Synthesis of 1,3-Thiazetidines and 2,1,4-Oxathiazolidines by High Yielding Novel Photochemical Rearrangements[1]

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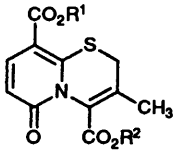
The 1,3-thiazetidines **3**, **6** and **9** have been prepared in good yield by photochemical rearrangement of the corresponding 1,3-thiazines and the rare fused 2,1,4-oxathiazolidines **12** and **17** have been prepared in good yield by photochemical rearrangement of the corresponding 1,3-thiazine sulfoxides

The 1,3-thiazetidine system is relatively rare and has been accessed by cycloadditions and by eliminative cyclisations.[2] We now report a facile and high yielding synthesis of fused and monocyclic 1,3-thiazetidines by photochemical rearrangement of *N*-acylthiazines. The very rare fused 2,1,4-oxathiazolidines have also been prepared by photochemical rearrangement of the corresponding 1,3-thiazine *S*-oxides.

When the pyrido[2,1-*b*]thiazine **1** ($R^1 = R^2 = Et$)[3] was irradiated as a dilute solution in dry degassed dioxane under nitrogen using a 125 W medium-pressure lamp and a Pyrex filter, an isomeric product, $C_{15}H_{17}NO_5S$ was obtained in nearly 70% yield. The ^1H NMR spectrum of the product showed that the pyridone ring was unchanged and indeed could be interpreted as being in keeping with the structure **2** ($R^1 = R^2 = Et$), the result of a simple 1,3-hydrogen migration. However, X-ray structure analysis, shown in Fig. 1, revealed that a more unusual rearrangement had occurred and that the product was the pyridothiazetidine **3** ($R^1 = R^2 = Et$). This product can be rationalised as having resulted from fission of the allylic CH_2–S bond to yield a diradical **4** which would couple as shown. The pyridone **1** ($R^1 = PhCH_2$, $R^2 = Me$) also underwent rearrangement to **3** ($R^1 = PhCH_2$, $R^2 = Me$) in 64% yield.



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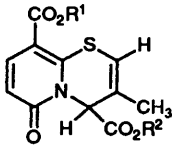

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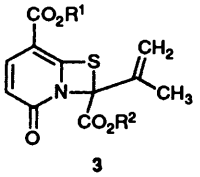

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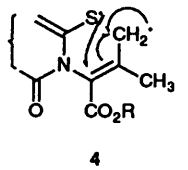

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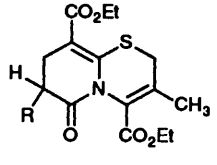

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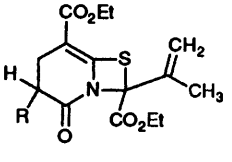

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The photochemical rearrangement was also shown to occur when the dihydropyridone **5** (R = H)[3] was used, affording a facile route to the thiazetidine **6** (R = H) in 68% yield. When the phthalimidodihydropyridone **5** (R = phthalimido)[3] was used, the product appeared to be one diastereoisomer of the thiazetidine **6** (R = phthalimido). The yield was 56% and the pyridothiazetidine **3** ($R^1 = R^2 = Et$) was obtained as a by-product.

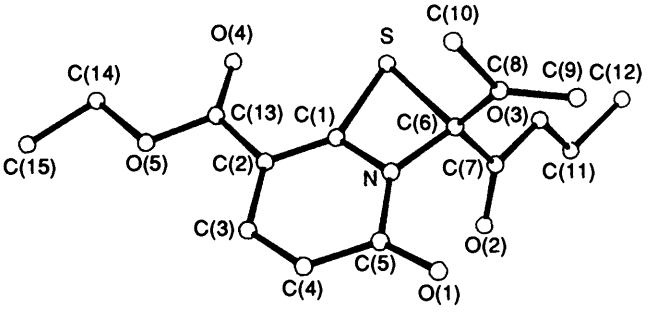
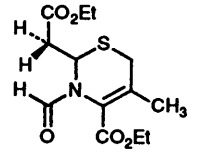


Fig. 1 Molecular structure of the pyrido-1,3-thiazetidine **3** ($R^1 = R^2 = Et$)

Since we had developed a useful route to fused 1,3-thiazetidines, we were interested to see if the method could be extended to monocyclic derivatives. We therefore prepared the *N*-formyl-1,3-thiazine **7** from the thiazine **8** by first reducing the compound at pH 3 using sodium cyanoborohydride and then formylating the unstable product with formic acetic anhydride. Photolysis of this compound gave a good yield of the monocyclic thiazetidine **9** which had spectra in keeping with our expectation from the spectra of the fused systems.

The photochemical rearrangement which we have discovered, therefore, affords access to 1,3-thiazetidines in good yield. It seems that the reaction involves fission at the allylic C–S bond and so it was of some interest to examine the result of a similar fission of an *S*-oxide. The pyridothiazine sulfoxide **10** was, therefore, prepared by oxidation of the thiazine **1** ($R^1 = R^2 = Et$) with 1 equiv. of *meta*-chloroperbenzoic acid. Photolysis of this *S*-oxide until the absorption at λ_{max} 339 nm had been replaced by an absorption at λ_{max} 291 gave a compound isomeric with the starting *S*-oxide in 66% yield. The spectra were indistinguishable from those expected of the thiazetidine *S*-oxide **11** but an X-ray structure analysis showed that the photochemical rearrangement had resulted in the fused 2,1,4-oxathiazolidine **12** as shown in Fig. 2. It is evident that, after fission of the allylic CH_2–S bond to give the diradical **13**, which is analogous to the diradical **4** in the thiazine rearrangement, the allylic radical is attacked by oxygen rather than sulfur, thus giving the oxathiazolidine.

We have, therefore, discovered access to a comparatively rare heterocyclic system. Previous work had shown that the com-



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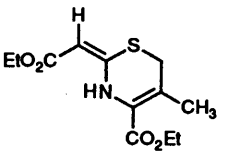

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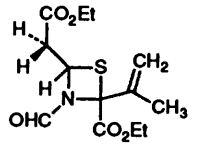

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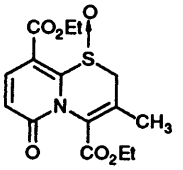

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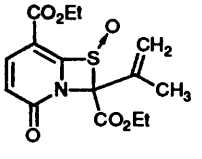

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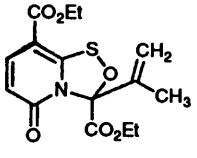

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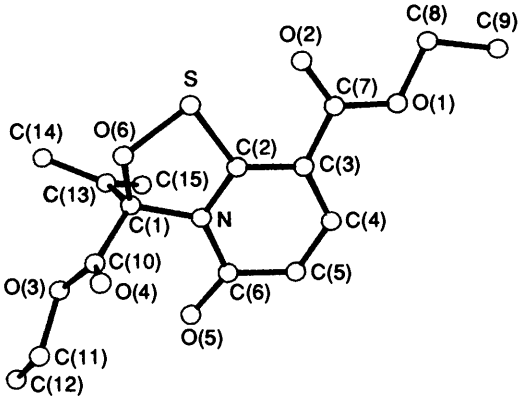


Fig. 2 Molecular structure of the pyrido-2,1,4-oxathiazolidine **12**

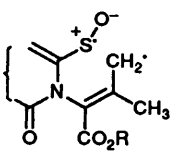
pounds **14**, prepared by 1,3-dipolar addition, were unstable to rearrangement to the oxazolidinethiones **15**.[4] This may account for the rarity of the system.

To test the generality of the method, the dihydropyridothiazine **5** (R = H) was converted into the sulfoxide **16** (R = H). Photolysis of this compound in dioxane gave a 60% yield of an oil $C_{15}H_{19}NO_6S$ which had spectra in keeping with its assignment as the 2,1,4-oxathiazolidine **17** (R = H). The phthalimidothiazine **15** (R = phthalimido) was converted into the diastereoisomeric sulfoxides **16** (R = phthalimido) but because of the low yield of these compounds, photolysis was not attempted.

We have discovered a novel and high yielding method of synthesis of two relatively rare heterocyclic systems using novel photochemical rearrangements. This will allow synthesis of sufficient quantities of these compounds to study their chemistry.

Experimental

M.p.s were determined on a Kofler hot-stage apparatus, IR spectra were recorded on Perkin Elmer 257, 457, 477 and PE



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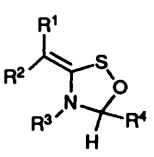

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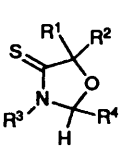

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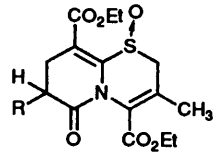

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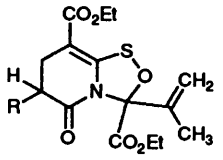

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1710 FT instruments and UV spectra on Pye Unicam SP800 and Phillips PU 8720 spectrophotometers. ^{1}H NMR spectra were recorded on Varian T60 (60 MHz), Perkin-Elmer R12 (60 MHz) and R32 (90 MHz), Bruker WP80 (80 MHz) and Bruker WH360 (360 MHz) instruments and ^{13}C NMR spectra on Bruker WP80 (20.15 MHz) and WH360 (90.55 MHz) instruments. *J* Values are recorded in Hz. Combustion analyses were recorded by Mrs. G. Olney and Miss K. Plowman, University of Sussex and mass spectra were obtained by Mr. A. Greenway on Kratos MS25 and MS80 instruments using electron impact (EI) ionisation. Thin layer chromatography was carried out using Merck Kieselgel GF_{254} 0.25 mm analytical plates.

Diethyl 2-Isopropenyl-4-oxo-1-thia-3-azabicyclo[4.2.0]*octa-5,7-diene-2,7-dicarboxylate* **3** (R^1 = R^2 = Et).—A solution of diethyl 3-methyl-6-oxo-2*H*,6*H*-pyrido[2,1-*b*][1,3]thiazine-4,9-dicarboxylate **1** (R^1 = R^2 = Et)[3] (0.25 g, 0.77 mmol) in dry degassed dioxane (*ca.* 400 cm^3) was irradiated in a Hanovia photochemical reactor with a 125 W medium-pressure mercury arc lamp under nitrogen, using a Pyrex filter. After 2 h, TLC (silica:ether–hexane, 3:1) showed the disappearance of starting material and the appearance of one new component. The solvent was removed under reduced pressure to yield a pale oil which was chromatographed (Chromatotron, silica:ether–hexane, 3:1). Crystallisation from ether–hexane yielded colourless plates (170 mg, 68%), m.p. 38–40 °C (Found: C, 55.8; H, 5.3; N, 4.4. $C_{15}H_{17}NO_5S$ requires C, 55.7; H, 5.3; N, 4.3%); *m/z* 323 (M^+); ν_{max}(liquid film)/cm^{-1} 1746 and 1723 (esters) and 1672 (pyridone); λ_{max}(MeOH)/nm 274, 302, 312 and 325sh (log ε 4.28, 3.87, 3.88 and 3.71); δ_H(C^2HCl_3, 60 MHz) 1.29 (3 H, t, *J* 7.3, Me), 1.32 (3 H, t, *J* 7.3, Me), 2.15 (3 H, d, *J* 1.5, MeC=), 4.30 (2 H, q, *J* 7.3, CH_2O), 4.36 (2 H, q, *J* 7.3, CH_2O), 5.45 (1 H, q, *J* 1.5, HC=), 5.70 (1 H, br s, HC=) and 6.28 and 7.77 (2 × 1 H, AB, *J* 10, pyridone); δ_C(C^2HCl_3, 20.15 MHz) 13.80 and 14.29 (2 × CH_3), 19.04 (CH_3C=), 61.10 and 63.56 (2 × CH_2), 104.30 (γ-pyridone), 116.31 (pyridone α-CH), 120.84 and 135.77 (olefinics), 139.31 (pyridone β-CH), 156.39 (δ-pyridone) and 158.78, 163.47 and 164.78 (3 × C=O).

Methyl 8-Benzyloxycarbonyl-3-isopropenyl-5-oxo-2-thia-4-azabicyclo[4.2.0]*octa-6,8-diene-3-carboxylate* **3** (R^1 = PhCH_2, R^2 = Me).—A solution of methyl 9-benzyloxycarbonyl-3-methyl-6-oxo-2*H*,6*H*-pyrido[2,1-*b*][1,3]thiazine-4-carboxylate **1** (R^1 = PhCH_2, R^2 = Me)[3] (300 mg, 0.81 mmol) in dry degassed benzene (350 cm^3) was irradiated at 8 °C with a 125 W high-pressure immersion mercury arc lamp through Pyrex filters under nitrogen overnight. The benzene was removed under reduced pressure to yield a pale oil which was chromatographed (silica gel:ether–hexane, 1:2) to give a yellow gum (192 mg, 64%); *m/z* 371 (M^+); ν_{max}(liquid film)/cm^{-1} 1725 (ester) and 1671 (amide); λ_{max}(MeOH)/nm 208 and 278 (log ε 4.21 and

4.12); $\delta_H(C^2HCl_3$, 360 MHz) 1.95 (3 H, s, CH_3), 3.79 (3 H, s, CH_3O), 5.17 (2 H, AB, CH_2O), 5.34 (1 H, s, olefinic), 5.57 (1 H, s, olefinic), 6.19 (1 H, d, *J* 9.9, pyridone α-CH), 7.27 (5 H, m, aromatics) and 7.69 (1 H, d, *J* 9.9, pyridone β-CH); $\delta_C(C^2HCl_3$, 90.55 MHz) 18.80 (CH_3), 53.70 (OCH_3), 66.50 (OCH_2), 81.30 and 103.80 (olefinics), 116.03 (pyridone α-C), 120.62 (olefinic), 128.07–128.39 (aromatics), 135.39 (N-C-S), 139.08 (pyridone β-C), 156.31 (S-C-N) and 158.34, 162.80 and 164.94 (3 × C=O).

Diethyl 2-Isopropenyl-4-oxo-1-thia-3-azabicyclo[4.2.0]*oct-7-ene-2,7-dicarboxylate* **6** (R = H).—A solution of diethyl 7,8-dihydro-3-methyl-6-oxo-2*H*,6*H*-pyrido[2,1-*b*][1,3]thiazine-4,9-dicarboxylate **5** (R = H)[3] (100 mg, 0.3 mmol) in dry, degassed diethyl ether (*ca.* 150 cm^3) was irradiated using a Hanovia photochemical reactor and a Quartz-Vicor filter with a 125 W medium-pressure mercury arc lamp under nitrogen. After 45 min the absorption in the UV at 313 nm had been replaced by an absorption at 283 nm and TLC (silica: ether–hexane 3:1) showed the complete disappearance of starting material. The solvent was removed under reduced pressure to yield a pale yellow oil which was purified by chromatography (Chromatotron: silica: ether–hexane, 3:1). The pure material was obtained as an oil which failed to crystallise (68 mg, 68%); *m/z* 325.0995 (M^+) ($C_{15}H_{19}NO_5S$ requires 325.0984); ν_{max}(liquid film)/cm^{-1} 1740 and 1710 (esters) and 1660 (pyridone); λ_{max}(MeOH)/nm 220 and 289 (log ε 4.12 and 4.11); $\delta_H(C^2HCl_3$, 60 MHz) 1.24 and 1.28 (2 × 3 H, 2 × t, *J* 7.1, 2 × CH_3), 1.97 (3 H, br s, CH_3C=), 2.58 (4 H, br s, 2 × CH_2), 4.07 and 4.18 (2 × 2 H, 2 × q, *J* 7.1, 2 × CH_2O), 5.18 (1 H, q, *J* 1.3, olefinic) and 5.31 (1 H, s, olefinic); $\delta_C(C^2HCl_3$, 20.15 MHz), 13.94 and 14.49 (2 × q, 2 × CH_3), 19.27 (q, CH_3C=), 20.22 (t, CH_2), 31.17 (t, CH_2), 60.33 and 63.07 (2 × t, 2 × CH_2O), 97.48, 119.23, 137.99 and 149.38 (olefinics) and 165.73, 165.91 and 166.35 (3 × s, 3 × C=O).

Photolysis of Diethyl 7,8-Dihydro-3-methyl-6-oxo-7-phthalimido-2H,6H-pyrido[2,1-b][1,3]*thiazine-4,9-dicarboxylate* **5** (R = phthalimido).—A solution of the phthalimido pyridone **5** (R = phthalimido)[3] (200 mg, 0.43 mmol) in anhydrous ether (150 cm^3) was photolysed using a 125 W high-pressure immersion mercury arc lamp through a Pyrex filter under nitrogen. After 3 h, TLC (silica: ether–hexane, 3:1) showed no starting material to be present. The solvent was removed under reduced pressure to yield an oil which was separated by chromatography (Chromatotron: silica: ether–hexane, 3:1) to yield two products. The major product was *diethyl 2-isopropenyl-4-oxo-5-phthalimido-1-thia-3-azabicyclo*[4.2.0]*oct-7-ene-2,7-dicarboxylate* **6** (R = phthalimido) which was recrystallised from chloroform–hexane (113 mg, 56%); m.p. 138–140 °C; *m/z* 470.1126 (M^+) ($C_{23}H_{22}N_2O_7S$ requires 470.1142); ν_{max}(KBr)/cm^{-1} 1780 and 1755 (imide), 1720 and 1690 (ester) and 1655 (amide); λ_{max}(MeOH)/nm 221, 234sh and 291 (log ε 4.77, 4.58 and 4.12); $\delta_H(C^2HCl_3$, 360 MHz) 1.29 and 1.39 (2 × 3 H, 2 × t, *J* 7.1, 2 × CH_3), 2.01 (3 H, d, *J* 0.57, CH_3C=), 3.02 (1 H, d × d, *J* 15.5 and 8.5, CH), 3.32 (1 H, d × d, *J* 15.5 and 13.7, CH), 4.21 and 4.22 (2 H, d × q, *J* 7.1, CH_2O), 4.39 (2 H, q, *J* 7.1, CH_2O), 5.15 (1 H, d × d, *J* 8.5 and 13.7 CHN), 5.39 (1 H, m, olefinic), 5.50 (1 H, s, olefinic), and 7.77 and 7.38 (4 H, m, aromatics); $\delta_C(C^2HCl_3$, 20.15 MHz) 13.86 and 14.37 (2 × CH_3), 18.53 (CH_3C=) 26.23 (CH_2), 48.28 (CHN), 60.54 and 63.24 (2 × CH_2O), 96.16 and 120.76 (olefinics), 123.57, 131.74 and 134.26 (aromatics), 136.49 and 148.24 (olefinics) and 160.21, 165.21 and 166.93 (3 × C=O).

The minor product could only be obtained contaminated by the main product **6** (R = phthalimido). It was evidently diethyl 2-isopropenyl-4-oxo-1-thia-3-azabicyclo[4.2.0]octa-5,7-diene-2,7-dicarboxylate **3** from its ^1H NMR spectrum.

Ethyl 2-Ethoxycarbonylmethyl-3-formyl-2,3-dihydro-5-methyl-6H-1,3-thiazine-4-carboxylate **7**.—Sodium cyanoborohydride (40 mg, 0.54 mmol) was added to a solution of the 1,3-thiazine **8**[3] (100 mg, 0.37 mmol) in tetrahydrofuran (20 cm^3) containing three drops of Bromocresol Green indicator. The pH was adjusted to pH 3 with dilute hydrochloric acid during the reaction. The reaction was stirred at room temperature and monitored by UV until completion (*ca.* 2 h). The mixture was partitioned between pH 7 buffer solution and chloroform. The chloroform extracts were dried (Na_2SO_4) and evaporated under reduced pressure to yield a yellow oil. This was treated with formic acetic anhydride (2 cm^3) and stirred overnight. The solvent was then removed under reduced pressure and the oil was chromatographed (silica gel: ether) (74 mg, 67%); *m/z*, 272.0945 (M^+ − CHO) $C_{12}H_{18}NO_4S$ requires 272.0956); λ_{max}(MeOH)/nm 227 and 255; $\delta_H(C^2HCl_3$, 360 MHz)—two isomers due to restricted rotation of amide: *major isomer* 1.25 (3 H, t, *J* 7, CH_3), 1.28 (3 H, t, *J* 7, CH_3), 2.14 (3 H, s, CH_3C=), 2.74 (2 H, d × q, *J* 9 and 6.5, CH_2S); 3.23 (2 H, *ABX*, *J* 12, 6.5 and 5, CH_2), 4.22 (4 H, m, CH_2O), 5.41 (1 H, d × d, *J* 5, CHN) and 8.23 (1 H, s, CH=O); minor isomer 1.27 (3 H, t, *J* 7, CH_3), 1.30 (3 H, t, *J* 7, CH_3), 2.22 (3 H, s, CH_3), 2.98 (2 H, AB, *J* 9, CH_2S), 3.23 (2 H, m, CH_2), 4.22 (4 H, m, CH_2O), 6.22 (1 H, q, NCH) and 8.04 (1 H, s, CH=O).

Ethyl 2-Ethoxycarbonylmethyl-1-formyl-4-isopropenyl-1,3-thiazetidine-2,4-carboxylate **9**.—The *N*-formylthiazine **7** (80 mg, 0.26 mmol) was photolysed at 8 °C in dry degassed benzene (350 cm^3) using a 125 W high-pressure immersion mercury arc lamp and a Pyrex filter under nitrogen overnight. The benzene was removed under reduced pressure to yield a pale oil which was chromatographed (silica gel: ether–hexane, 1:2) (49 mg, 61%); λ_{max}(MeOH)/nm 212 and 260; $\delta_H(C^2HCl_3$, 80 MHz) 1.34 (6 H, 2 × t, *J* 7.1, 2 × CH_3), 2.06 (3 H, d, *J* 0.7, CH_3C=), 2.82 (1 H, d × d, *J* 17.4 and 10.2, 0.5 CH_2), 3.75 (1 H, d × d, *J* 17.3 and 3.7, 0.5 CH_2), 4.21 (4 H, 2 × q, *J* 7.1, 2 × CH_2O), 5.17 (1 H, s, olefinic), 5.23 (H, m, olefinic), 5.42 (1 H, d × d, *J* 10.2 and 3.5, NCHS) and 8.23 (1 H, s, CHO).

Diethyl 3-Methyl-1,6-dioxo-2H,6H-pyrido[2,1-b][1,3]*thiazine-4,9-dicarboxylate* **10**.—Diethyl 3-methyl-6-oxo-2*H*,6*H*-pyrido[2,1-*b*][1,3]thiazine-4,9-dicarboxylate **1** ($R^1 = R^2$ = Et)[3] (100 mg, 0.31 mmol) and *m*-chloroperbenzoic acid (50 mg, 0.29 mmol) were dissolved in dry chloroform (10 cm^3) and the mixture was stirred for 1 h at room temperature, when the reaction was seen to be complete by UV spectroscopy (λ_{max}/nm 360 and 349 bands of starting material had disappeared and λ_{max}/nm 342 of product had appeared). The solvent was removed under reduced pressure and the residue subjected to preparative TLC (silica: Et_2O) to yield a white crystalline compound (93 mg) which was recrystallised from dichloromethane–diethyl ether (81 mg, 72%); m.p. 170–172 °C (Found: C, 52.9; H, 5.0; N, 4.2. $C_{15}H_{17}NO_6S$ requires C, 53.1; H, 5.0; N, 4.1%); *m/z* 339.0780 (M^+) ($C_{15}H_{17}NO_6S$ requires 339.0776); λ_{max}(MeOH)/nm 261 and 339 (log ε 4.01 and 3.78); ν_{max}(KBr)/cm^{-1} 1730 and 1710 (esters) and 1665 (pyridone); $\delta_H(C^2HCl_3$, 90 MHz), 1.23 (3 H, t, *J* 7, Me), 1.42 (3 H, t, *J* 7, Me), 2.37 (3 H, s, MeC=), 3.35 and 3.85 (2 H, AB, *J* 15, CH_2SO), 4.27 (2 H, d × q, *J* 7, and 3, CH_2O), 4.45 (2 H, q, *J* 7, CH_2O) and 6.75 and 7.90 (2 × 1 H, d × d, *J* 10, pyridone); $\delta_C(C^2HCl_3$, 25.15, MHz) 13.89 (q, Me), 14.14 (q, Me), 21.96 (q, *MeC*=), 50.72 (t, CH_2SO), 61.58 (t, CH_2O), 62.67 (t, CH_2O), 113.09 (s, pyridone β-H), 123.89 (d, pyridone α-CH), 124.86 and 130.63 (2 × s, olefinics), 138.64 (d, pyridone β-CH), 147.98 (s, SCN), 159.63, 161.63 and 163.15 (3 × s, 3 × C=O).

Diethyl 3-Isopropenyl-5-oxo-3H,5H-[1,2,4]*oxathiazolo*[4,3-a]*pyridine-3,8-dicarboxylate* **12**.—Diethyl 3-methyl-1,6-dioxo-2*H*,6*H*-pyrido[2,1-*b*][1,3]thiazine-4,9-dicarboxylate **10** (250

mg, 0.74 mmol) in dry degassed dioxane (*ca.* 150 cm^3) was photolysed under nitrogen using a Hanovia photochemical reactor with a 125 W medium-pressure mercury arc lamp and a Pyrex outer cooling jacket. After 2 h, the UV absorption at 339 nm had been replaced by absorption at 291 nm. The solvent was removed under reduced pressure to yield a pale oil which was purified by chromatography (Chromatotron: silica: ether–hexane, 3:1). The product was crystallised from ether–hexane to yield pale yellow prisms (166 mg, 66%); m.p. 40 °C (Found: C, 53.45; H, 5.2; N, 4.2. $C_{15}H_{17}NO_6S$ requires C, 53.1; H, 5.0; N, 4.1%); *m/z* 339; ν_{max}(KBr)/cm^{-1} 1760 and 1690 (esters) and 1625 (pyridone); λ_{max}(MeOH)/nm 293, 310, 319sh and 336sh (log ε 4.23, 4.18, 4.12 and 3.71); $\delta_H(C^2HCl_3$, 360 MHz) 1.31 and 1.38 (2 × 3 H, t, *J* 7.1, 2 × CH_3), 1.96 (3 H, br s, CH_3C=), 4.33 and 4.37 (2 H, q, *J* 7.1; 2 × CH_2O), 5.12 (1 H, br s, olefinic), 5.33 (1 H, d, *J* 1.4, olefinic), 6.25 (1 H, d, *J* 9.4, pyridone α-CH) and 7.68 (1 H, d, *J* 9.4, pyridone β-CH); $\delta_C(C^2HCl_3$, 90.5 MHz) 13.92 and 14.38 (q, CH_3) 18.65 (q, CH_3C=), 62.80 and 63.11 (2 × t, 2 × CH_2O), 99.55 (s, NCO), 103.02 (s, δ-pyridone), 115.86 (d, pyridone α-CH), 118.45 (t, olefinic), 136.88 (s, olefinic), 137.13 (d, pyridone β-CH) and 160.33, 164.46 and 166.39 (3 × C=O).

Diethyl 7,8-*Dihydro*-3-*methyl*-1,6-*dioxo*-2H,6H-*pyrido*[2,1-b][1,3]*thiazine*-4,9-*dicarboxylate* **16** (R = H).—Diethyl 7,8-dihydro-3-methyl-6-oxo-2*H*,6*H*-pyrido[2,1-*b*][1,3]thiazine-4,9-dicarboxylate **5** (R = H)[3] (100 mg, 0.31 mmol) and *m*-chloroperbenzoic acid (60 mg, 0.34 mmol) were dissolved in dry chloroform (10 cm^3) and the solution was stirred at room temperature for 6.5 h after which TLC (silica: ether–hexane, 3:1) showed the complete disappearance of starting material. The chloroform solution was washed successively with saturated aqueous sodium hydrogen carbonate and water and then dried ($MgSO_4$) and evaporated under reduced pressure to yield an off-white solid which was recrystallised from chloroform–hexane as white needles of the product (84 mg, 80%); m.p. 137–138 °C (Found: C, 52.8; H, 5.6; N, 3.7. $C_{15}H_{19}NO_6S$ requires C, 52.8; H, 5.6; N, 4.1%); *m/z* 341 (M^+); ν_{max}(KBr)/cm^{-1} 1725 and 1690; λ_{max}(MeOH)/nm 276 and 314 (log ε 3.44 and 3.48); $\delta_H(C^2HCl_3$, 360 MHz) 1.29 and 1.39 (2 × 3 H, 2 × t, *J* 7.1, 2 × CH_3), 2.32 (3 H, s, CH_3C=), 2.5–3.1 (4 H, m, 2 × CH_2), 3.21 and 3.69 (2 H, AB, *J* 13.8, CH_2S), 4.23 and 4.27 (2 H, 2 × q, *J* 7.1, CH_2O), and 4.36 and 4.37 (2 H, 2 × q, *J* 7.1, CH_2O); $\delta_C(C^2HCl_3$, 90.5 MHz) 14.01 (q, 2 × CH_3), 21.17 (t, CH_2), 21.61 (q, CH_3C=), 30.00 (t, CH_2), 51.97 (t, CH_2S), 61.39 and 62.34 (2 × t, ester CH_2), 119.12, 125.28, 132.63 and 148.03 (4 × s, olefinic), 161.90, 164.23 and 168.32 (3 × s, 3 × C=O).

Diethyl 6,7-*Dihydro*-3-*isopropenyl*-5-*oxo*-3H,5H-[1,2,4]*oxathiazolo*[4,3-a]*pyridine*-3,8-*dicarboxylate* **17** (R = H).—A solution of diethyl 7,8-dihydro-3-methyl-1,6-dioxo-2*H*,6*H*-pyrido[2,1-*b*][1,3]thiazine-4,9-dicarboxylate **16** (R = H) (100 mg, 0.29 mmol) in dry degassed dioxane (*ca.* 70 cm^3) was irradiated with a 125 W medium-pressure mercury lamp for 5 h through a Pyrex filter under nitrogen. The solvent was removed under reduced pressure to yield an oil which was purified by chromatography (Chromatotron: silica: ether–hexane, 1:3) to yield the product as a yellow oil (60 mg, 60%); *m/z* 341.0928 (M^+ $C_{15}H_{19}NO_6S$ requires 341.0933); ν_{max}(liquid film)/cm^{-1} 1750 and 1710 (esters) and 1650 (amide); λ_{max}(MeOH)/nm 261, 301sh, 314 and 327sh (log ε 3.84, 3.88, 3.97 and 3.87); $\delta_H(C^2HCl_3$, 60 MHz), 1.24 and 1.27 (2 × 3 H, 2 × t, *J* 7.3, 2 × CH_3), 1.84 (3 H, d, *J* 0.9, CH_3C=), 2.67 (4 H, s, 2 × CH_2), 4.16 (4 H, q, *J* 7.3, 2 × CH_2), 5.04 (1 H, s, olefinic) and 5.13 (1 H, m, olefinic); $\delta_C(C^2HCl_3$, 90.55 MHz), 13.99 and 14.48 (CH_3), 18.29 (CH_3C=), 19.29 (CH_2), 31.90 (CH_2), 62.21 and 62.86 (CH_2O), 92.78 (NCO), 100.05, 117.90, and 138.08 (olefinics), and 165.74, 166.75 and 168.83 (3 × C=O).

Diethyl 7,8-*Dihydro*-3-*methyl*-1,6-*dioxo*-7-*phthalimido*-2H,6H-*pyrido*[1,2-b][1,3]*thiazine*-4,9-*dicarboxylate* **16** (R = phthalimido).—A solution of *m*-chloroperbenzoic acid (40 mg, 0.23 mmol) in dry dichloromethane (1 cm^3) was added dropwise to a stirred solution of the phthalimidodihydropyridone **5** (R = phthalimido) (100 mg, 0.21 mmol) in dry dichloromethane (2 cm^3) at room temperature. After 3 h at room temperature the solution was washed with saturated aqueous sodium hydrogen carbonate, dried ($MgSO_4$) and evaporated under reduced pressure to yield an off-white solid. TLC (silica: ethyl acetate) showed three components to be present. These were separated by chromatography (Chromatotron: silica). Elution with ether–hexane gave unchanged starting material (21 mg; m.p. 105–107 °C), and further elution with ethyl acetate gave the diastereoisomeric sulfoxides **16** (R = phthalimido). The first of

Table 1 Crystal structure details

	Thiazetidine **3** (R¹ = R² = Et)	2,1,4-Oxathiazolidine **12**
Crystal size (mm^3)	0.35 × 0.28 × 0.1	0.5 × 0.3 × 0.3
Formula	$C_{15}H_{17}NO_5S$	$C_{15}H_{17}NO_6S$
M	323.4	339.4
Crystal system, space group	Monoclinic, $P2_1/c$	Triclinic $P\bar{1}$
a	12.602(6)	7.911(1)
b	9.736(5)	8.013(1)
c	13.073(7)	13.128(2)
α	90	87.88(1)
β	90.85(3)	79.55(1)
γ	90	77.87(1)
U(Å³), *Z*, D_c/g cm^{-3}	1603.8, 4, 1.34	800.1, 2, 1.41
Number of observed reflections	977	2488
R	0.109	0.093
wR	0.144	0.165
$(\Delta/\sigma)_{max}$	0.01	0.01

Table 2 Fractional atomic coordinates (× 10^4) of the thiazetidine **3** (R¹ = R² = Et) with esds in parentheses

	x	*y*	*z*
S	1527(3)	3257(4)	3674(3)
N	3268(8)	2412(11)	3557(10)
O(1)	5034(8)	2386(12)	3413(11)
O(2)	3405(10)	3744(12)	1750(9)
O(3)	2514(8)	5594(11)	2301(8)
O(4)	306(7)	604(10)	3765(9)
O(5)	1067(8)	−1524(10)	3793(7)
C(1)	2323(11)	1785(15)	3597(11)
C(2)	2208(12)	394(16)	3635(12)
C(3)	3174(12)	−395(17)	3596(13)
C(4)	4103(12)	268(16)	3525(14)
C(5)	4228(13)	1687(17)	3482(13)
C(6)	2983(10)	3858(13)	3509(11)
C(7)	3004(12)	4384(17)	2410(12)
C(8)	3419(11)	4733(17)	4308(13)
C(9)	3944(12)	5925(15)	4119(14)
C(10)	3312(15)	4203(20)	5431(13)
C(11)	2420(11)	6089(18)	1235(11)
C(12)	2029(13)	7514(19)	1335(13)
C(13)	1122(10)	−108(15)	3752(11)
C(14)	−14(12)	−2120(16)	3879(15)
C(15)	106(15)	−3672(16)	3781(14)

Table 3 Intramolecular distances (Å) and angles (°) of the thiazetidine **3** (R^1 = R^2 = Et) with esds in parentheses

(a) Bonds			
S–C(1)	1.752(9)	S–C(6)	1.942(8)
N–C(1)	1.340(11)	N–C(5)	1.405(12)
N–C(6)	1.454(10)	O(1)–C(5)	1.227(12)
O(2)–C(7)	1.184(11)	O(3)–C(7)	1.337(12)
O(3)–C(11)	1.477(11)	O(4)–C(13)	1.240(10)
O(5)–C(13)	1.382(11)	O(5)–C(14)	1.487(10)
C(1)–C(2)	1.364(13)	C(2)–C(3)	1.441(13)
C(2)–C(13)	1.463(12)	C(3)–C(4)	1.342(12)
C(4)–C(5)	1.392(14)	C(6)–C(7)	1.526(13)
C(6)–C(8)	1.450(13)	C(8)–C(9)	1.360(12)
C(8)–C(10)	1.565(14)	C(11)–C(12)	1.478(14)
C(14)–C(15)	1.524(13)		
(b) Angles			
C(1)–S–C(6)	72.4(4)	C(1)–N–C(5)	122.7(9)
C(1)–N–C(6)	102.9(8)	C(5)–N–C(6)	134.1(8)
C(7)–O(3)–C(11)	114.7(8)	C(13)–O(5)–C(14)	116.0(7)
S–C(1)–N	98.1(7)	S–C(1)–C(2)	138.5(9)
N–C(1)–C(2)	123.3(9)	C(1)–C(2)–C(3)	116.0(9)
C(1)–C(2)–C(13)	115.8(9)	C(3)–C(2)–C(13)	128.2(9)
C(2)–C(3)–C(4)	119(1)	C(3)–C(4)–C(5)	125(1)
N–C(5)–O(1)	116(1)	N–C(5)–C(4)	113(1)
O(1)–C(5)–C(4)	130(1)	S–C(6)–N	86.3(5)
S–C(6)–C(7)	103.6(6)	S–C(6)–C(8)	116.5(6)
N–C(6)–C(7)	110.9(8)	N–C(6)–C(8)	116.6(8)
C(7)–C(6)–C(8)	118.0(8)	O(2)–C(7)–O(3)	126(1)
O(2)–C(7)–C(6)	122(1)	O(3)–C(7)–C(6)	112.4(9)
C(6)–C(8)–C(9)	123(1)	C(6)–C(8)–C(10)	116.5(9)
C(9)–C(8)–C(10)	120(1)	O(3)–C(11)–C(12)	104.2(9)
O(4)–C(13)–O(5)	121.0(8)	O(4)–C(13)–C(2)	126.3(9)
O(5)–C(13)–C(2)	112.6(9)	O(5)–C(14)–C(15)	106.7(8)

Table 4 Fractional atomic coordinates (× 10^4) of the 2,1,4-oxathiazolidine **12** with esds in parentheses

	x	*y*	*z*
S	1775(2)	4298(2)	3382(1)
O(1)	3052(5)	3393(5)	6439(3)
O(2)	2581(6)	4951(5)	5013(3)
O(3)	1291(5))	−439(5)	1240(3)
O(4)	−1016(5)	1062(6)	2328(4)
O(5)	1850(6)	−1684(5)	3218(3)
O(6)	1071(5)	3375(5)	2427(3)
N	1912(5)	1081(5)	3450(3)
C(1)	1845(6)	1584(6)	2365(4)
C(2)	2065(6)	2375(6)	4024(4)
C(3)	2409(7)	2105(7)	5025(4)
C(4)	2549(8)	420(7)	5415(5)
C(5)	2308(8)	−854(7)	4857(4)
C(6)	2016(7)	−611(7)	3816(4)
C(7)	2670(7)	3607(7)	5496(4)
C(8)	3419(9)	4904(8)	6888(5)
C(9)	3812(11)	4385(11)	7959(6)
C(10)	519(7)	725(7)	1979(4)
C(11)	161(9)	−1606(9)	1076(6)
C(12)	1373(12)	−3036(10)	417(8)
C(13)	3643(7)	1329(7)	1679(4)
C(14)	3724(9)	2123(9)	646(5)
C(15)	5057(8)	469(10)	2032(6)

these, on trituration with diethyl ether, gave a solid (22 mg, 22%), m.p. 130–134 °C (Found: C, 55.4; H, 4.6; N, 5.5. $C_{23}H_{22}N_2O_8S$ requires C, 56.8; H, 4.5; N, 5.7%); ν_{max}(KBr)/cm^{-1} 1780 (imide), 1720 (ester) and 1660 (amide); λ_{max}(MeOH)/nm 270 and 304 (log ε 3.76 and 3.59); δ_H(C^2HCl_3, 360 MHz) 1.31 and 1.35 (2 × 3 H, 2 × t, *J* 7.1, 2 × CH_3), 2.34 (3 H, s, CH_3C=), 3.14 (1 H, d × d, *J* 17.4 and 7.2, CH), 3.56 (1 H, d × d, *J* 17.4 and 9.3, CH), 3.75 (2 H, AB, *J* 13.5, CH_2S), 4.3 (4 H, m, CH_2O), 5.17 (1 H, d × d, *J* 7.2 and 9.3, CHNPhth) and 7.78 and 7.86 (4 H, m, aromatics);

Table 5 Intramolecular distances (Å) and angles (°) of the oxathiazolidine **12** with esds in parentheses

(a) Bonds			
S–O(6)	1.710(1)	S–C(2)	1.721(2)
O(1)–C(7)	1.324(2)	O(1)–C(8)	1.470(2)
O(2)–C(7)	1.225(2)	O(3)–C(10)	1.341(2)
O(3)–C(11)	1.469(3)	O(4)–C(10)	1.194(2)
O(5)–C(6)	1.227(2)	O(6)–C(1)	1.436(2)
N–C(1)	1.473(2)	N–C(2)	1.342(2)
N–C(6)	1.412(2)	C(1)–C(10)	1.534(2)
C(1)–C(13)	1.517(3)	C(2)–C(3)	1.391(3)
C(3)–C(4)	1.416(3)	C(3)–C(7)	1.441(3)
C(4)–C(5)	1.342(3)	C(5)–C(6)	1.427(3)
C(8)–C(9)	1.518(4)	C(11)–C(12)	1.513(4)
C(13)–C(14)	1.474(3)	C(13)–C(15)	1.334(3)
(b) Angles			
O(6)–S–C(2)	89.76(8)	C(7)–O(1)–C(8)	115.1(2)
C(10)–O(3)–C(11)	112.9(2)	S–O(6)–C(1)	109.8(1)
C(1)–N–C(2)	112.1(1)	C(1)–N–C(6)	123.9(1)
C(2)–N–C(6)	123.6(2)	O(6)–C(1)–N	104.0(1)
O(6)–C(1)–C(10)	105.8(1)	O(6)–C(1)–C(13)	109.1(1)
N–C(1)–C(10)	108.7(1)	N–C(1)–C(13)	113.4(2)
C(10)–C(1)–C(13)	115.1(2)	S–C(2)–N	112.5(1)
S–C(2)–C(3)	126.4(1)	N–C(2)–C(3)	121.1(2)
C(2)–C(3)–C(4)	117.0(2)	C(2)–C(3)–C(7)	113.5(2)
C(4)–C(3)–C(7)	129.4(2)	C(3)–C(4)–C(5)	121.7(2)
C(4)–C(5)–C(6)	121.9(2)	O(5)–C(6)–N	117.5(2)
O(5)–C(6)–C(5)	127.9(2)	N–C(6)–C(5)	114.6(2)
O(1)–C(7)–O(2)	124.4(2)	O(1)–C(7)–C(3)	115.5(2)
O(2)–C(7)–C(3)	120.1(2)	O(1)–C(8)–C(9)	106.4(2)
O(3)–C(10)–O(4)	125.4(2)	O(3)–C(10)–C(1)	112.3(2)
O(4)–C(10)–C(1)	122.3(2)	O(3)–C(11)–C(12)	104.8(2)
C(1)–C(13)–C(14)	116.5(2)	C(1)–C(13)–C(15)	120.1(2)
C(14)–C(13)–C(15)	123.3(2)		

δ_C(C^2HCl_3, 20.15 MHz), 14.00 (q, 2 × CH_3), 21.24 (q, CH_3C=), 27.26 (t, CH_2), 47.77 (d, CHN), 52.81 (t, CH_2S), 61.75 and 62.59 (2 × t, 2 × CH_2O), 117.08 (s, olefinic), 123.80 and 134.53 (2 × d, aromatics), 131.75, 132.12, and 148.87 (3 × s, olefinics) and 164.27 and 167.15 (2 × C=O). The second sulfoxide gave white needles on trituration with diethyl ether (25 mg, 24%); m.p. 175–176 °C; *m/z* (+ve CI, NH_3), 487 (M^+ + 1); ν_{max}(KBr)/cm^{-1} 1780 (imide) and 1720 (ester); λ_{max}(MeOH)/nm 277 and 305 (log ε 3.55 and 3.42); δ_H(C^2HCl_3, 360 MHz) 1.37 and 1.39 (2 × 3 H, 2 × t, *J* 7.2, 2 × CH_3), 2.37 (3 H, s, CH_3C=), 3.20 (1 H, d × d, *J* 16 and 6, CH), 3.75 (2 H, AB, *J* 16, CH_2S), 3.83 (1 H, d × d, *J* 16 and 15.5, CH), 4.3 (4 H, m, CH_2O), 5.01 (1 H, d × d, *J* 6 and 15.5, CHNPhth) and 7.75 and 7.88 (4 H, m, aromatics).

X-Ray Structure Determinations of the Thiazetidine **3** (R^1 = R^2 = Et) *and the* 2,1,4-*Oxathiazolidine* **12**.—In both cases diffraction data were measured on an Enraf–Nonius CAD4 diffractometer using Mo-Kα radiation (λ = 0.710 69 Å) with a graphite monochromator. Cell parameters were calculated from the setting angles for 25 reflections with 14 < *θ* < 15°. Intensities were measured by a *θ*–2*θ* scan for 2 < *θ* < 25°. Two standard reflections monitored every hour showed no significant change. Data were corrected for Lorentz and polarisation effects but not for absorption. Reflections with $|F^2| > \sigma(F^2)$ were considered observed, where $\sigma|F^2| = \{\sigma^2(I) + (0.04I)^2\}^{\frac{1}{2}}/Lp$. Non-hydrogen atoms were located using MULTAN[5] and refined with anisotropic thermal parameters by full matrix least-squares using programs from the Enraf–Nonius SDP package and a weighting scheme of $w = \sigma^{-2}(F)$. Hydrogen atoms were not located and were omitted. Further details are given in Table 1. Atomic coordinates and intramolecular distances and angles are given in Tables 2 and 3 for the thiazetidine **3** (R^1 = R^2 = Et) and in Tables 4 and 5 for the 2,1,4-oxathiazolidine **12**. Tables of anisotropic thermal parameters are available from

the Cambridge Crystallographic Data Centre* and structure factors are available from the authors.

* For details of the scheme, see *Instructions for Authors* (1992), *J. Chem. Soc., Perkin Trans. 1*, 1992, Issue 1.

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