Studies related to Penicillins. Part 25.[1] Synthesis of *N*-Phenylacetyl and *N*-Triphenylmethyl Derivatives of 6-Aminopenam 1-Oxides[2]

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In boiling benzene, (3*R*,4*R*)-1-methylallyl-3-phenylacetamido-4-t-butylsulphinylazetidin-2-one (**11a**) is converted into (1*S*,5*R*,6*R*)-2,2-dimethyl-6-phenylacetamidopenam oxide (**9a**). (3*R*,4*R*)-1-Methylallyl-4-t-butylsulphinyl-3-triphenylmethylaminoazetidin-2-one (**11b**) and its (3*R*,4*S*)-diastereoisomer (**18**) react in an analogous manner to give (1*S*,5*R*,6*R*)-2,2-dimethyl-6-triphenylmethylaminopenam 1-oxide (**9b**) and its (1*R*,5*S*,6*R*)-diastereoisomer (**16**). 3-Methylallyl-5-triphenylmethyliminothiazolidin-4-one (**12**), whose structure has been established by *X*-ray crystallography, is also formed in the thermal reactions of compounds (**11b**) and (**18**).

The thermolysis of (3*R*,4*R*)-1-allyl-3-phenylacetamido-4-t-butylsulphinylazetidin-2-one (**11c**) and its 3-triphenylmethylamino counterpart (**11d**) gives rise to (1*S*,2*S*,5*R*,6*R*)-2-methyl-6-phenylacetamidopenam 1-oxide (**9d**) and its 6-triphenylmethylamino relative (**9e**). However, no bicyclic β-lactam derivatives are isolated from the *N*-phenylacetyl and *N*-triphenylmethyl derivatives (**21a,b**) of (3*R*,4*R*)-3-amino-1-prop-2-ynyl-4-t-butylsulphinylazetidin-2-one under thermal conditions.

It is well established that penicillanate oxides of type (**1**) afford low equilibrium concentrations of sulphenic acids of type (**2**) under thermal conditions.[3] In principle, therefore, it should be possible to prepare modified penicillanate oxides of type (**3**) from sulphenic acids of type (**4**). To achieve such an objective, two problems must be solved. Firstly, it is necessary to elaborate the modified butenoate moiety in the presence of the latent sulphenic acid function and, secondly, the reactive sulphenic acid group must be unmasked under conditions in which it will react intramolecularly with the alkene entity. The knowledge that 1-unsubstituted 4-thioazetidin-2-ones can undergo alkylations at position 1[4] and that the t-butylsulphinyl group can serve as a progenitor of the sulphenic acid function[5] led to the selection of the azetidinones (**5a,b**) as potential precursors of penicillanates of type (**3**).

Recently, we reported syntheses of the azetidinones (**5a,b**).[6] The former compound was obtained by treating the bromohydrin (**6**) [available from penicillin G potassium salt (**7a**) by a three-step sequence] with 2-methylpropane-2-thiol and triethylamine. Compound (**5b**) was isolated from the reaction of the sulphone (**8**) [prepared from the aminopenicillanic acid (**7b**) by a four-step sequence] with 2-methylpropane-2-thiol and potassium t-butoxide.

In this paper, we describe our efforts to convert the azetidinones (**5a,b**) into novel penam oxides.

Results and Discussion

Initially, the penam oxide (**9a**) was selected as a target. It was envisaged that this compound would be derivable from the azetidinones (**5a,b**) by way of the intermediates (**10a**) and (**11a**).

Treatment of the azetidinone (**5b**) with methylallyl bromide and potassium t-butoxide in tetrahydrofuran (THF) at −78 °C gave, after silica gel purification, the methylallyl derivative (**10b**) as a syrup in 85% yield. Under acidic conditions (*p*-$MeC_6H_4SO_3H{\cdot}H_2O$ in CH_2Cl_2–MeOH), compound (**10b**) was

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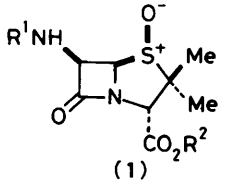
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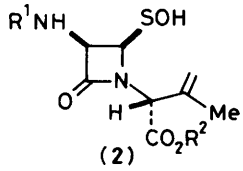
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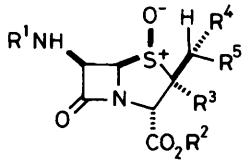
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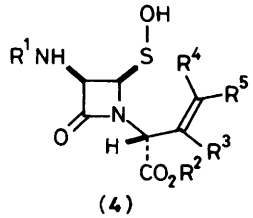
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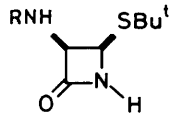
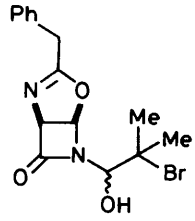

(5) a; R = $PhCH_2CO$
b; R = Ph_3C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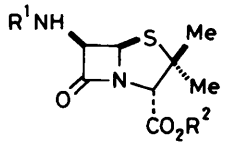
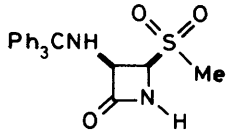

(7) a; R^1 = $PhCH_2CO$, R^2 = K
b; R^1 = R^2 = H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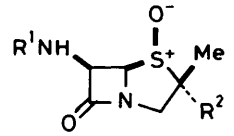
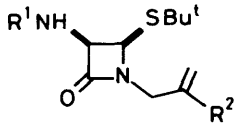


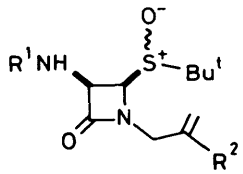
(9) **a**; R^1 = $PhCH_2CO$, R^2 = Me
b; R^1 = Ph_3C, R^2 = Me
c; R^1 = H, R^2 = Me
d; R^1 = $PhCH_2CO$, R^2 = H
e; R^1 = Ph_3C, R^2 = H



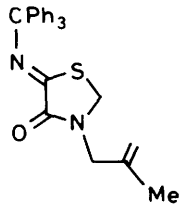
(10) **a**; R^1 = $PhCH_2CO$, R^2 = Me
b; R^1 = Ph_3C, R^2 = Me
c; R^1 = H, R^2 = Me
d; R^1 = $PhCH_2CO$, R^2 = H
e; R^1 = Ph_3C, R^2 = H
f; R^1 = R^2 = H

transformed into the syrupy aminoazetidinone (**10c**) (68% yield) which reacted with phenylacetyl chloride and triethylamine in dichloromethane to give the phenylacetamidoazetidinone (**10a**) (84% yield after SiO_2 chromatography) as a syrup. The last-cited compound was also obtained (46% yield after SiO_2 chromatography) by treatment of the azetidinone (**5a**) in *N*,*N*-dimethylformamide (DMF) with methylallyl bromide and a solution of potassium t-butoxide in t-butyl alcohol.

Oxidation of compound (**10a**) with sodium periodate in aqueous methanol gave the sulphoxide (**11a**), as a 3:1 mixture of diastereoisomers, in virtually quantitative yield. Although it was possible to isolate each diastereoisomer in a pure crystalline state after silica gel fractionation, the mixture was used for the next step.



(11) **a**; R^1 = $PhCH_2CO$, R^2 = Me
b; R^1 = Ph_3C, R^2 = Me
c; R^1 = $PhCH_2CO$, R^2 = H
d; R^1 = Ph_3C, R^2 = H



(12)

When heated in benzene under nitrogen, the sulphoxide (**11a**) was slowly converted into a new compound. Chromatographic purification led to the isolation of a major fraction (57% recovery by mass) which comprised a 5:1 mixture of the new compound and the minor diastereoisomer of the sulphoxide (**11a**) by ^1H n.m.r. spectroscopy; crystallisation of this mixture provided the new compound in a pure state in 50% yield. A small quantity (9% yield) of the major diastereoisomer of the sulphoxide (**11a**) was also recovered from the column.

The constitution of the product, as $C_{15}H_{18}N_2O_3S$, established that it was derived from the reactant (**11a**) by the loss of the elements of 2-methylpropene. Spectroscopic considerations left little doubt that the material was the hoped-for penam oxide (**9a**). In particular, i.r. spectroscopy revealed the presence of a strong absorption at 1 775 cm^{-1} for the β-lactam carbonyl group. In the ^1H n.m.r. spectrum ($CDCl_3$), the geminal dimethyl group appeared as two three-proton singlets at δ 1.30 and 1.53, the 3-methylene group as a one-proton double doublet (*J* 11 and 1 Hz) at δ 3.06 and a one-proton doublet at δ 3.88 (*J* 11 Hz), and the β-lactam hydrogen atoms as a one-proton doublet (*J* 4 Hz) at δ 4.86 and a one-proton doublet of double doublets (*J* 10, 4, and 1 Hz) at δ 5.98. Analogous long-range ^5J couplings have been observed in penams,[7] carbapenams,[8] isopenams,[9] and cephams.[10]

Having demonstrated that the basic strategy was a viable one, it was pertinent to enquire whether compound (**11b**) would react in an analogous manner. Successful ring closure at this level would be attractive since, in principle, the product (**9b**) would be convertible [by way of the aminopenam (**9c**)] into a wide range of acylaminopenams.

Oxidation of compound (**10b**) with sodium periodate gave the sulphoxide (**11a**) (76% yield after SiO_2 chromatography) as a single crystalline diastereoisomer. When heated in boiling benzene under nitrogen, compound (**11a**) was mainly converted into two new products. Chromatographic purification gave three fractions. The first and second fractions were isolated as crystalline solids in yields of 10 and 53%, respectively. The third fraction, obtained in 21% yield, was the starting sulphoxide (**11a**).

On the basis of its elemental composition and spectroscopic properties, the major product was identified as the penam oxide (**9b**). Thus the material possessed a strong i.r. absorption at 1 770 cm^{-1} for the β-lactam carbonyl group. In the ^1H n.m.r. spectrum ($CDCl_3$), the geminal dimethyl groups appeared as two three-proton singlets at δ 0.98 and 1.38, the 3-methylene group as a one-proton double doublet (*J* 11 and 1 Hz) at δ 2.83 and a one-proton doublet (*J* 11 Hz) at δ 3.79, and the β-lactam hydrogen atoms as a one-proton doublet (*J* 4 Hz) at δ 3.58 and a one-proton doublet of double doublets (*J* 12, 4, and 1 Hz) at δ 4.59.

The minor product, designated compound (**A**), possessed the molecular formula $C_{26}H_{24}N_2OS$, indicating that it was derived from the reactant (**11b**) by the loss of the elements of 2-methylpropene and water. I.r. spectroscopy revealed the absence of an NH absorption and a β-lactam-carbonyl group; it did, however, suggest the presence of an amide entity ($\nu_{max.}$ 1 695 and 1 685 cm^{-1}) and an imine or alkene linkage ($\nu_{max.}$ 1 640 cm^{-1}). ^1H N.m.r. spectroscopy ($CDCl_3$) showed that the methylallylamino function (characterised by a broad three-proton singlet at δ 1.71, a broad two-proton singlet at δ 4.12, and two broad one-proton singlets at δ 4.80 and 4.90) and the triphenylmethyl moiety (characterised by a broad fifteen-proton singlet at δ 7.21) were intact. Moreover, the presence of a sharp two-proton singlet at δ 4.20 suggested that compound (**A**) incorporated a methylene group that was probably flanked by at least one heteroatom. As well as featuring a molecular ion at *m*/*z* 442, the mass spectrum showed an ion at *m*/*z* 301 corresponding to $C_{20}H_{15}NS$ by mass measurement.

The foregoing evidence did not provide a unique structure for compound (**A**). Accordingly, an *X*-ray analysis was undertaken. The molecular structure, which was readily solved using direct

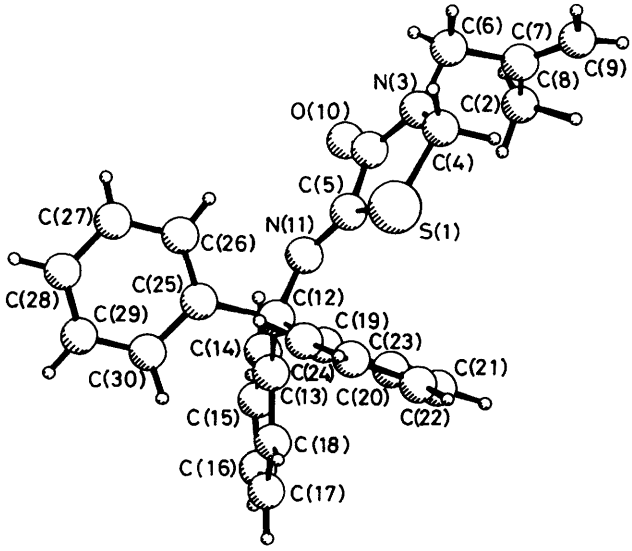


Figure. The molecular structure of compound (**12**)

Table 1. Fractional atomic co-ordinates (× 10^4) for compound (**12**)

Atom	*x/a*	*y/b*	*z/c*
S(1)	4 342(1)	5 982(2)	7 377(1)
C(2)	5 916(6)	6 122(8)	7 919(3)
N(3)	6 728(4)	5 087(5)	7 752(2)
C(4)	6 247(5)	4 259(6)	7 261(3)
C(5)	4 829(5)	4 600(5)	6 972(2)
C(6)	8 059(6)	4 939(8)	8 128(3)
C(7)	8 141(6)	4 129(9)	8 699(3)
C(8)	7 967(13)	2 575(11)	8 615(5)
C(9)	8 388(12)	4 684(13)	9 229(5)
O(10)	6 828(4)	3 358(4)	7 063(2)
N(11)	4 247(4)	3 879(4)	6 512(2)
C(12)	2 891(5)	4 008(5)	6 160(2)
C(13)	2 425(7)	2 491(6)	6 006(2)
C(14)	3 306(8)	1 475(8)	5 963(3)
C(15)	2 885(11)	109(9)	5 810(3)
C(16)	1 615(13)	−205(10)	5 700(4)
C(17)	716(12)	784(11)	5 737(3)
C(18)	1 124(8)	2 150(8)	5 892(3)
C(19)	2 034(4)	4 746(6)	6 515(2)
C(20)	1 819(5)	4 129(7)	7 038(3)
C(21)	1 129(6)	4 793(7)	7 407(3)
C(22)	653(6)	6 107(8)	7 255(3)
C(23)	861(7)	6 740(8)	6 735(4)
C(24)	1 533(6)	6 071(7)	6 364(3)
C(25)	2 886(5)	4 772(5)	5 546(2)
C(26)	3 834(7)	5 696(8)	5 512(3)
C(27)	3 824(8)	6 401(9)	4 968(4)
C(28)	2 862(8)	6 197(8)	4 450(3)
C(29)	1 910(8)	5 294(8)	4 467(3)
C(30)	1 911(6)	4 572(7)	5 008(3)

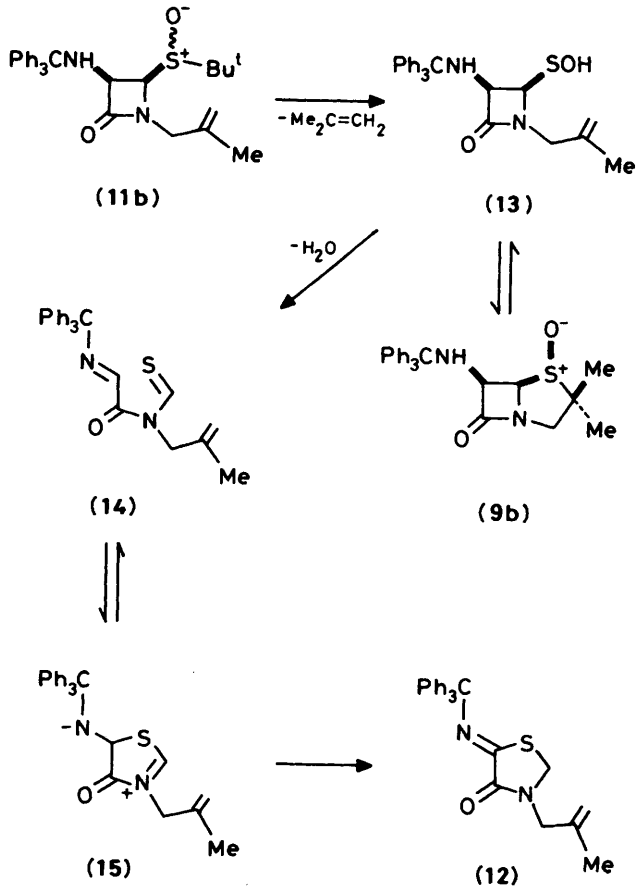
methods (see the Experimental section for crystal data and other information), is shown in the Figure together with its crystallographic numbering. Refined atomic co-ordinates are included in Table 1, while bond lengths and bond angles are available as a separate publication (see the Experimental section). Clearly, compound (**A**) was the thiazolidinone (**12**).*

Obviously, a major reorganisation is involved in the formation of the thiazolidinone (**12**) from the sulphoxide (**11b**). The observation that the penam oxide (**9b**) was also converted into the thiazolidinone (**12**) is of note. We infer from these findings that the sulphenic acid (**13**) is a common intermediate in the formation of the penam oxide (**9b**) from the sulphoxide (**11b**) and of the thiazolidinone (**12**) from the penam oxide (**9b**).

A possible pathway for the (**11b**)/(**9b**) ⟶ (**12**) transformation is outlined in Scheme 1. Thus by a fragmentation process,[11] the sulphenic acid (**13**) may give rise to the species (**14**) and water. Cyclisation of compound (**14**) may then lead to the dipolar intermediate (**15**). Finally, the product (**12**) may arise from the species (**15**) by an intramolecular [1,3]-hydride shift.†

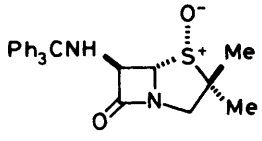
In the past, effort has been devoted to the synthesis of 5-epipenams.[12] It was of interest, therefore, to determine whether such compounds could be prepared by the present methodology. The penam (**16**) was selected as a target system to test this possibility.

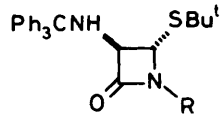
Treatment of the azetidinone (**17a**)[6] [a co-product from



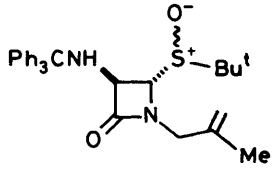
Scheme 1.

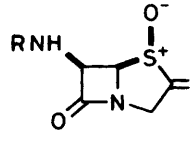
the reaction of the sulphone (**8**) with Bu^{t}SH–KOBu^t] with methylallyl bromide and potassium t-butoxide in THF at −78 °C gave the syrupy methylallyl derivative (**17b**) (90% yield after SiO_2 chromatography), which was transformed by the action of sodium periodate into the sulphoxide (**18**) obtained





(**17**) **a**; R = H
b; R = CH_2=C(Me)CH_2





(**19**) **a**; R = $PhCH_2CO$
b; R = Ph_3C

as a 6:1 mixture of diastereoisomers. Following silica gel fractionation, the major diastereoisomer was isolated as a crystalline solid in 70% yield; the minor diastereoisomer was obtained as a slightly impure syrup in 10% yield.

* Workers at Farmitalia–Carlo–Erba (Milan, Italy) have encountered analogous rearrangements with 1-oxides of 6β-triphenylmethylaminopenicillanates. We thank Dr. E. Perrone for informing us of these results.

† A referee has suggested that a thiol radical, formed by homolysis of a thiosulphinate [derived by self-condensation of the sulphenic acid (**13**)], may be involved in the formation of the product (**12**).

When heated under the usual conditions, the major diastereoisomer of the sulphoxide (**18**) was partially converted into two new products. Following silica gel purification, three fractions were isolated. The first and second fractions, isolated in respective yields of 56 and 10%, were identified as the thiazolidinone (**12**) and the starting sulphoxide (**18**). The third fraction, which was crystalline, was obtained in 10% yield.

On the basis of its spectroscopic properties, the third fraction was identified as the penam oxide (**16**). In particular, its i.r. spectrum featured a strong absorption at 1 755 cm^{-1} for the β-lactam moiety. Furthermore, its ^1H n.m.r. spectrum ($CDCl_3$) was characterised by the presence of two three-proton singlets at δ 1.00 and 1.33 for the geminal dimethyl group, two one-proton doublets (*J* 11 Hz) at δ 2.80 and 3.57 for the 3-methylene group, and a one-proton doublet (*J* 1.5 Hz) at δ 3.30 together with a one-proton broad singlet [which collapsed to a doublet (*J* 1.5 Hz) after D_2O had been added to the sample] at δ 4.50 for the β-lactam hydrogen atoms.

From the foregoing results, it appears that there is a greater tendency to form the thiazolidinone (**12**) in the thermolysis of the sulphoxide (**18**) than in the thermolysis of its counterpart (**11b**).

To examine further the scope of the cyclisation, efforts were made to prepare the penam oxides (**9d,e**).

Allylation of the azetidinone (**5a**) gave the crystalline allylazetidinone (**10d**) (55% yield after SiO_2 chromatography). The last-cited material was also prepared from the azetidinone (**5b**) by an allylation–detritylation–phenylacetylation sequence. Thus treatment of compound (**5b**) with allyl iodide and potassium t-butoxide in THF gave, after silica gel purification, the allylazetidinone (**10e**) as a syrup in 67% yield. Under acidic conditions, compound (**10e**) was transformed into the syrupy amino derivative (**10f**) (65% yield), which reacted with phenylacetyl chloride and triethylamine in dichloromethane to give the phenylacetamidoazetidinone (**10d**) (82% yield after SiO_2 chromatography).

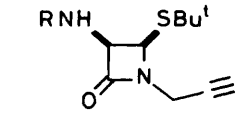
Compound (**10d**) underwent oxidation to give the syrupy sulphoxide (**11c**) (77% yield after SiO_2 chromatography) which appeared to be a single diastereoisomer by 60 MHz ^1H n.m.r. spectroscopy.

Under the usual thermal conditions, the sulphoxide (**11c**) was transformed into the syrupy penam oxide (**9d**) (35% yield after SiO_2 chromatography). The i.r. spectrum of compound (**9d**) showed a strong absorption at 1 780 cm^{-1} for the β-lactam carbonyl function. In the ^1H n.m.r. spectrum ($CDCl_3$), the 2-methyl group appeared as a three-proton doublet (*J* 6 Hz) at δ 1.50, the 2-methine and 3-methylene hydrogen atoms as a three-proton multiplet at δ 3.25—3.80, and the β-lactam hydrogen atoms as a one-proton doublet (*J* 4 Hz) at δ 4.69 together with a one-proton double doublet (*J* 10 and 4 Hz) at δ 5.94.

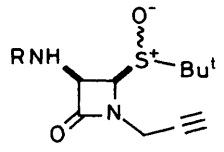
The sulphoxide (**11d**), obtained as a crystalline solid in 54% yield after silica gel fractionation, was prepared by oxidation of compound (**10e**). Under thermal conditions, it was transformed into a syrupy product (93% yield after SiO_2 chromatography), which was identified as the penam oxide (**9e**) on the basis of its spectroscopic properties. Thus the i.r. spectrum featured a strong absorption at 1 775 cm^{-1} for the β-lactam carbonyl entity. In the ^1H n.m.r. spectrum ($CDCl_3$), the three-proton doublet (*J* 6 Hz) at δ 1.26 was assigned to the 2-methyl group, the four-proton multiplet at δ 2.67—3.63 was attributed to the 2- and 5-hydrogen atoms and the 3-methylene group, and the one-proton double doublet (*J* 12 and 4 Hz) at δ 4.57 to the 6-hydrogen atom.

In a further examination of the scope of the methodology, efforts were made to prepare the penam oxides (**19a,b**).

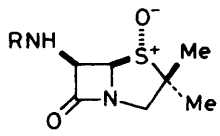
Treatment of the azetidinones (**5a,b**) with prop-2-ynyl bromide under basic conditions provided, after silica gel chromatography, the propynyl derivatives (**20a,b**). Both



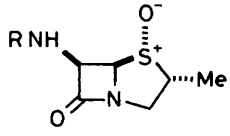
(**20**) **a**; R = $PhCH_2CO$
b; R = Ph_3C



(**21**) **a**; R = $PhCH_2CO$
b; R = Ph_3C



(**22**) **a**; R = $PhCH_2CONH$
b; R = Ph_3C



(**23**) **a**; R = $PhCH_2CONH$
b; R = Ph_3C

compounds were isolated as syrups, the former in 82% yield and the latter in 61% yield. Under the usual oxidation conditions, the t-butylthioazetidinones (**20a,b**) were converted into their corresponding sulphoxides (**21a,b**), apparently as single diastereoisomers. After silica gel purification, the former compound was isolated as a syrup in 62% yield and the latter as a syrup in 56% yield.

Disappointingly, in boiling benzene, compounds (**21a,b**) were converted into complex arrays of products which lacked the β-lactam entity according to i.r. spectroscopy.

At this juncture, it is appropriate to discuss the evidence for the stereochemistry of the oxide moiety in compounds (**9a—e**) and (**16**). In principle, structures (**22a,b**), (**23a,b**),* and (**24**) are also contenders. Solvent-induced chemical shifts [δ($CDCl_3$)–δ(C_6D_6)] have been extensively used to diagnose the configuration of penicillanate oxides, first by the groups of Cooper[13] and Barton[14] and then by Vanderhaeghe and co-workers.[15] A summary of such solvent effects upon the chemical shifts of representative protons of the penam oxides prepared in this study, together with relevant examples taken from the literature, is made in Table 2. An examination of the data shows that substantial up-field shifts of the 2α- and 2β-methyl groups and of the 3α- and 5-hydrogens occur in compounds (**9a,b**), on changing the solvent from deuteriochloroform to deuteriobenzene; there is only a small or no effect upon the 3β- and 6-hydrogens. Moreover, the 2α-methyl group shows a larger positive Δ value than the 2β-methyl group. These results compare favourably with those reported for the sulphoxide (**25a**)[16] but differ substantially from those observed for the sulphoxide (**26a**);[16] accordingly, the (1*S*)-configuration is assigned to compounds (**9a,b**).

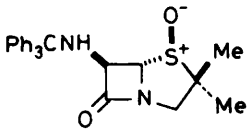
Although the data are less extensive (because of signal overlap), it is clear that the penam oxides (**9d,e**) behave in a manner similar to compounds (**9a,b**). In particular, the Δ values for the 5- and 6-hydrogens are very similar in the two series [it should be noted that, for compound (**26a**), the 6-hydrogen atom experiences a much larger up-field shift than the 5-hydrogen atom on going from $CDCl_3$ to C_6D_6]. In consequence, the (1*S*)-configuration [and therefore the (2*S*)-configuration] is assigned to compounds (**9d,e**).

* The addition of a sulphenic acid to a double bond occurs by way of a planar transition state (C. A. Kingsbury and D. J. Cram, *J. Am. Chem. Soc.*, 1960, **82**, 1810) and, in consequence, a *syn* relationship must exist between the 1-oxygen atom and the 2-methyl group.

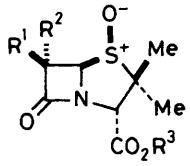
Table 2. Solvent effects upon the chemical shifts of representative protons in penam oxides [$\Delta = \delta(CDCl_3) - \delta(C_6D_6)$]

Compound		2α-Me	2β-Me	3α-H	3β-H	5-H	6-H
(**9a**)	$\delta(CDCl_3)$	1.30	1.53	3.06	3.90	4.86	5.98
	$\delta(C_6D_6)$	0.44	0.96	2.37	3.69	3.87	5.98
	Δ	+0.86	+0.67	+0.69	+0.21	+0.99	0
(**9b**)	$\delta(CDCl_3)$	0.98	1.38	2.83	3.79	3.58	4.59
	$\delta(C_6D_6)$	0.28	0.86	2.33	3.73	3.21	4.57
	Δ	+0.70	+0.52	+0.50	+0.06	+0.37	+0.02
(**9d**)	$\delta(CDCl_3)$		1.40	*a*	*a*	4.69	5.94
	$\delta(C_6D_6)$		0.78	*a*	*a*	3.75	5.98
	Δ		+0.62			+0.94	−0.04
(**9e**)	$\delta(CDCl_3)$		1.26	*a*	*a*	3.42	4.57
	$\delta(C_6D_6)$		0.70	2.54	3.44	2.97	4.44
	Δ		+0.52			+0.45	+0.13
(**16**)	$\delta(CDCl_3)$	1.00	1.33	2.80	3.57	3.30	4.50
	$\delta(C_6D_6)$	0.35	0.80	2.33	3.43	2.97	4.75
	Δ	+0.65	+0.53	+0.47	+0.41	+0.33	−0.25
(**25a**)[16]	$\delta(CDCl_3)$	1.23	1.73		4.69	5.03	6.10
	$\delta(C_6D_6)$	0.51	1.25		4.65	3.77	5.93
	Δ	+0.72	+0.48		+0.03	+1.26	+0.17
(**26a**)[16]	$\delta(CDCl_3)$	1.32	1.68		4.41	4.78	5.55
	$\delta(C_6D_6)$	1.18	1.37		4.42	4.38	4.60
	Δ	+0.14	+0.31		−0.01	+0.40	+0.95
(**25b**)[15a]	$\delta(CDCl_3)$	1.10	1.64		4.56	5.05	5.44
	$\delta(C_6D_6)$	0.61	1.31		4.57	4.58	5.17
	Δ	+0.49	+0.33		−0.01	+0.47	+0.27
(**26b**)[15a]	$\delta(CDCl_3)$	1.34	1.46		4.52	4.79	5.54
	$\delta(C_6D_6)$	1.19	0.89		4.33	4.93	5.09
	Δ	+0.15	+0.57		+0.19	−0.14	+0.45

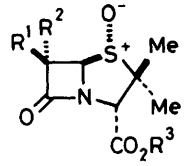
[a] The chemical shift of this proton could not be reliably determined because of signal overlap.



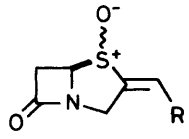
(**24**)



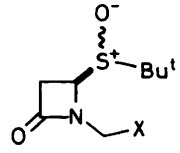
(**25**) **a**, R^1 = $PhOCH_2CONH$, R^2 = H, R^3 = Me
b, R^1 = H, R^2 = $PhOCH_2CONH$, R^3 = $PhCH_2$



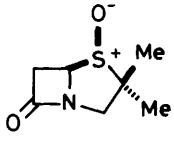
(**26**) **a**; R^1 = $PhOCH_2CONH$, R^2 = H, R^3 = Me
b; R^1 = H, R^2 = $PhOCH_2CONH$, R^3 = $PhCH_2$



(**27**)



(**28**) **a**; X = RC≡C
b; X = CH_2=C(Me)



(**29**)

It should be noted that the relative stereochemistry of the penam oxide (**16**) at positions 5 and 6 matches that of compounds (**25b**) and (**26b**). A comparison of the three compounds reveals that the penam oxide (**16**) is more closely akin to the penam oxide (**25b**)[15a] than its diastereoisomeric counterpart (**26b**).[15a] Accordingly, the relative stereochemistry of compound (**16**) matches that of the penam oxide (**25b**); in an absolute sense therefore, the (1*R*)-geometry is assigned to compound (**16**).

The foregoing results reveal that the *N*-alkylation of monocyclic azetidinones can be achieved in the presence of the 4-t-butylthio- and 3-phenylacetamido-/3-triphenylmethylamino-functions. They also show that the t-butylsulphinyl group provides a means of unmasking the sulphenic acid entity under conditions which are mild enough for intramolecular trapping reactions to be achieved. Clearly, the azetidinones (**5a,b**) hold considerable promise as precursors of a wide range of bicyclic analogues of the β-lactam antibiotics.

Other workers have used the strategy described herein, which we first reported in 1980,[2] to construct bicyclic β-lactam derivatives. Thus Arrowsmith and Greengrass[17] prepared a range of racemic methylenepenam oxides of type (**27**) (including the case where R = H) by the thermolysis of (±)-azetidinones

of type (**28a**). Their results are of particular interest in view of our experience with the related azetidinones (**21a,b**). Foley and Weigele[18] found that thermolysis of the (±)-azetidinone (**28b**) provided the (±)-penam oxide (**29**) together with its diastereoisomer (as a minor product).

Experimental

Dry solvents, referred to in the ensuing experiments, were prepared as follows: THF was dried over calcium hydride and, immediately prior to use, was distilled; DMF was stored over 4 Å molecular sieves; benzene was allowed to stand over sodium wire. Light petroleum refers to that fraction boiling in the range 40—60 °C. For chromatographic and other instrumental details, see Part 20.[19]

Reaction of the Azetidinone (**5b**) *with Methylallyl Bromide.*—To a stirred, cooled (Me_2CO–solid CO_2) solution of the azetidinone (**5b**)[6] (2.45 g, 5.88 mmol) and methylallyl bromide[20] (5 cm^3) in dry THF (50 cm^3) was added a solution of freshly sublimed potassium t-butoxide (1.32 g, 11.8 mmol) in dry THF (30 cm^3) (added in drops over 15 min). After 48 h at room temperature, the mixture was diluted with chloroform and washed twice with brine. Evaporation of the dried ($MgSO_4$) organic layer and purification of the syrupy product by silica gel chromatography (PhH–Et_2O, gradient elution) gave (3R,4R)-1-*methylallyl*-4-*t-butylthio*-3-*triphenylmethylaminoazetidin*-2-*one* (**10b**) (2.36 g, 85% yield) as a chromatographically homogeneous syrup. The material possessed the following properties: $[\alpha]_D$ + 87° (1% in $CHCl_3$); $\nu_{max.}$(film) *inter alia* 1 755 cm^{-1} (β-lactam C=O); $\lambda_{max.}$(EtOH) 208 (ε 21 000) and 222sh nm (6 000); δ(60 MHz; $CDCl_3$) 1.16 (9 H, s, CMe_3), 1.56 (3 H, s, CMe), 2.80 (1 H, d, *J* 6 Hz, Ph_3CNHCH), 3.35 and 3.85 (each 1 H, d, *J* 16 Hz, together NCH_2CMe), 4.34—4.75 (4 H, m, $C{=}CH_2$ and 3- and 4-H), and 7.00—7.50 (15 H, m, Ph_3C) (addition of D_2O caused the signal at δ 2.80 to disappear); *m/z* (*inter alia*) 470 (M^+), 243 ($C_{19}H_{15}^+$, base peak), 182, and 165 ($C_{13}H_9^+$) (Found: M^+, 470.2421. $C_{30}H_{34}N_2OS$ requires *M*, 470.2392).

Reaction of the Triphenylmethylaminoazetidinone (**10b**) *with Toluene*-p-*sulphonic Acid.*—To a solution of the triphenylmethylaminoazetidinone (**10b**) (1.79 g, 3.80 mmol) in dichloromethane (25 cm^3) was added toluene-*p*-sulphonic acid monohydrate (0.725 g, 3.81 mmol) dissolved in the minimum volume of methanol. After 30 min, the solution was washed twice with aqueous sodium hydrogen carbonate and extracted with 0.1M hydrochloric acid. The acidic extract was neutralised with aqueous sodium hydrogen carbonate and extracted (3 ×) with chloroform. Evaporation of the dried ($MgSO_4$) organic extracts gave (3R,4R)-3-*amino*-1-*methylallyl*-4-*t-butylthio*-*azetidin*-2-*one* (**10c**) (0.586 g, 68% yield) as a yellow syrup with the following properties: $\nu_{max.}$(film) (*inter alia*) 3 370 (NH) and 1 750 cm^{-1} (β-lactam C=O); δ(60 MHz; $CDCl_3$) 1.25 (9 H, s, CMe_3), 1.62 (3 H, s, CMe), 1.80 (2 H, s, NH_2), 3.35 and 3.80 (each 1 H, d, *J* 15 Hz, together NCH_2CMe), 4.31 (1 H, d, *J* 4 Hz, 3-H), and 4.65—4.80 (3 H, m, $C{=}CH_2$ and 4-H) (addition of D_2O caused the signal at δ 1.80 to disappear); *m/z* (*inter alia*) 228 (M^+), 172 ($M^+ - C_4H_8$), 171 ($M^+ - C_4H_9$), 155, and 116 (base peak) (Found: M^+, 228.1300. $C_{11}H_{20}N_2OS$ requires *M*, 228.1296).

Reaction of the Aminoazetidinone (**10c**) *with Phenylacetyl Chloride.*—To a stirred solution of the aminoazetidinone (**10c**) (0.586 g, 2.57 mmol) and phenylacetyl chloride (0.397 g, 2.57 mmol) in dichloromethane (30 cm^3) was added triethylamine (0.260 g, 2.57 mmol). After 30 min, the mixture was washed with aqueous sodium hydrogen carbonate and water. Evaporation of the dried ($MgSO_4$) organic layer and purification of the residue by silica gel chromatography (PhH–Et_2O, gradient elution) gave (3R,4R)-1-*methylallyl*-3-*phenylacetamido*-4-*t-butylthioazetidin*-2-*one* (**10a**) (0.747 g, 84% yield) as a syrup, with the following properties: $[\alpha]_D$ −16° (0.75% in EtOH); $\nu_{max.}$(film) (*inter alia*) 3 400br (NH), 1 750 (β-lactam C=O), and 1 665 cm^{-1} (amide C=O); $\lambda_{max.}$(EtOH) 223 (ε 17 500) and 258 nm (1 800); δ(60 MHz; $CDCl_3$) 1.07 (9 H, s, CMe_3), 1.64 (3 H, s, CMe), 3.22br and 3.89br (each 1 H, d, *J* 15 Hz, together NCH_2CMe), 3.52 (2 H, s, $PhCH_2CO$), 4.68—4.85 (3 H, m, $C{=}CH_2$ and 4-H), 5.44 (1 H, dd, *J* 9 and 4 Hz, 3-H), 6.68br (1 H, d, *J* 9 Hz, $CONHCH$), and 7.22 (5 H, s, Ph) [addition of D_2O caused the signal at δ 6.68 to disappear and that at δ 5.44 to collapse to a d (*J* 4 Hz)]; *m/z* (*inter alia*) 346 (M^+), 289 ($M^+ - C_4H_9$), 116, and 91 ($C_7H_7^+$, base peak) (Found: M^+, 346.1724. $C_{19}H_{26}N_2O_2S$ requires *M*, 346.1715).

Reaction of the Azetidinone (**5a**) *with Methylallyl Bromide.*—To a cooled (ice–NaCl), stirred solution of the azetidinone (**5a**)[6] (0.100 g, 0.34 mmol) in dry DMF (3 cm^3) was added methylallyl bromide[20] (0.046 g, 0.34 mmol) followed by a 1M solution of potassium t-butoxide in t-butyl alcohol (0.34 cm^3, 0.34 mmol). After 3 h, the mixture was treated with aqueous ammonium chloride and extracted with ethyl acetate. The organic layer, after having been washed with brine (4 ×), was dried ($MgSO_4$) and evaporated. Purification of the resultant gum by silica gel chromatography (EtOAc–light petroleum, gradient elution) gave a chromatographically homogeneous syrup (0.054 g, 46% yield) that was identical (^1H n.m.r. spectroscopy) with the azetidinone (**10a**).

Reaction of the t-Butylthioazetidinone (**10a**) *with Sodium Periodate.*—To a stirred solution of the t-butylthioazetidinone (**10a**) (0.962 g, 2.47 mmol) in methanol (250 cm^3) was added sodium periodate (2.00 g, 9.35 mmol) dissolved in the minimum volume of water. After 2 days, water was added to the mixture (to dissolve the precipitate of $NaIO_3$) which was then extracted (4 ×) with chloroform. The combined organic extracts were dried ($MgSO_4$) and evaporated to a syrup (0.877 g, 98% yield), considered to be the sulphoxide (**11a**) as a 3:1 mixture of diastereoisomers (^1H n.m.r. spectroscopy). The mixture was fractionated by silica gel chromatography (PhH–Et_2O, gradient elution).

The first-eluted component was the minor isomer of (3R,4R)-1-*methylallyl*-3-*phenylacetamido*-4-*t-butylsulphinylazetidin*-2-*one* (**11a**). The sample, when recrystallised from dichloromethane–diethyl ether, possessed the following properties: m.p. 118 °C; $[\alpha]_D$ +24° (0.5% in EtOH); $\nu_{max.}$(KBr) (*inter alia*) 3 350 (NH), 1 780 (β-lactam C=O), and 1 680 cm^{-1} (amide C=O); $\lambda_{max.}$(EtOH) 208 nm (ε 9 000); δ(60 MHz; $CDCl_3$) 1.15 (9 H, s, CMe), 1.69br (3 H, s, CMe_3), 3.60 (2 H, s, $PhCH_2CO$), 3.88 and 4.23 (each 1 H, d, *J* 15 Hz, together NCH_2CMe), 4.83—4.98 (3 H, m, $C{=}CH_2$ and 4-H), 5.80 (1 H, dd, *J* 11 and 4 Hz, 3-H), 6.98br (1 H, d, *J* 11 Hz, $CONHCH$), and 7.28 (5 H, s, Ph) [irradiation at δ 4.90 caused the signal at δ 5.80 to collapse to a d (*J* 11 Hz); addition of D_2O and Et_3N caused the signal at δ 6.98 to disappear and that at δ 5.88 to collapse to a d (*J* 4 Hz)]; *m/z* (*inter alia*) 257 ($M^+ - C_4H_9OS$, base peak), 229, 225, 213, 161, 118, and 91 ($C_7H_7^+$) (Found : C, 62.8; H, 7.2; N, 7.6. $C_{19}H_{26}N_2O_3S$ requires C, 62.95; H, 7.25; N, 7.75%).

The second-eluted material was the major sulphoxide of (3R,4R)-1-*methylallyl*-3-*phenylacetamido*-4-*t-butylsulphinyl*-*azetidin*-2-*one* (**11a**). The sample, when recrystallised from dichloromethane–diethyl ether, possessed the following properties: m.p. 108—110 °C; $[\alpha]_D$ +151° (1% in EtOH); $\nu_{max.}$(KBr) (*inter alia*) 3 280 (NH), 1 775 (β-lactam C=O), and 1 680 cm^{-1} (amide C=O); $\lambda_{max.}$(EtOH) 211 nm (ε 10 300); δ(60 MHz; $CDCl_3$) 1.11 (9 H, s, CMe_3), 1.70 (3 H, s, CMe), 3.59 (2 H, s, $PhCH_2CO$), 3.80 and 4.52br (each 1 H, d, *J* 15 Hz, together

NCH_2CMe), 4.67 (1 H, d, *J* 4 Hz, 4-H), 4.82br and 4.94br (each 1 H, s, together C=CH_2), 5.52 (1 H, dd, *J* 9 and 4 Hz, 3-H), 7.28 (5 H, s, Ph), and 8.35br (1 H, d, *J* 9 Hz, CON*H*CH) [addition of D_2O and Et_3N caused the signal at δ 8.35 to disappear and that at δ 5.52 to collapse to a d (*J* 4 Hz)]; *m/z* (*inter alia*) 257 (M^+ − C_4H_9OS), 213, 159, and 91 ($C_7H_7^+$, base peak) (Found: C, 63.2; H, 7.4; N, 7.8. $C_{19}H_{26}N_2O_3S$ requires C, 62.95; H, 7.25; N, 7.75%).

Thermolysis of the t-Butylsulphinylazetidinone (**11a**).—A solution of the t-butylsulphinylazetidinone (**11a**) (0.536 g, 1.48 mmol) (as a 3:1 mixture of diastereoisomers) in dry benzene (400 cm^3) was heated under reflux in an atmosphere of nitrogen. Evaporation, after 2 days, and purification of the resultant syrup by silica gel chromatography (PhH–Et_2O, gradient elution) gave two fractions.

The first-eluted material (0.303 g) was a 5:1 mixture of the penam oxide (**9a**) and the minor isomer of the starting sulphoxide (**11a**) according to ^1H n.m.r. spectroscopy. Crystallisation of the mixture from methanol–diethyl ether gave (1S,5R,6R)-2,2-*dimethyl*-6-*phenylacetamidopenam* 1-*oxide* (**9a**) (0.225 g, 50% yield) which possessed the following properties: m.p. 123—125 °C; $[\alpha]_D$ +205° (0.65% in EtOH); $\nu_{max.}$(KBr) (*inter alia*) 3 400 and 3 360 (NH), 1 775 (β-lactam C=O), and 1 695 and 1 680 cm^{-1} (amide C=O); $\lambda_{max.}$(EtOH) 211 nm (ε 7 500); δ(60 MHz; $CDCl_3$) 1.30 and 1.53 (each 3 H, s, together 2-Me_2), 3.06 (1 H, dd, *J* 11 and 1 Hz, 3α-H), 3.60 (2 H, s, PhCH_2CO), 3.90 (1 H, d, *J* 11 Hz, 3β-H), 4.86 (1 H, d, *J* 4 Hz, 5-H), 5.98 (1 H, ddd, *J* 10, 4, and 1 Hz, 6-H), 7.2br (1 H, d, *J* 10 Hz, CON*H*CH), and 7.30br (5 H, s, Ph) [addition of D_2O and Et_3N caused the signal at δ 7.2 to disappear and that at δ 5.98 to collapse to a dd (*J* 4 and 1 Hz)]; δ(60 MHz; C_6D_6) 0.44 and 0.96 (each 3 H, s, together 2-Me_2), 2.37 and 3.69 (each 1 H, d, *J* 11 Hz, together 3-H_2), 3.28 (2 H, s, PhCH_2CO), 3.87 (1 H, d, *J* 4 Hz, 5-H), 5.98 (1 H, dd, *J* 10 and 4 Hz, 6-H), and 7.2 (br s, solvent signal, Ph and CON*H*CH); *m/z* (*inter alia*) 306 (M^+), 288 (M^+ − H_2O), 257 (M^+ − HOS), 209, 175, 159, and 91 ($C_7H_7^+$, base peak) (Found: C, 58.7; H, 5.9; N, 9.1%; M^+, 306.1028. $C_{15}H_{18}N_2O_3S$ requires C, 58.80; H, 5.90; N, 9.15%; *M*, 306.1038).

The second-eluted material (0.049 g, 9% yield) was identical (^1H n.m.r. spectroscopy) with the major isomer of the sulphoxide (**11a**).

Reaction of the t-Butylthioazetidinone (**10b**) *with Sodium Periodate*.—To a stirred solution of the t-butylthioazetidinone (**10b**) (2.48 g, 5.27 mmol) in methanol (140 cm^3) was added sodium periodate (2.50 g, 11.7 mmol) dissolved in the minimum volume of water. After 3 days, water was added to the mixture (to dissolve the precipitate of $NaIO_3$) which was then extracted (3 ×) with chloroform. The combined organic extracts were dried ($MgSO_4$) and evaporated. Purification of the resultant yellow gum by silica gel chromatography (PhH–Et_2O, gradient elution) gave (3R,4R)-1-*methylallyl*-4-*t-butylsulphinyl*-3-*triphenylmethylaminoazetidin*-2-*one* (**11b**) (1.95 g, 76% yield) as a solid. The sample, when recrystallised from dichloromethane–diethyl ether, possessed the following properties: m.p. 172 °C; $[\alpha]_D$ +13° (6% in $CHCl_3$); $\nu_{max.}$(KBr) (*inter alia*) 3 440 (NH) and 1 765 cm^{-1} (β-lactam C=O); $\lambda_{max.}$(EtOH) 223 (ε 9 000) and 261 nm (2 500); δ(60 MHz; $CDCl_3$) 1.10 (9 H, s, CMe_3), 1.61 (3 H, s, CMe), 3.29 (1 H, d, *J* 8 Hz, Ph_3CN*H*CH), 3.50 (1 H, d, *J* 17 Hz, NC*H*HCMe, 4.34—4.91 (5 H, m, NCH*H*CMe, C=CH_2, and 3- and 4-H), and 7.00—7.35 (15 H, m, Ph_3C) (addition of D_2O caused the signal at δ 3.29 to disappear); *m/z* (*inter alia*) 486 (M^+), 243 ($C_{19}H_{13}^+$, base peak), 182, and 165 ($C_{13}H_9^+$) (Found: C, 74.3; H, 7.1; N, 5.8. $C_{30}H_{34}N_2O_2S$ requires C, 74.05; H, 7.05; N, 5.75%).

Thermolysis of the t-Butylsulphinylazetidinone (**11b**).—A solution of the t-butylsulphinylazetidinone (**11b**) (0.880 g, 1.81 mmol) in dry benzene (100 cm^3) under nitrogen was heated under reflux until the starting material had largely disappeared (t.l.c., *ca.* 48 h). Evaporation and purification of the product by silica gel chromatography (PhH–Et_2O, gradient elution) gave three fractions.

The first-eluted fraction, isolated as a solid (0.074 g, 10% yield), was considered to be 3-*methylallyl*-5-*triphenylmethylimino*-*thiazolidin*-4-*one* (**12**). The sample, isolated as colourless prisms after recrystallisation from chloroform–diethyl ether, possessed the following properties: m.p. 197 °C; $\nu_{max.}$(KBr) (*inter alia*) 1 695 and 1 685 (amide C=O), and 1 640 cm^{-1} (C=N); $\lambda_{max.}$(EtOH) 216 (ε 9 300) and 260 nm (3 500); δ(60 MHz; $CDCl_3$) 1.71br (3 H, s, CMe), 4.12br (2 H, br s, NCH_2CMe), 4.20 (2 H, s, 2-H_2), 4.80 and 4.90 (each 1 H, br s, together C=CH_2), and 7.21 (15 H, s, Ph_3C); δ(60 MHz; C_6D_6) 1.37 (3 H, br s, CMe), 3.34 (2 H, s, 2-H_2), 3.66 (2 H, br s, NCH_2CMe), 4.43 and 4.60 (each 1 H, br s, together C=CH_2), and 6.95—7.20 and 7.50—7.75 (10 and 5 H, each m, together Ph_3C); *m/z* (*inter alia*) 412 (M^+), 357 (M^+ − C_4H_7), 335, 301 ($C_{20}H_{15}NS^+$), 269, 243 ($C_{19}H_{15}^+$, base peak), and 165 ($C_{13}H_9^+$) (Found: C, 75.6; H, 5.7; N, 6.9%; M^+, 442.1658. $C_{26}H_{24}N_2OS$ requires C, 75.70; H, 5.85; N, 6.80%; *M*, 412.1609. Found *m/z* 301.0912. $C_{20}H_{15}NS$ requires *m/z* 301.0925).

The second-eluted fraction, also isolated as a solid (0.411 g, 53% yield) was (1S,5R,6R)-2,2-*dimethyl*-6-*triphenylmethylaminopenam* 1-*oxide* (**9b**). After having been recrystallised from chloroform–diethyl ether, the sample showed the following properties: m.p. 145—147 °C; $[\alpha]_D$ +149° (0.4% in EtOH); $\nu_{max.}$(KBr) (*inter alia*) 3 400br (NH) and 1 770 cm^{-1} (β-lactam C=O); $\lambda_{max.}$(EtOH) 210 (ε 23 500) and 228sh nm (10 200); δ(60 MHz; $CDCl_3$) 0.98 and 1.38 (each 3 H, s, together 2-Me_2), 2.83 (1 H, dd, *J* 11 and 1 Hz, 3α-H), 3.58 (1 H, d, *J* 4 Hz, 5-H), 3.79 (1 H, d, *J* 11 Hz, 3β-H), 4.08 (1 H, d, *J* 12 Hz, Ph_3CN*H*CH), 4.59 (1 H, ddd, *J* 12, 4, and 1 Hz, 6-H), and 7.05—7.60 (15 H, m, Ph_3C) [irradiation at δ 4.59 caused the signal at δ 3.58 to collapse to a s and that at δ 2.83 to collapse to a d (*J* 11 Hz); irradiation at δ 2.83 caused the signal at δ 3.79 to collapse to a s and that at δ 4.59 to collapse to a dd (*J* 12 and 4 Hz); addition of D_2O caused the signal at δ 4.08 to disappear and that at δ 4.59 to collapse to a dd (*J* 4 and 1 Hz)]; δ(60 MHz; C_6D_6) 0.28 and 0.86 (each 3 H, s, together 2-Me_2), 2.33 and 3.73 (each 1 H, d, *J* 11 Hz, together 3-H_2), 3.21 (1 H, d, *J* 3 Hz, 5-H), 4.48—4.66 (2 H, m, Ph_3CN*H* and 6-H), and 6.90—7.20 and 7.50—7.70 (10 and 5 H, each m, together Ph_3C) (irradiation at δ 2.33 caused the signal at 3.73 to collapse to a s and *vice versa*; irradiation at δ 4.52 caused the signal at δ 3.21 to collapse to a s); *m/z* (*inter alia*) 430 (M^+), 412, 332 ($C_{21}H_{18}NOS^+$), 243 ($C_{19}H_{15}^+$ base peak), and 165 ($C_{13}H_9^+$) (Found: C, 72.9; H, 6.2; N, 6.6%; M^+, 430.1742. $C_{26}H_{26}N_2O_2S$ requires C, 72.55; H, 6.10; N, 6.50%; *M*, 430.1715).

The third-eluted fraction (0.182 g, 21% yield) was identical (t.l.c. and ^1H n.m.r. spectroscopy) with the starting material (**11b**).

X-*Ray Crystal Structure Data for Compound* (**12**).—$C_{26}H_{24}N_2OS$, *M*, 412.5, monoclinic, *a* = 10.6662(9), *b* = 9.6118(9), *c* = 22.214(2) Å, β = 104.25 (1)°, *U* = 2 205(1) $Å^3$, space group $P2_1n$, *Z* = 4, D_c = 1.24 g cm^{-3}, *F*(000) = 872, μ(Mo-K_α) = 0.128 mm^{-1}.

A colourless prism, 0.06 × 0.10 × 0.40 mm, was selected for *X*-ray examination. All measurements were made with a CAD4 diffractometer with graphite monochromated Mo-K_α radiation. Unit cell dimensions were obtained by least-squares refinement on setting angles of 25 accurately centred reflections ($5.2 < \theta < 9.4°$). Intensity data were collected in the ω/2θ scan mode with a ω-scan width of 0.5 + 0.35tanθ and scan speed ranging

from 5 to 1° min^{-1} depending on the intensity gathered in a pre-scan. 2 552 Unique reflections [$0 < \theta < 25°$, $I > 0$] were measured, yielding 1 503 structure factors [$F > 3\ \sigma\ (F)$].

Lorenz, polarisation and absorption corrections were applied. Non-hydrogen atoms were located by direct methods and hydrogen atoms by means of difference Fourier maps. Full matrix least-squares refinement led to a final R value of 0.057 with non-hydrogen vibrational parameters anisotropic and hydrogen vibrational parameters isotropic. Fractional atomic co-ordinates for non-hydrogen atoms are presented in Table 1. The bond lengths, bond and torsional angles, fractional co-ordinates of the hydrogen atoms and their isotropic temperature factors, and the anisotropic temperature factors have been deposited with the Cambridge Crystallographic Data Centre.*

All calculations were performed on the University of Manchester Regional Computer Centre Amdahl 5890 computer. MULTAN[21] was used for structure solution and SHELX-76[22] for refinement. The molecule was drawn using PLUTO.[23]

Thermolysis of the Penam Oxide (**9b**).—A solution of the penam oxide (**9b**) (0.041 g, 0.1 mmol) in dry benzene (10 cm^3) was heated under reflux in an atmosphere of nitrogen. When the reaction was complete (t.l.c., *ca.* 2 days), the solution was concentrated to leave a material that was identical (t.l.c. and ^1H n.m.r. spectroscopy) with the thiazolidinone (**12**).

Reaction of the Azetidinone (**17a**) *with Methylallyl Bromide.*—To a stirred cooled (Me_2CO–solid CO_2) solution of the azetidinone (**17a**)[6] (2.07 g, 4.97 mmol) and methylallyl bromide[20] (6 cm^3) in dry THF (50 cm^3) under an atmosphere of nitrogen was added a solution of freshly sublimed potassium t-butoxide (1.12 g, 9.98 mmol) in dry THF (30 cm^3) (added in drops over 15 min). After 20 h at room temperature, the mixture was diluted with dichloromethane and washed with brine. Evaporation of the dried ($MgSO_4$) organic layer and purification of the resultant yellow syrup by silica gel chromatography (PhH–Et_2O, gradient elution) gave (3R,4S)-1-*methylallyl*-4-*t-butylthio*-3-*triphenylmethylaminoazetidin*-2-*one* (**17b**) (2.10 g, 90% yield). The material, obtained as a colourless, chromatographically homogeneous syrup, displayed the following properties: $[\alpha]_D$ −19° (3.5% in EtOH); $\nu_{max.}$(film) (*inter alia*) 1 755 cm^{-1} (β-lactam C=O); $\lambda_{max.}$(EtOH) 223 nm (ε 7 700); δ(60 MHz; $CDCl_3$) 1.20 (9 H, s, CMe_3), 1.70 (3 H, s, CMe), 2.74 (1 H, br s, Ph_3CNHCH), 3.40 and 3.92 (each 1 H, d, J 16 Hz, together NCH_2CMe), 4.00 (1 H, br s, 3-H), 4.57 (1 H, d, J 2 Hz, 4-H), 4.85 (2 H, br s, $C{=}CH_2$), and 7.15—7.50 (15 H, m, Ph_3C) [addition of D_2O caused the signal at δ 2.74 to disappear and that at δ 4.00 to collapse to a d (J 2 Hz)]; *m/z* (*inter alia*) 470 (M^+), 260, 243 ($C_{19}H_{15}^+$, base peak), 182, and 165 ($C_{13}H_9^+$) (Found: M^+, 470.2398. $C_{30}H_{34}N_2OS$ requires M, 470.2392).

Reaction of the t-Butylthioazetidinone (**17b**) *with Sodium Periodate.*—To a stirred solution of the t-butylthioazetidinone (**17b**) (2.00 g, 4.25 mmol) in methanol (85 cm^3) was added sodium periodate (2.50 g, 11.7 mmol) dissolved in the minimum volume of water. After 5 days, water was added to the mixture (to dissolve the precipitate of $NaIO_3$) which was then extracted (4 ×) with chloroform. The combined organic extracts were dried ($MgSO_4$) and concentrated. Purification of the resultant syrup by silica gel chromatography (PhH–Et_2O, gradient elution) gave two fractions.

The first-eluted material, isolated as a solid (1.45 g, 70% yield), was the major isomer of (3R,4S)-1-*methylallyl*-4-*t-butylsulphinyl*-3-*triphenylmethylaminoazetidin*-2-*one* (**18**). The sample, recrystallised from chloroform–diethyl ether, showed the following properties: m.p. 178—180 °C; $[\alpha]_D$ −97° (0.5% in EtOH); $\nu_{max.}$(KBr) (*inter alia*) 3 440 (NH) and 1 755 cm^{-1} (β-lactam C=O); $\lambda_{max.}$(EtOH) 219 nm (ε 12 600); δ(60 MHz; $CDCl_3$) 1.03 (9 H, s, CMe_3), 1.71 (3 H, s, CMe), 2.8 (1 H, br s, Ph_3CNHCH), 3.60 and 4.30 (each 1 H, br d, J 17 Hz, together NCH_2CMe), 4.08 (1 H, d, J 2 Hz, 4-H), 4.40 (1 H, br s, 3-H), 4.80 and 4.95 (each 1 H, br s, together $C{=}CH_2$), and 7.10—7.40 (15 H, m, Ph_3C) [addition of D_2O caused the signal at δ 2.8 to disappear and that at δ 4.40 to appear as a d (J 2 Hz)]; *m/z* (*inter alia*) 412 ($M^+ - C_4H_{10}O$), 243 ($C_{19}H_{15}^+$, base peak), and 165 ($C_{13}H_9^+$) (Found: C, 73.9; H, 6.8; N, 5.9. $C_{30}H_{34}N_2O_2S$ requires C, 74.05; H, 7.05; N, 5.75%).

The second-eluted material, isolated as a slightly impure syrup (0.200 g, *ca.* 10% yield), was considered to be predominantly the minor isomer of the sulphoxide (**18**). The sample showed the following properties: $\nu_{max.}$(film) (*inter alia*) 1 760 cm^{-1} (β-lactam C=O); δ(60 MHz; $CDCl_3$) (*inter alia*) 1.10 (s, CMe_3), 1.60 (s, CMe), 3.50 (d, J 17 Hz, $NCHHCMe$), 4.20—4.80 (m, $NCHHCMe$, $C{=}CH_2$, and 3- and 4-H), and 7.15—7.40 (m, Ph_3C); *m/z* (*inter alia*) 412 ($M^+ - C_4H_{10}O$), 243 ($C_{19}H_{15}^+$, base peak), and 165 ($C_{13}H_9^+$).

Thermolysis of the t-Butylsulphinylazetidinone (**18**).—A solution of the major isomer of the t-butylsulphinylazetidinone (**18**) (0.164 g, 0.34 mmol) in dry benzene (50 cm^3) was heated under reflux in an atmosphere of nitrogen. Evaporation, after 36 h, and purification of the product by silica gel chromatography (PhH–Et_2O, gradient elution) gave three fractions.

The first-eluted material, isolated as a solid (0.078 g, 56% yield), was identical (t.l.c. and ^1H n.m.r. spectroscopy) with the thiazolidinone (**12**).

The second-eluted material (0.017 g, 10% yield) was indistinguishable from the starting sulphoxide (**18**) (^1H n.m.r. spectroscopy).

The third-eluted material, also isolated as a solid (0.015 g, 10% yield), was (1R,5S,6R)-2,2-*dimethyl*-6-*triphenylmethylaminopenam* 1-*oxide* (**16**). After having been recrystallised from chloroform–diethyl ether, the sample possessed the following properties: m.p. 172—174 °C; $[\alpha]_D$ −210° (0.7% in EtOH); $\nu_{max.}$(KBr) (*inter alia*) 3 320 (NH) and 1 755 cm^{-1} (β-lactam C=O); $\lambda_{max.}$(EtOH) 211 (ε 17 000) and 222sh nm (11 600); δ(60 MHz; $CDCl_3$) 1.00 and 1.33 (each 3 H, s, together 2-Me_2), 1.74 (1 H, br s, Ph_3CNHCH), 2.80 and 3.57 (each 1 H, d, J 11 Hz, together 3-H_2), 3.30 (1 H, d, J 1.5 Hz, 5-H), 4.50 (1 H, br s, 6-H), and 7.15—7.50 (15 H, m, Ph_3C) [addition of D_2O caused the signal at δ 1.74 to disappear and that at δ 4.50 to appear as a d (J 1.5 Hz)]; δ(60 MHz; C_6D_6) 0.35 and 0.80 (each 3 H, s, 2-Me_2), 2.33 and 3.43 (each 1 H, d, J 11 Hz, together 3-H_2), 2.35 (1 H, br d, J 10 Hz, Ph_3CNHCH), 2.97 (1 H, d, J 1.5 Hz, 5-H), 4.75 (1 H, dd, J 10 and 1.5 Hz, 6-H), and 6.90—7.60 (15 H, m, Ph_3C) [addition of D_2O caused the signal at δ 2.35 to disappear and that at δ 4.75 to collapse to a d (J 1.5 Hz)]; *m/z* (*inter alia*) 430 (M^+), 413 (M^+ − OH), 243 ($C_{19}H_{15}^+$, base peak), 182, and 165 ($C_{13}H_9^+$).

Reaction of the Azetidinone (**5a**) *with Allyl Bromide.*—To a cooled (ice–NaCl), stirred solution of the azetidinone (**5a**)[6] (0.300 g, 1.03 mmol) in dry DMF (3 cm^3) under an atmosphere of nitrogen was added allyl bromide (0.125 g, 1.03 mmol) followed by a 1M solution of potassium t-butoxide in t-butyl alcohol (1.04 cm^3, 1.04 mmol). After 5 h, the mixture was treated with aqueous ammonium chloride and extracted with ethyl acetate. The organic layer, after having been washed with brine (4 ×), was dried ($MgSO_4$) and evaporated. Purification of the residue by silica gel chromatography (EtOAc–light petroleum, gradient elution) gave a solid (0.190 g, 55% yield) that was

* For details of CCDC deposition scheme, see 'Instructions for Authors (1988),' *J. Chem. Soc., Perkin Trans. 1*, 1988, Issue 1, p. xviii, paragraph 5.6.3.

identical (^{1}H n.m.r. spectroscopy and mass spectrometry) with the allylazetidinone (**10d**) derived from compound (**5b**). The sample, when recrystallised from chloroform–light petroleum, showed the following properties: m.p. 106—107 °C; $\nu_{max.}$(KBr) (*inter alia*) 3 380 (NH), 1 765 (β-lactam C=O), and 1 670 cm^{-1} (amide C=O) (Found: C, 65.4; H, 7.0; N, 8.6. $C_{18}H_{24}N_2O_2S$ requires C, 65.05; H, 7.30; N, 8.45%).

Reaction of the Azetidinone (**5b**) *with Allyl Iodide.*—To a stirred solution of azetidinone (**5b**)[6] (0.096 g, 0.23 mmol) in dry THF (10 cm^3) was added freshly sublimed potassium t-butoxide (0.051 g, 0.45 mmol) followed by allyl iodide (0.5 cm^3). After 3 h, the mixture was diluted with ethyl acetate and washed twice with brine. Evaporation of the dried ($MgSO_4$) organic layer and purification of the resultant syrup by silica gel chromatography (PhH–Et_2O, gradient elution) gave (3R,4R)-1-*allyl*-4-*t-butylthio*-3-*triphenylmethylaminoazetidin*-2-*one* (**10e**) (0.071 g, 67% yield) as a pale-yellow, chromatographically homogeneous syrup. The sample possessed the following properties: $[\alpha]_D$ + 60° (1.5% in EtOH); $\nu_{max.}$(film) (*inter alia*) 3 400br (NH) and 1 755 cm^{-1} (β-lactam C=O); $\lambda_{max.}$(EtOH) 211 (ε 19 800) and 227sh nm (9 900); δ(60 MHz; $CDCl_3$) 1.13 (9 H, s, CMe_3), 2.75 (1 H, d, *J* 7 Hz, Ph_3CNHCH), 3.39 (1 H, dd, *J* 16 and 6 Hz, NC*H*HCH), 3.99 (1 H, dm, separation 16 Hz, NCH*H*CH), 4.35—4.70 (2 H, m, 3- and 4-H), 4.80—5.80 (3 H, m, $CH{=}CH_2$), and 7.20—7.65 (15 H, m, Ph_3C) [addition of D_2O caused the signal at δ 2.75 to disappear and that at δ 4.35—4.70 to collapse to 2 d (each J 4 Hz)]; *m/z* (*inter alia*) 456 (M^+), 243 ($C_{19}H_{15}^+$, base peak), 213, and 165 ($C_{13}H_9^+$) (Found: M^+, 456.2247. $C_{29}H_{32}N_2OS$ requires *M*, 456.2235).

Reaction of the Triphenylmethylaminoazetidinone (**10e**) *with Toluene*-p-*sulphonic Acid.*—To a solution of the triphenylmethylaminoazetidinone (**10e**) (0.275 g, 0.60 mmol) in dichloromethane (10 cm^3) was added toluene-*p*-sulphonic acid monohydrate (0.115 g, 0.60 mmol) dissolved in the minimum volume of methanol. After 30 min, the mixture was diluted with dichloromethane and washed with aqueous sodium hydrogen carbonate and brine. The organic layer was then extracted with 0.1M hydrochloric acid. After having been neutralised with aqueous sodium hydrogen carbonate, the acidic layer was extracted (3 ×) with chloroform. The combined organic extracts were dried ($MgSO_4$) and evaporated to give (3*R*,4*R*)-1-allyl-3-amino-4-t-butylthioazetidin-2-one (**10f**) (0.083 g, 65% yield) as a chromatographically homogeneous, yellow syrup. The material possessed the following properties: $\nu_{max.}$(film) (*inter alia*) 3 350 (NH) and 1 750 cm^{-1} (β-lactam C=O); δ(60 MHz; $CDCl_3$) 1.30 (9 H, s, CMe_3), 1.80 (2 H, br s, NH_2), 3.53 (1 H, dd, *J* 15 and 6 Hz, NC*H*HCH), 4.05 (1 H, dm, separation 15 Hz, NCH*H*CH), 4.40 (1 H, d, *J* 4 Hz, 3-H), 4.80 (1 H, d, *J* 4 Hz, 4-H), and 4.95—5.85 (3 H, m, $CH{=}CH_2$) (addition of D_2O caused the signal at δ 1.80 to disappear).

Reaction of the Aminoazetidinone (**10f**) *with Phenylacetyl Chloride.*—To a stirred solution of the freshly prepared aminoazetidinone (**10f**) (0.083 g, 0.39 mmol) in dry dichloromethane (10 cm^3) was added phenylacetyl chloride (0.060 g, 0.39 mmol) followed by a solution of triethylamine (0.039 g, 0.39 mmol) in dry dichloromethane (1 cm^3) (added in drops over 1 min). After 30 min, the mixture was diluted with dichloromethane and washed twice with *ca.* 0.01M hydrochloric acid. Evaporation of the dried ($MgSO_4$) organic layer and purification of the product by silica gel chromatography (PhH–Et_2O, gradient elution) gave (3R,4R)-1-*allyl*-3-*phenylacetamido*-4-*t-butylthioazetidin*-2-*one* (**10d**) (0.106 g, 82% yield) as a chromatographically homogeneous, colourless syrup. The material possessed the following properties: $\nu_{max.}$(film) (*inter alia*) 3 300 (NH), 1 750 (β-lactam C=O), and 1 660 cm^{-1} (amide C=O); δ(60 MHz; $CDCl_3$) 1.15 (9 H, s, CMe_3), 3.47 (1 H, dd, *J* 16 and 7 Hz, NC*H*HCH), 3.70 (2 H, s, $PhCH_2CO$), 4.05 (1 H, dm, separation 16 Hz, NCH*H*CH), 4.85 (1 H, d, *J* 4 Hz, 4-H), 5.0—5.8 (4 H, m, $CH{=}CH_2$ and 3-H) 6.25 (1 H, d, *J* 10 Hz, CON*H*CH), and 7.25 (5 H, s, Ph) [addition of D_2O caused the signal at δ 6.25 to disappear and a d (*J* 4 Hz) to appear at δ 5.47]; *m/z* (*inter alia*) 332 (M^+), 275 ($M^+ - C_4H_9$), 102, and 91 ($C_7H_7^+$, base peak) (Found: M^+, 332. 1545. $C_{18}H_{24}N_2O_2S$ requires *M*, 332.1558).

Reaction of the t-Butylthioazetidinone (**10d**) *with Sodium Periodate.*—To a stirred solution of the t-butylthioazetidinone (**10d**) (0.152 g, 0.46 mmol) in methanol (25 cm^3) was added sodium periodate (0.500 g, 2.34 mmol) dissolved in the minimum volume of water. After 2 days, the mixture was diluted with water and extracted (3 ×) with dichloromethane. Evaporation of the combined, dried ($MgSO_4$) organic extracts and purification of the residue by silica gel chromatography (PhH–Et_2O, gradient elution) gave (3*R*,4*R*)-1-allyl-3-phenylacetamido-4-t-butylsulphinylazetidin-2-one (**11c**) (0.124 g, 77% yield) as a chromatographically homogeneous syrup. The material possessed the following properties: $\nu_{max.}$(film) (*inter alia*) 3 280 (NH), 1 775 (β-lactam C=O), and 1 675 cm^{-1} (amide C=O); δ(60 MHz; $CDCl_3$) 1.11 (9 H, s, CMe_3), 3.56 (2 H, s, $PhCH_2CO$), 3.81 (1 H, dd, *J* 16 and 6 Hz, NC*H*HCH), 4.20 (1 H, dm, separation 16 Hz, NCH*H*CH), 4.70 (1 H, d, *J* 4 Hz, 4-H), 5.0—6.0 (4 H, m, $CH{=}CH_2$ and 3-H), 7.25 (5 H, s, Ph), and 8.2 (1 H, br d, 10 Hz, CON*H*CH) [addition of D_2O caused the signal at δ 8.20 to disappear and a d (*J* 4 Hz) to appear at δ 5.40]; *m/z* (*inter alia*) 274 ($M^+ - C_4H_{10}O$), 243 ($M^+ - C_4H_9OS$), 215, 199, 159, and 91 ($C_7H_7^+$, base peak).

Thermolysis of the t-Butylsulphinylazetidinone (**11c**).—A solution of the t-butylsulphinylazetidinone (**11c**) (0.089 g, 0.26 mmol) in dry benzene (25 cm^3) was heated under reflux in an atmosphere of nitrogen. After 20 h, the solvent was evaporated and the residue was fractionated by silica gel chromatography (EtOAc–light petroleum, gradient elution) to give (1S,2S,5R,6R)-2-*methyl*-6-*phenylacetamidopenam* 1-*oxide* (**9d**) (0.026 g, 35% yield) as a colourless, chromatographically homogeneous syrup. The material showed the following properties: $\nu_{max.}$(film) (*inter alia*) 3 380 (NH), 1 780 (β-lactam C=O), and 1 670 cm^{-1} (amide C=O); δ(60 MHz; $CDCl_3$) 1.40 (3 H, d, *J* 6 Hz, 2-Me), 3.35—3.80 (3 H, m, 2-H and 3-H_2), 3.58 (2 H, s, $PhCH_2CO$), 4.69 (1 H, d, *J* 4 Hz, 5-H), 5.94 (1 H, dd, *J* 10 and 4 Hz, 6-H), and 7.2 (6 H, br s, Ph and CON*H*CH) [irradiation at δ 3.50 caused the signal at δ 1.40 to collapse to a s; irradiation at δ 4.69 caused the signal at δ 5.94 to collapse to a d (*J* 10 Hz); irradiation at δ 5.94 caused the signal at δ 4.69 to collapse to a s]; δ(60 MHz; C_6D_6) 0.78 (3 H, d, *J* 6 Hz, 2-Me), 1.90—2.70 (2 H, m, 2-H and 3α-H), 3.20—3.60 (3 H, m, $PhCH_2CO$ and 3β-H), 3.75 (1 H, d, *J* 4 Hz, 5-H), 5.98 (1 H, dd, *J* 10 and 4 Hz, 6-H), 7.1 (br s, solvent signal and Ph), and 7.35 (1 H, br d, *J* 10 Hz, CON*H*CH); *m/z* (*inter alia*) 292 (M^+), 275 (M^+ − OH), 159 ($C_{10}H_9NO^+$), and 91 ($C_7H_7^+$, base peak) (Found: M^+, 292.0885. $C_{14}H_{16}N_2O_3S$ requires *M*, 292.0882).

Reaction of the t-Butylthioazetidinone (**10e**) *with Sodium Periodate.*—To a stirred solution of the t-butylthioazetidinone (**10e**) (0.300 g, 0.66 mmol) in methanol (35 cm^3) was added sodium periodate (1.25 g, 5.84 mmol) dissolved in the minimum volume of water. After 2 days, the mixture was diluted with water and extracted (3 ×) with chloroform. Evaporation of the combined dried ($MgSO_4$) organic extracts and purification of the residue by silica gel chromatography (PhH–Et_2O, gradient elution) gave (3R,4R)-1-*allyl*-4-*t-butylsulphinyl*-3-*triphenylmethylaminoazetidin*-2-*one* (**11d**) (0.170 g, 54% yield) as a solid. The sample, when recrystallised from chloroform–diethyl ether, showed the following properties: m.p.

154—158 °C (decomp.); $[\alpha]_D$ +56° (0.9% in EtOH); $\nu_{max.}$(KBr) (*inter alia*) 3 400 (NH) and 1 760 cm^{-1} (β-lactam C=O); $\lambda_{max.}$(EtOH) 213 (ε 18 600) and 227sh nm (11 600); δ(60 MHz; $CDCl_3$) 1.10 (9 H, s, CMe_3), 3.31 (1 H, d, *J* 9 Hz, Ph_3CNHCH), 3.56 (1 H, dd, *J* 17 and 6.5 Hz, $NCHHCH$), 4.30 (1 H, d, *J* 4.5 Hz, 4-H), 4.40 (1 H, dm, separation 17 Hz, $NCHHCH$), 4.71 (1 H, dd, *J* 9 and 4.5 Hz, 3-H), 4.87—6.06 (3 H, m, $CH=CH_2$), and 7.2—7.6 (15 H, m, Ph_3C) [addition of D_2O caused the signal at δ 3.31 to disappear and that at δ 4.71 to collapse to a d (*J* 4.5 Hz)]; *m/z* (*inter alia*) 398 ($M^+ - C_4H_{10}O$), 243 ($C_{19}H_{15}^+$, base peak), and 165 ($C_{13}H_9^+$) (Found: C, 72.5; H, 6.7; N, 5.9. $C_{29}H_{32}N_2O_2S{\cdot}0.5H_2O$ requires C, 72.30; H, 6.90; N, 5.80%).

Thermolysis of the t-Butylthioazetidinone (**11d**).—A solution of the t-butylthioazetidinone (**11d**) (0.145 g, 0.30 mmol) in dry benzene (80 cm^3) was heated under reflux in a nitrogen atmosphere until the starting material had disappeared (t.l.c., *ca.* 3 days). Evaporation of the solvent and purification of the residue by silica gel chromatography (PhH–Et_2O, gradient elution) gave (1S,2S,5R,6R)-2-*methyl*-6-*triphenylmethylaminopenam* 1-*oxide* (**9e**) (0.116 g, 93% yield) as a colourless, chromatographically homogeneous syrup. The material possessed the following properties: $[\alpha]_D$ +166° (1.7% in EtOH); $\nu_{max.}$(film) (*inter alia*) 3 320 (NH) and 1 775 cm^{-1} (β-lactam C=O); $\lambda_{max.}$(EtOH) 216 (ε 19 900) and 225 sh nm (15 900); δ(60 MHz; $CDCl_3$) 1.26 (3 H, d, *J* 6 Hz, 2-Me), 2.67—3.63 (4 H, m, 2- and 5-H, and 3-H_2), 4.05 (1 H, d, *J* 12 Hz, Ph_3CNHCH), 4.57 (1 H, dd, *J* 12 and 4 Hz, 6-H), and 7.15—7.75 (15 H, m, Ph_3C) [addition of D_2O caused the signal at δ 4.05 to disappear and that at δ 4.57 to collapse to a d (*J* 4 Hz)]; δ(60 MHz; C_6D_6) 0.70 (3 H, d, *J* 6 Hz, 2-Me), 1.50—2.15 (1 H, m, 2-H), 2.54 (1 H, dd, *J* 11 and 8 Hz, 3α-H), 2.94—3.00 (1 H, m, 5-H), 3.44 (1 H, t, *J* 11 and 11 Hz, 3β-H), 4.44 (1 H, br s, Ph_3CNHCH and 6-H), and 6.90—7.20 and 7.45—7.70 (10 and 5 H, each m, together Ph_3C) [addition of D_2O caused the signals at δ 2.98—3.03 to collapse to a d (*J* 4 Hz) and that at δ 4.40 to appear as a d (1 H, *J* 4 Hz)]; δ(60 MHz; CD_3SOCD_3) 1.16 (3 H, d, *J* 6 Hz, 2-Me), 3.20—3.40 (3 H, m, 2-H and 3-H_2), 3.74 (1 H, d, *J* 4 Hz, 5-H), 4.05 (1 H, d, *J* 12 Hz, Ph_3CNHCH), 4.57 (1 H, dd, *J* 12 and 4 Hz, 6-H), and 7.20—7.60 (15 H, m, Ph_3C) [addition of D_2O caused the signal at δ 4.05 to disappear and that at δ 4.57 to collapse to a d (*J* 4 Hz)]; *m/z* (*inter alia*) 416 (M^+), 398 ($M^+ - H_2O$), 243 ($C_{19}H_{15}^+$, base peak), and 165 ($C_{13}H_9$).

Reaction of the Azetidinone (**5a**) *with Prop-2-ynyl Bromide.*—To a stirred, cooled (ice–NaCl) solution of the azetidinone (**5a**)[6] (0.100 g, 0.34 mmol) in dry DMF (2 cm^3) under nitrogen, was added prop-2-ynyl bromide (0.041 g, 0.34 mmol) followed by a 1M solution of potassium t-butoxide in t-butyl alcohol (0.34 cm^3, 0.34 mmol). After 5 h, the mixture was treated with aqueous ammonium chloride and extracted with ethyl acetate. The organic layer, after washing with brine (4 ×), was dried ($MgSO_4$) and concentrated. Purification of the resultant syrup by silica gel chromatography (EtOAc–light petroleum, gradient elution) gave (3R,4R)-3-*phenylacetamido*-1-(*prop*-2-*ynyl*)-4-*t-butylthioazetidin*-2-*one* (**20a**) (0.092 g, 82% yield) as a colourless, chromatographically homogeneous syrup. The material possessed the following properties: $\nu_{max.}$(film) (*inter alia*) 3 300 (NH), 2 120 (C≡C), 1 760 (β-lactam C=O), and 1 655 cm^{-1} (amide C=O); δ(60 MHz; $CDCl_3$) 1.19 (9 H, s, CMe_3), 2.18 (1 H, t, *J* 2 Hz, C≡CH), 3.49 and 4.13 (each 1 H, dd, *J* 17 and 2 Hz, together $NCH_2C{\equiv}C$), 3.52 (2 H, s, $PhCH_2CO$), 4.90 (1 H, dd, *J* 4 Hz, 4-H), 5.53 (1 H, dd, *J* 9 and 4 Hz, 3-H), 6.28 (1 H, br d, *J* 9 Hz, $CONHCH$), and 7.30 (5 H, s, Ph); *m/z* (*inter alia*) 331 (MH^+), 330 (M^+), 273 ($M^+ - C_4H_9$), and 91 ($C_7H_7^+$, base peak) (Found: M^+, 330.1425. $C_{18}H_{22}N_2O_2S$ requires *M*, 330.1402).

Reaction of the Azetidinone (**5b**) *with Prop-2-ynyl Bromide.*—To a stirred solution of the azetidinone (**5b**)[6] (0.225 g, 0.54 mmol) in dry THF (15 cm^3) was added freshly sublimed potassium t-butoxide (0.121 g, 1.08 mmol) followed, after 1 min, by prop-2-ynyl bromide (0.688 g, 5.61 mmol). After 14 h, the mixture was diluted with dichloromethane and washed (3 ×) with brine. Evaporation of the dried ($MgSO_4$) organic layer and purification of the resultant gum by silica gel chromatography (PhH–Et_2O, gradient elution) gave (3R,4R)-1-*prop*-2-*ynyl*-4-*t-butylthio*-3-*triphenylmethylaminoazetidin*-2-*one* (**20b**) (0.149 g, 61% yield) as a pale-yellow, chromatographically homogeneous syrup. The material showed the following properties: $[\alpha]_D$ −8° (1.4% in EtOH); $\nu_{max.}$(film) (*inter alia*) 3 310 (NH), 2 330 (C≡C), and 1 760 cm^{-1} (β-lactam C=O); $\lambda_{max.}$(EtOH) 223 (ε 8 000) and 263sh nm (1 000); δ(60 MHz; $CDCl_3$) 1.26 (9 H, s, CMe_3), 2.12 (1 H, t, *J* 2 and 2 Hz, C≡CH), 2.78 (1 H, d, *J* 8 Hz, Ph_3CNHCH), 3.56 and 4.26 (each 1 H, dd, *J* 18 and 2 Hz, together $NCH_2C{\equiv}C$), 4.51 (1 H, dd, *J* 8 and 4 Hz, 3-H), 4.76 (1 H, d, *J* 4 Hz, 4-H), and 7.10—7.55 (15 H, m, Ph_3C) [addition of D_2O caused the signal at δ 2.78 to disappear and that at δ 4.51 to collapse to a d (*J* 4 Hz)]; *m/z* (*inter alia*) 454 (M^+), 243 ($C_{19}H_{15}^+$, base peak), and 165 ($C_{13}H_9^+$) (Found: M^+, 454.2104. $C_{29}H_{30}N_2OS$ requires *M*, 254.2079).

Reaction of the t-Butylthioazetidinone (**20a**) *with Sodium Periodate.*—To a stirred solution of the t-butylthioazetidinone (**20a**) (0.080 g, 0.24 mmol) in methanol (10 cm^3) was added sodium periodate (0.154 g, 0.72 mmol) dissolved in the minimum volume of water. After 24 h, water was added to the mixture which was extracted with dichloromethane. Evaporation of the dried ($MgSO_4$) organic layer and purification of the residue by silica gel chromatography (EtOAc–light petroleum, gradient elution) gave (3*R*,4*R*)-3-phenylacetamido-1-(prop-2-ynyl)-4-t-butylsulphinylazetidin-2-one (**21a**) (0.052 g, 62% yield) as a chromatographically homogeneous syrup. The material possessed the following properties: $\nu_{max.}$(film) (*inter alia*) 3 300 (NH), 2 100 (C≡C), 1 780 (β-lactam C=O), and 1 675 cm^{-1} (amide C=O); δ(60 MHz; $CDCl_3$) 1.23 (9 H, s, CMe_3), 2.36 (1 H, t, *J* 3 and 3 Hz, C≡CH), 3.63 (2 H, s, $PhCH_2CO$), 3.93 and 4.74 (each 1 H, dd, *J* 18 and 3 Hz, together $NCH_2C{\equiv}C$), 4.93 (1 H, d, *J* 4 Hz, 4-H), 5.57 (1 H, dd, *J* 8 and 4 Hz, 3-H), 7.42 (5 H, s, Ph), and 8.45 (1 H, br d, *J* 8 Hz, $CONHCH$); *m/z* (*inter alia*) 272 ($M^+ - C_4H_{10}O$), 241 ($M^+ - C_4H_9OS$), 213, 197, 159, 154, and 91 ($C_7H_7^+$, base peak).

Reaction of the t-Butylthioazetidinone (**20b**) *with Sodium Periodate.*—To a stirred solution of the t-butylthioazetidinone (**20b**) (0.144 g, 0.32 mmol) in methanol (20 cm^3) was added sodium periodate (0.500 g, 2.34 mmol) dissolved in the minimum volume of water. After 18 h, water was added to the mixture which was extracted (3 ×) with dichloromethane. Evaporation of the combined, dried ($MgSO_4$) organic extracts and purification of the resultant syrup by silica gel chromatography (PhH–Et_2O, gradient elution) gave (3*R*,4*R*)-1-(prop-2-ynyl)-4-t-butylsulphinyl-3-trimethylmethylaminoazetidin-2-one (**21b**) (0.084 g, 56% yield) as a chromatographically homogeneous foam. The material showed the following properties: $[\alpha]_D$ +101° (0.1% in EtOH); $\nu_{max.}$(KBr) (*inter alia*) 3 300 (NH), 2 360 (C≡C), and 1 770 cm^{-1} (β-lactam C=O); $\lambda_{max.}$(EtOH) 215 (ε 12 500) and 258sh nm (900); δ(60 MHz; $CDCl_3$) 1.16 (9 H, s, CMe_2), 2.26 (1 H, t, *J* 2 and 2 Hz, C≡CH), 3.27 (1 H, d, *J* 9 Hz, Ph_3CNHCH), 3.60 and 4.64 (each 1 H, dd, *J* 18 and 2 Hz, together $NCH_2C{\equiv}C$), 4.37 (1 H, d, *J* 4 Hz, 4-H), 4.70 (1 H, dd, *J* 9 and 4 Hz, 3-H), and 7.15—7.50 (15 H, m, Ph_3C) [addition of D_2O caused the signal at δ 3.27 to disappear and that at δ 4.70 to collapse to a d (*J* 4 Hz)]; *m/z* (*inter alia*) 396 ($M^+ - C_4H_{10}O$), 243 ($C_{19}H_{15}^+$, base peak), and 165 ($C_{13}H_9^+$).

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