(54) Title: INOSINE MONOPHOSPHATE DEHYDROGENASE INHIBITORS AS PHOSPHONATE DERIVATIVES

(57) Abstract:
Phosphorus substituted mycophenolate derivatives with anti-cancer, anti-viral, anti-inflammatory and anti-tissue/organ transplant rejection properties having use as therapeutics and for other industrial purposes are disclosed. The compositions inhibit tumor growth, viral growth, inflammation, and tissue/organ transplant rejection and/or are useful therapeutically for the treatment or prevention of cancer, viral infection, inflammation and tissue/organ transplant rejection, as well as in assays for the detection of cancer, viral infection, inflammation and tissue/organ transplant rejection.
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THERAPEUTIC PHOSPHONATE DERIVATIVES

FIELD OF THE INVENTION

The invention relates generally to compounds with immunosuppressive, anti-inflammatory, anti-cancer and anti-viral activity.

PRIORITY OF THE INVENTION


BACKGROUND OF THE INVENTION

Improving the delivery of drugs and other agents to target cells and tissues has been the focus of considerable research for many years. Though many attempts have been made to develop effective methods for importing biologically active molecules into cells, both in vivo and in vitro, none has proved to be entirely satisfactory. Optimizing the association of the inhibitory drug with its intracellular target, while minimizing intercellular redistribution of the drug, e.g., to neighboring cells, is often difficult or inefficient.

Most agents currently administered to a patient parenterally are not targeted, resulting in systemic delivery of the agent to cells and tissues of the body where it is unnecessary, and often undesirable. This may result in adverse drug side effects, and often limits the dose of a drug (e.g., glucocorticoids and other anti-inflammatory drugs) that can be administered. By comparison, although oral administration of drugs is generally recognized as a convenient and economical method of administration, oral administration can result in either (a) uptake of the drug through the cellular and tissue barriers, e.g., blood/brain, epithelial, cell membrane, resulting in undesirable systemic distribution, or (b) temporary residence of the drug within the gastrointestinal tract. Accordingly, a major goal has been to develop methods for specifically targeting agents to cells
and tissues. Benefits of such treatment includes avoiding the general physiological effects of inappropriate delivery of such agents to other cells and tissues, such as uninfected cells.

Mycophenolic acid is a weakly-active antibiotic found in the fermentation broth of *Penicillium brevicompactum* (Allison et al. US4786637 and Nelson et al. US4753935). Mycophenolate mofetil, a prodrug of mycophenolic acid, is used for prevention of acute renal and cardiac allograft rejection in combination with cyclosporine (Sandoz' Sandimmune) and corticosteroids (The Pink Sheet, 1995, 57, 20). Mycophenolate mofetil is rapidly converted after oral or intravenous administration to its active metabolite, mycophenolic acid (Lee et al. *Pharm Res*, 1990, 7, 161). In fact, over 90% of the drug is cleared by glucuronidation and is excreted in the urine.

Mycophenolic acid is a noncompetitive, selective and reversible inhibitor of inosine monophosphate dehydrogenase (IMPDH), an important enzyme in the *de novo* synthesis of guanosine nucleotides in T and B lymphocytes (Brazelton, T. R., Morris, R. E. *Current Opinion in Immunology*, 1996, 8, 710), (Fulton, B, Markham, A, *Drugs*, 1996, 51,2,278). IMPDH catalyzes the NAD-dependent oxidation of inosine 5'-monophosphate (IMP) to xanthate 5'-monophosphate. Rapidly proliferating cells and/or viral infections are heavily dependent on the availability of large nucleotide pools to meet their metabolic requirements. Compounds blocking this *de novo* biosynthesis pathway will act selectively on these cell types and leave the other ones substantially unaffected. Several classes of IMPDH inhibitors are now in use or under development, such as inhibitors that bind to the substrate site (ribavirin) or the NAD site (mycophenolic acid) (Goldstein, B. M., Colby, T. D. *Current Medicinal Chemistry*, 1999, 6, 7, 519).
Mycophenolate mofetil requires a 2-3 g/day dosing regimen in conjunction with other immunosuppressants. Although MMF is comparatively benign, gastrointestinal adverse effects have been observed (Platz et al. Transplantation, 1991, 51, 1, 27). These adverse effects have been explained as the result of the combination therapy necessary for efficacy of the MMF drug. In some cases, adjustment of dosage of the immunosuppressants, particularly spreading the total dosage to 2 or more, may be sufficient (Behrad, M. Drug Saf 2001, 24, 9, 645). Reduction of the dose, increase of $t_{1/2}$, and improvement of efficacy by targeted delivery of this drug may be achieved by preparation of other prodrugs that have better intracellular trapping. The present invention describes preparation of phosphonate prodrugs of mycophenolic acid.

Organ transplant rejection is a major problem for transplant recipients. Although anti-rejection drugs are commonly used, they are not always effective and often times are toxic over the long term.

Inflammation is also a major problem for many people, and effective and safe drugs, with limited side effects, are in need.

Cancer is another major health problem worldwide. Although drugs targeting tumors and cancerous cells are in wide use and have shown effectiveness, toxicity and side-effects have limited their usefulness.

Finally, viral infections are a major public health problem worldwide. Although drugs targeting viruses are in wide use and have shown effectiveness, toxicity and development of resistant strains have limited their usefulness.

Assay methods capable of determining the presence, absence or amounts of organ rejection, inflammation, cancer and viral infections are of practical utility in the search for inhibitors as well as for diagnosing the presence of organ rejection, inflammation, cancer and viral infections.

Inhibitors of viruses are useful to limit the establishment and progression of infection by a virus as well as in diagnostic assays for viral infections.

Inhibitors of tumor growth are useful to limit the establishment and progression of cancer, as well as in diagnostic assays for cancer.

Inflammation inhibitors are useful for inhibiting inflammation. Finally, immunosuppressants are useful for suppressing the immune response to a foreign organ or tissue.
There is a need for anti-cancer, anti-viral, anti-inflammation and anti-rejection (i.e. immunosuppressive) therapeutic agents, i.e. drugs, having improved anti-cancer, anti-viral, anti-inflammation or immunosuppressive properties, as well as pharmacokinetic properties, including enhanced activity against development of cancer, viral infection, inflammation and organ rejection, improved oral bioavailability, greater potency and extended effective half-life in vivo. Such inhibitors should be active against various cancers, mutant virus strains, inflammation and tissue/organ rejection, have distinct resistance profiles, fewer side effects, less complicated dosing schedules, and orally active. In particular, there is a need for a less onerous dosage regimen, such as one pill, once per day.

SUMMARY OF THE INVENTION

Intracellular targeting may be achieved by methods and compositions that allow accumulation or retention of biologically active agents inside cells. The present invention provides novel analogs of compounds that inhibit tumor growth, viral infection, inflammation, and tissue/organ rejection. Such novel compounds possess all the utilities of mycophenolic acid and its derivatives, and optionally provide cellular accumulation as set forth below.

The present invention relates generally to the accumulation or retention of therapeutic compounds inside cells. The invention is more particularly related to attaining high concentrations of phosphonate-containing molecules in target cells. Such effective targeting may be applicable to a variety of therapeutic formulations and procedures.

Compositions of the invention include mycophenolic acid derivatives having at least one phosphonate group. Accordingly, in one embodiment the invention provides a compound of formula I or II
wherein:

$A^0$ is $A^1$;

$A^1$ is:

\[
\begin{align*}
    &\begin{array}{c}
        Y^2 \\
        \left[ \begin{array}{c}
            R^2 \\
            R^2
        \end{array} \right]
    \end{array} \\
    &\begin{array}{c}
        M12a \\
        M12b
    \end{array}
\end{align*}
\]

$A^3$ is:

\[
\begin{align*}
    &\begin{array}{c}
        Y^1 \\
        \left[ \begin{array}{c}
            R^2 \\
            R^2
        \end{array} \right]
    \end{array} \\
    &\begin{array}{c}
        M12a \\
        M12b
    \end{array}
\end{align*}
\]

$Y^1$ is independently O, S, N(R^x), N(OR^x), or N(N(R^x)(R^x));

$Y^2$ is independently a bond, O, N(R^x), N(OR^x), N(N(R^x)(R^x)), or $\text{S(O)}_{M2}$; and when $Y^2$ joins two phosphorous atoms $Y^2$ can also be C(R^2)(R^2);

$R^x$ is independently H, R^2, W^3, a protecting group, or the formula:

\[
\begin{align*}
    &\begin{array}{c}
        Y^1 \\
        \left[ \begin{array}{c}
            R^y \\
            R^y
        \end{array} \right]
    \end{array} \\
    &\begin{array}{c}
        M1a \\
        M12c \\
        M1c \\
        M1d
    \end{array}
\end{align*}
\]

$R^y$ is independently H, W^3, R^2 or a protecting group;

$R^1$ is independently H or alkyl of 1 to 18 carbon atoms;
R² is independently H, R³ or R⁴ wherein each R⁴ is independently substituted with 0 to 3 R³ groups;  
R³ is R³α, R³β, R³γ or R³δ, provided that when R³ is bound to a heteroatom, then R³ is R³α or R³δ;  
R³α is F, Cl, Br, I, -CN, N₃ or -NO₂;  
R³β is Y¹;  
R³γ is -R⁸, -N(R⁸)(R⁸), -SR⁸, -S(O)R⁸, -S(O)₂R⁸, -S(O)(OR⁸), -S(O)₂(OR⁸), -OC(Y¹)R⁸, -OC(Y¹)OR⁸, -OC(Y¹)(N(R⁸)(R⁸)), -SC(Y¹)R⁸, -SC(Y¹)OR⁸, -SC(Y¹)(N(R⁸)(R⁸)), -N(R⁸)C(Y¹)R⁸, -N(R⁸)C(Y¹)OR⁸, or -N(R⁸)₃C(Y¹)(N(R⁸)(R⁸));  
R³δ is -C(Y¹)R⁸, -C(Y¹)OR⁸ or -C(Y¹)(N(R⁸)(R⁸));  
R⁴ is an alkyl of 1 to 18 carbon atoms, alkenyl of 2 to 18 carbon atoms, or alkynyl of 2 to 18 carbon atoms;  
R⁵ is R⁴ wherein each R⁴ is substituted with 0 to 3 R³ groups;  
R⁵α is independently alkylene of 1 to 18 carbon atoms, alkenylene of 2 to 18 carbon atoms, or alkynylene of 2-18 carbon atoms any one of which alkylene, alkenylene or alkynylene is substituted with 0-3 R³ groups;  
W⁵ is W⁴ or W⁵;  
W⁴ is R⁵, -C(Y¹)R⁵, -C(Y¹)W⁵, -SO₂R⁵, or -SO₂W⁵;  
W⁵ is carbocycle or heterocycle wherein W³ is independently substituted with 0 to 3 R² groups;  
W⁶ is W³ independently substituted with 1, 2, or 3 A³ groups;  
M₂ is 0, 1 or 2;  
M₁₂a is 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11 or 12;  
M₁₂b is 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11 or 12;  
M₁₈a, M₁₈c, and M₁₈d are independently 0 or 1;  
M₁₂c is 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11 or 12; and  
R²₀ is ethyl or vinyl.  
The invention provides a pharmaceutical composition comprising an effective amount of a compound of the invention, or a pharmaceutically acceptable salt or solvate thereof, in combination with a pharmaceutically acceptable excipient.
The invention also provides a method of inhibiting tumor growth, viral infection, inflammation, or tissue/organ transplant rejection, comprising administering to a mammal afflicted with one of the above disorders with an amount of a compound of Formula I or II effective to inhibit the growth of said tumor cells, to inhibit growth of said virus, to inhibit inflammation, or to suppress the immune systems response to said transplanted tissue or organ..

The invention also provides a compound of Formula I or II for use in medical therapy (preferably for use in treating cancer, e.g. solid tumors), as well as the use of a compound of Formula I or II for the manufacture of a medicament useful for the treatment of cancer, e.g. solid tumors, for the treatment of viral infections, for the treatment of inflammation, or for immunosuppression.

The invention also provides processes and novel intermediates disclosed herein which are useful for preparing compounds of the invention. Some of the compounds of Formula I or II are useful to prepare other compounds of Formula I or II.

In another aspect of the invention, the tumor growth, viral infection, inflammation or tissue/organ transplant rejection is inhibited by a method comprising the step of treating a sample suspected of containing a tumor or a virus, or suspected of being inflammatied or rejected, with a compound or composition of the invention.

Compounds of the invention wherein R\textsuperscript{20} is ethyl or vinyl are typically more potent than the corresponding compounds wherein R\textsuperscript{20} is methoxy.

**DETAILED DESCRIPTION OF EXEMPLARY CLAIMS**

Reference will now be made in detail to certain embodiments of the invention, examples of which are illustrated in the accompanying structures and formulas. While the invention will be described in conjunction with the specific embodiments, it will be understood that they are not intended to limit the invention to those embodiments. On the contrary, the invention is intended to cover all alternatives, modifications, and equivalents, which may be included within the scope of the present invention as defined herein and by the claims.
Unless stated otherwise, the following terms and phrases as used herein are intended to have the following meanings:

When tradenames are used herein, applicants intend to independently include the tradename product and the active pharmaceutical ingredient(s) of the tradename product.

"Bioavailability" is the degree to which the pharmaceutically active agent becomes available to the target tissue after the agent's introduction into the body. Enhancement of the bioavailability of a pharmaceutically active agent can provide a more efficient and effective treatment for patients because, for a given dose, more of the pharmaceutically active agent will be available at the targeted tissue sites.

The terms "phosphonate" and "phosphonate group" include functional groups or moieties within a molecule that comprises a phosphorous that is 1) single-bonded to a carbon, 2) double-bonded to a heteroatom, 3) single-bonded to a heteroatom, and 4) single-bonded to another heteroatom, wherein each heteroatom can be the same or different. The terms "phosphonate" and "phosphonate group" also include functional groups or moieties that comprise a phosphorous in the same oxidation state as the phosphorous described above, as well as functional groups or moieties that comprise a prodrug moiety that can separate from a compound so that the compound retains a phosphorous having the characteristics described above. For example, the terms "phosphonate" and "phosphonate group" include phosphonic acid, phosphonic monoester, phosphonic diester, phosphonamidate, and phosphonothioate functional groups.

In one specific embodiment of the invention, the terms "phosphonate" and "phosphonate group" include functional groups or moieties within a molecule that comprises a phosphorous that is 1) single-bonded to a carbon, 2) double-bonded to an oxygen, 3) single-bonded to an oxygen, and 4) single-bonded to another oxygen, as well as functional groups or moieties that comprise a prodrug moiety that can separate from a compound so that the compound retains a phosphorous having such characteristics. In another specific embodiment of the invention, the terms "phosphonate" and "phosphonate group" include functional groups or moieties within a molecule that comprises a phosphorous that is 1) single-bonded to a carbon, 2) double-bonded to an oxygen, 3) single-bonded to
an oxygen or nitrogen, and 4) single-bonded to another oxygen or nitrogen, as well as functional groups or moieties that comprise a prodrug moiety that can separate from a compound so that the compound retains a phosphorous having such characteristics.

The term “prodrug” as used herein refers to any compound that when administered to a biological system generates the drug substance, i.e. active ingredient, as a result of spontaneous chemical reaction(s), enzyme catalyzed chemical reaction(s), photolysis, and/or metabolic chemical reaction(s). A prodrug is thus a covalently modified analog or latent form of a therapeutically-active compound.

“Prodrug moiety” refers to a labile functional group which separates from the active inhibitory compound during metabolism, systemically, inside a cell, by hydrolysis, enzymatic cleavage, or by some other process (Bundgaard, Hans, “Design and Application of Prodrugs” in A Textbook of Drug Design and Development (1991), P. Krogsgaard-Larsen and H. Bundgaard, Eds. Harwood Academic Publishers, pp. 113-191). Enzymes which are capable of an enzymatic activation mechanism with the phosphonate prodrug compounds of the invention include, but are not limited to, amidases, esterases, microbial enzymes, phospholipases, cholinesterases, and phosphates. Prodrug moieties can serve to enhance solubility, absorption and lipophilicity to optimize drug delivery, bioavailability and efficacy. A prodrug moiety may include an active metabolite or drug itself.

Exemplary prodrug moieties include the hydrolytically sensitive or labile acyloxymethyl esters \(-\text{CH}_2\text{OC}(=\text{O})\text{R}^9\) and acyloxymethyl carbonates \(-\text{CH}_2\text{OC}(=\text{O})\text{OR}^9\) where \(\text{R}^9\) is \(\text{C}_1-\text{C}_6\) alkyl, \(\text{C}_1-\text{C}_6\) substituted alkyl, \(\text{C}_6-\text{C}_{20}\) aryl or \(\text{C}_6-\text{C}_{20}\) substituted aryl. The acyloxyalkyl ester was first used as a prodrug strategy for carboxylic acids and then applied to phosphates and phosphonates by Farquhar et al. (1983) J. Pharm. Sci. 72: 324; also US Patent Nos. 4816570, 4968788, 5663159 and 5792756. Subsequently, the acyloxyalkyl ester was used to deliver phosphonic acids across cell membranes and to enhance oral bioavailability. A close variant of the acyloxyalkyl ester, the alkoxy carbonyloxyalkyl ester (carbonate), may also enhance oral bioavailability.
as a prodrug moiety in the compounds of the combinations of the invention. An exemplary acyloxymethyl ester is pivaloyloxymethoxy, (POM) \(-\text{CH}_2\text{OC}(=\text{O})\text{C(CH}_3)_3\). An exemplary acyloxymethyl carbonate prodrug moiety is pivaloyloxymethylcarbonate (POC) \(-\text{CH}_2\text{OC}(=\text{O})\text{OC(CH}_3)_3\).

The phosphonate group may be a phosphonate prodrug moiety. The prodrug moiety may be sensitive to hydrolysis, such as, but not limited to a pivaloyloxymethyl carbonate (POC) or POM group. Alternatively, the prodrug moiety may be sensitive to enzymatic potentiated cleavage, such as a lactate ester or a phosphonamidate-ester group.

Aryl esters of phosphorus groups, especially phenyl esters, are reported to enhance oral bioavailability (De Lombaert et al. (1994) *J. Med. Chem.* 37: 498). Phenyl esters containing a carboxylic ester ortho to the phosphate have also been described (Khamnei and Torrence, (1996) *J. Med. Chem.* 39:4109-4115). Benzyl esters are reported to generate the parent phosphonic acid. In some cases, substituents at the *ortho*-or *para*-position may accelerate the hydrolysis. Benzyl analogs with an acylated phenol or an alkylated phenol may generate the phenolic compound through the action of enzymes, *e.g.*, esterases, oxidases, etc., which in turn undergoes cleavage at the benzylic C–O bond to generate the phosphoric acid and the quinone methide intermediate. Examples of this class of prodrugs are described by Mitchell et al. (1992) *J. Chem. Soc. Perkin Trans. II* 2345; Glazier WO 91/19721. Still other benzylic prodrugs have been described containing a carboxylic ester-containing group attached to the benzylic methylene (Glazier WO 91/19721). Thio-containing prodrugs are reported to be useful for the intracellular delivery of phosphonate drugs. These proesters contain an ethylthio group in which the thiol group is either esterified with an acyl group or combined with another thiol group to form a disulfide. Deesterification or reduction of the disulfide generates the free thio intermediate which subsequently breaks down to the phosphoric acid and episolufide (Puech et al. (1993) *Antiviral Res.*, 22: 155-174; Benzaria et al. (1996) *J. Med. Chem.* 39: 4958). Cyclic phosphonate esters have also been described as prodrugs of phosphorus-containing compounds (Erion et al., US Patent No. 6312662).
"Protecting group" refers to a moiety of a compound that masks or alters the properties of a functional group or the properties of the compound as a whole. Chemical protecting groups and strategies for protection/deprotection are well known in the art. See e.g., *Protective Groups in Organic Chemistry*, Theodora W. Greene, John Wiley & Sons, Inc., New York, 1991. Protecting groups are often utilized to mask the reactivity of certain functional groups, to assist in the efficiency of desired chemical reactions, e.g., making and breaking chemical bonds in an ordered and planned fashion. Protection of functional groups of a compound alters other physical properties besides the reactivity of the protected functional group, such as the polarity, lipophilicity (hydrophobicity), and other properties which can be measured by common analytical tools. Chemically protected intermediates may themselves be biologically active or inactive.

Protected compounds may also exhibit altered, and in some cases, optimized properties *in vitro* and *in vivo*, such as passage through cellular membranes and resistance to enzymatic degradation or sequestration. In this role, protected compounds with intended therapeutic effects may be referred to as prodrugs. Another function of a protecting group is to convert the parental drug into a prodrug, whereby the parental drug is released upon conversion of the prodrug *in vivo*. Because active prodrugs may be absorbed more effectively than the parental drug, prodrugs may possess greater potency *in vivo* than the parental drug. Protecting groups are removed either *in vitro*, in the instance of chemical intermediates, or *in vivo*, in the case of prodrugs. With chemical intermediates, it is not particularly important that the resulting products after deprotection, e.g., alcohols, be physiologically acceptable, although in general it is more desirable if the products are pharmacologically innocuous.

Any reference to any of the compounds of the invention also includes a reference to a physiologically acceptable salt thereof. Examples of physiologically acceptable salts of the compounds of the invention include salts derived from an appropriate base, such as an alkali metal (for example, sodium), an alkaline earth (for example, magnesium), ammonium and NX₄⁺ (wherein X is C₁–C₄ alkyl). Physiologically acceptable salts of an hydrogen atom or an amino
group include salts of organic carboxylic acids such as acetic, benzoic, lactic, fumaric, tartaric, maleic, malonic, malic, isethionic, lactobionic and succinic acids; organic sulfonic acids, such as methanesulfonic, ethanesulfonic, benzenesulfonic and p-toluenesulfonic acids; and inorganic acids, such as hydrochloric, sulfuric, phosphoric and sulfamic acids. Physiologically acceptable salts of a compound of an hydroxy group include the anion of said compound in combination with a suitable cation such as Na\(^+\) and NX\(_4\)\(^+\) (wherein X is independently selected from H or a C\(_1\)–C\(_4\) alkyl group).

For therapeutic use, salts of active ingredients of the compounds of the invention will be physiologically acceptable, i.e. they will be salts derived from a physiologically acceptable acid or base. However, salts of acids or bases which are not physiologically acceptable may also find use, for example, in the preparation or purification of a physiologically acceptable compound. All salts, whether or not derived form a physiologically acceptable acid or base, are within the scope of the present invention.

“Alkyl” is C\(_1\)–C\(_{18}\) hydrocarbon containing normal, secondary, tertiary or cyclic carbon atoms. Examples are methyl (Me, -CH\(_3\)), ethyl (Et, -CH\(_2\)CH\(_3\)), 1-propyl (n-Pr, n-propyl, -CH\(_2\)CH\(_2\)CH\(_3\)), 2-propyl (i-Pr, i-propyl, -CH(CH\(_3\))\(_2\)), 1-butyl (n-Bu, n-butyl, -CH\(_2\)CH\(_2\)CH\(_2\)CH\(_3\)), 2-methyl-1-propyl (i-Bu, i-butyl, -CH\(_2\)CH(CH\(_3\))\(_2\)), 2-butyl (s-Bu, s-butyl, -CH(CH\(_3\))CH\(_2\)CH\(_3\)), 2-methyl-2-propyl (t-Bu, t-butyl, -C(CH\(_3\))\(_3\)), 1-pentyl (n-pentyl, -CH\(_2\)CH\(_2\)CH\(_2\)CH\(_2\)CH\(_3\)), 2-pentyl (-CH(CH\(_3\))CH\(_2\)CH\(_2\)CH\(_3\)), 3-pentyl (-CH(CH\(_2\)CH\(_3\))\(_2\)), 2-methyl-2-butyl (-C(CH\(_3\))\(_2\)CH\(_2\)CH\(_3\)), 3-methyl-2-butyl (-CH(CH\(_3\))CH(CH\(_3\))\(_2\)), 3-methyl-1-butyl (-CH\(_2\)CH\(_2\)CH(CH\(_3\))\(_2\)), 2-methyl-1-butyl (-CH\(_2\)CH(CH\(_3\))CH\(_2\)CH\(_3\)), 1-hexyl (-CH\(_2\)CH\(_2\)CH\(_2\)CH\(_2\)CH\(_2\)CH\(_3\)), 2-hexyl (-CH(CH\(_3\))CH\(_2\)CH\(_2\)CH\(_2\)CH\(_3\)), 3-hexyl (-CH(CH\(_2\)CH\(_3\))CH(CH\(_2\)CH\(_3\))), 2-methyl-2-pentyl (-C(CH\(_3\))\(_2\)CH\(_2\)CH\(_2\)CH\(_3\)), 3-methyl-2-pentyl (-CH(CH\(_3\))CH(CH\(_3\))CH\(_2\)CH\(_3\)), 4-methyl-2-pentyl (-CH(CH\(_3\))CH\(_2\)CH(CH\(_3\))\(_2\)), 3-methyl-3-pentyl (-C(CH\(_3\))(CH\(_2\)CH\(_3\))\(_2\)), 2-methyl-3-pentyl (-CH(CH\(_2\)CH\(_3\))CH(CH\(_3\))\(_2\)), 2,3-dimethyl-2-butyl (-C(CH\(_3\))\(_2\)CH(CH\(_3\))\(_2\)), 3,3-dimethyl-2-butyl (-CH(CH\(_3\))C(CH\(_3\))\(_3\)).
“Alkenyl” is C2-C18 hydrocarbon containing normal, secondary, tertiary or cyclic carbon atoms with at least one site of unsaturation, i.e. a carbon-carbon, $sp^2$ double bond. Examples include, but are not limited to, ethylene or vinyl (-CH=CH₂), allyl (-CH₂CH=CH₂), cyclopentenyl (-C₅H₇), and 5-hexenyl (-CH₂CH₂CH₂CH=CH₂).

“Alkynyl” is C2-C18 hydrocarbon containing normal, secondary, tertiary or cyclic carbon atoms with at least one site of unsaturation, i.e. a carbon-carbon, $sp$ triple bond. Examples include, but are not limited to, acetylenic (-C≡CH) and propargyl (-CH₂C≡CH).

“Alkyne” refers to a saturated, branched or straight chain or cyclic hydrocarbon radical of 1-18 carbon atoms, and having two monovalent radical centers derived by the removal of two hydrogen atoms from the same or two different carbon atoms of a parent alkane. Typical alkyne radicals include, but are not limited to, methylene (-CH₂-), 1,2-ethyl (-CH₂CH₂-), 1,3-propyl (-CH₂CH₂CH₂-), 1,4-butyl (-CH₂CH₂CH₂CH₂-), and the like.

“Alkenylene” refers to an unsaturated, branched or straight chain or cyclic hydrocarbon radical of 2-18 carbon atoms, and having two monovalent radical centers derived by the removal of two hydrogen atoms from the same or two different carbon atoms of a parent alkene. Typical alkenylene radicals include, but are not limited to, 1,2-ethylene (-CH=CH-).

“Alkynylene” refers to an unsaturated, branched or straight chain or cyclic hydrocarbon radical of 2-18 carbon atoms, and having two monovalent radical centers derived by the removal of two hydrogen atoms from the same or two different carbon atoms of a parent alkyne. Typical alkynylene radicals include, but are not limited to, acetylene (-C≡C-), propargyl (-CH₂C≡CH-), and 4-pentynyl (-CH₂CH₂CH₂C≡CH-).

“Aryl” means a monovalent aromatic hydrocarbon radical of 6-20 carbon atoms derived by the removal of one hydrogen atom from a single carbon atom of a parent aromatic ring system. Typical aryl groups include, but are not limited to, radicals derived from benzene, substituted benzene, naphthalene, anthracene, biphenyl, and the like.
"Arylalkyl" refers to an acyclic alkyl radical in which one of the hydrogen atoms bonded to a carbon atom, typically a terminal or sp\(^3\) carbon atom, is replaced with an aryl radical. Typical arylalkyl groups include, but are not limited to, benzyl, 2-phenylethan-1-yl, naphthylmethyl, 2-naphthylethan-1-yl, naphthobenzyl, 2-naphthophenylethan-1-yl and the like. The arylalkyl group comprises 6 to 20 carbon atoms, e.g., the alkyl moiety, including alkanyl, alkenyl or alkynyl groups, of the arylalkyl group is 1 to 6 carbon atoms and the aryl moiety is 5 to 14 carbon atoms.

"Substituted alkyl", "substituted aryl", and "substituted arylalkyl" mean alkyl, aryl, and arylalkyl respectively, in which one or more hydrogen atoms are each independently replaced with a non-hydrogen substituent. Typical substituents include, but are not limited to, -X, -R, -O\(^-\), -OR, -SR, -S\(^-\), -NR\(_2\), -NR\(_3\), =NR, -CX\(_3\), -CN, -OCN, -SCN, -N=C=O, -NCS, -NO\(_2\), -NO\(_3\), =N\(_2\), -N\(_3\), NC(=O)R, -C(=O)R, -C(=O)NRR -S(=O)\(_2\)O\(^-\), -S(=O)\(_2\)OH, -S(=O)\(_2\)R, -OS(=O)\(_2\)OR, -S(=O)\(_2\)NR, -S(=O)R, -OP(=O)O\(_2\)RR, -P(=O)O\(_2\)RR -P(=O)(O')\(_2\), -P(=O)(OH)\(_2\), -C(=O)R, -C(=O)X, -C(S)R, -C(O)OR, -C(O)O', -C(S)OR, -C(O)SR, -C(S)SR, -C(O)NRR, -C(S)NRR, -C(NR)NRR, where each X is independently a halogen: F, Cl, Br, or I; and each R is independently -H, alkyl, aryl, heterocycle, protecting group or prodrug moiety. Alkylene, alkenylene, and alkynylene groups may also be similarly substituted.

"Heterocycle" as used herein includes by way of example and not limitation these heterocycles described in Paquette, Leo A.; Principles of Modern Heterocyclic Chemistry (W.A. Benjamin, New York, 1968), particularly Chapters 1, 3, 4, 6, 7, and 9; The Chemistry of Heterocyclic Compounds, A Series of Monographs” (John Wiley & Sons, New York, 1950 to present), in particular Volumes 13, 14, 16, 19, and 28; and J. Am. Chem. Soc. (1960) 82:5566. In one specific embodiment of the invention "heterocycle" includes a "carbocycle" as defined herein, wherein one or more (e.g. 1, 2, 3, or 4) carbon atoms have been replaced with a heteroatom (e.g. O, N, or S).

Examples of heterocycles include by way of example and not limitation pyridyl, dihydropyridyl, tetrahydropyridyl (piperidyl), thiazolyl, tetrahydrothiophenyl, sulfur oxidized tetrahydrothiophenyl, pyrimidinyl, furanyl, thienyl, ppyrrol, pyrazolyl, imidazolyl, tetrazolyl, benzofuranyl,
thianaphthalenyl, indolyl, indolenyl, quinolinyl, isoquinolinyl, benzimidazolyl, piperidinyl, 4-piperidonyl, pyrrolidinyl, 2-pyrrolidonyl, pyrrolinyl, tetrahydrofuranyl, tetrahydroquinolinyl, tetrahydroisoquinolinyl, decahydroquinolinyl, octahydroisoquinolinyl, azocinyl, triazinyl, 6H-1,2,5-thiadiazinyl, 2H,6H-1,5,2-dithiazinyl, thienyl, thianthrenyl, pyranyl, isobenzofuranyl, chromenyl, xanthenyl, phenoxathinyl, 2H-pyrrolyl, isothiazolyl, isoxazolyl, pyrazinyl, pyridazinyl, indolizinyl, isoindolyl, 3H-indolyl, 1H-indazoly, purinyl, 4H-quinolizinyl, phthalazinyl, naphthyridinyl, quinoxalinyl, quinazolinyl, cinnolinyl, pteridinyl, 4aH-carbazolyl, carbazolyl, β-carbolinyl, phenanthridinyl, acridinyl, pyrimidinyl, phenanthrolinyl, phenazinyl, phenothiazinyl, furazanyl, phenoxazinyl, isochromanyl, chromanyl, imidazolidinyl, imidazolyl, pyrazolidinyl, pyrazolyl, piperazinyl, indolyl, isoindolyl, quinuclidinyl, morpholinyl, oxazolidinyl, benzotriazolyl, benzisoxazolyl, oxindolyl, benzoxazolyl, isatinoyl, and bis-tetrahydrofuranyl:

By way of example and not limitation, carbon bonded heterocycles are bonded at position 2, 3, 4, 5, or 6 of a pyridine, position 3, 4, 5, or 6 of a pyridazine, position 2, 4, 5, or 6 of a pyrimidine, position 2, 3, 5, or 6 of a pyrazine, position 2, 3, 4, or 5 of a furan, tetrahydrofuran, thiofuran, thiophene, pyrrole or tetrahydropyrrole, position 2, 4, or 5 of an oxazole, imidazole or thiazole, position 3, 4, or 5 of an isoxazole, pyrazole, or isothiazole, position 2 or 3 of an aziridine, position 2, 3, or 4 of an azetidine, position 2, 3, 4, 5, 6, 7, or 8 of a quinoline or position 1, 3, 4, 5, 6, 7, or 8 of an isoquinoline. Still more typically, carbon bonded heterocycles include 2-pyridyl, 3-pyridyl, 4-pyridyl, 5-pyridyl, 6-pyridyl, 3-pyridazinyl, 4-pyridazinyl, 5-pyridazinyl, 6-pyridazinyl, 2-pyrimidinyl, 4-pyrimidinyl, 5-pyrimidinyl, 6-pyrimidinyl, 2-pyrazinyl, 3-pyrazinyl, 5-pyrazinyl, 6-pyrazinyl, 2-thiazolyl, 4-thiazolyl, or 5-thiazolyl.

By way of example and not limitation, nitrogen bonded heterocycles are bonded at position 1 of an aziridine, azetidine, pyrrole, pyrrolidine, 2-pyrroline, 3-pyrroline, imidazole, imidazolidine, 2-imidazoline, 3-imidazoline, pyrazole,
pyrazoline, 2-pyrazoline, 3-pyrazoline, piperidine, piperazine, indole, indolone, 1H-indazole, position 2 of a isoindole, or isoindoline, position 4 of a morpholine, and position 9 of a carbazole, or β-carbol ine. Still more typically, nitrogen bonded heterocycles include 1-aziridyl, 1-azetidyl, 1-pyrrolyl, 1-imidazolyl, 1-pyrazolyl, and 1-piperidinyl.

"Carbocycle" refers to a saturated, unsaturated or aromatic ring having 3 to 7 carbon atoms as a monocycle, 7 to 12 carbon atoms as a bicycle, and up to about 20 carbon atoms as a polycycle. Monocyclic carbocycles have 3 to 6 ring atoms, still more typically 5 or 6 ring atoms. Bicyclic carbocycles have 7 to 12 ring atoms, e.g., arranged as a bicyclo [4,5], [5,5], [5,6] or [6,6] system, or 9 or 10 ring atoms arranged as a bicyclo [5,6] or [6,6] system. Examples of monocyclic carbocycles include cyclopropyl, cyclobutyl, cyclopentyl, 1-cyclopent-1-enyl, 1-cyclopent-2-enyl, 1-cyclopent-3-enyl, cyclohexyl, 1-cyclohex-1-enyl, 1-cyclohex-2-enyl, 1-cyclohex-3-enyl, phenyl, spiryl and naphthyl.

The term "chiral" refers to molecules which have the property of non-superimposability of the mirror image partner, while the term "achiral" refers to molecules which are superimposable on their mirror image partner.

The term "stereoisomers" refers to compounds which have identical chemical constitution, but differ with regard to the arrangement of the atoms or groups in space.

"Diastereomer" refers to a stereoisomer with two or more centers of chirality and whose molecules are not mirror images of one another. Diastereomers have different physical properties, e.g., melting points, boiling points, spectral properties, and reactivities. Mixtures of diastereomers may separate under high resolution analytical procedures such as electrophoresis and chromatography.

"Enantiomers" refer to two stereoisomers of a compound which are non-superimposable mirror images of one another.

The term "treatment" or "treating," to the extent it relates to a disease or condition includes preventing the disease or condition from occurring, inhibiting the disease or condition, eliminating the disease or condition, and/or relieving one or more symptoms of the disease or condition.
Stereochemical definitions and conventions used herein generally follow S. P. Parker, Ed., McGraw-Hill Dictionary of Chemical Terms (1984) McGraw-Hill Book Company, New York; and Elie, E. and Wilen, S., Stereochemistry of Organic Compounds (1994) John Wiley & Sons, Inc., New York. Many organic compounds exist in optically active forms, i.e., they have the ability to rotate the plane of plane-polarized light. In describing an optically active compound, the prefixes D and L or R and S are used to denote the absolute configuration of the molecule about its chiral center(s). The prefixes d and l or (+) and (-) are employed to designate the sign of rotation of plane-polarized light by the compound, with (-) or 1 meaning that the compound is levorotatory. A compound prefixed with (+) or d is dextrorotatory. For a given chemical structure, these stereoisomers are identical except that they are mirror images of one another. A specific stereoisomer may also be referred to as an enantiomer, and a mixture of such isomers is often called an enantiomeric mixture. A 50:50 mixture of enantiomers is referred to as a racemic mixture or a racemate, which may occur where there has been no stereoselection or stereospecificity in a chemical reaction or process. The terms “racemic mixture” and “racemate” refer to an equimolar mixture of two enantiomeric species, devoid of optical activity.

Protecting Groups

In the context of the present invention, protecting groups include prodrug moieties and chemical protecting groups.

Protecting groups are available, commonly known and used, and are optionally used to prevent side reactions with the protected group during synthetic procedures, i.e. routes or methods to prepare the compounds of the invention. For the most part the decision as to which groups to protect, when to do so, and the nature of the chemical protecting group "PG" will be dependent upon the chemistry of the reaction to be protected against (e.g., acidic, basic, oxidative, reductive or other conditions) and the intended direction of the synthesis. The PG groups do not need to be, and generally are not, the same if the compound is substituted with multiple PG. In general, PG will be used to protect functional groups such as carboxyl, hydroxyl, thio, or amino groups and to thus prevent side reactions or to otherwise facilitate the synthetic efficiency.
The order of deprotection to yield free, deprotected groups is dependent upon the intended direction of the synthesis and the reaction conditions to be encountered, and may occur in any order as determined by the artisan.

Various functional groups of the compounds of the invention may be protected. For example, protecting groups for -OH groups (whether hydroxyl, carboxylic acid, phosphonic acid, or other functions) include "ether- or ester-forming groups". Ether- or ester-forming groups are capable of functioning as chemical protecting groups in the synthetic schemes set forth herein. However, some hydroxyl and thio protecting groups are neither ether- nor ester-forming groups, as will be understood by those skilled in the art, and are included with amides, discussed below.


**Ether- and Ester-forming protecting groups**

Ester-forming groups include: (1) phosphonate ester-forming groups, such as phosphonamidate esters, phosphorothioate esters, phosphonate esters, and phosphon-bis-amidates; (2) carboxyl ester-forming groups, and (3) sulphur ester-forming groups, such as sulphonate, sulfate, and sulfinate.

The phosphonate moieties of the compounds of the invention may or may not be prodrug moieties, *i.e.* they may or may be susceptible to hydrolytic or enzymatic cleavage or modification. Certain phosphonate moieties are stable
under most or nearly all metabolic conditions. For example, a
dialkylphosphonate, where the alkyl groups are two or more carbons, may have
appreciable stability in vivo due to a slow rate of hydrolysis.

Within the context of phosphonate prodrug moieties, a large number of
structurally-diverse prodrugs have been described for phosphonic acids
(Freeman and Ross in Progress in Medicinal Chemistry 34: 112-147 (1997) and
are included within the scope of the present invention. An exemplary
phosphonate ester-forming group is the phenyl carbocycle in substructure A3
having the formula:


\[
\begin{align*}
& \text{wherein } R_1 \text{ may be } H \text{ or } C_1-C_{12} \text{ alkyl; } m1 \text{ is } 1, 2, 3, 4, 5, 6, 7 \text{ or } 8, \text{ and} \\
& \text{the phenyl carbocycle is substituted with } 0 \text{ to } 3 R_2 \text{ groups. Where } Y_1 \text{ is } O, \text{ a} \\
& \text{lactate ester is formed, and where } Y_1 \text{ is } N(R_2), N(OR_2) \text{ or } N(N(R_2)2, \text{ a} \\
& \text{phosphonamidate ester results.}
\end{align*}
\]

In its ester-forming role, a protecting group typically is bound to any
acidic group such as, by way of example and not limitation, a \(-\text{CO}_2\text{H}\) or
\(-\text{C(S)OH}\) group, thereby resulting in \(-\text{CO}_2R^x\) where \(R^x\) is defined herein. Also,
\(R^x\) for example includes the enumerated ester groups of WO 95/07920.

Examples of protecting groups include:

\[
\begin{align*}
& \text{C}_3-\text{C}_{12} \text{ heterocycle (described above) or aryl. These aromatic groups} \\
& \text{optionally are polycyclic or monocyclic. Examples include phenyl, spiryl, 2-} \\
& \text{and 3-pyrrolyl, 2- and 3-thienyl, 2- and 4-imidazolyl, 2-, 4- and 5-oxazolyl, 3-} \\
& \text{and 4-isoxazolyl, 2-, 4- and 5-thiazolyl, 3-, 4- and 5-isothiazolyl, 3- and 4-} \\
& \text{pyrazolyl, 1-, 2-, 3- and 4-pyridinyl, and 1-, 2-, 4- and 5-pyrimidinyl,}
\end{align*}
\]
C₃-C₁₂ heterocycle or aryl substituted with halo, R¹, R¹-O-C₁₋₃C₁₂ alkylene, C₁-C₁₂ alkoxy, CN, NO₂, OH, carboxy, carboxyester, thiol, thioester, C₁-C₁₂ haloalkyl (1-6 halogen atoms), C₂-C₁₂ alkenyl or C₂-C₁₂ alkynyl. Such groups include 2-, 3- and 4-alkoxyphenyl (C₁-C₁₂ alkyl), 2-, 3- and 4-methoxyphenyl, 2-, 3- and 4-ethoxyphenyl, 2,3-, 2,4-, 2,5-, 2,6-, 3,4- and 3,5-diethoxyphenyl, 2- and 3-carboethoxy-4-hydroxyphenyl, 2- and 3-ethoxy-4-hydroxyphenyl, 2- and 3-ethoxy-5-hydroxyphenyl, 2- and 3-ethoxy-6-hydroxyphenyl, 2-, 3- and 4-O-acetylphenyl, 2-, 3- and 4-dimethylaminophenyl, 2-, 3- and 4-methylmercaptophenyl, 2-, 3- and 4-halophenyl (including 2-, 3- and 4-fluorophenyl and 2-, 3- and 4-chlorophenyl), 2,3-, 2,4-, 2,5-, 2,6-, 3,4- and 3,5-dimethylphenyl, 2,3-, 2,4-, 2,5-, 2,6-, 3,4- and 3,5-bis(carboxyethyl)phenyl, 2,3-, 2,4-, 2,5-, 2,6-, 3,4- and 3,5-dimethoxyphenyl, 2,3-, 2,4-, 2,5-, 2,6-, 3,4- and 3,5-dihalophenyl (including 2,4-difluorophenyl and 3,5-difluorophenyl), 2-, 3- and 4-haloalkylphenyl (1 to 5 halogen atoms, C₁-C₁₂ alkyl including 4-trifluoromethylphenyl), 2-, 3- and 4-cyanophenyl, 2-, 3- and 4-nitrophenyl, 2-, 3- and 4-haloalkylbenzyl (1 to 5 halogen atoms, C₁-C₁₂ alkyl including 4-trifluoromethylbenzyl and 2-, 3- and 4-trichloromethylphenyl and 2-, 3- and 4-trichloromethylphenyl), 4-N-methylpiperidinyl, 3-N-methylpiperidinyl, 1-ethylpiperazinyl, benzyl, alkylsalicylphenyl (C₁-C₄ alkyl, including 2-, 3- and 4-ethylsalicylphenyl), 2-,3- and 4-acetylphenyl, 1,8-dihydroxynaphthyl (C₁₀H₆-OH) and arylxy ethyl [C₆-C₉ aryl (including phenoxy ethyl)], 2,2'-dihydroxybiphenyl, 2-, 3- and 4-N,N-dialkylaminophenol, -C₆H₄CH₂-N(CH₃)₂, trimethoxybenzyl, triethoxybenzyl, 2-alkyl pyridinyl (C₁₋₄ alkyl); esters of 2-carboxyphenyl; and C₁-C₄ alkylene-C₃-C₆ aryl (including benzyl, -CH₂-pyrrolyl, -CH₂-thienyl, -CH₂-imidazolyl, -CH₂-oxazolyl, -CH₂-isoxazolyl, -CH₂-thiazolyl, -CH₂-isothiazolyl, -CH₂-pyrazolyl, -CH₂-pyridinyl and -CH₂-pyrimidinyl) substituted in the aryl moiety by 3 to 5 halogen atoms or 1 to 2 atoms or groups selected from halogen, C₁-C₁₂ alkoxy (including methoxy and
ethoxy), cyano, nitro, OH, C₁₋₁₂ haloalkyl (1 to 6 halogen atoms; including -CH₂Cl), C₁₋₁₂ alkyl (including methyl and ethyl), C₂₋₁₂ alkenyl or C₂₋₁₂ alkenyl; alkoxy ethyl [C₁₋₆ alkyl including -CH₂(CH₂-O-CH₃) (methoxy ethyl)]; alkyl substituted by any of the groups set forth above for aryl, in particular OH or by 1 to 3 halo atoms (including -CH₃, -CH(CH₃)₂, -C(CH₃)₃, -CH₂CH₃, -(CH₂)₂CH₃, -(CH₂)₃CH₃, -(CH₂)₄CH₃, -(CH₂)₅CH₃, -CH₂CH₂F, -CH₂CH₂Cl, -CH₂CF₃, and -CH₂CCl₃);

propylmorpholinO, 2,3-dihydro-6-hydroxyindene, sesamol, catechol monoester, -CH₂-C(O)-N(R¹)₂, -CH₂-S(O)(R¹), -CH₂-S(O)₂(R¹), -CH₂-SH, -CH₂-CH(OH)CH₂R¹-CH₂(OH)CH₂R¹), cholesteryl, enolpyruvate (HOOC-C(=CH₂)), glycerol;

a 5 or 6 carbon monosaccharide, disaccharide or oligosaccharide (3 to 9 monosaccharide residues);

triglycerides such as α-D-β-diglycerides (wherein the fatty acids composing glyceride lipids generally are naturally occurring saturated or unsaturated C₆₋₂₆, C₆₋₁₈ or C₆₋₁₀ fatty acids such as linoleic, lauric, myristic, palmitic, stearic, oleic, palmitoleic, linolenic and the like fatty acids) linked to acyl of the parental compounds herein through a gleyceryl oxygen of the triglyceride;

phospholipids linked to the carboxyl group through the phosphate of the phospholipid;

phthalidyl (shown in Fig. 1 of Clayton et al., Antimicrob. Agents Chemotherapy, (1974) 5(6):670-671;

cyclic carbonates such as (5-R₄-2-oxo-1,3-dioxolen-4-yl) methyl esters (Sakamoto et al., Chem. Pharm. Bull. (1984) 32(6)2241-2248) where R₄ is R₁, R₄ or aryl; and

\[-\text{CH₂C(O)N}\bigg]\begin{tikzpicture}
\node (o) at (0,0) {O};
\end{tikzpicture}\];

The hydroxyl groups of the compounds of this invention optionally are substituted with one of groups III, IV or V disclosed in WO 94/21604, or with isopropyl.
Table A lists examples of protecting group ester moieties that for example can be bonded via oxygen to -C(O)O- and -P(O)(O-)₂ groups. Several amidates also are shown, which are bound directly to -C(O)- or -P(O)₂. Esters of structures 1-5, 8-10 and 16, 17, 19-22 are synthesized by reacting the compound herein having a free hydroxyl with the corresponding halide (chloride or acyl chloride and the like) and N,N-dicyclohexyl-N-morpholine carboxamidine (or another base such as DBU, triethylamine, CsCO₃, N,N-dimethylaniline and the like) in DMF (or other solvent such as acetonitrile or N-methylpyrrolidone).

When the compound to be protected is a phosphonate, the esters of structures 5-7, 11, 12, 21, and 23-26 are synthesized by reaction of the alcohol or alkoxide salt (or the corresponding amines in the case of compounds such as 13, 14 and 15) with the monochlorophosphonate or dichlorophosphonate (or another activated phosphonate).
TABLE A

1. -CH₂-C(O)-N(R₁)₂ *
2. -CH₂-S(O)(R₁)
3. -CH₂-S(O)₂(R₁)
4. -CH₂-O-C(O)-CH₂-C₆H₅
5. 3-cholesteryl
6. 3-pyridyl
7. N-ethylmorpholino
8. -CH₂-O-C(O)-C₆H₅
9. -CH₂-O-C(O)-CH₂CH₃
10. -CH₂-O-C(O)-C(CH₃)₃
11. -CH₂-CCl₃
12. -C₆H₅
13. -NH-CH₂-C(O)O-CH₂CH₃
14. -N(CH₃)-CH₂-C(O)O-CH₂CH₃
15. -NHR₁
16. -CH₂-O-C(O)-C₁₀H₁₅
17. -CH₂-O-C(O)-CH(CH₃)₂
18. -CH₂-C#H(OC(O)CH₂R₁)-CH₂-(OC(O)CH₂R₁)*
19. -CH₂-C(O)N
20. ~N
21. HO
22. -CH₂-O-C(O)-N
23. -CH₂CH₂-N
24. CH₃O(O)C
25. CH₃CH₂O(O)C
26. OCH₃

# - chiral center is (R), (S) or racemate.

Other esters that are suitable for use herein are described in EP 632048.
Protecting groups also includes "double ester" forming functionalities

such as -CH₂OC(O)OCH₃, -CH₂SCOCH₃, -CH₂OCON(CH₃)₂, or
alkyl- or aryl-acyloxyalkyl groups of the structure -CH(R¹ or W⁵)O((CO)R³⁷) or
-CH(R¹ or W⁵)((CO)OR³⁸) (linked to oxygen of the acidic group) wherein R³⁷
and R³⁸ are alkyl, aryl, or alkylaryl groups (see U.S. Patent No. 4968788).

Frequently R³⁷ and R³⁸ are bulky groups such as branched alkyl, ortho-
substituted aryl, meta-substituted aryl, or combinations thereof, including
normal, secondary, iso- and tertiary alkyls of 1-6 carbon atoms. An example is
the pivaloyloxyethyl group. These are of particular use with prodrugs for oral
administration. Examples of such useful protecting groups are

alkylacyloxyethyl esters and their derivatives, including -

CH(CH₂CH₂OCH₃)OC(O)C(CH₃)₃,
CH₂OC(O)C₁₀H₁₅, -CH₂OC(O)C(CH₃)₃, -CH(CH₂OCH₃)OC(O)C(CH₃)₃,
CH(CH(CH₃)₂)OC(O)C(CH₃)₃, -CH₂OC(O)CH₂CH(CH₃)₂,
CH₂OC(O)C₆H₁₁, -CH₂OC(O)C₆H₅, -CH₂OC(O)C₁₀H₁₅,
CH₂OC(O)CH₂CH₃, -CH₂OC(O)CH(CH₃)₂, -CH₂OC(O)C(CH₃)₃ and
CH₂OC(O)CH₂C₆H₅.

In some claims the protected acidic group is an ester of the acidic group
and is the residue of a hydroxyl-containing functionality. In other claims, an
amino compound is used to protect the acid functionality. The residues of
suitable hydroxyl or amino-containing functionalities are set forth above or are
found in WO 95/07920. Of particular interest are the residues of amino acids,
amino acid esters, polypeptides, or aryl alcohols. Typical amino acid,
polypeptide and carboxyl-esterified amino acid residues are described on pages
11-18 and related text of WO 95/07920 as groups L1 or L2. WO 95/07920
expressly teaches the amidates of phosphonic acids, but it will be understood that
such amidates are formed with any of the acid groups set forth herein and the
amino acid residues set forth in WO 95/07920.
Typical esters for protecting acidic functionalities are also described in WO 95/07920, again understanding that the same esters can be formed with the acidic groups herein as with the phosphonate of the '920 publication. Typical ester groups are defined at least on WO 95/07920 pages 89-93 (under R31 or R35), the table on page 105, and pages 21-13 (as R). Of particular interest are esters of unsubstituted aryl such as phenyl or arylalkyl such benzyl, or hydroxy-, halo-, alkoxy-, carboxy- and/or alkylestercarboxy-substituted aryl or alkylaryl, especially phenyl, ortho-ethoxyphenyl, or C1-C4 alkylestercarboxyphenyl (salicylate C1-C12 alkylesters).

The protected acidic groups, particularly when using the esters or amides of WO 95/07920, are useful as prodrugs for oral administration. However, it is not essential that the acidic group be protected in order for the compounds of this invention to be effectively administered by the oral route. When the compounds of the invention having protected groups, in particular amino acid amidates or substituted and unsubstituted aryl esters are administered systemically or orally they are capable of hydrolytic cleavage in vivo to yield the free acid.

One or more of the acidic hydroxyls are protected. If more than one acidic hydroxyl is protected then the same or a different protecting group is employed, e.g., the esters may be different or the same, or a mixed amidoate and ester may be used.

Typical hydroxy protecting groups described in Greene (pages 14-118) include substituted methyl and alkyl ethers, substituted benzyl ethers, silyl ethers, esters including sulfonic acid esters, and carbonates. For example:

- Ethers (methyl, t-butyl, allyl);
- Substituted Methyl Ethers (Methoxymethyl, Methylthiomethyl, t-Butyldimethyl, (Phenyl)methoxyethyl, Benzylaminomethyl, p-Methoxybenzylmethyl, (4-Methoxyphenyl)methyl, Guaiacolmethyl, t-Butoxyethyl, 4-Pentenyloxymethyl, Siloxyethyl, 2-Methoxyethoxymethyl, 2,2,2-Trichloroethoxymethyl, Bis(2-chloroethoxy)methyl, 2-(Trimethylsilyl)ethoxymethyl, Tetrahydropyranyl, 3-Bromotetrahydropyranyl, Tetrahydroptriopyranyl, 1-Methoxycyclohexyl, 4-Methoxytetrahydropyranyl, 4-Methoxytetrahydrothiopyranyl, 4-
Methoxytetrahydropyranoyl S,S-Dioxido, 1-[(2-Chloro-4-methyl)phenyl]-4-methoxypiperidin-4-yl, 1,4-Dioxan-2-yl, Tetrahydrofuranyl, Tetrahydrothiofuranyl, 2,3,3a,4,5,6,7,7a-Octahydro-7,8,8-trimethyl-4,7-methanobenzofuran-2-yl));

- Substituted Ethyl Ethers (1-Ethoxyethyl, 1-[(2-Chloroethoxy)ethyl, 1-Methyl-1-methoxyethyl, 1-Methyl-1-benzylxoxylethyl, 1-Methyl-1-benzoxo-2-fluoroethyl, 2,2,2-Trichloroethyl, 2-Trimethylsilylethyl, 2-(Phenylselenyl)ethyl,
- \( p \)-Chlorophenyl, \( p \)-Methoxyphenyl, 2,4-Dinitrophenyl, Benzyl);

- Substituted Benzyl Ethers (\( p \)-Methoxybenzyl, 3,4-Dimethoxybenzyl, \( o \)-Nitrobenzyl, \( p \)-Nitrobenzyl, \( p \)-Halobenzyl, 2,6-Dichlorobenzyl, \( p \)-Cyanobenzyl, \( p \)-Phenylbenzyl, 2- and 4-Picolyl, 3-Methyl-2-picolyl \( N \)-Oxido, Diphenylmethyl, \( p \),\( p' \)-Dinitrobenzhydryl, 5-Dibenzosuberyl, Triphenylmethyl, \( \alpha \)-Naphthylidiphenylmethyl, \( p \)-methoxyphenyldiphenylmethyl, Di(\( p \)-methoxyphenyl)phenylmethyl, Tri(\( p \)-methoxyphenyl)methyl, 4-(4'-Bromophenacyloxy)phenyldiphenylmethyl, 4,4',4''-Tris(4,5-dichlorophthalimidophenyl)methyl, 4,4',4''-Tris(levulinoyloxyphenyl)methyl, 4,4',4''-Tris(benzoxyloxyphenyl)methyl, 3-(Imidazol-1-ylmethyl)bis(4',4''-dimethoxyphenyl)methyl, 1,1-Bis(4-methoxyphenyl)-1'-pyrenylmethyl, 9-Anthryl, 9-(9-Phenyl)xantheryl, 9-(9-Phenyl-10-oxo)anthryl, 1,3-Benzodithiolan-2-yl, Benzisothiazolyl S,S-Dioxido);

- Silyl Ethers (Trimethylsilyl, Triethylsilyl, Trisopropylsilyl, Dimethylisopropylsilyl, Diethylisopropylsilyl, Dimethylthexylsilyl, \( t \)-Butyldimethylsilyl, \( t \)-Butyldiphenylsilyl, Tribenzylsilyl, Tri-\( p \)-xylylsilyl, Triphenylsilyl, Diphenylmethylsilyl, \( t \)-Butylmethoxyphenylysilyl);

- Esters (Formate, Benzoylformate, Acetate, Choroacetate, Dichloroacetate, Trichloroacetate, Trifluoroacetate, Methoxyacetate, Triphenylmethoxyacetate, Phenoxyacetate, \( p \)-Chlorophenoxyacetate, \( p \)-poly-Phenylacetate, 3-Phenypropionate, 4-Oxopentanoate (Levulinate), 4,4-(Ethylenedithio)pentanoate, Pivaloate, Adamantoate, Crotonate, 4-
Methoxycrotonate, Benzoate, \(p\)-Phenylbenzoate, 2,4,6-Trimethylbenzoate (Mesitoate));

- Carbonates (Methyl, 9-Fluorenylmethyl, Ethyl, 2,2,2-Trichloroethyl, 2-(Trimethylsilyl)ethyl, 2-(Phenylsulfonylethyl, 2-(Triphenylphosphonio)ethyl, Isobutyl, Vinyl, Allyl, \(p\)-Nitrophenyl, Benzyl, \(p\)-Methoxybenzyl, 3,4-Dimethoxybenzyl, \(o\)-Nitrobenzyl, \(p\)-Nitrobenzyl, \(S\)-Benzyl Thiocarbonate, 4-Ethoxy-1-naphthyl, Methyl Dithiocarbonate);

- Groups With Assisted Cleavage (2-Iodobenzoate, 4-Azidobutyrate, 4-Nitro-4-methylpentanoate, \(o\)-(Dibromomethyl)benzoate, 2-Formylbenzenesulfonate, 2-(Methylthiomethoxy)ethyl Carbonate, 4-(Methylthiomethoxy)butyrate, 2-(Methylthiomethoxymethyl)benzoate); Miscellaneous Esters (2,6-Dichloro-4-methylphenoxyacetate, 2,6-Dichloro-4-(1,1,3,3 tetramethylbutyl)phenoxyacetate, 2,4-Bis(1,1-dimethylpropyl)phenoxyacetate, Chlorodiphenylacetate, Isobutyrate,

- Monosuccinate, \((E)\)-2-Methyl-2-butenoate (Tigloate), \(o\)-(Methoxycarbonyl)benzoate, \(p\)-poly-Benzoate, \(\alpha\)-Naphthoate, Nitrate, Alkyl \(N,N,N',N'\)-Tetramethylphosphorodiamidate, \(N\)-Phenylcarbamate, Borate, Dimethylphosphiniothiyl, 2,4-Dinitrophenylsulfenate); and

- Sulfonates (Sulfate, Methanesulfonate (Mesylate), Benzylsulfonate, Tosylate).

Typical 1,2-diol protecting groups (thus, generally where two OH groups are taken together with the protecting functionality) are described in Greene at pages 118-142 and include Cyclic Acetals and Ketals (Methylene, Ethyldene, 1-t-Butylethylidene, 1-Phenylethylidene, (4-Methoxyphenyl)ethyldiene, 2,2,2-

- Trichloroethylidene, Acetonide (Isopropylidene), Cyclopentylidene, Cyclohexylidene, Cycloheptylidene, Benzylidene, \(p\)-Methoxybenzylidene, 2,4-Dimethoxybenzylidene, 3,4-Dimethoxybenzylidene, 2-Nitrobenzylidene); Cyclic Ortho Esters (Methoxymethylene, Ethoxymethylene, Dimethoxymethylene, 1-Methoxethylidene, 1-Ethoxyethylidene, 1,2-Dimethoxethylidene, \(\alpha\)-Methoxybenzylidene, 1-(\(N,N\)-Dimethylamino)ethylidene Derivative, \(\alpha\)-(\(N,N\)-Dimethylamino)benzylidene Derivative, 2-Oxacyclopentylidene); Silyl Derivatives (Di-t-butylsilylene Group, 1,3-(1,1,3,3-
Tetraisopropylsiloxanylidene), and Tetra-\(\tau\)-butoxydisiloxane-1,3-diylidene), Cyclic Carbonates, Cyclic Boronates, Ethyl Boronate and Phenyl Boronate.

More typically, 1,2-diol protecting groups include those shown in Table B, still more typically, epoxides, acetonides, cyclic ketals and aryl acetals.

**Table B**

![Diagrams of various chemical structures](image)

wherein R\(^9\) is C\(_1\)-C\(_6\) alkyl.

**Amino protecting groups**

Another set of protecting groups include any of the typical amino protecting groups described by Greene at pages 315-385. They include:

- Carbamates: (methyl and ethyl, 9-fluorenylmethyl, 9(2-sulfo)fluorenylmethyl, 9-(2,7-dibromo)fluorenylmethyl, 2,7-di-\(\tau\)-butyl-[9-(10,10-dioxo-10,10,10,10-tetrahydrothioxanthyl)]methyl, 4-methoxyphenacyl);
- Substituted Ethyl: (2,2,2-trichloroethyl, 2-trimethylsilyl ethyl, 2-phenylethyl, 1-(1-adamantyl)-1-methylethyl, 1,1-dimethyl-2-haloethyl, 1,1-dimethyl-2,2-dibromoethyl, 1,1-dimethyl-2,2,2-trichloroethyl, 1-methyl-1-(4-biphenyl)ethyl, 1-(3,5-di-\(\tau\)-butylphenyl)-1-methylethyl, 2-(2'- and 4'-pyridyl)ethyl, 2-(N,N-dicyclohexylcarboxamido)ethyl, \(\tau\)-butyl, 1-adamantyl, vinyl, allyl, 1-isopropylallyl, cinnamyl, 4-nitrocinnamyl, 8-quinoxyl, N-hydroxypiperidinyl, alkyldithio, benzyl, \(p\)-methoxybenzyl, \(p\)-nitrobenzyl, \(p\)-
bromobenzyl, p-chlorobenzyl, 2,4-dichlorobenzyl, 4-methylsulfinylbenzyl, 9-anthrylmethyl, diphenylmethyl);

- Groups With Assisted Cleavage: (2-methylthioethyl, 2-methylsulfonylethyl, 2-(p-toluenesulfonylethyl), [2-(1,3-dithianyl)]methyl, 4-methylthiophenyl, 2,4-dimethylthiophenyl, 2-phosphonioethy, 2-triphenylphosphonioisopropyl, 1,1-dimethyl-2-cyanoethyl, m-choro-p-acyloxybenzyl, p-(dihydroxyboryl)benzyl, 5-benzisoxazolylmethyl, 2-(trifluoromethyl)-6-chromonylethyl);

- Groups Capable of Photolytic Cleavage: (m-nitrophenyl, 3,5-dimethoxybenzyl, a-nitrobenzyl, 3,4-dimethoxy-6-nitrobenzyl, phenyl(o-nitrophenyl)methyl); Urea-Type Derivatives (phenothiazinyl-(10)-carbonyl, N'-p-toluenesulfonlaminoacarbonyl, N'-phenylaminothiocarbonyl);

- Miscellaneous Carbamates: (t-amyli, S-benzyl thiocarbamate, p-cyanobenzyl, cyclobutyl, cyclohexyl, cyclopentyl, cyclopropylmethyl, p-decyloxybenzyl, diisopropylmethyl, 2,2-dimethoxycarbonylvinyl, o-(N,N-dimethylcarboxamido)benzyl, 1,1-dimethyl-3-(N,N-dimethylcarboxamido)propyl, 1,1-dimethylpropynyl, di(2-pyridyl)methyl, 2-furanyl methyl, 2-Iodoethyl, Isobornyl, Isobutyl, Isonicotinyl, p-(p'-Methoxyphenylazo)benzyl, 1-methylcyclobutyl, 1-methylcyclohexyl, 1-methyl-1-cyclopropylmethyl, 1-methyl-1-(3,5-dimethoxyphenyl)ethyl, 1-methyl-1-(p-phenylazophenyl)ethyl, 1-methyl-1-phenylethyl, 1-methyl-1-(4-pyridyl)ethyl, phenyl, p-(phenylazo)benzyl, 2,4,6-tri-t-butylphenyl, 4-(trimethylammonium)benzyl, 2,4,6-trimethylbenzyl);

- Amides: (N-formyl, N-acetyl, N-chloroacetyl, N-trichloroacetyl, N-trifluoroacetyl, N-phenylacetyl, N-3-phenylpropionyl, N-picolinoyl, N-3-pyridylcarboxamide, N-benzyloxyphenylalanyl, N-benzoyl, N-p-phenylbenzoyl);

- Amides With Assisted Cleavage: (N-o-nitrophenylacetyl, N-o-nitrophenoxycacetyl, N-acetoacetyl, (N'-dithiobenzylxycarbonylamino)acetyl, N-3-(p-hydroxyphenyl)propionyl, N-3-(o-nitrophenyl)propionyl, N-2-methyl-2-(o-nitrophenoxo)propionyl, N-2-methyl-2-(o-phenylazophenoxo)propionyl, N-4-chlorobutryl, N-3-methyl-3-
nitrobutyryl, N-o-nitrocinnamoyl, N-acetylmethionine, N-o-nitrobenzoyl, N-o-(benzoyloxymethyl)benzoyl, 4,5-diphenyl-3-oxazolin-2-one);

- Cyclic Imide Derivatives: (N-phthalimide, N-dithiasuccinoyl, N-2,3-diphenylmaleoyl, N-2,5-dimethylpyrrolyl, N-1,1,4,4-tetramethyldisilylazacyclopentane adduct, 5-substituted 1,3-dimethyl-1,3,5-triazacyclochexan-2-one, 5-substituted 1,3-dibenzyl-1,3-5-triazacyclocHexan-2-one, 1-substituted 3,5-dinitro-4-pyridonyl);

- N-Alkyl and N-Aryl Amines: (N-methyl, N-allyl, N-[2-(trimethylsilyl)ethoxy]methyl, N-3-acetoxypropyl, N-(1-isopropyl-4-nitro-2-oxo-3-pyrrolin-3-yl), Quaternary Ammonium Salts, N-benzyl, N-di(4-methoxyphenyl)methyl, N-5-dibenzosuberyl, N-triphenylmethyl, N-(4-methoxyphenyl)diphenylmethyl, N-9-phenylfluorenyl, N-2,7-dichloro-9-fluorenylmethylene, N-ferrocenylmethyl, N-2-picolylamine N-oxide);

- Imine Derivatives: (N-1,1-dimethylthiomethylene, N-benzylidene, N-p-methoxybenzylidene, N-diphenylmethylene, N-[(2-pyridyl)mesityl]methylene, N,(N,N-dimethylaminomethylene, N,N-isopropylidene, N-p-nitrobenzylidene, N-salicylidene, N-5-chlorosalicylidene, N-(5-chloro-2-hydroxyphenyl)phenylmethylene, N-cyclohexylidene);

- Enamine Derivatives: (N-(5,5-dimethyl-3-oxo-1-cyclohexenyl));

- N-Metal Derivatives (N-borane derivatives, N-diphenylborinic acid derivatives, N-[phenyl(pentacarbonylchromium- or -tungsten)]carbenyl, N-copper or N-zinc chelate);

- N-N Derivatives: (N-nitro, N-nitroso, N-oxide);

- N-P Derivatives: (N-diphenylphosphinyl, N-dimethylthiophosphinyl, N-diphenylthiophosphinyl, N-dialkyl phosphoranyl, N-dibenzyl phosphoryl, N-diphenyl phosphoryl);

- N-Si Derivatives, N-S Derivatives, and N-Sulfenyl Derivatives: (N-benzenesulfenyl, N-o-nitrobenzenesulfenyl, N-2,4-dinitrobenzenesulfenyl, N-pentachlorobenzenesulfenyl, N-2-nitro-4-methoxybenzenesulfenyl, N-triphenylmethylsulfenyl, N-3-nitropyridinesulfenyl); and N-sulfonyl Derivatives (N-p-toluensulfonfyl, N-benzenesulfonfyl, N-2,3,6-trimethyl-4-methoxybenzenesulfonfyl, N-2,4,6-trimethoxybenzenesulfonfyl, N-2,6-
dimethyl-4-methoxybenzenesulfonfyl, N-pentamethylbenzenesulfonfyl, N-2,3,5,6,-tetramethyl-4-methoxybenzenesulfonfyl, N-4-methoxybenzenesulfonfyl, N-2,4,6-trimethylbenzenesulfonfyl, N-2,6-dimethoxy-4-methylbenzenesulfonfyl, N-2,2,5,7,8-pentamethylchroman-6-sulfonfyl, N-methanesulfonfyl, N-β-trimethylsilyethanesulfonfyl, N-9-anthracenesulfonfyl, N-4-(4',8'-dimethoxynaphthylmethyl)benzenesulfonfyl, N-benzylsulfonfyl, N-trifluoromethanesulfonfyl, N-phenacylsulfonfyl).

More typically, protected amino groups include carbamates and amides, still more typically, -NHC(O)R¹ or -N=CR¹N(R¹)₂. Another protecting group, also useful as a prodrug for amino or -NH(R²), is:


Amino acid and polypeptide protecting group and compounds

An amino acid or polypeptide protecting group of a compound of the invention has the structure R¹⁵NHCH(R¹⁶)C(O) -, where R¹⁵ is H, an amino acid or polypeptide residue, or R⁵, and R¹⁶ is defined below.

R¹⁶ is lower alkyl or lower alkyl (C₁-C₆) substituted with amino, carboxyl, amide, carboxyl ester, hydroxyl, C₆-C₇ aryl, guanidinyl, imidazolyl, indolyl, sulphur, sulfoxide, and/or alkylphosphate. R¹⁰ also is taken together with the amino acid α N to form a proline residue (R¹⁰ = -CH₂)₃-). However, R¹⁰ is generally the side group of a naturally-occurring amino acid such as H, -CH₃, -CH(CH₃)₂, -CH₂-CH(CH₃)₂, -CHCH₃-CH₂-CH₃, -CH₂-C₆H₅, -CH₂CH₂-S-CH₃, -CH₂OH, -CH(OH)-CH₃, -CH₂-SH, -CH₂-C₆H₄OH, -CH₂-CO-NH₂, -CH₂-CH₂-CO-NH₂, -CH₂-COOH, -CH₂-CH₂-COOH, -(CH₂)₄-NH₂ and -(CH₂)₃-NH-C(NH₂)-NH₂. R₁₀ also includes 1-guanidinoprop-3-yl, benzyl, 4-hydroxybenzyl, imidazol-4-yl, indol-3-yl, methoxyphenyl and ethoxyphenyl.

Another set of protecting groups include the residue of an amino-containing compound, in particular an amino acid, a polypeptide, a protecting
group, -NH$_2$, NH(C(O)R, -N(R)$_2$, NH$_2$ or -NH(R)(H), whereby for example a carboxylic acid is reacted, i.e. coupled, with the amine to form an amide, as in C(O)NR$_2$. A phosphonic acid may be reacted with the amine to form a phosphonamidate, as in -P(O)(OR)(NR$_2$).

In general, amino acids have the structure R$^{17}$C(O)CH(R$^{16}$)NH-, where R$^{17}$ is -OH, -OR, an amino acid or a polypeptide residue. Amino acids are low molecular weight compounds, on the order of less than about 1000 MW and which contain at least one amino or imino group and at least one carboxyl group. Generally the amino acids will be found in nature, i.e., can be detected in biological material such as bacteria or other microbes, plants, animals or man. Suitable amino acids typically are alpha amino acids, i.e. compounds characterized by one amino or imino nitrogen atom separated from the carbon atom of one carboxyl group by a single substituted or unsubstituted alpha carbon atom. Of particular interest are hydrophobic residues such as mono- or di-alkyl or aryl amino acids, cycloalkylamino acids and the like. These residues contribute to cell permeability by increasing the partition coefficient of the parental drug. Typically, the residue does not contain a sulfhydryl or guanidino substituent.

Naturally-occurring amino acid residues are those residues found naturally in plants, animals or microbes, especially proteins thereof. Polypeptides most typically will be substantially composed of such naturally-occurring amino acid residues. These amino acids are glycine, alanine, valine, leucine, isoleucine, serine, threonine, cysteine, methionine, glutamic acid, aspartic acid, lysine, hydroxylysine, arginine, histidine, phenylalanine, tyrosine, tryptophan, proline, asparagine, glutamine and hydroxyproline. Additionally, unnatural amino acids, for example, valanine, phenylglycine and homoarginine are also included. Commonly encountered amino acids that are not gene-encoded may also be used in the present invention. All of the amino acids used in the present invention may be either the D- or L- optical isomer. In addition, other peptidomimetics are also useful in the present invention. For a general review, see Spatola, A. F., in Chemistry and Biochemistry of Amino Acids.

When protecting groups are single amino acid residues or polypeptides they optionally are substituted at R³ of substituents A¹, A² or A³ in a compound of the invention. These conjugates are produced by forming an amide bond between a carboxyl group of the amino acid (or C-terminal amino acid of a polypeptide for example). Similarly, conjugates are formed between R³ and an amino group of an amino acid or polypeptide. Generally, only one of any site in the parental molecule is amidated with an amino acid as described herein, although it is within the scope of this invention to introduce amino acids at more than one permitted site. Usually, a carboxyl group of R³ is amidated with an amino acid. In general, the α-amino or α-carboxyl group of the amino acid or the terminal amino or carboxyl group of a polypeptide are bonded to the parental functionalities, i.e., carboxyl or amino groups in the amino acid side chains generally are not used to form the amide bonds with the parental compound (although these groups may need to be protected during synthesis of the conjugates as described further below).

With respect to the carboxyl-containing side chains of amino acids or polypeptides it will be understood that the carboxyl group optionally will be blocked, e.g., by R¹, esterified with R⁵ or amidated. Similarly, the amino side chains R¹⁶ optionally will be blocked with R¹ or substituted with R⁵.

Such ester or amide bonds with side chain amino or carboxyl groups, like the esters or amides with the parental molecule, optionally are hydrolyzable in vivo or in vitro under acidic (pH <3) or basic (pH >10) conditions.

Alternatively, they are substantially stable in the gastrointestinal tract of humans but are hydrolyzed enzymatically in blood or in intracellular environments. The esters or amino acid or polypeptide amidates also are useful as intermediates for the preparation of the parental molecule containing free amino or carboxyl groups. The free acid or base of the parental compound, for example, is readily formed from the esters or amino acid or polypeptide conjugates of this invention by conventional hydrolysis procedures.

When an amino acid residue contains one or more chiral centers, any of the D, L, meso, threo or erythro (as appropriate) racemates, scalemates or
mixtures thereof may be used. In general, if the intermediates are to be hydrolyzed non-enzymatically (as would be the case where the amides are used as chemical intermediates for the free acids or free amines), D isomers are useful. On the other hand, L isomers are more versatile since they can be susceptible to both non-enzymatic and enzymatic hydrolysis, and are more efficiently transported by amino acid or dipeptidyl transport systems in the gastrointestinal tract.

Examples of suitable amino acids whose residues are represented by $R^x$ or $R^y$ include the following:

Glycine;

Aminopolycarboxylic acids, e.g., aspartic acid, $\beta$-hydroxyaspartic acid, glutamic acid, $\beta$-hydroxyglutamic acid, $\beta$-methylaspartic acid, $\beta$-methylglutamic acid, $\beta$, $\beta$-dimethylaspartic acid, $\gamma$-hydroxyglutamic acid, $\beta$, $\gamma$-dihydroxyglutamic acid, $\beta$-phenylglutamic acid, $\gamma$-methylene glutamic acid, 3-amino adipic acid, 2-aminopimelic acid, 2-aminosuberic acid and 2-aminosebacic acid;

Amino acid amides such as glutamine and asparagine;

Polyamino- or polybasic-monocarboxylic acids such as arginine, lysine, $\beta$-aminoalanine, $\gamma$-aminobutyric, ornithine, citruline, homoarginine, homocitrulline, hydroxylysine, allohydroxylsine and diaminobutyric acid;

Other basic amino acid residues such as histidine;

Diaminodicarboxylic acids such as $\alpha$, $\alpha'$-diaminoussinic acid, $\alpha$, $\alpha'$-diaminoglutaric acid, $\alpha$, $\alpha'$-diaminoadipic acid, $\alpha$, $\alpha'$-diaminopimelic acid, $\alpha$, $\alpha'$-diamino- $\beta$-hydroxypimelic acid, $\alpha$, $\alpha'$-diaminoserbic acid, $\alpha$, $\alpha'$-diaminoazelaic acid, and $\alpha$, $\alpha'$-diamino sebacic acid;

Imino acids such as proline, hydroxyproline, allohydroxyproline, $\gamma$-methylproline, piperolic acid, 5-hydroxy piperolic acid, and azetidine-2-carboxylic acid;

A mono- or di-alkyl (typically C$_1$-C$_8$ branched or normal) amino acid such as alanine, valine, leucine, alpylglycine, butyric, norvaline, norleucine, heptyl ine, $\alpha$-methylserine, $\alpha$-amino-$\alpha$-methyl-$\gamma$-hydroxyvaleric acid, $\alpha$-amino-$\alpha$-methyl-$\delta$-hydroxyvaleric acid, $\alpha$-amino-$\alpha$-methyl-$\epsilon$-hydroxy caproic acid, isovaline, $\alpha$-methylglutamic acid, $\alpha$-aminoisobutyric acid, $\alpha$-aminodiethylactic acid
acid, α-aminodiisopropylacetic acid, α-aminodi-n-propylacetic acid, α-aminodiisobutylacetic acid, α-aminodi-n-butylacetic acid, α-aminoethylisopropylacetic acid, α-amino-n-propylacetic acid, α-aminodiisooamyacetic acid, α-methylaspartic acid, α-methylglutamic acid, 1-aminocyclopropane-1-carboxylic acid, isoleucine, allossoleucine, tert-leucine, β-methyltryptophan and α-amino-β-ethyl-β-phenylpropionic acid; β-phenylserinyl;

Aliphatic α-amino-β-hydroxy acids such as serine, β-hydroxyleucine, β-hydroxynorleucine, β-hydroxyornorvaline, and α-amino-β-hydroxystearic acid;

α-Amino, α-, γ-, δ- or ε-hydroxy acids such as homoserine, δ-hydroxyornorvaline, γ-hydroxyornorvaline and ε-hydroxynorleucine residues; canavine and canaline; γ-hydroxyornithine;
2-hexosaminic acids such as D-glucosaminic acid or D-galactosaminic acid;

α-Amino-β-thiols such as penicillamine, β-thiolnorvaline or β-thiolbutyriyne;

Other sulfur containing amino acid residues including cysteine; homocystine, β-phenylmethionine, methionine, S-allyl-L-cysteine sulfoxide, 2-thiolhistidine, cystathionine, and thiol ethers of cysteine or homocysteine;

Phenylalanine, tryptophan and ring-substituted α-amino acids such as the phenyl- or cyclohexylamino acids α-aminophenylacetic acid, α-amino cyclohexylacetic acid and α-amino-β-cyclohexylpropionic acid; phenylalanine analogues and derivatives comprising aryl, lower alkyl, hydroxy, guanidino, oxyalkylether, nitro, sulfur or halo-substituted phenyl (e.g., tyrosine, methyltyrosine and α-chloro-, p-chloro-, 3,4-dichloro, o-, m- or p-methyl-, 2,4,6-trimethyl-, 2-ethoxy-5-nitro-, 2-hydroxy-5-nitro- and p-nitro-phenylalanine); furyl-, thiényl-, pyridyl-, pyrimidinyl-, purinyl- or naphthyl-alanines; and tryptophan analogues and derivatives including kynurenine, 3-hydroxykynurenine, 2-hydroxytryptophan and 4-carboxytryptophan;

α-Amino substituted amino acids including sarcosine (N-methylglycine), N-benzylglycine, N-methylnalanine, N-benzylalanine, N-methylphenylalanine, N-benzylphenylalanine, N-methyvaline and N-benzylvaline; and
α-Hydroxy and substituted α-hydroxy amino acids including serine, threonine, allothreonine, phosphoserine and phosphothreonine.

Polypeptides are polymers of amino acids in which a carboxyl group of one amino acid monomer is bonded to an amino or imino group of the next amino acid monomer by an amide bond. Polypeptides include dipeptides, low molecular weight polypeptides (about 1500-5000 MW) and proteins. Proteins optionally contain 3, 5, 10, 50, 75, 100 or more residues, and suitably are substantially sequence-homologous with human, animal, plant or microbial proteins. They include enzymes (e.g., hydrogen peroxidase) as well as immunogens such as KLH, or antibodies or proteins of any type against which one wishes to raise an immune response. The nature and identity of the polypeptide may vary widely.

The polypeptide amidades are useful as immunogens in raising antibodies against either the polypeptide (if it is not immunogenic in the animal to which it is administered) or against the epitopes on the remainder of the compound of this invention.

Antibodies capable of binding to the parental non-peptidyl compound are used to separate the parental compound from mixtures, for example in diagnosis or manufacturing of the parental compound. The conjugates of parental compound and polypeptide generally are more immunogenic than the polypeptides in closely homologous animals, and therefore make the polypeptide more immunogenic for facilitating raising antibodies against it. Accordingly, the polypeptide or protein may not need to be immunogenic in an animal typically used to raise antibodies, e.g., rabbit, mouse, horse, or rat, but the final product conjugate should be immunogenic in at least one of such animals. The polypeptide optionally contains a peptidolytic enzyme cleavage site at the peptide bond between the first and second residues adjacent to the acidic heteroatom. Such cleavage sites are flanked by enzymatic recognition structures, e.g., a particular sequence of residues recognized by a peptidolytic enzyme.

Peptidolytic enzymes for cleaving the polypeptide conjugates of this invention are well known, and in particular include carboxypeptidases. Carboxypeptidases digest polypeptides by removing C-terminal residues, and are
specific in many instances for particular C-terminal sequences. Such enzymes and their substrate requirements in general are well known. For example, a dipeptide (having a given pair of residues and a free carboxyl terminus) is covalently bonded through its α-amino group to the phosphorus or carbon atoms of the compounds herein. In claims where W₁ is phosphonate it is expected that this peptide will be cleaved by the appropriate peptidolytic enzyme, leaving the carboxyl of the proximal amino acid residue to autocatalytically cleave the phosphonoamidate bond.

Suitable dipeptidyl groups (designated by their single letter code) are

YY, YV, VA, VR, VN, VD, VC, VE, VQ, VG, VH, VI, VL, VK, VM, VF, VP, VS, VT, VW, VY and VV.

Tripeptide residues are also useful as protecting groups. When a phosphonate is to be protected, the sequence -X^4-pro-X^5- (where X^4 is any amino acid residue and X^5 is an amino acid residue, a carboxyl ester of proline, or hydrogen) will be cleaved by luminal carboxypeptidase to yield X^4 with a free carboxyl, which in turn is expected to autocatalytically cleave the phosphonoamidate bond. The carboxy group of X^5 optionally is esterified with benzyl.

Dipeptide or tripeptide species can be selected on the basis of known transport properties and/or susceptibility to peptidases that can affect transport to intestinal mucosal or other cell types. Dipeptides and tripeptides lacking an α-amino group are transport substrates for the peptide transporter found in brush border membrane of intestinal mucosal cells (Bai, J.P.F., (1992) Pharm Res. 9:969-978). Transport competent peptides can thus be used to enhance bioavailability of the amide compounds. Di- or tripeptides having one or more amino acids in the D configuration are also compatible with peptide transport and can be utilized in the amide compounds of this invention. Amino acids in the D configuration can be used to reduce the susceptibility of a di- or tripeptide to hydrolysis by proteases common to the brush border such as aminopeptidase N. In addition, di- or tripeptides alternatively are selected on the basis of their relative resistance to hydrolysis by proteases found in the lumen of the intestine. For example, tripeptides or polypeptides lacking asp and/or glu are poor substrates for aminopeptidase A, di- or tripeptides lacking amino acid residues on the N-terminal side of hydrophobic amino acids (leu, tyr, phe, val, trp) are poor substrates for endopeptidase, and peptides lacking a pro residue at the penultimate position at a free carboxyl terminus are poor substrates for carboxypeptidase P. Similar considerations can also be applied to the selection of peptides that are either relatively resistant or relatively susceptible to hydrolysis by cytosolic, renal, hepatic, serum or other peptidases. Such poorly cleaved polypeptide amidates are immunogens or are useful for bonding to proteins in order to prepare immunogens.
Specific Embodiments of the Invention

Specific values described for radicals, substituents, and ranges, as well as specific embodiments of the invention described herein, are for illustration only; they do not exclude other defined values or other values within defined ranges.

In one specific embodiment of the invention $A^1$ is of the formula:

\[
\begin{align*}
\text{In another specific embodiment of the invention } A^1 \text{ is of the formula:} & \\
\text{In another specific embodiment of the invention } A^1 \text{ is of the formula:} & \\
\text{In another specific embodiment of the invention } A^1 \text{ is of the formula:}
\end{align*}
\]
In another specific embodiment of the invention A\(^1\) is of the formula:

and \(W^{5a}\) is a carbocycle or a heterocycle where \(W^{5a}\) is independently substituted with 0 or 1 \(R^2\) groups. A specific value for M12a is 1.

In another specific embodiment of the invention A\(^1\) is of the formula:

In another specific embodiment of the invention A\(^1\) is of the formula:

In another specific embodiment of the invention A\(^1\) is of the formula:
wherein W^5a is a carbocycle independently substituted with 0 or 1 R^2 groups;

In another specific embodiment of the invention A^1 is of the formula:

wherein Y^2b is O or N(R^2); and M12d is 1, 2, 3, 4, 5, 6, 7 or 8.

In another specific embodiment of the invention A^1 is of the formula:

wherein W^5a is a carbocycle independently substituted with 0 or 1 R^2 groups;

In another specific embodiment of the invention A^1 is of the formula:

wherein W^5a is a carbocycle or heterocycle where W^5a is independently substituted with 0 or 1 R^2 groups.

In another specific embodiment of the invention A^1 is of the formula:
wherein $Y^{2b}$ is O or N($R^2$); and M12d is 1, 2, 3, 4, 5, 6, 7 or 8.

In a specific embodiment of the invention $A^3$ is of the formula:

In another specific embodiment of the invention $A^3$ is of the formula:

In another specific embodiment of the invention $A^3$ is of the formula:
wherein $Y^{1a}$ is O or S; and $Y^{2a}$ is O, N($R^x$) or S.

In another specific embodiment of the invention $A^3$ is of the formula:

wherein $Y^{2b}$ is O or N($R^x$).

In another specific embodiment of the invention $A^3$ is of the formula:

wherein $Y^{2b}$ is O or N($R^x$); and $M_{12d}$ is 1, 2, 3, 4, 5, 6, 7 or 8.

In another specific embodiment of the invention $A^3$ is of the formula:

wherein $Y^{2b}$ is O or N($R^x$); and $M_{12d}$ is 1, 2, 3, 4, 5, 6, 7 or 8.
In another specific embodiment of the invention M12d is 1.

In another specific embodiment of the invention $A^3$ is of the formula:

In another specific embodiment of the invention $A^3$ is of the formula:

In another specific embodiment of the invention $W^5$ is a carbocycle.

In another specific embodiment of the invention $A^3$ is of the formula:

In another specific embodiment of the invention $W^5$ is phenyl.

In another specific embodiment of the invention $A^3$ is of the formula:
wherein \( Y^{1a} \) is O or S; and \( Y^{2a} \) is O, N(\( R^x \)) or S.

In another specific embodiment of the invention \( A^3 \) is of the formula:

\[
\begin{align*}
\text{O} & \quad \text{P} \\
& \quad \text{R}^x \quad \text{Y}^{2b} \\
& \quad \text{R}^2 \quad \text{Y}^{1a} \\
& \quad \text{M12a} \quad \text{R}^2
\end{align*}
\]

wherein \( Y^{2b} \) is O or N(\( R^x \)).

In another specific embodiment of the invention \( A^3 \) is of the formula:

\[
\begin{align*}
\text{O} & \quad \text{P} \\
& \quad \text{R}^x \quad \text{Y}^{2b} \\
& \quad \text{R}^1 \quad \text{M12d} \quad \text{R}^1 \quad \text{W}^3
\end{align*}
\]

wherein \( Y^{2b} \) is O or N(\( R^x \)); and M12d is 1, 2, 3, 4, 5, 6, 7 or 8.

In another specific embodiment of the invention \( R^1 \) is H.

In another specific embodiment of the invention \( A^3 \) is of the formula:

wherein the phenyl carbocycle is substituted with 0, 1, 2, or 3 \( R^2 \) groups.
In another specific embodiment of the invention $A^3$ is of the formula:

![Chemical Structure 1]

In another specific embodiment of the invention $A^3$ is of the formula:

![Chemical Structure 2]

In another specific embodiment of the invention $A^3$ is of the formula:

![Chemical Structure 3]

In another specific embodiment of the invention $A^3$ is of the formula:
In another specific embodiment of the invention $A^3$ is of the formula:

wherein $Y^{1a}$ is $O$ or $S$; and $Y^{2a}$ is $O$, $N(R^2)$ or $S$.

In another specific embodiment of the invention $A^3$ is of the formula:

wherein $Y^{1a}$ is $O$ or $S$; $Y^{2b}$ is $O$ or $N(R^2)$; and $Y^{2c}$ is $O$, $N(R^y)$ or $S$.

In another specific embodiment of the invention $A^3$ is of the formula:
where \( Y^{1a} \) is O or S; \( Y^{2b} \) is O or N(R^2); \( Y^{2d} \) is O or N(R^3); and M12d is 1, 2, 3, 4, 5, 6, 7 or 8.

In another specific embodiment of the invention \( A^3 \) is of the formula:

\[
\begin{array}{c}
\text{O} \\
\text{H} \\
\text{H} \\
\text{H} \\
\text{P} \\
\text{O}
\end{array}
\begin{array}{c}
\text{R}^2 \\
\text{O} \\
\text{R}^y
\end{array}
\]

\( M12d \);  

wherein \( Y^{2b} \) is O or N(R^3); and M12d is 1, 2, 3, 4, 5, 6, 7 or 8.

In another specific embodiment of the invention \( A^3 \) is of the formula:

\[
\begin{array}{c}
\text{O} \\
\text{H} \\
\text{H} \\
\text{H} \\
\text{P} \\
\text{O}
\end{array}
\begin{array}{c}
\text{R}^2 \\
\text{O} \\
\text{R}^2
\end{array}
\]

wherein \( Y^{2b} \) is O or N(R^3).

In another specific embodiment of the invention \( A^3 \) is of the formula:

\[
\begin{array}{c}
\text{O} \\
\text{H} \\
\text{H} \\
\text{H} \\
\text{P} \\
\text{O} \\
\text{O} \\
\text{R}^2
\end{array}
\]

\( M12d \);  

In another specific embodiment of the invention \( A^3 \) is of the formula:

\[
\begin{array}{c}
\text{Y}^1 \\
\text{P} \\
\text{Y}^2 \\
\text{R}^2 \\
\text{R}^2 \\
\text{M12a} \\
\text{Y}^2 \\
\text{W}^3
\end{array}
\]

\( R^x \);
In another specific embodiment of the invention \( A^3 \) is of the formula:

\[
\begin{align*}
&Y^{1a} \quad Y^{2a} \quad Y^{2b} \quad Y^{2c} \quad Y^{2d} \quad Y^{3} \\
\end{align*}
\]

wherein \( Y^{1a} \) is O or S; and \( Y^{2a} \) is O, N(\( R^2 \)) or S.

In another specific embodiment of the invention \( A^3 \) is of the formula:

\[
\begin{align*}
&O \quad Y^{1a} \quad Y^{2b} \quad Y^{2c} \quad Y^{2d} \\
\end{align*}
\]

wherein \( Y^{1a} \) is O or S; \( Y^{2b} \) is O or N(\( R^2 \)); and \( Y^{2c} \) is O, N(\( R^1 \)) or S.

In another specific embodiment of the invention \( A^3 \) is of the formula:

\[
\begin{align*}
&O \quad Y^{1a} \quad Y^{2b} \quad Y^{2c} \quad Y^{2d} \\
\end{align*}
\]

wherein \( Y^{1a} \) is O or S; \( Y^{2b} \) is O or N(\( R^1 \)); \( Y^{2d} \) is O or N(\( R^3 \)); and M12d is 1, 2, 3, 4, 5, 6, 7 or 8.

In another specific embodiment of the invention \( A^3 \) is of the formula:
wherein $Y^{2b}$ is O or N($R^3$); and M12d is 1, 2, 3, 4, 5, 6, 7 or 8.

In another specific embodiment of the invention $A^3$ is of the formula:

5 whereby $Y^{2b}$ is O or N($R^3$).

In another specific embodiment of the invention $A^3$ is of the formula:

wherein: $Y^{2b}$ is O or N($R^5$); and M12d is 1, 2, 3, 4, 5, 6, 7 or 8.

In another specific embodiment of the invention $A^3$ is of the formula:

wherein the phenyl carbocycle is substituted with 0, 1, 2, or 3 $R^2$ groups.

In another specific embodiment of the invention $A^3$ is of the formula:
wherein the phenyl carbocycle is substituted with 0, 1, 2, or 3 \( \text{R}^2 \) groups.

In another specific embodiment of the invention \( \text{A}^3 \) is of the formula:

In a specific embodiment of the invention \( \text{A}^0 \) is of the formula:

wherein each \( \text{R} \) is independently \((\text{C}_1-\text{C}_6)\text{alkyl}\).

In a specific embodiment of the invention \( \text{R}^x \) is independently \( \text{H} \), \( \text{R}^1 \), \( \text{R}^3 \), a protecting group, or the formula:

wherein:
R' is independently H, W^3, R^2 or a protecting group;
R^1 is independently H or alkyl of 1 to 18 carbon atoms;
R^2 is independently H, R^1, R^3 or R^4 wherein each R^4 is independently
substituted with 0 to 3 R^3 groups or taken together at a carbon atom, two R^2
groups form a ring of 3 to 8 carbons and the ring may be substituted with 0 to 3
R^3 groups;

In a specific embodiment of the invention R^5 is of the formula:

\[ \text{\ldots} \]

wherein Y^1a is O or S; and Y^2c is O, N(R^5) or S.

In a specific embodiment of the invention R^5 is of the formula:

\[ \text{\ldots} \]

wherein Y^1a is O or S; and Y^2d is O or N(R^5).

In a specific embodiment of the invention R^5 is of the formula:

\[ \text{\ldots} \]

In a specific embodiment of the invention R^5 is hydrogen or alkyl of 1 to
10 carbons.

In a specific embodiment of the invention R^5 is of the formula:
In a specific embodiment of the invention $R^x$ is of the formula:

In a specific embodiment of the invention $R^x$ is of the formula:

In a specific embodiment of the invention $Y^1$ is $O$ or $S$.

In a specific embodiment of the invention $Y^2$ is $O$, $N(R^3)$ or $S$.

In one specific embodiment of the invention $R^x$ is a group of the formula:

wherein:

$m_1a, m_1b, m_1c, m_1d$ and $m_1e$ are independently $0$ or $1$;
m12c is 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11 or 12;
R' is H, W, R2 or a protecting group;

provided that:

if m1a, m1c, and m1d are 0, then m1b, m1c and m1e are 0;
if m1a and m12c are 0 and m1d is not 0, then m1b and m1c are 0;
if m1a and m1d are 0 and m12c is not 0, then m1b and at least one of
m1c and m1e are 0;
if m1a is 0 and m12c and m1d are not 0, then m1b is 0;
if m12c and m1d are 0 and m1a is not 0, then at least two of m1b, m1c
and m1e are 0;
if m12c is 0 and m1a and m1d are not 0, then at least one of m1b and
m1c are 0; and
if m1d is 0 and m1a and m12c are not 0, then at least one of m1c and
m1e are 0.

In compounds of the invention W5 carbocycles and W5 heterocycles may
be independently substituted with 0 to 3 R2 groups. W5 may be a saturated,
unsaturated or aromatic ring comprising a mono- or bicyclic carbocycle or
heterocycle. W5 may have 3 to 10 ring atoms, e.g., 3 to 7 ring atoms. The W5
rings are saturated when containing 3 ring atoms, saturated or mono-unsaturated
when containing 4 ring atoms, saturated, or mono- or di-unsaturated when
containing 5 ring atoms, and saturated, mono- or di-unsaturated, or aromatic
when containing 6 ring atoms.

A W5 heterocycle may be a monocycle having 3 to 7 ring members (2 to
6 carbon atoms and 1 to 3 heteroatoms selected from N, O, P, and S) or a bicycle
having 7 to 10 ring members (4 to 9 carbon atoms and 1 to 3 heteroatoms
selected from N, O, P, and S). W5 heterocyclic monocycles may have 3 to 6 ring
atoms (2 to 5 carbon atoms and 1 to 2 heteroatoms selected from N, O, and S); or
5 or 6 ring atoms (3 to 5 carbon atoms and 1 to 2 heteroatoms selected from N
and S). W5 heterocyclic bicycles have 7 to 10 ring atoms (6 to 9 carbon atoms
and 1 to 2 heteroatoms selected from N, O, and S) arranged as a bicyclo [4,5],
[5,5], [5,6], or [6,6] system; or 9 to 10 ring atoms (8 to 9 carbon atoms and 1 to 2
hetero atoms selected from N and S) arranged as a bicyclo [5,6] or [6,6] system.
The \( W^5 \) heterocycle may be bonded to \( Y^2 \) through a carbon, nitrogen, sulfur or other atom by a stable covalent bond.

\( W^5 \) heterocycles include for example, pyridyl, dihydropyridyl isomers, piperidine, pyridazinyl, pyrimidinyl, pyrazinyl, \( s \)-triazinyl, oxazolyl, imidazolyl, thiazolyl, isoxazolyl, pyrazolyl, isothiazolyl, furanyl, thiofuranyl, thieryl, and pyrrolyl. \( W^5 \) also includes, but is not limited to, examples such as:

\[
\begin{align*}
\text{Pyridyl} & , & \text{Dihydropyridyl} & , & \text{Piperidine} \\
\text{Pyridazinyl} & , & \text{Pyrimidinyl} & , & \text{Pyrazinyl} \\
\text{S-triazinyl} & , & \text{Oxazolyl} & , & \text{imidazolyl} \\
\text{Thiazolyl} & , & \text{Isoxazolyl} & , & \text{Pyrazolyl} \\
\text{Isothiazolyl} & , & \text{Furanyl} & , & \text{Thiofuranyl} \\
\text{Thienyl} & , & \text{Pyrrolyl} & ,& \text{and} \\
\text{and} & & & & \\
\text{Carbocycles and heterocycles may be independently substituted with} & & & & \\
0 \text{ to } 3 \text{ } R^2 \text{ groups, as defined above. For example, substituted } W^5 \text{ carbocycles} & & & & \\
\text{include:} & & & & \\
\end{align*}
\]
Examples of substituted phenyl carbocycles include:

5 Intracellular Targeting

The phosphonate group of the compounds of the invention may cleave in vivo in stages after they have reached the desired site of action, i.e. inside a cell. One mechanism of action inside a cell may entail a first cleavage, e.g. by esterase, to provide a negatively-charged "locked-in" intermediate. Cleavage of a terminal ester grouping in a compound of the invention thus affords an unstable intermediate which releases a negatively charged "locked in" intermediate.

After passage inside a cell, intracellular enzymatic cleavage or modification of the phosphonate or prodrug compound may result in an intracellular accumulation of the cleaved or modified compound by a "trapping" mechanism. The cleaved or modified compound may then be "locked-in" the cell by a significant change in charge, polarity, or other physical property change which decreases the rate at which the cleaved or modified compound can exit the cell, relative to the rate at which it entered as the phosphonate prodrug. Other mechanisms by which a therapeutic effect are achieved may be operative as well.
Enzymes which are capable of an enzymatic activation mechanism with the phosphonate prodrug compounds of the invention include, but are not limited to, amidases, esterases, microbial enzymes, phospholipases, cholinesterases, and phosphatases.

Specific Compounds of the Invention

Typically, compounds of the invention have a molecular weight of from about 400 amu to about 10,000 amu; in a specific embodiment of the invention, compounds have a molecular weight of less than about 5000 amu; in another specific embodiment of the invention, compounds have a molecular weight of less than about 2500 amu; in another specific embodiment of the invention, compounds have a molecular weight of less than about 1000 amu; in another specific embodiment of the invention, compounds have a molecular weight of less than about 800 amu; in another specific embodiment of the invention, compounds have a molecular weight of less than about 600 amu; and in another specific embodiment of the invention, compounds have a molecular weight of less than about 600 amu and a molecular weight of greater than about 400 amu.

The compounds of the invention also typically have a logD(polarity) less than about 5. In one embodiment the invention provides compounds having a logD less than about 4; in another one embodiment the invention provides compounds having a logD less than about 3; in another one embodiment the invention provides compounds having a logD greater than about -5; in another one embodiment the invention provides compounds having a logD greater than about -3; and in another one embodiment the invention provides compounds having a logD greater than about 0 and less than about 3.

Selected substituents within the compounds of the invention are present to a recursive degree. In this context, “recursive substituent” means that a substituent may recite another instance of itself. Because of the recursive nature of such substituents, theoretically, a large number may be present in any given claim. For example, \( R^x \) contains a \( R^y \) substituent. \( R^y \) can be \( R^2 \), which in turn can be \( R^3 \). If \( R^3 \) is selected to be \( R^5 \), then a second instance of \( R^x \) can be selected. One of ordinary skill in the art of medicinal chemistry understands that the total number of such substituents is reasonably limited by the desired
properties of the compound intended. Such properties include, by example
and not limitation, physical properties such as molecular weight, solubility or log
P, application properties such as activity against the intended target, and
practical properties such as ease of synthesis.

By way of example and not limitation, \( W^3 \), \( R^y \) and \( R^3 \) are all recursive
substituents in certain claims. Typically, each of these may independently occur
20, 19, 18, 17, 16, 15, 14, 13, 12, 11, 10, 9, 8, 7, 6, 5, 4, 3, 2, 1, or 0, times in a
given claim. More typically, each of these may independently occur 12 or fewer
times in a given claim. More typically yet, \( W^3 \) will occur 0 to 8 times, \( R^y \) will
occur 0 to 6 times and \( R^3 \) will occur 0 to 10 times in a given claim. Even more
typically, \( W^3 \) will occur 0 to 6 times, \( R^y \) will occur 0 to 4 times and \( R^3 \) will occur
0 to 8 times in a given claim.

Recursive substituents are an intended aspect of the invention. One of
ordinary skill in the art of medicinal chemistry understands the versatility of
such substituents. To the degree that recursive substituents are present in an
claim of the invention, the total number will be determined as set forth above.

Whenever a compound described herein is substituted with more than
one of the same designated group, \( e.g., \) "\( R^{11} \)" or "\( R^6\)" , then it will be understood
that the groups may be the same or different, \( i.e., \) each group is independently
selected. Wavy lines indicate the site of covalent bond attachments to the
adjoining groups, moieties, or atoms.

In one embodiment of the invention, the compound is in an isolated and
purified form. Generally, the term "isolated and purified" means that the
compound is substantially free from biological materials (\( e.g., \) blood, tissue, cells,
etc.). In one specific embodiment of the invention, the term means that the
compound or conjugate of the invention is at least about 50 wt.% free from
biological materials; in another specific embodiment, the term means that the
compound or conjugate of the invention is at least about 75 wt.% free from
biological materials; in another specific embodiment, the term means that the
compound or conjugate of the invention is at least about 90 wt.% free from
biological materials; in another specific embodiment, the term means that the
compound or conjugate of the invention is at least about 98 wt.% free from
biological materials; and in another embodiment, the term means that the
compound or conjugate of the invention is at least about 99 wt.% free from biological materials. In another specific embodiment, the invention provides a compound or conjugate of the invention that has been synthetically prepared (e.g., ex vivo).

5 In one specific embodiment of the invention the compound is not an anti-inflammatory compound; in another embodiment, the compound is not an anticancer agent; in another embodiment, the compound is not a PNP-inhibitor; in another embodiment, the compound is not a compound that is active against immune-mediated conditions; in another embodiment, the compound is not a compound that is active against metabolic diseases; in another embodiment, the compound is not an antiviral agent; in another embodiment, the compound is not a nucleoside; in another embodiment, the compound is not a kinase inhibitor; in another embodiment, the compound is not an antimetabolite; in another embodiment, the compound is not an IMPDH inhibitor; and in another embodiment, the compound is not an anti-infective agent.

10 Cellular Accumulation

In one embodiment, the invention is provides compounds capable of accumulating in human PBMC (peripheral blood mononuclear cells). PBMC refer to blood cells having round lymphocytes and monocytes. Physiologically, PBMC are critical components of the mechanism against infection. PBMC may be isolated from heparinized whole blood of normal healthy donors or buffy coats, by standard density gradient centrifugation and harvested from the interface, washed (e.g. phosphate-buffered saline) and stored in freezing medium. PBMC may be cultured in multi-well plates. At various times of culture, supernatant may be either removed for assessment, or cells may be harvested and analyzed (Smith R. et al (2003) Blood 102(7):2532-2540). The compounds of this claim may further comprise a phosphonate or phosphonate prodrug. More typically, the phosphonate or phosphonate prodrug can have the structure A³ as described herein.

20 Typically, compounds of the invention demonstrate improved intracellular half-life of the compounds or intracellular metabolites of the compounds in human PBMC when compared to analogs of the compounds not
having the phosphonate or phosphonate prodrug. Typically, the half-life is improved by at least about 50%, more typically at least in the range 50-100%, still more typically at least about 100%, more typically yet greater than about 100%.

In one embodiment of the invention the intracellular half-life of a metabolite of the compound in human PBMCs is improved when compared to an analog of the compound not having the phosphonate or phosphonate prodrug. In such claims, the metabolite may be generated intracellularly, e.g. generated within human PBMC. The metabolite may be a product of the cleavage of a phosphonate prodrug within human PBMCs. The phosphonate prodrug may be cleaved to form a metabolite having at least one negative charge at physiological pH. The phosphonate prodrug may be enzymatically cleaved within human PBMC to form a phosphonate having at least one active hydrogen atom of the form P-OH.

'Stereoisomers

The compounds of the invention may have chiral centers, e.g., chiral carbon or phosphorus atoms. The compounds of the invention thus include racemic mixtures of all stereoisomers, including enantiomers, diastereomers, and atropisomers. In addition, the compounds of the invention include enriched or resolved optical isomers at any or all asymmetric, chiral atoms. In other words, the chiral centers apparent from the depictions are provided as the chiral isomers or racemic mixtures. Both racemic and diastereomeric mixtures, as well as the individual optical isomers isolated or synthesized, substantially free of their enantiomeric or diastereomeric partners, are all within the scope of the invention.

The racemic mixtures are separated into their individual, substantially optically pure isomers through well-known techniques such as, for example, the separation of diastereomeric salts formed with optically active adjuncts, e.g., acids or bases followed by conversion back to the optically active substances. In most instances, the desired optical isomer is synthesized by means of stereospecific reactions, beginning with the appropriate stereoisomer of the desired starting material.
The compounds of the invention can also exist as tautomeric isomers in certain cases. Although only one delocalized resonance structure may be depicted, all such forms are contemplated within the scope of the invention. For example, ene-amine tautomers can exist for purine, pyrimidine, imidazole, guanidine, amidine, and tetrazole systems and all their possible tautomeric forms are within the scope of the invention.

Salts and Hydrates

The compositions of this invention optionally comprise salts of the compounds herein, especially pharmaceutically acceptable non-toxic salts containing, for example, Na\(^+\), Li\(^+\), K\(^+\), Ca\(^{2+}\) and Mg\(^{2+}\). Such salts may include those derived by combination of appropriate cations such as alkali and alkaline earth metal ions or ammonium and quaternary amino ions with an acid anion moiety, typically a carboxylic acid. Monovalent salts are preferred if a water soluble salt is desired.

Metal salts typically are prepared by reacting the metal hydroxide with a compound of this invention. Examples of metal salts which are prepared in this way are salts containing Li\(^+\), Na\(^+\), and K\(^+\). A less soluble metal salt can be precipitated from the solution of a more soluble salt by addition of the suitable metal compound.

In addition, salts may be formed from acid addition of certain organic and inorganic acids, e.g., HCl, HBr, H\(_2\)SO\(_4\), H\(_3\)PO\(_4\) or organic sulfonic acids, to basic centers, typically amines, or to acidic groups. Finally, it is to be understood that the compositions herein comprise compounds of the invention in their un-ionized, as well as zwitterionic form, and combinations with stoichiometric amounts of water as in hydrates.

Also included within the scope of this invention are the salts of the parental compounds with one or more amino acids. Any of the amino acids described above are suitable, especially the naturally-occurring amino acids found as protein components, although the amino acid typically is one bearing a side chain with a basic or acidic group, e.g., lysine, arginine or glutamic acid, or a neutral group such as glycine, serine, threonine, alanine, isoleucine, or leucine.
Another aspect of the invention relates to methods of inhibiting tumor growth, viral infection, inflammation and tissue/organ transplant rejection comprising the step of treating a sample or subject suspected of needing such inhibition with a composition of the invention.

Compositions of the invention may act as inhibitors of tumor growth, viral infection, inflammation and tissue/organ transplant rejection, or as intermediates for such inhibitors or have other utilities as described below. The inhibitors will bind to locations on the surface or in a cavity of a cell having a geometry unique to Mycophenolate like compounds. Compositions binding a cell may bind with varying degrees of reversibility. Those compounds binding substantially irreversibly are ideal candidates for use in this method of the invention. Once labeled, the substantially irreversibly binding compositions are useful as probes for the detection of cancer, viruses, inflammation or tissue/organ transplant rejection. Accordingly, the invention relates to methods of detecting cancer, viruses, inflammation or tissue/organ transplant rejection in a sample or subject suspected of containing a tumor, containing a virus, being inflamed or rejecting a tissue/organ transplant, comprising the steps of: treating such a sample or subject with a composition comprising a compound of the invention bound to a label; and observing the effect of the sample on the activity of the label. Suitable labels are well known in the diagnostics field and include stable free radicals, fluorophores, radioisotopes, enzymes, chemiluminescent groups and chromogens. The compounds herein are labeled in conventional fashion using functional groups such as hydroxyl or amino.

Within the context of the invention samples suspected of containing a tumor, containing a virus, being inflamed or rejecting a tissue/organ transplant include natural or man-made materials such as living organisms; tissue or cell cultures; biological samples such as biological material samples (blood, serum, urine, cerebrospinal fluid, tears, sputum, saliva, tissue samples, and the like); laboratory samples; food, water, or air samples; bioproduct samples such as extracts of cells, particularly recombinant cells synthesizing a desired glycoprotein; and the like. Typically the sample will be suspected of containing an organism which induces cancer cell growth, frequently a pathogenic organism such as a tumor virus. Samples can be
contained in any medium including water and organic solvent/water mixtures. Samples include living organisms such as humans, and man made materials such as cell cultures.

The treating step of the invention comprises adding the composition of the invention to the sample or it comprises adding a precursor of the composition to the sample. The addition step comprises any method of administration as described above.

If desired, the anti-cancer, anti-virus, anti-inflammation, and/or anti-tissue/organ transplant rejection activity of a Mycophenolate-like compound after application of the composition can be observed by any method including direct and indirect methods of detecting such activity. Quantitative, qualitative, and semiquantitative methods of determining such activity are all contemplated. Typically one of the screening methods described above are applied, however, any other method such as observation of the physiological properties of a living organism are also applicable.

However, in screening compounds capable of inhibiting some viruses it should be kept in mind that the results of enzyme assays may not correlate with cell culture assays. Thus, a cell based assay should be the primary screening tool.

Screening for Anti-Cancer, Anti-Viral, Anti-Inflammatory, and Anti-Tissue/Organ Transplant Rejection Compounds

Compositions of the invention are screened for anti-cancer, anti-viral, anti-inflammatory and anti-tissue/organ transplant rejection activity by any of the conventional techniques for evaluating enzyme activity. Within the context of the invention, typically compositions are first screened for inhibitory activity in vitro and compositions showing inhibitory activity are then screened for activity in vivo. Compositions having in vitro Ki (inhibitory constants) of less then about 5 X 10^{-6} M, typically less than about 1 X 10^{-7} M and preferably less than about 5 X 10^{-8} M are preferred for in vivo use.

Useful in vitro screens have been described in detail and will not be elaborated here. However, the examples describe suitable in vitro assays.
**Pharmaceutical Formulations**

The compounds of this invention are formulated with conventional carriers and excipients, which will be selected in accord with ordinary practice. Tablets will contain excipients, glidants, fillers, binders and the like. Aqueous formulations are prepared in sterile form, and when intended for delivery by other than oral administration generally will be isotonic. All formulations will optionally contain excipients such as those set forth in the *Handbook of Pharmaceutical Excipients* (1986). Excipients include ascorbic acid and other antioxidants, chelating agents such as EDTA, carbohydrates such as dextrin, hydroxyalkylcellulose, hydroxyalkylmethylcellulose, stearic acid and the like. The pH of the formulations ranges from about 3 to about 11, but is ordinarily about 7 to 10.

While it is possible for the active ingredients to be administered alone it may be preferable to present them as pharmaceutical formulations. The formulations, both for veterinary and for human use, of the invention comprise at least one active ingredient, as above defined, together with one or more acceptable carriers therefor and optionally other therapeutic ingredients. The carrier(s) must be “acceptable” in the sense of being compatible with the other ingredients of the formulation and physiologically innocuous to the recipient thereof.

The formulations include those suitable for the foregoing administration routes. The formulations may conveniently be presented in unit dosage form and may be prepared by any of the methods well known in the art of pharmacy. Techniques and formulations generally are found in *Remington's Pharmaceutical Sciences* (Mack Publishing Co., Easton, PA). Such methods include the step of bringing into association the active ingredient with the carrier which constitutes one or more accessory ingredients. In general the formulations are prepared by uniformly and intimately bringing into association the active ingredient with liquid carriers or finely divided solid carriers or both, and then, if necessary, shaping the product.

Formulations of the present invention suitable for oral administration may be presented as discrete units such as capsules, cachets or tablets each
containing a predetermined amount of the active ingredient; as a powder or granules; as a solution or a suspension in an aqueous or non-aqueous liquid; or as an oil-in-water liquid emulsion or a water-in-oil liquid emulsion. The active ingredient may also be administered as a bolus, ejectuary or paste.

A tablet is made by compression or molding, optionally with one or more accessory ingredients. Compressed tablets may be prepared by compressing in a suitable machine the active ingredient in a free-flowing form such as a powder or granules, optionally mixed with a binder, lubricant, inert diluent, preservative, surface active or dispersing agent. Molded tablets may be made by molding in a suitable machine a mixture of the powdered active ingredient moistened with an inert liquid diluent. The tablets may optionally be coated or scored and optionally are formulated so as to provide slow or controlled release of the active ingredient therefrom.

For administration to the eye or other external tissues e.g., mouth and skin, the formulations are preferably applied as a topical ointment or cream containing the active ingredient(s) in an amount of, for example, 0.075 to 20% w/w (including active ingredient(s) in a range between 0.1% and 20% in increments of 0.1% w/w such as 0.6% w/w, 0.7% w/w, etc.), preferably 0.2 to 15% w/w and most preferably 0.5 to 10% w/w. When formulated in an ointment, the active ingredients may be employed with either a paraffinic or a water-miscible ointment base. Alternatively, the active ingredients may be formulated in a cream with an oil-in-water cream base.

If desired, the aqueous phase of the cream base may include, for example, at least 30% w/w of a polyhydric alcohol, i.e. an alcohol having two or more hydroxyl groups such as propylene glycol, butane 1,3-diol, mannitol, sorbitol, glycerol and polyethylene glycol (including PEG 400) and mixtures thereof. The topical formulations may desirably include a compound which enhances absorption or penetration of the active ingredient through the skin or other affected areas. Examples of such dermal penetration enhancers include dimethyl sulfoxide and related analogs.

The oily phase of the emulsions of this invention may be constituted from known ingredients in a known manner. While the phase may comprise merely an emulsifier (otherwise known as an emulgent), it desirably comprises a
mixture of at least one emulsifier with a fat or an oil or with both a fat and an oil. Preferably, a hydrophilic emulsifier is included together with a lipophilic emulsifier which acts as a stabilizer. It is also preferred to include both an oil and a fat. Together, the emulsifier(s) with or without stabilizer(s) make up the so-called emulsifying wax, and the wax together with the oil and fat make up the so-called emulsifying ointment base which forms the oily dispersed phase of the cream formulations.

Emulgents and emulsion stabilizers suitable for use in the formulation of the invention include Tween® 60, Span® 80, cetostearyl alcohol, benzyl alcohol, myristyl alcohol, glyceryl mono-stearate and sodium lauryl sulfate.

The choice of suitable oils or fats for the formulation is based on achieving the desired cosmetic properties. The cream should preferably be a non-greasy, non-staining and washable product with suitable consistency to avoid leakage from tubes or other containers. Straight or branched chain, mono- or dibasic alkyl esters such as di-isodecyl, isocetyl stearate, propylene glycol diester of coconut fatty acids, isopropyl myristate, decyl oleate, isopropyl palmitate, butyl stearate, 2-ethylhexyl palmitate or a blend of branched chain esters known as Crodamol CAP may be used, the last three being preferred esters. These may be used alone or in combination depending on the properties required. Alternatively, high melting point lipids such as white soft paraffin and/or liquid paraffin or other mineral oils are used.

Pharmaceutical formulations according to the present invention comprise one or more compounds of the invention together with one or more pharmacologically acceptable carriers or excipients and optionally other therapeutic agents. Pharmaceutical formulations containing the active ingredient may be in any form suitable for the intended method of administration. When used for oral use for example, tablets, troches, lozenges, aqueous or oil suspensions, dispersible powders or granules, emulsions, hard or soft capsules, syrups or elixirs may be prepared. Compositions intended for oral use may be prepared according to any method known to the art for the manufacture of pharmaceutical compositions and such compositions may contain one or more agents including sweetening agents, flavoring agents, coloring agents and
preserving agents, in order to provide a palatable preparation. Tablets containing the active ingredient in admixture with non-toxic pharmaceutically acceptable excipient which are suitable for manufacture of tablets are acceptable. These excipients may be, for example, inert diluents, such as calcium or sodium carbonate, lactose, lactose monohydrate, croscarmellose sodium, povidone, calcium or sodium phosphate; granulating and disintegrating agents, such as maize starch, or alginic acid; binding agents, such as cellulose, microcrystalline cellulose, starch, gelatin or acacia; and lubricating agents, such as magnesium stearate, stearic acid or talc. Tablets may be uncoated or may be coated by known techniques including microencapsulation to delay disintegration and adsorption in the gastrointestinal tract and thereby provide a sustained action over a longer period. For example, a time delay material such as glycercy monostearate or glycercy distearate alone or with a wax may be employed.

Formulations for oral use may be also presented as hard gelatin capsules where the active ingredient is mixed with an inert solid diluent, for example calcium phosphate or kaolin, or as soft gelatin capsules wherein the active ingredient is mixed with water or an oil medium, such as peanut oil, liquid paraffin or olive oil.

Aqueous suspensions of the invention contain the active materials in admixture with excipients suitable for the manufacture of aqueous suspensions. Such excipients include a suspending agent, such as sodium carboxymethylcellulose, methylcellulose, hydroxypropyl methylcellulose, sodium alginate, polyvinylpyrrolidone, gum tragacanth and gum acacia, and dispersing or wetting agents such as a naturally occurring phosphatide (e.g., lecithin), a condensation product of an alkylene oxide with a fatty acid (e.g., polyoxyethylene stearate), a condensation product of ethylene oxide with a long chain aliphatic alcohol (e.g., heptadecaethyleneoxyacetol), a condensation product of ethylene oxide with a partial ester derived from a fatty acid and a hexitol anhydride (e.g., polyoxyethylene sorbitan monooleate). The aqueous suspension may also contain one or more preservatives such as ethyl or n-propyl p-hydroxy-benzoate, one or more coloring agents, one or more flavoring agents and one or more sweetening agents, such as sucrose or saccharin.
Oil suspensions may be formulated by suspending the active ingredient in a vegetable oil, such as arachis oil, olive oil, sesame oil or coconut oil, or in a mineral oil such as liquid paraffin. The oral suspensions may contain a thickening agent, such as beeswax, hard paraffin or cetyl alcohol. Sweetening agents, such as those set forth above, and flavoring agents may be added to provide a palatable oral preparation. These compositions may be preserved by the addition of an antioxidant such as ascorbic acid.

Dispersible powders and granules of the invention suitable for preparation of an aqueous suspension by the addition of water provide the active ingredient in admixture with a dispersing or wetting agent, a suspending agent, and one or more preservatives. Suitable dispersing or wetting agents and suspending agents are exemplified by those disclosed above. Additional excipients, for example sweetening, flavoring and coloring agents, may also be present.

The pharmaceutical compositions of the invention may also be in the form of oil-in-water emulsions. The oily phase may be a vegetable oil, such as olive oil or arachis oil, a mineral oil, such as liquid paraffin, or a mixture of these. Suitable emulsifying agents include naturally-occurring gums, such as gum acacia and gum tragacanth, naturally occurring phosphatides, such as soybean lecithin, esters or partial esters derived from fatty acids and hexitol anhydrides, such as sorbitan monooleate, and condensation products of these partial esters with ethylene oxide, such as polyoxyethylene sorbitan monooleate. The emulsion may also contain sweetening and flavoring agents. Syrups and elixirs may be formulated with sweetening agents, such as glycerol, sorbitol or sucrose. Such formulations may also contain a demulcent, a preservative, a flavoring or a coloring agent.

The pharmaceutical compositions of the invention may be in the form of a sterile injectable preparation, such as a sterile injectable aqueous or oleaginous suspension. This suspension may be formulated according to the known art using those suitable dispersing or wetting agents and suspending agents which have been mentioned above. The sterile injectable preparation may also be a sterile injectable solution or suspension in a non-toxic parenterally acceptable diluent or solvent, such as a solution in 1,3-butane-diol or prepared as a lyophilized
powder. Among the acceptable vehicles and solvents that may be employed are water, Ringer's solution and isotonic sodium chloride solution. In addition, sterile fixed oils may conventionally be employed as a solvent or suspending medium. For this purpose any bland fixed oil may be employed including synthetic mono- or diglycerides. In addition, fatty acids such as oleic acid may likewise be used in the preparation of injectables.

The amount of active ingredient that may be combined with the carrier material to produce a single dosage form will vary depending upon the host treated and the particular mode of administration. For example, a time-release formulation intended for oral administration to humans may contain approximately 1 to 1000 mg of active material compounded with an appropriate and convenient amount of carrier material which may vary from about 5 to about 95% of the total compositions (weight:weight). The pharmaceutical composition can be prepared to provide easily measurable amounts for administration. For example, an aqueous solution intended for intravenous infusion may contain from about 3 to 500 μg of the active ingredient per milliliter of solution in order that infusion of a suitable volume at a rate of about 30 mL/hr can occur.

Formulations suitable for administration to the eye include eye drops wherein the active ingredient is dissolved or suspended in a suitable carrier, especially an aqueous solvent for the active ingredient. The active ingredient is preferably present in such formulations in a concentration of 0.5 to 20%, advantageously 0.5 to 10% particularly about 1.5% w/w.

Formulations suitable for topical administration in the mouth include lozenges comprising the active ingredient in a flavored basis, usually sucrose and acacia or tragacanth; pastilles comprising the active ingredient in an inert basis such as gelatin and glycerin, or sucrose and acacia; and mouthwashes comprising the active ingredient in a suitable liquid carrier.

Formulations for rectal administration may be presented as a suppository with a suitable base comprising for example cocoa butter or a salicylate.

Formulations suitable for intrapulmonary or nasal administration have a particle size for example in the range of 0.1 to 500 microns (including particle sizes in a range between 0.1 and 500 microns in increments microns such as 0.5,
1, 30 microns, 35 microns, etc.), which is administered by rapid inhalation through the nasal passage or by inhalation through the mouth so as to reach the alveolar sacs. Suitable formulations include aqueous or oily solutions of the active ingredient. Formulations suitable for aerosol or dry powder administration may be prepared according to conventional methods and may be delivered with other therapeutic agents such as compounds heretofore used in the treatment or prophylaxis of a given condition.

Formulations suitable for vaginal administration may be presented as pessaries, tampons, creams, gels, pastes, foams or spray formulations containing in addition to the active ingredient such carriers as are known in the art to be appropriate.

Formulations suitable for parenteral administration include aqueous and non-aqueous sterile injection solutions which may contain anti-oxidants, buffers, bacteriostats and solutes which render the formulation isotonic with the blood of the intended recipient; and aqueous and non-aqueous sterile suspensions which may include suspending agents and thickening agents.

The formulations are presented in unit-dose or multi-dose containers, for example sealed ampoules and vials, and may be stored in a freeze-dried (lyophilized) condition requiring only the addition of the sterile liquid carrier, for example water for injection, immediately prior to use. Extemporaneous injection solutions and suspensions are prepared from sterile powders, granules and tablets of the kind previously described. Preferred unit dosage formulations are those containing a daily dose or unit daily sub-dose, as herein above recited, or an appropriate fraction thereof, of the active ingredient.

It should be understood that in addition to the ingredients particularly mentioned above the formulations of this invention may include other agents conventional in the art having regard to the type of formulation in question, for example those suitable for oral administration may include flavoring agents.

The invention further provides veterinary compositions comprising at least one active ingredient as above defined together with a veterinary carrier therefor.

Veterinary carriers are materials useful for the purpose of administering the composition and may be solid, liquid or gaseous materials which are
otherwise inert or acceptable in the veterinary art and are compatible with the active ingredient. These veterinary compositions may be administered orally, parenterally or by any other desired route.

Compounds of the invention can also be formulated to provide controlled release of the active ingredient to allow less frequent dosing or to improve the pharmacokinetic or toxicity profile of the active ingredient. Accordingly, the invention also provided compositions comprising one or more compounds of the invention formulated for sustained or controlled release.

Effective dose of active ingredient depends at least on the nature of the condition being treated, toxicity, whether the compound is being used prophylactically (lower doses), the method of delivery, and the pharmaceutical formulation, and will be determined by the clinician using conventional dose escalation studies. It can be expected to be from about 0.0001 to about 100 mg/kg body weight per day. Typically, from about 0.01 to about 10 mg/kg body weight per day. More typically, from about .01 to about 5 mg/kg body weight per day. More typically, from about .05 to about 0.5 mg/kg body weight per day. For example, the daily candidate dose for an adult human of approximately 70 kg body weight will range from 1 mg to 1000 mg, preferably between 5 mg and 500 mg, and may take the form of single or multiple doses.

Routes of Administration

One or more compounds of the invention (herein referred to as the active ingredients) are administered by any route appropriate to the condition to be treated. Suitable routes include oral, rectal, nasal, topical (including buccal and sublingual), vaginal and parenteral (including subcutaneous, intramuscular, intravenous, intradermal, intrathecal and epidural), and the like. It will be appreciated that the preferred route may vary with for example the condition of the recipient. An advantage of the compounds of this invention is that they are orally bioavailable and can be dosed orally.

Combination Therapy

Active ingredients of the invention are also used in combination with other active ingredients. Such combinations are selected based on the condition
to be treated, cross-reactivities of ingredients and pharmaco-properties of the combination.

It is also possible to combine any compound of the invention with one or more other active ingredients in a unitary dosage form for simultaneous or sequential administration to a patient. The combination therapy may be administered as a simultaneous or sequential regimen. When administered sequentially, the combination may be administered in two or more administrations.

The combination therapy may provide "synergy" and "synergistic effect", *i.e.* the effect achieved when the active ingredients used together is greater than the sum of the effects that results from using the compounds separately. A synergistic effect may be attained when the active ingredients are: (1) co-formulated and administered or delivered simultaneously in a combined formulation; (2) delivered by alternation or in parallel as separate formulations; or (3) by some other regimen. When delivered in alternation therapy, a synergistic effect may be attained when the compounds are administered or delivered sequentially, *e.g.*, in separate tablets, pills or capsules, or by different injections in separate syringes. In general, during alternation therapy, an effective dosage of each active ingredient is administered sequentially, *i.e.* serially, whereas in combination therapy, effective dosages of two or more active ingredients are administered together.

**Metabolites of the Compounds of the Invention**

Also falling within the scope of this invention are the *in vivo* metabolic products of the compounds described herein. Such products may result for example from the oxidation, reduction, hydrolysis, amidation, esterification and the like of the administered compound, primarily due to enzymatic processes. Accordingly, the invention includes compounds produced by a process comprising contacting a compound of this invention with a mammal for a period of time sufficient to yield a metabolic product thereof. Such products typically are identified by preparing a radiolabelled (*e.g.*, C¹⁴ or H³) compound of the invention, administering it parenterally in a detectable dose (*e.g.*, greater than
about 0.5 mg/kg) to an animal such as rat, mouse, guinea pig, monkey, or to
man, allowing sufficient time for metabolism to occur (typically about 30
seconds to 30 hours) and isolating its conversion products from the urine, blood
or other biological samples. These products are easily isolated since they are
labeled (others are isolated by the use of antibodies capable of binding epitopes
surviving in the metabolite). The metabolite structures are determined in
conventional fashion, e.g., by MS or NMR analysis. In general, analysis of
metabolites is done in the same way as conventional drug metabolism studies
well-known to those skilled in the art. The conversion products, so long as they
are not otherwise found in vivo, are useful in diagnostic assays for therapeutic
dosing of the compounds of the invention even if they possess no therapeutic
activity of their own.

Recipes and methods for determining stability of compounds in surrogate
gastrointestinal secretions are known. Compounds are defined herein as stable
in the gastrointestinal tract where less than about 50 mole percent of the
protected groups are deprotected in surrogate intestinal or gastric juice upon
incubation for 1 hour at 37 °C. Simply because the compounds are stable to the
gastrointestinal tract does not mean that they cannot be hydrolyzed in vivo. The
phosphonate prodrugs of the invention typically will be stable in the digestive
system but are substantially hydrolyzed to the parental drug in the digestive
lumen, liver or other metabolic organ, or within cells in general.

**Exemplary Methods of Making the Compounds of the Invention.**

The invention also relates to methods of making the compositions of the
invention. The compositions are prepared by any of the applicable techniques of
organic synthesis. Many such techniques are well known in the art. However,
many of the known techniques are elaborated in *Compendium of Organic
Synthetic Methods* (John Wiley & Sons, New York), Vol. 1, Ian T. Harrison and
Vol. 5, Leroy G. Wade, Jr., 1984; and Vol. 6, Michael B. Smith; as well as

A number of exemplary methods for the preparation of the compositions of the invention are provided below. These methods are intended to illustrate the nature of such preparations are not intended to limit the scope of applicable methods.

Generally, the reaction conditions such as temperature, reaction time, solvents, work-up procedures, and the like, will be those common in the art for the particular reaction to be performed. The cited reference material, together with material cited therein, contains detailed descriptions of such conditions. Typically the temperatures will be -100°C to 200°C, solvents will be aprotic or protic, and reaction times will be 10 seconds to 10 days. Work-up typically consists of quenching any unreacted reagents followed by partition between a water/organic layer system (extraction) and separating the layer containing the product.

Oxidation and reduction reactions are typically carried out at temperatures near room temperature (about 20 °C), although for metal hydride reductions frequently the temperature is reduced to 0 °C to -100 °C, solvents are typically aprotic for reductions and may be either protic or aprotic for oxidations. Reaction times are adjusted to achieve desired conversions.

Condensation reactions are typically carried out at temperatures near room temperature, although for non-equilibrating, kinetically controlled condensations reduced temperatures (0 °C to -100 °C) are also common. Solvents can be either protic (common in equilibrating reactions) or aprotic (common in kinetically controlled reactions).

Standard synthetic techniques such as azeotropic removal of reaction by-products and use of anhydrous reaction conditions (e.g., inert gas environments) are common in the art and will be applied when applicable.

The terms “treated”, “treating”, “treatment”, and the like, when used in connection with a chemical synthetic operation, mean contacting, mixing, reacting, allowing to react, bringing into contact, and other terms common in the art for indicating that one or more chemical entities is treated in such a manner as to convert it to one or more other chemical entities. This means that “treati
compound one with compound two” is synonymous with “allowing compound one to react with compound two”, “contacting compound one with compound two”, “reacting compound one with compound two”, and other expressions common in the art of organic synthesis for reasonably indicating that compound one was “treated”, “reacted”, “allowed to react”, etc., with compound two. For example, treating indicates the reasonable and usual manner in which organic chemicals are allowed to react. Normal concentrations (0.01M to 10M, typically 0.1M to 1M), temperatures (-100 °C to 250 °C, typically -78 °C to 150 °C, more typically -78 °C to 100 °C, still more typically 0 °C to 100 °C), reaction vessels (typically glass, plastic, metal), solvents, pressures, atmospheres (typically air for oxygen and water insensitive reactions or nitrogen or argon for oxygen or water sensitive), etc., are intended unless otherwise indicated. The knowledge of similar reactions known in the art of organic synthesis are used in selecting the conditions and apparatus for “treating” in a given process. In particular, one of ordinary skill in the art of organic synthesis selects conditions and apparatus reasonably expected to successfully carry out the chemical reactions of the described processes based on the knowledge in the art.

Modifications of each of the exemplary schemes and in the examples (hereafter “exemplary schemes”) leads to various analogs of the specific exemplary materials produce. The above-cited citations describing suitable methods of organic synthesis are applicable to such modifications.

In each of the exemplary schemes it may be advantageous to separate reaction products from one another and/or from starting materials. The desired products of each step or series of steps is separated and/or purified (hereinafter separated) to the desired degree of homogeneity by the techniques common in the art. Typically such separations involve multiphase extraction, crystallization from a solvent or solvent mixture, distillation, sublimation, or chromatography. Chromatography can involve any number of methods including, for example: reverse-phase and normal phase; size exclusion; ion exchange; high, medium, and low pressure liquid chromatography methods and apparatus; small scale analytical; simulated moving bed (SMB) and preparative thin or thick layer chromatography, as well as techniques of small scale thin layer and flash chromatography.
Another class of separation methods involves treatment of a mixture with a reagent selected to bind to or render otherwise separable a desired product, unreacted starting material, reaction by product, or the like. Such reagents include adsorbents or absorbents such as activated carbon, molecular sieves, ion exchange media, or the like. Alternatively, the reagents can be acids in the case of a basic material, bases in the case of an acidic material, binding reagents such as antibodies, binding proteins, selective chelators such as crown ethers, liquid/liquid ion extraction reagents (LIX), or the like.

Selection of appropriate methods of separation depends on the nature of the materials involved. For example, boiling point, and molecular weight in distillation and sublimation, presence or absence of polar functional groups in chromatography, stability of materials in acidic and basic media in multiphase extraction, and the like. One skilled in the art will apply techniques most likely to achieve the desired separation.

A single stereoisomer, e.g., an enantiomer, substantially free of its stereoisomer may be obtained by resolution of the racemic mixture using a method such as formation of diastereomers using optically active resolving agents (Stereochemistry of Carbon Compounds, 1962) by E. L. Eliel, McGraw Hill; Lochmuller, C. H., (1975) J. Chromatogr., 113(3) 283-302). Racemic mixtures of chiral compounds of the invention can be separated and isolated by any suitable method, including: (1) formation of ionic, diastereomeric salts with chiral compounds and separation by fractional crystallization or other methods, (2) formation of diastereomeric compounds with chiral derivatizing reagents, separation of the diastereomers, and conversion to the pure stereoisomers, and (3) separation of the substantially pure or enriched stereoisomers directly under chiral conditions.

Under method (1), diastereomeric salts can be formed by reaction of enantiomerically pure chiral bases such as brucine, quinine, ephedrine, strychnine, α-methyl-β-phenylethylamine (amphetamine), and the like with asymmetric compounds bearing acidic functionality, such as carboxylic acid and sulfonic acid. The diastereomeric salts may be induced to separate by fractional crystallization or ionic chromatography. For separation of the optical isomers of
amino compounds, addition of chiral carboxylic or sulfonic acids, such as camphorsulfonic acid, tartaric acid, mandelic acid, or lactic acid can result in formation of the diastereomeric salts.

Alternatively, by method (2), the substrate to be resolved is reacted with one enantiomer of a chiral compound to form a diastereomeric pair (Elie, E. and Wilen, S. (1994) Stereochemistry of Organic Compounds, John Wiley & Sons, Inc., p. 322). Diastereomeric compounds can be formed by reacting asymmetric compounds with enantiomerically pure chiral derivatizing reagents, such as menthyl derivatives, followed by separation of the diastereomers and hydrolysis to yield the free, enantiomerically enriched xanthene. A method of determining optical purity involves making chiral esters, such as a menthyl ester, e.g., (-)-menthyl chloroformate in the presence of base, or Mosher ester, α-methoxy-α-(trifluoromethyl)phenyl acetate (Jacob III. (1982) J. Org. Chem. 47:4165), of the racemic mixture, and analyzing the NMR spectrum for the presence of the two atropisomeric diastereomers. Stable diastereomers of atropisomeric compounds can be separated and isolated by normal- and reverse-phase chromatography following methods for separation of atropisomeric naphthylisooquinolines (Hoye, T., WO 96/15111). By method (3), a racemic mixture of two enantiomers can be separated by chromatography using a chiral stationary phase (Chiral Liquid Chromatography (1989) W. J. Lough, Ed. Chapman and Hall, New York; Okamoto, (1990) J. of Chromatogr. 513:375-378). Enriched or purified enantiomers can be distinguished by methods used to distinguish other chiral molecules with asymmetric carbon atoms, such as optical rotation and circular dichroism.

Examples General Section

A number of exemplary methods for the preparation of compounds of the invention are provided herein, for example, in the Examples hereinbelow. These methods are intended to illustrate the nature of such preparations and are not intended to limit the scope of applicable methods. Certain compounds of the invention can be used as intermediates for the preparation of other compounds of
the invention. For example, the interconversion of various phosphonate compounds of the invention is illustrated below.

**INTERCONVERSIONS OF THE PHOSPHONATES R-LINK-P(O)(OR\(^1\))\(_2\), R-LINK-P(O)(OR\(^1\))(OH) AND R-LINK-P(O)(OH)\(_2\).**

The following schemes 32-38 described the preparation of phosphonate esters of the general structure R-link-P(O)(OR\(^1\))\(_2\), in which the groups R\(^1\) may be the same or different. The R\(^1\) groups attached to a phosphonate ester, or to precursors thereto, may be changed using established chemical transformations.

The interconversion reactions of phosphonates are illustrated in Scheme S32. The group R in Scheme 32 represents the substructure, *i.e.* the drug “scaffold, to which the substituent link-P(O)(OR\(^1\))\(_2\) is attached, either in the compounds of the invention, or in precursors thereto. At the point in the synthetic route of conducting a phosphonate interconversion, certain functional groups in R may be protected. The methods employed for a given phosphonate transformation depend on the nature of the substituent R\(^1\), and of the substrate to which the phosphonate group is attached. The preparation and hydrolysis of phosphonate esters is described in *Organic Phosphorus Compounds*, G. M. Kosolapoff, L. Maeir, eds, Wiley, 1976, p. 9ff.

which in turn can be either made from chlorophospholane or phosphoramidate intermediate. Phosphoroflouridate intermediate prepared either from pyrophosphate or phosphoric acid may also act as precursor in preparation of cyclic prodrugs (Watanabe et al., (1988) *Tetrahedron lett.*, 29:5763-66).


Aryl halides undergo Ni\(^{+2}\) catalyzed reaction with phosphite derivatives to give aryl phosphonate containing compounds (Balthazar, et al (1980) *J. Org. Chem.* 45:5425). Phosphonates may also be prepared from the chlorophosphonate in the presence of a palladium catalyst using aromatic triflates (Petrakis et al (1987) *J. Am. Chem. Soc.* 109:2831; Lu et al (1987) *Synthesis* 726). In another method, aryl phosphonate esters are prepared from aryl phosphates under anionic rearrangement conditions (Melvin (1981) *Tetrahedron Lett.* 22:3375; Casteel et al (1991) *Synthesis*, 691). N-Alkoxy aryl salts with alkali metal derivatives of cyclic alkyl phosphonate provide general synthesis for heteroaryl-2-phosphonate linkers (Redmore (1970) *J. Org. Chem.* 35:4114). These above mentioned methods can also be extended to compounds where the W^5 group is a heterocycle. Cyclic-1,3-propanyl prodrugs of phosphonates are also synthesized from phosphonic diacids and substituted propane-1,3-diols using a coupling reagent such as 1,3-dicyclohexylcarbodiimide (DCC) in presence of a base (*e.g.*, pyridine). Other carbodiimide based coupling agents like 1,3-disopropylcarbodiimide or water soluble reagent, 1-(3-dimethylaminopropyl)-3-ethylcarbodiimide hydrochloride (EDCI) can also be utilized for the synthesis of cyclic phosphonate prodrugs.

The conversion of a phosphonate diester **S32.1** into the corresponding phosphonate monoester **S32.2** (Scheme 32, Reaction 1) is accomplished by a number of methods. For example, the ester **S32.1** in which R^1 is an aralkyl group
such as benzyl, is converted into the monooester compound S32.2 by reaction with a tertiary organic base such as diazabicyclooctane (DABCO) or quinuclidine, as described in *J. Org. Chem.* (1995) 60:2946. The reaction is performed in an inert hydrocarbon solvent such as toluene or xylene, at about 110 °C. The conversion of the diester S32.1 in which R¹ is an aryl group such as phenyl, or an alkenyl group such as allyl, into the monooester S32.2 is effected by treatment of the ester S32.1 with a base such as aqueous sodium hydroxide in acetonitrile or lithium hydroxide in aqueous tetrahydrofuran. Phosphonate diesters S32.1 in which one of the groups R¹ is aralkyl, such as benzyl, and the other is alkyl, is converted into the monooesters S32.2 in which R¹ is alkyl by hydrogenation, for example using a palladium on carbon catalyst. Phosphonate diesters in which both of the groups R¹ are alkenyl, such as allyl, is converted into the monooester S32.2 in which R¹ is alkenyl, by treatment with chlorotris(triphenylphosphine)rhodium (Wilkinson's catalyst) in aqueous ethanol at reflux, optionally in the presence of diazabicyclooctane, for example by using the procedure described in *J. Org. Chem.* (1973) 38:3224, for the cleavage of allyl carboxylates.

The conversion of a phosphonate diester S32.1 or a phosphonate monoester S32.2 into the corresponding phosphonic acid S32.3 (Scheme 32, Reactions 2 and 3) can be effected by reaction of the diester or the monoester with trimethylsilyl bromide, as described in *J. Chem. Soc., Chem. Comm.*, (1979) 739. The reaction is conducted in an inert solvent such as, for example, dichloromethane, optionally in the presence of a silylating agent such as bis(trimethylsilyl)trifluoroacetamide, at ambient temperature. A phosphonate monoester S32.2 in which R¹ is aralkyl such as benzyl, is converted into the corresponding phosphonic acid S32.3 by hydrogenation over a palladium catalyst, or by treatment with hydrogen chloride in an ethereal solvent such as dioxane. A phosphonate monoester S32.2 in which R¹ is alkenyl such as, for example, allyl, is converted into the phosphonic acid S32.3 by reaction with Wilkinson's catalyst in an aqueous organic solvent, for example in 15% aqueous acetonitrile, or in aqueous ethanol, for example using the procedure described in *Helv. Chim. Acta.* (1985) 68:618. Palladium catalyzed hydrogenolysis of phosphonate esters S32.1 in which R¹ is benzyl is described in *J. Org. Chem.*
Platinum-catalyzed hydrogenolysis of phosphonate esters S32.1 in which R^1 is phenyl is described in *J. Am. Chem. Soc.* (1956) 78:2336.

The conversion of a phosphonate monoester S32.2 into a phosphonate diester S32.1 (Scheme 32, Reaction 4) in which the newly introduced R^1 group is alkyl, aralkyl, haloalkyl such as chloroethyl, or aralkyl is effected by a number of reactions in which the substrate S32.2 is reacted with a hydroxy compound R^1OH, in the presence of a coupling agent. Typically, the second phosphonate ester group is different than the first introduced phosphonate ester group, *i.e.* R^1 is followed by the introduction of R^2 where each of R^1 and R^2 is alkyl, aralkyl, haloalkyl such as chloroethyl, or aralkyl (Scheme 32, Reaction 4a) whereby S32.2 is converted to S32.1a. Suitable coupling agents are those employed for the preparation of carboxylate esters, and include a carbodiimide such as dicyclohexylcarbodiimide, in which case the reaction is preferably conducted in a basic organic solvent such as pyridine, or (benzotriazol-1-yl oxy)tripyrrrolidinophosphonium hexafluorophosphate (PYBOP, Sigma), in which case the reaction is performed in a polar solvent such as dimethylformamide, in the presence of a tertiary organic base such as diisopropylethylamine, or Aldrithiol-2 (Aldrich) in which case the reaction is conducted in a basic solvent such as pyridine, in the presence of a triaryl phosphine such as triphenylphosphine. Alternatively, the conversion of the phosphonate monoester S32.2 to the diester S32.1 is effected by the use of the Mitsunobu reaction, as described above (Scheme 7). The substrate is reacted with the hydroxy compound R^1OH, in the presence of diethyl azodicarboxylate and a triarylphtosphine such as triphenylphosphine. Alternatively, the phosphonate monoester S32.2 is transformed into the phosphonate diester S32.1, in which the introduced R^1 group is alkenyl or aralkyl, by reaction of the monoester with the halide R^1Br, in which R^1 is as alkenyl or aralkyl. The alkylation reaction is conducted in a polar organic solvent such as dimethylformamide or acetonitrile, in the presence of a base such as cesium carbonate. Alternatively, the phosphonate monoester is transformed into the phosphonate diester in a two step procedure. In the first step, the phosphonate monoester S32.2 is transformed into the chloro analog RP(O)(OR^1)Cl by reaction with thionyl chloride or oxalyl chloride and the like, as described in
Organic Phosphorus Compounds, G. M. Kosolapoff, L. Maeir, eds, Wiley, 1976, p. 17, and the thus-obtained product RP(O)(OR^1)Cl is then reacted with the hydroxy compound R^1OH, in the presence of a base such as triethylamine, to afford the phosphonate diester S32.1.

A phosphonic acid R-link-P(O)(OH)_2 is transformed into a phosphonate monoester RP(O)(OR^1)(OH) (Scheme 32, Reaction 5) by means of the methods described above of for the preparation of the phosphonate diester R-link-P(O)(OR^1)_2 S32.1, except that only one molar proportion of the component R^1OH or R^1Br is employed. Dialkyl phosphonates may be prepared according to the methods of: Quast et al (1974) Synthesis 490; Stowell et al (1990) Tetrahedron Lett. 3261; US 5663159.

A phosphonic acid R-link-P(O)(OH)_2 S32.3 is transformed into a phosphonate diester R-link-P(O)(OR^1)_2 S32.1 (Scheme 32, Reaction 6) by a coupling reaction with the hydroxy compound R^1OH, in the presence of a coupling agent such as Aldrithiol-2 (Aldrich) and triphenylphosphine. The reaction is conducted in a basic solvent such as pyridine. Alternatively, phosphonic acids S32.3 are transformed into phosphonic esters S32.1 in which R^1 is aryl, by means of a coupling reaction employing, for example, dicyclohexylcarbodiimide in pyridine at ca 70 °C. Alternatively, phosphonic acids S32.3 are transformed into phosphonic esters S32.1 in which R^1 is alkenyl, by means of an alkylation reaction. The phosphonic acid is reacted with the alkenyl bromide R^1Br in a polar organic solvent such as acetonitrile solution at reflux temperature, the presence of a base such as cesium carbonate, to afford the phosphonic ester S32.1.
Scheme 32

Preparation of phosphonate carbamates.


Scheme 33 illustrates various methods by which the carbamate linkage is synthesized. As shown in Scheme 33, in the general reaction generating carbamates, an alcohol S33.1, is converted into the activated derivative S33.2 in which Lv is a leaving group such as halo, imidazolyl, benztriazolyl and the like,
as described herein. The activated derivative S33.2 is then reacted with an amine S33.3, to afford the carbamate product S33.4. Examples 1 – 7 in Scheme 33 depict methods by which the general reaction is effected. Examples 8 - 10 illustrate alternative methods for the preparation of carbamates.

Scheme 33, Example 1 illustrates the preparation of carbamates employing a chloroformyl derivative of the alcohol S33.5. In this procedure, the alcohol S33.5 is reacted with phosgene, in an inert solvent such as toluene, at about 0 °C, as described in Org. Syn. Coll. Vol. 3, 167, 1965, or with an equivalent reagent such as trichloromethoxy chloroformate, as described in Org. Syn. Coll. Vol. 6, 715, 1988, to afford the chloroformate S33.6. The latter compound is then reacted with the amine component S33.3, in the presence of an organic or inorganic base, to afford the carbamate S33.7. For example, the chloroformyl compound S33.6 is reacted with the amine S33.3 in a water-miscible solvent such as tetrahydrofuran, in the presence of aqueous sodium hydroxide, as described in Org. Syn. Coll. Vol. 3, 167, 1965, to yield the carbamate S33.7. Alternatively, the reaction is performed in dichloromethane in the presence of an organic base such as diisopropylethylamine or dimethylaminopyridine.

Scheme 33, Example 2 depicts the reaction of the chloroformate compound S33.6 with imidazole to produce the imidazolide S33.8. The imidazolide product is then reacted with the amine S33.3 to yield the carbamate S33.7. The preparation of the imidazolide is performed in an aprotic solvent such as dichloromethane at 0 °C, and the preparation of the carbamate is conducted in a similar solvent at ambient temperature, optionally in the presence of a base such as dimethylaminopyridine, as described in J. Med. Chem., 1989, 32, 357.

Scheme 33 Example 3, depicts the reaction of the chloroformate S33.6 with an activated hydroxyl compound R"OH, to yield the mixed carbonate ester S33.10. The reaction is conducted in an inert organic solvent such as ether or dichloromethane, in the presence of a base such as dicyclohexylamine or triethylamine. The hydroxyl component R"OH is selected from the group of compounds S33.19 - S33.24 shown in Scheme 33, and similar compounds. For example, if the component R"OH is hydroxybenztriazole S33.19, N-hydroxysuccinimide S33.20, or pentachlorophenol, S33.21, the mixed carbonate
S33.10 is obtained by the reaction of the chloroformate with the hydroxyl compound in an ethereal solvent in the presence of dicyclohexylamine, as described in *Can. J. Chem.*, 1982, 60, 976. A similar reaction in which the component R"OH is pentfluorophenol S33.22 or 2-hydroxyypyridine S33.23 is performed in an ethereal solvent in the presence of triethylamine, as described in *Syn.*, 1986, 303, and *Chem. Ber.*, 118, 468, 1985.

Scheme 33 Example 4 illustrates the preparation of carbamates in which an alkyloxycarbonylimidazole S33.8 is employed. In this procedure, an alcohol S33.5 is reacted with an equimolar amount of carbonyl diimidazole S33.11 to prepare the intermediate S33.8. The reaction is conducted in an aprotic organic solvent such as dichloromethane or tetrahydrofuran. The acyloxyimidazole S33.8 is then reacted with an equimolar amount of the amine R'NH₂ to afford the carbamate S33.7. The reaction is performed in an aprotic organic solvent such as dichloromethane, as described in *Tet. Lett.*, 42, 2001, 5227, to afford the carbamate S33.7.

Scheme 33, Example 5 illustrates the preparation of carbamates by means of an intermediate alkoxy carbonyl benztriazole S33.13. In this procedure, an alcohol ROH is reacted at ambient temperature with an equimolar amount of benztriazole carbonyl chloride S33.12, to afford the alkoxy carbonyl product S33.13. The reaction is performed in an organic solvent such as benzene or toluene, in the presence of a tertiary organic amine such as triethylamine, as described in *Synthesis.*, 1977, 704. The product is then reacted with the amine R'NH₂ to afford the carbamate S33.7. The reaction is conducted in toluene or ethanol, at from ambient temperature to about 80 °C as described in *Synthesis.*, 1977, 704.

Scheme 33, Example 6 illustrates the preparation of carbamates in which a carbonate (R''O₂CO), S33.14, is reacted with an alcohol S33.5 to afford the intermediate alkoxy carbonyl intermediate S33.15. The latter reagent is then reacted with the amine R'NH₂ to afford the carbamate S33.7. The procedure in which the reagent S33.15 is derived from hydroxybenztriazole S33.19 is described in *Synthesis*, 1993, 908; the procedure in which the reagent S33.15 is derived from N-hydroxy succinimide S33.20 is described in *Tet. Lett.*, 1992, 2781; the procedure in which the reagent S33.15 is derived from 2-
hydroxypyridine S33.23 is described in Tet. Lett., 1991, 4251; the procedure in which the reagent S33.15 is derived from 4-nitrophenol S33.24 is described in Synthesis. 1993, 103. The reaction between equimolar amounts of the alcohol ROH and the carbonate S33.14 is conducted in an inert organic solvent at ambient temperature.

Scheme 33, Example 7 illustrates the preparation of carbamates from alkoxy carbonyl azides S33.16. In this procedure, an alkyl chloroformate S33.6 is reacted with an azide, for example sodium azide, to afford the alkoxy carbonyl azide S33.16. The latter compound is then reacted with an equimolar amount of the amine R'NH₂ to afford the carbamate S33.7. The reaction is conducted at ambient temperature in a polar aprotic solvent such as dimethyl sulfoxide, for example as described in Synthesis., 1982, 404.

Scheme 33, Example 8 illustrates the preparation of carbamates by means of the reaction between an alcohol ROH and the chloroformyl derivative of an amine S33.17. In this procedure, which is described in Synthetic Organic Chemistry, R. B. Wagner, H. D. Zook, Wiley, 1953, p. 647, the reactants are combined at ambient temperature in an aprotic solvent such as acetonitrile, in the presence of a base such as triethylamine, to afford the carbamate S33.7.

Scheme 33, Example 9 illustrates the preparation of carbamates by means of the reaction between an alcohol ROH and an isocyanate S33.18. In this procedure, which is described in Synthetic Organic Chemistry, R. B. Wagner, H. D. Zook, Wiley, 1953, p. 645, the reactants are combined at ambient temperature in an aprotic solvent such as ether or dichloromethane and the like, to afford the carbamate S33.7.

Scheme 33, Example 10 illustrates the preparation of carbamates by means of the reaction between an alcohol ROH and an amine R'NH₂. In this procedure, which is described in Chem. Lett. 1972, 373, the reactants are combined at ambient temperature in an aprotic organic solvent such as tetrahydrofuran, in the presence of a tertiary base such as triethylamine, and selenium. Carbon monoxide is passed through the solution and the reaction proceeds to afford the carbamate S33.7.
Scheme 33. Preparation of carbamates.

General reaction

\[
\begin{align*}
\text{ROH} & \xrightarrow{} \text{ROCL} & \text{R'NH}_2 & \xrightarrow{} \text{ROCONHR'} \\
\text{S33.1} & \text{S33.2} & \text{S33.3} & \text{S33.4}
\end{align*}
\]

Examples

1. \[
\begin{align*}
\text{ROH} & \xrightarrow{} \text{ROCOCI} & \text{R'NH}_2 & \xrightarrow{} \text{ROCONHR'} \\
\text{S33.5} & \text{S33.6} & \text{S33.3} & \text{S33.7}
\end{align*}
\]

2. \[
\begin{align*}
\text{ROH} & \xrightarrow{} \text{ROCOCI} & \text{R'NH}_2 & \xrightarrow{} \text{ROCONHR'} \\
\text{S33.5} & \text{S33.6} & \text{S33.3} & \text{S33.7}
\end{align*}
\]

3. \[
\begin{align*}
\text{ROH} & \xrightarrow{} \text{ROCOCI} & \text{R'OH} & \xrightarrow{} \text{ROCONHR'} \\
\text{S33.5} & \text{S33.6} & \text{S33.9} & \text{S33.10} & \text{S33.3} & \text{S33.7}
\end{align*}
\]

4. \[
\begin{align*}
\text{ROH} & \xrightarrow{} \text{ROCOCI} & \text{R'NH}_2 & \xrightarrow{} \text{ROCONHR'} \\
\text{S33.5} & \text{S33.11} & \text{S33.8} & \text{S33.3} & \text{S33.7}
\end{align*}
\]

5. \[
\begin{align*}
\text{ROH} & \xrightarrow{} \text{ROCl} & \text{R'NH}_2 & \xrightarrow{} \text{ROCONHR'} \\
\text{S33.5} & \text{S33.12} & \text{S33.13} & \text{S33.3} & \text{S33.7}
\end{align*}
\]
PREPARATION OF CARBOALKOXY-SUBSTITUTED PHOSPHONATE BISAMIDATES, MONOAMIDATES, DIESTERS AND MONOESTERS.

A number of methods are available for the conversion of phosphonic acids into amidates and esters. In one group of methods, the phosphonic acid is
either converted into an isolated activated intermediate such as a phosphoryl chloride, or the phosphonic acid is activated in situ for reaction with an amine or a hydroxy compound.


Phosphonic acids are converted into activated imidazolyl derivatives by reaction with carbonyl diimidazole, as described in *J. Chem. Soc., Chem. Comm.* (1991) 312, or *Nucleosides & Nucleotides* (2000) 19:1885. Activated sulfonyloxy derivatives are obtained by the reaction of phosphonic acids with trichloromethylsulfonyl chloride or with trisopropylbenzenesulfonyl chloride, as described in *Tet. Lett.* (1996) 7857, or *Bioorg. Med. Chem. Lett.* (1998) 8:663. The activated sulfonyloxy derivatives are then reacted with amines or hydroxy compounds to afford amidates or esters.


A number of additional coupling reagents have been described for the preparation of amidates and esters from phosphonic acids. The agents include Aldrithiol-2, and PYBOP and BOP, as described in *J. Org. Chem.*, 1995, 60, 5214, and *J. Med. Chem.* (1997) 40:3842, mesitylene-2-sulfonyl-3-nitro-1,2,4-triazole (MSNT), as described in *J. Med. Chem.* (1996) 39:4958,

Phosphonic acids are converted into amidates and esters by means of the Mitsunobu reaction, in which the phosphonic acid and the amine or hydroxy reactant are combined in the presence of a triaryl phosphine and a dialkyl azodicarboxylate. The procedure is described in Org. Lett., 2001, 3, 643, or J. Med. Chem., 1997, 40, 3842.


Schemes 34-37 illustrate the conversion of phosphonate esters and phosphonic acids into carboalkoxy-substituted phosphonbisamidates (Scheme 34), phosphonamidates (Scheme 35), phosphonate monoesters (Scheme 36) and phosphonate diesters, (Scheme 37). Scheme 38 illustrates synthesis of gem-dialkyl amino phosphonate reagents.

Scheme 34 illustrates various methods for the conversion of phosphonate diesters S34.1 into phosphonbisamidates S34.5. The diester S34.1, prepared as described previously, is hydrolyzed, either to the monoester S34.2 or to the phosphonic acid S34.6. The methods employed for these transformations are described above. The monoester S34.2 is converted into the monoamidate S34.3 by reaction with an aminoester S34.9, in which the group R² is H or alkyl; the group R⁴b is a divalent alkenylene moiety such as, for example, CHCH₃, CHCH₂CH₃, CH(CH(CH₃)₂), CH(CH₂Ph), and the like, or a side chain group present in natural or modified aminoacids; and the group R₃b is C₁₋C₁₂ alkyl, such as methyl, ethyl, propyl, isopropyl, or isobutyl; C₆₋C₂₀ aryl, such as phenyl.
or substituted phenyl; or C₆–C₂₀ arylalkyl, such as benzyl or benzylationyl. The reactants are combined in the presence of a coupling agent such as a carbodiimide, for example dicyclohexyl carbodiimide, as described in J. Am. Chem. Soc., (1957) 79:3575, optionally in the presence of an activating agent such as hydroxybenztriazole, to yield the amidate product S34.3. The amidate-forming reaction is also effected in the presence of coupling agents such as BOP, as described in J. Org. Chem. (1995) 60:5214, Aldrichiol, PYBOP and similar coupling agents used for the preparation of amides and esters. Alternatively, the reactants S34.2 and S34.9 are transformed into the monoamidate S34.3 by means of a Mitsunobu reaction. The preparation of amidates by means of the Mitsunobu reaction is described in J. Med. Chem. (1995) 38:2742. Equimolar amounts of the reactants are combined in an inert solvent such as tetrahydrofuran in the presence of a triaryl phosphine and a dialkyl azodicarboxylate. The thus-obtained monoaryl ester S34.3 is then transformed into amidate phosphonic acid S34.4. The conditions used for the hydrolysis reaction depend on the nature of the R¹ group, as described previously. The phosphonic acid amidate S34.4 is then reacted with an aminoester S34.9, as described above, to yield the bisamidate product S34.5, in which the amino substituents are the same or different. Alternatively, the phosphonic acid S34.6 may be treated with two different amino ester reagents simultaneously, i.e. S34.9 where R², R⁴b or R⁵b are different. The resulting mixture of bisamidate products S34.5 may then be separable, e.g. by chromatography.
An example of this procedure is shown in Scheme 34, Example 1. In this procedure, a dibenzyl phosphonate S34.14 is reacted with diazabicyclooctane (DABCO) in toluene at reflux, as described in J. Org. Chem., 1995, 60, 2946, to afford the monobenzyl phosphonate S34.15. The product is then reacted with equimolar amounts of ethyl alaninate S34.16 and dicyclohexyl carbodiimide in pyridine, to yield the amidate product S34.17. The benzyl group is then removed, for example by hydrogenolysis over a palladium catalyst, to give the monoacid product S34.18 which may be unstable according to J. Med. Chem. (1997) 40(23):3842. This compound S34.18 is then reacted in a Mitsunobu reaction with ethyl leucinate S34.19, triphenyl phosphine and
diethylazodicarboxylate, as described in *J. Med. Chem.*, 1995, 38, 2742, to produce the bisamidate product **S34.20**.

Using the above procedures, but employing in place of ethyl leucinate **S34.19** or ethyl alaninate **S34.16**, different aminoesters **S34.9**, the corresponding products **S34.5** are obtained.

Alternatively, the phosphonic acid **S34.6** is converted into the bisamidate **S34.5** by use of the coupling reactions described above. The reaction is performed in one step, in which case the nitrogen-related substituents present in the product **S34.5** are the same, or in two steps, in which case the nitrogen-related substituents can be different.

An example of the method is shown in Scheme 34, Example 2. In this procedure, a phosphonic acid **S34.6** is reacted in pyridine solution with excess ethyl phenylalalaninate **S34.21** and dicyclohexylcarbodiimide, for example as described in *J. Chem. Soc., Chem. Comm.*, 1991, 1063, to give the bisamidate product **S34.22**.

Using the above procedures, but employing, in place of ethyl phenylalananinate, different aminoesters **S34.9**, the corresponding products **S34.5** are obtained.

As a further alternative, the phosphonic acid **S34.6** is converted into the mono or bis-activated derivative **S34.7**, in which **Lv** is a leaving group such as chloro, imidazolyl, triisopropylbenzenesulfonyloxy etc. The conversion of phosphonic acids into chlorides **S34.7** (**Lv = Cl**) is effected by reaction with thionyl chloride or oxalyl chloride and the like, as described in *Organic Phosphorus Compounds*, G. M. Kosolapoff, L. Maier, eds, Wiley, 1976, p. 17. The conversion of phosphonic acids into monoimidazolides **S34.7** (**Lv = imidazolyl**) is described in *J. Med. Chem.*, 2002, 45, 1284 and in *J. Chem. Soc. Chem. Comm.*, 1991, 312. Alternatively, the phosphonic acid is activated by reaction with triisopropylbenzenesulfonyl chloride, as described in *Nucleosides and Nucleotides*, 2000, 10, 1885. The activated product is then reacted with the aminoester **S34.9**, in the presence of a base, to give the bisamidate **S34.5**. The reaction is performed in one step, in which case the nitrogen substituents present in the product **S34.5** are the same, or in two steps, via the intermediate **S34.11**, in which case the nitrogen substituents can be different.
Examples of these methods are shown in Scheme 34, Examples 3 and 5. In the procedure illustrated in Scheme 34, Example 3, a phosphonic acid S34.6 is reacted with ten molar equivalents of thionyl chloride, as described in Zh. Obschei Khim., 1958, 28, 1063, to give the dichloro compound S34.23. The product is then reacted at reflux temperature in a polar aprotic solvent such as acetonitrile, and in the presence of a base such as triethylamine, with butyl serinate S34.24 to afford the bisamidate product S34.25.

Using the above procedures, but employing, in place of butyl serinate S34.24, different aminoesters S34.9, the corresponding products S34.5 are obtained.

In the procedure illustrated in Scheme 34, Example 5, the phosphonic acid S34.6 is reacted, as described in J. Chem. Soc. Chem. Comm., 1991, 312, with carbonyl diimidazole to give the imidazolide S34.32. The product is then reacted in acetonitrile solution at ambient temperature, with one molar equivalent of ethyl alaninate S34.33 to yield the monodisplacement product S34.34. The latter compound is then reacted with carbonyl diimidazole to produce the activated intermediate S34.35, and the product is then reacted, under the same conditions, with ethyl N-methylalaninate S34.33a to give the bisamidate product S34.36.

Using the above procedures, but employing, in place of ethyl alaninate S34.33 or ethyl N-methylalaninate S34.33a, different aminoesters S34.9, the corresponding products S34.5 are obtained.

The intermediate monoamidate S34.3 is also prepared from the monoester S34.2 by first converting the monoester into the activated derivative S34.8 in which Lv is a leaving group such as halo, imidazolyl etc, using the procedures described above. The product S34.8 is then reacted with an aminoester S34.9 in the presence of a base such as pyridine, to give an intermediate monoamidate product S34.3. The latter compound is then converted, by removal of the R¹ group and coupling of the product with the aminoester S34.9, as described above, into the bisamidate S34.5.

An example of this procedure, in which the phosphonic acid is activated by conversion to the chloro derivative S34.26, is shown in Scheme 34, Example 4. In this procedure, the phosphonic monobenzyl ester S34.15 is reacted, in
dichloromethane, with thionyl chloride, as described in *Tet. Letters.*, 1994, 35, 4097, to afford the phosphoryl chloride S34.26. The product is then reacted in acetonitrile solution at ambient temperature with one molar equivalent of ethyl 3-amino-2-methylpropionate S34.27 to yield the monoamidate product S34.28. The latter compound is hydrogenated in ethylacetate over a 5% palladium on carbon catalyst to produce the monoacid product S34.29. The product is subjected to a Mitsunobu coupling procedure, with equimolar amounts of butyl alaninate S34.30, triphenyl phosphine, diethylazodicarboxylate and triethylamine in tetrahydrofuran, to give the bisamidate product S34.31.

Using the above procedures, but employing, in place of ethyl 3-amino-2-methylpropionate S34.27 or butyl alaninate S34.30, different aminoesters S34.9, the corresponding products S34.5 are obtained.

The activated phosphonic acid derivative S34.7 is also converted into the bisamidate S34.5 via the diamo compound S34.10. The conversion of activated phosphonic acid derivatives such as phosphoryl chlorides into the corresponding amino analogs S34.10, by reaction with ammonia, is described in *Organic Phosphorus Compounds,* G. M. Kosolapoff, L. Maeir, eds, Wiley, 1976. The bisamino compound S34.10 is then reacted at elevated temperature with a haloester S34.12 (Hal = halogen, i.e. F, Cl, Br, I), in a polar organic solvent such as dimethylformamide, in the presence of a base such as 4, 4-dimethylaminopyridine (DMAP) or potassium carbonate, to yield the bisamidate S34.5. Alternatively, S34.6 may be treated with two different amino ester reagents simultaneously, i.e. S34.12 where R\textsuperscript{4b} or R\textsuperscript{5b} are different. The resulting mixture of bisamidate products S34.5 may then be separable, e.g. by chromatography.

An example of this procedure is shown in Scheme 34, Example 6. In this method, a dichlorophosphonate S34.23 is reacted with ammonia to afford the diamide S34.37. The reaction is performed in aqueous, aqueous alcoholic or alcoholic solution, at reflux temperature. The resulting diamino compound is then reacted with two molar equivalents of ethyl 2-bromo-3-methylbutyrate S34.38, in a polar organic solvent such as N-methylpyrrolidinone at ca. 150 °C, in the presence of a base such as potassium carbonate, and optionally in the
presence of a catalytic amount of potassium iodide, to afford the bisamidate product S34.39.

Using the above procedures, but employing, in place of ethyl 2-bromo-3-methylbutyrate S34.38, different haloesters S34.12 the corresponding products S34.5 are obtained.

The procedures shown in Scheme 34 are also applicable to the preparation of bisamidates in which the aminoester moiety incorporates different functional groups. Scheme 34, Example 7 illustrates the preparation of bisamidates derived from tyrosine. In this procedure, the monoimidazolide S34.32 is reacted with propyl tyrosinate S34.40, as described in Example 5, to yield the monoamidate S34.41. The product is reacted with carbonyl diimidazole to give the imidazolide S34.42, and this material is reacted with a further molar equivalent of propyl tyrosinate to produce the bisamidate product S34.43.

Using the above procedures, but employing, in place of propyl tyrosinate S34.40, different aminoesters S34.9, the corresponding products S34.5 are obtained. The aminoesters employed in the two stages of the above procedure can be the same or different, so that bisamidates with the same or different amino substituents are prepared.

Scheme 35 illustrates methods for the preparation of phosphonate monoamidates.

In one procedure, a phosphonate monoester S34.1 is converted, as described in Scheme 34, into the activated derivative S34.8. This compound is then reacted, as described above, with an aminoester S34.9, in the presence of a base, to afford the monoamidate product S35.1.

The procedure is illustrated in Scheme 35, Example 1. In this method, a monophenyl phosphonate S35.7 is reacted with, for example, thionyl chloride, as described in J. Gen. Chem. USSR., 1983, 32, 367, to give the chloro product S35.8. The product is then reacted, as described in Scheme 34, with ethyl alaninate, to yield the amidate S35.10.

Using the above procedures, but employing, in place of ethyl alaninate S35.9, different aminoesters S34.9, the corresponding products S35.1 are obtained.
Alternatively, the phosphonate monoester $S_{34.1}$ is coupled, as described in Scheme 34, with an aminoester $S_{34.9}$ to produce the amidate $S_{35.1}$. If necessary, the $R^1$ substituent is then altered, by initial cleavage to afford the phosphonic acid $S_{35.2}$. The procedures for this transformation depend on the nature of the $R^1$ group, and are described above. The phosphonic acid is then transformed into the ester amidate product $S_{35.3}$, by reaction with the hydroxy compound $R^3$-$OH$, in which the group $R^3$ is aryl, heterocycle, alkyl, cycloalkyl, haloalkyl etc, using the same coupling procedures (carbodiimide, Aldrithiol-2, PYBOP, Mitsunobu reaction etc) described in Scheme 34 for the coupling of amines and phosphonic acids.

**Scheme 34 Example 1**

![Diagram of the reaction sequence]

$S_{34.14}$

$S_{34.15}$

$S_{34.16}$

$S_{34.17}$

$S_{34.18}$

$S_{34.19}$

$S_{34.20}$
Scheme 34 Example 2

\[
\begin{align*}
\text{R-link} & \quad \text{POH} \\
& \quad \text{OH} \\
\text{S34.6} \\
\end{align*}
\]

\[
\begin{align*}
\text{H}_2\text{NCH}(\text{Bn})\text{CO}_2\text{Et} \quad \text{S34.21} & \quad \text{R-link} \quad \text{P-OH} \\
& \quad \text{COOEt} \\
& \quad \text{Bn} \\
\text{S34.22} \\
\end{align*}
\]

Scheme 34 Example 3

\[
\begin{align*}
\text{R-link} & \quad \text{POH} \\
& \quad \text{OH} \\
\text{S34.6} \\
\end{align*}
\]

\[
\begin{align*}
\text{R-link} & \quad \text{P-Cl} \\
& \quad \text{H}_2\text{NCH}(\text{CH}_2\text{OH})\text{CO}_2\text{Bu} \\
& \quad \text{OH} \\
\text{S34.23} \\
\end{align*}
\]

\[
\begin{align*}
\text{R-link} & \quad \text{P-NH} \\
& \quad \text{CO}_2\text{Bu} \\
& \quad \text{OH} \\
\text{S34.24} \\
\end{align*}
\]

\[
\begin{align*}
\text{R-link} & \quad \text{P-NH} \\
& \quad \text{CO}_2\text{Bu} \\
& \quad \text{H}_2\text{NCH}_2\text{CH}(_2\text{Me})\text{CO}_2\text{Et} \\
\text{S34.25} \\
\end{align*}
\]

Scheme 34 Example 4

\[
\begin{align*}
\text{R-link} & \quad \text{POBn} \\
& \quad \text{OH} \\
\text{S34.15} \\
\end{align*}
\]

\[
\begin{align*}
\text{R-link} & \quad \text{POBn} \\
& \quad \text{Cl} \\
\text{S34.26} \\
\end{align*}
\]

\[
\begin{align*}
\text{R-link} & \quad \text{POBn} \\
& \quad \text{OH} \\
\text{S34.27} \\
\end{align*}
\]

\[
\begin{align*}
\text{R-link} & \quad \text{P-NH} \\
& \quad \text{CO}_2\text{Et} \\
& \quad \text{Me} \\
\text{S34.28} \\
\end{align*}
\]

\[
\begin{align*}
\text{R-link} & \quad \text{POH} \\
& \quad \text{NH} \\
\text{S34.29} \\
\end{align*}
\]

\[
\begin{align*}
\text{H}_2\text{NCH}(_2\text{Me})\text{CO}_2\text{Bu} \quad \text{S34.30} & \quad \text{R-link} \quad \text{P-NH} \\
& \quad \text{CO}_2\text{Et} \\
& \quad \text{Me} \\
\text{S34.31} \\
\end{align*}
\]
Examples of this method are shown in Scheme 35, Examples 1-3. In the sequence shown in Example 2, a monobenzyl phosphonate S35.11 is transformed by reaction with ethyl alaninate, using one of the methods described above, into the monoamidate S35.12. The benzyl group is then removed by catalytic hydrogenation in ethylacetate solution over a 5% palladium on carbon catalyst, to afford the phosphonic acid amidate S35.13. The product is then reacted in dichloromethane solution at ambient temperature with equimolar amounts of 1-(dimethylaminopropyl)-3-ethylcarbodiimide and trifluoroethanol S35.14, for example as described in Tet. Lett., 2001, 42, 8841, to yield the amidate ester S35.15.

In the sequence shown in Scheme 35, Example 3, the monoamidate S35.13 is coupled, in tetrahydrofuran solution at ambient temperature, with equimolar amounts of dicyclohexyl carbodiimide and 4-hydroxy-N-methylpiperidine S35.16, to produce the amidate ester product S35.17.

Using the above procedures, but employing, in place of the ethyl alaninate product S35.12 different monoacids S35.2, and in place of trifluoroethanol S35.14 or 4-hydroxy-N-methylpiperidine S35.16, different hydroxy compounds R^3OH, the corresponding products S35.3 are obtained.

Alternatively, the activated phosphonate ester S34.8 is reacted with ammonia to yield the amidate S35.4. The product is then reacted, as described in Scheme 34, with a haloester S35.5, in the presence of a base, to produce the amidate product S35.6. If appropriate, the nature of the R^1 group is changed, using the procedures described above, to give the product S35.3. The method is illustrated in Scheme 35, Example 4. In this sequence, the monophenyl phosphoryl chloride S35.18 is reacted, as described in Scheme 34, with ammonia, to yield the amino product S35.19. This material is then reacted in N-methylpyrrolidinone solution at 170° with butyl 2-bromo-3-phenylpropionate S35.20 and potassium carbonate, to afford the amidate product S35.21.

Using these procedures, but employing, in place of butyl 2-bromo-3-phenylpropionate S35.20, different haloesters S35.5, the corresponding products S35.6 are obtained.

The monoamidate products S35.3 are also prepared from the doubly activated phosphonate derivatives S34.7. In this procedure, examples of which
are described in *Synlett.*, 1998, 1, 73, the intermediate S34.7 is reacted with a limited amount of the aminoester S34.9 to give the mono-displacement product S34.11. The latter compound is then reacted with the hydroxy compound R^3^OH in a polar organic solvent such as dimethylformamide, in the presence of a base such as diisopropylethylamine, to yield the monoamidate ester S35.3.

The method is illustrated in Scheme 35, Example 5. In this method, the phosphoryl dichloride S35.22 is reacted in dichloromethane solution with one molar equivalent of ethyl N-methyl tyrosinate S35.23 and dimethylaminopyridine, to generate the monoamidate S35.24. The product is then reacted with phenol S35.25 in dimethylformamide containing potassium carbonate, to yield the ester amidate product S35.26.

Using these procedures, but employing, in place of ethyl N-methyl tyrosinate S35.23 or phenol S35.25, the aminoesters S34.9 and/or the hydroxy compounds R^3^OH, the corresponding products S35.3 are obtained.

**Scheme 35**

![Diagram representing the chemical reactions described in the text.](image-url)
Scheme 35 Example 4

R-link–P<sub>Cl</sub>Cl  \[ \rightarrow \] R-link–P<sub>Cl</sub>Cl

S35.18

R-link–P<sub>Cl</sub>Cl \[ \rightarrow \] R-link–P<sub>Cl</sub>NH<sub>2</sub>

S35.19

BrCH(Bn)CO₂Bu \[ \rightarrow \] R-link–P<sub>Cl</sub>NH

S35.20

Bn–CO₂Bu

S35.21

Scheme 35 Example 5

HO–N<sub>Me</sub>CO₂Et \[ \rightarrow \] R-link–P<sub>Cl</sub>N<sub>Me</sub>CO₂Et

S35.22

S35.23

S35.24

PhOH

S35.25

S35.26

Scheme 36 illustrates methods for the preparation of carboalkoxy-substituted phosphonate diesters in which one of the ester groups incorporates a carboalkoxy substituent.

In one procedure, a phosphonate monoester S34.1, prepared as described above, is coupled, using one of the methods described above, with a hydroxyester S36.1, in which the groups R<sup>4b</sup> and R<sup>5b</sup> are as described in Scheme 34. For example, equimolar amounts of the reactants are coupled in the presence of a carbodiimide such as dicyclohexyl carbodiimide, as described in *Aust. J. Chem.*, 1963, 609, optionally in the presence of dimethylaminopyridine, as described in *Tet.*, 1999, 55, 12997. The reaction is conducted in an inert solvent at ambient temperature.

The procedure is illustrated in Scheme 36, Example 1. In this method, a monophenyl phosphonate S36.9 is coupled, in dichloromethane solution in the
presence of dicyclohexyl carbodiimide, with ethyl 3-hydroxy-2-methylpropionate S36.10 to yield the phosphonate mixed diester S36.11.

Using this procedure, but employing, in place of ethyl 3-hydroxy-2-methylpropionate S36.10, different hydroxyesters S33.1, the corresponding products S33.2 are obtained.

The conversion of a phosphonate monoester S34.1 into a mixed diester S36.2 is also accomplished by means of a Mitsunobu coupling reaction with the hydroxyester S36.1, as described in Org. Lett., 2001, 643. In this method, the reactants S34.1 and S36.1 are combined in a polar solvent such as tetrahydrofuran, in the presence of a triarylphosphine and a dialkyl azodicarboxylate, to give the mixed diester S36.2. The R¹ substituent is varied by cleavage, using the methods described previously, to afford the monoacid product S36.3. The product is then coupled, for example using methods described above, with the hydroxy compound R³OH, to give the diester product S36.4.

The procedure is illustrated in Scheme 36, Example 2. In this method, a monoallyl phosphonate S36.12 is coupled in tetrahydrofuran solution, in the presence of triphenylphosphine and diethylazodicarboxylate, with ethyl lactate S36.13 to give the mixed diester S36.14. The product is reacted with tris(triphenylphosphine) rhodium chloride (Wilkinson catalyst) in acetonitrile, as described previously, to remove the allyl group and produce the monoacid product S36.15. The latter compound is then coupled, in pyridine solution at ambient temperature, in the presence of dicyclohexyl carbodiimide, with one molar equivalent of 3-hydroxypyridine S36.16 to yield the mixed diester S36.17.

Using the above procedures, but employing, in place of the ethyl lactate S36.13 or 3-hydroxypyridine, a different hydroxyester S36.1 and/or a different hydroxy compound R³OH, the corresponding products S36.4 are obtained.

The mixed diesters S36.2 are also obtained from the monoesters S34.1 via the intermediacy of the activated monoesters S36.5. In this procedure, the monoester S34.1 is converted into the activated compound S36.5 by reaction with, for example, phosphorus pentachloride, as described in J. Org. Chem., 2001, 66, 329, or with thionyl chloride or oxalyl chloride (Lv = Cl), or with triisopropylbenzenesulfonyl chloride in pyridine, as described in Nucleosides 104
and Nucleotides, 2000, 19, 1885, or with carbonyl diimidazole, as described in J. Med. Chem., 2002, 45, 1284. The resultant activated monoester is then reacted with the hydroxyester S36.1, as described above, to yield the mixed diester S36.2.

The procedure is illustrated in Scheme 36, Example 3. In this sequence, a monophenyl phosphonate S36.9 is reacted, in acetonitrile solution at 70 °C, with ten equivalents of thionyl chloride, so as to produce the phosphoryl chloride S36.19. The product is then reacted with ethyl 4-carbamoyl-2-hydroxybutyrate S36.20 in dichloromethane containing triethylamine, to give the mixed diester S36.21.

Using the above procedures, but employing, in place of ethyl 4-carbamoyl-2-hydroxybutyrate S36.20, different hydroxyesters S36.1, the corresponding products S36.2 are obtained.

The mixed phosphonate diesters are also obtained by an alternative route for incorporation of the R^3O group into intermediates S36.3 in which the hydroxyester moiety is already incorporated. In this procedure, the monoacid intermediate S36.3 is converted into the activated derivative S36.6 in which L_v is a leaving group such as chloro, imidazole, and the like, as previously described. The activated intermediate is then reacted with the hydroxy compound R^3OH, in the presence of a base, to yield the mixed diester product S36.4.

The method is illustrated in Scheme 36, Example 4. In this sequence, the phosphonate monoacid S36.22 is reacted with trichloromethanesulfonyl chloride in tetrahydrofuran containing collidine, as described in J. Med. Chem., 1995, 38, 4648, to produce the trichloromethanesulfonyloxy product S36.23. This compound is reacted with 3-(morpholinomethyl)phenol S36.24 in dichloromethane containing triethylamine, to yield the mixed diester product S36.25.

Using the above procedures, but employing, in place of with 3-(morpholinomethyl)phenol S36.24, different alcohols R^3OH, the corresponding products S36.4 are obtained.

The phosphonate esters S36.4 are also obtained by means of alkylation reactions performed on the monoesters S34.1. The reaction between the
monoacid S34.1 and the haloester S36.7 is performed in a polar solvent in the presence of a base such as diisopropylethylamine, as described in Anal. Chem., 1987, 59, 1056, or triethylamine, as described in J. Med. Chem., 1995, 38, 1372, or in a non-polar solvent such as benzene, in the presence of 18-crown-6, as described in Syn. Comm., 1995, 25, 3565.

The method is illustrated in Scheme 36, Example 5. In this procedure, the monoacid S36.26 is reacted with ethyl 2-bromo-3-phenylpropionate S36.27 and diisopropylethylamine in dimethylformamide at 80 °C to afford the mixed diester product S36.28.

Using the above procedure, but employing, in place of ethyl 2-bromo-3-phenylpropionate S36.27, different haloesters S36.7, the corresponding products S36.4 are obtained.
Scheme 36 Example 1

Scheme 36 Example 2

Scheme 36 Example 3

EtO₂CH(OH)CH₂CH₂CONH₂
Scheme 36 Example 4

\[
\begin{align*}
\text{R-link} & \quad \text{R-link} \\
\quad \text{PO(OH)} & \quad \text{PO(O)} \\
\quad \text{Me} & \quad \text{Me} \\
\quad \text{CO}_2\text{Et} & \quad \text{CO}_2\text{Et} \\
\text{S36.22} & \quad \text{S36.23}
\end{align*}
\]

\[
\begin{align*}
\quad & \quad \text{R-link} \\
\quad & \quad \text{PO(O)} \\
\quad & \quad \text{Me} \\
\quad & \quad \text{CO}_2\text{Et} \\
\quad & \quad \text{S36.24}
\end{align*}
\]

\[
\begin{align*}
\quad & \quad \text{R-link} \\
\quad & \quad \text{PO(O)} \\
\quad & \quad \text{Me} \\
\quad & \quad \text{CO}_2\text{Et} \\
\quad & \quad \text{S36.25}
\end{align*}
\]

Scheme 36 Example 5

\[
\begin{align*}
\text{R-link} & \quad \text{BrCH(Bn)CO}_2\text{Et} \\
\text{PO(OH)} & \quad \text{PO(OCH(Bn)CO}_2\text{Et}} \\
\text{OCH}_2\text{CF}_3 & \quad \text{OCH}_2\text{CF}_3 \\
\text{S36.26} & \quad \text{S36.27} \quad \text{S36.28}
\end{align*}
\]

Scheme 37 illustrates methods for the preparation of phosphonate diesters in which both the ester substituents incorporate carboalkoxy groups.

The compounds are prepared directly or indirectly from the phosphonic acids S34.6. In one alternative, the phosphonic acid is coupled with the hydroxyester S37.2, using the conditions described previously in Schemes 34-36, such as coupling reactions using dicyclohexyl carbodiimide or similar reagents, or under the conditions of the Mitsunobu reaction, to afford the diester product S37.3 in which the ester substituents are identical.

This method is illustrated in Scheme 37, Example 1. In this procedure, the phosphonic acid S34.6 is reacted with three molar equivalents of butyl lactate

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S37.5 in the presence of Aldrithiol-2 and triphenyl phosphine in pyridine at ca. 70 °C, to afford the diester S37.6.

Using the above procedure, but employing, in place of butyl lactate S37.5, different hydroxyesters S37.2, the corresponding products S37.3 are obtained.

Alternatively, the diesters S37.3 are obtained by alkylation of the phosphonic acid S34.6 with a haloester S37.1. The alkylation reaction is performed as described in Scheme 36 for the preparation of the esters S36.4.

This method is illustrated in Scheme 37, Example 2. In this procedure, the phosphonic acid S34.6 is reacted with excess ethyl 3-bromo-2-methylpropionate S37.7 and diisopropylethylamine in dimethylformamide at ca. 80 °C, as described in Anal. Chem., 1987, 59, 1056, to produce the diester S37.8.

Using the above procedure, but employing, in place of ethyl 3-bromo-2-methylpropionate S37.7, different haloesters S37.1, the corresponding products S37.3 are obtained.

The diesters S37.3 are also obtained by displacement reactions of activated derivatives S34.7 of the phosphonic acid with the hydroxyesters S37.2. The displacement reaction is performed in a polar solvent in the presence of a suitable base, as described in Scheme 36. The displacement reaction is performed in the presence of an excess of the hydroxyester, to afford the diester product S37.3 in which the ester substituents are identical, or sequentially with limited amounts of different hydroxyesters, to prepare diesters S37.3 in which the ester substituents are different.

The methods are illustrated in Scheme 37, Examples 3 and 4. As shown in Example 3, the phosphoryl dichloride S35.22 is reacted with three molar equivalents of ethyl 3-hydroxy-2-(hydroxymethyl)propionate S37.9 in tetrahydrofuran containing potassium carbonate, to obtain the diester product S37.10.

Using the above procedure, but employing, in place of ethyl 3-hydroxy-2-(hydroxymethyl)propionate S37.9, different hydroxyesters S37.2, the corresponding products S37.3 are obtained.

Scheme 37, Example 4 depicts the displacement reaction between equimolar amounts of the phosphoryl dichloride S35.22 and ethyl 2-methyl-3-
hydroxypropionate S37.1, to yield the monoester product S37.12. The reaction is conducted in acetonitrile at 70° in the presence of diisopropylethylamine. The product S37.12 is then reacted, under the same conditions, with one molar equivalent of ethyl lactate S37.13, to give the diester product S37.14.

Using the above procedures, but employing, in place of ethyl 2-methyl-3-hydroxypropionate S37.1 and ethyl lactate S37.13, sequential reactions with different hydroxyesters S37.2, the corresponding products S37.3 are obtained.

Scheme 37

Scheme 37 Example 1

Scheme 37 Example 2
The invention will now be illustrated by the following non-limiting Examples.

Example 1: Preparation of Representative Compound of the Invention.

A representative compound of the invention can be prepared as illustrated below.
Individual Steps
6-Allyloxy-3-methyl-4-trifluoromethanesulfonyloxy-phthalic acid dimethyl ester

To a solution of 6-allyloxy-4-hydroxy-3-methyl-phthalic acid dimethyl ester (8.06 g, 28.8 mmol) [synthesized according to: J. W. Patterson, *Tetrahedron*, 1993, 49, 4789-4798] and pyridine (11.4 g, 144.0 mmol) in dichloromethane (DCM) (20 mL) at 0°C was added triflic anhydride (12.19 g, 43.2 mmol). The reaction was stirred at 0°C for 2 hours after which additional triflic anhydride (3 mL) was added. Stirring at 0°C was continued for an additional hour. The reaction mixture was poured into a mixture of DCM and HCl (1N). The layers were separated and the aqueous layer was extracted with DCM. The combined organic layers were dried over sodium sulfate. Filtration and evaporation of solvents *in vacuo* yielded a crude product, which was purified by silica gel chromatography to provide 8.39 g of the product as an oil. $^1$H NMR (300 MHz, CDCl$_3$): $\delta = 2.32$ (s, 3H), 3.89 (s, 6H), 4.60 (m, 2H), 5.33 (d, $J = 9.3$ Hz, 1H), 5.41 (d, $J = 18.6$ Hz, 1H), 5.95 (m, 1H), 6.95 (s, 1H) ppm; $^{19}$F NMR (282 MHz, CDCl$_3$): $\delta = -74$ ppm.

6-Hydroxy-3-methyl-4-trifluoromethanesulfonyloxy-phthalic acid dimethyl ester

To a solution of 6-allyloxy-3-methyl-4-trifluoromethanesulfonyloxy-phthalic acid dimethyl ester (8.39 g, 20.3 mmol) in toluene (20 mL) was added
tetrakis(triphenylphosphine) palladium (0.47 g, 0.40 mmol) and diethylamine (2.97 g, 40.86 mmol) at room temperature under an atmosphere of nitrogen. Stirring at room temperature was continued until all starting material was consumed. The crude reaction mixture was partitioned between diethyl ether and HCl (0.1 N). The organic layer was washed with brine and dried over sodium sulfate. Filtration and evaporation of solvents in vacuo yielded a crude material, which was purified by silica gel chromatography to provide 4.16 g (55%) of the desired product as an off-white solid. $^1$H NMR (300 MHz, CDCl$_3$): $\delta = 2.20$ (s, 3H), 3.93 (s, 3H), 3.95 (s, 3H), 7.01 (s, 1H) ppm; $^{19}$F NMR (282 MHz, CDCl$_3$): $\delta = -74$ ppm.

6-Hydroxy-3-methyl-4-vinyl-phthalic acid dimethyl ester

To a solution of 6-hydroxy-3-methyl-4-trifluoromethanesulfonyloxy-phthalic acid dimethyl ester (2.17 g, 5.85 mmol) in N-methyl pyrrolidinone (15 mL) was added lithium chloride (743 mg, 17.5 mmol) and triphenylarsine (179 mg, 0.585 mmol). Tributylvinyltin (2.04 g, 6.43 mmol) was added followed by tris(tribenzylideneacetone)dipalladium(0)-chloroform adduct (90 mg, 0.087 mmol). The reaction was placed under an atmosphere of nitrogen and heated at 60°C for 18 hours. The reaction was cooled to room temperature and poured onto a mixture of ice (20 g), EtOAc (40 mL), and potassium fluoride (1 g). Stirring was continued for 1 hour. The aqueous layer was extracted with EtOAc and the organic extracts filtered through Celite. The combined organic layers were washed with water and dried over sodium sulfate. Filtration and evaporation of solvents in vacuo yielded a crude material, which was purified by silica gel chromatography to provide 1.27 g (87%) of the product as an off-white solid. $^1$H NMR (300 MHz, CDCl$_3$): $\delta = 2.16$ (s, 3H), 3.91 (s, 3H), 3.92 (s, 3H), 7.01 (s, 1H) ppm. 

$^1$H NMR (300 MHz, CDCl$_3$): $\delta = 2.20$ (s, 3H), 3.93 (s, 3H), 3.95 (s, 3H), 7.01 (s, 1H) ppm; $^{19}$F NMR (282 MHz, CDCl$_3$): $\delta = -74$ ppm.
5.46 (dd, J = 11.1, 1.2 Hz, 1H), 5.72 (dd, J = 17.1, 0.9 Hz, 1H), 6.86 (dd, J = 17.1, 11.1 Hz, 1H), 7.14 (s, 1H), 10.79 (s, 1H) ppm.

4-Ethyl-6-hydroxy-3-methyl-phthalic acid dimethyl ester

6-Hydroxy-3-methyl-4-vinyl-phthalic acid dimethyl ester (1.27 g, 5.11 mmol) was dissolved in benzene (10 mL) and EtOAc (10 mL). Tristriphenylphosphine rhodium chloride (150 mg) was added and the reaction was placed under an atmosphere of hydrogen. Stirring at room temperature was continued. After 14 hours, the solvents were removed in vacuo and the crude material was purified by silica gel chromatography to provide 1.14 g (88%) of the desired product as an off-white solid. $^1$H NMR (300 MHz, CDCl$_3$): δ = 1.19 (t, J = 7.8 Hz, 3H), 2.10 (s, 3H), 2.60 (q, J = 7.8 Hz, 2H), 3.89 (s, 6H), 6.87 (s, 1H), 10.79 (s, 1H) ppm.

16-Allyloxy-4-ethyl-3-methyl-phthalic acid dimethyl ester

4-Ethyl-6-hydroxy-3-methyl-phthalic acid dimethyl ester (1.01 g, 4.02 mmol) was dissolved in DMF (5 mL). Potassium carbonate (3.33 g, 24.14 mmol) was added, followed by allylbromide (2.92 g, 24.14 mmol). The suspension was heated at 60°C. After 14 hours, the reaction was cooled to room temperature and filtered. The solvents were removed in vacuo and the crude material was purified by silica gel chromatography to provide 0.976 g (83%) of the desired product as a colorless oil. $^1$H NMR (300 MHz, CDCl$_3$): δ = 1.16 (t, J = 7.2 Hz, 3H), 2.20 (s, 3H), 2.62 (q, J = 7.2 Hz, 2H), 3.83 (s, 3H), 3.84 (s, 3H), 4.57 (m, 2H), 5.26 (dd,
$J = 9.3, 1.5 \text{ Hz, 1H}$, $5.41 \text{ (dd, } J = 13.5, 1.5 \text{ Hz, 1H)}$, $5.98 \text{ (m, 1H)}$, $6.82 \text{ (s, 1H)}$ ppm.

5

**4-ALLYL-5-ETHYL-3-HYDROXY-6-METHYL-PHTHALIC ACID DIMETHYL ESTER**

6-Allyloxy-4-ethyl-3-methyl-phthalic acid dimethyl ester (1.25 g, 4.28 mmol) was heated at 210°C under an atmosphere of nitrogen. After 14 hours, the reaction was cooled to room temperature. The crude material was purified by silica gel chromatography to provide 0.971 g (77%) of the desired product as a colorless oil. $^1H$ NMR (300 MHz, CDCl$_3$): $\delta = 1.14 \text{ (t, } J = 7.8 \text{ Hz, 3H)}$, $2.17 \text{ (s, 3H)}$, $2.68 \text{ (q, } J = 7.8 \text{ Hz, 2H)}$, $3.49 \text{ (m, 2H)}$, $3.86 \text{ (s, 3H)}$, $3.89 \text{ (s, 3H)}$, $4.89 - 5.01 \text{ (m, 2H)}$, $5.93 \text{ (m, 1H)}$, $11.22 \text{ (s, 1H)}$ ppm.

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**5 6-ALLYL-5-ETHYL-7-HYDROXY-4-METHYL-3H-ISOBENZOFURAN-1-ONE**

4-Allyl-5-ethyl-3-hydroxy-6-methyl-phthalic acid dimethyl ester (0.971 g, 3.32 mmol) was dissolved in MeOH (8 mL) at room temperature. A solution of sodium hydroxide (0.798 g, 19.95 mmol) in water (10 mL) was added and the suspension was heated at 55°C. After 16 hours, the reaction was cooled to room temperature and washed with diethyl ether. The aqueous layer was acidified (1N HCl) and the suspension was extracted with EtOAc. The combined organic layers were dried over sodium sulfate. Filtration and evaporation of solvents in vacuo yielded the desired bis acid as a white solid (0.846 g, 98%, M$^+$ = 263).

The bis acid was dissolved in acetic acid (6 mL) and HCl (conc., 1.5 mL). The reaction was heated at 80°C. Zn dust (0.635 g, 9.72 mmol, each) was
added in portions every hour for 7 hours. Stirring at 80°C was continued for additional 10 hours. The reaction was cooled to room temperature, and water was added. The resultant suspension was extracted with EtOAc. The combined organic extracts were washed with sodium bicarbonate solution and dried over sodium sulfate. Filtration and evaporation of solvents in vacuo yielded the crude product, which was purified by silica gel chromatography to provide 0.375 g (50%) of the product as a white solid. $^1$H NMR (300 MHz, CDCl$_3$): $\delta = 1.14$ (t, $J = 7.5$ Hz, 3H), 2.18 (s, 3H), 2.71 (q, $J = 7.5$ Hz, 2H), 3.49 (m, 2H), 4.95 (d, $J = 17.1$ Hz, 1H), 5.02 (d, $J = 10.2$ Hz, 1H), 5.23 (s, 2H), 5.98 (m, 1H), 7.66 (s, 1H) ppm.

5 6-Allyl-5-ethyl-4-methyl-7-(2-trimethylsilyl-ethoxy)-3H-isobenzofuran-1-one

To a solution of 6-allyl-5-ethyl-7-hydroxy-4-methyl-3H-isobenzofuran-1-one (199 mg, 0.857 mmol), PPh$_3$ (337 mg, 1.286 mmol), and 2-trimethylsilylethanol in THF (3 mL) at 0°C was added diisopropyl azodicarboxylate (259 mg, 1.286 mmol). The resulting yellow solution was allowed to warm to room temperature and stirred for one hour. The solvent was removed in vacuo and the crude material was dissolved in diethyl ether (3 mL). Hexanes (1.5 mL) were added. Triphenylphosphine oxide was removed by filtration and the filtrate was concentrated and purified by silica gel chromatography to provide the desired product (261 mg, 92%) as a clear oil. $^1$H NMR (300 MHz, CDCl$_3$): $\delta = 0.04$ (s, 9H), 1.15 (t, $J = 7.8$ Hz, 3H), 1.25 (m, 2H), 2.20 (s, 3H), 2.73 (q, $J = 7.8$ Hz, 2H), 3.54 (m, 2H), 4.28 (m, 2H), 4.95 (d, $J = 17.1$ Hz, 1H), 5.02 (d, $J = 10.2$ Hz, 1H), 5.15 (s, 2H), 5.95 (m, 1H) ppm.
[6-Ethyl-7-methyl-3-oxo-4-(2-trimethylsilyl-ethoxy)-1,3-dihydro-

isobenzofuran-5-yl]-acetaldehyde

A solution of 6-allyl-5-ethyl-4-methyl-7-(2-trimethylsilyl-ethoxy)-3H-
isobenzofuran-1-one (261 mg, 0.788 mmol) in MeOH (5 mL), CH₂Cl₂ (5 mL) and pyridine (50 μL) was cooled to −78°C using a dry ice/acetone bath according to the procedure of Smith, D. B. et al., J. Org. Chem., 1996, 61, 6, 2236. A stream of ozone was bubbled through the reaction via a gas dispersion tube until the reaction became blue in color (15 minutes). The ozone line was replaced with a stream of nitrogen and bubbling continued for another 15 minutes, by which time the blue color had disappeared. To this solution, at −78°C, was added thiourea (59.9 mg, 0.788 mmol) in one portion, and the cooling bath was removed. The reaction was allowed to warm to room temperature and stirred for 15 hours. The reaction mixture was filtered and then partitioned between CH₂Cl₂ and water. The aqueous layer was extracted with CH₂Cl₂ one more time and the organic extracts were combined, washed with aqueous 1N HCl, saturated NaHCO₃ and brine and dried over sodium sulfate. Filtration and evaporation of solvents in vacuo yielded the crude product, which was purified by silica gel chromatography to afford 181 mg (69 %) of the product as a white solid. ¹H NMR (300 MHz, CDCl₃): δ = 0.04 (s, 9H), 1.11 (t, J = 7.5 Hz, 3H), 1.19 (m, 2H), 2.21 (s, 3H), 2.66 (q, J = 7.5 Hz, 2H), 3.90 (s, 2H), 4.36 (m, 2H), 5.18 (s, 2H), 9.71 (s, 1H) ppm.
4-[6-Ethyl-7-methyl-3-oxo-4-(2-trimethylsilyl-ethoxy)-1,3-dihydro-isobenzofuran-5-yl]-2-methyl-but-2-enal

[6-Ethyl-7-methyl-3-oxo-4-(2-trimethylsilyl-ethoxy)-1,3-dihydro-isobenzofuran-5-yl]-acetaldehyde (90 mg, 0.269 mmol) and 2-(triphenyl-phosphorylidene)-propionaldehyde (72.9 mg, 0.23 mmol) in toluene (3 mL) were heated at 100°C. After 15 hours, a second portion of 2-(triphenyl-phosphorylidene)-propionaldehyde (33 mg, 0.11 mmol) was added and the reaction mixture was heated for additional 9 hours. The toluene was removed in vacuo, and the residue was purified by silica gel chromatography to provide 77.6 mg (77%) of the desired product as a pale yellow oil. $^1$H NMR (300 MHz, CDCl$_3$): $\delta = 0.03$ (s, 9H), 1.15 (t, $J = 7.5$ Hz, 3H), 1.21 (m, 2H), 1.93 (s, 3H), 2.21 (s, 3H), 2.71 (q, $J = 7.5$ Hz, 2H), 3.82 (d, $J = 6.9$ Hz, 2H), 4.34 (m, 2H), 5.18 (s, 2H), 6.38 (m, 1H), 9.35 (s, 1H) ppm.

5-Ethyl-6-(4-hydroxy-3-methyl-but-2-enyl)-4-methyl-7-(2-trimethylsilyl-ethoxy)-3H-isobenzofuran-1-one
4-[6-Ethyl-7-methyl-3-oxo-4-(2-trimethylsilyl-ethoxy)-1,3-dihydroisobenzofuran-5-yl]-2-methyl-but-2-enal (77.6 mg, 0.207 mmol) was dissolved in MeOH (4 mL). A solution of CeCl₃ (51.1 mg, 0.207 mmol) in MeOH/water (9/1, 0.66 mL) was added and the solution was cooled to 0°C. A solution of lithium borohydride in THF (2M, 0.105 mL) was added dropwise. After 15 minutes, the reaction was quenched with 1N HCl (0.5 mL). The MeOH was removed in vacuo and the crude material was partitioned between DCM and water. The aqueous layer was extracted with DCM and the combined organic layers were washed with sodium bicarbonate solution and dried over sodium sulfate. Filtration and evaporation of solvents yielded a crude oil, which was purified by silica gel chromatography to provide 57.2 mg (73%) of the desired product. ¹H NMR (300 MHz, CDCl₃): δ = 0.04 (s, 9H), 1.15 (t, J = 7.8 Hz, 3H), 1.26 (m, 2H), 1.86 (s, 3H), 2.19 (s, 3H), 2.72 (q, J = 7.8 Hz, 2H), 3.52 (d, J = 6.3 Hz, 2H), 3.99 (s, 2H), 4.34 (m, 2H), 5.14 (s, 2H), 5.32 (m, 1H) ppm.

![Chemical structure diagram]

6-(4-Bromo-3-methyl-but-2-enyl)-5-ethyl-4-methyl-7-(2-trimethylsilyl-ethoxy)-3H-isobenzofuran-1-one

5-Ethyl-6-(4-hydroxy-3-methyl-but-2-enyl)-4-methyl-7-(2-trimethylsilyl-ethoxy)-3H-isobenzofuran-1-one (57.2 mg, 0.152 mmol) was dissolved in DCM (3.5 mL). Polymer-bound triphenylphosphine (3 mmol/g, 152.1 mg) was added and the mixture was mechanically stirred at room temperature. Carbon tetrabromide (151.3 mg, 0.456 mmol) was added and the solution was stirred at room temperature. After 2 hours, the reaction was filtered and the solvent was removed in vacuo. The crude material was purified by silica gel chromatography to provide 58.0 mg (87%) of the desired product. ¹H NMR
(300 MHz, CDCl₃): δ = 0.04 (s, 9H), 1.15 (t, J = 7.8 Hz, 3H), 1.25 (m, 2H), 1.95 (s, 3H), 2.20 (s, 3H), 2.70 (q, J = 7.8 Hz, 2H), 3.52 (d, J = 6.3 Hz, 2H), 3.94 (s, 2H), 4.28 (m, 2H), 5.14 (s, 2H), 5.50 (m, 1H) ppm.

\[ \text{Br-} \]
\[
\begin{align*}
\text{1) } & \text{P(OMe)}_3 \\
& \text{110°C, 2 hrs} \\
\text{2) } & \text{TMSBr, CH}_3\text{CN} \\
& \text{lutidine}
\end{align*}
\]

10 \{4-[6-Ethyl-7-methyl-3-oxo-4-(2-trimethylsilyl-ethoxy)-1,3-dihydro-isobenzofuran-5-yl]-2-methyl-but-2-enyl\}-phosphonic acid

A solution of 4-[6'-ethyl-7'-methyl-3'-oxo-4'-(2''-trimethylsilyl-ethoxy)-1',3'-dihydro-isobenzofuran-5'-yl]-2-methyl-but-2-enyl bromide (58 mg, 0.132 mmol) in trimethylphosphite (0.8 mL) was heated at 110°C. After 2 hours the reaction was complete. The reaction was cooled to room temperature and the excess trimethylphosphite was removed \textit{in vacuo}. The crude material was used in the next step without further purification.

The crude product of the Arbuzov reaction was dissolved in MeCN (0.8 mL). Trimethylsilyl bromide (202.2 mg, 1.321 mmol) was added and the reaction was stirred at room temperature. After 15 minutes, lutidine (155.7 mg, 1.453 mmol) was added and stirring at room temperature was continued. After 2 hours, additional trimethylsilyl bromide (202.2 mg, 1.321 mmol) was added and stirring at room temperature was continued. After 4 hours, the reaction was quenched with MeOH (2 mL). The solvents were evaporated \textit{in vacuo}, and the crude material was purified by RP-HPLC (eluent: water / MeCN). The product-containing fractions were combined and lyophilized to yield 2.3 mg (5.1%) of the free phosphonic acid. ¹H NMR (300 MHz, DMSO-d₆): δ = 1.07 (t, J = 7.5 Hz, 3H), 1.84 (s, 3H), 2.14 (s, 3H), 2.64 (q, J = 7.5 Hz, 2H), 3.34 (m, 4H), 5.06 (m, 1H), 5.25 (s, 2H) ppm; ³¹P NMR (121 MHz, DMSO-d₆): δ = 22.19 ppm; MS = 341 [M⁺+1].
Example 2: Preparation of Representative Compound of the Invention.

Representative compounds of the invention can be prepared as illustrated below.

\[
\text{TMS} \quad \begin{array}{c}
\overset{\text{CHO}}{\text{Ph}_3\text{P}} \\
\text{Toluene, 100C}
\end{array} \\
\overset{\text{LiBH}_4, \text{CeCl}_3}{\text{MeOH}} \\
\overset{\text{PPh}_3, \text{CBr}_4}{\text{TMS}} \\
\overset{\text{P(OMe)}_3}{110^\circ\text{C}, 2\text{ hrs}} \\
\overset{\text{TMSBr, CH}_3\text{CN}}{\text{OH}} \quad \begin{array}{c}
\overset{\text{OH}}{\text{HO}} \\
\text{MeO} \quad \text{OMe}
\end{array}
\]
Individual Steps

[2-Ethyl-4-[6-ethyl-7-methyl-3-oxo-4-(2-trimethylsilanyl-ethoxy)-1,3-dihydro-isobenzofuran-5-yl]-but-2-enal

[6-Ethyl-7-methyl-3-oxo-4-(2-trimethylsilanyl-ethoxy)-1,3-dihydro-isobenzofuran-5-yl]-acetaldehyde (90 mg, 0.269 mmol) and 2-(triphenylphosphorylidene)-butyraldehyde (98.4 mg, 0.296 mmol) in toluene (3 mL) were heated at 100°C. After 15 hours, a second portion of 2-(triphenylphosphorylidene)-butyraldehyde (98.4 mg, 0.296 mmol) was added and the reaction mixture was heated for additional 33 hours. After concentration, the residue was purified by silica gel chromatography to provide 50.3 mg (48%) of the desired product as a pale yellow oil.

5-Ethyl-6-(3-hydroxymethyl-pent-2-enyl)-4-methyl-7-(2-trimethylsilany lethoxy)-3II-isobenzofuran-1-one

2-Ethyl-4-[6-ethyl-7-methyl-3-oxo-4-(2-trimethylsilanyl-ethoxy)-1,3-dihydro-isobenzofuran-5-yl]-but-2-enal (50.3 mg, 0.129 mmol) was dissolved in MeOH (3 mL). A solution of CeCl₃ (31.9 mg, 0.129 mmol) in MeOH/water (9/1, 0.66 mL) was added and the solution was cooled to 0°C. A solution of
lithium borohydride in THF (2M, 0.065 mL) was added dropwise. After 10 minutes, the reaction was quenched with 1N HCl (0.5 mL). The methanol was removed in vacuo and the crude material was partitioned between DCM and water. The aqueous layer was extracted with DCM and the combined organic layers were washed with sodium bicarbonate solution and were dried over sodium sulfate. Filtration and evaporation of solvents in vacuo yielded a crude oil, which was purified by silica gel chromatography to provide 35.4 mg (70%) of the desired product. $^{1}$H NMR (300 MHz, CDCl$_3$): $\delta = 0.04$ (s, 9H), 1.10 – 1.19 (m, 6H), 1.26 (m, 2H), 2.19 (s, 3H), 2.32 (q, $J = 7.5$ Hz, 2H), 2.72 (q, $J = 7.5$ Hz, 2H), 3.54 (d, $J = 6.6$ Hz, 2H), 4.05 (s, 2H), 4.26 (m, 2H), 5.14 (s, 2H), 5.27 (m, 1H) ppm.

![Chemical structure](image)

6-(3-Bromomethyl-pent-2-enyl)-5-ethyl-4-methyl-7-(2-trimethylsilanyl-ethoxy)-3H-isobenzofuran-1-one

5-Ethyl-6-(3-hydroxymethyl-pent-2-enyl)-4-methyl-7-(2-trimethylsilanyl-ethoxy)-3H-isobenzofuran-1-one (35.4 mg, 0.090 mmol) was dissolved in DCM (3.0 mL). Polymer-bound triphenylphosphine (3 mmol/g, 90.7 mg) was added, and the mixture was mechanically stirred at room temperature. Carbon tetrabromide (90.2 mg, 0.272 mmol) was added and the solution was stirred at room temperature. After 2 hours, the reaction was filtered and the solvent was removed in vacuo. The crude material was purified by silica gel chromatography to provide 32.0 mg (78%) of the desired product. The material was used in the next step without further characterization.
[2-Ethyl-4-(6-ethyl-4-hydroxy-7-methyl-3-oxo-1,3-dihydro-isobenzofuran-5-yl)-but-2-enyl]-phosphonic acid

A solution of 6-(3-bromomethyl-pent-2-enyl)-5-ethyl-4-methyl-7-(2-trimethylsilanyl-ethoxy)-3H-isobenzofuran-1-one (32 mg, 0.070 mmol) in trimethylphosphite (0.8 mL) was heated at 110 °C. After 2 hours, the reaction was complete. The reaction was cooled to room temperature and the excess trimethylphosphite was removed in vacuo. The crude material was used in the next step without further purification.

The crude product of the Arbuzov reaction was dissolved in MeCN (0.8 mL). Trimethylsilyl bromide (108.0 mg, 0.706 mmol) was added and the reaction was stirred at room temperature. After 2 hours, a second batch of trimethylsilyl bromide (108.0 mg, 0.706 mmol) was added. After 3 hours, the reaction was quenched with MeOH (2 mL). The solvents were evaporated in vacuo and the crude material was purified by RP-HPLC (eluent: water / MeCN). The product-containing fractions were combined and lyophilized to yield 15.7 mg (63%) of the product. $^1$H NMR (300 MHz, DMSO-d6): $\delta = 0.98 - 1.09$ (m, 6H), 2.10 (s, 3H), 2.30 (m, 2H), 2.64 (q, $J = 7.5$ Hz, 2H), 3.38 (m, 4H), 5.03 (m, 1H), 5.25 (s, 2H) ppm; $^{31}$P NMR (121 MHz, DMSO-d6): $\delta = 22.26$ ppm; MS = 355 [M$^+ + 1$].

Example 3: Preparation of Representative Compounds of the Invention.

Representative compounds of the invention can be prepared as illustrated below.
Individual Steps

(2-{4-[6-Ethyl-7-methyl-3-oxo-4-(2-trimethylsilanyl-ethoxy)-1,3-dihydro-isobenzofuran-5-yl]-2-methyl-but-2-enylamino]-ethyl}-phosphonic acid diethyl ester)

4-{6-Ethyl-7-methyl-3-oxo-4-(2-trimethylsilanyl-ethoxy)-1,3-dihydro-isobenzofuran-5-yl]-2-methyl-but-2-enal (19.7 mg, 0.052 mmol) and aminoethylphosphonic acid diethyl ester oxalate salt (15.6 mg, 0.057 mmol) were dissolved in DMF (0.5 mL). Acetic acid (15.7 mg, 0.263 mmol) was added, followed by sodium triacetoxyborohydride (22.3 mg, 0.105 mmol). After 4 hours, the crude reaction mixture was purified by RP-HPLC (eluent: water/MeCN) to provide 27.7 mg (97%) of the desired product after lyophilization. $^1$H NMR (300 MHz, CDCl$_3$): $\delta = 0.04$ (s, 9H), 1.14 (t, $J = 7.5$ Hz, 3H), 1.26 (m, 2H), 1.30 (t, $J = 7.2$ Hz, 6H), 1.95 (s, 3H), 2.19 (s, 3H), 2.23 (m, 2H), 2.68 (q, $J = 7.5$ Hz, 2H), 3.18 (m, 2H), 3.53 (s, 2H), 4.13 (m, 4H), 4.28 (m, 2H).

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(m, 2H), 5.15 (s, 2H), 5.51 (m, 1H) ppm; $^{31}$P NMR (121 MHz, CDCl$_3$): $\delta = 27.39$ ppm; MS = 540 [M$^+$+1].

(2-{4-[6-Ethyl-7-methyl-3-oxo-4-(2-trimethylsilanyloxy)-1,3-dihydro-isobenzofuran-5-yl]-2-methyl-but-2-enylamino}-ethyl)-phosphonic acid diethyl ester (27.7 mg, 0.051 mmol) was dissolved in DMF (0.5 mL) and DCM (0.5 mL). Trimethylsilyl bromide (78.3 mg, 0.512 mmol) was added and the reaction was stirred at room temperature. After 20 hours, the reaction was quenched with MeOH (0.3 mL). The solvents were evaporated in vacuo and the crude material was purified by RP-HPLC (eluent: water/MeCN). The product-containing fractions were combined and lyophilized to yield 14.2 mg (57%) of the free phosphonic acid [MS: 484 M$^+$+1].

The material was dissolved in DCM (0.5 mL). TFA (0.05 mL) was added and stirring at room temperature was continued. After 20 minutes, the solvents were removed in vacuo and the crude material was purified by RP-HPLC (eluent: water/MeCN * 0.1% TFA). The product-containing fractions were combined and lyophilized to yield 7.6 mg (52%) of the product as the TFA salt. $^{1}$H NMR (300 MHz, DMSO-d$_6$): $\delta = 1.07$ (t, $J = 7.5$ Hz, 3H), 1.84 (s, 3H), 1.90 (m, 2H), 2.11 (s, 3H), 2.63 (q, $J = 7.5$ Hz, 2H), 2.99 (m, 2H), 3.43 (d, $J = 6.3$ Hz, 2H), 3.51 (s, 2H), 5.26 (s, 2H), 5.45 (m, 1H) ppm; $^{31}$P NMR (121 MHz, DMSO-d$_6$): $\delta = 20.02$ ppm; MS = 384 [M$^+$+1].
Example 4: Preparation of Representative Compounds of the Invention.

Representative compounds of the invention can be prepared as illustrated below.

\[
\text{HOPO}_3\text{OH} \xrightarrow{\text{DCC, PhOH, pyr}} \text{SiMe}_3 \xrightarrow{\text{70}^\circ\text{C, 4 hrs}} \text{O}_3\text{O}
\]

\[
\text{PhOPO}_3\text{OPh} \xrightarrow{\text{NaOH, MeCN, H}_2\text{O}} \text{SiMe}_3
\]

\[
\text{PhOPO}_3\text{OH} \xrightarrow{\text{H}_2\text{N}} \text{O} \xrightarrow{\text{i) DIEA, DMAP, DMF, ii) PyBOP}} \text{SiMe}_3
\]

\[
\text{PhOPO}_3\text{HN} \xrightarrow{\text{TFA/DCM}} \text{O} \xrightarrow{-20^\circ\text{C - 0}^\circ\text{C}} \text{OH}
\]
Individual Steps

\[
\text{HO}^+ \text{PO}^\cdot \text{OH} \xrightarrow{\text{1) DCC, PhOH, pyr, } 70^\circ \text{C, 4 hrs}} \text{NaOH, MeCN, } \text{H}_2\text{O}
\]

\[
\begin{array}{c}
\text{H}_2\text{N} \xrightarrow{i) \text{ DIEA, DMAP, DMF,}} \text{O} \\
\text{i) PyBOP}
\end{array}
\]

\begin{align*}
2-\{(4-[6'-\text{ethyl}-7'-\text{methyl}-3'-\text{oxo}-4'-\text{-(2''-trimethylsilanyl-ethoxy)\text{-1,3-dihydro-isobenzofuran-5'yl]}-2\text{-methyl-but-2-enyl]-phenoxy-phosphinoylamino)}	ext{-propionic acid ethyl ester}}
\end{align*}

\[4-\{6'-\text{ethyl}-7'-\text{methyl}-3'-\text{oxo}-4'-\text{-(2''-trimethylsilanyl-ethoxy)\text{-1',3'-dihydro-isobenzofuran-5'yl]}-2\text{-methyl-but-2-en-phosphonic acid (44.8 mg, 0.101 mmol), dicyclohexylcarbodiimide (52.6 mg, 0.254 mmol), and phenol (95.8 mg, 1.018 mmol) were dissolved in pyridine (0.3 mL) and heated at 70^\circ \text{C for 4 hours. The reaction mixture was cooled to room temperature and the}}
\]
\[
\text{pyridine was removed in vacuo. The crude material was partitioned between DCM and HCl (0.1N). The aqueous layer was extracted with DCM and the}}
\]
\[
\text{combined organic layers were dried over sodium sulfate. Filtration and}}
\]
\[
\text{evaporation of solvents in vacuo yielded a crude material, which was used in the next step without further purification.}
\]
\[
\text{The crude material was dissolved in MeCN (0.8 mL) and water (0.3 mL). Aqueous sodium hydroxide solution (2N, 0.8 mL) was added in portions (0.2 mL). After all starting material was consumed, the organic solvent was removed}}
\]
\[
\text{in vacuo and the crude material was partitioned between chloroform and aqueous HCl (1N). The aqueous layer was extracted with chloroform. The combined}}
\]
\[
\text{organic layers were dried over sodium sulfate. Filtration and evaporation of}}
\]
solvents yielded the crude product as a mixture of mono phenyl ester and the symmetrical anhydride.

The crude material of the previous step and ethyl (L)-alanine hydrochloride salt (78.1 mg, 0.509 mmol) were dissolved in DMF (0.4 mL). DMAP (1.2 mg, catalytic) was added, followed by diisopropylethylamine (131.3 mg, 1.018 mmol). Stirring at room temperature was continued. After 20 minutes, complete conversion of the anhydride was observed. After 2 hours, PyBOP (101 mg, 0.202 mmol) was added and stirring at room temperature was continued. The reaction was filtered and the crude reaction solution was purified by RP-HPLC (eluent: water/McCN). The product-containing fractions were combined and lyophilized to yield the product (15.7 mg, 25% over three steps) as a white powder. $^1$H NMR (300 MHz, CDCl$_3$): $\delta = 0.03$ (s, 9H), 1.13 – 1.28 (m, 8H), 2.03 (s, 3H), 2.19 (s, 3H), 2.62 – 2.74 (m, 4H), 3.38 (m, 1H), 3.53 (t, $J$ = 6.3 Hz, 2H), 4.03 (m, 3H), 4.30 (m, 2H), 5.14 (s, 2H), 5.31 (m, 1H), 7.11 – 7.17 (m, 3H), 7.25 – 7.30 (m, 2H) ppm; $^{31}$P NMR (121 MHz, CDCl$_3$): $\delta = 27.04$, 27.73 ppm; MS =615 [M$^+$+1].

\[
\begin{align*}
\text{TMS} & \quad \text{TFA/DCM} \\
-20^\circ C & \quad -0^\circ C
\end{align*}
\]

\[
\begin{align*}
\text{O} & \quad \text{PhO}^+ \\
\text{HN} & \quad \text{O} \\
\text{TFA/DCM} & \quad -20^\circ C \quad -0^\circ C \\
\text{O} & \quad \text{PhO}^+ \\
\text{HN} & \quad \text{O}
\end{align*}
\]

2-{[4-(6-Ethyl-4-hydroxy-7-methyl-3-oxo-1,3-dihydro-isobenzofuran-5-yl)-2-methyl-but-2-enyl]-phenoxy-phosphinoylamino}-propionic acid ethyl ester

2-{[4-(6-Ethyl-7-methyl-3-oxo-4-(2-trimethylsilyl-ethoxy)-1,3-dihydro-isobenzofuran-5-yl]-2-methyl-but-2-enyl]-phenoxy-
phosphinoylamino)-propionic acid ethyl ester (7.5 mg, 0.012 mmol) was dissolved in TFA/DCM (10%, 0.3 mL) at −20°C. The reaction mixture was warmed to 0°C and stirred at this temperature for 45 minutes. Pyridine (0.09 mL) was added the solvents were removed in vacuo. The crude material was purified by RP-HPLC (eluent: water/MeCN). The product-containing fractions were combined and lyophilized, yielding a white powder (5.5 mg, 87%). $^1$H NMR (300 MHz, CDCl$_3$): δ = 1.12 – 1.29 (m, 6H), 2.03 (s, 3H), 2.17 (s, 3H), 2.65 – 2.74 (m, 4H), 3.38 (m, 1H), 3.53 (t, J = 6.3 Hz, 2H), 4.03 (m, 3H), 5.22 (s, 2H), 5.36 (m, 1H), 7.11 – 7.16 (m, 3H), 7.24 – 7.30 (m, 2H), 7.72 (m, 1H) ppm; $^{31}$P NMR (121 MHz, CDCl$_3$): δ = 27.11, 27.57 ppm; MS =515 [M$^+$+1].

**Example 5: Specific Embodiments of the Invention**

Several specific compounds of the invention are illustrated below.

Example 6: Preparation of Representative Compounds of the Invention

Additional representative compounds of the invention, and intermediates thereof, can be prepared according to the methods presented below.
1. Olefin formation
2. Introduction of phosphonate
3. Deprotection

\[
\begin{align*}
&\text{Linker} = 0-8 \text{ atoms, preferably 1-6;} \\
&R^1 = \text{ethyl or vinyl;} \\
&R^2 = \text{methyl;} \quad \text{and} \\
&R^3 = \text{H, methyl, or ethyl;}
\end{align*}
\]

**Preparation of Ethyl Aldehyde Intermediate**

An aldehyde intermediate wherein \( R^1 \) is ethyl can be prepared as described below.

\[
\begin{align*}
&1) \text{MeOH, AcCl, rt} \\
&2) \text{TMSCH}_2\text{CH}_2\text{OH, DIED, PPh}_3 \\
&3) \text{O}_3, \text{MeOH, CH}_2\text{Cl}_2, \text{thiourea}
\end{align*}
\]

The starting material, synthesized according to *J. Med. Chem.*, 1996, 39, 4181-4196, is transformed to the desired aldehyde intermediate by protection of the phenol followed by cleavage of the alkene double bond as illustrated above.
Preparation of Vinyl Aldehyde Intermediate

An aldehyde intermediate wherein R\textsuperscript{1} is ethyl can be prepared as described below.

\begin{equation*}
\begin{array}{c}
\text{TMS} \\
\text{O} \\
\text{C} \quad \text{O} \\
\text{H} \\
1) \text{NaBH}_4, \text{MeOH} \\
2) \text{Ac}_2\text{O}, \text{pyridine} \\
3) \text{Br}_2, \text{CH}_2\text{Cl}_2
\end{array}
\end{equation*}

\begin{equation*}
\begin{array}{c}
\text{TMS} \\
\text{AcO} \\
\text{O} \\
\text{Br} \\
1) \text{Pd(0),tributyl vinyltin,} \\
2) \text{Dess-Martin periodinate}
\end{array}
\end{equation*}

The starting aldehyde is dissolved in an organic solvent such as methanol and sodium borohydride is added. At the end of the reaction, aqueous HCl solution is added and the solvent is removed \textit{in vacuo}. Further purification is achieved by chromatography.

The resulting alcohol is dissolved in an organic solvent such as dichloromethane (DCM). Pyridine and acetic anhydride are added and stirring at room temperature is continued. At the end of the reaction additional DCM is added and the solution is washed with aqueous HCl solution, aqueous sodium bicarbonate solution, and dried over sodium sulfate. Filtration and evaporation of the solvent \textit{in vacuo} gives the crude product. Further purification is achieved by chromatography.
The acetate is dissolved in DCM and bromine is added, according to a procedure from *J. Med. Chem.*, 1996, 39, 4181-4196. At the end of the reaction, additional DCM is added and the solution is washed with aqueous sodium thiosulfate solution and brine. The organic layer is dried over sodium sulfate.

Filtration and evaporation of solvents yields the crude material. Further purification is achieved by chromatography.

The product of the previous step, lithium chloride, triphenylarsine, tributylvinyltin, and tris(dibenzylideneacetone)dipalladium(0)-chloroform adduct are heated in an organic solvent such as *N*-methylpyrrolidinone at an elevated temperature of approximately 55°C, according to a procedure from *J. Med. Chem.*, 1996, 39, 4181-4196. At the end of the reaction, the mixture is cooled to room temperature and poured into a mixture of ice, potassium fluoride, water, and ethyl acetate. Stirring is continued for one hour. The suspension is filtered through Celite and extracted with ethyl acetate. The combined organic extracts are dried over sodium sulfate. The solvents are removed *in vacuo* and the crude material is further purified by chromatography.

The product of the previous step is dissolved in an organic solvent such as DCM or THF. 1,1,1-tris(acyloxy)-1,1-dihydro-1,2benziodoxol-3-(1H)-one (Dess-Martin reagent) is added and the solution is stirred at room temperature, according to a procedure from *J. Org. Chem.*, 1984, 48, 4155-4156. At the end of the reaction diethyl ether is added, followed by aqueous sodium hydroxide solution. The layers are separated and the organic layer is washed with aqueous sodium hydroxide solution, water, and dried over sodium sulfate. Filtration and evaporation of solvents yields the crude product. Further purification is achieved by chromatography to provide the vinyl aldehyde.

**Example 7: Preparation of Representative Compound of the Invention**, [4-((6-ethyl-4-hydroxy-7-methyl-3-oxo-1,3-dihydro-isobenzofuran-5-yl)-2-methyl-but-2-enyloxy)methyl]-phosphonic acid.
The title compound was prepared from 5-ethyl-6-(4-hydroxy-3-methyl-but-2-enyl)-4-methyl-7-(2-trimethylsilyl-ethoxy)-3H-isobenzofuran-1-one (prepared as described in Example 1) and diisopropyl bromomethylphosphonate using procedures similar to those described herein; MS (negative mode): 369.3 [M⁺ - 1].

**Example 8: Preparation of Representative Compound of the Invention.**

A specific compound of the invention can be prepared as follows.

A solution of dicyclohexyl carbodiimide and DMAP in DMF was added to a solution of [4-(6-ethyl-4-hydroxy-7-methyl-3-oxo-1,3-dihydro-isobenzofuran-5-yl)-2-methyl-but-2-enyloxymethyl]-phosphonic acid (prepared as described in Example 7) and phenol slowly at reduced temperature. The mixture was allowed to warm to room temperature and was then heated to about 140 °C. The residue was purified by chromatography to provide the corresponding monophenyl ester.

To a solution of the monophenyl ester and ethyl lactate in pyridine was added PyBOP. The resulting material was purified by chromatography to provide 2-[[4-(6-ethyl-4-hydroxy-7-methyl-3-oxo-1,3-dihydro-isobenzofuran-5-yl)-2-methyl-but-2-enyloxymethyl]-phenoxy-phosphinoylamino]propionic acid ethyl ester; MS (positive mode): 546.3 [M⁺ + 1] & 568.3 [M⁺ + Na].
Example 9: Preparation of Representative Compound of the Invention, 2-\{(2-[4-(6-ethyl-4-hydroxy-7-methyl-3-oxo-1,3-dihydro-isobenzofuran-5-yl)-2-methyl-but-2-enylamino]-ethyl)-phenoxy-phosphinoylamino\}-propionic acid ethyl ester.

![Chemical Structure](image)

The title compound was prepared from 4-[6-ethyl-7-methyl-3-oxo-4-(2-trimethylsilanyl-ethoxy)-1,3-dihydro-isobenzofuran-5-yl]-2-methyl-but-2-enal (see Example 1) by reductive amination with 2-[(2-aminoethyl)-phenoxy-phosphinoylamino]-propionic acid ethyl ester followed by deprotection; MS (positive mode): 559.4 [M⁺ + 1] & 581.3 [M⁺ + Na].

Example 10: Preparation of Representative Compound of the Invention, 2-\{(1-Ethoxycarbonyl-ethylamino)\} \{(2-[4-(6-ethyl-4-hydroxy-7-methyl-3-oxo-1,3-dihydro-isobenzofuran-5-yl)-2-methyl-but-2-enylamino]-ethyl\}-phosphinoylamino\}-propionic acid ethyl ester

![Chemical Structure](image)

The title compound was prepared from 4-[6-ethyl-7-methyl-3-oxo-4-(2-trimethylsilanyl-ethoxy)-1,3-dihydro-isobenzofuran-5-yl]-2-methyl-but-2-enal
(see Example 1) by reductive amination with 2-[(2-aminoethyl)-(1-ethoxycarbonyl-ethylamino)-phosphinoylamino]-propionic acid ethyl ester followed by deprotection; MS (positive mode): 582.4 [M⁺ + 1] & 604.3 [M⁺ + Na].

Example 11: Preparation of Representative Compound of the Invention.

![Chemical structure](image)

Individual steps:
(2-{2-[6-Ethyl-7-methyl-3-oxo-4-(2-trimethylsilyl-ethoxy)-1,3-dihydroisobenzofuran-5-yl]-ethylamino}-ethyl)-phosphonic acid diethyl ester

[6-Ethyl-7-methyl-3-oxo-4-(2-trimethylsilyl-ethoxy)-1,3-dihydroisobenzofuran-5-yl]-acetaldehyde (31.4 mg, 0.094 mmol), 2-amino-ethylphosphonic acid diethyl ester oxalate salt (28.0 mg, 0.103 mmol), and acetic acid (28.2 mg, 0.470 mmol) were dissolved in dimethylformamide (0.5 mL) at room temperature. After 10 minutes, solid sodium triacetoxyborohydride (39.8 mg, 0.188 mmol) was added and stirring at room temperature was continued. After all starting material was consumed, the reaction mixture was purified by RP-HPLC (eluent: water/acetonitrile*0.05% TFA). The product containing fractions were combined and lyophilized. The product was obtained as an oil.

MS (positive mode): 500.3 [M⁺ + 1].
(2-{2-[6-Ethyl-7-methyl-3-oxo-4-(2-trimethylsilanyl-ethoxy)-1,3-dihydroisobenzofuran-5-yl]-ethylamino}-ethyl)-phosphonic acid.

(2-{2-[6-Ethyl-7-methyl-3-oxo-4-(2-trimethylsilanyl-ethoxy)-1,3-dihydroisobenzofuran-5-yl]-ethylamino}-ethyl)-phosphonic acid diethyl ester, obtained crude from 0.094mmol of starting material in the previous step, was dissolved in dimethylformamide (0.7 mL) and dichloromethane (0.7 mL) at room temperature. Trimethylsilyl bromide (143.9 mg, 0.940 mmol) was added.

Stirring at room temperature was continued. After 5 hours all starting material was consumed. The solvent was removed in vacuo, and the crude reaction mixture was purified by RP-HPLC (eluent: water/acetonitrile*0.05% TFA). The product-containing fractions were combined and lyophilized to yield the desired material (19.2 mg, 0.0433 mmol, 46 % over two steps).

$^1$H NMR (DMSO-d$_6$, 300MHz) $\delta = 0.01$ (s, 9H), 1.09 (t, $J = 7.8$ Hz, 3H), 1.19 (m, 2H), 1.89 (m, 2H), 2.16 (s, 3H), 2.72 (m, 2H), 2.95 (m, 4H), 3.13 (m, 2H), 4.28 (m, 2H), 5.27 (s, 2H) ppm.
{2-[2-(6-Ethyl-4-hydroxy-7-methyl-3-oxo-1,3-dihydro-isobenzofuran-5-yl)-ethylamino]-ethyl]-phosphonic acid

(2-[2-(6-Ethyl-7-methyl-3-oxo-4-(2-trimethylsilanyl-ethoxy)-1,3-dihydro-isobenzofuran-5-yl]-ethylamino)-ethyl]-phosphonic acid (12.9 mg, 0.0231 mmol) was dissolved in dichloromethane (0.1 mL). The solution was cooled to 0°C. A cold (0°C) solution of trifluoroacetic acid (0.05 mL) in dichloromethane (0.35 mL) was added and stirring at 0°C was continued. After 2 hours all starting material was consumed. Pyridine (0.05 mL) was added and all volatiles were removed *in vacuo*. The crude material was purified by RP-HPLC (eluent: water/acetonitrile*0.05% TFA). The product-containing fractions were combined and lyophilized, yielding the product (7.9 mg, 0.0172 mmol, 74%).

$^1$H NMR (DMSO-d$_6$, 300MHz) $\delta$ = 1.08 (t, $J$ = 7.2 Hz, 3H), 1.94 (m, 2H), 2.12 (s, 3H), 2.70 (m, 2H), 2.96 (m, 4H), 3.10 (m, 2H), 5.27 (s, 2H) ppm.

$^{31}$P NMR (DMSO-d$_6$, 121MHz) $\delta$ = 19.73 ppm.

*Example 12: Preparation of Representative Compound of the Invention.*
Individual steps:

1. Reaction with NaB(OAc)$_3$H leads to the formation of the phosphorus-containing molecule.
2. Further reactions with TFA/DCM result in the final structure.

The process involves the synthesis of a phosphorus-containing compound through the attachment of various functional groups and the use of specific reagents for modification.
{2-[4-(4-tert-Butoxycarbonyloxy-6-ethyl-7-methyl-3-oxo-1,3-dihydroisobenzofuran-5-yl)-2-methyl-but-2-enylamino]-ethyl}-phosphonic acid diethyl ester

Carbonic acid tert-butyl ester 6-ethyl-7-methyl-5-(3-methyl-4-oxo-but-2-enyl)-3-oxo-1,3-dihydro-isobenzofuran-4-yl ester (50.0 mg, 0.1336 mmol), 2-aminoethyl-phosphonic acid diethyl ester oxalate salt (39.8 mg, 0.1469 mmol), and acetic acid (16.0 mg, 0.2672 mmol) were dissolved in dimethylformamide (0.5 mL) at room temperature. After 10 minutes, solid sodium triacetoxyborohydride (56.6 mg, 0.2672 mmol) was added and stirring at room temperature was continued. After all starting material was consumed, all volatiles were removed in vacuo. The product was obtained as an oil and was used crude in the next step. MS (positive mode): 539.7 [M⁺ + 1].

{2-[4-(4-tert-Butoxycarbonyloxy-6-ethyl-7-methyl-3-oxo-1,3-dihydroisobenzofuran-5-yl)-2-methyl-but-2-enylamino]-ethyl}-phosphonic acid diethyl ester

{2-[4-(4-tert-Butoxycarbonyloxy-6-ethyl-7-methyl-3-oxo-1,3-dihydroisobenzofuran-5-yl)-2-methyl-but-2-enylamino]-ethyl}-phosphonic acid diethyl ester (from the previous step, <0.133 mmol) was dissolved in dichloromethane (0.2 mL). Trifluoroacetic acid (0.2 mL) was added and stirring at room temperature was continued. After 2 hours all starting material was consumed.
The dichloromethane was removed \textit{in vacuo}. The crude reaction product was dissolved in dimethylformamide and was purified by RP-HPLC (eluent: water/acetonitrile*0.05% TFA). The product containing fractions were combined and lyophilized, yielding the product as the trifluoroacetate salt (31.7 mg, 0.0572 mmol, 43% over two steps).

$^1$H NMR (DMSO-d$_6$, 300 MHz) $\delta$ = 1.07 (t, $J$ = 7.2 Hz, 3H), 1.21 (t, $J$ = 7.2 Hz, 6H), 1.84 (s, 3H), 2.06 - 2.17 (m, 5H), 2.63 (q, $J$ = 7.2 Hz, 2H), 2.98 (m, 2H), 3.43 (d, $J$ = 6.6 Hz, 2H), 3.52 (m, 2H), 3.98 (m, 4H), 5.26 (s, 2H), 5.45 (t, $J$ = 6.0 Hz, 1H) ppm.

$^{31}$P NMR (DMSO-d$_6$, 121 MHz) $\delta$ = 25.75 ppm.

MS (positive mode): 439.7 [M$^+ +$ 1].

\textbf{Example 13: Preparation of Representative Compound of the Invention.}

\begin{center}
\includegraphics[width=0.7\textwidth]{example13.png}
\end{center}

2-(S)-[4-(6-Ethyl-4-hydroxy-7-methyl-3-oxo-1,3-dihydro-isobenzofuran-5-yl)-2-methyl-but-2-enyl]-phenoxy-phosphinoylamino]-propionic acid 3-(morpholin-4-yl)propyl ester: this product was prepared using methods similar to those described for Example 4 except using alanine 3-morpholinopropyl ester. $^1$H NMR (300 MHz, CDCl$_3$) $\delta$ 1.11 - 1.25 (m, 6H), 1.79 (m, 2H), 2.03 (s, 3H), 2.17 (s, 3H), 2.37 (m, 6H), 2.68 (m, 4H), 3.40 (m, 1H), 3.71 (m, 4H), 4.07 (m, 3H), 5.2 (s, 2H), 5.32 (q+q, 1H), 7.09-7.16 (m, 3H), 7.24-7.27 (m, 2H) ppm; $^{31}$P (121.4 MHz, CDCl$_3$) $\delta$ 27.11, 27.65; MS (m/z) 615 [M$+$H$^+$].
Example 14: Preparation of Representative Compound of the Invention.

2-(S)-{4-(6-Ethyl-4-hydroxy-7-methyl-3-oxo-1,3-dihydro-isobenzofuran-5-yl)-2-methyl-but-2-enyl[phenoxyl-phosphinoylamino]-propionic acid (S)-pyrrolidin-2-ylmethyl ester: this product was prepared using methods similar to those described for Example 4 except using 2-(2-amino-propionyloxymethyl)-pyrrolidine-1-carboxylic acid tert-butyl ester. $^1$H NMR (300 MHz, CD$_3$OD) $\delta$ 1.10-1.22 (m, 6H), 1.73 (m, 2H), 2.03 (m, 5H), 2.19 (s, 3H), 2.77 (m, 4H), 3.29 (m, 3H), 3.54 (m, 2H), 3.96 (m, 1H), 4.05-4.51 (m, 2H), 5.28 (s, 2H), 5.40(q, 1H), 7.15-7.20 (m, 3H), 7.26-7.37 (m, 2H) ppm; $^{31}$P (121.4 MHz, CD$_3$OD) $\delta$ 30.12, 30.54; MS (m/z) 571 [M+H]$^+$. 

Example 15: Preparation of Representative Compound of the Invention.
2-(S)-{[4-(6-Ethyl-4-hydroxy-7-methyl-3-oxo-1,3-dihydro-isobenzofuran-5-yl)-2-methyl-but-2-enyl]-phenoxy-phosphinoylamino}-propionic acid (S)-pyrrolidin-3-yl ester: this product was prepared using methods similar to those described for Example 4 except using 3-(2-amino-propionyloxy)-pyrrolidine-1-carboxylic acid 2-trimethylsilyl-ethyl ester. $^1$H NMR (300 MHz, CD$_3$OD) δ 1.15 (m, 6H), 2.03 (s+s, 3H), 2.19 (s, 3H), 2.10-2.30 (m, 2H), 2.76 (m, 4H), 3.32-3.58 (m, 4H), 3.53 (m, 2H), 3.90 (m, 1H), 5.22 (m, 1H), 5.28 (s, 2H), 5.36(m, 1H), 7.08-7.16 (m, 3H), 7.27-7.34 (m, 2H) ppm; $^{31}$P (121.4 MHz, CD$_3$OD) δ 29.27, 29.82; MS (m/z) 557 [M+H]$^+$. 

**Example 16: Preparation of Representative Compound of the Invention.**
2-(S)-{[4-(6-Ethyl-4-hydroxy-7-methyl-3-oxo-1,3-dihydro-isobenzofuran-5-yl)-2-methyl-but-2-enyl]-phenoxy-phosphinoyl amino]-propionic acid piperidin-4-yl ester: this product was prepared using methods similar to those described for Example 4 except using 4-(2-amino-propionyloxy)-piperidine-1-carboxylic acid 2-trimethylsilyl-ethyl ester. H NMR (300 MHz, CD3OD) δ 1.15 (m, 6H), 1.82 (m, 4H), 2.02 (s, 3H), 2.18 (s, 3H), 2.78 (m, 4H), 3.20 (m, 4H), 3.53 (m, 2H), 3.94 (m, 1H), 4.79 (m, 1H), 5.22 (m, 1H), 5.27 (s, 2H), 5.36 (m, 1H), 7.08-7.18 (m, 3H), 7.26-7.33 (m, 2H) ppm; 31P (121.4 MHz, CD3OD) δ 29.61, 30.12; MS (m/z) 571 [M+H]+.

Example 17: Preparation of Representative Compound of the Invention.

2-(S)-{[4-(6-Ethyl-4-hydroxy-7-methyl-3-oxo-1,3-dihydro-isobenzofuran-5-yl)-2-methyl-but-2-enyl]-difluoroethoxy-phosphinoyl amino]-propionic acid ethyl ester: this product was prepared using {4-[6-ethyl-7-methyl-3-oxo-4-(2-trimethylsilyl-ethyl)-1,3-dihydro-isobenzofuran-5-yl]-2-methyl-but-2-enyl}- phosphonic acid and trifluoroethanol and methods similar to those described herein. H NMR (300 MHz, CDCl3) δ 1.14 (m, 3H), 1.24-1.36 (m, 6H), 1.96 (s, 3H), 2.18 (s, 3H), 2.55-2.76 (m, 4H), 3.25 (m, 1H), 3.48 (m, 2H), 3.92-4.45 (m, 4H), 5.22 (s, 2H), 5.29 (m+m, 1H), 7.70 (s+s, 1H) ppm; 31P (121.4 MHz, CDCl3) δ 31.55, 32.32; MS (m/z) 522 [M+H]+.
Example 18: Preparation of Representative Compound of the Invention.

Individual Steps

\[ \text{4-[(6-Ethyl-7-methyl-3-oxo-4-(2-trimethylsilyl-ethoxy)-1,3-dihydro-
isobenzofuran-5-yl]-2-methyl-but-2-enyl]-phosphonic acid N-}(\text{t-}) \]
**butoxycarbonylisoindolin-5-yl ester anhydride** A solution of {4-[6-ethyl-7-methyl-3-oxo-4-(2-trimethylsilanyl-ethoxy)-1,3-dihydro-isobenzofuran-5-yl]-2-methyl-but-2-enyl}-phosphonic acid, 5-hydroxy-1,3-dihydro-isoindole-2-carboxylic acid tert-butyl ester and DCC in pyridine was stirred at 70 °C for 4 hr. The reaction mixture was concentrated and re-dissolved in acetonitrile (2 mL). The solution was treated with 2N NaOH, stirred at room temperature for 18 hr, neutralized with concentrated HCl, and extracted with CH₂Cl₂. The organic layer was concentrated and purified by RP HPLC, affording the desired product; MS (m/z) 1323 [M+Na]⁺.

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**2-(S)-{4-(4-Hydroxy-6-ethyl-7-methyl-3-oxo-1,3-dihydro-isobenzofuran-5-yl)-2-methyl-but-2-enyl}-(isoindolin-5-oxy)-phosphinoylamino}-propionic acid ethyl ester:** this product was prepared using methods similar to those described for Example 4 except using {4-[6-ethyl-7-methyl-3-oxo-4-(2-trimethylsilany-lethoxy)-1,3-dihydro-isobenzofuran-5-yl]-2-methyl-but-2-enyl}-phosphonic acid N-(butoxycarbonyl)isoindolin-5-yl ester anhydride. ¹H NMR (300 MHz, CD₃OD) δ 1.18 (m, 9H), 2.02 (s, 3H), 2.19 (s, 3H), 2.79 (m, 4H), 3.55 (m, 2H), 3.90 (m, 1H), 4.04 (m, 2H), 4.59 (m, 4H), 5.28 (s, 2H), 5.38 (m, 1H), 7.13-7.32 (m, 3H) ppm; ³¹P (121.4 MHz, CD₃OD) δ 30.22, 30.9; MS (m/z) 557 [M+H]⁺.

---

**Example 19: Preparation of Representative Compound of the Invention.**
{4-[6-Ethyl-7-methyl-3-oxo-4-(2-trimethylsilanyloxy)-1,3-dihydroisobenzofuran-5-yl]-2-methyl-but-2-enyl}-phosphonic acid dimethyl ester:
A solution of 6-(4-Bromo-3-methyl-but-2-enyl)-5-ethyl-4-methyl-7-(2-trimethylsilanyloxy)-3H-isobenzofuran-1-one (103 mg, 0.234 mmol) in trimethylphosphite (829 µL, 7.03 mmol) was heated at 100 °C for 3 hours, when the reaction was complete judged from TLC. The reaction was worked up by removal of the liquid under reduced pressure and purifying the residue by silica gel chromatography using EtOAc-Hexanes (0-100%) to provide 94 mg (85%) of the desired product; \(^{1}H\) NMR (300 MHz, CDCl\(_{3}\)) \(\delta\) 0.03 (s, 9H), 1.15 (t, J= 7 Hz, 3H), 1.20- 1.28 (m, 2H), 1.95 (d, J= 2 Hz, 3H), 2.18 (s, 3H), 2.52 (d, J= 22 Hz, 2H), 2.70 (q, J= 7 Hz, 2H), 3.51 (t, J= 6 Hz, 2H), 3.70 (d, J= 11 Hz, 6H), 4.22- 4.29 (m, 2H), 5.13 (s, 2H), 5.20 (q, J= 7 Hz, 1H); \(^{31}P\) (121.4 MHz, CDCl\(_{3}\)) \(\delta\) 30.1; MS (m/z) 368 [(M-TMSE)+H]+.
[4-(6-Ethyl-4-hydroxy-7-methyl-3-oxo-1,3-dihydro-isobenzofuran-5-yl)-2-methyl-but-2-enyl]-phosphonic acid dimethyl ester: A solution of [4-(6-Ethyl-7-methyl-3-oxo-4-(2-trimethylsilanyl-ethoxy)-1,3-dihydro-isobenzofuran-5-yl]-2-methyl-but-2-enyl]-phosphonic acid dimethyl ester (94 mg, 0.200 mmol) in CH$_2$Cl$_2$ (2 mL) was stirred with TFA (0.2 mL) at ambient temperature for 40 minutes, when the reaction was complete as indicated by LCMS. The solvent was removed in vacuo and the residue was dissolved in DMF (1.5 mL). The sample was purified by preparative reverse-phase HPLC (acetonitrile, water with 0.1% CF$_3$COOH) to provide 73 mg (99%) of the desired product as a white solid; $^1$H NMR (300 MHz, CDCl$_3$) $\delta$ 1.14 (t, $J$= 7 Hz, 3H), 1.96 (d, $J$= 4 Hz, 3H), 2.17 (s, 3H), 2.55 (d, $J$= 22 Hz, 2H), 2.71 (q, $J$= 7 Hz, 2H), 3.47 (t, $J$= 6 Hz, 2H), 3.71 (d, $J$= 11 Hz, 6H), 5.22 (s, 2H), 5.26 (q, $J$= 7 Hz, 1H), 7.58 (br s, 1H); $^{31}$P (121.4 MHz, CDCl$_3$) $\delta$ 30.4; MS ($m$/z) 369 [M+H]$^+$. 

Example 20: Preparation of Representative Compound of the Invention.

Diastereomer separation of 2(S)-[2-benzoxycarbonylamino-ethyl]-phenoxy-phosphinoylamino]-propionic acid ethyl ester by chiral column chromatography

The diastereomers of 2(S)-[2-benzoxycarbonylamino-ethyl]-phenoxy-phosphinoylamino]-propionic acid ethyl ester were resolved by chiral HPLC using a commercially available Chiralpak AS-H, 5 $\mu$m, 20x250 mm semi-
preparative HPLC column with a Chiralpak AS, 20μm, 21x50 mm guard column. These columns were purchased from Chiral Technologies, Inc., Exton, Philadelphia, U.S.A.

The diasteromeric mixture was dissolved in a mobile phase and loaded onto the chromatographic system. The first peak to elute from the column was designated as diastereomer A and the second peak as diastereomer B. The mobile phase solvents were removed in vacuo to yield each of pure diastereomers as a white solid.

The chromatographic conditions were as follows:

Mobile phase: EtOH / n-Heptane (60:40, v/v)
Flow rate: 6.5 ml/min
Run time: 30 min.

Detection: UV at 254 nm
Temperature: Ambient
Sample preparation: 100 mg/mL in mobile phase solvents
Loading: 1.5 mL (150 mg)

Elution profile:

Retention time of diastereomer A = 14.2 min.

Retention time of diastereomer B = 16.7 min.

Diastereomer A; $^1$H NMR (300 MHz, CDCl$_3$) δ 1.34 (m, 6H), 2.16 (dt, 3H), 3.41 (t, 1H), 3.63 (m, 2H), 4.10 (m, 2H+1H), 5.12 (s, 2H), 5.65 (brs, 1H), 7.13-7.20 (m, 2H), 7.27-7.35 (m, 3H) ppm; $^{31}$P (121.4 MHz, CDCl$_3$) δ 29.82 ppm.

Diastereomer B; $^1$H NMR (300 MHz, CDCl$_3$) δ 1.23 (t, 3H), 1.31 (d, 3H), 2.14 (m, 2H), 3.59 (m, 2H), 4.00 (q, 1H), 4.13 (q, 2H), 5.11 (s, 2H), 5.55 (brs, 1H), 7.13-7.21 (m, 2H), 7.27-7.35 (m, 3H) ppm; $^{31}$P (121.4 MHz, CDCl$_3$) δ 29.42 ppm.
2-((2-[4-(6-Ethyl-4-hydroxy-7-methyl-3-oxo-1,3-dihydro-isobenzofuran-5-yl)-2-methyl-but-2-enamino]-ethyl)-phenoxy-phosphinoylamino)-phosphonic acid ethyl ester A: A solution of 4-[6-Ethyl-7-methyl-3-oxo-4-(2-trimethylsilyl-ethoxy)-1,3-dihydro-isobenzofuran-5-yl]-2-methyl-but-2-enal (253 mg, 0.67 mmol) was stirred with 2-[(2-aminoethyl)-phenoxy-phosphinoylamino]-propionic acid ethyl ester diastereomer A (350 mg, 0.81 mmol) in CH$_2$Cl$_2$ (10 mL) for 1 hour at ambient temperature. Sodium triacetoxyborohydride (215 mg, 1.0 mmol) was added to the solution and the reaction was allowed to proceed for overnight. The reaction was quenched by addition of a saturated aqueous solution of NaHCO$_3$ and the product was extracted with EtOAc. The organic layer was removed under reduced pressure and the residue was resuspended in a 10% TFA/ CH$_2$Cl$_2$ (5 mL) at 0°C for 2 hours. The reaction mixture was neutralized by adding pyridine (0.5 mL). After concentration the crude product was purified by RP HPLC using a C18 column with a gradient of H$_2$O, 0.1% TFA-acetonitrile, to provide 219 mg (58%) of the product.

$^1$H NMR (300 MHz, CD$_3$OD) $\delta$ 1.13 -1.25 (m, 9H), 2.0 (s, 3H), 2.15 (s, 3H), 2.50-2.52 (m, 2H), 2.75 (q, 2H), 3.41 (m, 2H), 3.50 (d, 2H), 3.67 (s, 2H), 3.97 (m, 1H), 4.07-4.17 (m, 2H), 5.18 (s, 2H), 5.64-5.68 (m, 1H), 7.18 (m, 3H),
7.37 (m,2H) ppm; $^{31}$P (121.4 MHz, CD$_3$OD) δ 28.05 ppm; MS (m/z) 557.0 [M-H]$^+$, 558.9 [M+H]$^+$. 

Example 21: Preparation of Representative Compound of the Invention.

2-((2-[4-(6-Ethyl-4-hydroxy-7-methyl-3-oxo-1,3-dihydro-isobenzofuran-5-yl)-2-methyl-but-2-enylamino]-ethyl)-phenoxy-phosphinoylamino)-phosphonic acid ethyl ester B: A solution of 4-[6-Ethyl-7-methyl-3-oxo-4-(2-trimethylsilyl-ethoxy)-1,3-dihydro-isobenzofuran-5-yl]-2-methyl-but-2-enal (253 mg, 0.67 mmol) was stirred with 2-[(2-aminoethyl)-phenoxy-phosphinoylamino]-propionic acid ethyl ester B (see Example 20; 350 mg, 0.81 mmol) in CH$_2$Cl$_2$ (10 mL) for 1 hour at ambient temperature. Sodium triacetoxyborohydride (215 mg, 1.0 mmol) was added to the solution and the reaction was allowed to proceed for overnight. The reaction was quenched by addition of a saturated aqueous solution of NaHCO$_3$ and the product was extracted with EtOAc. The organic layer was removed under reduced pressure and the residue was resuspended in a 10% TFA/CH$_2$Cl$_2$ (5 mL) at 0°C for 2 hours. The reaction mixture was neutralized by adding pyridine (0.5 mL). After
concentration the crude product was purified by RP HPLC using a C18 column
with a gradient of H₂O, 0.1% TFA-acetonitrile, to provide 257 mg (68%) of the
product. ¹H NMR (300 MHz, CD₃OD) δ 1.13 -1.25 (m, 6H), 1.26 (d, 2H), 2.0 (s,
3H), 2.15 (s, 3H), 2.50-2.52 (m, 2H), 2.75 (q, 2H), 3.41 (m, 2H), 3.50 (d, 2H),
3.67 (s, 2H), 3.97 (m, 1H), 4.07-4.17 (m, 2H), 5.18 (s, 2H), 5.64 - 5.68 (m, 1H),
7.18 (m, 3H), 7.37 (m,2H) ppm; ³¹P (121.4 MHz, CD₃OD) δ 27.38 ppm; MS
(m/z) 557.0 [M-H]⁺, 558.9 [M+H]⁺.

Example 22: Preparation of Representative Compound of the Invention.

![Chemical structure diagram]

2-(S)-[4-(6-Ethyl-4-hydroxy-7-methyl-3-oxo-1,3-dihydro-isobenzofuran-5-
yl)-2-methyl-but-2-enylamino]-phenoxy-phosphinoylamino]-propionic acid

isopropyl ester: this product was prepared using 4-[6-ethyl-7-methyl-3-oxo-4-
(2-trimethylsilyl-ethoxy)-1,3-dihydro-isobenzofuran-5-yl]-2-methyl-but-2-
enal and 2-[(2-aminoethyl)phenoxy-phosphinoylamino]-propionic acid ethyl
ester and methods similar to those described herein. ¹H NMR (300 MHz,
CD₃OD) δ 1.13-1.28 (m, 12H), 1.99 (s, 3H), 2.18 (s, 3H), 2.40 (m, 2H), 2.74 (q,
2H), 3.38 (m, 2H), 3.58 (d, 2H), 3.65 (s, 2H), 3.92 (m, 1H), 4.96 (m, 1H), 5.25
(s, 2H), 5.66(brt, 1H), 7.16-7.25 (m, 3H), 7.34-7.41 (m, 2H) ppm; ³¹P (121.4
MHz, CD₃OD) δ 27.32, 28.02; MS (m/z) 573 [M+H]⁺.

Example 23: Preparation of Representative Compound of the Invention.
The starting benzyl carbamate (573 mg, 1.30 mmol) was dissolved in EtOH (6 mL) and AcOH (149 µL, 2.60 mmol). Then 10% Pd/C (117 mg) was added and the reaction was stirred under H₂ (1 atm) for 2 hours. The Pd/C was removed by filtration through Celite and the solvent was removed through coevaporation with CH₂Cl₂ 3 times. The aldehyde (300 mg, 0.801 mmol) was then added to the amine and the resulting mixture was dissolved in CH₂Cl₂ (10 mL). The reaction was allowed to stir for 2 hours at room temperature. NaBH(OAc)₃ (255 mg, 1.20 mmol) was then added and the reaction was allowed to stir for 12 hours. The reaction was then directly loaded on a column and purified (1% MeOH/CH₂Cl₂ 5% MeOH/CH₂Cl₂). The resulting white foam (270 mg, 0.405 mmol) was then dissolved in CH₂Cl₂ (4 mL) and cooled to 0 °C. A solution of 40% TFA/CH₂Cl₂ (3 mL) was then added and the reaction was allowed to stir at 0 °C for 2 hours. Pyridine (2 mL) was then added and the reaction was allowed to come to room temperature. The reaction mixture was concentrated and purified by Gilson RP column to give the product (194 mg, 0.344 mmol, 43%).

¹H NMR (300 MHz, CD₃OD) δ 5.64 (1H, t, J = 6.9 Hz), 5.28 (2H, s), 4.56-35 (2H, m), 4.25-4.10 (2H, m), 4.10-3.90 (1H, m), 3.62 (2H, s), 3.58 (2H, d, J = 6.9 Hz), 3.35-3.15 (2H, m), 2.77 (2H, q, J = 7.5 Hz), 2.42-2.25 (2H, m), 2.20 (3H, s), 1.98 (3H, s), 1.45-1.39 (3H, m), 1.31-1.23 (3H, m), 1.17 (3H, t, J = 7.5 Hz); ³¹P NMR (121 MHz, CD₃OD) δ 32.1, 32.3; ¹⁹F NMR (290 MHz, CD₃OD) δ -77.1 (t, J = 9.3 Hz), -77.2 (t, J = 9.3 Hz), -77.5 (s, TFA) LC-MS (method: 0.5
min 95% H₂O/5% MeCN → 5 min 0% H₂O/100% MeCN, rt = 2.8 min. MS calc'd for C₁₉H₂₁F₂N₂O₂P (MH⁺): 565.2. Found 564.8.

Example 24: Preparation of Representative Compound of the Invention.

The starting benzyl carbamate (602 mg, 1.30 mmol) was dissolved in EtOH (6 mL) and AcOH (149 μL, 2.60 mmol). Then 10% Pd/C (117 mg) was added and the reaction was stirred under H₂ (1 atm) for 2 hours. The Pd/C was removed by filtration through Celite and the solvent was removed through coevaporation with CH₂Cl₂ 3 times. The aldehyde (300 mg, 0.801 mmol) was then added to the amine and the resulting mixture was dissolved in CH₂Cl₂ (10 mL). The reaction was allowed to stir for 2 hours at room temperature. NaBH(OAc)₃ (255 mg, 1.20 mmol) was then added and the reaction was allowed to stir for 12 hours. The reaction was washed with brine 3 times, dried (MgSO₄), concentrated, and purified (1% MeOH/CH₂Cl₂ 5% MeOH/CH₂Cl₂). The resulting white foam (509 mg, 0.741 mmol) was then dissolved in CH₂Cl₂ (6 mL) and cooled to 0 °C. A solution of 40% TFA/CH₂Cl₂ (4.5 mL) was then added and the reaction was allowed to stir at 0 °C for 2 hours. Pyridine (2 mL) was then added and the reaction was allowed to come to room temperature. The reaction mixture was concentrated and purified by Gilson RP column to give the
product (320 mg, 0.545 mmol, 68%). $^1$H NMR (300 MHz, CD$_3$OD) $\delta$ 7.12-6.97 (3H, m), 5.67 (1H, bt), 5.21 (2H, s), 4.22-3.82 (3H, m), 3.75-3.70 (2H, m), 3.60 (2H, d, $J$ = 6.7 Hz), 3.50-3.25 (2H, m), 2.78 (2H, q, $J$ = 7.3 Hz), 2.60-2.30 (2H, m), 2.32 (6H, s), 2.18 (3H, s), 2.01 (3H, s), 1.40-1.10 (9H, m); $^{31}$P NMR (121 MHz, CD$_3$OD) $\delta$ 27.7, 26.4; LC-MS (method: 0.5 min 95% H$_2$O/5% MeCN → 5 min 0% H$_2$O/100% MeCN, rt = 3.1 min. MS calc’d for C$_{31}$H$_{44}$N$_2$O$_7$P (MH$^+$): 587.3. Found 586.9.

**Example 25: Preparation of Representative Compound of the Invention.**

A solution of the starting material (25mg, 0.037mmol) in a 1:1 solution of TEA-$\cdot$H$_2$O (2.5 mL of each) was stirred at 40 °C for 2 hours when the hydrolysis was complete indicated by LCMS. The reaction was worked up by removal of the solvents and dissolving the residue in water and washing with Et$_2$O (3 x 20 mL). The aqueous layer was dried and the product was recrystallized from MeOH-Et$_2$O to provide 16.9 mg (89%) of the product with 0.67 eq of TEA salt as a white solid. $^1$H NMR (300 MHz, CD$_3$OD) $\delta$ 1.14- 1.21 (m, 6H), 1.28- 1.35 (m, 6H), 1.81 (dt, $J$ = 16, 7 Hz, 2H), 1.98 (s, 3H), 2.20 (s, 3H), 2.77 (q, $J$= 8 Hz, 2H), 3.15- 3.24 (m, 4H), 3.46- 3.58 (m, 6H), 3.77 (dq, $J$= 7 Hz, 1H), 5.27 (s, 2H), 5.60 (t, $J$= 6 Hz, 1H); $^{31}$P (121.4 MHz, CD$_3$OD) $\delta$ 19.5; MS (m/z) 455 [M+H]$^+$. 

**Example 26: Preparation of Representative Compound of the Invention.**

Diastereomer separation of 2(S)-(2-benzyloxycarbonylamino-ethyl)-2,6-
dimethylphenoxy-phosphinoylamino]-propionic acid ethyl ester by chiral column chromatography

Diastereomer separation was achieved using methods similar to those described for separation of diastereomeric 2(S)-[(2-benzyloxy carbonylamino-ethyl)-phenoxy-phosphinoylamino]-propionic acid ethyl ester.

The chromatographic conditions were as follows:

Mobile phase: EtOH/n-Heptane (30:70, v/v)
Flow rate: 10 ml/min
Run time: 20 min.

Detection: UV at 254 nm
Temperature: Ambient
Sample preparation: 100 mg/mL in mobile phase solvents
Loading: 1.5 mL (150 mg)

Diastereomer A; $^1$H NMR (300 MHz, CDCl$_3$) $\delta$ 1.14 (d, 3H), 1.25 (t, 3H), 2.23 (dq, 3H), 2.34 (s, 6H), 3.16 (t, 1H), 3.65 (m, 2H), 4.13 (m, 2H+1H), 5.12 (s, 2H), 5.82 (brs, 1H), 6.94-7.05 (m, 3H), 7.30-7.36 (m, 5H) ppm; $^{31}$P (121.4 MHz, CDCl$_3$) $\delta$ 29.35 ppm.

Diastereomer B; $^1$H NMR (300 MHz, CDCl$_3$) $\delta$ 1.21 (t, 3H), 1.35 (d, 3H), 2.19 (m, 2H), 3.35 (s, 6H), 3.57 (m, 2H+1H), 4.04 (m, 2H+1H), 5.11 (s, 2H), 5.62
(brs, 1H), 7.94-7.04 (m, 3H), 7.30-7.35 (m, 5H) ppm; $^{31}$P (121.4 MHz, CDCl$_3$) δ 28.67 ppm.

![Diagram of chemical structures](image)

2-({2-[4-(6-Ethyl-4-hydroxy-7-methyl-3-oxo-1,3-dihydro-isobenzofuran-5-yl)-2-methyl-but-2-enylamino]-ethyl}-2,6-dimethylphenoxy-phosphinoylamo)-phosphonic acid ethyl ester A: A solution of 4-[6-Ethyl-7-methyl-3-oxo-4-(2-trimethylsilanyl-ethoxy)-1,3-dihydro-isobenzofuran-5-yl]-2-methyl-but-2-enal (60 mg, 0.16 mmol) was stirred with 2-[(2-aminoethyl)2,6-dimethylphenoxy-phosphinoylamo]-propionic acid ethyl ester A (90 mg, 0.19 mmol) in CH$_2$Cl$_2$ (2 mL) for 1 hour at ambient temperature. Sodium triacetoxyborohydride (50 mg, 0.32 mmol) was added to the solution and the reaction was allowed to proceed overnight. The reaction was quenched by addition of a saturated aqueous solution of NaHCO$_3$ and the product was extracted with EtOAc. The organic layer was removed under reduced pressure and the residue was resuspended in a 10% TFA/CH$_2$Cl$_2$ at 0°C for 2 hours. The reaction mixture was concentrated and the product was purified by RP HPLC using a C18 column with a gradient of H$_2$O, 0.1% TFA-acetonitrile, to provide 51 mg (54%) of the product as a white solid. $^1$H NMR (300 MHz, CD$_3$OD) δ 1.13 -1.25 (m, 9H), 2.0 (s, 3H), 2.15 (s, 3H), 2.28 (s, 6H), 2.50-2.52 (m, 2H),
2.75 (q, 2H), 3.41 (m, 2H), 3.50 (d, 2H), 3.67 (s, 2H), 3.97 (m, 1H), 4.07-4.17 (m, 2H), 5.18 (s, 2H), 5.64-5.68 (m, 1H), 7.03 (m, 3H) ppm; $^{31}$P (121.4 MHz, CD$_3$OD) $\delta$ 27.76 ppm; MS (m/z) 587.4 [M+H]$^+$.

5 Example 27: Preparation of Representative Compound of the Invention.

![Diagram]

1. NaBH(OAc)$_3$

2. 10% TFA/DCM

Isomer B

2-(2-[4-(6-Ethyl-4-hydroxy-7-methyl-3-oxo-1,3-dihydro-isobenzofuran-5-yl)-2-methyl-but-2-enylamino]-ethyl]-2,6-dimethylphenoxy-phosphinoylaminono)-phosphonic acid ethyl ester B: A solution of 4-[6-Ethyl-7-methyl-3-oxo-4-(2-trimethylsilanyl-ethoxy)-1,3-dihydro-isobenzofuran-5-yl]-2-methyl-but-2-enal (60 mg, 0.16 mmol) was stirred with 2-[(2-aminoethyl)2,6-dimethylphenoxy-phosphinoylaminono]-propionic acid ethyl ester B (see Example 26; 90 mg, 0.19 mmol) in CH$_2$Cl$_2$ (2 mL) for 1 hour at ambient temperature. Sodium triacetoxyborohydride (50 mg, 0.32 mmol) was added to the solution and the reaction was allowed to proceed overnight. The reaction was quenched by addition of a saturated aqueous solution of NaHCO$_3$ and the product was extracted with EtOAc. The organic layer was removed under reduced pressure and the residue was resuspended in a 10% TFA/CH$_2$Cl$_2$ at 0°C for 2 hours. The
reaction mixture was concentrated and the product was purified by RP HPLC using a C18 column with a gradient of H2O, 0.1% TFA-acetonitrile, to provide 51 mg (54%) of the product as a white solid. $^1$H NMR (300 MHz, CD$_3$OD) $\delta$ 1.13 -1.25 (m, 6H), 1.28 (d, 3H), 2.0 (s, 3H), 2.15 (s, 3H), 2.28 (s, 6H), 2.50-2.52 (m, 2H), 2.75 (q, 2H), 3.41 (m, 2H), 3.50 (d, 2H), 3.67 (s, 2H), 3.97 (m, 1H), 4.07-4.17 (m, 2H), 5.18 (s, 2H), 5.64-5.68 (m, 1H), 7.03 (m, 3H) ppm; $^{31}$P (121.4 MHz, CD$_3$OD) $\delta$ 26.44 ppm; MS (m/z) 587.0 [M+H]$^+$. 

Example 28: Preparation of Representative Compound of the Invention.

Diastereomer separation of 2(S)-[(2-benzylxycarbonylamino-ethyl)-(2,2,2-trifluoroethoxy)-phosphinoylamino]-propionic acid ethyl ester by chiral column chromatography

Diastereomer separation was achieved using methods similar to those described for separation of diastereomeric 2(S)-[(2-benzylxycarbonylamino-ethyl)-phenoxy-phosphinoylamino]-propionic acid ethyl ester.

The chromatographic conditions were as follows:

- Mobile phase: isopropanol
- Flow rate: 2.5 ml/min
- Run time: 150 min.
- Detection: UV at 254 nm
- Temperature: Ambient
- Sample preparation: 100 mg/mL in mobile phase solvents
- Loading: 1.0 mL (100 mg)

Elution profile: Retention time of diastereomer A = 43 min.
Retention time of diastereomer B = 120 min.

Diastereomer A; $^1$H NMR (300 MHz, CDCl$_3$) δ 1.29 (t, 3H), 1.42 (d, 3H), 2.08 (m, 2H), 3.37 (t, 1H), 3.54 (m, 2H), 4.03 (q, 1H), 4.21 (q, 2H), 4.35 (m, 2H), 5.11 (s, 2H), 5.35 (brs, 1H), 7.37 (m, 5H) ppm; $^{31}$P (121.4 MHz, CDCl$_3$) δ 33.74 ppm.

Diastereomer B; $^1$H NMR (300 MHz, CDCl$_3$) δ 1.29 (t, 3H), 1.43 (d, 3H), 2.11 (dt, 2H), 3.4-3.7 (m, 2H+1H), 4.02 (q, 1H), 4.20 (q, 2H), 4.26 (M, 2H), 5.10 (q, 2H), 5.43 (brs, 1H), 7.94-7.04 (m, 3H), 7.37 (m, 5H) ppm; $^{31}$P (121.4 MHz, CDCl$_3$) δ 34.68 ppm.

2-([4-[(6-Ethyl-4-hydroxy-7-methyl-3-oxo-1,3-dihydro-isobenzofuran-5-yl)-2-methyl-but-2-enylamino]-ethyl]-trifluoroethoxy-phosphinoylamino]-phosphonic acid ethyl ester A: A solution of 4-[(6-Ethyl-7-methyl-3-oxo-4-(2-trimethylsilanyl-ethoxy)-1,3-dihydro-isobenzofuran-5-yl]-2-methyl-but-2-enal (60 mg, 0.16 mmol) was stirred with 2-[(2-aminoethyl)-trifluoroethoxy-phosphinoylamino]-propionic acid ethyl ester A (90 mg, 0.20 mmol) in CH$_2$Cl$_2$ (4 mL) for 1 hour at ambient temperature. Sodium triacetoxysilaborhydride (50
mg, 0.32 mmol) was added to the solution and the reaction was allowed to proceed overnight. The reaction was quenched by addition of a saturated aqueous solution of NaHCO₃ and the product was extracted with EtOAc. The organic layer was removed under reduced pressure and the residue was resuspended in a 15% TFA/CH₂Cl₂ for 6 hours. The reaction mixture was concentrated and the product was purified by RP HPLC using a C18 column with a gradient of H₂O, 0.1% TFA-acetonitrile, to provide 45 mg of the product as a white solid. \(^1\)H NMR (300 MHz, CD₃OD) δ 1.13 (t, 3H), 1.27 (t, 3H), 1.40 (d, 3H), 2.0 (s, 3H), 2.15 (s, 3H), 2.23-2.34 (m, 2H), 2.75 (q, 2H), 3.41 (m, 2H), 3.56 (d, 2H), 3.67 (s, 2H), 3.95-4.17 (m, 1H), 4.14-4.22 (m, 2H), 4.48-4.90 (m, 2H), 5.26 (s, 2H), 5.63 (m, 1H) ppm; \(^{31}\)P (121.4 MHz, CD₃OD) δ 31.33 ppm.

**Example 29: Preparation of Representative Compound of the Invention.**

2-[(2-[4-(6-Ethyl-4-hydroxy-7-methyl-3-oxo-1,3-dihydro-isobenzofuran-5-yl)-2-methyl-but-2-enylamino]-ethyl]-trifluoroethoxy-phosphinoylamino)-phosphonic acid ethyl ester B: A solution of 4-[6-Ethyl-7-methyl-3-oxo-4-(2-trimethylsilyl-ethoxy)-1,3-dihydro-isobenzofuran-5-yl]-2-methyl-but-2-enal (60 mg, 0.16 mmol) was stirred with 2-[(2-aminoethyl)-trifluoroethoxy-
phosphinoylamino]-propionic acid ethyl ester B (see Example 28; 90 mg, 0.20 mmol) in CH₂Cl₂ (4 mL) for 1 hour at ambient temperature. Sodium triacetoxyborohydride (50 mg, 0.32 mmol) was added to the solution and the reaction was allowed to proceed overnight. The reaction was quenched by addition of a saturated aqueous solution of NaHCO₃ and the product was extracted with EtOAc. The organic layer was removed under reduced pressure and the residue was resuspended in a 15% TFA/CH₂Cl₂ for 6 hours. The reaction mixture was concentrated and the product was purified by RP HPLC using a C18 column with a gradient of H₂O, 0.1% TFA-acetonitrile, to provide 45 mg of the product as a white solid. ¹H NMR (300 MHz, CD₃OD) δ 1.13 (t, 3H), 1.27 (t, 3H), 1.40 (d, 3H), 1.87 (s, 3H), 2.01 (s, 3H), 2.23-2.34 (m, 2H), 2.75 (q, 2H), 3.21 (m, 2H), 3.56 (d, 2H), 3.67 (s, 2H), 3.95-4.17 (m, 1H), 4.14-4.22 (m, 2H), 4.48-4.90 (m, 2H), 5.26 (s, 2H), 5.63 (m, 1H) ppm; ³¹P (121.4 MHz, CD₃OD) δ 31.98 ppm.

Example 30: Preparation of Representative Compound of the Invention.

2-((2-[4-(6-Ethyl-4-hydroxy-7-methyl-3-oxo-1,3-dihydro-isobenzofuran-5-yl)-2-methyl-but-2-enyl-methanesulfonyl-amino]-ethyl)-phenoxy-phosphinoylamino)-phosphonic acid ethyl ester: A solution of 2-[(2-{4-[6-
ethyl-7-methyl-3-oxo-4-(2-trimethylsilanyloxy)-1,3-dihydro-isobenzofuran-5-yl]-2-methyl-but-2-enylamino]-ethyl-phenoxy-phosphinoylamino]-phosphonic acid ethyl ester (60 mg, 0.086 mmol) in CH₂Cl₂ (1 mL) was stirred with methanesulfonyl chloride (33 µL, 0.43 mmol) and pyridine (70 µL, 0.86 mmol) at ambient temperature overnight. The reaction was quenched by addition of 2 drops of water. The reaction mixture was concentrated and purified by RP HPLC using a C18 column with a gradient of H₂O, 0.1% TFA-acetonitrile, 0.1% TFA to provide 35 mg of the product (56%) as a clear gel. This material (35 mg) was re-suspended in a 10% TFA/CH₂Cl₂ (1 mL) solution at 0°C for 15 min. The reaction mixture was neutralized by adding pyridine (0.1 mL). The crude was purified by RP HPLC using a C18 column with a gradient of H₂O, 0.1% TFA-acetonitrile, to provide 15 mg (50%) of the desired product. ¹H NMR (300 MHz, CD₃OD) δ 1.13 -1.25 (m, 9H), 2.0 (s, 3H), 2.15 (s, 3H), 2.50-2.52 (m, 2H), 2.75 (q, 2H), 2.92 (s, 3H), 3.41 (m, 2H), 3.50 (d, 2H), 3.67 (s, 2H), 3.97 (m, 1H), 4.07-4.17 (m, 2H), 5.18 (s, 2H), 5.64- 5.68 (m, 1H), 7.18 (m, 3H), 7.37 (m,2H) ppm; ³¹P (121.4 MHz, CD₃OD) δ 29.17, 30.05 ppm; MS (m/z) 635.2 [M-H]^+, 636.8 [M+H]^+.

Example 31: Preparation of Representative Compound of the Invention.

```
1. TMS-\text{OH}
   O-C-N-S-Cl
   \text{O-O}

2. 10\%\text{TFA}/\text{DCM}
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2-(2-[6-Ethyl-4-hydroxy-7-methyl-3-oxo-1,3-dihydro-isobenzofuran-5-yl]-2-methyl-but-2-enyl-N-aminosulfonyl-amino-[ethyl]-phenoxy-phosphinoylamino)-phosphonic acid ethyl ester: To a solution of chlorosulfonylisocyanate (9 μL, 0.1 mmol) in DCM (3 mL) was added 2-trimethylsilylethanol (14 μL, 0.1 mmol) at 0°C. The mixture was stirred at 0°C for 30 min before triethylamine (14 μL, 0.1 mmol) was added. The resulting mixture was then added dropwise to a ice-cooled solution of 2-[2-[6-ethyl-7-methyl-3-oxo-4-(2-trimethylsilanyl-ethoxy)-1,3-dihydro-isobenzofuran-5-yl]-2-methyl-but-2-enylamino]-ethyl-phenoxy-phosphinoylamino]-phosphonic acid ethyl ester (70 mg, 0.1 mmol) in CH₂Cl₂ (0.5 mL) and triethylamine (14 μL, 0.1 mmol). The reaction was stirred at room temperature for 30 min. After evaporation of solvent, the residue was dissolved in EtOAc and extracted with 0.5N HCl and brine. The organic layer was dried over sodium sulfate and concentrated to dryness. The crude material was purified by RP HPLC to afford 38 mg (42%) of the desired sulfonyl urea. This material was re-suspended in a 10% TFA/ CH₂Cl₂ (1 mL) solution at -20°C for 2 hours. The reaction mixture was neutralized by adding pyridine (0.1 mL). The crude was purified by RP HPLC using a C18 column with a gradient of H₂O and acetonitrile, to provide 18 mg (67%) of the desired product. ³¹H NMR (300 MHz, CD₃OD) δ 1.13 -1.25 (m, 9H), 2.0 (s, 3H), 2.15 (s, 3H), 2.50-2.52 (m, 2H), 2.75 (q, 2H), 3.41 (m, 2H), 3.50 (d, 2H), 3.67 (s, 2H), 3.97 (m, 1H), 4.07-4.17 (m, 2H), 5.18 (s, 2H), 5.64-5.68 (m, 1H), 7.18 (m, 3H), 7.37 (m, 2H) ppm; ³¹P (121.4 MHz, CD₃OD) δ 30.14, 30.98 ppm; MS (m/z) 637.9 [M+H]^+.  

Example 32: Preparation of Representative Compound of the Invention.
(2-[[4-(4-Hydroxy-6-ethyl-7-methyl-3-oxo-1,3-dihydro-isobenzofuran-5-yl)-2-methyl-but-2-enyl]-methanesulfonyl-amino]-ethyl)-phosphonic acid: 2-

(2-[4-(6-Ethyl-4-hydroxy-7-methyl-3-oxo-4-(2-trimethylsilanyl-ethoxy)-1,3-dihydro-isobenzofuran-5-yl)-2-methyl-but-2-enyl-methanesulfonyl-amino]-ethyl)-phenoxy-phosphinylamino)-phosphonic acid ethyl ester (30 mg, 0.047 mmol) was suspended in 10% TFA/DCM (1mL) at 0°C and stirred for 15 min. The reaction mixture was neutralized by adding pyridine (0.1mL). After

evaporation of solvent, the residue was dissolved in acetonitrile (1mL) and to this solution was added water (0.5mL) and NaOH (40mg). The reaction was stirred at room temperature for 2 hours before adding 2N HCl to acidify it to pH 1. The mixture was then partitioned with n-butanol. The organic layer was dried over sodium sulfate and concentrated to dryness. The crude material was purified using RP HPLC to provide 9.6 mg of the desired product (44 %) as a white solid. $^1$H NMR (300 MHz, CD$_3$OD) $\delta$ 1.15 (t, 3H), 1.85 (s, 3H), 1.97 (m, 2H), 2.18 (s, 3H), 2.76 (q, 2H), 2.82 (s, 3H), 3.24- 3.35 (m, 2H), 3.52 (d, 2H, $J$= 7 Hz), 3.72 (s, 2H), 5.25 (s, 2H), 5.41- 5.48 (m, 1H) ppm; $^{31}$P (121.4 MHz, CD$_3$OD) $\delta$ 23.7 ppm; MS (m/z) 461.5 [M+H]$^+$. 

Example 33: Preparation of Representative Compound of the Invention.
(2-\{1-[4-(6-Ethyl-4-hydroxy-7-methyl-3-oxo-1,3-dihydro-isobenzofuran-5-yl)-2-methyl-but-2-enyl]-ureido\}-ethyl\}-phosphonic acid: To a solution of 2-
\[2-\{4-[6-ethyl-7-methyl-3-oxo-4-(2-trimethylsilanyl-ethoxy)-1,3-dihydro-isobenzofuran-5-yl\}-2-methyl-but-2-enylamino\}\}-ethyl\}-phenoxyphosphinoylamino\}-phosphonic acid ethyl ester (50 mg, 0.07 mmol) in CH$_2$Cl$_2$
(0.8 mL) was added trimethylsilylisocyanate (162 µL, 0.17 mmol). After stirring overnight, DCM (5 mL) was added and the mixture was extracted with saturated aqueous sodium bicarbonate and brine. The organic layer was dried over sodium sulfate and concentrated to dryness. The residue was purified by RP HPLC to afford 29 mg (58 %) of product. This product was re-suspended in a 10% TFA/CH$_2$Cl$_2$ (1 mL) solution at 0°C for 10 min. The reaction mixture was neutralized by adding pyridine (0.1 mL). The crude material was dissolved in acetonitrile (1 mL) and water (0.5 mL) and NaOH (catalytic amount) was added. The mixture was kept at room temperature for 2 weeks. After acidification, the solution was extracted with n-butanol. The organic layer was dried over sodium sulfate and concentrated to dryness. The residue was purified by RP HPLC using a C18 column with a gradient of H$_2$O and acetonitrile, to provide 3.5 mg of product. $^1$H NMR (300 MHz, CD$_3$OD) δ 1.15 (t, 3H), 1.85 (s, 3H), 1.97 (m, 2H), 2.18 (s, 3H), 2.76 (q, 2H), 3.24- 3.35 (m, 2H), 3.52 (d, 2H, J= 7 Hz), 3.72 (s, 2H), 5.10 (m, 1H), 5.25 (s, 2H) ppm; $^{31}$P (121.4 MHz, CD$_3$OD) δ 26.11 ppm; MS (m/z) 426.8 [M+H]$^+$. 
Example 34: Preparation of Representative Compound of the Invention.

(2-{[4-(4-Hydroxy-6-ethyl-7-methyl-3-oxo-1,3-dihydro-isobenzofuran-5-yl)-2-methyl-but-2-enyl]-N-aminosulfonyl-amino}-ethyl)-phosphonic acid: To a solution of 2-((2-{[4-(6-ethyl-4-hydroxy-7-methyl-3-oxo-1,3-dihydro-isobenzofuran-5-yl)-2-methyl-but-2-enyl-N-aminosulfonyl-amino]-ethyl}-phenoxy-phosphinoylamino)-phosphonic acid ethyl ester (13 mg, 0.02 mmol) in water (0.5 mL) and acetonitrile (1 mL) was added NaOH (16 mg, 0.4 mmol). The solution mixture was stirred at room temperature for 2 hours. After acidifying the solution with 2N HCl, the solution was extracted with n-butanol. The organic layer was dried over sodium sulfate and concentrated to dryness. The residue was purified by RP HPLC to afford 3 mg (32%) of desired product.

$^1$H NMR (300 MHz, CD$_3$OD) δ 1.15 (t, 3H), 1.85 (s, 3H), 1.97 (m, 2H), 2.18 (s, 3H), 2.76 (q, 2H), 3.24- 3.35 (m, 2H), 3.52 (d, 2H, J= 7 Hz), 3.72 (s, 2H), 5.25 (s, 2H), 5.41- 5.48 (m, 1H) ppm; $^{31}$P (121.4 MHz, CD$_3$OD) δ 19.5 ppm; MS (m/z) 462.5 [M+H]$^+$.  

Example 35: Preparation of Representative Compound of the Invention.
{2-[4-(6-Ethyl-4-hydroxy-7-methyl-3-oxo-1,3-dihydro-isobenzofuran-5-y1)-2-methyl-but-2-enyloxycarbonylamino]-ethyl}-phosphonic acid: To a solution of {2-[4-(6-ethyl-7-methyl-3-oxo-4-(2-trimethylsilanyl-ethoxy)-1,3-dihydro-isobenzofuran-5-y1)-2-methyl-but-2-enyloxycarbonylamino]-ethyl}-phosphonic acid diethyl ester (30 mg, 0.05 mmol) in CH₂Cl₂ (0.5 mL) and DMF (0.5 mL) were sequentially added 2,6-lutidine (0.21 mL, 1.73 mmol) and bromotrimethylsilane (0.171 mL, 1.32 mmol), and the mixture was stirred at room temperature for 18 hr. MeOH (3 mL) was added and the mixture was concentrated. The residue was purified by RP HPLC to afford the corresponding phosphonic acid. This intermediated was dissolved in CH₂Cl₂ containing 10% trifluoroacetic acid (2 mL). After 1 hr at 0 °C, pyridine (0.3 mL) was added and the mixture was concentrated. The residue was purified by RP HPLC to afford the desired product (9 mg, 42%). ¹H NMR (300 MHz, CD₃OD) δ 1.15 (t, 3H, J= 7.8 Hz), 1.84 (s, 3H), 1.81-1.92 (m, 2H), 2.20 (s, 3H), 2.74 (q, 2H, J= 7.8 Hz), 3.37 (m, 2H), 3.51 (d, 2H, J= 6.3 Hz), 4.41 (s, 2H), 5.27 (s, 2H), 5.39 (brt, 1H) ppm; ³¹P (121.4 MHz, CD₃OD) δ 24.20; MS (m/z) 428 [M+H]⁺.

Example 36: Preparation of Representative Compound of the Invention.
Trifluoromethanesulfonic acid 6-(4-hydroxy-3-methyl-but-2-enyl)-4-methyl-1-oxo-7-(2-trimethylsilyl-ethoxy)-1,3-dihydro-isobenzofuran-5-yl ester: To a solution of 5-Hydroxy-6-(4-hydroxy-3-methyl-but-2-enyl)-4-methyl-7-(2-trimethylsilyl-ethoxy)-3H-isobenzofuran-1-one (200 mg, 0.549 mmol), N-
phenylbistriflimide (196 mg, 0.549 mmol), and DMAP (13.4 mg, 0.110 mmol) in CH₂Cl₂ (5.5 mL) was added TEA (100 µL, 0.824 mmol) at room temperature. The mixture was stirred for 2.5 hours when the starting material was consumed. The reaction was worked up by dilution with CH₂Cl₂ followed by saturated aqueous solution of NH₄Cl. The organic layer was separated and washed again with saturated aqueous solution of NH₄Cl. The organic layer was dried under reduced pressure and the residue was purified by silica gel chromatography using EtOAc-Hexanes (0-100%) to provide 134 mg (49%) of the desired product as a clear oil; ¹H NMR (300 MHz, CDCl₃) δ 0.05 (s, 9H), 1.22-1.30 (m, 2H), 1.46 (br s, 1H), 1.81 (s, 3H), 2.29 (s, 3H), 3.61 (d, J= 6 Hz, 2H), 3.99 (s, 2H), 4.36-4.43 (m, 2H), 5.20 (s, 2H), 5.39 (app t, J= 6 Hz, 1H); ¹⁹F NMR (282.6 MHz, CDCl₃) δ -73.5; MS (m/z) 519 [M+Na]⁺.

6-(4-Hydroxy-3-methyl-but-2-enyl)-4-methyl-7-(2-trimethylsilyl-ethoxy)-5-vinyl-3H-isobenzofuran-1-one: A mixture of trifluoromethanesulfonic acid 6-(4-hydroxy-3-methyl-but-2-enyl)-4-methyl-1-oxo-7-(2-trimethylsilyl-ethoxy)-1,3-dihydro-isobenzofuran-5-yl ester (58 mg, 0.117 mmol), LiCl (15 mg, 0.35 mmol), triphenylarsine (4 mg, 0.012 mmol), and Pd₂dba₃·CHCl₃ (2.4 mg, 0.23 µmol) was suspended in NMP (0.35 mL) under an argon atmosphere. The brown reaction was sonicated for 2 minutes. To the mixture was added tributylvinyltin (38 µL, 0.13 mmol) at room temperature. The reaction was warmed to 60 °C for 2 hours, when the reaction was complete as detected by LCMS. The reaction was worked up by addition of water, EtOAc and KF (35 mg). The mixture was stirred vigorously for 30 minutes. The organic layer was separated and filtered through a pad of diatomaceous earth. The solvent was removed under reduced pressure and the residue was dried by silica gel chromatography using EtOAc-Hexanes (0-100%) to provide 41 mg (93%) of the
desired product as a white film; $^1$H NMR (300 MHz, CDCl$_3$) δ 0.04 (s, 9H), 1.22-1.30 (m, 2H), 1.44 (br s, 1H), 1.82 (s, 3H), 2.19 (s, 3H), 3.51 (d, J= 6 Hz, 2H), 3.98 (s, 2H), 4.25-4.32 (m, 2H), 5.15 (s, 2H), 5.28 (dd, J= 18, 2 Hz, 1H), 5.33 (t, J= 6 Hz, 1H), 5.67 (dd, J= 11, 2 Hz, 1H), 6.70 (dd, J= 18, 11 Hz, 1H); MS (m/z) 397 [M+Na]$^+$.

6-(4-Bromo-3-methyl-but-2-enyl)-4-methyl-7-(2-trimethylsilanyl-ethoxy)-5-vinyl-3H-isobenzofuran-1-one: To a solution of 6-(4-Hydroxy-3-methyl-but-2-enyl)-4-methyl-7-(2-trimethylsilanyl-ethoxy)-5-vinyl-3H-isobenzofuran-1-one (41 mg, 0.109 mmol) in CH$_2$Cl$_2$ (0.50 mL) was added a solution of triphenylphosphine (60 mg, 0.230 mmol) and carbon tetrabromide (76 mg, 0.230 mmol) in CH$_2$Cl$_2$ (0.50 mL). The reaction was monitored for completion by LC/MS. The reaction was worked up by removal of the volatiles and purification of the residue by silica gel column chromatography using EtOAc-Hexanes (0-100%) to provide the desired product; MS (m/z) 459 [M+Na]$^+$.

{2-Methyl-4-[7-methyl-3-oxo-4-(2-trimethylsilanyl-ethoxy)-6-vinyl-1,3-dihydro-isobenzofuran-5-yl]-but-2-enyl]-phosphonic acid dimethyl ester: A solution of 6-(4-Bromo-3-methyl-but-2-enyl)-4-methyl-7-(2-trimethylsilanyl-ethoxy)-5-vinyl-3H-isobenzofuran-1-one (11 mg, 0.025 mmol) in trimethylphosphite (90 µL, 0.754 mmol) was heated at 100 °C for 3 hours when the reaction was complete judged from TLC. The reaction was worked up by
removal of the liquid under reduced pressure and azeotroping the product from CH$_2$Cl$_2$ three more times to provide the desired product; MS (m/z) 489 [M+Na]$^+$. 

\[
\text{TMS} \quad 10\% \text{TFA, CH$_2$Cl$_2$} \quad \text{TMS}
\]

[4-(4-Hydroxy-7-methyl-3-oxo-6-vinyl-1,3-dihydro-isobenzofuran-5-yl)-2-methyl-but-2-enyl]-phosphonic acid: A solution of [2-Methyl-4-[7-methyl-3-oxo-4-(2-trimethylsilyl-ethoxy)-6-vinyl-1,3-dihydro-isobenzofuran-5-yl]-but-2-enyl]-phosphonic acid dimethyl ester (12 mg, 0.025 mmol) in CH$_2$Cl$_2$ (1 mL) was stirred with TFA (0.1 mL) at ambient temperature for 30 minutes when the reaction was complete as indicated by LCMS. The solvent was removed in vacuo and the residue was dissolved in DMF (1.5 mL). The sample was purified by preparative reverse-phase HPLC (acetonitrile, water with 0.1% CF$_3$COOH) to provide the desired product as a white solid; $^1$H NMR (300 MHz, CDCl$_3$) δ 1.91 (d, J= 4 Hz, 3H), 2.15 (s, 3H), 2.55 (d, J= 22 Hz, 2H), 3.47 (t, J= 6 Hz, 2H), 3.72 (d, J= 11 Hz, 6H), 5.24 (s, 2H), 5.23- 5.32 (m, 1H), 5.28 (dd, J= 18, 2 Hz, 1H), 5.67 (dd, J= 11, 2 Hz, 1H), 6.69 (dd, J= 18, 11 Hz, 1H); MS (m/z) 367 [M+Na]$^+$. 

Example 37: Preparation of Representative Compound of the Invention.

\[
\text{TMSBr, 2,6-lutidine} \quad \text{TMSBr, 2,6-lutidine}
\]

[4-(6-Ethyl-4-hydroxy-7-methyl-3-oxo-1,3-dihydro-isobenzofuran-5-yl)-but-2-enyl]-phosphonic acid: 4-(6-Ethyl-4-hydroxy-7-methyl-3-oxo-1,3-dihydro-isobenzofuran-5-yl)-but-2-enyl]-phosphonic acid dimethyl ester (23 mg, 0.065
mmol) was dissolved in DCM (0.5 mL) and TMSBr (85.7 μL, 0.65 mmol) and 2,6-lutidine (75 μL, 0.65 mmol) were added. The reaction solution was allowed stir at room temperature overnight before quenching with MeOH. The reaction mixture was dried under reduced pressure and the residue was purified by RP HPLC using a C18 column with a gradient of H₂O and acetonitrile to provide 15 mg (71%) of the desired product as a white solid. (300 MHz, CD₃OD): δ = 1.15 (t, 3H), 2.19 (s, 3H), 2.46 (dd, 2H), 2.70 (q, 2H), 3.48 (m, 2H), 5.22 (s, 2H), 5.31 (m, 1H), 5.75 (m,1H), ppm; ³¹P NMR (121 MHz, CDCl₃): δ = 25.56 ppm; MS (m/z) 325.6 [M-H]⁺, 327.3 [M+H]⁺.

Example 38: Preparation of Representative Compound of the Invention.

Diastereomer separation of 2(S)-[(2-benzylxycarbonylamino-ethyl)-phenoxy-phosphinoylamino]-propionic acid isopropyl ester by chiral column chromatography

\[
\text{Ph} \quad \text{O} \quad \text{N} \quad \text{S} \quad \text{O} \quad \text{Ph} \\
\text{HN} \quad \text{O} \quad \text{C} \quad \text{O} \\
\text{O} \quad \text{O} \quad \text{O} \quad \text{O}
\]

Diastereomer separation was achieved using methods similar to those described for separation of diastereomeric 2(S)-[(2-benzylxycarbonylamino-ethyl)-phenoxy-phosphinoylamino]-propionic acid ethyl ester.

The chromatographic conditions were as follows:

Mobile phase: EtOH/n-Heptane (60:40, v/v)  
Flow rate: 6.5 ml/min  
Run time: 30 min.  
Detection: UV at 254 nm  
Temperature: Ambient  
Sample preparation: 100 mg/mL in mobile phase solvents
Loading: 1.5 mL (150 mg)

Elution profile:

Retention time of diastereomer A = 14.2 min.

Retention time of diastereomer B = 16.9 min.

5

Diastereomer A; $^1$H NMR (300 MHz, CDCl$_3$) $\delta$ 1.21 (m, 9H), 2.16 (dt, 3H), 3.42 (t, 1H), 3.67 (m, 2H), 4.04 (m, 1H), 4.97 (m, 1H), 5.12 (s, 2H), 5.66 (brs, 1H), 7.13-7.20 (m, 2H), 7.27-7.35 (m, 3H) ppm; $^{31}$P (121.4 MHz, CDCl$_3$) $\delta$ 29.82 ppm.

10

Diastereomer B; $^1$H NMR (300 MHz, CDCl$_3$) $\delta$ 1.21 (d, 6H), 1.29 (d, 3H), 2.11 (m, 2H), 3.54 (m, 2H+1H), 3.96 (m, 1H), 4.98 (m, 1H), 5.11 (s, 2H), 5.56 (brs, 1H), 7.13-7.21 (m, 2H), 7.27-7.35 (m, 3H) ppm; $^{31}$P (121.4 MHz, CDCl$_3$) $\delta$ 29.46 ppm.

20

2-([2-[4-(6-Ethyl-4-hydroxy-7-methyl-3-oxo-1,3-dihydro-isobenzofuran-5-yl)-2-methyl-but-2-enylamino]-ethyl]-phenoxy-phosphinoylamino)phosphonic acid isopropyl ester A: A solution of 4-[6-Ethyl-7-methyl-3-oxo-4-(2-trimethylsilanyl-ethoxy)-1,3-dihydro-isobenzofuran-5-yl]-2-methyl-but-2-
enal (450 mg, 1.2 mmol) was stirred with 2-[(2-aminoethyl)-phenoxyphosphinoylamino]-propionic acid isopropyl ester A (490 mg, 1.56 mmol) in CH₂Cl₂ (5 mL) for 1 hour at ambient temperature. Sodium triacetoxyborohydride (381 mg, 1.8 mmol) was added to the solution. The reaction was allowed to proceed overnight and then quenched by addition of a saturated aqueous solution of NaHCO₃. The product was extracted with EtOAc. The organic layer was removed under reduced pressure and the residue was re-suspended in 10% TFA/CH₂Cl₂ (5 mL) at 0°C for 2 hours. The reaction mixture was neutralized by the addition of pyridine (0.5 mL). After concentration the crude product was purified by RP HPLC using a C18 column with a gradient of H₂O, 0.1% TFA-acetonitrile, to provide 295 mg (43%) of the product. \(^1\)H NMR (300 MHz, CD₃OD) δ 1.13 -1.25 (m, 12H), 2.0 (s, 3H), 2.15 (s, 3H), 2.50-2.52 (m, 2H), 2.75 (q, 2H), 3.41 (m, 2H), 3.50 (d, 2H), 3.67 (s, 2H), 3.97 (m, 1H), 4.97 (m, 1H), 5.24 (s, 2H), 5.66 (m, 1H), 7.18 (m, 3H), 7.37 (m, 2H) ppm; \(^{31}\)P (121.4 MHz, CD₃OD) δ 28.07 ppm; MS (m/z) 571.3 [M-H]⁺, 573.0 [M+H]⁺.

**Example 39: Preparation of Representative Compound of the Invention.**
2-[(2-[4-(6-Ethyl-4-hydroxy-7-methyl-3-oxo-1,3-dihydro-isobenzofuran-5-yl)-2-methyl-but-2-enylamino-ethyl]-phenoxy-phosphinylamino)phosphonic acid isopropyl ester B: A solution of 4-[6-Ethyl-7-methyl-3-oxo-4-(2-trimethylsilanyl-ethoxy)-1,3-dihydro-isobenzofuran-5-yl]-2-methyl-but-2-enal (450 mg, 1.2 mmol) was stirred with 2-[(2-aminoethyl)-phenoxy-phosphinylamino]-propionic acid isopropyl ester B (see Example 38; 490 mg, 1.56 mmol) in CH₂Cl₂ (5 mL) for 1 hour at ambient temperature. Sodium triacetoxyborohydride (381 mg, 1.8 mmol) was added to the solution. The reaction was allowed to proceed overnight and then quenched by addition of a saturated aqueous solution of NaHCO₃. The product was extracted with EtOAc. The organic layer was removed under reduced pressure and the residue was re-suspended in a 10% TFA/CH₂Cl₂ (5 mL) at 0°C for 2 hours. The reaction mixture was neutralized by the addition of pyridine (0.5 mL). After concentration the crude product was purified by RP HPLC using a C18 column with a gradient of H₂O, 0.1% TFA-acetonitrile, to provide 271 mg (40%) of the product. ¹H NMR (300 MHz, CD₃OD) δ 1.13 -1.25 (m, 9H), 1.25 (d, 3H), 2.0 (s, 3H), 2.17 (s, 3H), 2.50-2.52 (m, 2H), 2.75 (q, 2H), 3.41 (m, 2H), 3.50 (d, 2H), 3.67 (s, 2H), 3.97 (m, 1H), 4.97 (m, 1H), 5.24 (s, 2H), 5.65 (t, 1H), 7.18 (m, 3H), 7.37 (m, 2H) ppm; ³¹P (121.4 MHz, CD₃OD) δ 27.36 ppm; MS (m/z) 571.3 [M-H]⁺, 573.0 [M+H]⁺.

**Example 40: Preparation of Representative Compound of the Invention.**

Diasteromer separation of 2(S)-[(2-benzyloxy carbonylamino-ethyl)-phenoxy-phosphinylamino]-propionic acid cyclobutyl ester by chiral column chromatography
Diastereomer separation was achieved using methods similar to those described for separation of diastereomeric 2(S)-[(2-benzylxycarbonylamino-ethyl)-phenoxy-phosphinoylamino]-propionic acid ethyl ester.

5 The chromatographic conditions were as follows:

Mobile phase: EtOH
Flow rate: 4.5 ml/min
Run time: 30 min.

10 Detection: UV at 254 nm
Temperature: Ambient
Sample preparation: 180 mg/mL in mobile phase solvents
Loading: 0.5 mL (90 mg)

15 Elution profile: Retention time of diastereomer A = 21.2 min.
Retention time of diastereomer B = 24.9 min.

Diastereomer A; $^1$H NMR (300 MHz, CDCl$_3$) $\delta$ 1.24 (d, 3H), 1.65 (m, 2H), 1.78 (m, 1H), 1.97-2.37 (m, 6H), 3.42 (t, 1H), 3.67 (m, 2H), 4.04 (m, 1H), 4.97 (m, 1H), 5.12 (s, 2H), 5.66 (brs, 1H), 7.13-7.20 (m, 2H), 7.27-7.35 (m, 3H) ppm; $^{31}$P (121.4 MHz, CDCl$_3$) $\delta$ 29.82 ppm.

Diastereomer B; $^1$H NMR (300 MHz, CDCl$_3$) $\delta$ 1.30 (d, 3H), 1.58 (m, 2H), 1.80 (m, 1H), 1.95-2.37 (m, 6H), 3.47 (t, 1H), 3.57 (m, 2H), 3.96 (m, 1H), 4.95 (m, 1H), 5.11 (s, 2H), 5.55 (brs, 1H), 7.13-7.21 (m, 2H), 7.27-7.35 (m, 3H) ppm; $^{31}$P (121.4 MHz, CDCl$_3$) $\delta$ 29.43 ppm.
2-((2-[4-(6-Ethyl-4-hydroxy-7-methyl-3-oxo-1,3-dihydro-isobenzofuran-5-yl)-2-methyl-but-2-enylamino]-ethyl-phenoxy-phosphinoylamino)-phosphonic acid cyclobutyl ester B: A solution of 4-[6-Ethyl-7-methyl-3-oxo-4-(2-trimethylsilyl-ethoxy)-1,3-dihydro-isobenzofuran-5-yl]-2-methyl-but-2-enal (600 mg, 1.6 mmol) was stirred with 2-[(2-aminoethyl)-phenoxy-phosphinoylamino]-propionic acid cyclobutyl ester B (830 mg, 1.82 mmol) in CH$_2$Cl$_2$ (5 mL) for 1 hour at ambient temperature. Sodium triacetoxyborohydride (509 mg, 2.4 mmol) was added to the solution. The reaction was allowed to proceed overnight and then quenched by addition of a saturated aqueous solution of NaHCO$_3$. The product was extracted with EtOAc. The organic layer was removed under reduced pressure and the residue was resuspended in a 10% TFA/CH$_2$Cl$_2$ (15 mL) at 0°C for 2 hours. The reaction mixture was neutralized by the addition of saturated aqueous sodium bicarbonate solution (0.5 mL). The organic layer was separated and concentrated to dryness. The crude product was purified by RP HPLC using a C18 column with a gradient of H$_2$O, 0.1% TFA-acetonitrile, to provide 270 mg (24%) of the product. $^1$H NMR (300 MHz, CD$_3$OD) δ 1.13 (t, 3H), 1.26 (d, 3H), 1.58-1.79 (m, 2H), 2.0 (s, 3H), 2.07 (m, 2H), 2.18 (s, 3H), 2.25-2.42 (m, 4H), 2.75 (q, 2H), 3.41 (m, 2H), 3.57 (d, 2H), 3.67 (s, 2H), 3.97 (m, 1H), 4.97 (m, 1H), 5.24 (s,
Example 41: Preparation of Representative Compound of the Invention.

2-((2-([4-(6-Ethyl-4-hydroxy-7-methyl-3-oxo-1,3-dihydro-isobenzofuran-5-yl)-2-methyl-but-2-enyl-methyl-amino]-ethyl)-phenoxy-phosphinoylamino)-phosphonic acid isopropyl ester A:

To a solution of 2-([4-([6-ethyl-4-hydroxy-7-methyl-3-oxo4--(2-trimethylsilanyl-ethoxy)-1,3-dihydro-isobenzofuran-5-yl}-2-methyl-but-2-enylamino]-ethyl)-phenoxy-phosphinoylamino)-phosphonic acid isopropyl ester (70 mg, 0.104 mmol) in 1:1 DCM/EtOH (1.5 mL) was added 37% HCHO (76 µL), sodium cyanoborohydride (26 mg, 0.42 mmol) and acetic acid (24 µL). The mixture was stirred at room temperature for 16 hours before adding saturated aqueous solution of NaHCO₃. The solution mixture was extracted with ethyl acetate. The organic layer was dried over sodium sulfate and concentrated to dryness. The crude product was re-suspended in a 10% TFA/CH₂Cl₂ (1 mL) solution at 0°C for 2 hours. The reaction mixture was neutralized by adding saturated sodium bicarbonate solution (2 mL) then extracted with EtOAc. The organic layer was dried over sodium sulfate and concentrated to dryness. The
crude mixture was purified by RP HPLC using a C18 column with a gradient of H$_2$O, 0.05% TFA-acetonitrile, to provide 25 mg (35%) of the product. $^1$H NMR (300 MHz, CD$_3$OD) $\delta$ 1.13 -1.25 (m, 12H), 2.0 (s, 3H), 2.15 (s, 3H), 2.50-2.52 (m, 2H), 2.75 (q, 2H), 2.85 (s, 3H), 3.41 (m, 2H), 3.50 (d, 2H), 3.67 (s, 2H), 3.97 (m, 1H), 4.97 (m, 1H), 5.24 (s, 2H), 5.66 (m, 1H), 7.18 (m, 3H), 7.37 (m,2H) ppm; $^{31}$P (121.4 MHz, CD$_3$OD) $\delta$ 27.75 ppm; MS (m/z) 587.0 [M+H]$^+$. 

Example 42: Preparation of Representative Compound of the Invention.

(2-[[4-(6-Ethyl-4-hydroxy-7-methyl-3-oxo-1,3-dihydro-isobenzofuran-5-yl)-2-methyl-but-2- enyl]-methyl-amino]-ethyl)-phosphonic acid: To a solution of 2-[[4-(6-Ethyl-4-hydroxy-7-methyl-3-oxo-1,3-dihydro-isobenzofuran-5-yl)-2-methyl-but-2-enyl-methyl-amino]-ethyl]-phenoxy-phosphinoylamino)-phosphonic acid isopropyl ester (7 mg, 0.012 mmol) in acetonitrile (0.5 mL) and H$_2$O (0.4 mL) was added 1N NaOH (0.4 mL). The mixture was stirred at ambient temperature overnight and quenched by addition of aqueous 1N HCl (0.4 mL). The solvents were removed in vacuo and the product was purified by preparative reverse-phase HPLC (acetonitrile, water with 0.05% CF$_3$COOH) to provide 3.5 mg (60%) of the desired product. $^1$H NMR (300 MHz, CD$_3$OD) $\delta$ = 1.16 (t, 3H), 1.94 (m, 2H), 1.99 (s, 3H), 2.12 (m,2H), 2.20 (s, 3H), 2.76 (s, 3H), 3.3 (m, 2H), 3.60 (m, 2H), 3.71 (m, 2H), 5.27 (s, 2H), 5.72 (m, 1H) ppm. $^{31}$P (121.4 MHz, CD$_3$OD) $\delta$ 20.19 ppm; MS (m/z) 398.2 [M+H]$^+$. 

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Example 43: Preparation of Representative Compound of the Invention.

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\text{O}
\end{array} \quad \begin{array}{c}
\text{TMS}
\end{array}
\]

1) TMSBr, CH₃CN
2) TFA/DCM

Individual Steps
(2-{2-Ethyl-4-[6-ethyl-7-methyl-3-oxo-4-(2-trimethylsilyl-ethoxy)-1,3-dihydro-isobenzofuran-5-yl]-but-2-enylamino}-ethyl)-phosphonic acid diethyl ester

2-Ethyl-4-[6-ethyl-7-methyl-3-oxo-4-(2-trimethylsilyl-ethoxy)-1,3-dihydro-isobenzofuran-5-yl]-but-2-enal (26.6 mg, 0.068 mmol) and aminoethylphosphonic acid diethylester oxalate salt (20.4 mg, 0.075 mmol) were dissolved in DMF (0.8 mL). Acetic acid (20.5 mg, 0.342 mmol) was added, followed by sodium triacetoxoborohydride (27.6 mg, 0.137 mmol). After 8 hours, the crude reaction mixture was purified by RP-HPLC (eluent: water/MeCN) to provide 24.9 mg (65%) of the desired product after lyophilization. $^1$H NMR (300 MHz, CDCl$_3$): $\delta$ = 0.05 (s, 9H), 1.10 - 1.24 (m, 8H), 1.35 (t, $J$ = 7.5 Hz, 6H), 2.19 (s, 3H), 2.23 (m, 2H), 2.35 (q, $J$ = 7.8 Hz, 2H), 2.70 (q, $J$ = 7.2 Hz, 2H), 3.25 (m, 2H), 3.56 (m, 4H), 4.15 (m, 4H), 4.29 (m, 2H), 5.15 (s, 2H), 5.47 (m, 1H) ppm; $^{31}$P NMR (121 MHz, CDCl$_3$): $\delta$ = 27.71 ppm; MS = 554 [M$^+$+1].
{2-[2-Ethyl-4-(6-ethyl-4-hydroxy-7-methyl-3-oxo-1,3-dihydroisobenzofuran-5-yl)-but-2-enylamino]-ethyl}-phosphonic acid

(2-{2-Ethyl-4-[6-ethyl-7-methyl-3-oxo-4-(2-trimethylsilanyloxy)-1,3-dihydro-isobenzofuran-5-yl]-but-2-enylamino}-ethyl)-phosphonic acid diethyl ester (24.9 mg, 0.045 mmol) was dissolved in DMF (0.5 mL) and DCM (0.5 mL). Trimethylsilyl bromide (68.7 mg, 0.449 mmol) was added and the reaction was stirred at room temperature. After 20 hours, the reaction was quenched with MeOH (0.15 mL). The solvents were evaporated in vacuo and the crude material was purified by RP-HPLC (eluent: water/MeCN). The product-containing fractions were combined and lyophilized to yield 8.0 mg of the free phosphonic acid [MS: 498 M^+1].

This material was dissolved in DCM (0.5 mL). TFA (0.05 mL) was added, and stirring at room temperature was continued. After 20 minutes, the solvents were removed in vacuo and the crude material was purified by RP-HPLC (eluent: water/MeCN * 0.1% TFA). The product-containing fractions were combined and lyophilized to yield 4.4 mg (54%) of the product as the TFA salt. \(^1\)H NMR (300 MHz, DMSO-d6): \(\delta = 1.05\) (m, 6H), 1.60 (m, 2H), 2.10 (s, 3H), 2.67 (q, \(J = 7.5\) Hz, 2H), 2.63 (q, \(J = 6.9\) Hz, 2H), 2.93 (m, 2H), 3.45 (m, 4H), 5.24 (s, 2H), 5.36 (m, 1H) ppm.; \(^31\)P NMR (121 MHz, DMSO-d6): \(\delta = 16.93\) ppm; MS = 398 [M^+1].
Claims

We claim:

1. A compound of formula I or II

wherein:

A\(^0\) is A\(^1\);

A\(^1\) is:

\[
\text{Y}^2_{M12a} \quad \text{Y}^2_{M12b}
\]

A\(^3\) is:

\[
\text{Y}^2_{M12a} \quad \text{Y}^2_{M12b}
\]

Y\(^1\) is independently O, S, N(R\(^x\)), N(OR\(^x\)), or N(N(R\(^x\))(R\(^x\))); Y\(^2\) is independently a bond, O, N(R\(^x\)), N(OR\(^x\)), N(N(R\(^x\))(R\(^x\))), or \(-\text{S(O)}_{M2-}\); and when Y\(^2\) joins two phosphorous atoms Y\(^2\) can also be C(R\(^2\))(R\(^2\)); R\(^x\) is independently H, R\(^2\), W\(^3\), a protecting group, or the formula:
\[
\begin{align*}
R' & \text{ is independently H, } W^3, R^2 \text{ or a protecting group;} \\
R' & \text{ is independently H or alkyl of 1 to 18 carbon atoms;} \\
R' & \text{ is independently H, } R^3 \text{ or } R^4 \text{ wherein each } R^4 \text{ is independently } \\
\text{substituted with 0 to 3 } R^3 \text{ groups;} \\
R' & \text{ is } R^{3a}, R^{3b}, R^{3c} \text{ or } R^{3d}, \text{ provided that when } R^3 \text{ is bound to a } \\
\text{heteroatom, then } R^3 \text{ is } R^{3c} \text{ or } R^{3d}; \\
R^{3a} & \text{ is F, Cl, Br, I, -CN, N}_3 \text{ or -NO}_2; \\
R^{3b} & \text{ is } Y^1; \\
R^{3c} & \text{ is } -R^x, -N(R^x)(R^x), -SR^x, -S(O)R^x, -S(O)_{2}R^x, -S(O)(OR^x), - \\
& \text{S(O)}_{2}(OR^x), -OC(Y^1)R^x, -OC(Y^1)OR^x, -OC(Y^1)(N(R^x)(R^x)), -SC(Y^1)R^x, - \\
& SC(Y^1)OR^x, -SC(Y^1)(N(R^x)(R^x)), -N(R^x)C(Y^1)R^x, -N(R^x)C(Y^1)OR^x, \text{ or } - \\
& N(R^x)C(Y^1)(N(R^x)(R^x)); \\
R^{3d} & \text{ is } -C(Y^1)R^x, -C(Y^1)OR^x \text{ or } -C(Y^1)(N(R^x)(R^x)); \\
R^4 & \text{ is an alkyl of 1 to 18 carbon atoms, alkenyl of 2 to 18 carbon atoms, } \\
\text{or alkynyl of 2 to 18 carbon atoms;} \\
R^5 & \text{ is } R^4 \text{ wherein each } R^4 \text{ is substituted with 0 to 3 } R^3 \text{ groups;} \\
R^{3a} & \text{ is independently alkenylene of 1 to 18 carbon atoms, alkenylene of 2 to } \\
\text{18 carbon atoms, or alkynylene of 2-18 carbon atoms any one of which alkylene, } \\
\text{alkenylene or alkynylene is substituted with 0-3 } R^3 \text{ groups;} \\
W^3 & \text{ is } W^4 \text{ or } W^5; \\
W^4 & \text{ is } R^5, -C(Y^1)R^x, -C(Y^1)W^5, -SO_2R^5, \text{ or } -SO_2W^5; \\
W^5 & \text{ is carbocycle or heterocycle wherein } W^5 \text{ is independently substituted } \\
\text{with 0 to 3 } R^2 \text{ groups;} \\
W^6 & \text{ is } W^3 \text{ independently substituted with 1, 2, or 3 } A^3 \text{ groups;} \\
M2 & \text{ is 0, 1 or 2;} \\
M12a & \text{ is 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11 or 12;} \\
M12b & \text{ is 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11 or 12;} \\
M1a, M1c, \text{ and } M1d & \text{ are independently 0 or 1;} \\
m & \text{ is } 0, 1 \text{ or 2.}
\end{align*}
\]
M12c is 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11 or 12; and
R² is ethyl or vinyl.

2. The compound of claim 1 wherein A¹ is of the formula:

3. The compound of claim 1 wherein A¹ is of the formula:

4. The compound of claim 1 wherein A¹ is of the formula:

5. The compound of claim 1 wherein A¹ is of the formula:
6. The compound of claim 1 wherein $A^1$ is of the formula:

\[
\begin{align*}
\text{W}^5a & \quad \text{A}^3 \\
\left( \begin{array}{c}
R^2 \\
R^2 \\
M12a
\end{array} \right) & ;
\end{align*}
\]

and $W^5a$ is a carbocycle or a heterocycle where $W^5a$ is independently substituted with 0 or 1 $R^2$ groups.

7. The compound of claim 1 wherein $M12a$ is 1.

8. The compound of claim 1 wherein $A^1$ is of the formula:

\[
\begin{align*}
\left[ \text{Y}^2 \left( \begin{array}{c}
R^2 \\
R^2 \\
M12a
\end{array} \right) \right] & \text{W}^5 \\
\text{A}^3 \\
\text{M12b}
\end{align*}
\]

9. The compound of claim 1 wherein $A^1$ is of the formula:

\[
\begin{align*}
\text{W}^5 & \quad \text{A}^3 \\
\left( \begin{array}{c}
R^2 \\
R^2 \\
M12a
\end{array} \right) & .
\end{align*}
\]

10. The compound of claim 1 wherein $A^1$ is of the formula:
$W^{5a}$ is a carbocycle independently substituted with 0 or 1 $R^2$ groups;

11. The compound of claim 1 wherein $A^1$ is of the formula:

$Y^{2b}$ is O or N($R^2$); and

$M12d$ is 1, 2, 3, 4, 5, 6, 7 or 8.

12. The compound of claim 1 wherein $A^1$ is of the formula:

$W^{5a}$ is a carbocycle independently substituted with 0 or 1 $R^2$ groups;

13. The compound of claim 1 wherein $A^1$ is of the formula:
$W^{5a}$ is a carbocycle or heterocycle where $W^{5a}$ is independently substituted with 0 or 1 $R^2$ groups.

14. The compound of claim 1 wherein $A^1$ is of the formula:

\[ \text{Diagram of compound} \]

$Y^{2b}$ is O or N($R^2$); and
$M12d$ is 1, 2, 3, 4, 5, 6, 7 or 8.

15. The compound of any one of claims 1-14 wherein $A^3$ is of the formula:

\[ \text{Diagram of compound} \]

16. The compound of any one of claims 1-14 wherein $A^3$ is of the formula:

\[ \text{Diagram of compound} \]
17. The compound of any one of claims 1-14 wherein \( A^3 \) is of the formula:

\[
\begin{align*}
&\begin{array}{c}
\text{Y}^{1a} \text{ is O or S; and} \\
\text{Y}^{2a} \text{ is O, N(R)}^x \text{ or S.}
\end{array}
\end{align*}
\]

5

18. The compound of any one of claims 1-14 wherein \( A^3 \) is of the formula:

\[
\begin{align*}
&\begin{array}{c}
\text{Y}^{2b} \text{ is O or N(R)}^x \text{.}
\end{array}
\end{align*}
\]

19. The compound of any one of claims 1-14 wherein \( A^3 \) is of the formula:

\[
\begin{align*}
&\begin{array}{c}
\text{Y}^{2b} \text{ is O or N(R)}^x \text{; and} \\
\text{M12d is 1, 2, 3, 4, 5, 6, 7 or 8.}
\end{array}
\end{align*}
\]

20. The compound of any one of claims 1-14 wherein \( A^3 \) is of the formula:
Y_{2b} is O or N(R^5); and
M12d is 1, 2, 3, 4, 5, 6, 7 or 8.

21. The compound of claim 20 wherein M12d is 1.

22. The compound of any one of claims 1-14 wherein A^3 is of the formula:

23. The compound of any one of claims 1-14 wherein A^3 is of the formula:

24. The compound of claim 23 wherein W^5 is a carbocycle.
25. The compound of any one of claims 1-14 wherein $A^3$ is of the formula:

![Chemical structure](image)

26. The compound of claim 25 wherein $W^5$ is phenyl.

27. The compound of claim 26 wherein $M12b$ is 1.

28. The compound of any one of claims 1-14 wherein $A^3$ is of the formula:

![Chemical structure](image)

$Y^{1a}$ is O or S; and
$Y^{2a}$ is O, N($R^3$) or S.

29. The compound of any one of claims 1-14 wherein $A^3$ is of the formula:

![Chemical structure](image)

and $Y^{2b}$ is O or N($R^3$).
30. The compound of any one of claims 1-14 wherein A³ is of the formula:

\[
\begin{align*}
\text{Y}^{2b} & \text{ is O or N(R³); and} \\
\text{M12d} & \text{ is 1, 2, 3, 4, 5, 6, 7 or 8.}
\end{align*}
\]

31. The compound of claim 30 wherein R¹ is H.

32. The compound of claim 30 wherein M12d is 1.

33. The compound of any one of claims 1-14 wherein A³ is of the formula:

\[
\begin{align*}
\text{wherein the phenyl carbocycle is substituted with 0, 1, 2, or 3 R² groups.}
\end{align*}
\]

34. The compound of any one of claims 1-14 wherein A³ is of the formula:
35. The compound of any one of claims 1-14 wherein \( A^3 \) is of the formula:

\[
\begin{align*}
\text{[Chemical Structure]} \quad \text{[Chemical Structure]} \quad \text{[Chemical Structure]} \quad \text{[Chemical Structure]}
\end{align*}
\]

36. The compound of any one of claims 1-14 wherein \( A^3 \) is of the formula:

\[
\begin{align*}
\text{[Chemical Structure]} \quad \text{[Chemical Structure]} \quad \text{[Chemical Structure]} \quad \text{[Chemical Structure]} \quad \text{[Chemical Structure]}
\end{align*}
\]

37. The compound of any one of claims 1-14 wherein \( A^3 \) is of the formula:
38. The compound of any one of claims 1-14 wherein $A^3$ is of the formula:

$Y^{1a}$ is O or S; and
$Y^{2a}$ is O, $N(R^2)$ or S.

39. The compound of any one of claims 1-14 wherein $A^3$ is of the formula:

$Y^{1a}$ is O or S;
$Y^{2b}$ is O or $N(R^2)$; and
$Y^{2c}$ is O, $N(R^y)$ or S.

40. The compound of any one of claims 1-14 wherein $A^3$ is of the formula:
Y^{1a} is O or S;
Y^{2b} is O or N(R^2);
Y^{2d} is O or N(R^\prime); and
M12d is 1, 2, 3, 4, 5, 6, 7 or 8.

41. The compound of any one of claims 1-14 wherein A^3 is of the formula:

\[ \text{M12d} \]

Y^{2b} is O or N(R^2); and
M12d is 1, 2, 3, 4, 5, 6, 7 or 8.

42. The compound of any one of claims 1-14 wherein A^3 is of the formula:

\[ \text{M12d} \]

and Y^{2b} is O or N(R^2).

43. The compound of any one of claims 1-14 wherein A^3 is of the formula:
44. The compound of any one of claims 1-14 wherein A³ is of the formula:

45. The compound of any one of claims 1-14 wherein A³ is of the formula:

Y¹α is O or S; and
Y²α is O, N(R²) or S.

46. The compound of any one of claims 1-14 wherein A³ is of the formula:

Y¹α is O or S;
47. The compound of any one of claims 1-14 wherein \( A^3 \) is of the formula:

\[
\begin{align*}
Y^{2a} & \text{ is } O \text{ or } N(R^2); \\
Y^{2c} & \text{ is } O, N(R^3) \text{ or } S. \\
Y^{1a} & \text{ is } O \text{ or } S; \\
Y^{2b} & \text{ is } O \text{ or } N(R^2); \\
Y^{2d} & \text{ is } O \text{ or } N(R^3); \text{ and} \\
M12d & \text{ is } 1, 2, 3, 4, 5, 6, 7 \text{ or } 8.
\end{align*}
\]

48. The compound of any one of claims 1-14 wherein \( A^3 \) is of the formula:

\[
\begin{align*}
Y^{2b} & \text{ is } O \text{ or } N(R^2); \text{ and} \\
M12d & \text{ is } 1, 2, 3, 4, 5, 6, 7 \text{ or } 8.
\end{align*}
\]

49. The compound of any one of claims 1-14 wherein \( A^3 \) is of the formula:

\[
\begin{align*}
\text{and } Y^{2b} & \text{ is } O \text{ or } N(R^2).
\end{align*}
\]
50. The compound of wherein A² is of the formula:

\[
\frac{\gamma}{2} \quad (\text{CH}_2)_{1-10} \quad \text{O} \quad \text{P} \quad \text{O} \quad \text{R}
\]

wherein each R is independently (C₁-C₆)alkyl.

51. The compound of any one of claims 1-50 wherein R²₀ is ethyl.

52. The compound of any one of claims 1-50 wherein R²₀ is vinyl.

53. A compound described in the Examples herein.

54. A pharmaceutical composition comprising a pharmaceutical carrier and a compound as described in any one of claims 1-53.

55. A unit dosage form comprising a compound as described in any one of claims 1-53, and a pharmaceutically acceptable carrier.

56. A method of inhibiting tumor growth comprising the step of contacting a sample or subject suspected of containing a tumor with a compound as described in any one of claims 1-53.

57. The method of claim 55 wherein the tumor is in vivo.

58. A method for the treatment or prevention of the symptoms or effects of cancer in an animal which comprises administering to said animal a formulation comprising a therapeutically effective amount of a compound as described in any one of claims 1-53.
59. The method of claim 58 wherein the compound is formulated with a pharmaceutically acceptable carrier.

60. The use of a compound as described in any one of claims 1-53 to prepare a medicament for treatment of cancer.

61. The use of claim 60 wherein the formulation further comprises a second active ingredient.

62. A method of inhibiting the activity of a virus comprising the step of contacting a sample suspected of containing a virus with a compound as described in any one of claims 1-53.

63. The method of claim 62 wherein the virus is in vivo.

64. A method for the treatment or prevention of the symptoms or effects of viral infection in an animal which comprises administering to said animal a formulation comprising a therapeutically effective amount of a compound as described in any one of claims 1-53.

65. The method of claim 64 wherein the compound is formulated with a pharmaceutically acceptable carrier.

66. The use of a compound as described in any one of claims 1-53 to prepare a medicament for treatment of a virus infection.

67. The use of claim 66 wherein the formulation further comprises a second active ingredient.

68. A method of inhibiting inflammation comprising the step of contacting a sample or subject suspected of being inflamed with a compound as described in any one of claims 1-53.
69. The method of claim 68 wherein the inflammation is \textit{in vivo}.

70. A method for the treatment or prevention of the symptoms or effects of inflammation in an animal which comprises administering to said animal a formulation comprising a therapeutically effective amount of a compound as described in any one of claims 1-53.

71. The method of claim 70 wherein the compound is formulated with a pharmaceutically acceptable carrier.

72. The use of a compound as described in any one of claims 1-53 to prepare a medicament for treatment of inflammation.

73. The use of claim 72 wherein the formulation further comprises a second active ingredient.

74. A method for the treatment or prevention of the symptoms or effects of tissue or organ transplant rejection in an animal which comprises administering to said animal a formulation comprising a therapeutically effective amount of a compound as described in any one of claims 1-53.

75. The method of claim 74 wherein the compound is formulated with a pharmaceutically acceptable carrier.

76. The use of a compound as described in any one of claims 1-53 to prepare a medicament for treatment of tissue or organ transplant rejection.

77. The use of claim 76 wherein the formulation further comprises a second active ingredient.