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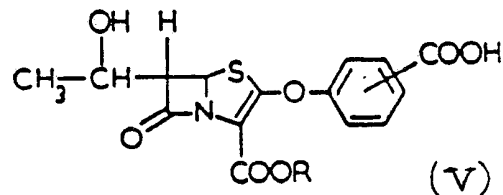
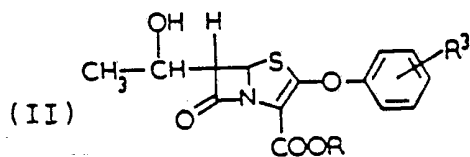
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GB A 2151630 GB A 2122619 GB A 2102798
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(58) Field of search
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(54) 7-oxo-4-thia-1-azabicyclo(3,2,0)hept-2-ene derivatives

(57) Compounds of formula II and V



in which R is hydrogen or a carboxy protecting group and R³ is an activated carboxy group the R³ or COOH group being present at the 3- or 4-position on the phenyl ring, are intermediates for the production of compounds having *antibacterial* and/or *β-lactamase inhibiting* activity.

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7-OXO-4-THIA-1-AZABICYCLO[3,2,0]HEPT-2-ENE DERIVATIVES

This invention relates to penem derivatives, to a process for their preparation, to pharmaceutical preparations comprising them, and to intermediates for use in the preparation of substances having antibacterial activity and/or β -lactamase inhibitory and/or inactivating activity.

7-Oxo-4-thia-1-azabicyclo[3,2,0]hept-2-ene has the following formula A, and derivatives thereof having an aliphatic side chain at position 6 are numbered as shown in formula B:



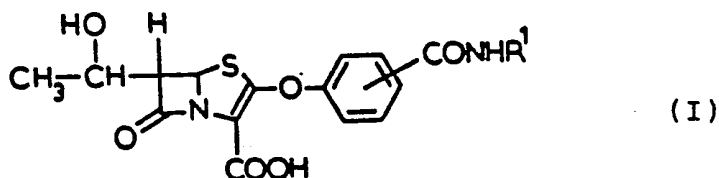
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By an alternative system of nomenclature, the above nucleus A may be described as a "penem", in which case the ring numbering is as shown in formula C, with derivatives having an aliphatic side chain at position 6 being numbered as shown in formula D:



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The present invention provides a compound of formula I



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in which R¹ represents a hydrogen atom or an alkyl group having from 1 to 4 carbon atoms, for example, a methyl, ethyl, n-propyl, iso-propyl, n-butyl, iso-butyl, sec-butyl or t-butyl group, the -CONHR¹ group being present at the 3- or 4-position on the phenyl ring.

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R¹ preferably represents a hydrogen atom.

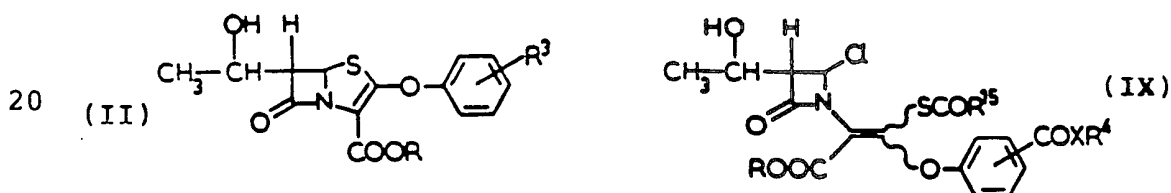
The present invention also provides esters of a compound of formula I at the 2-carboxyl group, for example,

esters that can be converted by hydrolysis, by photolysis, by reduction or, especially, by esterase enzyme action, to give the free acid of formula I. The present invention further provides esters at the 8-hydroxy group, especially lower alkanoyloxy groups at the 8-position.

The present invention further provides salts of a compound of formula I, especially physiologically tolerable salts thereof.

The stereochemistry at positions 5, 6 and 8 of a compound of formula I can be R or S, independently (R and S being as defined by the Cahn-Ingold-Prelog system of nomenclature). The preferred stereochemistry at position 5 is R, at position 6 is S, and at position 8 is R.

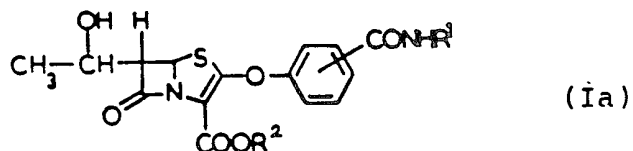
The present invention also provides a process for the production of a compound of the general formula I, or an ester or salt thereof, which comprises reacting a compound of formula II or of formula IX



in which R represents a hydrogen atom or a carboxy protecting group, R³ represents an activated carboxylic acid group, R⁴ represents an alkyl group having from 1 to 4 carbon atoms, or a phenyl group which may be unsubstituted or substituted by one or more substituents, which may be the same or different, selected from chlorine and fluorine atoms, cyano and nitro groups, and alkoxy groups, R¹⁵ represents a phenyl group or an alkyl group having from 1 to 4 carbon atoms, and X represents an oxygen or sulphur atom, with an amine of formula III



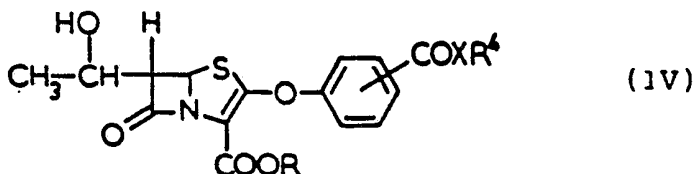
in which R¹ is as defined above to give a compound of formula I or an ester thereof of formula Ia



in which R^2 represents a carboxy protecting group and, if desired, carrying out any one or more of the following steps in any desired order:

- a) hydrolysing an ester of formula Ia to give the
5 corresponding free acid of formula I,
- b) reacting a free acid of formula I or a salt thereof with an agent capable of forming an ester, for example, with an alcohol, a phenol or a reactive derivative thereof to give an ester of formula Ia,
- 10 c) carrying out an acid or base catalysed ester interchange on an ester of formula Ia to give a different ester of formula Ia,
- d) reacting a free acid of formula I with a base to give a salt at the carboxylic acid group at position 2,
- 15 e) reacting a free acid of formula I or an ester of formula Ia having a basic group with an acid to give an acid addition salt thereof,
- f) hydrolysing the ester group from an ester of formula Ia in the presence of a salt-forming agent, for example, an
20 alkali metal salt, to give a salt of a compound of formula I,
- g) reacting a salt of a compound of formula I with an acid to give a free acid of formula I, and
- h) reacting a compound of formula I or a salt thereof, or
25 an ester of formula Ia, with an organic acid to give a compound of formula I or an ester of formula Ia having an esterified hydroxy group at the 8-position.

In a particularly preferred case, the activated carboxylic acid group R^3 in compound II is a group of
30 formula $-COXR^4$ in which X and R^4 are as defined above, giving a compound of formula IV



In a compound of formula IV or formula IX, R^4 preferably represents a phenyl group substituted by one or more chlorine and/or fluorine atoms. When X represents a

sulphur or oxygen atom, R^4 especially represents a pentafluorophenyl group, and when X represents a sulphur atom, 4-chlorophenyl and 2,4,5-trichlorophenyl groups are also particularly preferred as R^4 .

5 Reaction of the compound of formula IV with the amino compound of formula III is preferably carried out at a temperature within the range of from -40 to $+40^\circ\text{C}$, preferably from 0 to 20°C . The choice of solvent is wide, provided that the solvent does not itself react with any of
10 the reagents or intermediates. For this reason it is often preferable to use a solvent or solvent mixture that is substantially free of water. Examples of suitable solvents are dimethylformamide and acetonitrile.

The reaction between an amine of formula III and a
15 compound of formula IV may be carried out in the presence of a metal salt, especially a salt of a metal selected from Groups IB, IIB and VIII of the Periodic Classification of the Elements (cf E. Cartmell & G.W.A. Fowles, Valency and Molecular Structure, Butterworths, 1966), for example,
20 a salt of copper, rhodium, mercury, zinc, cadmium or, especially, silver. The salt is, for example, a salt with an organic or inorganic acid, for example, with perchloric, tetrafluoroboric, acetic, trifluoromethanesulphonic, or trifluoroacetic acid, or with imidazole. Examples of
25 preferred salts are silver acetate, silver trifluoroacetate, silver trifluoromethanesulphonate, and silver imidazolide.

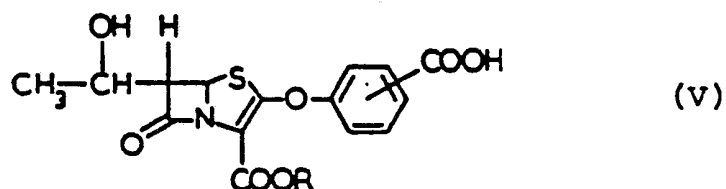
The degree of advantage resulting from the presence of a metal salt during the reaction between an amine of
30 formula III and a compound of formula IV depends on the reactivity of the $-\text{COXR}^4$ group in the compound of formula IV, and may be determined empirically, for example, there is not generally a substantial advantage when X represents an oxygen atom. In the case of a compound of formula IV
35 having a pentafluorophenythio-(carbonyl) ester group, a metal salt may be used if desired, but the resulting advantage is not large, whereas for other compounds of formula IV in which X represents a sulphur atom, the

presence of a metal salt during the reaction with an amine of formula III results in a greatly improved yield.

A compound of formula IX may be reacted with an amine of formula III under conditions analogous to those
5 described above for the reaction between compounds IV and III to give a compound of formula I or an ester thereof directly. In this case, it is generally necessary to use at least two molar equivalents of the amine. In formula IX, R⁴ especially represents a pentafluorophenyl group.

10 An advantage of the preferred compounds of formula IV over other compounds of formula II is that the activated carboxylic acid group -COXR⁴ can be introduced at an early stage in the reaction sequence leading to the production of compound IV and is carried through the reaction sequence as
15 shown in Reaction Scheme I below. The production of the other activated acids of formula II involves an extra activating step as shown in Reaction Scheme II below, as in this case, these compounds must be produced via a free carboxylic acid of formula V

20



25 in which R is as defined above.

Overall, a free carboxylic acid group (in compound V) is converted into an amide group (in compound I). The intermediate activated compound of formula II may be produced in a separate reaction step and isolated, if
30 desired, or it may be converted in situ into a compound of formula I.

The conversion of a carboxylic acid group into an amide group is well known in chemistry, and there is available to those versed in the art a wide range of
35 reagents and methods. In general, the reagents function by converting a carboxylic acid group into an activated derivative thereof, which derivative is then reacted with an amine. Examples of the activation of a carboxylic acid,

group are by conversions as follows:

(i) to an activated ester, for example, to a phenyl ester using, for example, a bisphenyl carbonate;

(ii) to a phosphorous or phosphoric ester, or a phosphoric acid anhydride, using for example, a phosphinyl halide or a phosphoryl halide;

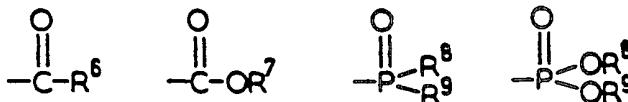
(iii) to a carboxylic acid anhydride, especially a mixed anhydride, using for example, an acid chloride or bromide, for example, pivaloyl bromide, a carbodiimide, for example, 10 dicyclohexylcarbodiimide or 1-(3-dimethylaminopropyl)-3-ethylcarbodiimide, or a chloroformate;

(iv) to an imidazolidine using, for example, N,N'-carbonyl-diimidazole;

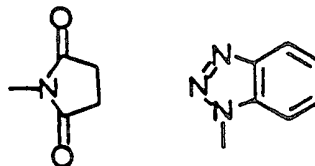
(v) to an acid chloride using, for example, thionyl 15 chloride; or

(vi) to an O-acylurea using, for example, a carbodiimide, for example, as described above, and if desired, converting the O-acylurea into an active ester, for example, an ester with 1-hydroxybenzotriazole or with N-hydroxysuccinimide.

20 Examples of activated acid groups R^3 that can be converted into groups of formula $-CONHR^1$ under reaction conditions that do not affect other parts of the compound of formula II (other than groups $-COXR^4$ as defined above) are, for example, groups of the formula $-COOR^5$ in which R^5 25 represents one of the following groups



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in which R^6 represents an alkyl group having up to 4 carbon atoms, especially a t-butyl group; R^7 represents an alkyl group having up to 4 carbon atoms, especially an iso-butyl

group; R⁸ and R⁹, which may be the same or different, each represents an alkyl group having up to 4 carbon atoms or a phenyl group.

The above methods are examples of the techniques
5 available in the art, and do not constitute an exhaustive list. For further information see, for example, M. Bodanszky, Y.S. Klausner and M.A. Ondetti, "Peptide Synthesis", J. Wiley and Sons, New York, 1976, and N.F. Norton, Organic Reactions, Vol. 12, 157 (1962).

10 Some of the methods for converting a carboxylic acid group into an amide are extremely mild and therefore well suited to the conversion of a penem containing a carboxylic acid group into a penem containing an amide group without damage to any other part of the molecule. Thus, for
15 example, a solution of a carboxylic acid of formula V in an inert solvent, for example, dichloromethane, acetonitrile or tetrahydrofuran, may be treated with a carbodiimide, for example, dicyclohexylcarbodiimide and 1-hydroxybenzotriazole at a temperature within the range of
20 from -40 to +40°C, preferably from 0 to 20°C, to form the benzotriazol-1-yl ester.

An activated penem of formula II formed from a free acid of formula V may be reacted in situ with the amino compound of formula III to form a compound of formula I or
25 an ester thereof, or the activated penem of formula II may first be isolated and purified before reaction with the amino compound. Reaction of the activated penem in either case with the amino compound III is preferably carried out at a temperature within the range of from -40 to +40°C,
30 preferably from 0 to 20°C. The choice of solvent is wide, provided that the solvent does not itself react with any of the reagents or intermediates. For this reason it is often preferable to use a solvent or solvent mixture that is substantially free of water.

35 The compound of formula I produced from compound II or from compound IV may be converted, if desired, into an ester of formula Ia, and an ester of formula Ia produced from compound II or IV may be converted into the

corresponding free acid of formula I, as described above. Other acid/ester/salt interconversions can also be carried out as described above.

As indicated above, a compound of formula I may be in the form of an ester at the carboxy group at position 2, that is to say, a compound of formula Ia. Such an ester is particularly one that can be converted into the free acid by hydrolysis, photolysis, reduction or esterase enzyme action. Examples of such esters are those formed with unsubstituted or substituted aliphatic alcohols or phenols having up to 20 carbon atoms in total. In an esterified carboxy group of formula $-\text{COOR}^2$, the group R^2 may be, for example, a straight or branched chain substituted or unsubstituted alkyl, alkenyl or alkynyl group having up to 18 carbon atoms, preferably up to 8 carbon atoms, and especially up to 4 carbon atoms, for example, a methyl, ethyl, n-propyl, iso-propyl, n-butyl, sec-butyl, iso-butyl, tert-butyl, n-pentyl, n-hexyl, allyl or vinyl group. An aliphatic group R^2 , especially a methyl or ethyl group, may be substituted, for example, by an acyloxy group (further details of such groups are given below) or by an aminoalkanoxy group, or an ethyl group R^2 may be substituted by an optionally substituted amino group at the 2-position, or a methyl group R^2 may be substituted by one or more unsubstituted or substituted phenyl groups. A phenyl group, either as a phenol or as a substituent of an aliphatic group, may be substituted, for example, by one or more substituents, selected especially from nitro groups and halogen atoms. Examples of phenyl substituted-aliphatic groups are benzyl, p-nitrobenzyl, benzhydryl and trityl groups.

As indicated above, an ester group is especially one that can be removed by hydrolysis, photolysis, reduction or enzyme action, or two or more of these methods may be used, for example, reduction followed by hydrolysis. A group R^2 that can be removed readily without substantial degradation of the rest of the molecule is particularly useful as a carboxy protecting group. Examples of esters that are readily split by reduction are phenyl substituted-methyl esters, which may be unsubstituted or substituted, for

example, benzyl, p-nitrobenzyl, benzhydryl and trityl esters.

Reduction of an ester, for example, a phenyl substituted-methyl ester, for example, a p-nitrobenzyl ester, may be carried out using hydrogen and a metal catalyst, for example, a noble metal catalyst, for example, platinum, palladium or rhodium, which catalyst may be supported, for example, on charcoal or kieselguhr.

Alternatively, a p-nitrobenzyl ester may be converted into the corresponding free acid by a two-step method, with an initial reduction of the nitro group followed by hydrolysis. The nitro group may be reduced by noble metal catalysed hydrogenation, for example, using platinum, or palladium on carbon, or by a metal reducing agent, for example, zinc in acetic acid. Other metal reducing agents are, for example, aluminium amalgam, and iron and ammonium chloride, see for example, British Patent Specification No. 1,582,960. Reduction of the nitro group is followed by hydrolysis which may occur in situ during reduction of the nitro group or which may be carried out subsequently by treatment with an acid or a base.

An o-nitrobenzyl ester may be converted into the corresponding free acid by photolysis.

Certain ester groups may be split off by base hydrolysis, for example, acetylmethyl and acetoxymethyl ester groups.

There may be used an esterifying group that is removable under physiological conditions, that is to say, the esterifying group is split off in vivo to give the free acid or the carboxylate, for example, an acyloxymethyl or acyloxyethyl ester, for example, an acetoxymethyl, 1'-(acetoxyl)ethyl or pivaloyloxymethyl ester, a 5-methyldioxalen-2-on-4-yl-methyl ester, an aminoalkanoyloxymethyl ester, for example, a glycyloxymethyl, L-valyloxymethyl or L-leucyloxymethyl ester, or a phthalidyl ester, or a 1'-(alkoxycarbonyloxy)ethyl ester, for example, a 1'-(methoxycarbonyloxy)ethyl or 1'-(ethoxycarbonyloxy)ethyl ester, or an optionally substituted 2-aminoethyl ester, for example,

a 2-diethylaminoethyl or 2-(1-morpholino)-ethyl ester (acyl and alkanoyl groups having 1 to 12 carbon atoms).

Preferred esters are the p-nitrobenzyl, phthalidyl, pivaloyloxymethyl, ethoxycarbonyloxymethyl, 5-methyl-
5 dioxalen-2-on-4-yl-methyl, acetylmethyl, acetoxymethyl, 1'-(acetoxymethyl)ethyl, 1'-(acetyl)ethyl and 1'-(ethoxycarbonyloxy)ethyl esters.

An ester of a compound of formula I, or of any other free acid described herein, may be prepared by reaction of
10 the appropriate free acid with an alcohol, a phenol or a reactive derivative thereof. The reaction is preferably carried out under mild conditions in order to prevent rupture of the ring system, for example, under neutral or mild acidic or basic conditions, and at temperatures within
15 the range of from -70 to +35°C.

An ester derived from an alcohol may also be produced by reaction of a reactive derivative of the alcohol, for example, a halide, for example, a chloride, bromide or iodide, or hydrocarbonsulphonyl derivative, for example, a
20 mesyl or tosyl ester, with a salt of an acid of formula I or of another free acid described herein, for example, an alkali or alkaline earth metal salt, for example, a lithium, sodium, potassium, calcium or barium salt, or an amine salt, for example, a triethylammonium salt. The
25 reaction is preferably carried out in a substituted sulphoxide or amide solvent, for example, in dimethyl sulphoxide, dimethylformamide, or hexamethylphosphoramide or, alternatively, an ester may be prepared by reaction of the acid with the alcohol or phenol in the presence of a
30 condensing agent, for example, dicyclohexylcarbodiimide.

The present invention also provides salts of those compounds of formula I that have salt-forming groups, especially the salts of a free acid of formula I and acid addition salts of compounds of formula I having a basic
35 group. The salts are especially physiologically tolerable salts, for example, alkali metal and alkaline earth metal salts, for example, sodium, potassium, lithium, calcium, and magnesium salts, ammonium salts, and salts with organic.

amines; also physiologically tolerable acid addition salts.

These may be formed with a suitable inorganic or organic acid, for example, hydrochloric acid, sulphuric acid, or an organic carboxylic or organic sulphonic acid, for example, p-toluene-sulphonic acid.

5 A salt of a free acid of formula I may be produced by reacting the free acid with the appropriate base in a solvent, preferably under those conditions under which the salt precipitates. A preferred base is potassium 2-ethyl
10 hexanoate.

A salt may be produced directly from an ester by splitting off the ester group under suitable reaction conditions, for example, catalytic reduction of an ester, for example, a p-nitrobenzyl ester, in an aqueous/organic
15 solvent, for example, comprising water and ethyl acetate, dioxane or tetrahydrofuran, in the presence of a metal salt, especially a metal bicarbonate, for example, in an equivalent amount or in a slight excess, yields the salt directly.

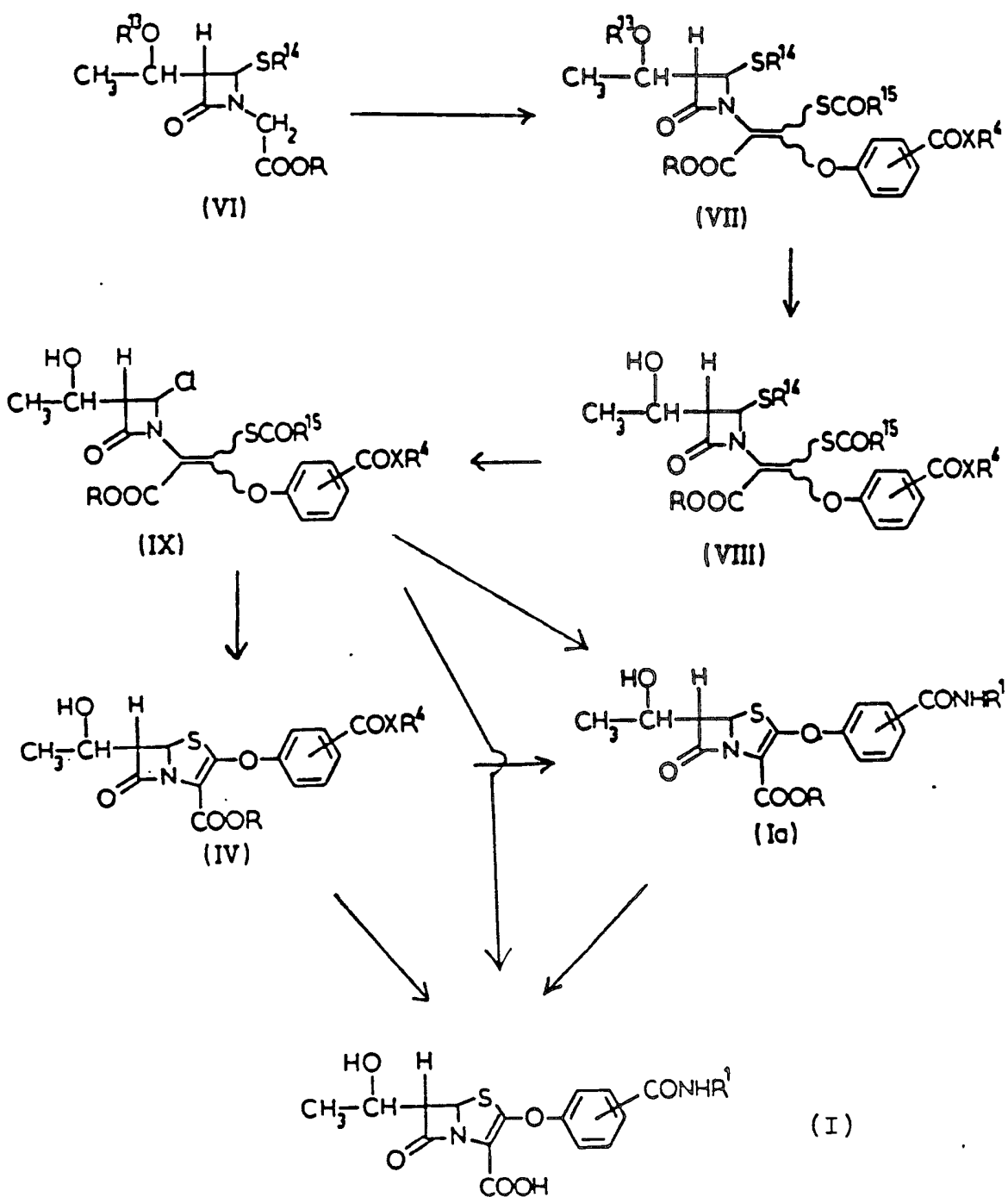
20 As described above, a compound of formula I may also form an ester at the 8-hydroxy group. Such an ester group is especially one that can be removed in vivo to give the free hydroxy group, that is to say, an ester group that can be removed under physiological conditions. Examples
25 of suitable esterifying groups are those of the formula $R_x\text{-CO}$, in which R_x represents a hydrogen atom or a straight or branched chain alkyl group having from 1 to 4 carbon atoms, especially a methyl, ethyl or t-butyl group, or represents a phenyl group or a phenoxyalkyl group in which
30 the alkyl moiety is straight-chained or branched and has up to 4 carbon atoms, and is especially a methyl group.

An ester group at the 8-position may be the only ester group present, or it may be present in addition to an ester group at the 2-carboxyl group. An ester group may be intro-
35 duced at the 8-hydroxy group using an organic acid or a derivative thereof by those methods described above in connection with esterification of the 2-carboxy group with an alcohol. A particularly convenient method is

to react a compound of formula I or an ester thereof of formula Ia with an activated acid derivative, for example, an acid anhydride. In this case, it is advantageous to carry out the reaction in the presence of a catalyst, for example, 4-dimethylaminopyridine.

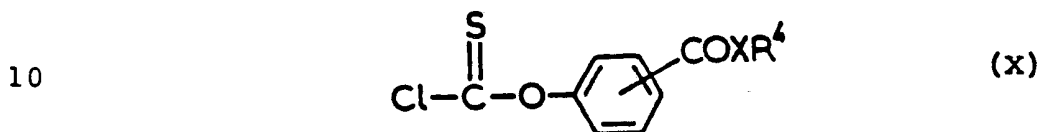
A compound of formula IV may be produced as shown in the following Reaction Scheme I:

Reaction scheme I

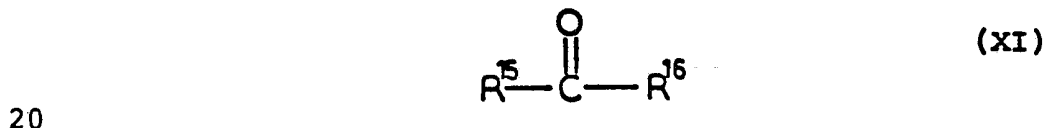


In Reaction Scheme I, X, R, R¹ and R⁴ are as defined above, and preferred meanings for R⁴ are as given above; R¹³ represents a hydrogen atom or a hydroxy protecting group, and R¹⁴ and R¹⁵ each independently represents a phenyl group or an alkyl group having up to 4 carbon atoms.

Compound VI is reacted, in the presence of a base, with a compound of formula X



in which X and R⁴ are as defined above, followed by reaction with an activated carboxylic acid derivative which comprises the group R¹⁵ as defined above, for example, with an acyl halide of formula XI



in which R¹⁵ is as defined above and R¹⁶ represents a chlorine or bromine atom.

While many phenyl chlorothionoformates are known, certain compounds of formula X have not been described before; they may be prepared by methods analogous to those described for the preparation of known compounds, see for example, Rivier & Schalch, *Helv. Chem. Acta.*, Vol 6, 1923, p605, and Reich & Martin, *Chem. Berichte*, Vol 98, 1965, p2063.

The reaction between compound X and compound VI is carried out in the presence of a base, preferably having a pK_a > 20, preferably a metallated amine, and examples of preferred bases are lithium diisopropylamide, lithium hexamethyldisilazide, lithium 2,2,6,6-tetramethylpiperidide, lithium cyclohexyl isopropylamide, and sodamide.

The reaction is generally carried out in an aprotic

solvent, for example, an oxygenated hydrocarbon, preferably an ether, for example, diethyl ether, tetrahydrofuran, dioxane, glyme or diglyme. The reaction temperature is, for example, from -120 to +30°C, preferably from -78 to
5 -20°C.

The amount of base used is, for example, from 1 to 3 moles, calculated per mole of compound VI, preferably from 1.5 to 2.5 moles of base. The compound of formula X is preferably used in an amount of from 1 to 1.5 moles per
10 mole of compound VI, preferably from 1 to 1.1 moles of compound X per mole of compound VI.

The reaction may be carried out as follows: The base may be added to a stirred solution of compounds VI and X. Alternatively, to a stirred solution of compound VI under
15 an inert atmosphere is added the base and subsequently a solution of compound X in the same or a different solvent.

The activated acid derivative, preferably of formula XI, is preferably added to the mixture resulting from the reaction of compounds VI and X, especially in an amount of
20 from 1 to 2 moles calculated on compound VI. The reaction is preferably carried out at a temperature of from -40 to +40 °C, adding the compound of formula XI to the reaction mixture at the temperature at which the reaction between compounds VI and X took place, and then warming, or
25 working-up at this temperature.

The -SCOR¹⁵ group in the resulting compound of formula VII may be E or Z to the -COOR group. (The terms E and Z are as defined on page 142 of Allinger et al, "Organic Chemistry" 1971, Worth, New York.) The isomers may be
30 separated for the subsequent reaction, but this is not generally necessary, and the isomeric mixture is generally used as both isomers give a compound of formula I.

It is preferable that R¹³ in compound VI represents a hydroxy protecting group to prevent the hydroxy group from
35 reacting with the compound of formula X. The protective group is then removed from compound VII in order to obtain the desired 5R stereochemistry in the final product. The protective group may be removed in any conventional manner

to give compound VIII. Preferred hydroxy-protecting groups R^{13} are those that are compatible with the synthesis of the compound of formula VII and which may be removed under conditions in which the resulting compound VIII is stable.

5 Compound VIII has been found to be substantially stable in the presence of a proton source, for example, hydrogen chloride, aqueous hydrochloric acid or aqueous hydrofluoric acid. Accordingly, one type of preferred hydroxy protecting group R^{13} is that which can be removed under

10 acidic conditions. Such groups are well known in the art and are, for example, tetrahydropyranyl and tetrahydrofuranly groups; acetal and ketal groups, for example, of formula



in which R^{17} and R^{18} , which may be the same or different, each represents a hydrogen atom or a lower alkyl group, preferably a methyl group, or R^{17} and R^{18} together with the

20 carbon atoms to which they are attached, represent a cycloalkyl ring having from 4 to 7 carbon atoms, and R^{19} represents a lower alkyl group, preferably a methyl or ethyl group, or R^{17} and R^{19} , together with the carbon atom

25 and the oxygen atom to which they are attached, respectively, represent a tetrahydropyranyl ring; also silyl ethers, for example, having three substituents on the silicon atom, and preferably up to 24 carbon atoms in total, the three substituents being the same or different,

30 and selected from alkyl, alkenyl and cycloalkyl groups, and phenyl and phenalkyl groups which may be unsubstituted or substituted as defined above, for example, $-\text{SiR}^8\text{R}^9\text{R}^{10}$ groups, in which R^8 , R^9 and R^{10} are as defined above, that is to say, they may be the same or different, and each

35 represents a lower alkyl group or a phenyl group, for example, giving trimethylsilyl, triethylsilyl, diphenyl-t-butylsilyl, dimethyl-t-butylsilyl, and methyldiphenylsilyl groups; and stannyl groups, for

example, having up to 24 carbon atoms and three substituents, which may be the same or different, selected from alkyl, alkenyl, cycloalkyl, alkoxy and phenoxy groups, and phenyl and phenalkyl groups which may be unsubstituted
5 or substituted, for example, groups of the formula SnR^{20}
 $\text{R}^{21} \text{R}^{22}$, in which R^{20} , R^{21} and R^{22} , which may be the same or different, each represents a lower alkyl group, for example, a tri-n-butylstannyl group. (The term "lower" is used in the present specification to denote groups having
10 up to 4 carbon atoms.)

Preferred R^{13} groups are tetrahydropyranyl, 2-methoxyprop-2-yl, trimethylsilyl and, especially, triethylsilyl and t-butyldimethylsilyl groups.

Such groups may be removed by acid hydrolysis, for
15 example, using 0.1 to 2M, preferably 0.5M hydrochloric acid, for example, 6M HCl in, for example, tetrahydrofuran, cf. Belgian Patent Specification No. 881 012; n- Bu_4NF in an acidic medium, for example, in acetic acid, cf. Belgian Patent Specification No. 882 764; or aqueous hydrogen
20 fluoride, for example, in the presence of acetonitrile, cf. J. Chem. Soc. Perkin 1, 1981, 2055.

The resulting compound VIII having a free hydroxy group is then chlorinated using an agent capable of splitting a carbon-sulphur bond and of introducing a
25 chlorine atom. Such agents are well known in the art and include, for example, molecular chlorine, sulphuryl chloride, t-butyl hypochlorite and cyanogen chloride.

The reaction is generally carried out at a temperature within the range of from -60 to +20°C. The reaction is
30 generally carried out in a solvent or diluent that is non-protic, and is inert under the reaction conditions, for example, an ether, a hydrocarbon or a halogenated hydrocarbon, for example, dioxane, benzene, chloroform or methylene chloride. A mixture of two or more solvents may
35 be used. Examples of halogenating systems are: chlorine in chloroform, chlorine in benzene and t-butyl hypochlorite in benzene. In the latter two cases, the temperature is preferably from 5 to 20°C, and normally from 5 to 10°C.

Generally, 1 to 2 moles of chlorine are used per mole of compound VIII, cf. S. Kukolja, J. Amer. Chem. Soc. (1971), 93, 6267 and P.C. Cherry, C.E. Newall and N.S. Watson, J.C.S. Chem. Comm. 1979 p. 663.

5 The resulting compound of formula IX may be converted into a compound of formula IV in the presence of a base. The base used for this reaction should not affect the -COXR⁴ group. The base may be inorganic or organic, and may be chosen, for example, from ammonia, or an alkali
10 metal, especially a sodium or potassium, carbonate, bicarbonate, or hydroxide; a primary amine, for example, methylamine, ethylamine, aniline or benzylamine; an alkali metal alkoxide, for example, sodium methoxide; or a
15 heterocyclic base, for example, having a pK_a within the range of from 5 to 9, for example, imidazole, pyridine or a substituted pyridine, for example, an alkyl, amino or alkylamino-substituted pyridine, for example, 4-methylpyridine or 4-dimethylaminopyridine. Imidazole is particularly preferred.

20 The reaction is generally carried out in a solvent or diluent, the choice of which is wide, provided that it is inert under the reaction conditions. Examples of solvents and diluents are oxygenated hydrocarbons, for example, alcohols, for example, having up to 4 carbon atoms, for
25 example, ethanol; ethers, for example, having up to 4 carbon atoms, for example, diethyl ether, also tetrahydrofuran and dioxane; ketones, for example, having up to 4 carbon atoms, for example, acetone and methyl ethyl ketone; esters, for example, methyl acetate and ethyl
30 acetate; and amides, for example, dimethylformamide and dimethylacetamide; also chlorinated hydrocarbons, for example, chloroform, methylene chloride and carbon tetrachloride; aromatic hydrocarbons, for example, benzene and toluene; and other solvents for example, acetonitrile
35 and nitromethane. A mixture of two or more solvents may be used, and solvents are preferably used in admixture with water, preferably a water-miscible solvent is used in admixture with 5 to 20% (v/v) water.

The reaction is generally carried out at a temperature within the range of from 0 to 40°C, preferably from 0 to 20°C.

A compound of formula IV may be converted into a
5 compound of formula I or Ia as described above.

As mentioned above, if the base that is reacted with compound IX is an amine of formula III



10 in which R^1 is as defined above, then compound IX can be converted directly into compound I or Ia. In this case it is generally necessary to use two or more moles of the amine of formula III per mole of compound IX. For direct conversion to compound I or Ia, R^4 in compound IX
15 preferably represents a 4-chlorophenyl or 2,4,5-trichlorophenyl group when X represents a sulphur atom or, especially, represents a pentafluorophenyl group when X represents an oxygen or sulphur atom. Particularly preferred are compounds of formula IX wherein X represents
20 an oxygen atom and R^4 represents a pentafluorophenyl group.

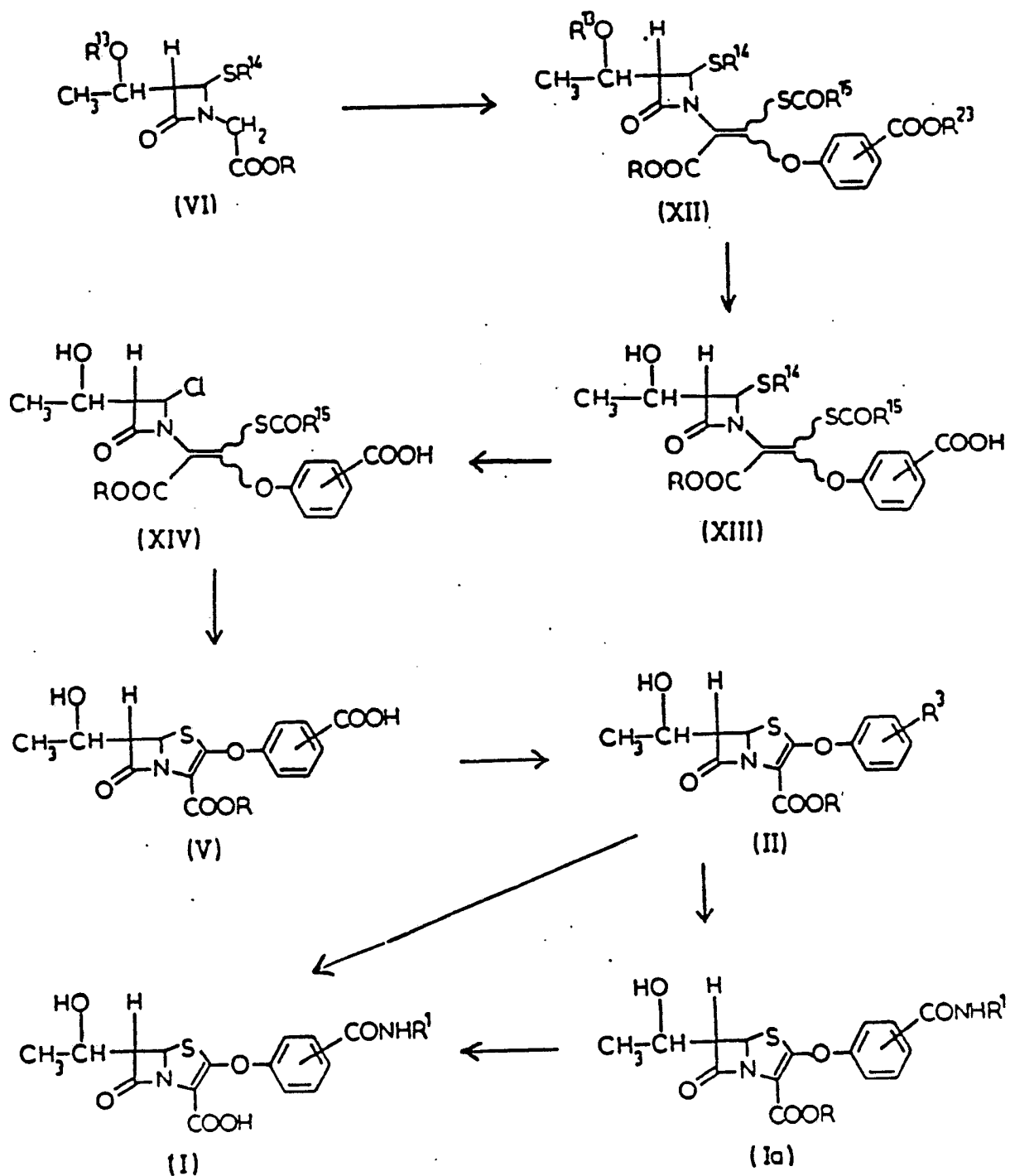
Compound IX may be converted to compound I or Ia via the in situ formation of compound IV, or the XR^4 group in compound IX may be displaced by the amine before
25 cyclisation. Both pathways are part of the present invention.

A compound of formula I or an ester of formula Ia may be prepared as shown in the following Reaction Scheme II:

30

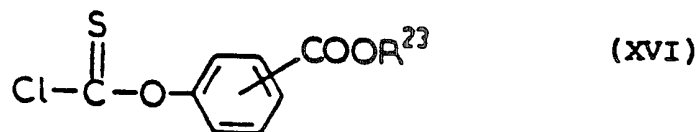
35

Reaction Scheme II



in which R, R¹, R³, R¹³, R¹⁴ and R¹⁵ are as defined above, and R²³ represents a carboxy protecting group.

A compound of formula VI may be converted into a compound of formula XII by reaction, in the presence of a
5 base, with a compound of formula XVI



10

in which R²³ is as defined above, followed by reaction with an activated carboxylic acid derivative which comprises the group R¹⁵, for example, with an acyl halide of formula XI as defined above to give a compound of formula XII. These
15 reactions are carried out as described in Reaction Scheme I for the reaction of the corresponding compounds VI and X followed by reaction with compound XI to give the corresponding compound of formula VII.

In compound XII, R²³ represents a carboxy protecting
20 group, and it is preferable to use a carboxy protecting group that can be removed under the same conditions as the hydroxy protecting group R¹³, that is to say, preferably under acidic conditions. Examples of such hydroxy protecting groups are given above with reference to
25 compound VII. Preferably R²³ is a silyl group, for example, as described above for R¹³, and is especially a diphenyl-t-butylsilyl group. Compound XII can thus be converted into compound XIII in one step by the simultaneous removal of the two protecting groups R¹³ and
30 R²³.

The chlorination of compound XIII may be carried out as described above in Reaction Scheme I for the chlorination of compound VIII, and the resulting compound of formula XIV may be converted into a compound of formula
35 V in the presence of a base, as described above in Reaction Scheme I for the ring closure of compound IX to give compound II.

A compound of formula V may be converted into a

compound of formula II and then into a compound of formula I or Ia as described above.

5 In both of the above Reaction Schemes, in some cases it may be preferable to retain the carboxy protecting group R until after formation of the desired compound of formula Ia. The carboxy protecting group R is as defined above, and preferably represents a p-nitrobenzyl group. In other cases, for example, when a compound of formula IV is used,
10 it may be desirable that R represents a hydrogen atom. A carboxy protecting group R may be removed from the 2-carboxy group at any appropriate point in the reaction sequence.

If desired, an ester group -COOR can be
15 transesterified by ester interchange at any stage of the reaction scheme, and especially after formation of an ester of formula Ia, to give another ester of formula Ia, for example, an ester that can be converted into the free acid of formula I or a carboxylate under physiological
20 conditions. Alternatively, a resulting ester of formula Ia can be converted into the free acid or a salt; a free acid can be esterified or converted into a salt; or a salt can be converted into the free acid, an ester or a different salt. In each case, the salt is especially a
25 physiologically tolerable salt, and an ester is especially one that can be removed under physiological conditions. Examples of such procedures are given above.

At each stage of either of the reaction sequences, the desired compound may be isolated from the reaction mixture
30 and, if desired, purified by the appropriate techniques used for the purification of organic compounds, for example, chromatography and crystallisation.

As indicated above, various intermediates may be produced in the form of mixtures of isomers of various
35 kinds. Such mixtures may be separated or resolved at any stage, or an isomeric mixture may be used per se for subsequent reactions.

Chlorination of the 4R-isomer of a compound of formula VIII or XIII gives predominantly the 4S-isomer of

compound IX or XIV, respectively. The proportion of
4S:4R-isomers of compound IX or XIV depends on the
chlorination agent and reaction conditions used, but in
general varies from 3:1 to as high as 18:1. The 4R- and
5 4S-isomers can be separated readily, for example, by
chromatography. A compound of formula IX or XIV also has
E/Z isomerism at the double bond, and in some cases, the
chlorinated compound of formula IX or XIV is obtained in
the form of a substantially pure E or Z isomer. In other
10 cases, an E/Z isomeric mixture is obtained, and the 4R- and
4S-isomers may be separated further into the individual E
and Z isomers if desired. It is not generally necessary to
separate the E and Z isomers, but it is preferable to
separate the 4R- and 4S- isomers before conversion into a
15 compound of formula IV or V, respectively, as the 4S-isomer
is converted by reaction with a base into the more
desirable 5R-isomer of formula IV or V and, subsequently,
of formula I or Ia.

As mentioned above, a compound of formula I may have
20 the R or S stereochemistry independently at positions 5, 6
and 8. Any mixture of two or more isomeric forms may be
resolved, if desired, or a compound of formula I can be
used in the form of an isomeric mixture. The preferred
stereochemistry at position 5 in compound I is generally R,
25 corresponding to that in naturally occurring penicillins
and cephalosporins, at position 6 is S and at position 8 is
R.

The compounds of formula I, esters thereof at the
2-carboxylic acid group, and salts thereof are
30 β -lactamase inhibitors, and the compounds are generally
stable to the action of β -lactamases produced by gram
positive organisms, for example, Staphylococcus aureus and
gram negative organisms, for example, Enterobacter cloacae.

They also possess antibacterial properties themselves and
35 may be used in humans and other animals, for example, to
treat bacterial infections caused by gram-positive and
gram-negative bacteria, for example, Staphylococcus aureus,
Streptococcus pyogenes, Bacillus subtilis, Escherichia

coli, Pseudomonas aeruginosa, and Proteus morganii, some strains of which are penicillin resistant.

It has been found that compounds of formula I (and esters thereof at the 2-carboxylic acid group) having an esterified hydroxy group at the 8-position also have antibacterial and/or β -lactamase inhibiting properties, in particular since the 8-ester group can be cleaved in vivo by esterases. In addition, esterification at the 8-hydroxy group can enhance the degree of absorption on oral administration.

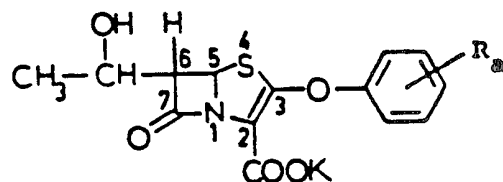
Compounds of the present formula I are included broadly within the general formula I of our co-pending UK Patent application 2 102 798, but the compounds of the present formula I were not specifically disclosed nor manufactured therein. Moreover, compounds of the present formula I have certain advantages with respect to antimicrobial activity compared with the corresponding unsubstituted phenoxy compound of our earlier application, for example, 5R-3-(4-carbamoylphenoxy)-6S-(1R-hydroxy-ethyl)-7-oxo-4-thia-1-azabicyclo[3,2,0]hept-2-ene-2-carboxylate has greater antibacterial activity against a variety of microorganisms, particularly β -lactamase producing organisms than does the corresponding unsubstituted 3-phenoxy compound, as shown in the Table below:

The antimicrobial activity was determined by measuring the Minimum Inhibitory Concentration (MIC). The MIC of the compounds was determined by a standard test, the "agar dilution test" according to Lorian (Antibiotics in Laboratory Medicine, Williams and Wilkins, Baltimore/London 1980) as follows:

A two-fold decreasing concentration series of each compound was prepared in Petri dishes containing 15 ml of Mueller Hinton agar (Difco). One Petri dish containing only the Mueller Hinton agar served as control for bacterial growth. Each Petri dish was inoculated with a multi-point inoculator (Denley), which transferred 0.6 μ l of a 1:100 diluted 18 hours culture of the appropriate test bacterium.

After 16 to 18 hours of incubation at 37°C, the Petri dishes were examined for growth of bacteria. The lowest concentration of the compound which causes complete inhibition of growth is taken as the MIC.

5 Table of antimicrobial activity



10 Minimum Inhibitory Concentration
in µg/ml

Organism	R = H	R = 4-CONH
<u>Str. pyogenes</u> 77A	0.05	0.05
<u>Str. pyogenes</u> 308 A	0.05	0.025
15 <u>Str. faecium</u> D	12.5	6.25
<u>Staph. aureus</u> SG 511	0.19	0.05
<u>Staph. aureus</u> 285	0.39	0.1
<u>Staph. aureus</u> 503	0.39	0.1
<u>Bac. subtilis</u> ATCC 6633	0.1	0.05
20 <u>E. coli</u> 055	3.125	0.19
<u>E. coli</u> DC2	1.56	0.78
<u>E. coli</u> TEM	12.5	0.39
<u>E. coli</u> 1507 E	1.56	0.39
<u>Kl. aerog.</u> 1082 E	1.56	0.39
25 <u>Kl. aerog.</u> 1522 E	12.5	0.78
<u>Ent. cloacae</u> 1321 E	12.5	0.78
<u>Salm. typhimurium</u> MZ II	6.25	0.78
<u>E. coli</u> KN 126	25	0.39

30 The present invention accordingly provides a pharmaceutical preparation which comprises a compound of formula I, or a physiologically tolerable salt or ester thereof, or a mixture of two or more such substances as active ingredient, in admixture or conjunction with a pharmaceutically suitable carrier. The
35 preparation may also comprise one or more other pharmaceutically active substances, for example another antibacterial substance, especially one having a β -lactam ring. The preparations may be in a form suitable for enteral or parenteral administration, for

example, for oral, intravenous or intramuscular administration, for example, as tablets, capsules, syrups, or sterile injectable or infusion solutions. The preparations are advantageously in unit dosage form and preferably comprise from 10 to 2000 mg of the active ingredient per unit dose. The daily dosage of the active ingredient is generally from 20 to 8000 mg, in divided doses, generally up to 4 doses.

The invention also provides the use of a compound of formula I or a physiologically tolerable ester or salt thereof for the manufacture of a medicament for the treatment of bacterial infections.

The invention further provides a method of treating mammals, especially humans, to combat a bacterial infection, which comprises administering to the mammal a compound of formula I or a physiologically tolerable ester or salt thereof.

The invention further provides a pharmaceutical preparation which comprises an active ingredient as defined above, in unit dosage form.

The invention also provides a pharmaceutical preparation which comprises an active ingredient as defined above, or a physiologically tolerable salt thereof or a mixture of two or more such substances, and one or more further pharmaceutically active substances, in unit dosage form.

Unit dosages are preferably as described above.

Of the compounds of formula I, 3-(4-carbamoylphenoxy)-6-(1-hydroxyethyl)-7-oxo-4-thia-1-azabicyclo[3,2,0]hept-2-ene-2-carboxylic acid and 3-(3-carbamoylphenoxy)-6-(1-hydroxyethyl)-7-oxo-4-thia-1-azabicyclo[3,2,0]hept-2-ene-2-carboxylic acid are preferred, especially the 5R,6S,8R-isomer of each of these compounds, and esters and salts thereof.

The present invention also provides compounds of the general formulae XII, XIII, XIV, III and II.

All the compounds of the present invention may exist in various isomeric forms. With the proviso that in formula I and esters and salts thereof the CONHR¹ group must be present at the 3- or 4-position on the phenyl ring, the invention includes all isomeric forms, either in the form of isolated isomers or of mixtures of any two or more isomers.

The following Examples illustrate the invention, but are not limiting. The expert will appreciate that other compounds of the present invention may be prepared analogously.

5

EXAMPLE 1

Diphenyl-(2-methylprop-2-yl)silyl-4-hydroxybenzoate

To a solution of 20g of 4-hydroxybenzoic acid and 10g of imidazole in 100 ml of dry dimethylformamide at 0°C was added 40g of t-butylchlorodiphenylsilane. The mixture was stirred at 0°C for 30 minutes, then at 20°C for 18 hours, and then partitioned between diethyl ether and water. The organic layer was washed with water, with 10% aqueous potassium hydrogen carbonate, with water and with brine, and then dried over magnesium sulphate. Evaporation in vacuo of the solvent afforded 47.5g of the title compound as a crystalline white powder.

¹H NMR (CDCl₃) δ 1.18 (9H, s); 6.16 (1H, broad s); 6.68 and 7.95 (4H, AA'BB' J8.8Hz); 7.35-7.50 (6H, m); 7.70-7.90 (4H, m).

EXAMPLE 2

Diphenyl-(2-methylprop-2-yl)silyl 4-chlorothioformyloxybenzoate

To a solution of 40.7 ml of thiophosgene in 300 ml of dry diethyl ether at -78°C was added dropwise a solution of 20g of diphenyl-(2-methylprop-2-yl)silyl 4-hydroxybenzoate and 8.5ml of triethylamine. After having been stirred for a further 30 minutes at -78°C and 90 minutes at room temperature, the mixture was partitioned between diethyl ether and water. The organic layer was washed with water and brine, was dried over calcium chloride, and then evaporated in vacuo to afford 25.9g of an orange oil.

Chromatography over silica gel and elution with hexane-ethyl acetate mixtures afforded 16.8g of the title compound.

¹H NMR (CDCl₃) δ 1.19 (9H, s); 7.26 and 8.24 (4H, AA'BB' J8.8Hz); 7.4-7.6 (6H, m); 7.7-7.9 (4H, m).

EXAMPLE 3

4-Nitrobenzyl 2-(3S-[1R-[dimethyl(2-methylprop-2-yl)silyloxy]ethyl]-4R-ethylthio-azetidin-2-on-1-yl)-3-(4-diphenyl-[2-methylprop-2-yl]silyloxycarbonylphenoxy)-3-trimethyl-
5 acetylthiopropenoate

To a stirred solution at -40°C of 25g of 4-nitrobenzyl 2-(3S-[1R-dimethyl(2-methylprop-2-yl)silyloxyethyl]-4R-ethylthioazetidin-2-on-1-yl)acetate was added a solution of 35g of diphenyl-(methylprop-2-yl)silyl 4-chlorothioformyl-
10 oxybenzoate in 200ml of dry tetrahydrofuran, followed by a mixture of 155 mmol of *n*-butyllithium and 155 mmol of hexamethyldisilazane in 200 ml of dry tetrahydrofuran which had been precooled to -78°C. After 5 minutes, 13.8 ml of trimethylacetyl bromide was added and the mixture stirred
15 for a further 60 minutes at -40°C, and then poured directly into a mixture of 500 ml of diethyl ether and 500 ml of 0.1M hydrochloric acid. The aqueous layer was extracted in diethyl ether, and the combined organic extracts were washed with brine, dried over aqueous magnesium sulphate
20 and evaporated in vacuo to afford 50g of an orange oil. The product was used without further purification.

EXAMPLE 4

4-Nitrobenzyl 3-(4-carboxyphenoxy)-2-(4R-ethylthio-3S-[1R-hydroxyethyl]azetidin-2-on-1-yl)-3-trimethylacetylthio-
25 propenoate

A mixture of 50g of 4-nitrobenzyl 2-(3S-[1R-[dimethyl-(2-methylprop-2-yl)silyl]oxyethyl]-4R-ethylthio-azetidin-2-on-1-yl)-3-(4-{diphenyl[2-methylprop-2-yl]silyloxy-
30 carbonyl}phenoxy)-3-trimethylacetylthiopropenoate, 500ml of tetrahydrofuran and 100ml of 5.5M hydrochloric acid was stirred at room temperature for 24 hours, and then partitioned between diethyl ether and water. The organic layer was washed with water, and with brine, was dried over
35 anhydrous magnesium sulphate, and evaporated in vacuo. Chromatography of the residue over silica gel, and elution with hexane-ethyl acetate-formic acid mixtures afforded 10.2g of the title compound.

ν_{\max} (CDCl₃) 1765 cm⁻¹

¹H NMR (CDCl₃) δ 1.05 and 1.13 (9H, 2s); 1.20-1.30 (6H, m); 2.6-2.8 (2H, m); 3.27 (1H, dd J2.5 and 4.5Hz); 4.2-4.4 (1H, m); 5.30 (1H, d J2.5Hz); 5.31 (2H, AB, J13.5Hz); 7.10 and 8.03 (4H, AA'BB', J9Hz); 7.60 and 8.24 (4H, AA'BB' J9Hz).

EXAMPLE 5

4-Nitrobenzyl 3-(4-carboxyphenoxy)-2-(4S-chloro-3S-[1R-hydroxyethyl]azetidino-2-on-1-yl)-3-trimethylacetylthiopropenoate

To a stirred solution of 10g of 4-nitrobenzyl 3-(4-carboxyphenoxy)-2-(4R-ethylthio-3S-[1R-hydroxyethyl]-azetidino-2-on-1-yl)-3-trimethylacetylthiopropenoate in 60 ml of chloroform at -60°C was added a solution of 192 mmoles of chlorine in 17.8 ml of carbon tetrachloride. After 30 minutes, the reaction mixture was left to warm to room temperature, and the solvent was then removed in vacuo. Chromatography over silica gel using hexane-ethyl acetate-formic acid mixtures afforded 7.3g of the title compound as a pale yellow foam.

ν_{\max} (CDCl₃) 1787, 1731 cm⁻¹

¹H NMR (CDCl₃) δ 1.06 and 1.10 (9H, 2s); 1.39 (3H, d J6.2Hz); 3.53 (1H, dd J4.3 and 9.5 Hz); 4.33 (1H, dq J6.2 and 9.5Hz); 5.30 (2H, s); 6.14 (1H, d J4.3Hz); 7.10 and 8.09 (4H, AA'BB' J8.8Hz); 7.56 and 8.25 (4H, AA'BB' J8.7Hz)

EXAMPLE 6

4-Nitrobenzyl 5R,3-(4-carboxyphenoxy)-6S-(1R-hydroxyethyl)-7-oxo-4-thia-1-azabicyclo[3,2,0]hept-2-ene-2-carboxylate

To a stirred solution of 5.3g of 4-nitrobenzyl 3-(4-carboxyphenoxy)-2-(4S-chloro-3S-[1R-hydroxyethyl]-azetidino-2-on-1-yl)-3-trimethylacetylthiopropenoate in a mixture of 90 ml of dioxane and 10 ml of water at 5°C was added 1.78g of imidazole. After 30 minutes at 5°C, the mixture was warmed to room temperature, and then partitioned

between ethyl acetate and water. The organic layer was washed successively with water, 1M-citric acid, water, and brine, was dried over magnesium sulphate, and the solvent removed in vacuo. Chromatography over silica gel using

5 ethyl acetate-

hexane-formic acid mixtures afforded 3.2g of the title compound as a pale yellow solid. Further purification by crystallisation from ethyl acetate yielded 1.8g of a white solid.

10 ν_{\max} (CDCl₃) 1788, 1794(sh) cm⁻¹
¹H NMR (CDCl₃) δ 1.39 (3H, d J6.3Hz); 3.83 (1H, dd J1.4 and 6.7Hz); 4.30 (1H, m); 5.21 and 5.40 (2H, AB J13.7Hz); 5.71 (1H, d J1.4Hz); 7.20 and 8.11 (4H, AA'BB' J8.9Hz); 7.51 and 8.18 (4H, AA'BB' J8.8Hz).

15

EXAMPLE 7

4-Nitrobenzyl 5R,3-(4-benzotriazol-1-yloxy-carbonyl - phenoxy)-6S-(1R-hydroxyethyl)-7-oxo-4-thia-1-azabicyclo-[3,2,0]hept-2-ene-2-carboxylate

20 To a solution of 1g of 4-nitrobenzyl 5R,3-(4-carboxy-phenoxy)-6S-(1R-hydroxyethyl)-7-oxo-4-thia-1-azabicyclo-[3,2,0]hept-2-ene-2-carboxylate in 8 ml of dry acetonitrile was added a solution of 420 mg of 1-hydroxybenzotriazole hydrate in 1 ml of tetrahydrofuran, followed after 5
25 minutes by a solution of 1.02g of redistilled dicyclohexyl-carbodiimide in 2 ml of acetonitrile. The mixture was stirred for 60 minutes, and was then filtered. The filtrate was evaporated in vacuo and the residue chromatographed on silica gel. Elution with hexane-ethyl
30 acetate mixtures and evaporation in vacuo afforded a solid which was dissolved in 5 ml of ethyl acetate and the solution cooled to 0°C. The material which crystallised out was filtered and washed with a little hexane-ethyl acetate mixture to afford 650 mg of the title compound. A
35 further 300 mg of the title compound was obtained by concentration of the mother liquors.

¹H NMR (CDCl₃) δ 1.41 (3H, d J6.3Hz); 3.88 (1H, dd J1.5 and 6.6Hz); 4.32 (1H, m); 5.22 and 5.43 (2H, AB

J13.7Hz); 5.77 (1H, d J1.5Hz); 7.33 and 8.20 (4H, AA'BB', J8.8Hz); 7.4-7.7 (5H, m); 8.11 (1H, d J8.4Hz); 8.32 (2H, d J9.0Hz).

5 EXAMPLE 8

4-Nitrobenzyl 5R,6S-(1R-hydroxyethyl)-7-oxo-3-(4-propyl-carbamoylphenoxy)-4-thia-1-azabicyclo-[3,2,0]hept-2-ene-2-carboxylate

10 Method A

To a stirred solution of 100 mg of 4-nitrobenzyl 5R,3-(4-carboxyphenoxy)-6S-(1R-hydroxyethyl)-7-oxo-4-thia-1-azabicyclo[3,2,0]hept-2-ene-2-carboxylate in 5 ml of dry dichloromethane at -20°C was added 27 µl of N-methyl-
15 morpholine, followed by 32.8 µl of pivaloyl bromide. After 30 minutes, 40.4 µl of *n*-propylamine was added, and the mixture warmed to room temperature. The mixture was worked up as follows: the mixture was partitioned between water and dichloromethane; the organic layer was washed with
20 1M-citric acid, with water, with saturated aqueous sodium hydrogen carbonate, with brine, and was dried over anhydrous magnesium sulphate. Evaporation *in vacuo*, and chromatography of the residue over silica gel with elution with hexane-ethyl acetate mixtures afforded 20 mg of the
25 title compound.

ν_{\max} (CH₂Cl₂) 1784 cm⁻¹

¹H NMR (DMSO-d₆) δ 0.89 (3H, t J7.4Hz); 1.16 (3H, d J6.2Hz); 1.52 (2H, m); 3.20 (2H, m); 3.91 (1H, dd J1.2 and 5.8Hz); 4.01 (1H, m)
30 5.23 (1H, d J4.6Hz); 5.27 and 5.40 (2H, AB J14.3Hz); 5.77 (1H, d J1.2Hz); 7.35 and 7.89 (4H, AA'BB' J8.7Hz); 7.57 and 8.17 (4H, AA'BB' J8.7Hz); 8.49 (1H, t J5.3Hz).

Method B

35 To a stirred suspension of 100 mg of 4-nitrobenzyl 5R,3-(4-carboxyphenoxy)-6S-(1R-hydroxyethyl)-7-oxo-4-thia-1-azabicyclo[3,2,0]hept-2-ene-2-carboxylate in 5 ml of dry dichloromethane at -20°C was added 22.6 µl of N-methyl-

morpholine, followed after 5 minutes by 39.2 μ l of diphenylphosphinyl chloride. After 30 minutes at -20°C , 22.6 μ l of N-methylmorpholine and 16.9 μ l of *n*-propylamine were added and the mixture was stirred for a further 30 minutes at -20°C , and was then worked up as described in Method A to afford 20 mg of the title compound as a pale yellow viscous oil.

Method C

10 To a stirred suspension of 100 mg of 4-nitrobenzyl 5R,3-(4-carboxyphenoxy)-6S-(1R-hydroxyethyl)-7-oxo-4-thia-1-azabicyclo[3,2,0]hept-2-ene-2-carboxylate in 5 ml of dry dichloromethane at -20°C was added 27 μ l of N-methylmorpholine, followed after 5 minutes by 32.8 μ l of
15 trimethylacetyl bromide. After 30 minutes at -20°C , 27 μ l of N-methylmorpholine and 20.2 μ l of *n*-propylamine were added and the mixture was stirred for a further 30 minutes at -20°C , and was then worked up as described in Method A to afford 30 mg of the title compound as a pale yellow
20 viscous oil.

EXAMPLE 9

Potassium 5R,6S-(1R-hydroxyethyl)-7-oxo-3-(4-propylcarbamoylphenoxy)-4-thia-1-azabicyclo[3,2,0]hept-2-ene-2-carboxylate
25

A mixture of 46 mg of 4-nitrobenzyl 5R,6S-(1R-hydroxyethyl)-7-oxo-3-(4-propylcarbamoylphenoxy)-4-thia-1-azabicyclo[3,2,0]hept-2-ene-2-carboxylate, 8.7 mg of potassium hydrogen carbonate, 132 mg of 5% palladium on charcoal, 10 ml of ethyl acetate and 10 ml of water was hydrogenated at
30 345 kPa (50 psi) for 90 minutes and then filtered through diatomaceous earth ("Hiflo", Trade Mark). The aqueous layer was separated and lyophilised to afford 30 mg of the title compound.

35 ^1H NMR (DMSO- d_6) δ 0.87 (3H, t J7.3Hz); 1.15 (3H, d J6.3Hz); 1.5 (2H, m); 3.15 (2H, m); 3.58 (1H, dd J1 and 7.5Hz); 3.91 (1H, m); 5.58 (1H, d J1Hz); 7.10 and 7.82 (4H, AA'BB' J8.6Hz); 8.39 (1H, broad m).

EXAMPLE 10

4-Nitrobenzyl 5R,3-(4-carbamoylphenoxy)-6S-(1R-hydroxyethyl)-7-oxo-4-thia-1-azabicyclo[3,2,0]hept-2-ene-2-carboxylate

5 To a stirred solution of 900 mg of 4-nitrobenzyl 5R,3-(4-(benzotriazol-1-yl)oxycarbonylphenoxy)-6S-(1R-hydroxyethyl)-7-oxo-4-thia-1-azabicyclo[3,2,0]hept-2-ene-2-carboxylate in 5 ml of tetrahydrofuran was added 228 μ l of triethylamine, followed after 5 minutes by a solution
10 of 126 mg of ammonium acetate in 200 μ l of water. After the mixture had been stirred for a further 30 minutes, the precipitate was filtered off and washed with ethyl acetate and acetonitrile to afford 300 mg of the title compound. A further 100 mg of product was obtained from the mother
15 liquors. m.p. 145°C (dec)

^1H NMR (DMSO- d_6) δ 1.15 (3H, d J6.2Hz); 3.90 (1H, dd J1.4 and 5.9Hz); 4.00 (1H, m); 5.25 (1H, broad s); 5.28 and 5.40 (2H, AB, J14.2Hz); 5.77 (1H, d J1.4Hz); 7.33 and 7.91 (4H, AA'BB' J8.8Hz); 7.44 (1H, broad s); 7.56
20 and 8.16 (4H, AA'BB' J8.8Hz); 8.02 (1H, broad s).

EXAMPLE 11

Potassium 5R,3-(4-carbamoylphenoxy)-6S-(1R-hydroxyethyl)-7-oxo-4-thia-1-azabicyclo[3,2,0]hept-2-ene-2-carboxylate

25 A mixture of 340 mg of 4-nitrobenzyl 5R,3-(4-carbamoylphenoxy)-6S-(1R-hydroxyethyl)-7-oxo-4-thia-1-azabicyclo[3,2,0]hept-2-ene-2-carboxylate, 340 mg of 10% palladium on charcoal, 10 ml of dioxane, 72.9 mg of potassium hydrogen carbonate and 10 ml of water was
30 hydrogenolysed at 345 kPa (50 psi) for 60 minutes, and then filtered through diatomaceous earth. Lyophilisation of the filtrate afforded 280 mg of a yellowish solid, which was dissolved in water and extracted with ethyl acetate. Lyophilisation of the aqueous layer afforded 255 mg of the
35 title product as an off-white solid.

m.p. 159°C (dec)

^1H NMR (D $_2$ O) δ 1.32 (3H, d J6.4Hz); 3.98 (1H, dd J1.3

and 6.0 Hz); 4.28 (1H, m); 5.74 (1H, d J1.3Hz); 7.33 and 7.87 (4H, AA'BB' J8.8Hz).

EXAMPLE 12

5 4-Nitrobenzyl 5R,6S-(1R-hydroxyethyl)-3-(4-methylcarbamoyl-
phenoxy)-7-oxo-4-thia-1-azabicyclo[3,2,0]hept-2-ene-
2-carboxylate

To a stirred solution of 200 mg of 4-nitrobenzyl
5R,3-(4-(benzotriazol-1-yl)oxycarbonylphenoxy)-6S-(1R-
10 hydroxyethyl)-7-oxo-4-thia-1-azabicyclo [3,2,0]hept-2-ene-2
-carboxylate in 2 ml of dry tetrahydrofuran at 0°C was
added 47.7 µl of triethylamine followed by 26.5 µl of a 40%
by weight aqueous solution of methylamine. After 30
minutes at 0°C, and 60 minutes at room temperature, the
15 mixture was partitioned between ethyl acetate and water;
the organic layer was washed with 1M-citric acid, with
brine, was dried over anhydrous magnesium sulphate and
evaporated in vacuo. Chromatography of the residue over
silica gel, and elution with hexane-ethyl acetate mixtures
20 afforded 95 mg of the title compound.

ν_{\max} (CDCl₃) 1780 cm⁻¹
1H NMR (CDCl₃) δ 1.38 (3H, d J6.3Hz); 3.02 (3H, d
J4.9Hz); 3.79 (1H, dd J1.5 and 6.7Hz); 4.3 (1H, m);
5.22 and 5.41 (2H, AB J14.4Hz); 5.67 (1H, d J1.5Hz);
25 6.15 (1H, broad s); 7.18 and 7.77 (4H, AA'BB' J8.8Hz);
7.53 and 8.17 (4H, AA'BB' J8.8Hz).

EXAMPLE 13

30 Potassium 5R,6S-(1R-hydroxyethyl)-3-(4-methylcarbamoyl-
phenoxy)-7-oxo-4-thia-1-azabicyclo[3,2,0]hept-2-ene-
2-carboxylate

A mixture of 196 mg of 4-nitrobenzyl 5R,6S-(1R-
hydroxyethyl)-3-(4-methylcarbamoylphenoxy)-7-oxo-4-thia-1-
azabicyclo[3,2,0]hept-2-ene-2-carboxylate, 40.4 mg of
35 potassium hydrogen carbonate, 10 ml of ethyl acetate, 10 ml
of water and 392 mg of 10% palladium on charcoal was
hydrogenated at about 345 kPa (50 psi) for 100 minutes, was
then filtered through diatomaceous earth. The aqueous

layer was separated and lyophilised to afford 131 mg of a crude product. An aqueous solution of this product was acidified at 0°C to pH2, and traces of insoluble material removed by filtration. Lyophilisation of the filtrate
5 afforded 116 mg of the product, which was dissolved in water. 31.9 Mg of potassium hydrogen carbonate was added and the solution refiltered through diatomaceous earth, and lyophilised to afford 112 mg of the title compound.

¹H NMR (D₂O) δ 1.29 (3H, d J6.4Hz); 2.91 (3H, s); 3.94
10 (1H, dd J1 and 5Hz); 4.25 (1H, m); 5.71 (1H, d J1Hz);
7.29 and 7.77 (4H, AA'BB' J8.8Hz).

EXAMPLE 14

Diphenyl-(2-methylprop-2-yl)silyl 3-hydroxybenzoate

15 To stirred solution of 50.4g of 3-hydroxybenzoic acid in 200 ml of dry dimethylformamide at 0°C was added 24.85g of imidazole, followed by 100g of diphenyl-(2-methylprop-2-yl)silyl chloride. The mixture was stirred at room temperature for 16 hours, and partitioned between ethyl
20 acetate and cold water. The organic layer was washed with water, with an aqueous potassium hydrogen carbonate solution and with brine, was dried over anhydrous magnesium sulphate and evaporated to dryness. The resulting white solid was slurried in dry chloroform and filtered to afford
25 72g of the title compound.

¹H NMR (acetone-d₆) δ 1.18 (9H, s); 6.8-7.9 (14H, m);
8.7 (1H, broad s).

EXAMPLE 15

30 Diphenyl-(2-methylprop-2-yl)silyl 3-chlorothioformyloxybenzoate

To a stirred solution of 130 ml of thiophosgene in 250 ml of dry diethyl ether at -78°C was added dropwise a mixture of 72g of diphenyl-(2-methylprop-2-yl)silyl
35 3-hydroxybenzoate and 29 ml of triethylamine in 200 ml of dry diethyl ether. The mixture was stirred at -78°C for 30 minutes, at room temperature for 120 minutes, and then partitioned between diethyl ether and water. The organic

layer was washed with cold water and with brine, and was dried over anhydrous calcium chloride. Evaporation in vacuo, and repeated addition of dry diethyl ether and re-evaporation in vacuo afforded 86.5g of the title compound as a viscous orange oil.

5 ^1H NMR (CDCl_3) δ 1.20 (9H, s); 7.35-7.55 (7H, m); 7.54 (1H, t J7.8Hz); 7.74 (4H, dm J 6Hz); 7.90 (1H, dd J2.2 and 1.6Hz); 8.11 (1H, dm J7.8Hz).

EXAMPLE 16

10 4-Nitrobenzyl 2-(3S-{1R-[dimethyl(2-methylprop-2-yl)-silyloxy]ethyl}-4R-ethylthioazetidin-2-on-1-yl)-3-(3-diphenyl-[2-methylprop-2-yl]silyloxycarbonyl phenoxy)-3-trimethylacetylthiopropenoate

By a procedure analogous to that described in Example 3, and using 15 g of 4-nitrobenzyl 2-(3S-{1R[dimethyl-
15 (2-methylprop-2-yl)silyloxy]ethyl}-4R-ethylthioazetidin-2-on-1-yl)acetate, 17 g of diphenyl(2-methylprop-2-yl)silyl 3-chlorothioformyloxybenzoate, 70 mmol of *n*-butyllithium, 14.7 ml of hexamethyldisilazane, 750 ml of dry tetrahydro-
20 furan, and 11.4 ml of trimethylacetyl bromide there was obtained 40 g of the title compound as an orange oil, which was used without further purification.

ν_{max} (film) 1710 and 1765 cm^{-1}

25 ^1H NMR (CDCl_3) δ 0.05 (6H, s); 0.83 (9H, s); 0.91 (9H, s); 1.04 and 1.11 (9H, 2s); 1.2-1.4 (6H, m); 2.5-2.9 (2H, m); 3.3 (1H, m); 4.35 (1H, m); 5.36 (2H, m); 5.48 (1H, d J2Hz); 7.3-8.4 (18H, m).

EXAMPLE 17

30 4-Nitrobenzyl 3-(3-carboxyphenoxy)-2-(4R-ethylthio-3S-[1R-hydroxyethyl]azetidin-2-on-1-yl)-3-trimethylacetylthiopropenoate

A mixture of 40 g of 4-nitrobenzyl 2-(3S- 1R[dimethyl-
35 (2-methylprop-2-yl)silyloxy]ethyl -4R-ethylthioazetidin-2-on-1-yl)-3-(3- diphenyl[2-methylprop-2-yl]silyloxy-carbonyl phenoxy)-3-trimethylacetylthiopropenoate, 150 ml of tetrahydrofuran, and 44 ml of 5.5M-hydrochloric acid was

stirred at room temperature for 16 hours, and was then partitioned between ethyl acetate and water. The organic layer was washed with water and with brine, was dried over anhydrous magnesium sulphate, and was evaporated in vacuo.

5 Chromatography of the residue over silica gel, and elution with hexane-ethyl acetate-formic acid mixtures afforded 6.0g of the title product as an E/Z mixture.

ν_{\max} 1735, 1715(sh), 1770(sh), 3450 cm^{-1}

$^1\text{H NMR}$ (CDCl_3) δ 1.00 and 1.07 (9H, 2s); 1.2-1.4 (6H, m)
10 2.6-2.9 (2H, m); 3.28 (1H, dd J2.7 and 4.4Hz); 4.3 (1H, m); 5.32 (2H, AB J13.5Hz); 5.37 (1H, d J2.7Hz); 7.29 (1H, m); 7.37 (1H, dd J2 and 7.8Hz); 7.59 and 7.40 (2H, AA'BB' J7.8Hz); 7.71 (1H, m); 7.86 (1H, dm J7.8Hz); 8.08 and 8.22 (2H, AA'BB' J7.8Hz).

15

EXAMPLE 18

4-Nitrobenzyl 3-(3-carboxyphenoxy)-2-(4S-chloro-3S-(1R-hydroxyethyl)azetid-2-on-1-yl)-3-trimethylacetylthiopropenoate

20 To a stirred solution of 5.5g of 4-nitrobenzyl 3-(3-carboxyphenoxy)-2-(4R-ethylthio-3S-[1R-hydroxyethyl]azetid-2-on-1-yl)-3-trimethylacetylthiopropenoate in 50 ml of dry deuteriochloroform at -40°C was added a solution of 10.6 mmol of chlorine in carbon tetrachloride.
25 The mixture was stirred for a further 30 minutes at -40°C , and for 30 minutes at room temperature, and was evaporated in vacuo. Chromatography of the residue over silica gel, and elution with hexane-ethyl acetate-formic acid mixtures afforded 4.6g of the title compound.

30 ν_{\max} (CDCl_3) 1700, 1730, 1783 cm^{-1}

$^1\text{H NMR}$ (CDCl_3) δ 1.03 and 1.07 (9H, 2s); 1.40 (3H, d J6.4Hz); 3.55 (1H, m); 4.4 (1H, m); 5.32 (1H, s); 6.15 and 6.20 (1H, 2d J4.2Hz); 7.29 (1H, m); 7.4-7.7 (3H, m); 7.74 (1H, m); 7.9-8.05 (1H, m);
35 8.12 and 8.24 (2H, 2d J8.8Hz).

EXAMPLE 19

4-Nitrobenzyl 5R,3-(3-carboxyphenoxy)-6S-(1R-hydroxy-

ethyl)-7-oxo-4-thia-1-azabicyclo[3,2,0]hept-2-ene-2-carboxylate

To a stirred solution of 2.02g of 4-nitrobenzyl
3-(3-carboxyphenoxy)-2-(4S-chloro-3S-(1R-hydroxyethyl)-
5 azetidin-2-on-1-yl)-3-trimethyl-acetylthiopropenoate in 80
ml of a mixture of dioxane and water (9:1 v/v) at 5°C was
added 682 mg of imidazole. The mixture was stirred for a
further 30 minutes at 5°C, and was then partitioned between
ethyl acetate and water. The aqueous layer was acidified
10 to pH2 by the addition of 1M-citric acid, and extracted
with ethyl acetate. The combined organic layers were
washed with 1M-citric acid, with water and with brine, were
dried over anhydrous magnesium sulphate and evaporated in
vacuo. The residue was chromatographed over silica gel;
15 elution with hexane-ethyl acetate-formic acid mixtures aff-
orded 992 mg of the title compound as a pale yellow foam.
 ν_{\max} (CDCl₃) 1710, 1788 cm⁻¹
¹H NMR (CDCl₃) δ 1.38 (3H, d J6.4Hz); 3.81 (1H, dd J1.4
and 6.7Hz); 4.3 (1H, m); 5.24 and 5.43 (2H, AB
20 J13.8Hz); 5.69 (1H, d J1.4Hz); 7.38-7.5 (2H, m); 7.55
and 8.18 (4H, AA'BB' J8.8Hz); 7.85 (1H, m); 7.99 (1H,
m).

EXAMPLE 20

25 4-Nitrobenzyl 5R,3-(3-{benzotriazol-1-yl}oxycarbonylphen-
oxy)-6S-(1R-hydroxyethyl)-7-oxo-4-thia-1-azabicyclo[3,2,0]-
hept-2-ene-2-carboxylate

To a stirred solution of 200 mg of 4-nitrobenzyl
5R,3-(3-carboxyphenoxy)-6S-(1R-hydroxyethyl)-7-oxo-4-thia-
30 1-azabicyclo[3,2,0]hept-2-ene-2-carboxylate in 8 ml of
acetonitrile at room temperature was added a solution of
111 mg of 1-hydroxybenzotriazole hydrate in 4 ml of
tetrahydrofuran, followed after 5 minutes by a mixture of
158 mg of 1-(3-dimethylaminopropyl)-3-ethylcarbodiimide
35 hydrochloride, 2 ml of acetonitrile and 2 ml of
tetrahydrofuran. The mixture was stirred for 3 hours at
room temperature; filtration afforded 17 mg of the title
compound. The filtrate was partitioned between ethyl

acetate and water; the organic layer was washed with water, dried over anhydrous magnesium sulphate and evaporated in vacuo to afford a further 172 mg of the title compound as a pale yellow solid.

5 ^1H NMR (DMSO- d_6) δ 1.16 (3H, d J6.2Hz); 3.91 (1H, dd J1.0 and 5.7Hz); 4.02 (1H, m); 5.22 (1H, d J4.4Hz); 5.28 and 5.41 (2H, AB J14.2Hz); 5.77 (1H, d J1.0Hz); 7.4-8.0 (9H, m); 7.98 (1H, d J8.6Hz); 8.18 (2H, d J8.7Hz).

10

EXAMPLE 21

3-[5R,6S-(1R-hydroxyethyl)-2-(4-nitrobenzyloxycarbonyl)-7-oxo-4-thia-1-azabicyclo[3,2,0]hept-2-en-3-yl]oxybenzoic anhydride

15 To a stirred solution of 100 mg of 4-nitrobenzyl 5R,3-(3-carboxyphenoxy)-6S-(1R-hydroxyethyl)-7-oxo-4-thia-1-azabicyclo[3,2,0]hept-2-ene-2-carboxylate in 4 ml of acetonitrile was added 79 mg of 1-(3-dimethylaminopropyl)-3-ethylcarbodiimide hydrochloride. After stirring for 20
20 minutes, the mixture was partitioned between ethyl acetate and water; the organic layer was washed with water then with brine, and was then dried over anhydrous magnesium sulphate. Evaporation in vacuo afforded 78 mg of the title compound.

25 ^1H NMR (DMSO- d_6) δ 1.15 (3H, d J6.25Hz); 3.91 (1H, dd J1.3 and 5.9Hz); 4.01 (1H, m); 5.22 (1H, d J4.6Hz); 5.29 and 5.42 (2H, ABq J14.4Hz); 5.76 (1H, d J1.3Hz); 7.55-8.32 (8H, m)

30 EXAMPLE 22

4-Nitrobenzyl 5R,6S-(1R-hydroxyethyl)-3-(3-methyl-carbamoylphenoxy)-7-oxo-4-thia-1-azabicyclo[3,2,0]hept-2-ene-2-carboxylate

Method A

35 To a stirred mixture of 235 mg of 4-nitrobenzyl 5R,3-(3-benzotriazol-1-yl oxycarbonylphenoxy)-6S-(1R-hydroxyethyl)-7-oxo-4-thia-1-azabicyclo[3,2,0]hept-2-ene-2-carboxylate, 8 ml of redistilled dimethylformamide and 53 μl

of triethylamine at 0°C was added 34 µl of a 40% (by weight) solution of methylamine in water. After 30 minutes, the reaction mixture was allowed to warm to room temperature, and was stirred for a further 45 minutes. The mixture was
5 partitioned between ethyl acetate and water; the organic layer was washed with 1M-citric acid, with water, with saturated aqueous sodium hydrogen carbonate, and with brine, was dried over anhydrous magnesium sulphate, and was then evaporated in vacuo. Chromatography of the residue
10 over silica gel, eluting with hexane-ethyl acetate mixtures afforded 94 mg of the title compound.

¹H NMR (CDCl₃) δ 1.35 (3H, d J6.3Hz); 3.00 (3H, d J4.8Hz); 3.75 (1H, dd J1.4 and 6.7Hz); 4.25 (1H, m); 5.21 and 5.41 (2H, AB J13.8Hz); 5.64 (1H, d J1.4Hz);
15 6.19 (1H, m); 7.26-7.65 (6H, m); 8.16 (2H, d J8.8Hz).

Method B

To a stirred solution of 78 mg of 3-[5R,6S-(1R-hydroxyethyl)-2-(4-nitrobenzyloxycarbonyl)-7-oxo-4-thia-1-
20 azabicyclo[3,2,0]hept-2-en-3-yl]oxybenzoic anhydride in 2 ml of redistilled dimethylformamide was added 15 µl of a 40% by weight aqueous solution of monomethylamine. After 18 hours the mixture was partitioned between ethyl acetate and water; the organic layer was washed with 1M-citric acid,
25 with water, with a saturated sodium hydrogen carbonate solution, with brine; was dried over anhydrous magnesium sulphate and was evaporated in vacuo to yield 33 mg of the title compound.

30 EXAMPLE 23

4-Nitrobenzyl 5R,3-(3-carbamoylphenoxy)-6S-(1R-hydroxyethyl)-7-oxo-4-thia-1-azabicyclo[3,2,0]hept-2-ene-2-carboxylate

To a stirred solution of 139 mg of 4-nitrobenzyl 5R,3-
35 (3-benzotriazol-1-yl oxycarbonylphenoxy)-6S-(1R-hydroxyethyl)-7-oxo-4-thia-1-azabicyclo[3,2,0]hept-2-ene-2-carboxylate, 4 ml of redistilled dimethylformamide and 52 µl of triethylamine was added 27.1 mg of ammonium acetate.

After being stirred for a further 90 minutes, the mixture was partitioned between ethyl acetate and water; the organic layer was washed with 1M-citric acid, with water, with a saturated sodium hydrogen carbonate solution, with brine; was dried over anhydrous magnesium sulphate and was evaporated in vacuo to afford 64 mg of the title compound.

ν_{\max} (CHCl₃) 1725 and 1785 cm⁻¹

¹H NMR (DMSO-d₆) δ 1.17 (3H, d J7.2Hz); 3.89 (1H, m); 4.02 (1H, m); 5.21 (1H, d J4.5Hz); 5.29 and 5.40 (2H, AB J14.2Hz); 5.74 (1H, d J1.3Hz); 7.4-8.0 (7H, m); 8.09 (1H, broad s); 8.18 (2H, d J8.8Hz).

EXAMPLE 24

Potassium 5R,3-(3-carbamoylphenoxy)-6S-(1R-hydroxyethyl)-7-oxo-4-thia-1-azabicyclo[3,2,0]hept-2-ene-2-carboxylate

A mixture of 106 mg of 4-nitrobenzyl 5R,3-(3-carbamoylphenoxy)-6S-(1R-hydroxyethyl)-7-oxo-4-thia-1-azabicyclo[3,2,0]hept-2-ene-2-carboxylate, 21.8 mg of potassium hydrogen carbonate, 150 mg of 10% palladium on charcoal, 5 ml of dioxan and 5 ml of water was hydrogenated at 420 kPa (60 psi) for 60 minutes, was filtered through diatomaceous earth and lyophilised. The yellow solid was dissolved in water, washed with ethyl acetate and lyophilised to afford 40 mg of the title compound.

¹H NMR (D₂O) δ 1.28 (3H, d J6.6Hz); 3.92 (1H, dd J1.5 and 6.2Hz); 4.23 (1H, m); 5.68 (1H, d J1.5Hz); 7.39-7.20 (4H, m).

EXAMPLE 25

Potassium 5R,6S-(1R-hydroxyethyl)-3-(3-methylcarbamoylphenoxy)-7-oxo-4-thia-1-azabicyclo[3,2,0]hept-2-ene-2-carboxylate

A mixture of 142 mg of 4-nitrobenzyl 5R,6S-(1R-hydroxyethyl)-3-(3-methylcarbamoylphenoxy)-7-oxo-4-thia-1-azabicyclo[3,2,0]hept-2-ene-2-carboxylate, 28 mg of potassium hydrogen carbonate, 150 mg of 10% palladium on charcoal, 5 ml of dioxan and 5 ml of water was hydrogenated at 345kPa (50 psi) for 60 minutes, was filtered through

diatomaceous earth and lyophilised to afford 76 mg of the title compound.

^1H NMR (D_2O) δ 1.30 (3H, d J6.4Hz); 2.92 (3H, s); 3.94 (1H, dd J 1 and 6.1Hz); 4.25 (1H, m); 5.69 (1H, d J1Hz); 7.0-7.7 (4H, m).

EXAMPLE 26

Pentafluorophenyl 4-acetoxybenzoate

A solution of 10.8 g of 4-acetoxybenzoyl chloride in 10 dry acetonitrile was treated with 10 g of pentafluorophenol, and stirred at 0°C whilst 4.4 ml of pyridine was added dropwise. The solution was permitted to warm to room temperature then heated to reflux temperature until the reaction was complete. Solvent was evaporated in vacuo and 15 the residue obtained partitioned between ethyl acetate and water. The organic solution was washed with further portions of water and brine and dried over magnesium sulphate. Evaporation afforded 18 g of the title compound.

ν_{max} (film) 1760 cm^{-1}
20 ^1H NMR (CDCl_3) δ 2.25 (3H, s); 7.21, 8.21 (4H, AA'BB', J=9 Hz).

EXAMPLE 27

Pentafluorophenyl 4-hydroxybenzoate

25 Pentafluorophenyl 4-acetoxybenzoate (10g) in tetrahydrofuran was treated with 50 ml of 5M hydrochloric acid and 150 ml of tetrahydrofuran and stirred at room temperature overnight. The solvents were evaporated in vacuo to give a product which was purified by column 30 chromatography (silica; ethyl acetate/hexane mixtures as eluant) to afford the title compound (8g).

ν_{max} (film) 1760 cm^{-1}
35 ^1H NMR (CDCl_3) δ 6.86, 7.01 (4H, AA'BB', J=9 Hz); 7.30 (1H, broad s).

EXAMPLE 28

Pentafluorophenyl 4-chlorothiocarbonyloxybenzoate

A solution of 1.34g of sodium hydroxide in water was.

added dropwise over 15 minutes with vigorous stirring to a solution of 8.45g of pentafluorophenyl 4-hydroxybenzoate and 3.2 ml of thiophosgene in 100 ml of chloroform at -20°C. The mixture was stirred at 5°C until the reaction was complete and the organic layer separated, dried over calcium chloride and the solvent evaporated. Chromatography of the residue on silica gel eluting with hexane/ethyl acetate mixtures afforded 5.9g of the title compound.

10 ν_{\max} (film) 1760 cm^{-1}
 $^1\text{H NMR}$ (CDCl_3) δ 7.32, 8.30 (4H, AA'BB', J=8 Hz)

EXAMPLE 29

4-Nitrobenzyl-2-[3(S)-1(R)-dimethyl-(2-methylprop-2-yl)-silyloxyethyl)-4(R)-ethylthioazetid-2-on-1-yl]-3-[4-(pentafluorophenoxy)phenoxy]-3-trimethylacetyl-thiopropenoate

To a stirred solution of 4-nitrobenzyl 2-[3(S)-(1(R)-dimethyl-(2-methylprop-2-yl)-silyloxyethyl)-4(R)-ethylthioazetid-2-on-1-yl]acetate (6.76g) and pentafluorophenyl 4-chlorothiocabonyloxybenzoate (5.89g) in dry tetrahydrofuran at -40°C under argon was added a solution of a mixture of 6.65 ml of hexamethyldisilazane and 19.7 ml of a 1.6 molar hexane solution of n-butyllithium in dry tetrahydrofuran. The mixture was stirred at -40°C for 20 minutes and 3.72 ml of pivaloyl bromide was added. After stirring at -40°C for a further hour, the mixture was poured into cold 0.1 molar aqueous hydrochloric acid and extracted with ether. The combined organic layers were washed with saturated sodium bicarbonate, with brine, and were then dried over magnesium sulphate and evaporated to dryness. Chromatography over silica gel, eluting with hexane/ethyl acetate mixtures afforded the title compound (10.9g).

35 ν_{\max} (film) 1760 cm^{-1}
 $^1\text{H NMR}$ (CDCl_3) δ 0.02 (6H, s); 0.81, 0.89 (9H, 2s); 1.09, 1.16 (9H, 2s); 1.16-1.32 (6H, m); 2.51-2.79 (2H, m); 3.24-3.32 (1H, m); 4.22-4.29 (1H, m); 5.25-5.47

(3H, m); 6.95-8.24 (8H, m).

EXAMPLE 30

5 4-Nitrobenzyl-2-[4(R)-ethylthio-3(S)-[1(R)-hydroxyethyl]-
azetidin-2-on-1-yl]-3-[4-(pentafluorophenoxy-carbonyl)-
phenoxy]-3-trimethylacetylthiopropenoate

To a stirred solution of 10.9 g of 4-nitrobenzyl
2-[3(S)-(1(R)-dimethyl-(2-methylprop-2-yl)-silyloxyethyl)-
4(R)-ethylthioazetidin-2-on-1-yl]-3-[4-(pentafluorophenyl-
10 carbonyl)-phenoxy]-3-trimethylacetylthiopropenoate in 218
ml of tetrahydrofuran at room temperature was added 43 ml
of 5M hydrochloric acid. The mixture was stirred until
t.l.c. showed the reaction to be complete. The mixture was
15 partitioned between ethyl acetate and water, the separated
organic layer washed with sodium bicarbonate solution and
brine and dried over magnesium sulphate. Evaporation of
the filtered solution followed by chromatography of the
residue (silica gel, ethyl acetate/hexane mixtures as
20 eluant) afforded the title compound (3.7g).

20 The product is isolated as a mixture of E and Z
isomers, observed as double peaks in the nmr spectrum. The
E and Z isomers are separable by chromatography if required.

ν_{\max} (film) 1760 cm^{-1}

25 ^1H NMR (CDCl_3) δ 1.09 (9H, s); 1.16-1.34 (6H, m); 1.75
(1H, broad s); 2.69-2.76 (2H, m); 3.26 (1H, dd, J=2.5 Hz
and 4.8 Hz); 4.2-4.3 (1H, m); 5.26 (1H, d, J=2.5 Hz);
5.26, 5.34 (2H, ABq, J=9 Hz); 7.18, 8.17 (4H, AA'BB', J=8.8
Hz); 7.60, 8.24 (4H, AA'BB', J=8.8 Hz).

30 Signals due to the minor propenoate isomer were also
detectable.

EXAMPLE 31

35 4-Nitrobenzyl-2-[4(S)-chloro-3(S)-[1(R)-hydroxyethyl]-
azetidin-2-on-1-yl]-3-[4-(pentafluorophenoxy-carbonyl)-
phenoxy]-3-trimethylacetylthiopropenoate

To a stirred solution of 3.73g of 4-nitrobenzyl
2-[4(R)-ethylthio-3(S)-(1(R)-hydroxyethyl)-azetidin-2-on-
1-yl]-3-[4-(pentafluorophenoxy-carbonyl)phenoxy]-

3-trimethylacetylthiopropenoate in 25 ml of dry chloroform at -40°C was added a solution of 5.6 mmol chlorine in 7.2 ml of carbon tetrachloride, and the solution was stirred for 30 minutes. The reaction mixture was allowed to reach room temperature and evaporated to dryness. Chromatography of the residue (silica gel, hexane/ethyl acetate mixtures as eluant) gave the title compound (2.5g).

^1H NMR (CDCl_3) δ 1.10 (9H, s); 1.39 (3H, d, J=6.3 Hz); 1.61 (1H, broad s); 3.54 (1H, dd, J=4.3 Hz and 9.4 Hz); 4.29-4.35 (1H, m); 5.33 (2H, s); 6.13 (1H, d, J=4.3 Hz); 7.17,8.19 (4H, AA'BB', J=8.8 Hz); 7.56,8.25 (4H, AA'BB', J=8.8 Hz).

EXAMPLE 32

4-Nitrobenzyl 5(R),6(S)-[1(R)-hydroxyethyl]-7-oxo-3-[4-(pentafluorophenoxycarbonyl)phenoxy]-4-thia-1-azabicyclo[3.2.0]hept-2-ene-2-carboxylate

243 mg of imidazole was added to a stirred solution of 3.73 g of 4-nitrobenzyl 2-[4(S)-chloro-3(S)-(1(R)-hydroxyethyl)-azetidino-1-yl]-3-[4-(pentafluorophenoxycarbonyl)-phenoxy]-3-trimethylacetylthiopropenoate in 22 ml of dioxan-water (9:1 v/v) at 5°C. Stirring was continued for 30 minutes and the mixture was then allowed to reach room temperature and was partitioned between ethyl acetate and water. The organic layer was washed with cold dilute hydrochloric acid, saturated sodium bicarbonate and brine, dried over magnesium sulphate and evaporated in vacuo to dryness. Chromatography of the residue over silica gel and eluting with hexane/ethyl acetate mixtures afforded the title compound (2.56 g).

$\text{max (KBr)} \quad 1770 \text{ cm}^{-1}$
 ^1H NMR (CDCl_3) 1.39 (3H, d, J=6.3 Hz); 1.75 (1H, broad); 3.85 (1H, dd, J=1.4 Hz and 6.5 Hz); 4.28-4.33 (1H, m); 5.21,5.40 (2H, ABq, J=14.7 Hz); 5.74 (1H, d, J=1.4 Hz); 7.27,8.18 (4H, AA'BB', J=8.9Hz); 7.62,8.22 (4H, AA'BB', J=8.7Hz).

EXAMPLE 33

4-Nitrobenzyl 5R,3-(4-carbamoylphenoxy)-6S-(1R-hydroxyethyl)-7-oxo-4-thia-1-azabicyclo[3,2,0]hept-2-ene-2-carboxylate

5 To a solution of 1.00 g of 4-nitrobenzyl 5R,6S-(1R-hydroxyethyl)-7-oxo-3-[4-(pentafluorophenoxycarbonyl)-phenoxy]-4-thia-1-azabicyclo[3,2,0]hept-2-ene-2-carboxylate in 15 ml of acetonitrile at 0°C was added a solution of 75 mg of ammonia dissolved in 5 ml of dry ethanol. The
10 mixture was stirred at 0°C for 15 minutes, and at room temperature for 1 hour. The precipitate was filtered off from the mixture, washed with ethyl acetate and dried in vacuo to afford 413 mg of the title compound with physical properties identical to those given in Example 10.

15

EXAMPLE 34

Acetoxyethyl 5R,3-(4-carbamoylphenoxy)-6S-(1R-hydroxyethyl)-7-oxo-4-thia-1-azabicyclo[3,2,0]hept-2-ene-2-carboxylate

20 To a solution of 100 mg of potassium 5R,3-(4-carbamoylphenoxy)-6S-(1R-hydroxyethyl)-7-oxo-4-thia-1-azabicyclo[3,2,0]hept-2-ene-2-carboxylate in 1 ml of dry dimethylacetamide at 0°C was added a solution of 85 µl of 1-chloroethyl acetate and 77 mg of sodium iodide in 1 ml of
25 dry dimethylacetamide. The mixture was stirred for 18 hours and then partitioned between ethyl acetate and water. The organic layer was washed with water, was dried over anhydrous magnesium sulphate, and was evaporated to dryness. Chromatography of the residue over silica gel and
30 elution with hexane/ethyl acetate/acetonitrile mixtures afforded 17 mg of the title compound.

¹H NMR (CDCl₃) δ 1.35 and 1.37 (3H, 2d, J=6 Hz); 1.45 and 1.46 (3H, 2d, J=6.5 Hz); 3.76 (1H, dd J=1.2 and 5.8 Hz); 4.13 (1H, m); 5.66 (1H, d, J=1.2 Hz); 5.7 (1H, broad s);
35 6.1 (1H, broad s); 6.92 (1H, m); 7.19 and 7.20 (2H, 2d, J=8.8 Hz); 7.84 (2H, d, J=8.8 Hz).

EXAMPLE 35

(5-Methyl-2-oxo-1,3-dioxolen-4-yl)methyl 5R,3-(4-carbamoylphenoxy)-6S-(1R-hydroxyethyl)-7-oxo-4-thia-1-azabicyclo[3,2,0]hept-2-ene-2-carboxylate

5 To a solution of 100 mg of potassium 5R,3-(4-carbamoylphenoxy)-6S-(1R-hydroxyethyl)-7-oxo-4-thia-1-azabicyclo[3,2,0]hept-2-ene-2-carboxylate in 1 ml of dimethylacetamide at 0°C was added a solution of 55 mg of 4-bromomethyl-5-methyl-1,3-dioxolen-2-one in 0.5 ml of
10 dimethylacetamide. The mixture was stirred for 18 hours and then partitioned between ethyl acetate and water. The organic layer was washed with water, was dried over anhydrous magnesium sulphate, and was evaporated to dryness. Chromatography of the residue over silica gel and
15 elution with hexane/ethyl acetate/acetonitrile mixtures afforded 39 mg of the title compound.

$^1\text{H NMR}$ (CD_3CN) δ 1.23 (3H, d, J=6.3 Hz); 2.07 (3H, s); 3.84 (1H, dd J=1.5 and 5.5 Hz); 4.14 (1H, m); 4.8 and 4.95 (2H, AB, J=14.1 Hz); 5.71 (1H, d, J=1.5 Hz); 6.1 (1H, broad s);
20 6.8 (1H, broad s); 7.24 and 7.85 (4H, AA'BB', J=8.8 Hz)

EXAMPLE 36

Ethoxycarbonyloxymethyl 5R,3-(4-carbamoylphenoxy)-6S-(1R-hydroxyethyl)-7-oxo-4-thia-1-azabicyclo[3,2,0]-
25 hept-2-ene-2-carboxylate

To a solution of 100 mg of potassium 5R,3-(4-carbamoylphenoxy)-6S-(1R-hydroxyethyl)-7-oxo-4-thia-1-azabicyclo[3,2,0]hept-2-ene-2-carboxylate in 1 ml of dry dimethylformamide at 0°C was added a solution of 85 μl of
30 ethyl-iodomethyl-carbonate in 0.5 ml of dry dimethylformamide. The mixture was stirred for 3 hours and then partitioned between ethyl acetate and water. The organic layer was washed with water, was dried over anhydrous magnesium sulphate, and was evaporated to dryness. Chromatography of the residue over silica gel and
35 elution with hexane/ethyl acetate/acetonitrile mixtures afforded 63 mg of the title compound.

$^1\text{H NMR}$ (CD_3CN) δ 1.22 (3H, d J=7 Hz); 1.24 (3H, t J=7 Hz);

3.83 (1H, dd J=1.5 and 5.5 Hz); 4.13 (1H, m); 5.70 (1H, d J=1.5 Hz); 5.72 and 5.79 (2H, AB J=6 Hz); 6.1 (1H, broad s); 6.9 (1H, broad s); 7.28 and 7.88 (4H, AA'BB' J=8.8 Hz)

5 EXAMPLE 37

Acetoxymethyl 5R,3-(4-carbamoylphenoxy)-6S-(1R-hydroxyethyl)-7-oxo-4-thia-1-azabicyclo[3,2,0]hept-2-ene-2-carboxylate

To a solution of 180 mg of potassium 5R,3-(4-carbamoylphenoxy)-6S-(1R-hydroxyethyl)-7-oxo-4-thia-1-azabicyclo[3,2,0]hept-2-ene-2-carboxylate in 1 ml of dry dimethylformamide at 0°C was added a solution of 190 mg of iodomethyl acetate in 1 ml of dry dimethylformamide. The mixture was stirred for 3 hours and then partitioned between ethyl acetate and water. The organic layer was washed with water, was dried over anhydrous magnesium sulphate, and was evaporated to dryness. Chromatography of the residue over silica gel and elution with hexane/ethyl acetate/acetonitrile mixtures afforded 56 mg of the title compound.

¹H NMR (CD₃CN) δ 1.22 (3H, d J=6.3 Hz); 2.01 (3H, s); 3.83 (1H, dd J=1.5 and 5.5 Hz); 4.13 (1H, m); 5.70 (1H, d J=1.5 Hz); 5.71 and 5.77 (2H, AB J=6 Hz); 6.1 (1H, broad s); 6.9 (1H, broad s); 7.27 and 7.88 (4H, AA'BB' J=8.8 Hz)

25 EXAMPLE 38

4-Nitrobenzyl 5R,6S-(1R-acetoxyethyl)-3-(4-carbamoylphenoxy)7-oxo-4-thia-1-azabicyclo[3,2,0]hept-2-ene-2-carboxylate

To a suspension of 200 mg of 4-nitrobenzyl 5R,3-(4-carbamoylphenoxy)-6S-(1R-hydroxyethyl)-7-oxo-4-thia-1-azabicyclo[3,2,0]hept-2-ene-2-carboxylate in 5 ml of dry tetrahydrofuran at 20°C was added 5 mg of 4-dimethylaminopyridine and 389 μl of acetic anhydride. The mixture was stirred for 15 minutes and then partitioned between ethyl acetate and water. The organic layer was washed with aqueous sodium bicarbonate solution, with water, with brine, was dried over anhydrous magnesium

sulphate, and was evaporated to dryness. Chromatography of the residue over silica gel and elution with hexane/ethyl acetate/acetonitrile mixtures afforded 157 mg of the title compound.

- 5 ν_{\max} (CDCl₃) 1793 cm⁻¹
¹H NMR (CDCl₃) δ 1.42 (3H, d J=6.4 Hz); 2.05 (3H, s);
3.91 (1H, dd J=1.5 and 7.6 Hz); 5.2 (1H, m); 5.23 and
5.39 (2H, AB J=13.7 Hz); 5.64 (1H, d J=1.5 Hz); 5.9 (2H,
broad s); 7.19 and 7.83 (4H, AA'BB' J=8.8 Hz); 7.52 and
10 8.18 (4H, AA'BB' J=8.8 Hz).

EXAMPLE 39

Potassium 5R,6S-(1R-acetoxyethyl)-3-(4-carbamoyl-
phenoxy)-7-oxo-4-thia-1-azabicyclo[3,2,0]hept-2-ene-

15 2-carboxylate

A mixture of 150 mg of 4-nitrobenzyl 5R,6S-(1R-acetoxyethyl)-3-(4-carbamoylphenoxy)-7-oxo-4-thia-1-azabicyclo[3,2,0]hept-2-ene-2-carboxylate, 5 ml of dioxane, 5 ml of water, 150 mg of 10% palladium on charcoal, and
20 28.5 mg of potassium bicarbonate was hydrogenolysed under 3 atmospheres of hydrogen for 60 minutes at room temperature, and was then filtered through diatomaceous earth.

Lyophilisation of the filtrate afforded a yellow solid, which was dissolved in water and extracted with ethyl
25 acetate. Lyophilisation of the aqueous layer afforded 99 mg of the title compound.

¹H NMR (D₂O) δ 1.38 (3H, d J=6.4 Hz); 2.14 (3H, s); 4.21 (1H, dd J=1.4 and 5.4 Hz); 5.3 (1H, m); 5.82 (1H, d J=1.4 Hz); 7.34 and 7.88 (4H, AA'BB' J=9 Hz).

30

EXAMPLE 40

S-Phenyl 4-(acetoxy)thiobenzoate

Copper (I) thiophenoxide (4.06g) was added to a solution of 4-acetoxybenzoyl chloride (4.67g) in dry
35 acetonitrile (40ml). The mixture was heated to reflux for 2 hours, cooled, and the solvent evaporated in vacuo. The residue was taken up in ethyl acetate, and the filtered solution washed successively with a cold, dilute ammonia

solution, water and brine. Evaporation of the solution, which had been dried over magnesium sulphate, afforded the desired thioester (5.53g).

¹H NMR (CDCl₃) δ 2.30 (3H, s); 7.00-7.60 (5H, m); 7.14, 7.98 (4H, AA'BB', J=9 Hz).

EXAMPLE 41

S-Phenyl 4-(hydroxy)thiobenzoate

S-Phenyl 4-(acetoxy)thiobenzoate (5.53g) in tetrahydrofuran was treated with 25 ml of 5.6M hydrochloric acid and stirred at room temperature overnight. The solvents were evaporated in vacuo to give a product which was purified by column chromatography (silica; ethyl acetate/hexane mixtures as eluant) to afford the title compound (4.08g).

¹H NMR (d⁶-DMSO) δ 7.58 (5H, broad s); 7.06, 8.03 (4H, AA'BB', J=9 Hz)

EXAMPLE 42

S-Phenyl 4-(chlorothiocarbonyloxy)thiobenzoate

A solution of sodium hydroxide (1.55g) in 150 ml of water was added dropwise with vigorous stirring to a solution of 8.8g of S-phenyl 4-(hydroxy)thiobenzoate and 3.70 ml of thiophosgene in 250 ml of chloroform, the temperature being kept below 10°C. The mixture was stirred at room temperature for 2 hours and the organic layer separated. The organic layer was washed successively with water and brine, dried over calcium chloride, and evaporated to dryness in vacuo to give 11.57g of the title compound.

ν_{max} (film) 1665 cm⁻¹

¹H NMR (CDCl₃) δ 7.28, 8.14 (4H, AA'BB', J=9 Hz); 7.40-7.58 (5H, m)

EXAMPLE 43

4-Nitrobenzyl 2-[3(S)-(1(R)-dimethyl-(2-methylprop-2-yl)-silyloxyethyl)-4(R)-ethylthioazetid-2-on-1-yl]-3-[4-(phenylthio-(carbonyl))-phenoxy]-3-trimethylacetylthio-

propenoate

To a stirred solution of 4-nitrobenzyl 2-[3(S)-(1(R)-
dimethyl-(2-methylprop-2-yl)-silyloxyethyl)-4(R)-ethyl-
thioazetidin-2-on-1-yl]acetate (3.91g) and S-phenyl
5 4-(chlorothiocarboxyloxy)thiobenzoate (5g) in dry
tetrahydrofuran at -40°C under argon was added a solution
of a mixture of 5.1 ml of hexamethyldisilazane and 15.2 ml
of a 1.6 molar hexane solution of n-butyllithium in dry
tetrahydrofuran. The mixture was stirred at -40°C for 20
10 minutes and 3.06 ml of trimethylacetyl bromide was added.
After stirring at -40°C for a further hour, the mixture was
poured into cold 0.1 molar aqueous hydrochloric acid and
extracted with ether. The combined organic layers were
15 washed with saturated sodium bicarbonate, with brine, and
were then dried over magnesium sulphate and evaporated to
dryness. Chromatography over silica gel, eluting with
hexane/ethyl acetate mixtures afforded the title compound
(5.02g).

¹H NMR (CDCl₃) δ 0.01, 0.02 (6H, 2s); 0.77, 0.83 (9H,
2s); 1.03, 1.11 (9H, 2s); 1.15-1.50 (6H, m); 2.50-2.85
20 (2H, m); 3.15-3.25 (1H, m); 4.15-4.25 (1H, m); 5.20-
5.45 (3H, m); 6.85-7.60 (9H, m); 7.90-8.25 (4H, m).

EXAMPLE 44

25 4-Nitrobenzyl 2-[4(R)-ethylthio-3(S)-(1(R)-hydroxyethyl)-
azetidin-2-on-1-yl]-3-[4-(phenylthio-(carbonyl))-phenoxy]-
3-trimethylacetylthiopropenoate

To a stirred solution of 5.04g of 4-nitrobenzyl
2-[3(S)-(1(R)-dimethyl-(2-methylprop-2-yl)-silyloxyethyl)-
30 4(R)-ethylthioazetidin-2-on-1-yl]-3-[4-(phenylthio-
(carbonyl))-phenoxy]-3-trimethylacetylthiopropenoate in 80
ml of tetrahydrofuran at room temperature was added 5 ml of
water and 5 ml of concentrated hydrochloric acid. The
mixture was stirred until t.l.c. showed the reaction to be
35 complete. The mixture was partitioned between ethyl
acetate and water, the separated organic layer washed with
sodium bicarbonate solution and brine and dried over
magnesium sulphate. Evaporation of the filtered

solution followed by chromatography of the residue (silica gel, ethyl acetate/hexane mixtures as eluant) afforded the title compound (2.75 g).

The product is isolated as a mixture of E and Z isomers, observed as double peaks in the nmr spectrum. The E and Z isomers are separable by chromatography if required. ¹H NMR (CDCl₃) δ 1.12, 1.19 (9H, s); 1.25-1.45 (6H, m); 1.68, 1.80 (1H, 2d, broad s); 2.67-2.90 (2H, m); 3.27-3.33 (1H, m); 4.22-4.50 (1H, m); 5.25-5.47 (3H, m); 7.08-7.68 (9H, m); 7.99-8.35 (4H, m). Small signals due to the minor propenoate isomer were also detectable.

EXAMPLE 45

4-Nitrobenzyl 2-[4(S)-chloro-3(S)-(1(R)-hydroxyethyl)-azetidin-2-on-1-yl]-3-[4-(phenylthio-(carbonyl))-phenoxy]-3-trimethylacetylthiopropenoate

To a stirred solution of 2.75g of 4-nitrobenzyl 2-[4(R)-ethylthio-3(S)-(1(R)-hydroxyethyl)-azetidin-2-on-1-yl]-3-[4-(phenylthio-(carbonyl))-phenoxy]-3-trimethylacetylthiopropenoate in 25 ml of dry chloroform at -40°C was added a solution of 5.3 mmol of chlorine in 7 ml of carbon tetrachloride, and the solution was stirred for 30 minutes. The reaction mixture was allowed to reach room temperature and evaporated to dryness. Chromatography of the residue (silica gel, hexane/ethyl acetate mixtures as eluant) gave the title compound (1.98g)

¹H NMR (CDCl₃) δ 1.09 (9H, s); 1.41 (3H, d, J=6.3 Hz); 2.30 (1H, broad s); 3.54 (1H, dd, J=4.3 Hz and 9.6 Hz); 4.27-4.40 (1H, m); 5.34 (2H, apparent s); 6.16 (1H, d, J=4.3 Hz); 7.08-7.63 (9H, m); 7.98-8.28 (4H, m)

EXAMPLE 46

4-Nitrobenzyl 5(R),6(S)-[1(R)-hydroxyethyl]-7-oxo-3-[4-(phenylthio-(carbonyl))phenoxy]-4-thia-1-azabicyclo[3.2.0]hept-2-ene-2-carboxylate

0.542 g of imidazole was added to a stirred solution of 5.06 g of 4-nitrobenzyl 2-[4(S)-chloro-3(S)-(1(R)-hydroxy-

ethyl)-azetidin-2-on-1-yl]-3-[4-(phenylthio-(carbonyl))-
phenoxy]-3-trimethylacetylthiopropenoate in dioxan-water
(9:1 v/v) at 5°C. Stirring was continued for 30 minutes
5 and the mixture was then allowed to reach room temperature
and was partitioned between ethyl acetate and water. The
organic layer was washed with cold dilute hydrochloric
acid, saturated sodium bicarbonate and brine, dried over
magnesium sulphate and evaporated in vacuo to dryness.
Chromatography of the residue over silica gel and eluting
10 with hexane/ethyl acetate mixtures afforded the title
compound (3.24 g).

ν_{\max} (CDCl₃) 1786 cm⁻¹
¹H NMR (CDCl₃) δ 1.39 (3H, d, J=6.3 Hz); 1.80 (1H, broad
s); 3.83 (1H, dd, J=1.1 Hz and 6.7 Hz); 4.23-4.44 (1H,
15 m); 5.22, 5.41 (2H, ABq, J=13.7 Hz); 5.71 (1H, d, J=1.1
Hz); 7.22, 8.05 (4H, AA'BB', J=8.8 Hz); 7.52, 8.19 (4H,
AA'BB', J=8.7 Hz); 7.40-7.54 (5H, m).

EXAMPLE 47

20 4-Nitrobenzyl 5(R),6(S)-[1(R)-hydroxyethyl]-7-oxo-3-
[4-(N-propylcarbonyl)phenoxy]-4-thia-1-azabicyclo-
[3.2.0]hept-2-ene-2-carboxylate

14.5 μ l of n-propylamine in dry acetonitrile was added
dropwise over 10 minutes to a cool (0°C), stirred solution
25 of 51 mg of 4-nitrobenzyl 5(R),6(S)-[1(R)-hydroxyethyl]
-7-oxo-3-[4-(phenylthio-carbonyl)phenoxy]-4-thia-1-aza-
bicyclo[3.2.0]hept-2-ene-2-carboxylate and 34 mg of silver
trifluoromethanesulphonate in dry acetonitrile. The
mixture was stirred at room temperature protected from
30 light until the reaction was complete. The solution was
filtered and the filtrate evaporated in vacuo and the
residue chromatographed on silica gel using hexane/ethyl
acetate mixtures as eluant to give 23 mg of the title
compound.

35 ν_{\max} (CDCl₃) 1784 cm⁻¹
¹H NMR (CDCl₃) δ 1.00 (3H, t, J=7.3 Hz); 1.38 (3H, d,
J=6.3 Hz); 1.57-1.76 (2H, m); 3.37-3.49 (2H, m); 3.79
(1H, dd, J=1.4 Hz and 6.8 Hz); 4.25-4.37 (1H, m);

5.23, 5.43 (2H, ABq, J=13.8 Hz); 5.67 (1H, d, J=1.4 Hz);
6.15 (1H, t, J=8.8 Hz); 7.18, 7.78 (4H, AA'BB', J=8.8 Hz);
7.54, 8.81 (4H, AA'BB', J=8.8 Hz).

5 EXMAPLE 48

4-Nitrobenzyl 5(R),6(S)-[1(R)-hydroxyethyl]-3-
[4-(N-methylcarbamoyl)phenoxy]-7-oxo-4-thia-1-
azabicyclo[3.2.0]hept-2-ene-2-carboxylate

44 mg of the above compound were obtained from 87.5 mg
10 of 4-nitrobenzyl 5(R),6(S)-[1(R)-hydroxyethyl]-3-
[4-(phenylthio-carbonyl)phenoxy]-7-oxo-4-thia-1-aza-
bicyclo[3.2.0]hept-2-ene-2-carboxylate by a procedure
analogous to that described in Example 47, using 58 mg of
silver trifluoromethanesulphonate and 0.45 mmol of
15 methylamine (as an ethereal solution).

ν_{\max} (CHCl₃) 1780 cm⁻¹

¹H NMR (d⁶-acetone) δ 1.19 (3H, d, J=6.4 Hz); 2.86 (3H,
s); 3.80 (1H, dd, J=1.5 Hz and 6.3 Hz); 4.06-4.17 (1H,
m); 5.17, 5.34 (2H, ABq, J=14.2 Hz); 5.74 (1H, d, J=1.5
20 Hz); 7.22, 7.85 (4H, AA'BB', J=8.8 Hz); 7.55, 8.08 (4H,
AA'BB', J=8.8 Hz); 7.71 (1H, broad s)

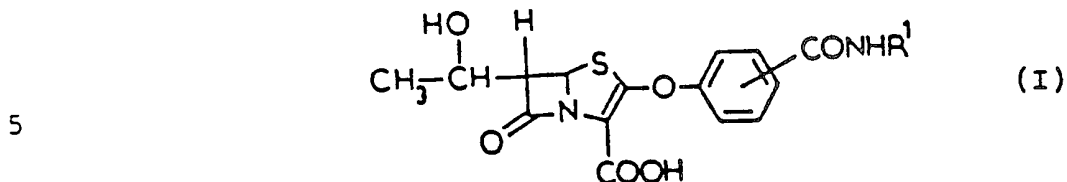
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CLAIMS:

1. A compound of formula I



10 in which R¹ represents a hydrogen atom or an alkyl group having from 1 to 4 carbon atoms, the CONHR¹ group being present on the 3- or 4-position of the phenyl ring, and esters thereof at the 2-carboxy group and/or at the 8-hydroxy group.

2. 3-(3-Carbamoylphenoxy)-6-(1-hydroxyethyl)-7-oxo-4-thia-1-azabicyclo[3,2,0]hept-2-ene-2-carboxylic acid.

15 3. 3-(3-Carbamoylphenoxy)-6-(1-hydroxyethyl)-7-oxo-4-thia-1-azabicyclo[3,2,0]hept-2-ene-2-carboxylic acid.

4. 5R,3-(4-Carbamoylphenoxy)-6S-(1R-hydroxyethyl)-7-oxo-4-thia-1-azabicyclo[3,2,0]hept-2-ene-2-carboxylic acid.

5. 5R,3-(3-Carbamoylphenoxy)-6S-(1R-hydroxyethyl)-7-oxo-4-thia-1-azabicyclo[3,2,0]hept-2-ene-2-carboxylic acid.

20 6. A compound of formula I as claimed in claim 1 having an esterified carboxy group at the 2-position, which esterified carboxy group can be cleaved by hydrolysis, by photolysis, by reduction or by esterase enzyme action to give the free carboxylic acid group, or a carboxylate salt.

25 7. An ester as claimed in claim 6, which has been formed between a free acid as claimed in claim 1 and an unsubstituted or substituted aliphatic alcohol or phenol having up to 20 carbon atoms in total.

30 8. An ester as claimed in claim 6 or claim 7, wherein the esterified carboxy group at position 2 is a -COOR² group, in which R² represents a methyl or ethyl group which is substituted by an acyloxy group or by an aminoalkanoyloxy group, or represents an ethyl group substituted by an optionally substituted amino group at the 2-position, or 35 represents a methyl group substituted by one or more unsubstituted or substituted phenyl groups.

9. An ester as claimed in claim 8, wherein a phenyl group is substituted by one or more substituents selected from nitro groups and halogen atoms.

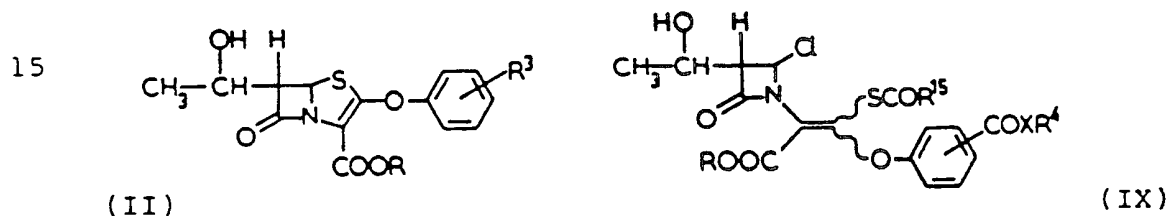
10. An ester as claimed in claim 9, wherein
R² is a benzyl, p-nitrobenzyl, benzhydryl or
trityl group.
11. An ester as claimed in claim 6, wherein the ester
group is cleavable by esterase enzyme action under
5 physiological conditions to give the free acid, or a
carboxylate salt.
12. An ester as claimed in claim 11, which is an
acyloxymethyl or 1'-(acyloxy)ethyl ester, a
5-methyldioxalen-2-on-4-yl-methyl ester, an
10 aminoalkanoyloxymethyl ester, a phthalidyl ester, a
1'-(alkoxycarbonyloxy)ethyl ester, an alkoxycarbonyloxy-
methyl ester, or an optionally substituted 2-aminoethyl ester.
13. An ester as claimed in claim 12, being a
glycyloxymethyl, L-valyloxymethyl, L-leucyloxymethyl,
15 1'-(methoxycarbonyloxy)ethyl, 2-diethylaminoethyl or
2-(1-morpholino)-ethyl ester.
14. A p-nitrobenzyl, phthalidyl, pivaloyloxymethyl,
ethoxycarbonyloxymethyl, 5-methyldioxalen-2-on-4-yl-methyl,
acetylmethyl, acetoxymethyl, 1'-(acetoxy)ethyl, 1'(acetyl)-
20 ethyl, 1'-(ethoxycarbonyloxy)ethyl or ethoxycarbonyloxy-
methyl ester of a compound as claimed in claim 1.
15. A salt of a compound as claimed in claim 1.
16. A physiologically tolerable salt of a compound as
claimed in claim 1.
- 25 17. A salt as claimed in claim 16, which is an alkali
metal or alkaline earth metal salt, an ammonium salt, a
salt with an organic amine, or is a physiologically
tolerable acid addition salt.
18. A compound, ester or salt as claimed in any one of
30 claims 1 to 17, wherein the 8-hydroxy group is esterified.
19. A compound as claimed in claim 18, wherein the 8-ester
group is removable under physiological conditions.
20. A compound as claimed in claim 19, wherein the 8-ester
group is a group R_xCO- in which R_x represents a hydrogen
35 atom or a straight or branched chain alkyl group having
from 1 to 4 carbon atoms, or represents a phenyl group or a
phenoxyalkyl group in which the alkyl moiety is straight-
chained or branched and has from 1 to 4 carbon atoms.

21. An ester or salt as claimed in any one of claims 6 to 20, of a compound as claimed in any one of claims 2, 3 and 5.

22. An ester or salt as claimed in any one of claims 6 to 20, of a compound as claimed in claim 4.

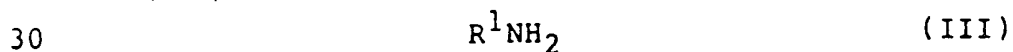
23. A compound, ester or salt as claimed in any one of claims 1 to 20, having R stereochemistry at position 5, S stereochemistry at position 6, and R stereochemistry at position 8.

24. A process for the production of a compound of the formula I as claimed in claim 1, or an ester at the 2-carboxy group and/or at the 8-hydroxy group, or a salt thereof, which comprises reacting a compound of formula II or of formula IX

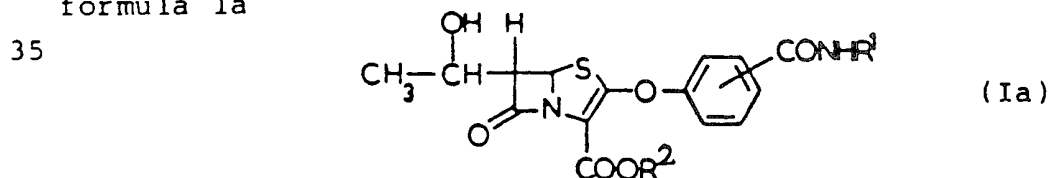


20 in which R represents a hydrogen atom or a carboxy protecting group, R³ represents an activated carboxylic acid group, R⁴ represents an alkyl group having 1 to 4 carbon atoms, or a phenyl group which may be unsubstituted or substituted by one or more substituents, which may be

25 the same or different, selected from chlorine and fluorine atoms, cyano and nitro groups, and alkoxy groups, R¹⁵ represents a phenyl group or an alkyl group having from 1 to 4 carbon atoms, and X represents an oxygen or sulphur atom, with an amine of formula III



in which R¹ is as defined in claim 1, to give a compound of formula I as claimed in claim 1, or an ester thereof of formula Ia

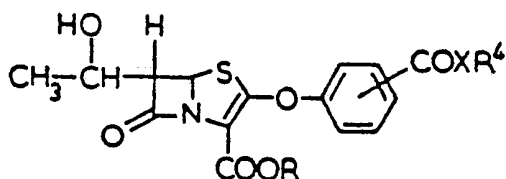


in which R^2 represents a carboxy protecting group and, if desired, carrying out any one or more of the following steps in any desired order:

- a) hydrolysing an ester of formula Ia to give the
5 corresponding free acid of formula I,
- b) reacting a free acid of formula I or a salt thereof with an agent capable of forming an ester, for example, with an alcohol, a phenol or a reactive derivative thereof to give an ester of formula Ia,
- 10 c) carrying out an acid or base catalysed ester interchange on an ester of formula Ia to give a different ester of formula Ia,
- d) reacting a free acid of formula I with a base to give a salt at the carboxylic acid group at position 2,
- 15 e) reacting a free acid of formula I or an ester of formula Ia having a basic group with an acid to give an acid addition salt thereof,
- f) hydrolysing the ester group from an ester of formula Ia in the presence of a salt-forming agent, for example, an
20 alkali metal salt, to give a salt of a compound of formula I,
- g) reacting a salt of a compound of formula I with an acid to give a free acid of formula I, and
- h) reacting a compound of formula I or a salt thereof, or
25 an ester of formula Ia, with an organic acid or a derivative thereof, to give a compound of formula I or an ester of formula Ia having an esterified hydroxy group at the 8-position.

25. A process as claimed in claim 24, wherein the
30 activated carboxylic acid group R^3 in compound II is a group of formula $-COXR^4$, in which X and R^4 are defined as in claim 24, giving a compound of formula IV

35



(IV)

in which R is as defined in claim 24.

26. A process as claimed in claim 25, wherein in a compound of formula IV, R⁴ represents a phenyl group substituted by one or more chlorine and/or fluorine atoms.

5 27. A process as claimed in claim 26, wherein when X represents a sulphur or oxygen atom, R⁴ represents a pentafluorophenyl group, and when X represents a sulphur atom, R⁴ represents a 4-chlorophenyl or 2,4,5-trichlorophenyl group.

10 28. A process as claimed in any one of claims 25 to 27, wherein the reaction of the compound of formula IV with the amino compound of formula III is carried out at a temperature within the range of from -40 to +40°C.

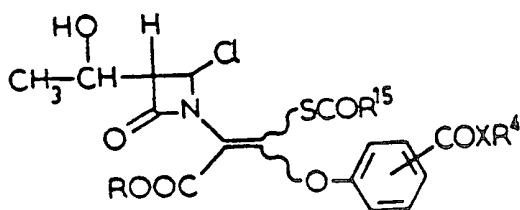
15 29. A process as claimed in any one of claims 25 to 28 wherein the reaction between an amine of formula III and a compound of formula IV is carried out in the presence of a metal salt.

20 30. A process as claimed in claim 29, wherein the metal salt is a salt of a metal selected from Groups IB, IIB and VIII of the Periodic Classification of the Elements.

31. A process as claimed in claim 30, wherein the metal salt is a copper, rhodium, mercury, zinc, cadmium or silver salt of an inorganic or organic acid, for example, perchloric, tetrafluoroboric, acetic,
25 trifluoromethanesulphonic, or trifluoroacetic acid, or of imidazole.

32. A process as claimed in claim 31, wherein the salt is silver acetate, silver trifluoroacetate, silver trifluoromethanesulphonate, or silver imidazolid.

30 33. A process as claimed in any one of claims 25 to 32, wherein a compound of formula IV is produced by treating a compound of formula IX



(IX)

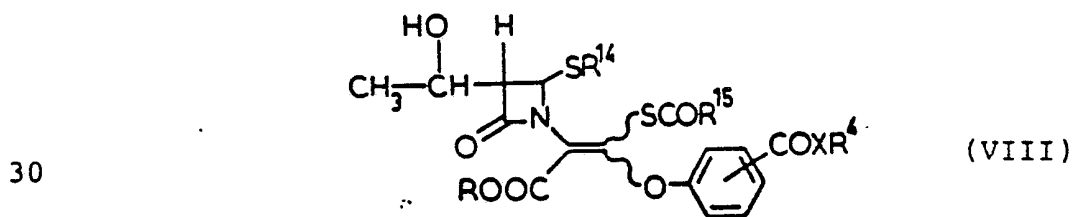
in which R, R⁴, R¹⁵ and X are defined as in claim 24, with a base.

34. A process as claimed in claim 33, wherein the base is ammonia; an alkali metal, especially a sodium or potassium carbonate, bicarbonate, or hydroxide; a primary amine, for example, methylamine, ethylamine, aniline or benzylamine; an alkali metal alkoxide, for example, sodium methoxide; or a heterocyclic base, for example, having a pKa within the range of from 5 to 9, for example, pyridine, an alkyl, amino or alkylamino-substituted pyridine, for example, 4-methylpyridine or 4-dimethylpyridine, or especially imidazole.

35. A process as claimed in claim 33, wherein the compound of formula IV is produced and is converted in situ into a compound of formula I or an ester thereof by reacting a compound of formula IX with an amine of formula III as defined in claim 24.

36. A process as claimed in claim 24 or claim 35, wherein in formula IX when X represents a sulphur or oxygen atom R⁴ represents a pentafluorophenyl group, and when X represents a sulphur atom, R⁴ also represents a 4-chlorophenyl or 2,4,5-trichlorophenyl group.

37. A process as claimed in claim 24 or in any one of claims 33 to 36, wherein a compound of formula IX is produced by chlorinating a compound of formula VIII

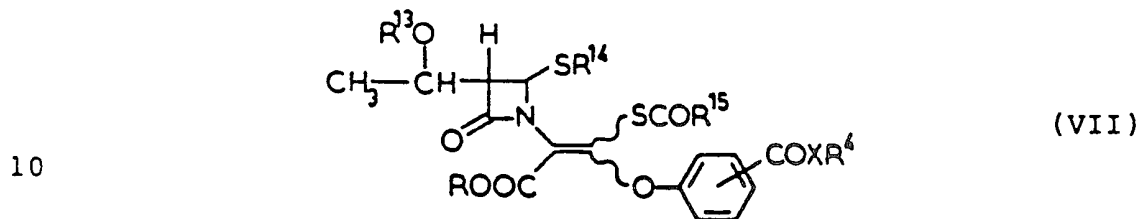


in which R, X, R⁴ and R¹⁵ are as defined in claim 24, and R¹⁴ represents a phenyl group or an alkyl group having 1 to 4 carbon atoms.

38. A process as claimed in claim 37, wherein the chlorination is carried out using molecular chlorine,

sulphuryl chloride, *t*-butyl hypochlorite or cyanogen chloride.

39. A process as claimed in claim 37 or claim 38, wherein a compound of formula VIII is produced by removing a hydroxy protecting group R¹³ from a compound of formula VII



15 in which R, X, R⁴ and R¹⁵ are defined as in claim 24 and R¹⁴ is as defined in claim 37, and R¹³ represents a hydrogen atom or a hydroxy protecting group.

40. A process as claimed in claim 39, wherein R¹³ represents a hydroxy protecting group which can be removed under acidic conditions.

20 41. A process as claimed in claim 40, wherein R¹³ represents a tetrahydropyranyl or tetrahydrofuranyl group; an acetal or ketal group, for example, of formula



30 in which R¹⁷ and R¹⁸, which may be the same or different, each represents a hydrogen atom or a lower alkyl group, preferably a methyl group, or R¹⁷ and R¹⁸ together with the carbon atom to which they are attached, represent a cycloalkyl ring having from 4 to 7 carbon atoms, and R¹⁹ represents a lower alkyl group, preferably a methyl or ethyl group, or R¹⁷ and R¹⁹ together with the carbon atom and the oxygen atom to which they are attached, respectively, represent a tetrahydropyranyl ring; a silyl ether, for example, having three substituents on the silicon atom, and preferably up to 24 carbon atoms in total the three substituents being the same or different, and

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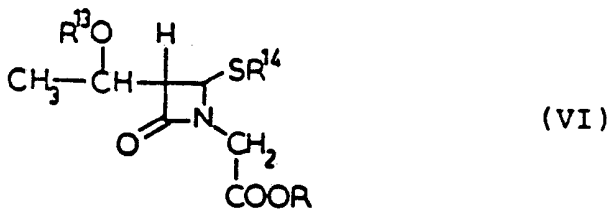
selected from alkyl, alkenyl and cycloalkyl groups, and phenyl and phenalkyl groups which may be unsubstituted or substituted as defined above; or a stannyl group, for example, having up to 24 carbon atoms and three substituents, which may be the same or different, selected from alkyl, alkenyl, cycloalkyl, alkoxy and phenoxy groups, and phenyl and phenalkyl groups which may be unsubstituted or substituted.

42. A process as claimed in claim 41, wherein a silyl ether is a $-\text{SiR}^{10} \text{R}^{11} \text{R}^{12}$ group, in which R^{10} , R^{11} and R^{12} , are the same or different, and each represents a lower alkyl group or a phenyl group, and a stannyl group is a group of the formula $\text{SnR}^{20} \text{R}^{21} \text{R}^{22}$, in which R^{20} , R^{21} and R^{22} , which may be the same or different, each represents a lower alkyl group.

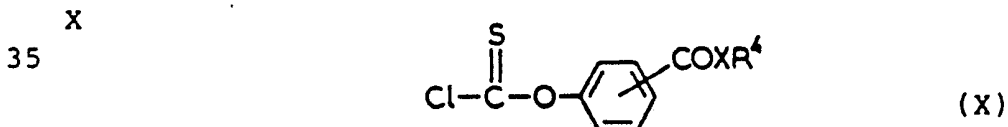
43. A process as claimed in claim 42, wherein a silyl group is a diphenyl-t-butylsilyl or methyldiphenylsilyl group, and a stannyl group is a tri-n-butylstannyl group.

44. A process as claimed in claim 41, wherein R^{13} represents a tetrahydropyranyl, 2-methoxyprop-2-yl, trimethylsilyl, triethylsilyl or t-butyldimethylsilyl group.

45. A process as claimed in any one of claims 39 to 44, wherein a compound of formula VII is produced by reacting a compound of formula VI



in which R is as defined in claim 24, R^{13} is as defined in any one of claims 39 to 44, and R^{14} is as defined in claim 37, in the presence of a base, with a compound of formula



in which X and R⁴ are as defined in claim 24, followed by reaction with an activated carboxylic acid derivative which comprises the group R¹⁵ as defined in claim 24, for example, with an acyl halide of formula XI

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in which R¹⁵ is as defined in claim 24 and R¹⁶ represents a chlorine or bromine atom.

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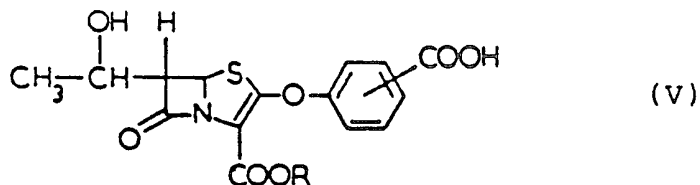
46. A process as claimed in claim 45, wherein the base has a $\text{pK}_a > 20$, and is preferably a metallated amine.

47. A process as claimed in claim 46, wherein the base is lithium diisopropylamide, lithium hexamethyldisilazide, lithium 2,2,6,6-tetramethylpiperidide, lithium cyclohexyl isopropylamide or sodamide.

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48. A process as claimed in claim 24, wherein a compound of formula II is produced by reacting a compound of formula V

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25 with an agent capable of activating the free carboxy group on the phenoxy group.

49. A process as claimed in claim 48, wherein the carboxylic acid group bonded to the phenyl group is converted into one of the following groups:

30

(i) to an activated ester;

(ii) to a phosphorous or phosphoric ester, or a phosphoric acid anhydride;

(iii) to a carboxylic acid anhydride;

(v) to an acid chloride; or

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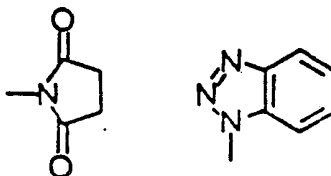
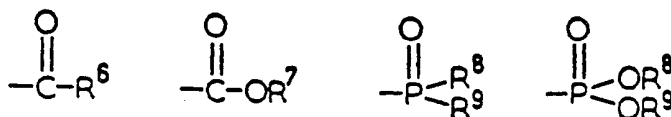
(vi) to an O-acylurea and if desired, converting the O-acylurea into an active ester.

50. A process as claimed in claim 49, wherein the

carboxylic acid is converted into another group as follows:

- (i) to a phenyl ester using a bisphenyl carbonate;
- (ii) to a phosphorus or phosphoric ester, or a phosphoric acid anhydride, using a phosphinyl halide or a phosphoryl halide;
- (iii) to a carboxylic acid anhydride using an acid chloride or bromide, a carbodiimide, or a chloroformate;
- (iv) to an imidazolidine using N,N'-carbonyl-diimidazole;
- (v) to an acid chloride using thionyl chloride; or
- (vi) to an O-acylurea using a carbodiimide, and if desired, converting the O-acylurea into an ester with 1-hydroxybenzotriazole or with N-hydroxysuccinimide.

51. A process as claimed in claim 24, 48, 49 or 50, wherein R³ represents a group of the formula -COOR⁵ in which R⁵ represents one of the following groups



30 in which R⁶ represents an alkyl group having up to 4 carbon atoms; R⁷ represents an alkyl group having up to 4 carbon atoms; R⁸ and R⁹, which may be the same or different, each represents an alkyl group having up to 4 carbon atoms or a phenyl group.

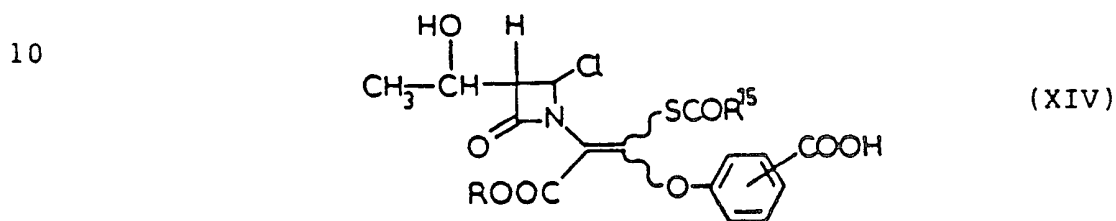
52. A process as claimed in claim 51, wherein R⁶ represents a t-butyl group, R⁷ represents an iso-butyl group.

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53. A process as claimed in any one of claims 48 to 52, wherein an activated penem of formula II formed from a free

acid of formula V is reacted in situ with the amino compound of formula III to form a compound of formula I or an ester thereof, or the activated penem of formula II is first isolated and purified before reaction with the amino
5 compound.

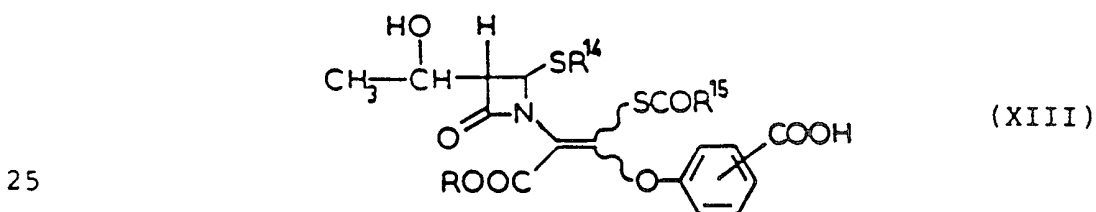
54. A process as claimed in any one of claims 48 to 53, wherein a compound of formula V is produced by treating a compound of formula XIV



15 in which R and R¹⁵ are as defined in claim 24, with a base.

55. A process as claimed in claim 54, wherein the base is as defined in claim 34.

56. A process as claimed in claim 54 or claim 55, wherein a compound of formula XIV is produced by chlorinating a
20 compound of formula XIII

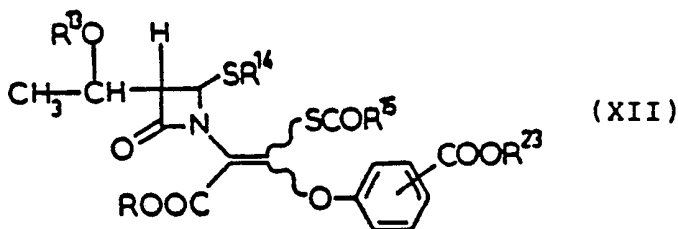


in which R and R¹⁵ are as defined in claim 24 and R¹⁴ is as defined in claim 37.

57. A process as claimed in claim 56, wherein the
30 chlorinating agent is as defined in claim 38.

58. A process as claimed in claim 56 or claim 57, wherein a compound of formula XIII is produced by removing a hydroxy protecting group R¹³ and a carboxy protecting group R²³ from a compound of formula XII

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in which R and R¹⁵ are as defined in claim 24, R¹⁴ is as defined in claim 37, R¹³ is as defined in claim 39, and R²³ represents a carboxy protecting group, the removal of the two protecting groups R¹³ and R²³ being carried out

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59. A process as claimed in claim 58, wherein the carboxy protecting group R²³ can be removed under the same conditions as the hydroxy protecting group R¹³.

60. A process as claimed in claim 59, wherein the protecting groups R¹³ and R²³ are both removable under acidic conditions.

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61. A process as claimed in claim 60, wherein R¹³ is as defined in any one of claims 41 to 44.

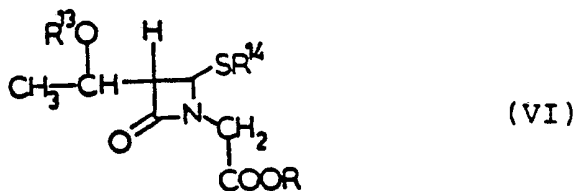
62. A process as claimed in claim 60 or claim 61, wherein R²³ represents a silyl group.

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63. A process as claimed in claim 62, wherein R²³ represents a diphenyl-t-butylsilyl group.

64. A process as claimed in any one of claims 58 to 63, wherein a compound of formula XII is produced by reacting a compound of formula VI

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in which R and R¹³ are as defined in claim 39, in the presence of a base with a compound of formula XVI

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in which R²³ is as defined in any one of claims 58 to 63, followed by reaction with an activated acid derivative comprising the group R¹⁵.

5 65. A process as claimed in claim 64, wherein the activated acid derivative is a compound of formula XI as defined in claim 45.

66. A process as claimed in claim 64 or claim 65, wherein the base is as defined in claim 46 or claim 47.

10 67. A process as claimed in claim 24, carried out substantially as described in any one of Examples 8 to 13, 22 to 25, 33 to 39, 47 and 48.

68. A compound of formula I as claimed in claim 1, or an ester or salt thereof, whenever produced by a process as claimed in any one of claims 24 to 67.

15 69. A compound of formula I as claimed in claim 1, or a salt thereof, or an ester at the 2-carboxylic acid group and/or at the 8-hydroxy group, substantially as described in any one of Examples 8, 9, 12, 13, 22 to 25, 47 and 48 herein.

20 70. A compound as claimed in claim 4, or an ester or salt thereof, substantially as described in any one of Examples 10, 11, and 33 to 39 herein.

71. A pharmaceutical preparation which comprises a compound of formula I, an ester thereof at the 2-carboxylic acid group and/or at the 8-hydroxy group, or a physiologically tolerable salt thereof, as claimed in any one of claims 1 to 23, 68 to 70, in admixture or conjunction with a pharmaceutically suitable carrier.

25 72. A pharmaceutical preparation as claimed in claim 71, which comprises a compound as claimed in claim 4 or an ester or salt as claimed in claim 22, in admixture or conjunction with a pharmaceutically suitable carrier.

73. A pharmaceutical preparation as claimed in claim 72, wherein the compound, ester or salt is substantially as described in any one of Examples 10, 11 and 33 to 39 herein.

35 74. The use of a compound, ester or salt as claimed in any

one of claims 1 to 23, 68 to 70, for the manufacture of a medicament for the treatment of bacterial infections.

75. A compound of formula II as defined in claim 24.

76. A compound of formula V as defined in claim 48.

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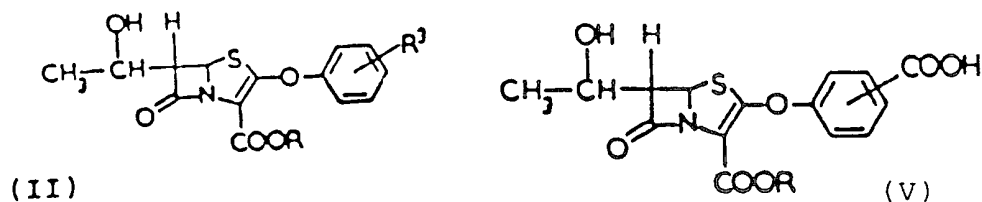
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The preceding claims have been superseded by the following claims:-

1. A compound of formula II or of formula V

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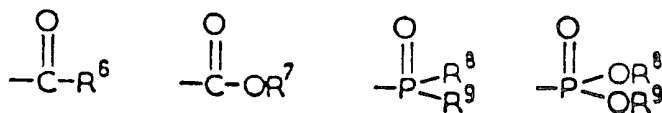


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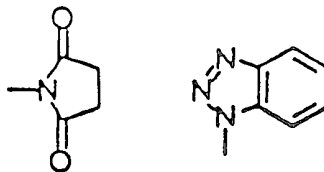
in which R represents a hydrogen atom or a carboxy protecting group and R^3 represents an activated carboxy group.

2. A compound of formula II as claimed in claim 1, wherein R^3 represents a group of the formula $-\text{COOR}^5$ in which R^5 represents one of the following groups

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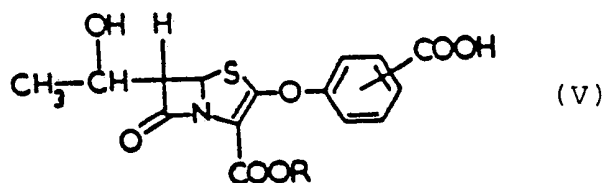


in which R^6 represents an alkyl group having up to 4 carbon atoms; R^7 represents an alkyl group having up to 4 carbon atoms; R^8 and R^9 , which may be the same or different, each represents an alkyl group having up to 4 carbon atoms or a phenyl group.

3. A compound as claimed in claim 2, wherein R^6 represents a t-butyl group and R^7 represents an iso-butyl group.
4. A process for the production of a compound of formula II as claimed in claim 1, which comprises reacting a

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compound of formula V



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in which R is defined as in claim 1, with an agent capable of activating the free carboxy group on the phenoxy group.

5. A process as claimed in claim 4, wherein the carboxylic acid group bonded to the phenyl group is converted into one of the following groups:

- (i) to an activated ester;
- (ii) to a phosphorous or phosphoric ester, or a phosphoric acid anhydride;

15 (iii) to a carboxylic acid anhydride;

(iv) to an imidazolide;

(v) to an acid chloride; or

(vi) to an O-acylurea and if desired, converting the O-acylurea into an active ester.

20 6. A process as claimed in claim 5, wherein the carboxylic acid is converted into another group as follows:

(i) to a phenyl ester using a bisphenyl carbonate;

(ii) to a phosphorus or phosphoric ester, or a phosphoric acid anhydride, using a phosphinyl halide or a phosphoryl halide;

25 (iii) to a carboxylic acid anhydride using an acid chloride or bromide, a carbodiimide, or a chloroformate;

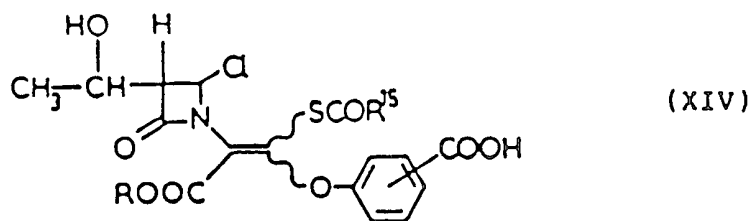
(iv) to an imidazolide using N,N'-carbonyl-diimidazole;

(v) to an acid chloride using thionyl chloride; or

30 (vi) to an O-acylurea using a carbodiimide, and if desired, converting the O-acylurea into an ester with 1-hydroxybenzotriazole or with N-hydroxysuccinimide.

7. A process for the production of a compound of formula V as claimed in claim 1, which comprises treating a compound

35 of formula XIV



in which R is as defined in claim 1 and R¹⁵ represents a phenyl group or an alkyl group having from 1 to 4 carbon atoms, with a base.

10 8. A process as claimed in claim 7, wherein the base is ammonia; an alkali metal; a primary amine; an alkali metal alkoxide; or a heterocyclic base.

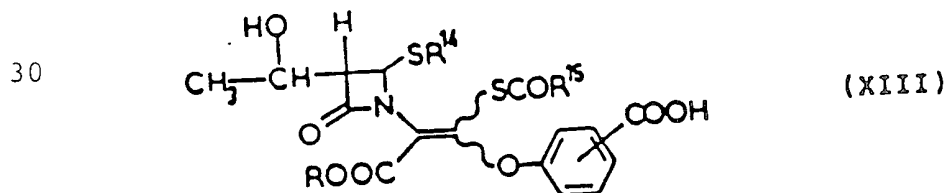
9. A process as claimed in claim 8, wherein the base is a sodium or potassium carbonate, bicarbonate, or hydroxide; 15 methylamine, ethylamine, aniline or benzylamine; sodium methoxide or a heterocyclic base having a pKa within the range of from 5 to 9.

10. A process as claimed in claim 9, wherein the base is pyridine or an alkyl, amino or alkylamino-substituted 20 pyridine.

11. A process as claimed in claim 10, wherein the base is 4-methylpyridine or 4-dimethylaminopyridine.

12. A process as claimed in claim 8, wherein the base is imidazole.

25 13. A process as claimed in any one of claims 7 to 12, wherein a compound of formula XIV is produced by chlorinating a compound of formula XIII

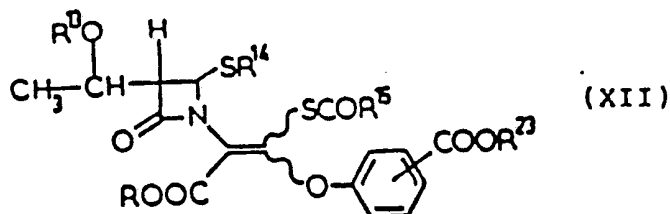


in which R and R¹⁵ are as defined in claim 7 and R¹⁴ 35 represents a phenyl group or an alkyl group having from 1 to 4 carbon atoms.

14. A process as claimed in claim 64, wherein the chlorinating agent is molecular chlorine, sulphuryl

chloride, *t*-butyl hypochlorite or cyanogen chloride.

15. A process as claimed in claim 13 or claim 14, wherein a compound of formula XIII is produced by removing a hydroxy protecting group R^{13} and a carboxy protecting group R^{23} from a compound of formula XII.



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in which R and R^{15} are as defined in claim 7, R^{14} is as defined in claim 13, R^{13} represents a hydroxy protecting group, and R^{23} represents a carboxy protecting group, the removal of the two protecting groups R^{13} and R^{23} being carried out successively or simultaneously.

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16. A process as claimed in claim 15, wherein the carboxy protecting group R^{23} can be removed under the same conditions as the hydroxy protecting group R^{13} .

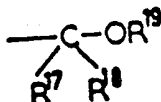
17. A process as claimed in claim 16, wherein the protecting groups R^{13} and R^{23} are both removable under acidic conditions.

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18. A process as claimed in claim 17, wherein R^{13} represents a tetrahydropyranyl or tetrahydrofuranyl group; an acetal or ketal group; a silyl ether or a stannyl group.

25

19. A process as claimed in claim 18, wherein R^{13} represents an acetal or ketal group of formula



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in which R^{17} and R^{18} , which may be the same or different, each represents a hydrogen atom or a lower alkyl group, or R^{17} and R^{18} together with the carbon atom to which they are attached, represent a cycloalkyl ring having from 4 to 7 carbon atoms, and R^{19} represents a lower alkyl group, or R^{17} and R^{19} together with the carbon atom and the oxygen atom to which they are attached, respectively, represent a tetrahydropyranyl ring; a silyl ether having three

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substituents on the silicon atom and up to 24 carbon atoms in total, the three substituents being the same or different, and selected from alkyl, alkenyl and cycloalkyl groups, and phenyl and phenalkyl groups which may be
5 unsubstituted or substituted as defined above; or a stannyl group having up to 24 carbon atoms and three substituents, which may be the same or different, selected from alkyl, alkenyl, cycloalkyl, alkoxy and phenoxy groups, and phenyl and phenalkyl groups which may be unsubstituted or
10 substituted.

20. A process as claimed in claim 19, wherein a silyl ether is a $-\text{SiR}^{10} \text{R}^{11} \text{R}^{12}$ group, in which R^{10} , R^{11} and R^{12} , are the same or different, and each represents a lower alkyl group or a phenyl group, and a stannyl group is a
15 group of the formula $\text{SnR}^{20} \text{R}^{21} \text{R}^{22}$, in which R^{20} , R^{21} and R^{22} , which may be the same or different, each represents a lower alkyl group.

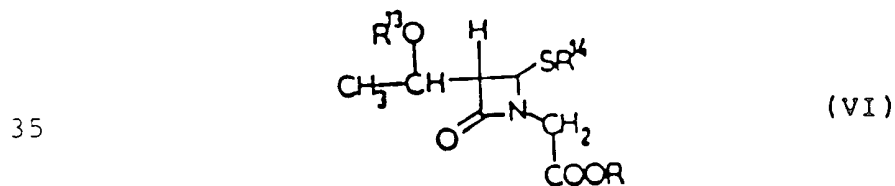
21. A process as claimed in claim 20, wherein a silyl group is a diphenyl-t-butylsilyl or methyldiphenylsilyl
20 group, and a stannyl group is a tri-n-butylstannyl group.

22. A process as claimed in claim 18, wherein R^{13} represents a tetrahydropyranyl, 2-methoxyprop-2-yl, trimethylsilyl, triethylsilyl or t-butyldimethylsilyl
group.

25 23. A process as claimed in any one of claims 17 to 22, wherein R^{23} represents a silyl group.

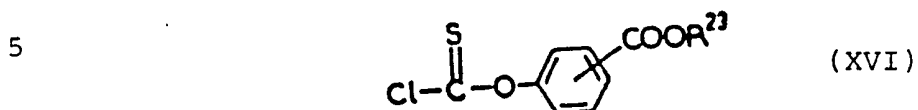
24. A process as claimed in claim 23, wherein R^{23} represents a diphenyl-t-butylsilyl group.

25. A process as claimed in any one of claims 15 to 24,
30 wherein a compound of formula XII is produced by reacting a compound of formula VI



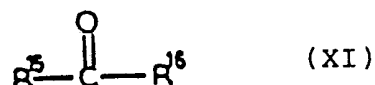
in which R is as defined in claim 1, and R^{13} is as defined

in claim 15, in the presence of a base with a compound of formula XVI



10 in which R²³ is as defined in any one of claims 15 to 17, 23 and 24, followed by reaction with an activated carboxylic acid derivative comprising the group R¹⁵ as defined in claim 7.

26. A process as claimed in claim 25, wherein the activated carboxylic acid derivative is an acyl halide of
15 formula XI



20 in which R¹⁵ is as defined in claim 7 and R¹⁶ represents a chlorine or bromine atom.

27. A process as claimed in claim 25 or claim 26, wherein the base has a pK_a > 20.

28. A process as claimed in claim 27, wherein the base is
25 a metallated amine.

29. A process as claimed in claim 28, wherein the base is lithium diisopropylamide, lithium hexamethyldisilazide, lithium 2,2,6,6-tetramethylpiperidide, lithium cyclohexyl isopropylamide or sodamide.

30 30. A process as claimed in claim 7, carried out substantially as described in Example 6 or Example 19 herein.

31. A compound of formula V as claimed in claim 1, whenever produced by a process as claimed in any one of
35 claims 7 to 31.

32. A process as claimed in any one of claims 4 to 6, wherein the compound of formula V is as claimed in claim 31.

33. A process as claimed in claim 6, carried out substantially as described in Example 7 or Example 20 herein.

34. A compound of formula II as claimed in claim 1, whenever produced by a process as claimed in any one of claims 4 to 6, 32 and 33.