–light petroleum) to give **7h–7j** as colourless oils (80%, 85%, 85% respectively).

**2-Phenyl-5-(trimethylsilyl)furan 7 h.** Isolated as an oil (Found $[M]^+$, 216.0969. $C_{13}H_{16}OSi$ requires $[M]^+$, 216.0970); $\nu_{max}$ (neat)/$cm^{-1}$ 3089, 2958, 1608, 1469, 1249, 1120, 1018; $\delta_H$ ($CDCl_3$) 0.29

(9H, s, $CH_3)_3Si$), 6.62 (1H, d, *J* 3.3), 6.63 (1H, d, *J* 3.3), 7.19–7.25 (1H, m), 7.31–7.40 (2H, m), 7.65–7.72 (1H, m); $\delta_C$ ($CDCl_3$) 0.35, 106.6, 123.05, 125.65, 128.9, 130.1, 132.85, 159.5, 161.6; *m*/*z* 217 (M + 1, 100%), 201 (M − $CH_3$, 61), 73 ($Si(CH_3)_3$, 58).

**2-Phenyl-5-[dimethyl(1,1,2-trimethylpropyl)silyl]furan 7i.** Isolated as an oil (Found $[M]^+$, 286.1753. $C_{18}H_{26}OSi$ requires $[M]^+$, 286.1753); $\nu_{max}$ (neat)/$cm^{-1}$ 2958, 1608, 1469, 1251, 1157, 757; $\delta_H$ ($CDCl_3$) 0.32 (6H, s, $Si(CH_3)_2$), 0.87 (6H, d, *J* 6.92, $CH(CH_3)_2$), 0.94 (6H, s, -$(CH_3)_2$-), 1.65 (1H, septet, *J* 6.92, –CH–), 6.61 (1H, d, *J* 3.30), 6.66 (1H, d, *J* 3.30), 7.21–7.26 (1H, m), 7.32–7.39 (2H, m), 7.65–7.71 (1H, m); $\delta_C$ ($CDCl_3$) 18.6, 21.0, 23.9, 34.8, 105.1, 123.4, 123.95, 124.0, 127.2, 128.6, 131.2, 157.7, 159.5; *m*/*z* 287 (M + 1, 100%), 271 (M − $CH_3$, 41), 201 (M − $C_6H_{13}$, 45), 143 (M − $SiC_8H_{19}$, 28).

**2-Phenyl-5-(triisopropylsilyl)furan 7j.** Isolated as an oil (Found $[M]^+$, 300.1904. $C_{19}H_{28}OSi$ requires $[M]^+$, 300.1909); $\nu_{max}$ (neat)/$cm^{-1}$ 2942, 2865, 1608, 1465, 1382, 1189, 1018, 883; $\delta_H$ ($CDCl_3$) 1.13 (18H, d, *J* 6.93, $CH_3$), 1.31 (3H, septet, *J* 6.93, CH), 6.65 (1H, d, *J* 3.30), 6.73 (1H, d, *J* 3.30), 7.17–7.27 (1H, m), 7.31–7.40 (2H, m), 7.64–7.72 (1H, m); $\delta_C$ ($CDCl_3$) 10.98, 18.73, 104.91, 123.45, 123.88, 127.14, 128.62, 131.28, 156.80, 157.73; *m*/*z* 301 (M + 1, 71%), 257 (M − $CH(CH_3)_2$, 72), 215 (M − $[CH(CH_3)_2]_2$, 15), 187 (33), 171 (M − $[CH(CH_3)_2]_3$, 30), 157 ($Si(CH(CH_3)_2)_3$, 100).

### 2,5-Bis[dimethyl(1,1,2-trimethylpropyl)silyl]furan 1e

To a solution of furan (5.0 g, 73.5 mmol) in dry tetrahydrofuran (20 ml) at −10 °C was added *n*-butyllithium (59 ml of a 2.5 M solution in hexanes, 0.147 mol). The mixture was stirred for 2 h and allowed to warm to 0 °C. Dimethyl(1,1,2-trimethylpropyl)-chlorosilane (57.7 g, 147 mmol equiv.) was then added dropwise and the solution stirred overnight at ambient temperature. The reaction mixture was hydrolysed with aqueous ammonium chloride (30 ml) and the aqueous layer was extracted with ethyl acetate (3 × 50 ml). The organic layer was dried and concentrated under reduced pressure and the residue purified by flash chromatography (5% ethyl acetate–light petroleum) to give the title compound as a colourless oil (22.5 g, 87%) (Found $[M]^+$, 352.2629. $C_{20}H_{40}OSi_2$ requires $[M]^+$, 352.2618; $\nu_{max}$ (neat)/$cm^{-1}$ 2960, 2871, 1465, 1376, 1249, 1049, 923; $\delta_H$ ($CDCl_3$) 0.31 (12H, s, $CH_3Si$), 0.89 (12H, d, *J* 6.92, $CH_3$), 0.92 (12H, s, $CH_3$), 1.63 (2H, q, *J* 6.92, CH), 6.62 (2H, s); $\delta_C$ ($CDCl_3$) −3.85, 18.5, 21.0, 23.9, 34.9, 120.0, 163.75; *m*/*z* 352 (M, 55%), 147 ($C_8H_{18}Si$, 100).

### General procedures for the reactions with ethyl carbamate, thionyl chloride and a base

**Method A.** A solution of ethyl carbamate (383 mg, 4.3 mmol), thionyl chloride, freshly distilled from quinoline (512 mg, 0.31 ml, 4.3 mmol) and pyridine (2 ml) in benzene (20 ml) was stirred under nitrogen at ambient temperature for 30 min. The furan (1 mmol) was added to the yellow solution and the mixture heated under reflux until the furan was consumed (TLC) (see Table 4). The solvent was evaporated under reduced pressure and the resulting residue dissolved in dichloromethane (15 ml); the solution washed with aqueous hydrochloric acid (2 M, 2 × 10 ml), water (2 × 10 ml) and dried. The organic solvent was evaporated under reduced pressure and the crude product purified by flash chromatography (Table 4) and crystallisation.

**Method B.** As with Method A but with benzene replaced by an equal volume of toluene (see Table 4).

**Method C.** As with Method A but with benzene replaced by an equal volume of chlorobenzene, the pyridine replaced by isoquinoline (2.8 ml) and the amount of thionyl chloride increased to 8.6 mmol (see Table 4).

The following isothiazoles were made by these methods in the yields shown in Table 4: 5-benzoyl-3-phenylisothiazole **2a**,[1b] 5-benzoyl-3,4-diphenylisothiazole **4a**,[1b] 5-benzoyl-4-bromo-3-phenylisothiazole **4b**,[1b,2] 3-*tert*-butyl-5-pivaloylisothiazole **2c**,[1b] 5-benzoyl-3-methylisothiazole;[1c] these compounds were identical with those reported previously.

**Ethyl 5-benzoylisothiazole-3-carboxylate 8b.** Isolated as an oil (Found $[M + 1]^+$, 262.0533. $C_{13}H_{11}NO_3S$ requires $[M + 1]^+$, 262.0538); $\nu_{max}$ (neat)/$cm^{-1}$ 2981, 2929, 1722, 1650, 1596, 1511, 1448, 1380, 1234, 1139, 1024, 842; $\delta_H$ ($CDCl_3$) 1.46 (3H, t, *J* 7.26, $CH_3$), 4.48 (2H, q, *J* 7.26, $CH_2$), 7.52–7.61 (2H, m), 7.65–7.74 (1H, m), 7.92–7.98 (2H, m), 8.18 (1H, s); $\delta_C$ ($CDCl_3$) 14.15, 62.2, 128.5, 128.9, 129.3, 134.0, 136.3, 159.6, 160.3, 166.3, 185.5; *m*/*z* 262 (M + 1, 100%), 214 (15), 148 (33).

**5-Benzoylisothiazole-3-carboxylic acid 8a.** By alkaline hydrolysis of the above ester, mp 138 °C (Found $[M]^+$, 233.0139. $C_{11}H_7NO_3S$ requires $[M]^+$, 233.0147); $\nu_{max}$ (KBr)/$cm^{-1}$ 3189–2838, 1644, 1513, 1446, 1255, 715; $\delta_H$ ($CDCl_3$) 7.58–7.69 (2H, m), 7.72–7.81 (1H, m), 7.93–8.19 (2H, m), 8.20 (1H, s); $\delta_C$ ($CDCl_3$) 128.7, 128.9, 129.1, 129.4, 134.2, 135.9, 160.9, 161.25, 165.7, 185.7; *m*/*z* 233 ($M^+$, 56%), 188 (M − $CO_2H$, 7), 156 (15), 105 (100).

*Crystal data for* ***8a****.* $C_{11}H_7NO_3S$, $M = 233.2$, monoclinic, $P2_1/c$ (no. 14), $a = 6.313(1)$, $b = 10.912(1)$, $c = 15.324(2)$ Å, $\beta = 96.85(1)$ °, $V = 1048.1(1)$ $Å^3$, $Z = 4$, $D_c = 1.478$ g $cm^{-3}$, $\mu$(Cu-K$\alpha$) = 26.9 $cm^{-1}$, $T = 293$ K, colourless blocks; 1698 independent measured reflections, $F^2$ refinement, $R_1 = 0.034$, $wR_2 = 0.091$, 1548 independent observed absorption corrected reflections [$|F_o| > 4\sigma(|F_o|)$, $2\theta \leq 126°$], 150 parameters. CCDC reference number 157793. See http://www.rsc.org/suppdata/p1/b1/b101157j/ for crystallographic files in.cif or other electronic format.

**5-Benzoylisothiazole-3-carbonitrile 8c.** Mp 88 °C (Found $[M + 1]^+$, 215.0280. $C_{11}H_6N_2OS$ requires $[M + 1]^+$, 215.0279); $\nu_{max}$ (neat)/$cm^{-1}$ 3108, 2923, 2856, 2240, 1646, 1596, 1448, 1370, 1276, 1106; $\delta_H$ ($CDCl_3$) 7.54–7.64 (2H, m), 7.68–7.78 (1H, m), 7.88–7.95 (2H, m), 7.96 (1H, s); $\delta_C$ ($CDCl_3$) 129.2, 129.3, 129.85, 129.9, 134.5, 135.9, 139.7, 167.1, 184.5; *m*/*z* 215 (M + 1, 100%).

**5-Benzoylisothiazole-3-carbaldehyde *O*-methyloxime 8d.** Isolated as an oil (Found $[M + 1]^+$, 247.0549. $C_{12}H_{10}N_2O_2S$ requires $[M + 1]^+$, 247.0541); $\nu_{max}$ (neat)/$cm^{-1}$ 2937, 1650, 1598, 1448, 1413, 1286, 1056; $\delta_H$ ($CDCl_3$) 4.01 (3H, s, $OCH_3$), 7.50–7.58 (m, 2H), 7.63–7.71 (1H, m), 7.92–7.96 (2H, m), 7.97 (1H, s), 8.21 (1H, s); $\delta_C$ ($CDCl_3$) 62.6, 123.5, 128.8, 129.3, 133.7, 136.5, 144.1, 162.25, 164.8, 186.1; *m*/*z* 247 (M + 1, 38%), 215 (M − $OCH_3$, 85), 57 (–C=N-$OCH_3$).

**3,5-Dibenzoylisothiazole 8f.** Isolated as an oil (Found $[M + 1]^+$, 294.0589. $C_{17}H_{11}NO_2S$ requires $[M + 1]^+$, 294.0589; $\nu_{max}$ (neat)/$cm^{-1}$ 3062, 1650, 1596, 1448, 1236, 844; $\delta_H$ ($CDCl_3$) 7.45–7.72 (6H, m), 7.92–8.01 (2H, m), 8.28 (1H, s), 8.29–8.33 (2H, m); $\delta_C$ ($CDCl_3$) 128.3, 128.9, 129.4, 130.9, 133.5, 133.9, 135.6, 136.25, 165.4, 166.9, 185.9, 186.2; *m*/*z* 294 (M + 1, 100%), 216 (M − Ph, 25), 105 (PhCO, 39).

**5-Benzoyl-3-phenylsulfonylisothiazole 8g.** Mp 131–133 °C (Found C, 58.4; H, 3.3; N, 4.25. $C_{16}H_{11}NO_3S_2$ requires C, 58.4; H, 3.3; N, 4.25%); $\nu_{max}$ (KBr)/$cm^{-1}$ 3102, 3064, 1649, 1596, 1448, 1330, 1080; $\delta_H$ ($CDCl_3$) 7.52–7.63 (4H, m), 7.65–7.76 (2H, m), 7.88–7.96 (2H, m), 8.06–8.12 (2H, m), 8.14 (1H, m); $\delta_C$ ($CDCl_3$) 125.6, 128.7, 129.0, 129.25, 129.4, 134.3, 134.35, 135.7, 138.3, 167.15, 167.6, 184.8; *m*/*z* 329 (M + 1, 100%), 160 (18).

*Crystal data for* ***8g***. $C_{16}H_{11}NO_3S_2$, $M = 329.4$, monoclinic, $C2/c$ (no. 15), $a = 21.714(3)$, $b = 9.275(1)$, $c = 15.384(1)$ Å, $\beta = 101.43(1)°$, $V = 3036.8(5)$ Å$^3$, $Z = 8$, $D_c = 1.441$ g cm$^{-3}$, $\mu$(Mo-K$\alpha$) = 3.61 cm$^{-1}$, $T = 293$ K, colourless blocks; 2660 independent measured reflections $F^2$ refinement, $R_1 = 0.040$, $wR_2 = 0.099$, 2195 independent observed reflections [$|F_o| > 4\sigma(|F_o|)$, $2\theta \leq 50$ °], 176 parameters. CCDC reference number 157791. See http://www.rsc.org for crystallographic files in.cif or other electronic format.

**5-Benzoyl-3-(trimethylsilyl)isothiazole 8h.** Isolated as an oil (Found [M + 1]$^+$, 262.0726. $C_{13}H_{15}NOSiS$ requires [M + 1]$^+$, 262.0722); $\nu_{max}$ (neat)/cm$^{-1}$ 3108, 2923, 2856, 2240, 1646, 1596, 1448, 1370, 1276, 1106; $\delta_H$ ($CDCl_3$) 7.50–7.61 (2H, m), 7.63–7.71 (1H, m), 7.80 (1H, s), 7.91–7.98 (2H, m); *m/z* 262 (M + 1, 100%), 246 (M − $CH_3$, 22), 156 (M − PhCO, 12).

**5-Benzoyl-3-[dimethyl(1,1,2-trimethylpropyl)silyl]isothiazole 8i.** Isolated as an oil (Found [M + 1]$^+$, 332.1504. $C_{18}H_{25}NOSiS$ requires [M + 1]$^+$, 332.1504); $\nu_{max}$ (neat)/cm$^{-1}$ 3064, 2958, 2867, 1650, 1590, 1465, 875; $\delta_H$ ($CDCl_3$) 0.42 (6H, s, $Si(CH_3)_2$), 0.83 (6H, d, *J* 6.9, $CH(CH_3)_2$), 0.93 (6H, s, -$(CH_3)_2$-), 1.64 (1H, septet, *J* 6.9, -CH-), 7.48–7.58 (2H, m), 7.61–7.69 (1H, m), 7.80 (1H, s), 7.90–7.96 (2H, m); $\delta_C$ ($CDCl_3$) −3.5, 18.5, 20.95, 24.05, 34.6, 128.8, 129.25, 130.15, 133.4, 137.7, 162.6, 179.8, 186.8; *m/z* 332 (M + 1, 100%), 316 (M − $CH_3$, 18).

**5-Benzoyl-3-(triisopropylsilyl)isothiazole 8j.** Mp 58 °C (Found C, 65.9; H, 7.8; N, 4.0. $C_{19}H_{27}NOSiS$ requires C, 66.0; H, 7.9; N, 4.05%); $\nu_{max}$ (KBr)/cm$^{-1}$ 2942, 2863, 1650, 1596, 1459, 1324, 1228, 1018, 883; $\delta_H$ ($CDCl_3$) 1.17 (18H, d, *J* 7.26, $CH_3$), 1.46 (3H, septet, *J* 7.26, CH), 7.47–7.57 (2H, m), 7.62–7.69 (1H, m), 7.79 (1H, s), 7.91–7.98 (2H, m); $\delta_C$ ($CDCl_3$) 11.25, 18.4, 128.8, 129.3, 133.5, 134.0, 137.8, 162.4, 176.8, 186.8; *m/z* 346 (M + 1, 100%), 302 (M − $CH(CH_3)_2$, 52), 157 ($Si(CH(CH_3)_2)_3$, 12).

*Crystal data for* ***8j***. $C_{19}H_{27}NOSiS$, $M = 345.6$, triclinic, $P\bar{1}$ (no. 2), $a = 8.079(1)$, $b = 8.191(1)$, $c = 15.983(2)$ Å, $\alpha = 77.49(1)$, $\beta = 86.74(1)$, $\gamma = 71.46(1)°$, $V = 978.9(2)$ Å$^3$, $Z = 2$, $D_c = 1.172$ g cm$^{-3}$, $\mu$(Cu-K$\alpha$) = 20.7 cm$^{-1}$, $T = 293$ K, colourless needles; 3064 independent measured reflections, $F^2$ refinement, $R_1 = 0.037$, $wR_2 = 0.101$, 2750 independent observed absorption corrected reflections [$|F_o| > 4\sigma(|F_o|)$, $2\theta \leq 124°$], 209 parameters. CCDC reference number 157790. See http://www.rsc.org/suppdata/p1/b1/b101157j/ for crystallographic files in.cif or other electronic format.

**5-Benzoyl-3-chloro-4-[dimethyl(1,1,2-trimethylpropyl)silyl]-isothiazole 9i.** Colourless needles mp 36 °C (Found [M + 1]$^+$, 366.1113. $C_{18}H_{25}NOSSiCl$ requires [M + 1]$^+$, 366.1109); $\nu_{max}$ (KBr /cm$^{-1}$ 2952, 2900, 2871, 1661 (C=O), 1590, 1456, 1351, 1251, 1225, 1171, 1096, 810, 740; $\delta_H$ ($CDCl_3$) 0.26 (6H, s, $SiMe_2$), 0.83 (6H, d, *J* 6.6, *CH*$Me_2$), 0.97 (6H, s, $CHMe_2$), 1.81 (1H, septet, *J* 6.6, -CH-), 7.51 (2H, t, *J* 7.26, $H_{Ph\text{-}meta}$), 7.66 (1H, t, *J* 7.4, $H_{Ph\text{-}para}$), 7.87 (2H, d, *J* 7.26, $H_{Ph\text{-}ortho}$); $\delta_C$ ($CDCl_3$) −0.59, −0.94, 18.94, 22.17, 25.71, 34.16, 129.21, 130.55, 134.98, 136.38, 137.58, 155.13, 172.02, 189.69; *m/z* 366 (M + 1, 100%), 280 (M − [$Me_2CHCMe_2$], 25).

**5-Benzoyl-3-chloro-4-(triisopropylsilyl)isothiazole 9j.** As colourless needles from ethanol, mp 69 °C (Found [M + 1]$^+$, 380.1271. $C_9H_{27}NOSiCl$ requires [M + 1]$^+$, 380.1263); $\nu_{max}$ (KBr)/cm$^{-1}$ 2946, 2885, 2865, 1657 (C=O), 1593, 1578, 1452, 1352, 1233, 1212, 1171, 1091, 885; $\delta_H$ ($CDCl_3$) 1.06 (18H, d, *J* 7.6, $CH_3$), 1.60 (3H, septet, *CH*$Me_2$), 7.51 (2H, t, *J* 7.9, $H_{Ph\text{-}meta}$), 7.67 (1H, t, *J* 7.3, $H_{Ph\text{-}para}$), 7.92 (2H, d, *J* 7.3, H $_{ortho}$); $\delta_C$ ($CDCl_3$) 12.55, 19.39, 129.14, 130.74, 134.98, 137.32, 155.58, 173.08, 189.32; *m/z* 380 (M + 1, 100%), 336 (M − [$Me_2CH$], 17).

*Crystal data for* ***9j***. $C_{19}H_{26}NOSiSCl$, $M = 380.0$, orthorhombic, *Pbca* (no. 61), $a = 7.493(1)$, $b = 17.788(4)$, $c = 30.694(3)$ Å, $V = 4091(1)$ Å$^3$, $Z = 8$, $D_c = 1.234$ g cm$^{-3}$, $\mu$(Cu-K$\alpha$) = 32.0 cm$^{-1}$, $T = 293$ K, colourless blocks; 3392 independent measured reflections, $F^2$ refinement, $R_1 = 0.047$, $wR_2 = 0.123$, 2853 independent observed absorption corrected reflections [$|F_o| > 4\sigma(|F_o|)$, $2\theta \leq 128$ °], 206 parameters. CCDC reference number 157789. See http://www.rsc.org/suppdata/p1/b1/b101157j/ for crystallographic files in.cif or other electronic format.

**5-Benzoyl-3-chloroisothiazole 8k.** Yellow oil (Found C, 53.9; H, 2.5; N, 6.2. $C_{10}H_6NSOCl$ requires C, 54.0; H, 2.8; N, 6.3%); $\nu_{max}$ (neat)/cm$^{-1}$ 3104, 3064, 2955, 2924, 1694, 1597, 1579, 1504, 1447, 1310, 1277, 1140, 833; $\delta_H$ ($CDCl_3$) 7.49 (1H, s), 7.56 (2H, t, *J* 7.6, $H_{Ph\text{-}meta}$), 7.7 (1H, t, *J* 7.4, $H_{Ph\text{-}para}$), 7.93 (2H, d, *J* 7, $H_{Ph\text{-}ortho}$); $\delta_C$ ($CDCl_3$) 126.64, 129.48, 129.64, 134.44, 136.58, 150.16, 166.28, 185.32; *m/z* ($CI^+$) 224 (M + 1, 100%), 188 (M − [Cl], 19.5), 146 (M − [$C_6H_5$], 7), 105 (15), 59 (87).

***S*-Phenyl 3-phenylisothiazole-5-carbothioate 13.** As pale pink crystals, mp 77 °C (Found [M + 1]$^+$, 298.0363. $C_{16}H_{11}NOS_2$ requires [M + 1]$^+$, 298.0360); $\nu_{max}$ (KBr)/cm$^{-1}$ 3000, 2923, 1670, 1384, 1164, 1021, 919; $\delta_H$ ($CDCl_3$) 7.40–7.55 (8H, m), 7.92–8.10 (2H, m), 8.12 (1H, s); $\delta_C$ ($CDCl_3$) 122.8, 125.75, 126.9, 128.9, 129.5, 129.8, 130.1, 133.85, 134.7, 163.9, 168.1, 180.9; *m/z* 298 (M + 1, 100%), 188 (M − PhS, 72).

*Crystal data for* ***13***. $C_{16}H_{11}NOS_2$, $M = 297.4$, triclinic, $P\bar{1}$ (no. 2), $a = 8.867(1)$, $b = 8.972(1)$, $c = 10.346(1)$ Å, $\alpha = 88.03(1)$, $\beta = 68.42(1)$, $\gamma = 68.79(1)°$, $V = 708.9(1)$ Å$^3$, $Z = 2$, $D_c = 1.393$ g cm$^{-3}$, $\mu$(Mo-K$\alpha$) = 3.69 cm$^{-1}$, $T = 293$ K, pale pink prisms; 2481 independent measured reflections, $F^2$ refinement, $R_1 = 0.042$, $wR_2 = 0.108$, 1974 independent observed reflections [$|F_o| > 4\sigma(|F_o|)$, $2\theta \leq 50°$], 158 parameters. CCDC reference number 157792. See http://www.rsc.org/suppdata/p1/b1/b101157j/ for crystallographic files in.cif or other electronic format.

**5-Benzoyl-3-phenylthioisothiazole 14.** Isolated as an oil (Found [M + 1]$^+$, 298.0360. $C_{16}H_{11}NOS_2$ requires [M + 1]$^+$, 298.0360); $\nu_{max}$ (neat)/cm$^{-1}$ 3060, 2928, 2852, 1650, 1598, 1440, 1309, 1276; $\delta_H$ ($CDCl_3$) 7.31 (1H, s), 7.37–7.45 (3H, m), 7.46–7.55 (2H, m), 7.60–7.68 (3H, m), 7.84–7.91 (2H, m); $\delta_C$ ($CDCl_3$) 126.6, 128.9, 129.3, 129.6, 130.7, 133.8, 133.9, 134.75, 136.8, 164.1, 164.2, 185.8; *m/z* 297 (M$^+$, 55%), 192 (M − PhCO, 13), 109 (SPh, 49), 105 (PhCO, 79), 77 (Ph, 100).

**Ethyl 5-pivaloylisothiazole-3-carboxylate.** Isolated as an oil (Found [M + 1]$^+$, 242.0857. $C_{11}H_{15}NO_3S$ requires [M + 1]$^+$, 242.0851); $\nu_{max}$ (neat)/cm$^{-1}$ 2975, 1724, 1666, 1513, 1236, 989, 977; $\delta_H$ ($CDCl_3$) 1.40 (9H, s, $CH_3$), 1.45 (3H, t, *J* 7.75, $CH_3$), 4.49 (2H, q, *J* 7.75, $CH_2$), 8.20 (1H, s); $\delta_C$ ($CDCl_3$) 14.55, 27.45, 44.6, 62.5, 127.4, 160.1, 160.75, 165.7, 198.3; *m/z* 242 (M + 1, 37%), 189 (30), 95 (100).

**Bis(5-phenylfuran-2-yl) sulfide 11.** Mp 115–117 °C (Found [M + 1]$^+$, 319.0789. $C_{20}H_{14}O_2S$ requires [M + 1]$^+$, 319.0789); $\nu_{max}$ (neat)/cm$^{-1}$ 3060, 2925, 1504, 1469; $\delta_H$ ($CDCl_3$) 6.61 (2H, d, *J* 3.3), 6.71 (2H, d, *J* 3.3), 7.20–7.31 (2H, m), 7.32–7.42 (4H, m), 7.62–7.71 (4H, m); $\delta_C$ ($CDCl_3$) 106.8, 118.9, 124.0, 127.9, 128.8, 130.2, 142.2, 157.0. Compound **10** was also obtained (30%) by treatment of 2-phenylfuran in pyridine with sulfur dichloride (1 equiv.) at ambient temperature for 15 h; the same yield was obtained, with extensive decomposition, upon heating under reflux for 2 h.

## Acknowledgements

We are grateful to Zeneca, SB, Pfizer, Parke-Davis, MDL Information Systems (UK) Ltd and the University of Sunderland for financial support and Miss Yolande Caro, University of Santiago de Compostela, Spain for some experimental assistance.

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