

Reactions of acyl isothiocyanates with 9-diazafluorene: a route to macromolecules having pairs of orthogonal fluorene groups

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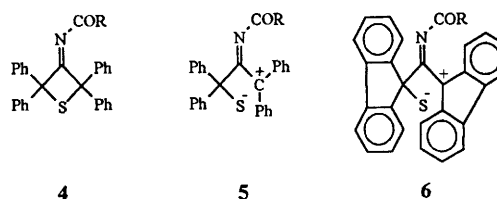
The title reactions give 4,5-dihydrooxazoles containing two orthogonal fluorene groups suitable for the elaboration of semi-rigid macromolecules.

Anthracene is known to undergo a Diels–Alder reaction with benzyne to give the rigid carbon framework of triptycene.¹ This is the simplest member of a whole series of iptycenes with well defined cavities, useful for the study of host–guest phenomena.² In contrast, fluorene cannot undergo Diels–Alder reactions in order to obtain iptycene-like molecules, but instead the 9-position of fluorene can be utilised to construct three-dimensional frameworks having orthogonal fluorene rings. In principle, this can be done by attaching an even number of fluorene units to a central core in such a way that the fluorene moieties have alternating sp^3 and sp^2 C-9 atoms. This paper describes a reaction that leads to such systems.

Our approach is based on the reactions of acyl isothiocyanates **1a–c** with 9-diazafluorene which furnished the oxazole derivatives **3a–c** in high yields (>60%) *via* decomposition of the thermolabile spiro compounds **2a–c**. The latter were isolated in two cases (**2a** and **2b**), and shown to lose sulfur upon mild heating in solution. These reactions contrast sharply with those of acyl isothiocyanates and diphenyldiazomethane where the thietan-3-imines **4** were the ultimate products formed.³

A mechanistic rationalization for the formation of the spiro compounds is given in our previous communication,³ and their different thermal behaviour by changing phenyl for fluorenyl

substituents is readily understood by a consideration of the structures **5** and **6**. Indeed, the zwitterion **5** possesses a stable carbocation and is a plausible intermediate in the formation of the thietan-3-imines **4**. In contrast, the zwitterion **6** is antiaromatic so that the spiro compounds **2a–c** prefer the alternative pathway of desulfurization.



The structures of the products were fully characterized by ¹H NMR spectroscopy. For instance, in the 400 MHz spectra of **3a–c** the hydrogen atoms of the spiro fluorene group absorb in pairs, giving two doublets and two triplets, whereas the fluorenylidene group exhibits four doublets and four triplets, each integrating for one proton. Of particular significance are the upfield shifts of one α and one β fluorenylidene hydrogen (doublet at δ_H 6.5 and triplet at δ_H 6.6 respectively) which both lie in the shielding region of the other fluorene group. The ¹³C NMR and mass spectral data further confirm the structure assignments.

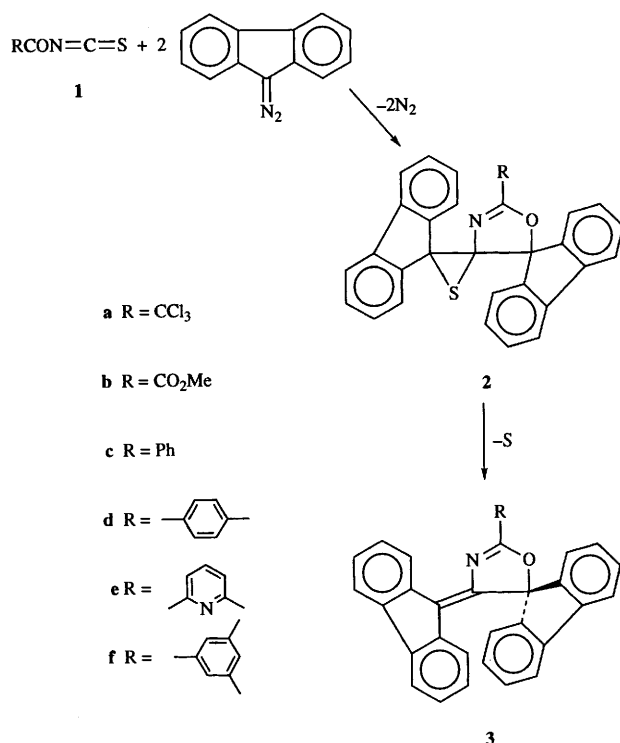
The orthogonal disposition of the two fluorene groups could now be multiplied by using bis-, tris- and tetrakis-acyl isothiocyanates. Thus, terephthaloyl isothiocyanate **1d** and 2,6-bis(isothiocyanatocarbonyl)pyridine **1e** furnished the bisoxazoles **3d** (63%) and **3e** (39%) respectively which have two pairs of orthogonal fluorene groups. Similarly, the macromolecules **7** (57%) and **8** (21%) were obtained from 1,3,5-tris(isothiocyanatocarbonyl)benzene **1f** and 5,10,15,20-tetrakis[4-(isothiocyanatocarbonyl)phenyl]porphyrin respectively. These compounds, having rigid peripheral groups and flexible cavities, are potential candidates for the encapsulation of guest molecules.

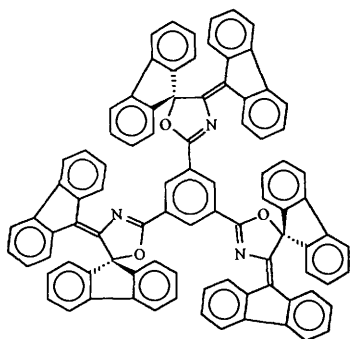
Experimental

Mps were determined using a Reichert Thermovar apparatus. IR spectra were recorded on a Perkin-Elmer 1720 FT spectrometer, NMR spectra on a Bruker WM-250 or AMX-400 spectrometer and mass spectra (EI) on a Hewlett Packard 5989 or Kratos MS50 TC (for high resolution) instrument, operating at 70 eV.

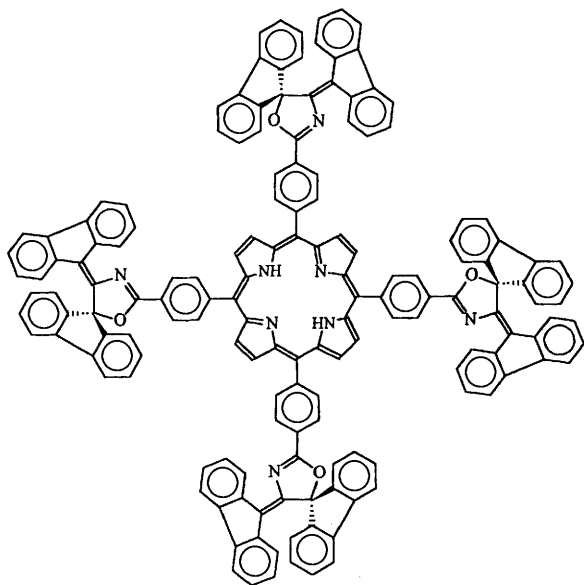
Reaction of trichloroacetyl isothiocyanate with 9-diazafluorene

A solution of isothiocyanate **1a** (532 mg, 2.6 mmol)⁴ and 9-diazafluorene (1g, 5.2 mmol)⁵ in dry tetrahydrofuran (5 cm³) was left overnight at room temperature under a nitrogen





7



8

atmosphere. After concentration of the solution, addition of diethyl ether and cooling, the precipitated spiro compound **2a** was filtered off (835 mg, 60%). The filtrate was chromatographed on silica gel with chloroform-hexane (2:1) as the eluent to give the spiro compound **3a** (268 mg, 21%).

When the reaction was carried out with equimolar amounts of reagents (10 mmol), the evolved nitrogen was collected (10 mmol) and the spiro compound **2a** was obtained in 86% yield. Spiro compound **2a** could then be desulfurized quantitatively into compound **3a** upon melting.

4',5'-Dihydro-2'-trichloromethyltrispiro{fluorene-9,5'-[1,3]-oxazole-4',2''-thiirane-3'',9''-fluorene} 2a. Mp 158 °C (decomp.) (from CHCl_3); $\nu_{\text{max}}(\text{KBr})/\text{cm}^{-1}$ 1642s; $\delta_{\text{H}}(\text{CDCl}_3, 400 \text{ MHz})$ 6.00 (1 H, d), 6.48 (1 H, t), 6.68 (2 H, m), 6.95 (1 H, t), 6.97–7.05 (1 H, m), 7.31 (1 H, d), 7.32–7.38 (2 H, d + t), 7.41 (1 H, t), 7.48 (1 H, t), 7.55 (1 H, t), 7.62 (2 H, d), 7.90 (1 H, d) and 8.10 (1 H, d); $\delta_{\text{C}}(\text{CDCl}_3)$ 56.3 and 96.7 (fluorene C-9), 82.2 (oxazole C-4), 86.3 (CCl_3), 119.0–131.3 (16 fluorene CH), 140.1–141.9 (8 fluorene C_i) and 165.0 (oxazole C-2); m/z 533/531 (M^{+} , 3%), 501/499 ($\text{M}^{+} - \text{S}$, 4), 382 ($\text{M}^{+} - \text{S} - \text{CCl}_3$, 11), 337/335 ($\text{M}^{+} - \text{fluorene} + \text{thiirane}$, 18/20) and 190 ($\text{C}_{13}\text{H}_8\text{CN}^{+}$, 100) (Found: C, 65.2; H, 3.0. $\text{C}_{29}\text{H}_{16}\text{Cl}_3\text{NOS}$ requires C, 65.37; H, 3.03%).

4'-(Fluorene-9''-diyl)-4',5'-dihydro-2'-trichloromethylspiro{fluorene-9,5'-[1,3]oxazole} 3a. Mp 227 °C (from CH_2Cl_2 -hexane); $\nu_{\text{max}}(\text{KBr})/\text{cm}^{-1}$ 1611m and 1576s; $\delta_{\text{H}}(\text{CDCl}_3, 400 \text{ MHz})$ 6.49 (1 H, d), 6.58 (1 H, t), 7.04 (1 H, t), 7.26 (2 H, t), 7.35 (1 H, t), 7.40 (1 H, t), 7.43 (2 H, d), 7.45–7.55 (3 H, t + d), 7.62 (1 H, d), 7.80 (2 H, d) and 9.00 (1 H, d);

$\delta_{\text{C}}(\text{CDCl}_3)$ 86.6 (CCl_3), 99.9 (spiro C), 119.0–131.3 (12 fluorene CH), 129.7 and 149.0 (vinyl C), 134.9–141.5 (6 fluorene C_i) and 166.3 (oxazole C-2); m/z 501/499 (M^{+} , 26%), 382 ($\text{M}^{+} - \text{CCl}_3$, 100), 354 ($\text{M}^{+} - \text{CCl}_3 - \text{CO}$, 19), 339 ($\text{M}^{+} - \text{CCl}_3 - \text{CO} - \text{NH}$, 98), 284 (13), 190 ($\text{C}_{13}\text{H}_8\text{CN}^{+}$, 63), 164 ($\text{C}_{13}\text{H}_8^{+}$, 55), 163 (97) and 117/119 (CCl_3^{+} , 20/19).

Reaction of methoxalyl isothiocyanate with 9-diazo fluorene

A solution of isothiocyanate **1b** (302 mg, 2.08 mmol)⁶ and 9-diazo fluorene (800 mg, 4.2 mmol) in dry tetrahydrofuran (3.5 cm^3) was kept at room temperature under nitrogen atmosphere for 3 days. The precipitated spiro compound **2b** was filtered off (318 mg) and the filtrate was diluted with diethyl ether to give another crop of product **2b** (175 mg) (overall yield 50%); both crops were washed with diethyl ether. From the filtrate, 9,9'-bifluorenylidene (118 mg, 17%, mp 187 °C)⁷ and spiro compound **3b** (113 mg, 12%) were isolated by chromatography on silica gel with chloroform-hexane (1:2) as the eluent.

When the reaction was carried out at 35 °C for 4 days, desulfurization of **2b** was complete and the spiro compound **3b** was isolated in 61% yield.

Methyl 4',5'-dihydrotrispiro{fluorene-9,5'-[1,3]oxazole-4',2''-thiirane-3'',9''-fluorene}-2'-carboxylate 2b. Yellow crystals which decompose at 210 °C; $\nu_{\text{max}}(\text{KBr})/\text{cm}^{-1}$ 1754s and 1633s; $\delta_{\text{H}}(\text{CDCl}_3, 400 \text{ MHz})$ 3.91 (3 H, s), 5.99 (1 H, d), 6.47 (1 H, t), 6.61 (1 H, d), 6.65 (1 H, t), 6.94 (1 H, t), 7.00 (1 H, t), 7.30 (1 H, d), 7.36 (1 H, d), 7.40 (2 H, t), 7.45 (1 H, t), 7.52 (1 H, t), 7.61 (2 H, d), 7.85 (1 H, d) and 8.10 (1 H, d); $\delta_{\text{C}}(\text{CDCl}_3)$ 53.6 (OMe), 56.4 and 94.1 (fluorene C-9), 82.1 (oxazole C-4), 118.9–131.1 (16 fluorene CH), 140.0–142.3 (8 fluorene C_i), 157.1 (C=O) and 158.5 (oxazole C-2); m/z 473 (M^{+} , 0.9%), 441 ($\text{M}^{+} - \text{S}$, 89), 382 ($\text{M}^{+} - \text{S} - \text{CO}_2\text{Me}$, 66), 356 (34), 355 (38), 354 ($\text{M}^{+} - \text{S} - \text{CO}_2\text{Me} - \text{CO}$, 26), 339 ($\text{M}^{+} - \text{S} - \text{CO}_2\text{Me} - \text{CONH}$, 100), 205 (15), 190 ($\text{C}_{13}\text{H}_8\text{CN}^{+}$, 50), 164 (33), 163 (62), 64 (48) and 59 (MeOCO^{+} , 66) (Found: C, 76.0; H, 4.1. $\text{C}_{30}\text{H}_{19}\text{NO}_3\text{S}$ requires C, 76.09; H, 4.04%).

Methyl 4'-(fluorene-9''-diyl)-4',5'-dihydrospiro{fluorene-9,5'-[1,3]oxazole}-2'-carboxylate 3b. Mp 299 °C (yellow crystals from CHCl_3 - Et_2O); $\nu_{\text{max}}(\text{KBr})/\text{cm}^{-1}$ 1741s and 1638w; $\delta_{\text{H}}(\text{CDCl}_3, 400 \text{ MHz})$ 4.01 (3 H, s, OMe), 6.46 (1 H, d), 6.54 (1 H, t), 7.01 (1 H, t), 7.21 (2 H, t), 7.33 (1 H, t), 7.35 (2 H, d), 7.40 (1 H, t), 7.44 (2 H, t), 7.48 (1 H, d), 7.59 (1 H, d), 7.76 (2 H, d) and 9.03 (1 H, d); $\delta_{\text{C}}(\text{CDCl}_3)$ 53.7 (OMe), 97.3 (spiro C), 118.9–131.1 (12 fluorene CH), 130.3 and 149.7 (vinyl C), 135.0–141.5 (6 fluorene C_i), 157.6 (C=O) and 158.7 (oxazole C-2); m/z 441 (M^{+} , 58%), 382 ($\text{M}^{+} - \text{CO}_2\text{Me}$, 60), 355 (36), 354 ($\text{M}^{+} - \text{CO}_2\text{Me} - \text{CO}$, 25), 339 ($\text{M}^{+} - \text{CO}_2\text{Me} - \text{CONH}$, 100), 337 (17), 190 ($\text{C}_{13}\text{H}_8\text{CN}^{+}$, 22), 164 ($\text{C}_{13}\text{H}_8^{+}$, 25), 163 (47) and 59 (MeOCO^{+} , 25) (Found: C, 81.5; H, 4.4. $\text{C}_{30}\text{H}_{19}\text{NO}_3$ requires C, 81.62; H, 4.34%).

Reaction of benzoyl isothiocyanate with 9-diazo fluorene

A solution of isothiocyanate **1c** (0.43 g, 2.6 mmol) and 9-diazo fluorene (1 g, 5.2 mmol) in dry tetrahydrofuran (1.5 cm^3) was kept at room temperature under a nitrogen atmosphere for 3 days. The reaction mixture was worked up by column chromatography on silica gel with chloroform-hexane (1:2) as the eluent to give **3c** (832 mg, 70%) and 9,9'-bifluorenylidene (32 mg, 4%).

4'-(Fluorene-9''-diyl)-4',5'-dihydro-2'-phenylspiro{fluorene-9,5'-[1,3]oxazole} 3c. Mp 169 °C (from CHCl_3 - Et_2O); $\nu_{\text{max}}(\text{KBr})/\text{cm}^{-1}$ 1605w, 1583w and 1544s; $\delta_{\text{H}}(\text{CDCl}_3, 400 \text{ MHz})$ 6.54 (1 H, d), 6.60 (1 H, t), 7.02 (1 H, t), 7.23 (2 H, t), 7.38 (1 H, t), 7.41 (2 H, d), 7.42–7.52 (5 H, m), 7.60 (2 H, t), 7.70 (1 H, d), 7.84 (2 H, d), 8.25 (2 H, d) and 9.30 (1 H, d); $\delta_{\text{C}}(\text{CDCl}_3)$ 96.0 (spiro C), 118.9–142.4 (22 aromatic C), 124.5 and 153.5 (vinyl C) and 169.3 (oxazole C-2); m/z 459 (M^{+} , 100%), 356 (48), 355 (88), 354 ($\text{M}^{+} - \text{PhCO}$, 36), 163 (21), 105 (PhCO^{+} , 84) and 77 (Ph^{+} , 66) (Found: M^{+} , 459.1636. $\text{C}_{34}\text{H}_{21}\text{NO}$ requires M , 459.1623).

Reaction of terephthaloyl isothiocyanate with 9-diazafluorene

A solution of isothiocyanate **1d** (369 mg, 1.49 mmol) and 9-diazafluorene (2 g, 10.4 mmol) in dry tetrahydrofuran (3 cm³) was stirred at room temperature for 6 days. The precipitate **3d** was filtered off and from the filtrate a second crop of **3d** was obtained by crystallizing the residue from chloroform–diethyl ether. The combined crops were washed with acetone and crystallized from hot chloroform to give pure 1,4-bis{4'-(fluorene-9''-diyl)-4',5'-dihydrospiro[fluorene-9,5'-[1,3]-oxazol]-2'-yl}benzene **3d** as an orange fluorescent material (786 mg, 63%), mp > 360 °C; ν_{\max} (KBr)/cm⁻¹ 1606m and 1542s; δ_{H} (CDCl₃, 400 MHz) 6.52 (2 H, d), 6.58 (2 H, t), 7.02 (2 H, t), 7.22 (4 H, t), 7.36 (2 H, t), 7.40 (4 H, d), 7.48 (6 H, t), 7.56 (2 H, d), 7.68 (2 H, d), 7.84 (4 H, d), 8.33 (4 H, s) and 9.25 (2 H, d); δ_{C} (CDCl₃) 96.3 (spiro C), 119.0–142.2 (aromatic C), 125.7 and 152.9 (vinyl C) and 168.2 (oxazole C-2); m/z 840 (M⁺, 53%), 502 (24), 355 (41), 354 (38), 340 (96), 339 (100), 191 (24), 190 (20), 168 (21), 165 (35), 148 (26), 69 (25) and 44 (85) (Found: M⁺, 840.2780; C₆₂H₃₆N₂O₂ requires *M*, 840.2777).

Reaction of 2,6-bis(isothiocyanatocarbonyl)pyridine with 9-diazafluorene

A solution of the isothiocyanate **1e** (370 mg, 1.49 mmol)⁸ and 9-diazafluorene (2 g, 10.4 mmol) in dry tetrahydrofuran (3 cm³) was stirred at room temperature under a nitrogen atmosphere for 5 days. The reaction mixture was chromatographed on silica gel with chloroform–hexane (1:3) and chloroform as eluents to give yellow 2,6-bis{4'-(fluorene-9''-diyl)-4',5'-dihydrospiro[fluorene-9,5'-[1,3]oxazol]-2'-yl}pyridine **3e** which was crystallized from chloroform–diethyl ether (492 mg, 39%), mp > 330 °C; ν_{\max} (KBr)/cm⁻¹ 1607w and 1545s; δ_{H} (CDCl₃, 400 MHz) 6.50 (2 H, d), 6.56 (2 H, t), 7.00 (2 H, t), 7.19 (4 H, t), 7.30–7.35 (4 H, m), 7.39 (4 H, d), 7.45 (4 H, t), 7.52 (2 H, d), 7.62–7.67 (2 H, m), 7.80 (4 H, d), 8.06 (1 H, t, pyridine), 8.50 (2 H, d, pyridine) and 9.20–9.25 (2 H, m); δ_{C} (CDCl₃) 97.0 (spiro C), 118.8–130.8 and 137.6 (aromatic CH), 135.5, 139.0, 139.1, 140.5, 141.6 and 141.9 (fluorene C_i), 147.0 (pyridine C_i), 126.8 and 152.4 (vinyl C) and 167.2 (oxazole C-2); m/z 841 (M⁺, 16%), 354 (24), 340 (83) and 339 (100) (Found: M⁺, 841.2699. C₆₁H₃₅N₃O₂ requires *M*, 841.2729).

Reaction of 1,3,5-tris(isothiocyanatocarbonyl)benzene with 9-diazafluorene

A solution of the isothiocyanate **1f** (0.35 g, 1.04 mmol) and 9-diazafluorene (2 g, 10.4 mmol) in dry tetrahydrofuran (3 cm³) was stirred at room temperature under a nitrogen atmosphere for 7 days. The reaction mixture was twice chromatographed on silica gel, first with chloroform–hexane (1:1) and then with ethyl acetate–hexane (3:5) as the eluent to give yellow 1,3,5-tris{4'-(fluorene-9''-diyl)-4',5'-dihydrospiro[fluorene-9,5'-[1,3]oxazol]-2'-yl}benzene **7** (723 mg, 57%), mp > 330 °C (from CHCl₃–hexane); ν_{\max} (KBr)/cm⁻¹ 1609w and 1544s; δ_{H} (CDCl₃, 400 MHz) 6.50 (3 H, d), 6.56 (3 H, t), 7.00 (3 H, t), 7.19 (6 H, t), 7.33, 7.38 and 7.43 (18 H, t + d + t), 7.54 (3 H, d), 7.67 (3 H, d), 7.79 (6 H, d), 9.14 (3 H, s) and 9.32 (3 H, d); δ_{C} (CDCl₃) 96.7 (spiro C), 119.0–130.9 (12 fluorene CH), 126.0 and 152.3 (vinyl C), 128.5 and 132.7 (benzene C), 135.6, 139.0,

139.2, 140.4, 141.5 and 141.9 (fluorene C_i) and 167.3 (oxazole C-2) (Found: C, 88.6; H, 4.2. C₉₀H₅₁N₃O₃ requires C, 88.43; H, 4.21%).

Reaction of 5,10,15,20-tetrakis[4-(isothiocyanatocarbonyl)-phenyl]porphyrin with 9-diazafluorene

A suspension of the isothiocyanate (0.5 g, 0.52 mmol) (prepared from the corresponding tetracarboxylic acid)⁹ and 9-diazafluorene (1.41 g, 7.33 mmol) in dry tetrahydrofuran (3 cm³) was stirred at room temperature under nitrogen atmosphere for 10 days. After addition of diethyl ether (10 cm³) and cooling, the precipitate was filtered off, washed with a large excess of diethyl ether, and twice chromatographed on silica gel with dichloromethane–hexane (first 10:3 and then 1:1) as the eluent to give the purple fluorescent 5,10,15,20-tetrakis-(4-{4'-(fluorene-9''-diyl)-4',5'-dihydrospiro[fluorene-9,5'-[1,3]-oxazol]-2'-yl}phenyl) porphyrin **8** which was crystallized from CH₂Cl₂–Et₂O (234 mg, 21%), mp > 330 °C; ν_{\max} (KBr)/cm⁻¹ 1606m, 1569m and 1540s; δ_{H} (CDCl₃, 400 MHz) –2.75 (2 H, s, NH), 6.61 (4 H, d), 6.63 (4 H, t), 7.05 (4 H, t), 7.31 (8 H, t), 7.37 (4 H, t), 7.45–7.60 (24 H, 2 t + 2 d), 7.72 (4 H, d), 7.89 (8 H, d), 8.38 and 8.64 (16 H, benzene CH), 8.92 (8 H, pyrrole CH) and 9.42 (4 H, d); δ_{C} (CDCl₃) 119.5 (porphyrin meso-C), 119.0–130.9 (fluorene CH), 125.0, 126.7, 134.9 and 146.4 (benzene C), 126.7 and 153.4 (vinyl C), 135.8, 139.1, 139.3, 140.2, 141.7 and 142.4 (fluorene C_i) and 169.3 (oxazole C-2).

Acknowledgements

Financial support from the NFWO and the Ministerie voor Wetenschapsbeleid is gratefully acknowledged. This work has been accomplished with fellowships from the IWONL (for A. F.) and the NFWO (for W. D.).

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Paper 6/00206D

Received 10th January 1996

Accepted 15th February 1996