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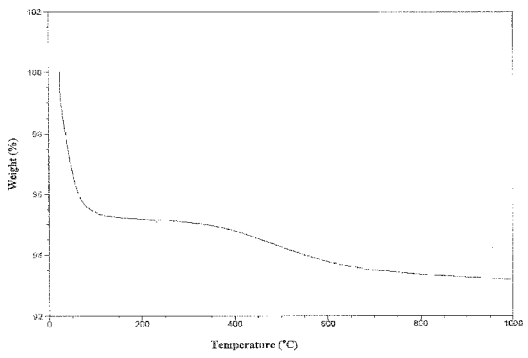
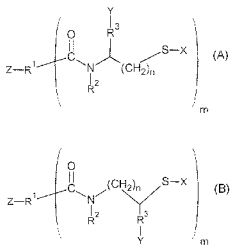


Figure 1



(57) Abstract: Sulfur-containing ligands and methods of their utilization for binding metals and/or main group elements and removing them from fluids, solids, gases and/or tissues are disclosed. The ligands are of the general structure (A): or structure (B) where R^1 comprises benzene, pyridine, pyridin-4-one, naphthalene, anthracene, phenanthrene or alkyl groups, R^2 comprises hydrogen, alkyls, aiyls, a carboxyl group, carboxylate esters, organic groups or biological groups, R^3 comprises alkyls, aryls, a carboxyl group, carboxylate esters, organic groups or biological groups, X comprises hydrogen, lithium, sodium, potassium, rubidium, cesium, francium, alkyls, aryls, a carboxyl group, carboxylate esters, thiophosphate, N-acetyl cysteine, mercaptoacetic acid, mercaptopropionic acid, thiolsalicylate, organic groups or biological groups, n independently equals 1-10, m = 1 -6, Y comprises hydrogen, polymers, silicas or silica supported substrates, and Z comprises hydrogen, alkyls, aryls, a carboxyl group, carboxylate esters, a hydroxyl group, NH_2, HSO_3, halogens, a carbonyl group, organic groups, biological groups, polymers, silicas or silica supported substrates.

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THIOL-CONTAINING COMPOUNDS FOR THE REMOVAL OF ELEMENTS FROM CONTAMINATED MILIEU AND METHODS OF USE

CROSS REFERENCE TO RELATED APPLICATIONS

[0001] This application claims priority to U.S. Provisional Application Serial Nos. 61/246,278, 61/246,282 and 61/246,360, all three filed on September 28, 2009, the entire disclosures of which are all incorporated herein in their entirety.

FIELD OF THE INVENTION

[0002] The present invention relates to compounds utilized in covalent binding to a wide range of metals and main group elements, and more specifically to sulfur-containing ligands and the utilization of such to remove contaminants from solids, liquids and gases.

BACKGROUND OF THE INVENTION

[0003] Heavy metal and main group element pollution is an existing and growing worldwide problem. During the past few decades, federal and state governments have instituted environmental regulations to protect the quality of surface and ground water from contaminants. In response to these regulatory requirements, numerous products have been developed to precipitate contaminants from surface water, ground water and soil. Examples of compositions and methods utilized in precipitating metals from water and soil are detailed in U.S. Patent No. 6,586,600, the entire disclosure of which is hereby incorporated by reference.

[0004] There are numerous industrial and environmental situations where ligands capable of binding metals and main group elements can be utilized for remediation purposes. For example, waste water issuing from waste treatment facilities, chlor-alkali industries, metal finishing industries and certain municipal landfills often present contamination problems. Similarly, the metal content of water exiting both functional and abandoned mines is a significant environmental issue in geographical areas with a heavy mining industry. Soil and surface waters located in areas near natural gas pump houses suffer a similar metal contamination problem. Gasses emitted from coal-fired power plants and the incineration of municipal and medical

waste contain mercury. Thus, there is a need for ligands capable of binding and removing metals and main group elements from gasses, aqueous and non-aqueous solutions and solid substrates.

[0005] It is known in the art to use sulfur-containing compounds to bind heavy metals. For example, Thio-Red® is a chemical reagent used for precipitating divalent heavy metals from water. This product is a complex aqueous solution of sodium (with or without potassium) thiocarbonate, sulfides, and other sulfur species. Thio-Red® ultimately removes Cu, Hg, Pb, and Zn from aqueous solutions through the formation of metal sulfides (i.e. CuS, HgS, PbS, and ZnS), rather than metal thiocarbonates. Sodium and potassium dialkyldithiocarbamates such as HMP-2000®, are also widely used as metal precipitants. However, the limited ability of most reagents presently used on a commercial basis to form stable, covalent bonds with heavy metals is a major concern for remediation applications. Reagents that lack sufficient or metal-specific binding sites may produce metal precipitates that are unstable over time and under certain pH conditions. Such unstable precipitates may release bound metal back into the environment, thereby proving unsatisfactory as treatment or remediation agents. Further, these reagents may form simple metal sulfides which bacteria are capable of methylating (in the case of Hg, forming the water-soluble cation, $MeHg^{+}$). Accordingly, there is a need for ligands which not only bind metals and main group elements, but also bind these elements in such a manner as to form stable, insoluble precipitates which retain the contaminant element(s) over a wide range of environmental conditions and over extended periods of time.

[0006] Likewise, it is known to use a variety of chelators for chelation therapy of metals. Many studies today reflect the increasing exposure of the population to mercury and other toxic heavy metals. Examples of currently approved binders for treating heavy metal toxicity such as mercury toxicity are dimercaptopropanesulfonate (DMPS) and dimercaptosuccinic acid (DMSA), which were introduced during World War II to combat industrial exposure to heavy metals. Conventional compounds such as DMPS and DMSA, while often referred to as "chelators," are not truly chelators in the chemical sense of the word. This is because there is insufficient space between the sulfurs on adjacent carbon atoms to allow a large metal atom to bind to both sulfurs at the same time, which is a requirement for

forming a true "chelate." Rather, DMPS and DMSA form bound sandwich complexes with metal, where for example two binder molecules bind to a single mercury atom. This provides a weaker attachment than would be the case with a true chelator, which would form two bonds between the thiol (-SH) groups and the Hg^{2+}. Also, based on their negatively charged properties, binders like DMSA, DMPS and EDTA have a non-specific attraction for all metal ions, including the essential metals Ca^{2+}, Mg^{2+}, Mn^{2+}, etc. The rapid excretion of these binders from the body through the urine can have the negative effect of depleting the body of these essential metals. Deaths have occurred by essential metal depletion by charged binding compounds during a process called chelation therapy, and this medical treatment must therefore be done by an experienced physician.

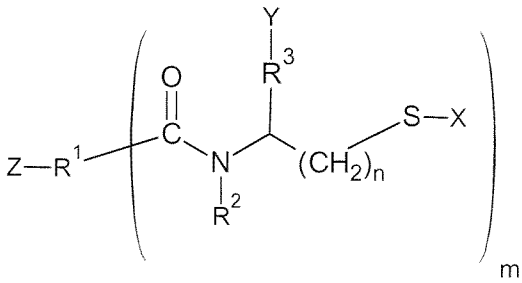
[0007] Heavy metals such as mercury are typically lipid-soluble or can pass through the cell membrane via native divalent metal ion carriers (e.g. for Ca^{2+}, Mg^{2+}) as the M^{2+} form, and may therefore concentrate intracellularly and more so in the adipose, or fatty, tissue or in other tissues high in lipid content, including without limitation the central nervous system. Indeed, mercury and other heavy metals preferentially partition to and concentrate in the hydrophobic aspects of mammals, fish, and the like, such as fatty tissues, cell membranes, lipid-containing areas of the interior of a cell, and the like.

[0008] Thus, the currently available, approved heavy metal binders have several disadvantages with regard to their overall chemical nature that could be improved on by the synthesis of better-designed, true chelators that have safer excretory properties such as higher affinity for the metals and/or main group elements and excretion through the feces instead of the urine. Such better-designed, true chelators would desirably be uncharged, lipid-soluble or hydrophobic compounds, or alternatively convertible from water soluble (for suitability for delivery via the bloodstream) to lipid-soluble compounds in the body, to allow them to partition into the fatty (hydrophobic) tissues where the mercury or other heavy metal burden is primarily located. Further, such chelators would possess low or, better yet, no observable toxicity to mammals alone in the absence of heavy metal exposures. They would be true chelators that would bind heavy metals and main group elements exceptionally tightly, preventing toxic effects and also preventing release or concentration in toxic

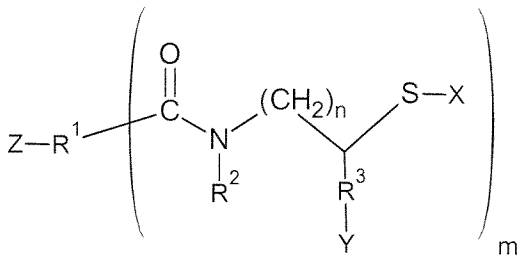
form in any organ of the body. Still further, desirably the chelators would be excreted through the biliary transport system of the liver into the feces instead of through the kidneys (a very sensitive organ to heavy metal exposure) and into the urine. Still yet further, it would be desirable to provide improved chelators which readily convert between water-soluble and lipid-soluble forms, allowing excretion by the desired route, i.e., via the kidney for the water-soluble form and via the biliary transport system of the liver into the feces for the lipid-soluble form.

SUMMARY OF THE INVENTION

[0009] In one embodiment, chelate ligands are of the general formula:



or



where R^1 is selected from a group including benzene, pyridine, pyridin-4-one, naphthalene, anthracene, phenanthrene and alkyl groups, R^2 is independently selected from a group including hydrogen, alkyls, aryls, a carboxyl group, carboxylate esters, organic groups and biological groups, R^3 is independently selected from a group including alkyls, aryls, a carboxyl group, carboxylate esters, organic groups and biological groups, X is independently selected from a group including hydrogen, lithium, sodium, potassium, rubidium, cesium, francium, alkyls, aryls, a carboxyl group, carboxylate esters, cysteine, homocysteine, glutathione, lipoic acid, dihydrolipoic acid, thiophosphate, N-acetyl cysteine, mercaptoacetic acid, mercaptopropionic acid, γ-glutamyl cysteine, phytochelatins, thiolsalicylate, organic groups and biological groups, n independently equals 1-10, m = 1-6, Y is

independently selected from a group including hydrogen, polymers, silicas and silica supported substrates, and Z is selected from a group including hydrogen, alkyls, aryls, a carboxyl group, carboxylate esters, a hydroxyl group, NH_2, HSO_3, halogens, a carbonyl group, organic groups, biological groups, polymers, silicas and silica supported substrates, with the proviso that when R^1 represents an alkyl group, at least one X cannot simultaneously represent hydrogen.

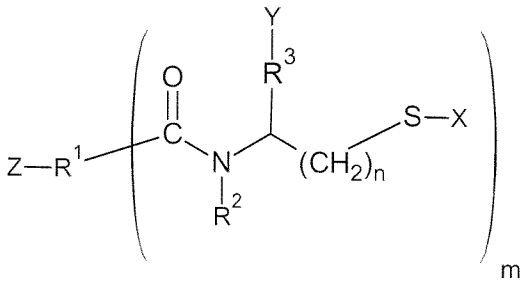
[0010] In another aspect, the present invention relates to methods of removing metals and/or main group elements from a starting material. The methods comprise contacting a starting material with an effective amount of a sulfur-containing chelate ligand as described above for a sufficient time to form a stable ligand-metal and/or ligand-main group element complex(es), said metal and/or main group element complex(es) remaining essentially irreversibly bound to said ligand over a range of acidic and basic pH values.

[0011] In another aspect, the present invention relates to methods of removing metals and/or main group elements from a lipid-containing tissue in a human and/or animal body. The methods comprise intravenously delivering an amount of a sulfur-containing chelate ligand as described above to a lipid-containing tissue in a body, forming a ligand-metal and/or ligand-main group element complex(es), and excreting the complex(es) from the body. We have observed that certain prior art uncharged, hydrophobic compounds, such as those disclosed in U.S. Patent No. 6,586,600 to Atwood et al., have exceptionally low toxicity when injected or ingested by test animals. Disadvantageously, the water-insolubility of these hydrophobic compounds makes them poor candidates for intravenous applications. Intravenous (IV) application has the advantage of speed of general delivery and the ability to treat an unconscious patient. Therefore, in the present disclosure, analogs of uncharged, non-toxic chelators are described which may initially be provided as charged, water soluble compounds. These water-soluble compounds are converted in the blood to uncharged lipid soluble compounds which can enter the membranes and other hydrophobic aspects of cells and tissues, and even cross the blood brain barrier.

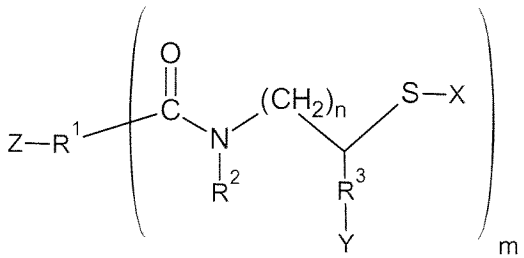
[0012] Further, the present disclosure provides uncharged, non-toxic lipid soluble analogs that can be converted by intracellular enzymes once internalized into water soluble chelators. These same compounds can be treated externally with enzymes

(esterases) to make them water soluble for IV applications. This may be especially useful if treatment is required that does not enter cells or cross the blood brain barrier and still retain high heavy metal and/or main group element affinity.

[0013] In one embodiment of this aspect, the described chelators are thiol/thiolate compounds including an aromatic ring structure, further including additional functional groups on the organic ring structure and/or on the pendent thiol chains. A representative structure for the compounds is set forth below. In that structure, Z and Y may be a variety of combinations of organic, organometallic and inorganic groups, including without limitation OH, COOH, NH_2, HSO_3, halogens, and the like. X may be one or more of hydrogen, halogens, organic groups providing thioethers and related derivatives, or metals selected without limitation from the Group 1 and 2 elements recited in the Periodic Table of the Elements, or may include charged molecules having a terminal sulfhydryl include without limitation glutathione, cysteine, homocysteine, lipoic acid, dihydrolipoic acid, thiophosphate, N-acetyl cysteine, mercaptoacetic acid, mercaptopropionic acid, γ-glutamyl cysteine, phytochelatins, thiolsalicylate, and the like. The reference character n may represent any integer from 1-10. Other aromatic groups contemplated include naphthalene, anthracene, phenanthrene, and the like as set forth above.



or



[0014] Other aspects of the present invention will become apparent to those skilled in this art from the following description wherein there is shown and described exemplary embodiments of this invention. As it will be realized, the invention is

capable of further embodiments and its several details are capable of modification in various, obvious aspects without departing from the invention. Accordingly, the drawings and descriptions will be regarded as illustrative in nature and not as restrictive.

BRIEF DESCRIPTION OF THE FIGURES

[0015] The following detailed description of specific embodiments of the present disclosure can be best understood when read in conjunction with the following drawings, in which:

[0016] Fig. 1 shows the weight loss results of a thermogravimeteric analysis on Si60 from a temperature range of 30 °C to 1000 °C with a temperature increase of 20 ° C/min and a flow rate of 110/55 mmHg (inlet/outlet pressure) performed in air atmosphere;

[0017] Fig 2 shows the weight loss results of a thermogravimeteric analysis on $SiNH_2$ from a temperature range of 30 ° C to 1000 ° C with a temperature increase of 20 ° C/min and a flow rate of 110/55 mmHg (inlet/outlet pressure) performed at air atmosphere;

[0018] Fig. 3 shows the weight loss results of a thermogravimeteric analysis on SiAB9 produced from a first experimental procedure from a temperature range of 30 ° C to 1000 ° C with a temperature increase of 20 ° C/min and a flow rate of 110/55 mmHg (inlet/outlet pressure) performed at air atmosphere;

[0019] Fig. 4 shows the weight loss results of a thermogravimeteric analysis on SiAB9 produced from a second experimental procedure from a temperature range of 30 ° C to 1000 ° C with a temperature increase of 20 ° C/min and a flow rate of 110/55 mmHg (inlet/outlet pressure) performed at air atmosphere;

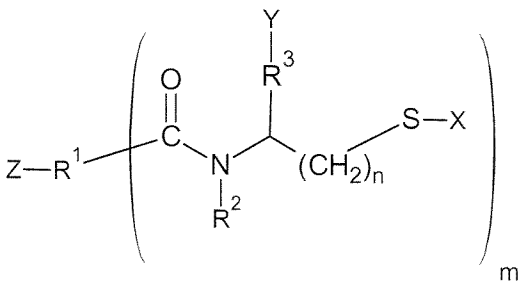
[0020] Fig. 5 shows the chemical structures of various hydrophobic chelators according to the present invention, which are converted to hydrophilic chelators within the microenvironment; and

[0021] Figures 6a and 6b show the chemical structures of various chelators according to the present invention, which may be introduced into a body in a hydrophilic state, reduced to a hydrophobic state in the body for partitioning into lipid-rich areas, and subsequently enzymatically returned to a hydrophilic state *in vivo*.

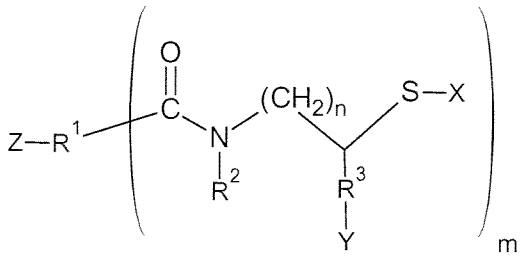
DETAILED DESCRIPTION OF ILLUSTRATIVE EMBODIMENTS

[0022] As summarized above, the present invention relates to novel sulfur-containing chelate ligands which bind metals and/or main group elements resulting in ligand-metal and/or ligand-main group element complex(es) which remain stable at a wide range of pH values. In forming the ligand-metal and/or ligand-main group element complex(es), the novel ligands are capable of forming covalent bonds with the metals and/or main group elements that may not be broken under most acidic or basic conditions. The ligands of the present invention are suitable for binding metals and/or main group elements which are in or are capable of being placed in a positive oxidation state, including, but not limited to, yttrium, lanthanum, hafnium, vanadium, chromium, uranium, manganese, iron, cobalt, nickel, palladium, platinum, copper, silver, gold, zinc, cadmium, mercury, lead, tin and the like. The ligands of the present invention are also suitable for binding main group elements which are in or are capable of being placed in a positive oxidation state, hereinafter defined as including gallium, indium, thallium, boron, silicon, germanium, arsenic, antimony, selenium, tellurium, polonium, bismuth, molybdenum, thorium, plutonium and the like.

[0023] In one aspect, the present invention relates to chelate ligands consisting of an organic group from which depends at least one alkyl chain that terminates in a sulfur-containing group. The chelate ligands may be of the general formula:



or

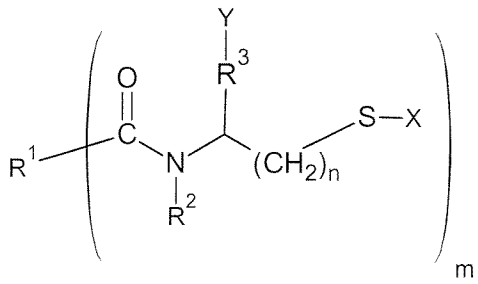


where R^1 may be selected from a group comprising organic groups that include, but are not limited to, benzene, pyridine, pyridin-4-one, naphthalene, anthracene, phenanthrene and alkyl groups such as $(CH_2)_y$ where y = 2-8, R^2 may be independently selected from a group comprising hydrogen, alkyls, aryls, a carboxyl group, carboxylate esters, other organic groups that include, but are not limited to, acyls and amides, and biological groups that include, but are not limited to, amino acids and proteins such as cysteine, R^3 may be independently selected from a group comprising alkyls, aryls, carboxyl groups, carboxylate esters, other organic groups that include, but are not limited to, acyls and amides, and biological groups that include, but are not limited to, proteins and amino acids such as cysteine, X may be independently selected from a group comprising hydrogen, lithium, sodium, potassium, rubidium, cesium, francium, alkyls, aryls, a carboxyl group, carboxylate esters, cysteine, homocysteine, glutathione, lipoic acid, dihydrolipoic acid, thiophosphate, N-acetyl cysteine, mercaptoacetic acid, mercaptopropionic acid, γ-glutamyl cysteine, phytochelatins, thiolsalicylate, organic groups and biological groups, n may independently equal 1-10, m may equal 1-6, Y may be independently selected from a group comprising hydrogen, polymers, silicas and silica supported substrates, and Z may be independently selected from a group comprising hydrogen, alkyls, aryls, a carboxyl group, carboxylate esters, a hydroxyl group, NH_2, HSO_3, halogens, a carbonyl group, organic groups, biological groups, polymers, silicas and silica supported substrates. In some embodiments n may independently equal to 1-6 or 1-4. In some embodiments m may equal 1-2 or 4-6, and in certain interesting embodiments, m equals 2. In embodiments where $m \geq 2$, the sulfur atoms of multiple alkyl chains may share a single X constituent. In such embodiments, X may be independently selected from a group comprising beryllium, magnesium, calcium, strontium, barium and radium.

[0024] While not wishing to be bound by any particular theory, it is believed that the stability of the metal and/or main group element complexes formed through utilization of the ligands of the present invention is derived from the multiple interactions between the metal and/or main group element atoms and the sulfur and/or nitrogen atoms on the ligand. Accordingly, it is believed that the sulfur and/or nitrogen atoms form a multidentate bonding arrangement with a metal and/or main group element atom. In embodiments of ligands that include multiple alkyl chains (*i.e.*, $m \geq 2$), a metal and/or main group element atom may be bound through interactions with the multiple sulfur and/or nitrogen atoms of the ligand. In embodiments of ligands that include a single alkyl chain (*i.e.*, $m = 1$), a metal and/or main group element atom may be bound through interactions with the sulfur and/or nitrogen atoms of multiple ligands. However, metal and/or main group element atoms may also be bound by the sulfur and/or nitrogen atoms of several ligands that include multiple alkyl chains. Accordingly, the ligands may form metal and/or main group element complexes though the interactions between the metal and/or main group element atoms and the sulfur and/or nitrogen atoms of a single ligand, as well as form polymeric metal and/or main group element complexes through the interactions between the metal and/or main group element atoms and the sulfur and/or nitrogen atoms of multiple ligands.

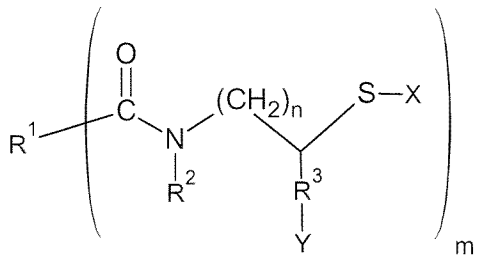
[0025] The compounds may be bonded to supporting material Y at R^3. Depending on the value of m, Y may comprise polymers, silicas, silica supported substrates or hydrogen. If $m = 1$, then Y may be selected from a group comprising hydrogen, polymers, silicas and silica supported substrates, alumina and other metal oxide materials. If $m > 1$, then each Y may be independently selected from a group comprising hydrogen, polymers, silicas, silica supported substrates, alumina and other metal oxide materials. Thus, where $m > 1$, the compound may bond to supporting material Y at a single R^3, at all of the R^3 groups, or any combination thereof. Furthermore, Y may comprise filtration beads or be otherwise embedded or impregnated in a filtration medium. For example, in one embodiment, Y may comprise polystyrene beads such that the sulfur-containing compounds are supported on the polystyrene beads for the filtration of contaminants.

[0026] In one useful embodiment, the chelate ligands may be of the general formula:



where R^1 may be selected from a group comprising benzene, pyridine, naphthalene, anthracene, phenanthrene and alkyl groups, R^2 may be independently selected from a group comprising hydrogen, alkyls, aryls, a carboxyl group, carboxylate esters, organic groups and biological groups, R^3 may be independently selected from a group comprising alkyls, aryls, a carboxyl group, carboxylate esters, organic groups and biological groups, X may be independently selected from a group comprising hydrogen, lithium, sodium, potassium, rubidium, cesium, francium, cysteine and glutathione, n independently equals 1-10, m = 1-6, and Y may be independently selected from a group comprising hydrogen, polymers, silicas and silica supported substrates, with the proviso that when R^1 represents an alkyl group, at least one X cannot simultaneously represent hydrogen.

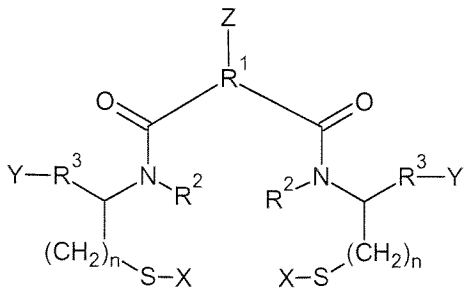
[0027] In another useful embodiment, chelate ligands may be of the general formula:



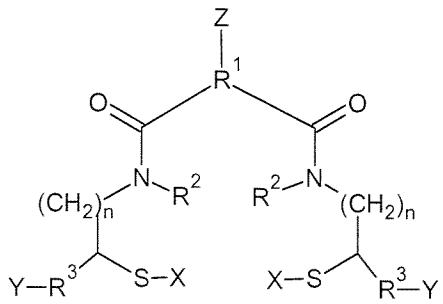
where R^1 may be selected from a group comprising benzene, pyridine, naphthalene, anthracene, phenanthrene and alkyl groups, R^2 may be independently selected from a group comprising hydrogen, alkyls, aryls, a carboxyl group, carboxylate esters, organic groups and biological groups, R^3 may be independently selected from a group comprising alkyls, aryls, a carboxyl group, carboxylate esters, organic groups and biological groups, X may be independently selected from a group comprising hydrogen, lithium, sodium, potassium, rubidium, cesium, francium, cysteine and

glutathione, n independently equals 1-10, m = 1-6, and Y may be independently selected from a group comprising hydrogen, polymers, silicas and silica supported substrates.

[0028] In another useful embodiment, the present invention relates to chelate ligands consisting of an organic structure from which depend two alkyl chains terminating in sulfur-containing groups. The chelate ligands may be of the general formula:



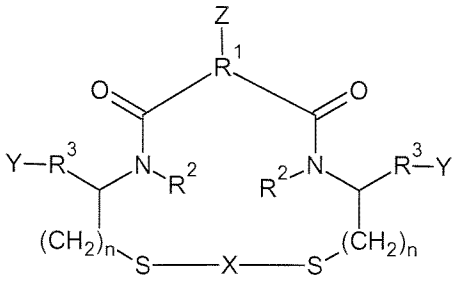
or



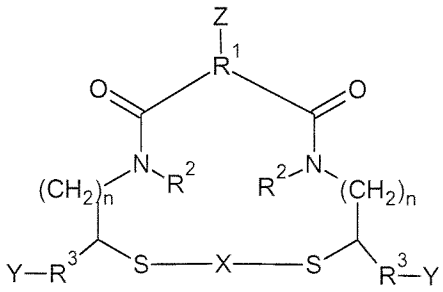
where R^1 may be selected from a group comprising benzene, pyridine, pyridin-4-one, naphthalene, anthracene, phenanthrene and alkyl groups, R^2 may be independently selected from a group comprising hydrogen, alkyls, aryls, a carboxyl group, carboxylate esters, organic groups and biological groups, R^3 may be independently selected from a group comprising alkyls, aryls, a carboxyl group, carboxylate esters, organic groups and biological groups, X may be independently selected from a group comprising hydrogen, lithium, sodium, potassium, rubidium, cesium, francium, cysteine and glutathione, n independently equals 1-10, Y may be independently selected from a group comprising hydrogen, polymers, silicas and silica supported substrates, and Z may be independently selected from a group comprising hydrogen, alkyls, aryls, a carboxyl group, carboxylate esters, a hydroxyl group, NH_2, HSO_3,

halogens, a carbonyl group, organic groups, biological groups, polymers, silicas and silica supported substrates.

[0029] In another useful embodiment, the present invention relates to chelate ligands consisting of an organic structure from which depend two alkyl chains terminating in sulfur-containing groups. However, in this embodiment, the two sulfur atoms of the two alkyl chains share one X constituent. The chelate ligands may be of the general formula:

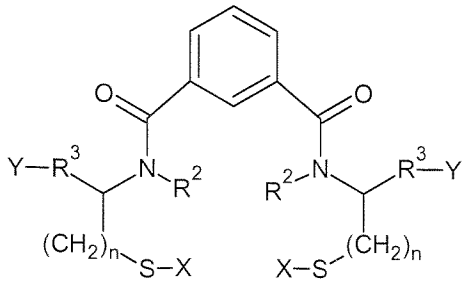


or

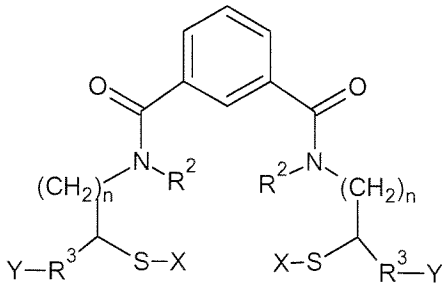


where R^1 may be selected from a group comprising benzene, pyridine, pyridin-4-one, naphthalene, anthracene, phenanthrene and alkyl groups, R^2 may be independently selected from a group comprising hydrogen, alkyls, aryls, a carboxyl group, carboxylate esters, organic groups and biological groups, R^3 may be independently selected from a group comprising alkyls, aryls, a carboxyl group, carboxylate esters, organic groups and biological groups, X may be selected from a group comprising beryllium, magnesium, calcium, strontium, barium and radium, n independently equals 1-10, Y may be independently selected from a group comprising hydrogen, polymers, silicas and silica supported substrates, and Z may be independently selected from a group comprising hydrogen, alkyls, aryls, a carboxyl group, carboxylate esters, a hydroxyl group, NH_2, HSO_3, halogens, a carbonyl group, organic groups, biological groups, polymers, silicas and silica supported substrates.

[0030] In another useful embodiment, the present invention relates to chelate ligands consisting of a ring structure from which depend two alkyl chains terminating in sulfur-containing groups. The chelate ligands may be of the general formula:

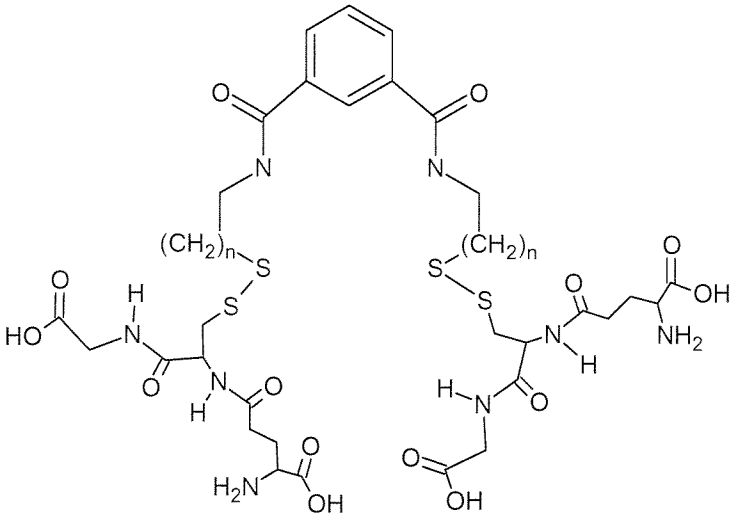


or

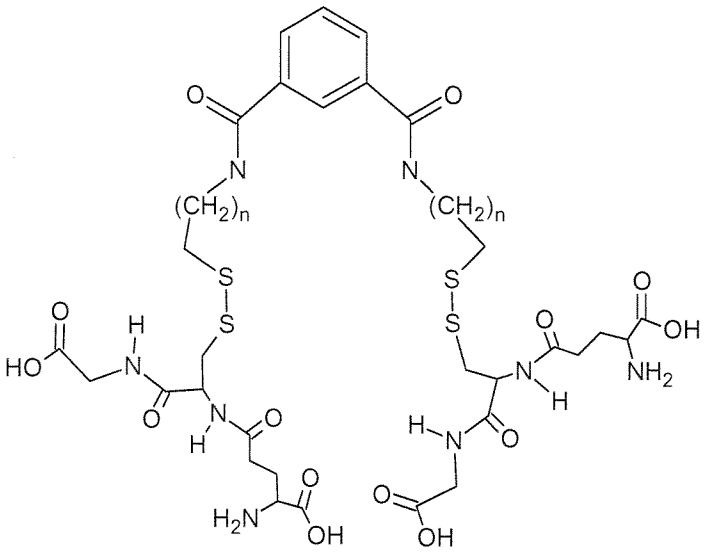


where R^2 may be independently selected from a group comprising hydrogen, alkyls, aryls, a carboxyl group, carboxylate esters, organic groups and biological groups, R^3 may be independently selected from a group comprising alkyls, aryls, a carboxyl group, carboxylate esters, organic groups and biological groups, X may be independently selected from a group comprising hydrogen, lithium, sodium, potassium, rubidium, cesium, francium, cysteine and glutathione, n independently equals 1-10, and Y may be independently selected from a group comprising hydrogen, polymers, silicas and silica supported substrates. As disclosed in U.S. Patent No. 6,586,600, chelate ligands of the above general formula, wherein the R^3 groups (as well as the R^2 groups) comprise hydrogen, both n equal 1, and both Y comprise hydrogen, may be referred to as "B9."

[0031] In another useful embodiment of B9, the chelate ligands are of the formula:

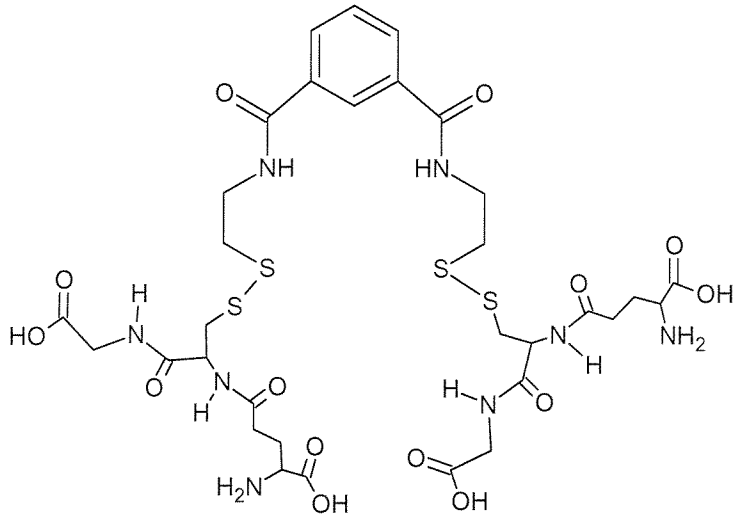


or

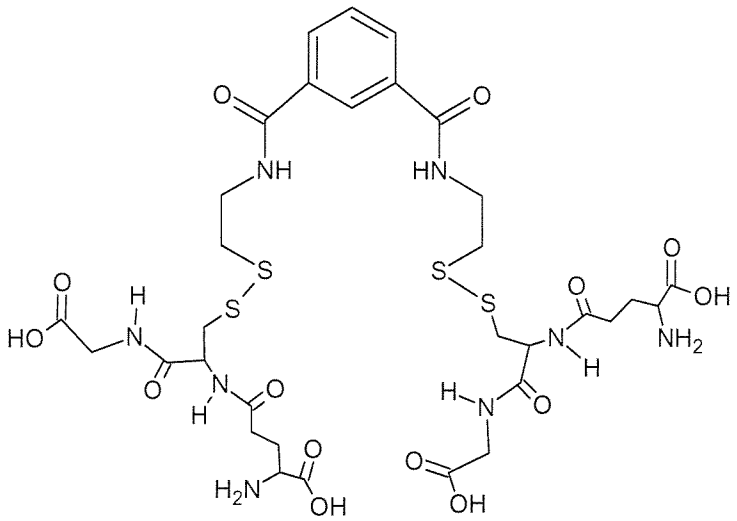


where n independently equals 1-10. Chelate ligands of this general formula may be referred to as "glutathione B9" or abbreviated to "GB9."

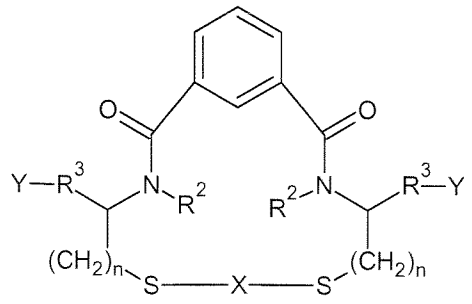
[0032] In one useful embodiment of GB9, the chelate ligand is of the formula:



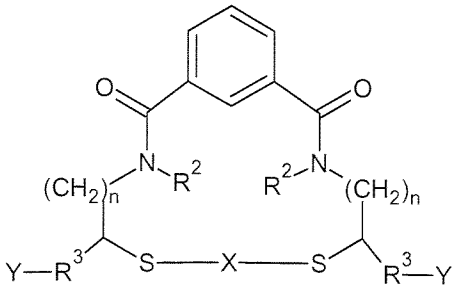
or



[0033] In another useful embodiment, the present invention relates to chelate ligands consisting of a ring structure from which depend two alkyl chains terminating in sulfur-containing groups. In this embodiment the two sulfur atoms of the two alkyl chains share one X group. The chelate ligands may be of the general formula:

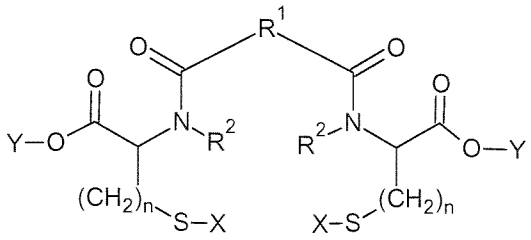


or

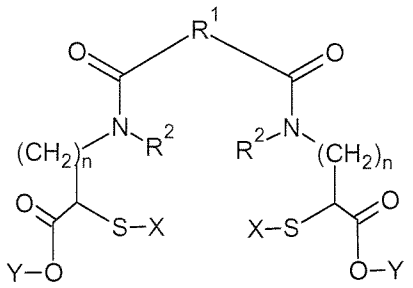


where R^2 may be independently selected from a group comprising hydrogen, alkyls, aryls, a carboxyl group, carboxylate esters, organic groups and biological groups, R^3 may be independently selected from a group comprising alkyls, aryls, a carboxyl group, carboxylate esters, organic groups and biological groups, X may be selected from a group comprising beryllium, magnesium, calcium, strontium, barium and radium, n independently equals 1-10, and Y may be independently selected from a group comprising hydrogen, polymers, silicas and silica supported substrates.

[0034] In another useful embodiment, the chelate ligands are of the formula:



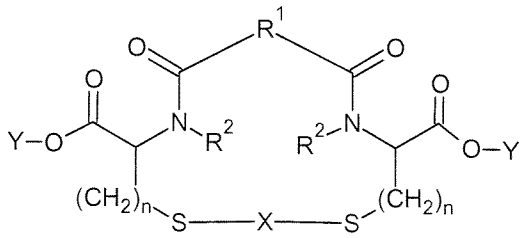
or



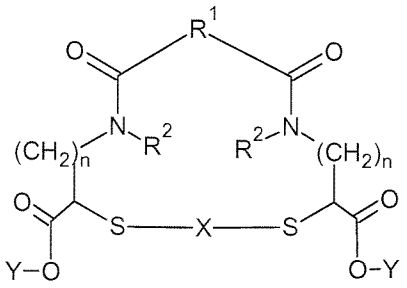
where R^1 may be selected from a group comprising benzene, pyridine, naphthalene, anthracene, phenanthrene and alkyl groups, R^2 may be independently selected from a group comprising alkyls, aryls, a carboxyl group, carboxylate esters, organic groups and biological groups, X may be independently selected from a group comprising

hydrogen, lithium, sodium, potassium, rubidium, cesium, francium, cysteine, and glutathione, n independently equals 1-10, and Y may be independently selected from a group comprising hydrogen, polymers, silicas and silica supported substrates. Chelate ligands of these general formulas may be referred to as "acid B9" or abbreviated to "AB9."

[0035] In one useful embodiment of AB9, the chelate ligands are of the formula:

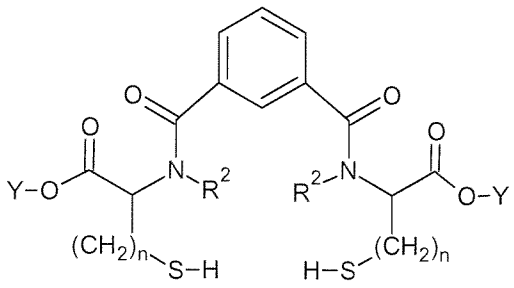


or

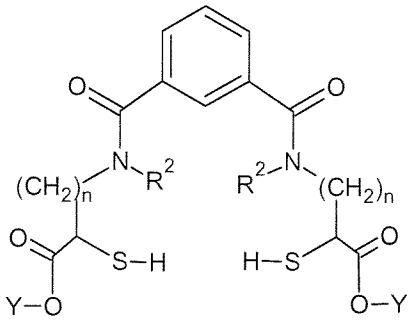


where R^1 may be selected from a group comprising benzene, pyridine, naphthalene, anthracene, phenanthrene and alkyl groups, R^2 may be independently selected from a group comprising hydrogen, alkyls, aryls, a carboxyl group, carboxylate esters, organic groups and biological groups, X may be independently selected from a group comprising beryllium, magnesium, calcium, strontium, barium and radium, n independently equals 1-10, and Y may be independently selected from a group comprising hydrogen, polymers, silicas and silica supported substrates.

[0036] In another useful embodiment of AB9, the chelate ligands are of the formula:

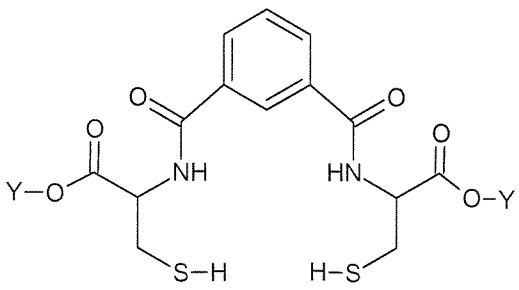


or

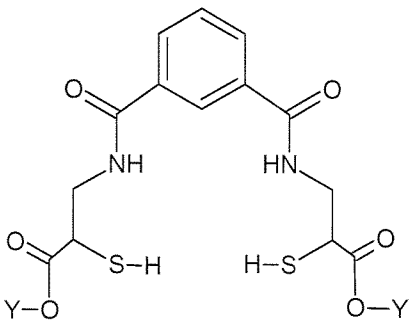


where R^2 may be independently selected from a group comprising hydrogen, alkyls, aryls, a carboxyl group, carboxylate esters, organic groups and biological groups, n independently equals 1-10, and Y may be independently selected from a group comprising hydrogen, polymers, silicas and silica supported substrates.

[0037] In another useful embodiment of AB9, the chelate ligands are of the formula:

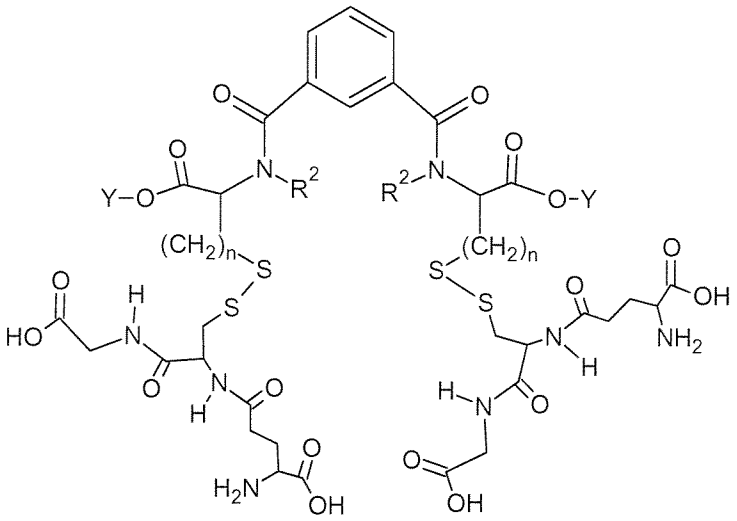


or

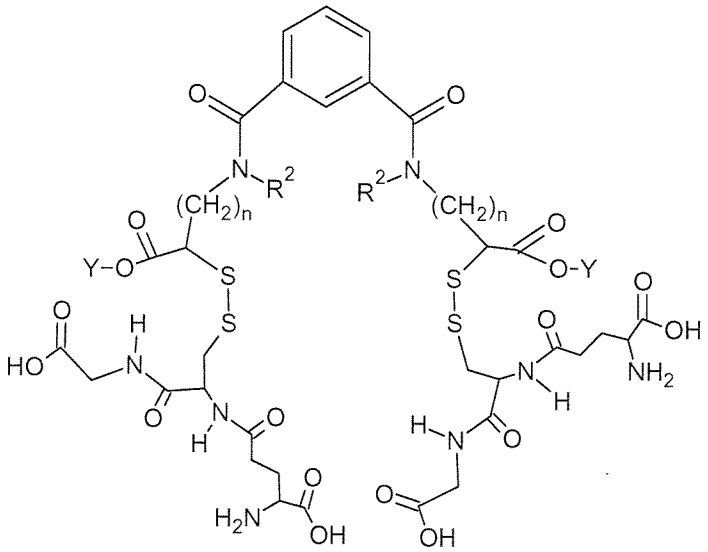


where Y may be independently selected from a group comprising hydrogen, polymers, silicas and silica supported substrates.

[0038] In another useful embodiment of AB9, the chelate ligands are of the formula:

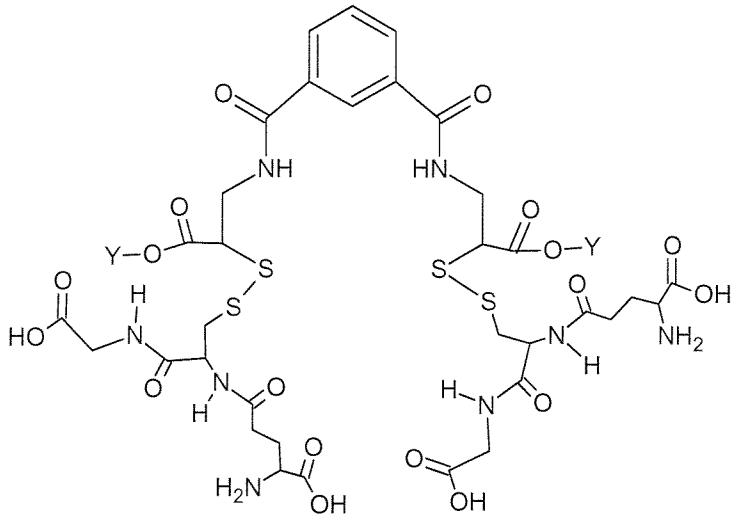


or

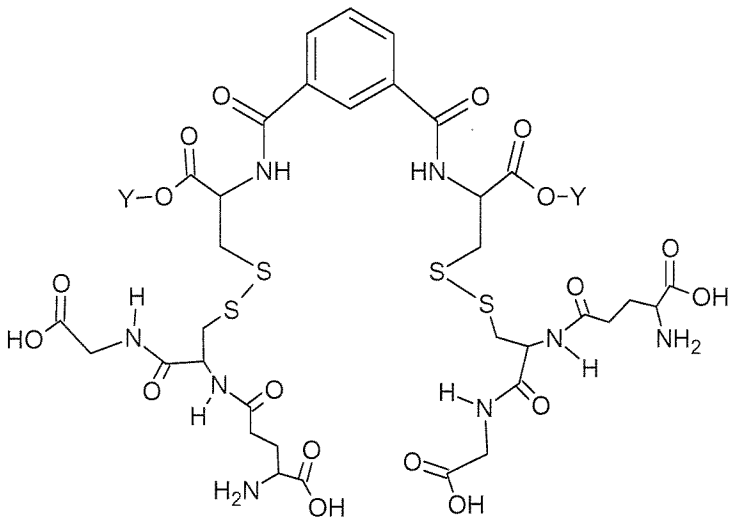


where R^2 may be independently selected from a group comprising hydrogen, alkyls, aryls, a carboxyl group, carboxylate esters, organic groups and biological groups, n independently equals 1-10, and Y may be independently selected from a group comprising hydrogen, polymers, silicas and silica supported substrates. Chelate ligands of this general formula may be referred to as "glutathione AB9" or abbreviated to "GAB9."

[0039] In one useful embodiment of GAB9, the chelate ligand is of the formula:

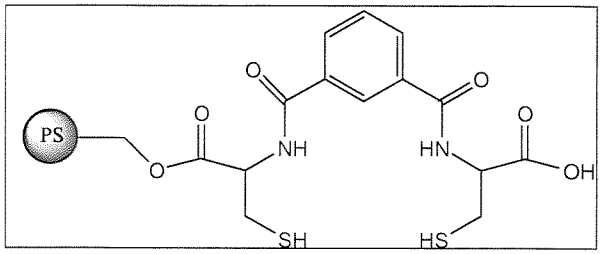


or



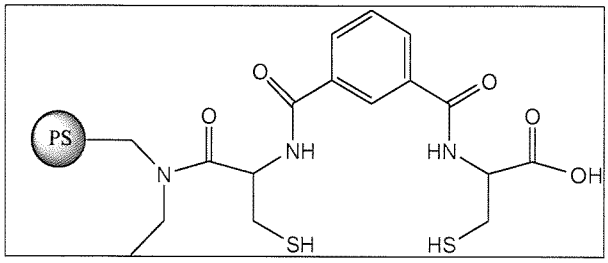
where Y may be independently selected from a group comprising hydrogen, polymers, silicas and silica supported substrates.

[0040] In another useful embodiment of AB9, the AB9 may be material supported with a structure of:

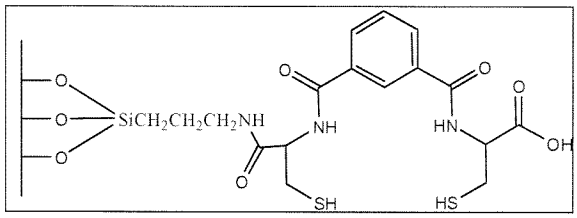


where PS may be polystyrene or a co-polymer containing polystyrene. In one even more particular embodiment, PS may be chloromethylated polystyrene-co-divinylbenzene (2 % DVB, 200 – 400 mesh).

[0041] In one particular embodiment of the material supported AB9, the material may be derivatized prior to the addition of AB9, or its equivalent, providing a structure with the formula:

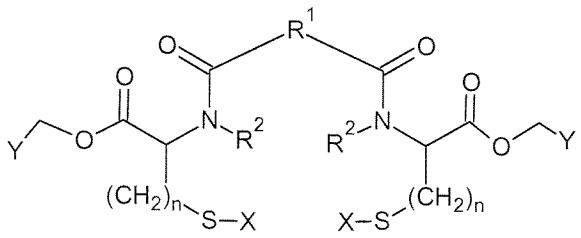


[0042] Alternatively, AB9 may be loaded onto amine functionalized silica (Silica-NH_2). In one exemplary embodiment, Silica-NH_2, produced by binding γ-aminopropyltriethoxysilane on silica-60 (Si60), may be refluxed in a solution of AB9 in ethanol producing a structure of the formula:

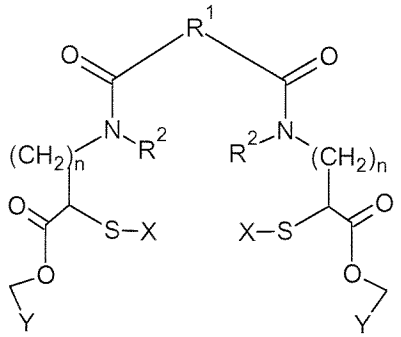


[0043] In an alternative preparation, $SiNH_2$ may be treated with AB9 in the presence of dicyclohexylcarbodiimide (DCC) to facilitate the coupling of the AB9 to the amine of the PS.

[0044] In another useful embodiment, the chelate ligands are of the formula:

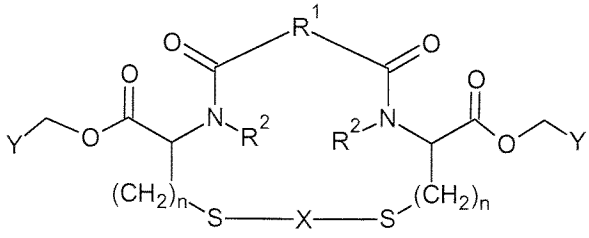


or

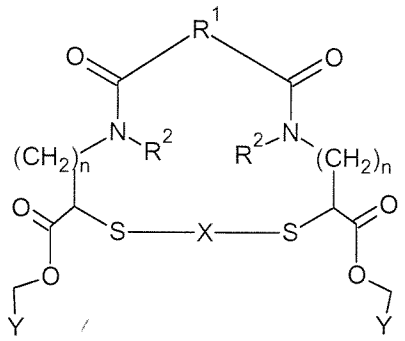


where R^1 may be selected from a group comprising benzene, pyridine, naphthalene, anthracene, phenanthrene and alkyl groups, R^2 may be independently selected from a group comprising hydrogen, alkyls, aryls, a carboxyl group, carboxylate esters, organic groups and biological groups, X may be independently selected from a group comprising hydrogen, lithium, sodium, potassium, rubidium, cesium, francium, cysteine and glutathione, n independently equals 1-10, and Y is a methyl group. Chelate ligands of these general formulas may be referred to as "methyl ester AB9" or abbreviated to "MEAB9."

[0045] In one useful embodiment of MEAB9, the chelate ligands are of the formula:

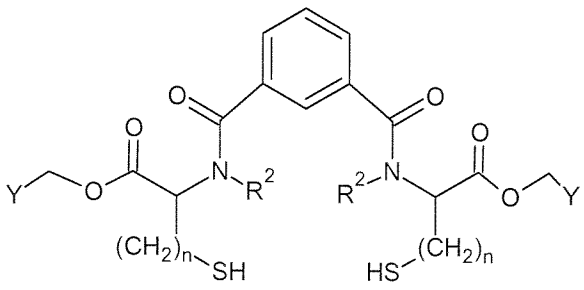


or

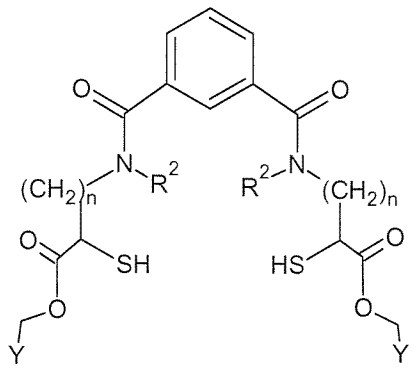


where R^1 may be selected from a group comprising benzene, pyridine, naphthalene, anthracene, phenanthrene and alkyl groups, R^2 may be independently selected from a group comprising hydrogen, alkyls, aryls, a carboxyl group, carboxylate esters, organic groups and biological groups, X may be independently selected from a group comprising beryllium, magnesium, calcium, strontium, barium and radium, n independently equals 1-10, and Y is a methyl group.

[0046] In another useful embodiment of MEAB9, the chelate ligands are of the formula:

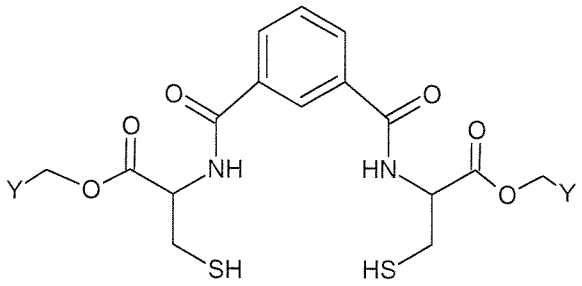


or

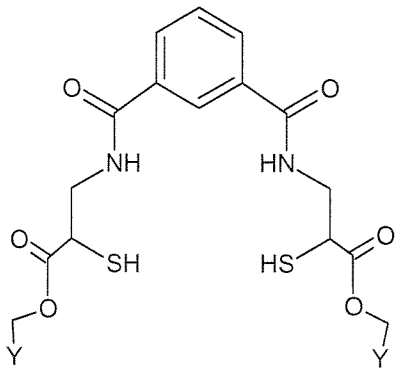


where R^2 may be independently selected from a group comprising hydrogen, alkyls, aryls, a carboxyl group, carboxylate esters, organic groups and biological groups, n independently equals 1-10, and Y is a methyl group.

[0047] In another useful embodiment of MEAB9, the chelate ligands are of the formula:

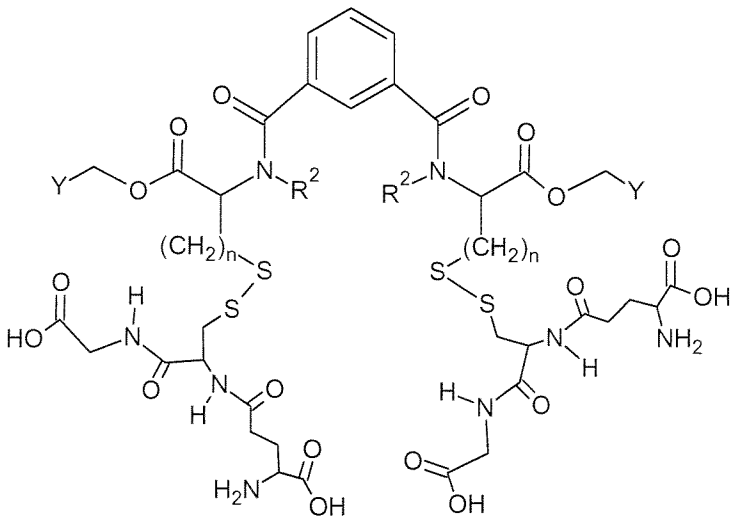


or

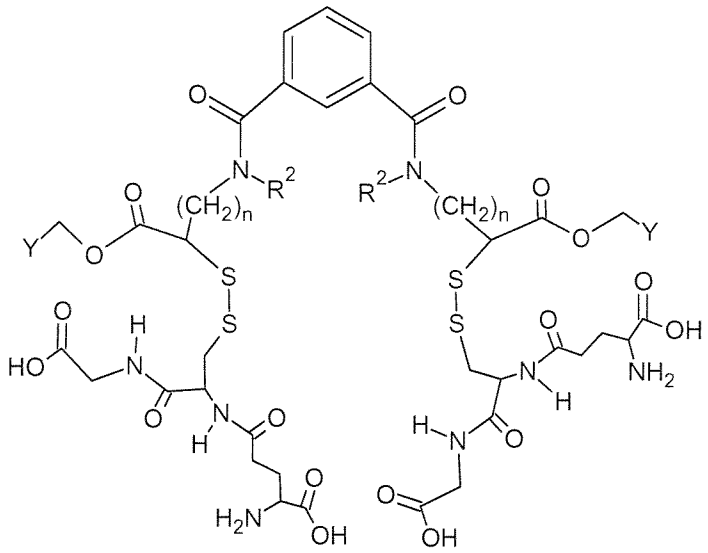


where Y is a methyl group.

[0048] In another useful embodiment of MEAB9, the chelate ligands are of the formula:

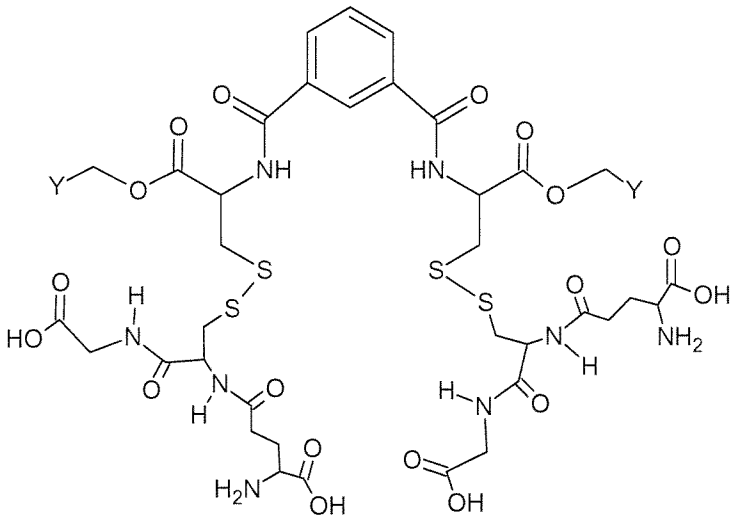


or

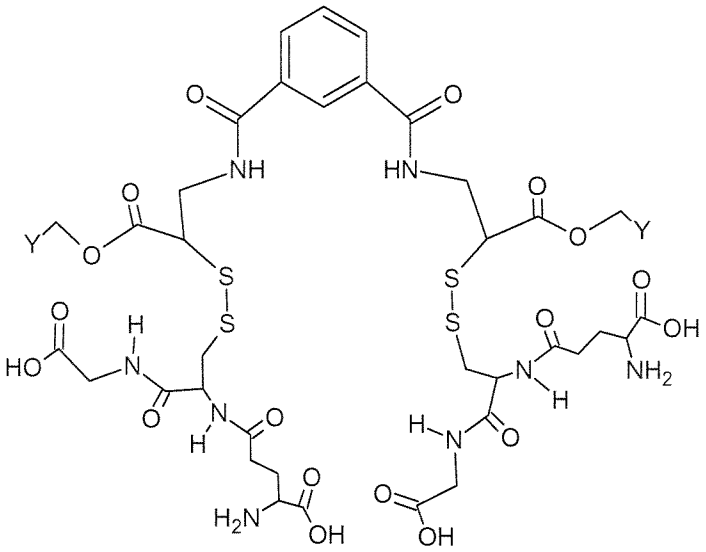


where R^2 may be independently selected from a group comprising hydrogen, alkyls, aryls, a carboxyl group, carboxylate esters, organic groups and biological groups, n independently equals 1-10, and Y is a methyl group. Chelate ligands of this general formula may be referred to as "glutathione methyl ester AB9" or abbreviated to "GMEAB9."

[0049] In one useful embodiment of GMEAB9, the chelate ligands are of the formula:

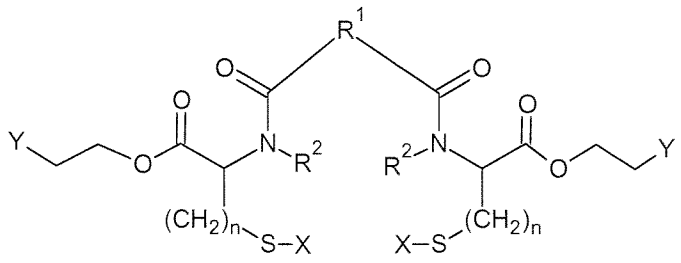


or

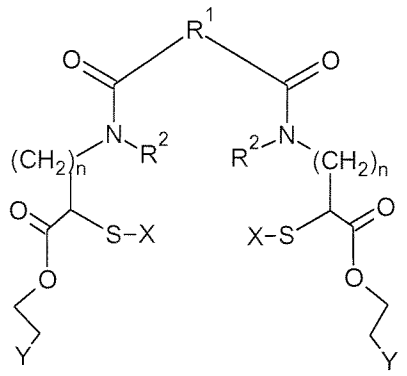


where Y is a methyl group.

[0050] In another useful embodiment, the chelate ligands are of the formula:

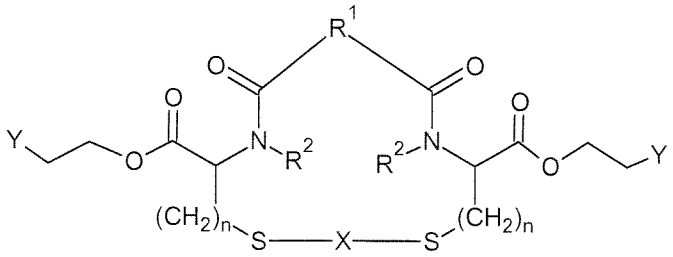


or

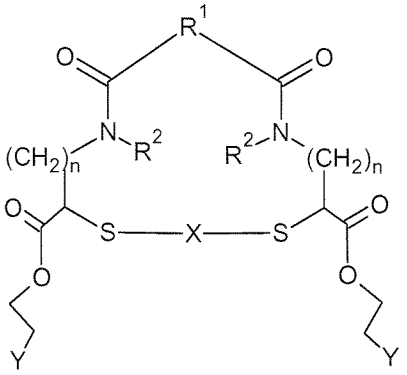


where R^1 may be selected from a group comprising benzene, pyridine, naphthalene, anthracene, phenanthrene and alkyl groups, R^2 may be independently selected from a group comprising hydrogen, alkyls, aryls, a carboxyl group, carboxylate esters, organic groups and biological groups, X may be independently selected from a group comprising hydrogen, lithium, sodium, potassium, rubidium, cesium, francium, cysteine and glutathione, n independently equals 1-10, and Y is an ethyl group. Chelate ligands of this general formula may be referred to as "ethyl ester AB9" or abbreviated to "EEAB9."

[0051] In one useful embodiment of EEAB9, the chelate ligands are of the formula:

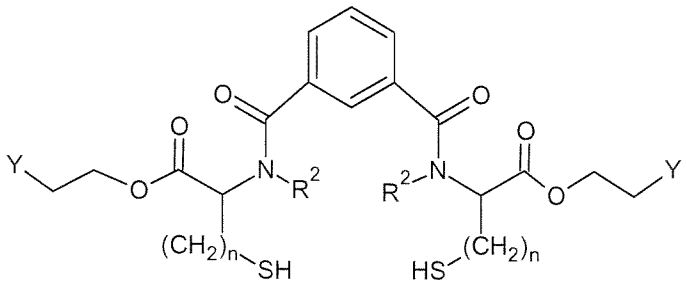


or

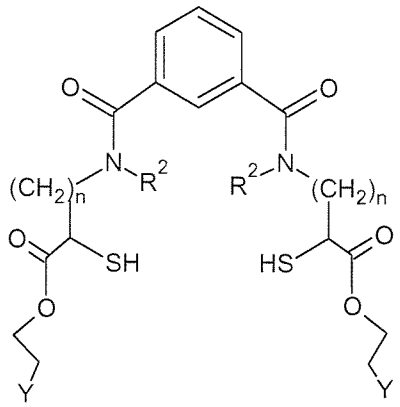


where R^1 may be selected from a group comprising benzene, pyridine, naphthalene, anthracene, phenanthrene and alkyl groups, R^2 may be independently selected from a group comprising hydrogen, alkyls, aryls, a carboxyl group, carboxylate esters, organic groups and biological groups, X may be independently selected from a group comprising beryllium, magnesium, calcium, strontium, barium and radium, n independently equals 1-10, and Y is an ethyl group.

[0052] In another useful embodiment of EEAB9, the chelate ligands are of the formula:

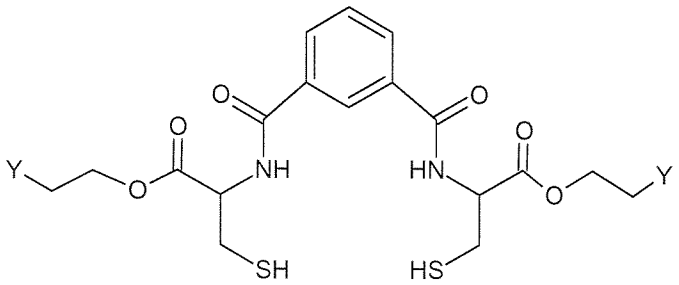


or

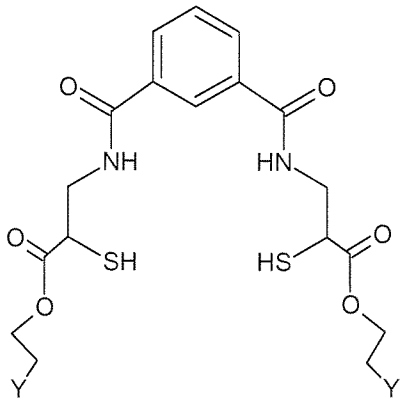


where R^2 may be independently selected from a group comprising hydrogen, alkyls, aryls, a carboxyl group, carboxylate esters, organic groups and biological groups, n independently equals 1-10, and Y is an ethyl group.

[0053] In another useful embodiment of EEAB9, the chelate ligands are of the formula:

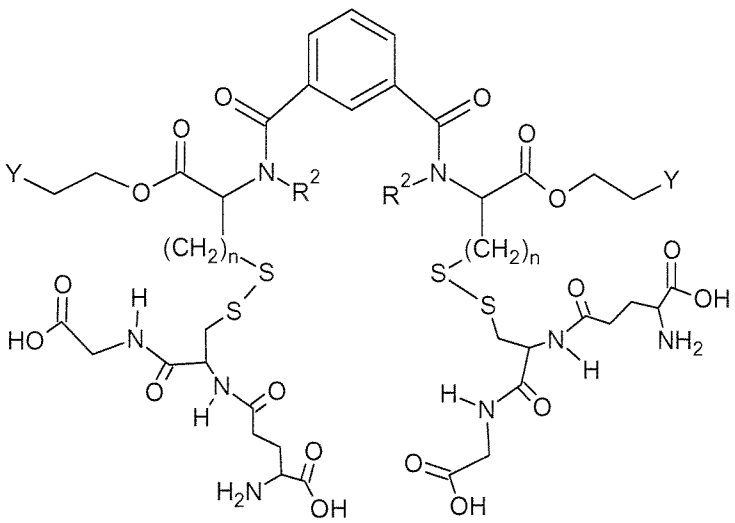


or

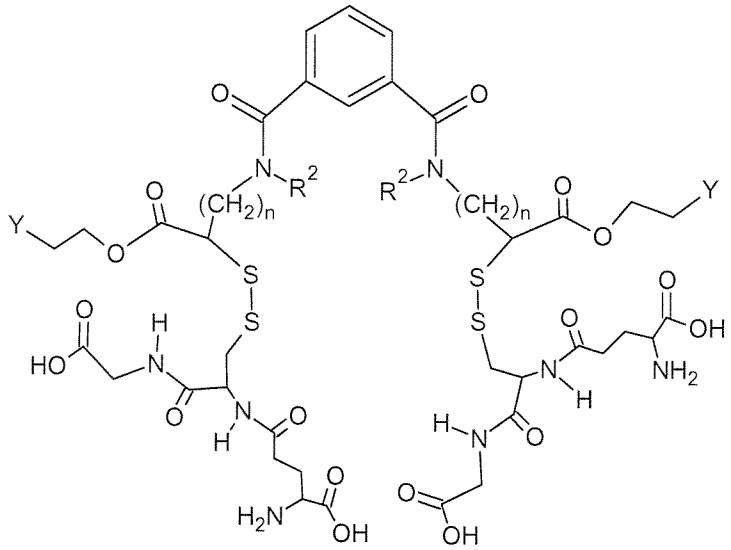


where Y is an ethyl group.

[0054] In another useful embodiment of EEAB9, the chelate ligands are of the formula:

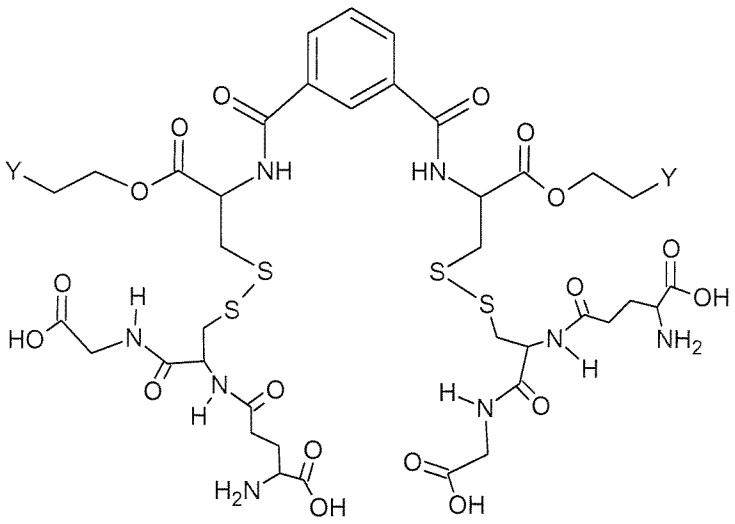


or

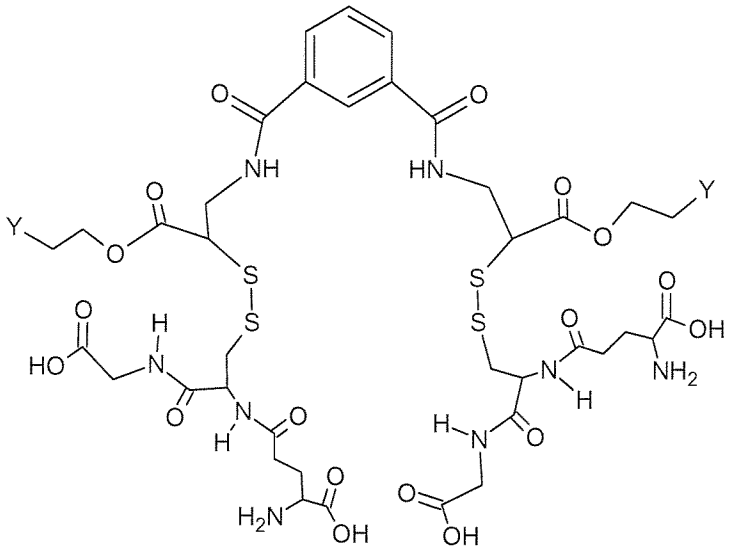


where R^2 may be independently selected from a group comprising hydrogen, alkyls, aryls, a carboxyl group, carboxylate esters, organic groups and biological groups, n independently equals 1-10, and Y is an ethyl group. Chelate ligands of this general formula may be referred to as "glutathione ethyl ester AB9" or abbreviated to "GEEAB9."

[0055] In one useful embodiment of GEEAB9, the chelate ligands are of the formula:

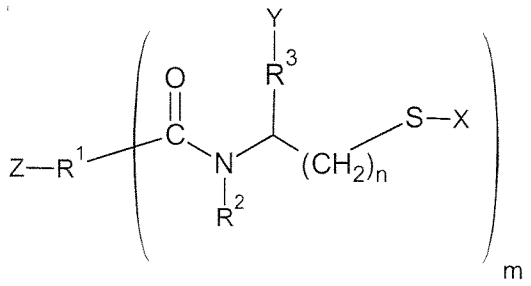


or

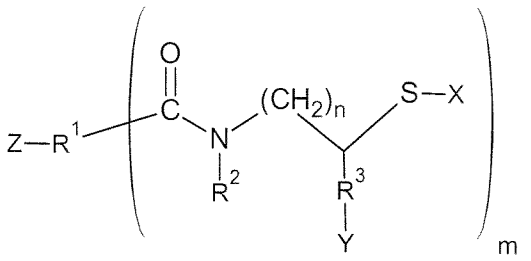


where Y is an ethyl group.

[0056] In another useful embodiment, the chelate ligands are of the formula:



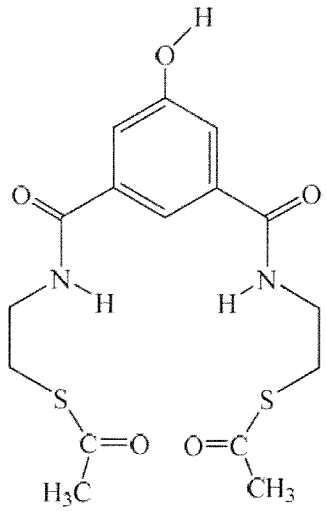
or



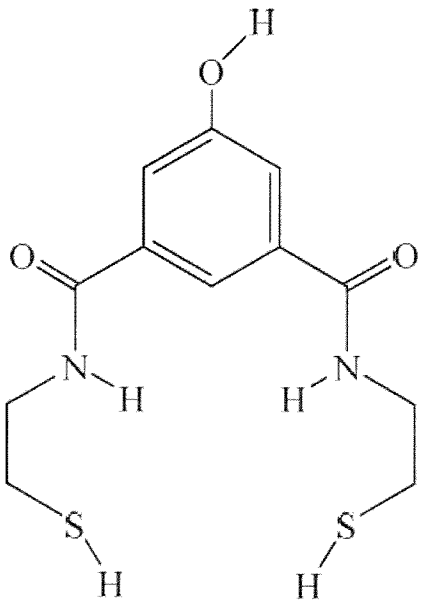
where R^1 is selected from a group including benzene, pyridine, pyridin-4-one, naphthalene, anthracene, phenanthrene and alkyl groups, R^2 is independently selected from a group including hydrogen, alkyls, aryls, a carboxyl group, carboxylate esters, organic groups and biological groups, R^3 is independently selected from a group including alkyls, aryls, a carboxyl group, carboxylate esters, organic groups and

biological groups, X is independently selected from a group including hydrogen, lithium, sodium, potassium, rubidium, cesium, francium, beryllium, magnesium, calcium, strontium, barium, radium, alkyls, aryls, a carboxyl group, carboxylate esters, cysteine, homocysteine, glutathione, lipoic acid, dihydrolipoic acid, thiophosphate, N-acetyl cysteine, mercaptoacetic acid, mercaptopropionic acid, γ-glutamyl cysteine, phytochelatins, thiolsalicylate, organic groups and biological groups, n independently equals 1-10, m=1-6, Y is independently selected from a group including hydrogen, polymers, silicas and silica supported substrates, and Z is selected from a group including hydrogen, alkyls, aryls, a carboxyl group, carboxylate esters, a hydroxyl group, NH_2, HSO_3, halogens, a carbonyl group, organic groups, biological groups, polymers, silicas and silica supported substrates.

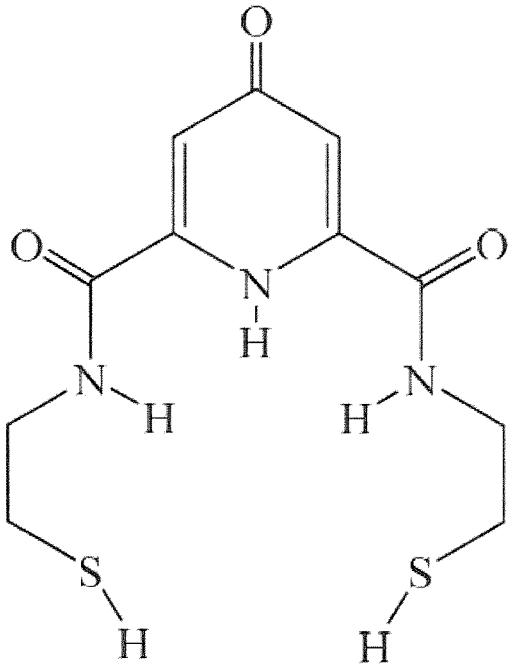
[0057] One exemplary compound comprises R^1 = benzene, R^2 = hydrogen, R^3 = hydrogen, m=2, n=1, X = an acetyl group, Y = hydrogen, and Z = a hydroxyl group as is shown below:



[0058] Another exemplary compound comprises R^1 = benzene, R^2 = hydrogen, R^3 = hydrogen, m=2, n=1, X = hydrogen, Y = hydrogen, and Z = a hydroxyl group as is shown below:

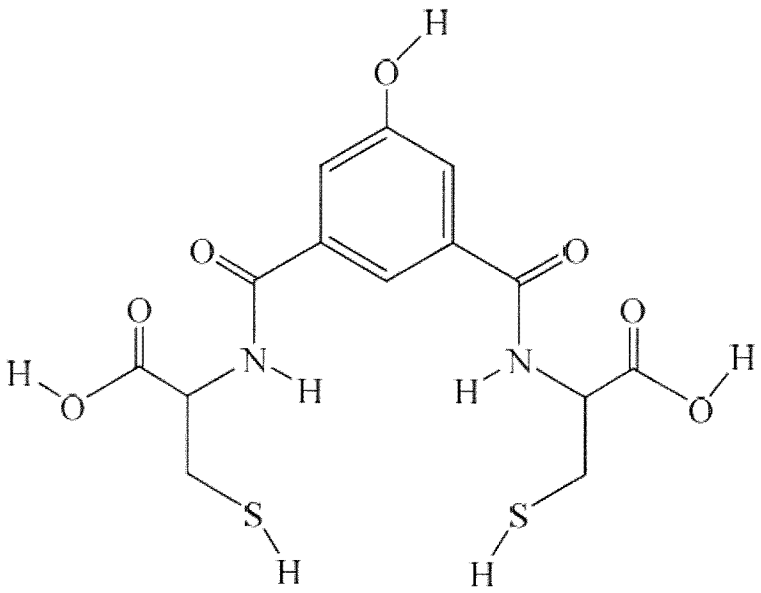


[0059] Another exemplary compound comprises R^1 = pyridin-4-one, R^2 = hydrogen, R^3 = hydrogen, m=2, n=1, X = hydrogen, Y = hydrogen, and Z = a hydroxyl group as is shown below:

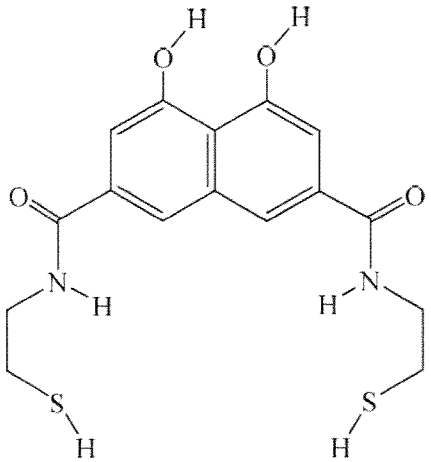


[0060] Within the scope of the present disclosure, other new compounds can be prepared having different combinations of Z, Y, n and X groups. For example, one exemplary compound utilizing cysteine in the synthetic procedure can comprise R^1 =

benzene, R^2 = hydrogen, R^3 = a carboxyl group, m=2, n=1, X = hydrogen, Y = hydrogen, and Z = a hydroxyl group as is shown below:



[0061] As will be appreciated by one skilled in the art, it is possible to utilize aromatic groups other than benzene and pyridine for the introduction of the thiol and thiolate groups. For example, naphthalene, anthracene, phenanthrene, etc. can be used. For example, one such exemplary compound can comprise R^1 = naphthalene, R^2 = hydrogen, R^3 = hydrogen, m=2, n=1, X = hydrogen, Y = hydrogen, and Z = hydroxyl groups:



[0062] Accordingly, the novel ligands of the present invention may also be adapted to a variety of environmental situations requiring binding and/or removal of metals and/or main group elements, such as, for example, additives in flue gas desulphurization (FGD) scrubbers to remove metals and/or main group elements from coal-fired power plant emissions, treatment of industrial waste water, treatment of acid mine drainage, soil remediation, and the like. As will be appreciated by those skilled in the art, the chelate ligands of the present invention may be utilized alone or in varying combinations to achieve the objects of the present invention.

[0063] In one aspect, the present disclosure relates to a method of removing metals and/or main group elements from a starting material. The method of the present invention comprises contacting a starting material (gas, liquid or solid) with an effective amount of a novel sulfur-containing chelate ligand as described above for a sufficient time to form at least one stable ligand-metal and/or ligand-main group element complex(es). The ligand-metal and/or ligand-main group element complex(es) may remain stable through a range of acidic and basic pH values. In other words, the ligand-metal and/or ligand-main group element complex(es) do not release appreciable amounts of the contaminant element(s) through a range of acidic and basic pH values. For example, the B9-Hg complex precipitate does not release appreciable amounts of mercury within a pH range from about 1 to about 13. However, generally, ligand-metal and/or ligand-main group element complex(es) do not release appreciable amounts of the contaminant elements within a pH range from about 6 to about 8.

[0064] In another aspect, the present disclosure relates to a method of treating water, such as surface, ground, or waste water, containing metals and/or main group elements, comprising admixing said water with an effective amount of the sulfur-containing chelate ligand as described above for a sufficient time to form at least one stable ligand-metal and/or ligand-main group element complex(es), and separating said complex(es) from said water.

[0065] In still another aspect, the present disclosure relates to a method of treating aqueous acid mine drainage or water from actual mining processes containing soft heavy metals and/or main group elements, comprising admixing said acid mine drainage or water from actual mining processes with an effective amount of the

sulfur-containing chelate ligand as described above for a sufficient time to form at least one stable ligand-metal and/or ligand-main group element complex(es), and separating said complex(es) from said acid mine drainage.

[0066] In still another aspect, the present disclosure relates to a method of remediation of soil containing soft heavy metals and/or main group elements, comprising admixing said soil with an effective amount of the sulfur-containing chelate ligand as described above for a sufficient time to form at least one stable ligand-metal and/or ligand-main group element complex(es). The soil so treated may then be left in situ or removed for disposal without concerns regarding leaching of said metals and/or main group elements into the environment.

[0067] In yet another aspect, the present disclosure relates to a method of treating a gas, such as an emissions gas from a power plant containing soft heavy metals and/or main group elements, comprising passing said gas through a filter utilizing an effective amount of the sulfur-containing chelate ligand as described above to form at least one stable ligand-metal and/or ligand-main group complex(es), therefore filtering said complex from said gas.

[0068] In yet another aspect, the present disclosure relates to a method of therapeutically treating a human and/or animal with the sulfur-containing chelate ligands described above, to methods for altering the hydrophobicity or hydrophilicity of such chelators in order to tailor the tissue to which the chelators partition, and to various chelate ligands synthesized to accomplish those methods. The chelators find use in binding and clearance of a variety of heavy metals and/or main group elements, including without limitation mercury, lead, arsenic, cadmium, tin, bismuth, indium, nickel, copper, thallium, gold, silver, platinum, uranium, iron, molybdenum, thorium, polonium, plutonium, antimony, and the like.

[0069] Broadly, the method comprises selecting chelate ligands as described herein and modifying the ligands to the desired state of hydrophilicity or hydrophobicity in accordance with the tissue into which the chelator is desired to partition. Still further, the method described herein contemplates modifying such chelators such that an initially hydrophilic chelator derivative is rendered hydrophobic after administration, to more effectively partition into intracellular areas and lipid-containing tissues. Even

further, it is contemplated to provide a chelator derivative which is initially hydrophobic for partitioning into lipid-containing tissues for clearance via a fecal route, and after such partitioning is rendered hydrophilic for clearance via the kidney.

[0070] Still yet further, it is contemplated to provide uncharged, ester-containing chelate ligands which are initially hydrophilic, to allow uniform delivery throughout the body such as by an intravenous route. After delivery, the chelator is reduced to a hydrophobic condition for partitioning into lipid-containing areas. Following intracellular localization, the hydrophobic chelate ligand is converted again to a hydrophilic state. It will be appreciated that this latter aspect provides a chelate ligand which is uniformly deliverable throughout the body (such as by IV procedures), which partitions into lipid-containing areas where heavy metals concentrate, and which is available for clearance via both kidney and the fecal route. This is similar in function to the method of action of, for example, P450 detoxifying enzymes, which oxidize hydrophobic, uncharged organic molecules which are then converted to water soluble forms by addition of water soluble compounds (e.g. glutathione, sulfate) for removal through naturally designed systems.

[0071] In one embodiment of the described method, a chelate ligand such as those described above may be coupled to a charged molecule having a terminal sulfhydryl group to provide a hydrophilic derivative for delivery. After distribution of the derivative, such as by intravenous delivery, the derivative reverts to the hydrophilic form via a reductive process in the bloodstream, releasing the original hydrophobic chelate ligand and the previously coupled charged molecule. In particular embodiments of this aspect, the charged molecule is coupled to the starting chelate ligand compound via disulfide bonds, which are readily reduced in the body to release the charged molecule and the hydrophobic chelate ligand which then partitions into lipid-containing tissue. Such charged compounds should be non-toxic, natural compounds having a free thiol group.

[0072] Once in the microenvironment of the tissue, the hydrophobic chelate ligand partitions into lipid-containing tissues, existing in close proximity to a majority of the body burden of heavy metals and thereby improving the effectiveness of the chelator by such proximity. A variety of natural and synthetic charged molecules including

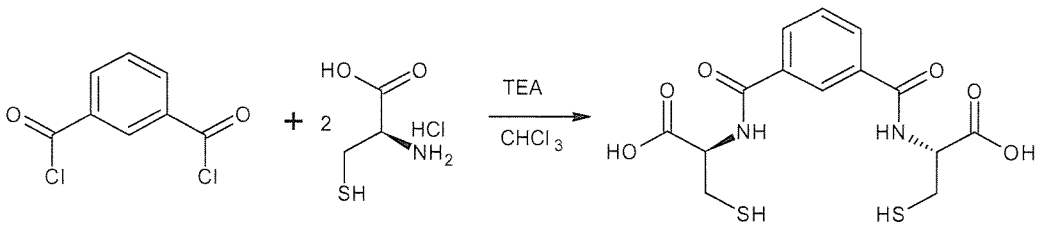
terminal sulfhydryl groups are contemplated herein (*e.g.*, glutathione, cysteine, homocysteine, lipoic acid, dihydrolipoic acid, thiophosphate, N-acetyl cysteine, mercaptoacetic acid, mercaptopropionic acid, γ-glutamyl cysteine, phytochelatins and thiolsalicylate).

[0073] In the microenvironment of the cells or tissues, cellular esterases hydrolyze the uncharged ester groups into charged carboxylic acids. This conversion renders the chelators hydrophilic, and excretable via the kidney in a rapid manner. Because the chelate ligands described herein are true chelators rather than mere binders, excretion via a kidney route does not carry the risk of release of bound metal in the kidney as is the case for currently approved metal binders used in other methods of chelation therapy.

[0074] The compositions and methods of the present invention may be accomplished by various means which are illustrated in the examples below. These examples are intended to be illustrative only, as numerous modifications and variations will be apparent to those skilled in the art. Examples 1-8 are directed to embodiments of the above-detailed chelate ligands, and Examples 9-18 are directed to embodiments of the above-detailed chelate ligands that are material supported.

EXAMPLE 1

[0075] This example details the synthesis of one non-limiting embodiment of AB9 by the following scheme:

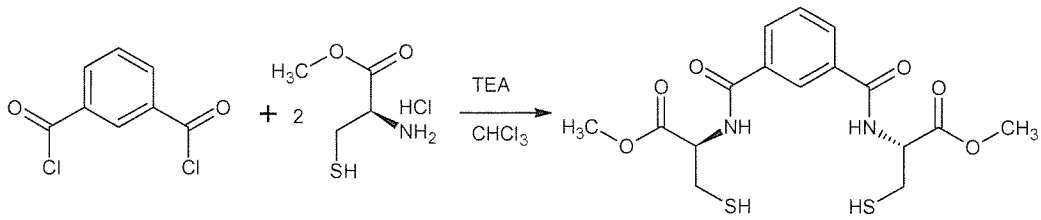


0.78 grams of L-cysteine hydrochloride (5.0 mmol) obtained from Sigma-Aldrich® was dissolved in 100 mL deionized water. 1.02 grams of triethylamine (10 mmol; 1.4 mL), hereinafter referred to as "TEA," and 0.5 grams of isophthaloyl chloride (2.5 mmol) obtained from TCI® were each dissolved separately in 20 mL of tetrahydrofuran, hereinafter referred to as "THF," obtained from Acros Organics®. The TEA dissolved in THF was slowly added to the solution of L-cysteine hydrochloride in deionized water, which was stirring in a flask under a flow of N_2 gas.

After stirring for 5-10 minutes, the isophthaloyl chloride dissolved in THF was slowly added to the flask. As the reaction proceeded, the color of the reaction mixture turned to light yellow. The reaction mixture continued stirring for 16-18 hours. At the end of the 16-18 hours, the aqueous layer was extracted utilizing 100 mL of ethyl acetate. The ethyl acetate layer was then dried over sodium sulfate, filtered, and evacuated to dryness. The product was recovered as a light yellow solid. The product was soluble in $CHCl_3$, acetone, ethanol and water.

EXAMPLE 2

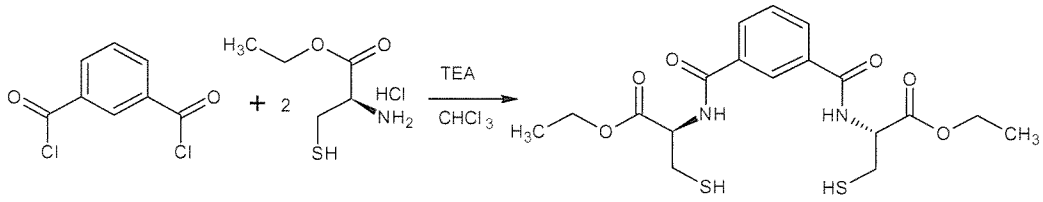
[0076] This example details the synthesis of one non-limiting embodiment of MEAB9 by the following scheme:



2.57 grams of L-cysteine methyl ester hydrochloride (15 mmol) was dissolved in 150 mL of $CHCl_3$. 1.52 grams of TEA (15 mmol; 2.07 mL) was dissolved in 25 mL of $CHCl_3$. 1.0 gram of isophthaloyl chloride (5 mmol) was dissolved in 40 mL of $CHCl_3$. The TEA solution and the isophthaloyl chloride solution were slowly added to the L-cysteine methyl ester hydrochloride solution. The reaction was stirred for 24 hours. The reaction solution was then filtered and the filtrate was washed three times with 200 mL of 10% Omnitrace® hydrochloric acid. After washing, the $CHCl_3$ layer was filtered again and dried over anhydrous Na_2SO_4. The $CHCl_3$ was then removed under vacuum and the product was obtained as a highly viscous oily liquid. The oily liquid was dissolved again in $CHCl_3$ and the $CHCl_3$ was subsequently removed under vacuum. This process was repeated twice and the resulting white solid was then washed twice with diethyl ether. The remaining solvent was removed and the solid was dried under vacuum. The product was recovered as a white solid. The product was soluble in $CHCl_3$, acetone, ethanol and water.

EXAMPLE 3

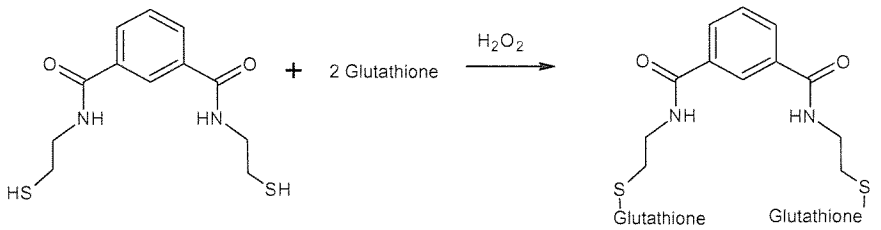
[0077] This example details the synthesis of one non-limiting embodiment of EEAB9 by the following scheme:



2.72 grams of L-Cysteine ethyl ester hydrochloride (15 mmol) was dissolved in 150 mL of $CHCl_3$. 1.48 grams of TEA (15 mmol; 2.02 mL) was dissolved in 25 mL of $CHCl_3$. 1 gram of isophthaloyl chloride (5 mmol) was dissolved in 40 mL of $CHCl_3$. The TEA solution and the isophthaloyl chloride solution were slowly added to the L-cysteine ethyl ester hydrochloride solution. The reaction was stirred for 24 hours. The reaction solution was then filtered and the filtrate was washed with 1.5 L of 20% Omnitrace® hydrochloric acid. After washing, the $CHCl_3$ layer was filtered again and dried over anhydrous Na_2SO_4. The $CHCl_3$ was then removed under vacuum and the product was obtained as a highly viscous oily liquid. The oily liquid was dissolved again in $CHCl_3$ and the $CHCl_3$ was subsequently removed under vacuum. This process was repeated twice and the resulting white solid was then washed twice with diethyl ether. The remaining solvent was removed and dried under vacuum. The product was recovered as a white solid. The product was soluble in $CHCl_3$, acetone, ethanol and water.

EXAMPLE 4

[0078] This example details the synthesis of one non-limiting embodiment of GB9 by the following scheme:



0.284 grams (1mM) of B9 was dissolved in tetrahydrofuran (THF)/H_2O (50:50 v:v) with 0.76 grams glutathione. 1 mL of 10% H_2O_2 was added with stirring and allowed to react overnight at room temperature. The reaction mix was pumped through a diethylaminoethyl-cellulose (DEAE cellulose) column (2 cm by 20 cm long) in the hydroxide form and washed with 200 ml of distilled water. Bound material was

eluted using a 0-400 mM gradient of triethylammonium bicarbonate (TEAB) buffer with 10 mL fractions being collected. Elution of B9 containing product was monitored by an ultraviolet flow-through device. Only one peak was detected in the material that bound to the DEAE cellulose and eluted with the elution buffer. Collected fractions containing UV absorbance were evaporated to dryness over four co-evaporations with methanol/water to remove TEAB. The resulting material was a fine white powder that readily dissolved in water and provided an ultraviolet spectra nearly identical to the starting material (B9). The structure of this compound (termed GB9) is set forth above. The material was tested by thin-layer chromatography (TLC) by two different TLC procedures. On a silica gel matrix developed with 50:50 THF/ethanol, the Rf values for the starting and ending compound were 0.5 and 0.05, respectively. On a PEI-cellulose matrix developed with 0.4 M ammonium bicarbonate solution the Rf values for B9 and GB9 were 0.0 and 0.75, respectively.

[0079] In addition, GAB9, GMEAB9 and GEEAB9 may also be synthesized utilizing similar methods.

EXAMPLE 5

[0080] 2.80 grams of AB9 (7.5 mmol) dissolved in 75 mL of 95% ethanol was added to a stirred solution of 2.0 grams of $Cd(C_2H_3O_2)_2 \cdot 2H_2O$ (7.5 mmol) dissolved in 100 mL of deionized water. A white precipitate, the compound AB9-Cd, formed upon mixing of the two solutions. The mixture was stirred 7 - 8 hours before being filtered under vacuum. The resulting white compound was rinsed three times each with 100 mL of deionized water and 100 mL of 95% ethanol. The compound was then dried under vacuum, producing a yield of 2.13 grams. The melting point of the compound was 241-244°C. The compound was insoluble in water, ethanol, acetone, dimethyl sulfoxide, chloroform and hexane.

EXAMPLE 6

[0081] 0.99 grams of AB9 (2.66 mmol) dissolved in 75 mL of 95% ethanol was added to a stirred solution of 0.71 grams of $HgCl_2$ (2.61 mmol) dissolved in 100 mL of deionized water. A white precipitate, the compound AB9-Hg, formed upon mixing of the two solutions. The mixture stirred 6 hours before being filtered under vacuum. The white compound was rinsed three times each with 100 mL of deionized water and 100 mL of 95% ethanol. The compound was then dried under vacuum, producing a

yield of 0.97 grams. The melting point of the compound was 153-155 ^{0}C. The compound was insoluble in water, ethanol, acetone, dimethyl sulfoxide, chloroform and hexane.

EXAMPLE 7

[0082] 2.0 grams of AB9 (5.4 mmol) dissolved in 75 mL of 95% ethanol was added to a stirred solution of 1.5 grams of $PbCl_2$ (5.4 mmol) dissolved in 150 mL of deionized water. A white precipitate, the compound AB9-Pb, formed upon mixing of the two solutions. The mixture was stirred 7 -8 hours before being filtered under vacuum. The white compound was rinsed three times each with 100 mL of deionized water and 100 mL of 95% ethanol. The compound was then dried under vacuum, producing a yield of 1.68 grams. The melting point of the compound was 220-225 ^{0}C. The compound was insoluble in water, ethanol, acetone, dimethyl sulfoxide, chloroform or hexane.

EXAMPLE 8

[0083] 192 milligrams of MEAB9 (0.5 mmol) dissolved in 20 mL ethanol was added to a stirred solution of 130 milligrams of $HgCl_2$ (0.5 mmol) dissolved in 20 mL deionized water. A white precipitate, the compound MEAB9-Hg, formed upon mixing of the two solutions. The mixture stirred for 5 hours before being filtered under vacuum. The white compound was washed with 200 mL of deionized water and 200 mL of ethanol and dried under air to produce a yield of 0.16 grams. The melting point of this compound was 166 - 169 ^{0}C. The compound was soluble in dimethyl sulfoxide and highly basic water.

EXAMPLE 9

[0084] 200 milligrams of EEAB9 (0.5 mmol) dissolved in ethanol was added to a stirred solution of 0.71 grams of $HgCl_2$ (0.5 mmol) dissolved in deionized water. A white precipitate, the compound EEAB9-Hg, formed upon mixing of the two solutions. The mixture was stirred for 5 hours before being filtered under vacuum. The white compound was washed with 150 mL of deionized water and 150 mL of ethanol and dried under air to produce a yield of 0.20 grams. The melting point of the compound was 150 - 153 ^{0}C. The compound was soluble in dimethyl sulfoxide and highly basic water.

EXAMPLE 10

[0085] EEAB9 (as detailed in Example 3 above) was injected subcutaneously into rats at levels as high as 1.5 millimoles per kg of body weight. This represented 100 to 1,000 times the concentration expected to be used in chelation therapies for heavy metal toxicity. No detectable negative effects were observed as determined by physical activity and weight gain.

EXAMPLE 11

[0086] Rats were injected every three days with the EEAB9 (as detailed in Example 3 above) at 300, 400 and 1,500 micromoles per kg body weight with no observable toxic effects or weight loss. This represented an exposure of over 2,700 micromoles per kg body weight over a 10 day period with no observable toxic effect.

EXAMPLE 12

[0087] Individual goldfish were placed in 200 ml water with 10mM sodium chloride in 250 ml Erlenmeyer flasks (pH 7.00). Air was pumped into the flasks to maintain a healthy supply of oxygen. The 24 hour day was divided in to a 12 hour light/dark photoperiod. The goldfish were allowed to acclimatize for a week before the experiment was conducted, with daily water changes. Goldfish were fed standard fish food for 15 minutes each day before the water was changed.

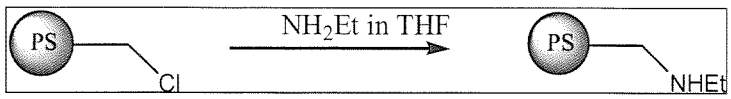
[0088] The chelate ligands were dissolved in dimethyl sulfoxide (DMSO, 0.5 ml) before addition to the flasks. The experimental treatments evaluated are as listed in Table 1 below, and included mercuric acetate, B9, EEAB9, GB9, GEEAB9, and DMSO in the amounts shown in Table 1. B9 and EEAB9 were dissolved in DMSO (0.5 ml) before addition to the water. No precipitate was formed during the dissolution. When mercuric acetate solution in water was added, a precipitate formed. As shown in Table 1, the goldfish exposed to mercuric acetate without chelator died within 30 minutes, whereas the fish exposed to the chelate ligands according to the present disclosure did not die even when exposed to lethal levels of mercuric acetate.

Table 1. Exposure of goldfish to mercuric acetate with and without chelators.

			Time 30 min	1hr	6hr	12hr	24 hr
Flask	Compound	Amount					
1	Mercuric acetate	0.5 mM	Dead				
2	Mercuric acetate	0.5 mM	Dead				
3	CT01	1.0 mM	Alive	Alive	Alive	Alive	Alive
4	CT01	1.0 mM	Alive	Alive	Alive	Alive	Alive
5	CT03	1.0 mM	Alive	Alive	Alive	Alive	Alive
6	CT03	1.0 mM	Alive	Alive	Alive	Alive	Alive
7	CT01 + Mercuric acetate	1.0mM + 0.5 mM	Alive	Alive	Alive	Alive	Alive
8	CT01 + Mercuric acetate	1.0mM + 0.5 mM	Alive	Alive	Alive	Alive	Alive
9	CT03 + Mercuric acetate	1.0mM + 0.5 mM	Alive	Alive	Alive	Alive	Alive
10	CT03 + Mercuric acetate	1.0mM + 0.5 mM	Alive	Alive	Alive	Alive	Alive
11	CT01G	1.0 mM	Alive	Alive	Alive	Alive	Alive
12	CT01G	1.0 mM	Alive	Alive	Alive	Alive	Alive
13	CT01G+Mercuric acetate	1.0 mM + 0.5 mM	Alive	Alive	Alive	Alive	Alive
14	CT01G+Mercuric acetate	1.0 mM + 0.5 mM	Alive	Alive	Alive	Alive	Alive
15	CT03G + Mercuric acetate	1.0 mM + 0.5 mM	Alive	Alive	Alive	Alive	Alive
16	CT03G + Mercuric acetate	1.0 mM + 0.5 mM	Alive	Alive	Alive	Alive	Alive
17	Mercuric acetate +DMSO	0.5mM + 0.5ml	Dead				
18	Mercuric acetate+DMSO	0.5mM + 0.5ml	Dead				
19	CONTROL (DMSO)	0.5ml	Alive	Alive	Alive	Alive	Alive
20	CONTROL (DMSO)	0.5ml	Alive	Alive	Alive	Alive	Alive
21	CONTROL		Alive	Alive	Alive	Alive	Alive
22	CONTROL		Alive	Alive	Alive	Alive	Alive

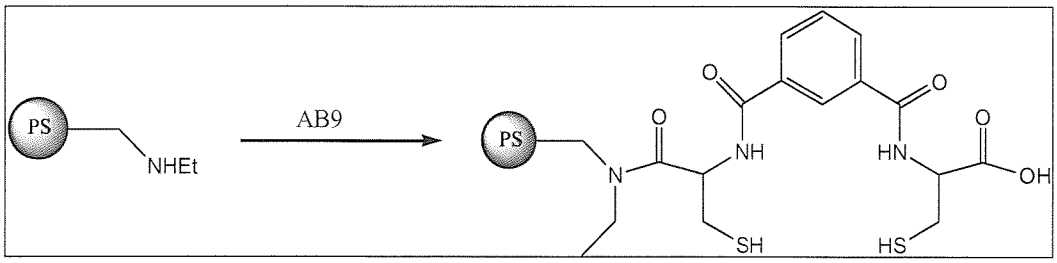
EXAMPLE 13

[0089] In this example, AB9 loaded polystyrene (PS-AB9) was attempted by first derivatizing PS-CH_2Cl. This follows the literature procedure found in Roscoe, S.B., et. al, *Journal of Polymer Science: Part A: Polymer Chemistry*, **2000**, 38, 2979-2992. First PS-CH_2-NHEt was prepared.



[0090] PS beads were stirred with 2.0 M solution of ethylamine in THF for 2 days and then rinsed with water and THF and a series of (v/v) mixtures of water/THF (2:1, 1:1, 1:2) to purify the product which was then dried at about 40 °C. The product was characterized by infrared spectroscopy and found to match the spectrum found in the literature.

[0091] Second, the acid group of AB9 was bound to the amine group of PS-CH_2-NHEt.



[0092] PS-CH_2-NHEt was stirred with an ethanol or methanol solution of AB9 for about 24 hours. In the alternative, other solvents such as pyridine could also be used. The beads were washed with ethanol or methanol and dried at about 40 °C. The product was characterized by infrared spectroscopy and elemental analysis.

EXAMPLE 14

[0093] In this example PS-AB9 was prepared by derivatizing polystyrene beads but on a 20 g scale. Polystyrene beads (20 g) were stirred with 120 ml 2.0 M solution of ethylamine in THF for 2 days. After 2 days, the beads were then filtered and rinsed with 200 mL of THF and 200 mL of water and a series of (v/v) mixtures of water/THF (2:1, 1:1, 1:2, 200 mL each) and then dried at about 40 °C. PS-CH_2-NHEt beads (20 g) where then refluxed with AB9 (30 g) in 300 mL of ethanol for about two days. The beads were filtered and washed about five times with 200 mL of ethanol and dried at about 40 °C. The products from each step were characterized by infrared spectroscopy.

EXAMPLE 15

[0094] In this characterization, the loading of AB9 on derivatized polystyrene (5 g and 20 g scales) was determined. PS-CH_2-AB9 beads (500 mg) were digested at 110 °C by the addition of 10 mL of water, 10 mL concentrated HNO_3, 10 mL 1:1 HNO_3, 5

mL H_2O_2 and 10 mL concentrated HCl. After digestion, the solutions were filtered to isolate the beads and the final volume of sample was 50 mL. The solutions were then analyzed by ICP to determine the sulfur content which indicates the amount of AB9 bound on the polystyrene.

Sulfur Loading on PS-AB9 (5 g Scale)

g S/0.5 g beads	mmol S/0.5 g beads	mmol AB9/0 .5 g beads	mmol AB9/ g of PS-AB9	g of AB9/g of PSAB 9	mmol of Cl/ g of PS-AB9	low % AB9 loadin g	high % AB9 loadin g	Removal of g Hg/g of PSAB9 (Theo.)	Removal of mmol Hg/g of PSAB9 (Theo.)
0.007	0.22	0.11	0.22	0.08	1.0-1.5	15	22	0.044	0.22

Sulfur Loading on PS-AB9 (20 g Scale)

Sample	mg/L S (in solution)	g S/kg PS (loading)
1	13.93 ± 0.45	1.39 ± 0.04
2	14.17 ± 0.20	1.42 ± 0.02
3	14.03 ± 0.04	1.40 ± 0.00
average	14.04 ± 0.23	1.40 ± 0.02

EXAMPLE 16

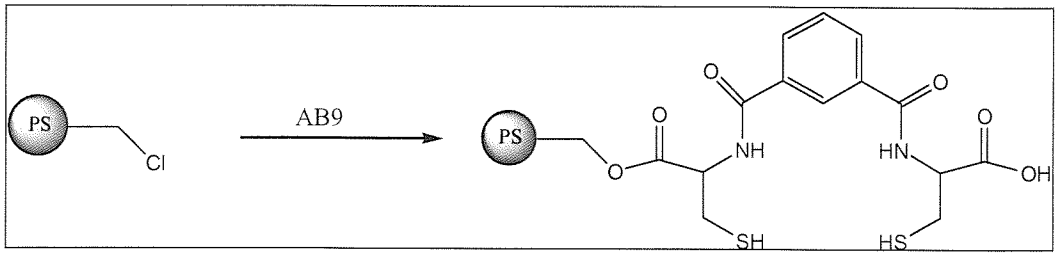
[0095] In this example Hg binding with PS-AB9 was tested. PS-CH_2-AB9 (202 mg, 400 mg and 600 mg) was added to $HgCl_2$ (15ppm) in 25 ml of water and stirred one day at room temperature. After stirring, the beads were isolated by filtering through a 0.2 μm environmental express filter and the solutions were digested for inductively coupled plasma spectrometry analysis. This was conducted at 110 °C by sequentially adding, 10 mL 1:1 HNO_3, 5 mL conc. HNO_3, 5 mL H_2O_2 and 10 mL conc. HCl.

Hg Binding by PS-AB9

Solution	Calc Conc. (ppm)	% Hg Bound
Stock solution	3.874 ± 0.073	N/A
0.2 gm PSAB9	1.963 ± 0.029	49.3%
0.4 gm PSAB9	0.826 ± 0.015	78.7%
0.6 gm PSAB9	0.798 ± 0.016	79.4%

EXAMPLE 17

[0096] In this example, AB9 loaded polystyrene was attempted using a direct reaction. While this procedure has yet to be successfully demonstrated, it is likely that the reaction can be made successful by changing reagents, conditions and other variables.



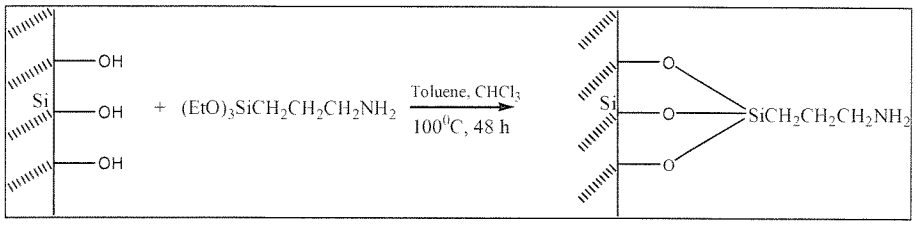
[0097] A solution of excess AB9 in ethanol could be added to polystyrene beads (chloromethylated polystyrene-*co*- divinylbenzene (2% DVB) (200-400 mesh). This may ensure that each polystyrene bead reacted with an excess of AB9 to prevent cross-linking of the ligand. The mixture could be stirred for ~24 hours with and without heating to drive off HCl. If the resulting solution is acidic, any remaining acid could be neutralized with 5 % $NaHCO_3$. Alternatively, NEt_3 may be added with the ligand solution, without heating, to effect HCl elimination as $[HNEt_3]Cl$. The beads may then be washed with ethanol and water and dried at ~40 °C. Infrared characterization could be conducted to observe the PS-attached group, SH, NH and the remaining carboxylate. Elemental analysis could be used to determine the amount of AB9 present on the PS beads. Additionally, the PS-AB9 may be treated with dilute HCl and the AB9 isolated and analyzed.

EXAMPLE 18

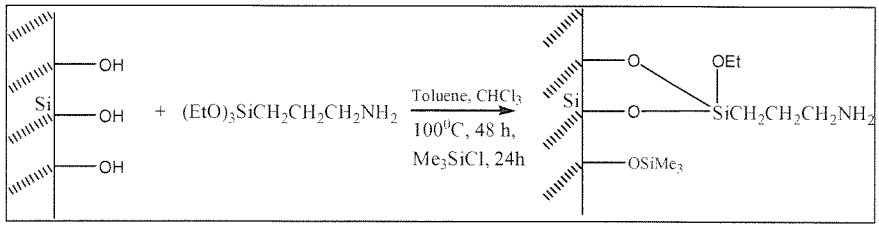
[0098] In this example, amine-functionalized silica ($SiNH_2$) was produced for AB9 binding. This was conducted following the procedure set forth in: Cai, M. et al, *Journal of Molecular Catalysis A: Chemical.* 2007, *268,* 82 and Jyothi, T. M., et al; *Chem. Int. Ed.* 2001, *40,* 2881. A suspension of silica-60 (20 g) in toluene (500 mL) was refluxed with γ-aminopropyltriethoxysilane (15.70 g, 71.36 mmol) in chloroform (40 mL) at ~100 °C for 48 h. After refluxing, the solid was filtered and washed with $CHCl_3$ (5 x 80 mL), and dried under vacuum for 12 h. The dried solid was then soaked in a solution of Me_3SiCl (31.28 g, 286.97 mmol) in toluene (350 ml) at room

temperature for 24 h. After soaking, the solid was filtered and washed with acetone (10 × 40 mL) and diethyl ether (10 × 15 mL) and dried under vacuum at 100 °C for 5 h. This resulted in isolation of 25.81 g of solid. Me_3SiCl will bind with any unreacted –OH on the solid to form $–OSiMe_3$ to block the reactivity of the hydroxyl groups on the silica surface.

Derivatization of silica surface with γ-aminopropyltriethoxysilane.



$SiMe_3Cl$ derivatization of unprotected hydroxyl groups.



[0099] From literature, the inclusion of thiol functionalities on the surface of silica particles is characterized by elemental analysis (Cai, 2007), powder X-ray diffraction and scanning electron microscopy (Nakamura, 2007). Elemental analysis provides nitrogen content on the silica particle. X-ray diffraction is used to find out the regularity of particles and the change in particle size was determined by scanning electron microscopy.

[00100] Infrared Spectroscopy (cm^{-1}) was used to determine the functionality (-NH_2, -CH_2-, -OH) on the silica surface. A broad peak at 3434 and 3050 (-CH_2-) was observed. It was found that the peak intensity at 3459 was decreased drastically after treatment of silica particles with amine. Elemental analysis of Si-NH_2 (%) produced: C 7.71; H 2.42; N 2.72; O 9.37; Si 32.87; S 0.03; (Silica-60: C 0.05; H 1.26; N 0.01; O 7.22; Si 42.60; S <0.01). The nitrogen content was found to be 1.94 mmol/of $SiNH_2$/g Si60.

[00101] Referring now to Fig 1 and Fig. 2, thermogravimetric analysis was performed on Silica-60 and $SiNH_2$ at a temperature range of 30 °C to 1000 °C, a

temperature increase of 20 °C/min; and a flow rate of 110/55 mmHg (inlet/outlet pressure); all at air atmosphere. The TGA analysis of Silica-60 (Si60), $SiNH_2$ showed that the pattern of weight loss changed significantly when Si60 was treated with γ-aminopropyltriethoxysilane. The initial weight losses in both traces correspond to loss of coordinated water. The Si60 with terminal hydroxyl groups is capable of hydrogen bonding a much larger amount of water than the Si60-NH_2. Subsequent heating of Si60 causes condensation of the terminal hydroxyl groups to eliminate water. For Silica-60-NH_2 the mass loss represents loss of the organic amine from the silica surface.

EXAMPLE 19

[00102] In this example the binding of AB9 on a silica surface modified with amine ($SiNH_2$) was performed wherein two different methods were attempted to functionalize the silica surface.

[00103] Under the first method, $SiNH_2$ (9.0 g) solid in N,N'-dimethyl formamide (DMF) (200 mL) was stirred with AB9 (6.5 g, 17.43 mmol) in the presence of dicyclohexylcarbodiimide (DCC, 14.63 mmol, 3.0 g) and diisopropylethylamine (DIPEA, 22.82 mmol, 4 mL) for 6 h. The solid was then filtered and washed with DMF (200 mL), dichloromethane (DCM, 250 mL) and methanol (250 mL). After washing, the solid was dried under vacuum for 8 h. This resulted in isolation of 8.41 g of solid.

[00104] From literature, the inclusion of thiol functionalities on the surface of silica particles is characterized by elemental analysis (Cai, 2007), Raman spectroscopy, powder X-ray diffraction and scanning electron microscopy (Nakamura, 2007). Due to strong Raman scattering, the thiol groups are detected by Raman spectroscopy. Elemental analysis provides nitrogen content on the silica particle. X-ray diffraction is used to find out the regularity of particles and the change in particle size was determined by scanning electron microscopy.

[00105] Infrared spectroscopy (cm^{-1}) produced a broad peak at 3440 and very small peak at 3050. Also there was peak at 1538 (-NH). Elemental Analysis (%) produced: C 8.34; H 2.42; N 2.75; O 6.85; Si 34.05; S 0.22; (Si60: C 0.05; H 1.26; N 0.01; O

7.22; Si 42.60; S <0.01). The sulfur content was also found to be 0.034 mmol SiAB9/g of Si60.

[00106] Referring now to Fig. 3, thermogravimetric analysis was performed on $SiNH_2$ treated with AB9 in the presence of DCC at a temperature range of – 30^0C to 1000^0C, a temperature increase of 20 °C/min; and a flow rate of 110/55 mmHg; all at air atmosphere. It was found that there is no significant change in thermogravimetric analysis of SiAB9. This might be due to small amount of AB9 present per g of SiAB9. But the pattern of TGA of SiAB9 synthesized by refluxing in EtOH changed from the TGA of $SiNH_2$. This might be due to larger amount of AB9 per g of SiAB9, which is also evident from the ICP analysis data of sulfur.

[00107] Inductively coupled plasma spectrometry was further performed. SiAB9 beads (500 mg) were digested at 110 °C by addition of 10 mL water, 10 mL 1:1 HNO_3, 5 mL conc. HNO_3, 5 mL H_2O_2 and 10 mL conc. HCl. After digestion, the solutions were filtered to isolate the beads and the final volume of the sample was 50 mL. The solutions were then analyzed by ICP to determine the sulfur content:

Sulfur loading on SiAB9-10g scale

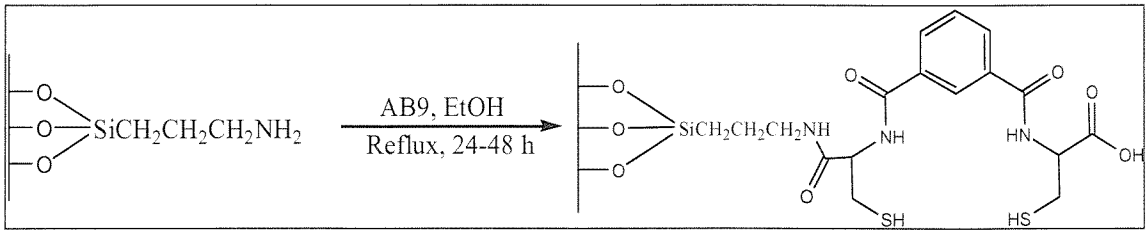
g S/0.5 g beads	mmol S/0.5 g beads	mmol AB9/ g of SiAB9	g of AB9/g of SiAB9	Removal of mmols Hg/g of SiAB9 (Theo.)	Removal of g Hg/g of SiAB9 (Theo.)
0.0013	0.04	0.04	0.015	0.04	0.008

Sulfur loading on SiAB9-10g scale

Sample	mg/L S (in solution)	g S/kg SiAB9 (loading)
1	2.57 ± 0.04	0.13 ± 0.00
2	2.75 ± 0.12	0.14 ± 0.00
average	2.66 ± 0.08	0.135 ± 0.00

[00108] Under the second method, $SiNH_2$ (9.0 g) was refluxed in a solution of AB9 (22.78 mmol, 8.50 g) in ethanol (500 mL) for 24 h. After refluxing, the solid was filtered and washed with ethanol (12 x 50 mL) and dried under vacuum. This resulted in isolation of 8.6 g of solid.

Reaction of $SiNH_2$ and AB9 with Heating



[00109] Characterization was performed following the methods used for the first method. Infrared spectroscopy (cm^{-1}) produced a broad peak at 3440 and also broad and very small peak at 3050. There was another peak at 1515 (-NH). Elemental analysis (%) produced: C 10.33; H 2.68; N 2.89; O 12.04; Si 26.88; S 0.76; (Si60: C 0.05; H 1.26; N 0.01; O 7.22; Si 42.60; S <0.01). The sulfur content was also found to be 0.24 mmol/g of SiAB9. The EA data showed that the second experimental method (refluxing in EtOH) gave the higher AB9 loading than the first experimental method (using DCC and other reagents). SiAB9 obtained from refluxing EtOH had 0.12 mmol of AB9/g of beads (0.24 mmol of S/g of beads) which is in good agreement with the value obtained from the sulfur analysis by inductively coupled plasma spectroscopy.

[00110] Referring now to Fig. 4, thermogravimetric analysis was performed on $SiNH_2$ treated with AB9 refluxed in EtOH at a temperature range of 30 °C to 1000 °C, a temperature increase of 20 °C/min; and a flow rate of 110/55 mmHg; all at air atmosphere. Furthermore, inductively coupled plasma analysis was performed. SiAB9 beads (500 mg) were digested at 110^0C by addition of 10 mL water, 10 mL 1:1 HNO_3, 5 mL conc. HNO_3, 5 mL H_2O_2 and 10 mL conc. HCl. After digestion, the solutions were filtered to isolate the beads and the final volume of sample was 50 mL. The solutions were then analyzed by ICP to determine the sulfur content:

Sulfur loading on SiAB9-10g prep

g S/0.5 g beads	mmol S/0.5 g beads	mmol AB9/ g of SiAB9	g of AB9/g of SiAB9	Theoretical mmol Hg/g of SiAB9	Theoretical g Hg/g of SiAB9 (Theo.)
0.004	0.14	0.14	0.05	0.14	0.027

Sulfur loading on SiAB9-10g prep

Sample	mg/L S (in solution)	g S/kg SiAB9 (loading)
1	8.62 ± 0.02	0.43 ± 0.00
2	8.71 ± 0.20	0.44 ± 0.02
average	8.67 ± 0.11	0.435 ± 0.01

[00111] As the specific surface BET of Si60 is 500 m^2/g, the AB9 coverage is 0.14 mmol/500 m^2/g.

EXAMPLE 20

[00112] In this example aqueous Hg(II) was remediated with a combination of Si60 and SiAB9 with $HgCl_2$. It was found that loading of AB9 per g of SiAB9 is higher in the SiAB9 obtained from the second experimental method. Therefore, the Hg remediation in the solution phase was conducted using SiAB9 obtained from refluxing EtOH.

[00113] Si60 (200 mg and 600 mg) was added to $HgCl_2$ (~5 ppm) in water (50 mL) and stirred for 1 day at room temperature. The pH of the solution was 5.5-6.0 and was monitored by Corning 313 pH meter. After stirring, the beads were isolated by filtration through a 0.2 μm filter (Environmental Express) and the solutions were digested for ICP analysis. This was conducted at 110 °C by adding, 10 mL 1:1 HNO_3, 5 mL conc. HNO_3, 5 mL H_2O_2 and 10 mL conc. HCl. The removal of Hg by Si60 was then determined:

Determination of Hg removal by Si60

Solution	Calc Conc. (ppm)	% Removal
Stock solution	5.823 ± 0.071	N/A
0.2 g Si60	4.425 ± 0.047	24%
0.6 g Si60	2.895 ± 0.058	50%

[00114] SiAB9 (200 mg and 600 mg) was added to $HgCl_2$ (~5 ppm) in water (50 mL) and stirred for 1 day at room temperature. pH of the solution was 5.5-6.0 and was monitored by Corning 313 pH meter. After stirring, the beads were isolated by filtration through a 0.2 μm filter (Environmental Express) and the solutions were

digested for ICP analysis. This was conducted at 110 °C by sequentially adding, 10 mL 1:1 HNO_3, 5 mL conc. HNO_3, 5 mL H_2O_2 and 10 mL conc. HCl.

[00115] The removal of Hg by SiAB9 was then determined:

Determination of Hg Removal by SiAB9

Solution	Calc Conc. (ppm)	% Removal
Stock solution	5.823 ± 0.071	N/A
0.2 g SiAB9	0.316 ± 0.002	95%
0.6 g SiAB9	0.173 ± 0.024	97%

[00116] The Hg remediation study showed that SiAB9 remediates about 95-97% of Hg with increasing SiAB9 loading. But at the same time it was found that Si60 also remediates 25-50% Hg with increasing Si60 loading. This is probably due to adsorption of Hg on the surface of Silica-60.

EXAMPLE 21

[00117] In this example aqueous As(III) was remediated with a combination of Si60 and SiAB9 synthesized by refluxing in EtOH with $NaAsO_2$.

[00118] Si60 (200 mg and 600 mg) was added to $NaAsO_2$ (~200 ppb) in water (50 mL) and stirred for 1 day at room temperature. After stirring, the beads were isolated by filtration through a 0.45 μm filter (Environmental Express) and the solutions were digested for inductively coupled plasma spectrometry analysis. This was conducted at 95 °C by adding 2.5 mL conc. HNO_3.

[00119] The removal of As(III) by SiAB9 was then determined at pH levels 5, 7 and 9:

Determination of As removal by Si60 at pH 5

Sample ID	Conc. (μg/L)	Stdev.	% Remed.
As stock	208.45	± 10.86	N/A
0.2 g Si60	207.10	± 5.59	0.6%
0.6 g Si60	199.10	± 3.58	4.5%

Determination of As removal by Si60 at pH 7

Sample ID	Conc. (µg/L)	Stdev.	% Remed.
As stock	225.80	± 0.23	N/A
0.2 g Si60	214.50	± 5.36	5.0%
0.6 g Si60	203.90	± 7.75	9.7%

Determination of As removal by Si60 at pH 9

Sample ID	Conc. (µg/L)	Stdev.	% Remed.
As stock	218.20	± 5.02	N/A
0.2 g Si60	213.90	± 5.35	2.0%
0.6 g Si60	206.30	± 4.74	5.5%

[00120] In the SiAB9 (synthesized by refluxing in EtOH) with $NaAsO_2$ remediation of As(III), SiAB9 (200 mg and 600 mg) was added to $NaAsO_2$ (~200 ppb) in water (50 mL) and stirred for 1 day at room temperature. After stirring, the beads were isolated by filtration through a 0.45 µm filter (Environmental Express) and the solutions were digested for inductively coupled plasma spectrometry analysis. This was conducted at 95 °C by adding 2.5 mL conc. HNO_3.

[00121] The removal of As(III) by SiAB9 was then determined at pH levels 5, 7 and 9:

Determination of As removal by SiAB9 at pH 5

Sample ID	Conc. (µg/L)	Stdev.	% Remed.
As stock	208.45	± 10.86	N/A
0.2 g Si AB9	115.40	± 7.27	44.6%
0.6 g Si AB9	< 5.0	N/A	100%

Determination of As removal by SiAB9 at pH 7

Sample ID	Conc. (µg/L)	Stdev.	% Remed.
As stock	225.80	± 0.23	N/A
0.2 g Si AB9	137.00	± 1.78	39.3%
0.6 g Si AB9	64.30	± 2.96	71.5%

Determination of As removal by SiAB9 at pH 9

Sample ID	Conc. (µg/L)	Stdev.	% Remed.
As stock	218.20	± 5.02	N/A
0.2 g SiAB9	156.80	± 10.98	28.1%
0.6 g Si AB9	< 5.0	N/A	100.0%

[00122] It was found that Si60 alone did not remediate As from aqueous medium. Whereas the efficiency of SiAB9 to remove As decreases with increasing pH at low loading of SiAB9. But with increasing loading, SiAB9 remediates As(III) very efficiently.

EXAMPLE 22

[00123] In this example gas phase binding of Hg(0) with Si60 and SiAB9 was explored. Si60-AB9 (from EtOH reaction) with a 0.14 mmol AB9/g loading was used. In the alternative, binding could take place in other fluids (i.e. gasses or liquids) with the presence of the polymer or solid supported chemical compound. In the present example, the sample (3 g) was placed in the filter frit above the permeation tube with the Hg(0) gas flowing at 100 mL/min for one hour through the sample and then passed, with gas dispersion tubes, into two liquid traps containing a 150 mL solution of 5% nitric acid and 10% hydrochloric acid. This captures the Hg(0) that was not caught by the solid sample. The solid sample was taken from the filter frit and washed with ethanol to release any physisorbed Hg(0). Then 2g of the solid sample was digested using the EPA 30-50B method and analyzed on the ICP along with the traps, which did not need to be digested.

[00124] The Silica-AB9 was able to fill 85% of its binding sites with Hg. There were some Hg(0) vapor to pass. However, doing a smaller PTFF run or a larger sample size for an hour may reach the desired 100% Hg(0) vapor capture.

[00125] It is noted that terms like "preferably," "commonly," and "typically" are not utilized herein to limit the scope of the disclosure or to imply that certain features are critical, essential, or even important to the structure or function of the disclosure.

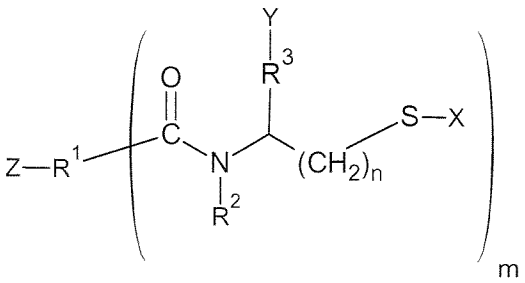
Rather, these terms are merely intended to highlight alternative or additional features that may or may not be utilized in a particular embodiment of the present disclosure.

[00126] For the purposes of describing and defining the present disclosure it is noted that the term "substantially" is utilized herein to represent the inherent degree of uncertainty that may be attributed to any quantitative comparison, value, measurement, or other representation. The term "substantially" is also utilized herein to represent the degree by which a quantitative representation may vary from a stated reference without resulting in a change in the basic function of the subject matter at issue.

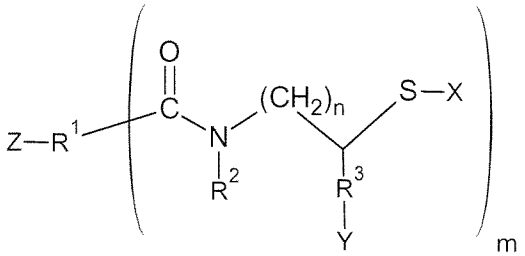
[00127] Having described the disclosure in detail and by reference to specific embodiments thereof, it will be apparent that modifications and variations are possible without departing from the scope of the disclosure. More specifically, although some aspects of the present disclosure are identified as advantageous, it is contemplated that the present disclosure is not necessarily limited to these aspects of the disclosure.

What is claimed:

1. A chemical compound, comprising:



or



where R^1 is selected from a group comprising benzene, pyridine, pyridin-4-one, naphthalene, anthracene, phenanthrene and alkyl groups, R^2 is independently selected from a group comprising hydrogen, alkyls, aryls, a carboxyl group, carboxylate esters, organic groups and biological groups, R^3 is independently selected from a group comprising alkyls, aryls, a carboxyl group, carboxylate esters, organic groups and biological groups, X is independently selected from a group comprising hydrogen, lithium, sodium, potassium, rubidium, cesium, francium, alkyls, aryls, a carboxyl group, carboxylate esters, cysteine, homocysteine, glutathione, lipoic acid, dihydrolipoic acid, thiophosphate, N-acetyl cysteine, mercaptoacetic acid, mercaptopropionic acid, γ-glutamyl cysteine, phytochelatins, thiolsalicylate, organic groups and biological groups, n independently equals 1-10, m = 1-6, Y is independently selected from a group comprising hydrogen, polymers, silicas and silica supported substrates, and Z is selected from a group comprising hydrogen, alkyls, aryls, a carboxyl group, carboxylate esters, a hydroxyl group, NH_2, HSO_3, halogens, a carbonyl group, organic groups, biological groups, polymers, silicas and silica supported substrates, with the proviso that when R^1 represents an alkyl group, at least one X cannot simultaneously represent hydrogen.

2. The chemical compound of claim 1, wherein m = 2.

3. The chemical compound of claim 2, wherein at least one R^3 comprises a carboxyl group.

4. The chemical compound of claim 3, wherein at least one X comprises glutathione.

5. The chemical compound of claim 3, wherein at least one R^3 comprises a carboxylic acid, a methyl-ester or an ethyl-ester.

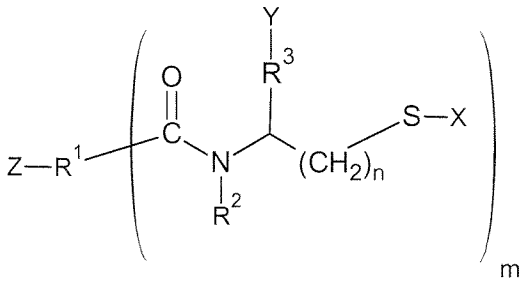
6. The chemical compound of claim 1, wherein both R^2 comprise hydrogen, both R^3 comprise a carboxyl group, both X comprise glutathione and both n equal 1.

7. The chemical compound of claim 1, wherein R^1 is benzene.

8. The chemical compound of claim 1, wherein R^1 is naphthalene.

9. The chemical compound of claim 1, wherein R^1 is bonded to two Z compounds.

10. A method of removing at least one metal and/or main group element from a starting material selected from a group comprising a fluid, a solid, a gas or any mixture thereof, the method comprising binding at least one metal and/or main group element with an effective amount of chelate ligand or a material supported chemical compound having a chemical formula comprising:



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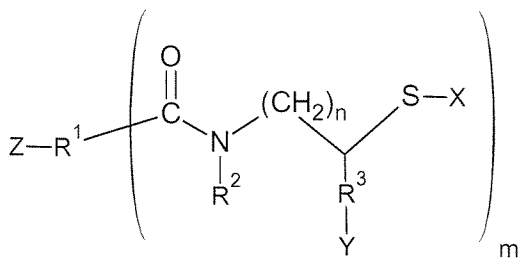


where R^1 is selected from a group comprising benzene, pyridine, pyridin-4-one, naphthalene, anthracene, phenanthrene and alkyl groups, R^2 is independently selected from a group comprising hydrogen, alkyls, aryls, a carboxyl group, carboxylate esters, organic groups and biological groups, R^3 is independently selected from a group comprising alkyls, aryls, a carboxyl group, carboxylate esters, organic groups and biological groups, X is independently selected from a group comprising hydrogen, lithium, sodium, potassium, rubidium, cesium, francium, alkyls, aryls, a carboxyl group, carboxylate esters, cysteine, homocysteine, glutathione, lipoic acid, dihydrolipoic acid, thiophosphate, N-acetyl cysteine, mercaptoacetic acid, mercaptopropionic acid, γ-glutamyl cysteine, phytochelatins, thiolsalicylate, organic groups and biological groups, n independently equals 1-10, m = 1-6, Y is independently selected from a group comprising hydrogen, polymers, silicas and silica supported substrates, and Z is selected from a group comprising hydrogen, alkyls, aryls, a carboxyl group, carboxylate esters, a hydroxyl group, NH_2, HSO_3, halogens, a carbonyl group, organic groups, biological groups, polymers, silicas and silica supported substrates, with the proviso that when R^1 represents an alkyl group, at least one X cannot simultaneously represent hydrogen.

11. The method of claim 10, wherein the at least one metal and/or main group element may be any metal and/or main group element in or capable of being placed in a positive oxidation state.

12. The method of claim 10, wherein the at least one metal and/or main group element is selected from a group comprising yttrium, lanthanum, hafnium, vanadium, chromium, uranium, manganese, iron, cobalt, nickel, palladium, platinum, copper, silver, gold, zinc, cadmium, mercury, lead, tin, gallium, indium, thallium, boron, silicon, germanium, arsenic, antimony, selenium, tellurium, polonium, bismuth, molybdenum, thorium, plutonium, aluminum, barium, beryllium, magnesium, strontium, calcium, radium and mixtures thereof.

13. The method of claim 10, wherein the at least one metal and/or main group element remains bound to the chelate ligands or material supported chemical compounds at pH values from about 6 to about 8.

14. The method of claim 10, wherein m = 2.

15. The method of claim 14, wherein at least one R^3 comprises a carboxyl group.

16. The method of claim 15, wherein at least one X comprises glutathione.

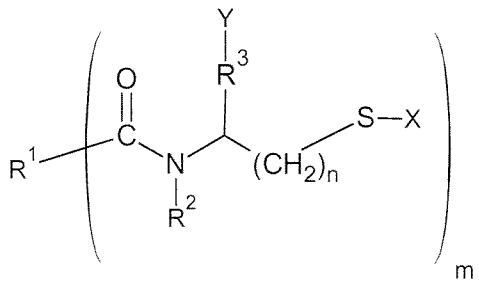
17. The method of claim 16, wherein at least one R^3 comprises a carboxylic acid, a methyl-ester or an ethyl-ester.

18. The method of claim 10, wherein R^1 is benzene.

19. The method of claim 10, wherein R^1 is naphthalene.

20. The method of claim 10, wherein R^1 is bonded to two Z compounds.

21. A method of removing at least one metal and/or main group element from a human and/or animal tissue, the method comprising delivering a therapeutically effective amount of chelate ligand to the tissue and binding at least one metal and/or main group element with an effective amount of chelate ligand having a chemical formula comprising:



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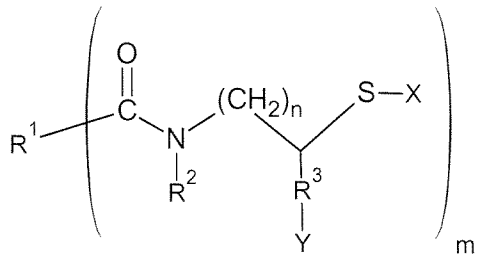


where R^1 is selected from a group comprising benzene, pyridine, naphthalene, anthracene, phenanthrene and alkyl groups, R^2 is independently selected from a group comprising hydrogen, alkyls, aryls, a carboxyl group, carboxylate esters, organic groups and biological groups, R^3 is independently selected from a group comprising alkyls, aryls, a carboxyl group, carboxylate esters, organic groups and biological

groups, X is independently selected from a group comprising hydrogen, lithium, sodium, potassium, rubidium, cesium, francium, cysteine, homocysteine, glutathione, lipoic acid, dihydrolipoic acid, thiophosphate, N-acetyl cysteine, mercaptoacetic acid, mercaptopropionic acid, γ-glutamyl cysteine, phytochelatins, thiolsalicylate, n independently equals 1-10, m = 1-6, and Y is independently selected from a group comprising hydrogen, polymers, silicas and silica supported substrates with the proviso that when R^1 represents an alkyl group, at least one X cannot simultaneously represent hydrogen.

22. The method of claim 21, wherein m = 2.

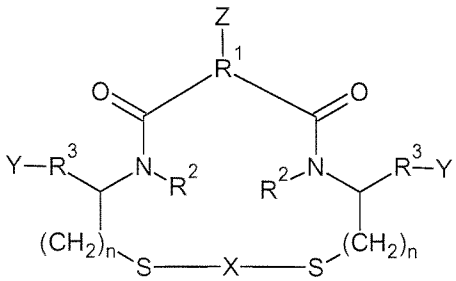
23. The method of claim 22, wherein at least one R^3 comprises a carboxyl group.

24. The method of claim 23, wherein at least one X comprises glutathione.

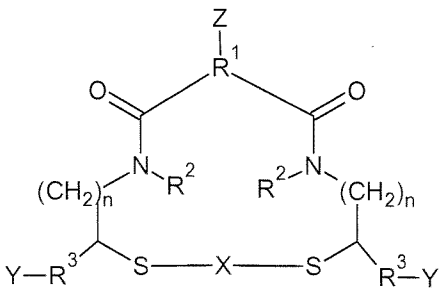
25. The method of claim 24, wherein at least one R^3 comprises a carboxylic acid, a methyl-ester or an ethyl-ester.

26. The method of claim 21, wherein both R^2 comprise hydrogen, both R^3 comprise a carboxyl group, both X comprise glutathione and both n equal 1.

27. A chemical compound, comprising:



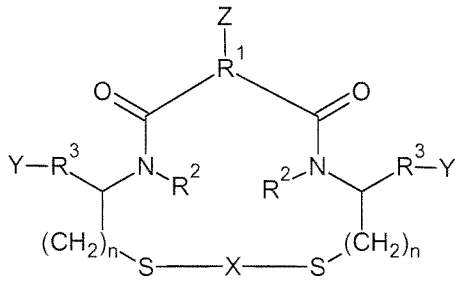
or



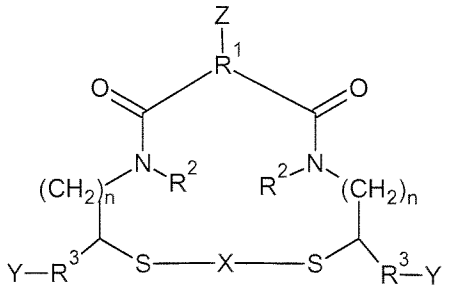
where R^1 is selected from a group comprising benzene, pyridine, pyridin-4-one naphthalene, anthracene and alkyl groups, R^2 is independently selected from a group comprising hydrogen, alkyls, aryls, a carboxyl group, carboxylate esters, organic groups and biological groups, R^3 is independently selected from a group comprising alkyls, aryls, a carboxyl group, carboxylate esters, organic groups and biological groups, X is selected from a group comprising beryllium, magnesium, calcium, strontium, barium and radium, n independently equals 1-10, Y is independently selected from a group comprising hydrogen, polymers, silicas and silica supported substrates, and Z is selected from a group comprising hydrogen, alkyls, aryls, a carboxyl group, carboxylate esters, a hydroxyl group, NH_2, HSO_3, halogens, a carbonyl group, organic groups, biological groups, polymers, silicas and silica supported substrates.

28. The chemical compound of claim 27, wherein at least one R^3 comprises a carboxyl group, methyl-ester or ethyl-ester.

29. A method of removing at least one metal and/or main group element from a starting material selected from a group comprising a fluid, a solid, a gas or any mixture thereof, the method comprising binding at least one metal and/or main group element with an effective amount of chelate ligand or a material supported chemical compound having a chemical formula comprising:



or



where R^1 is selected from a group comprising benzene, pyridine, pyridin-4-one naphthalene, anthracene and alkyl groups, R^2 is independently selected from a group comprising hydrogen, alkyls, aryls, a carboxyl group, carboxylate esters, organic groups and biological groups, R^3 is independently selected from a group comprising alkyls, aryls, a carboxyl group, carboxylate esters, organic groups and biological groups, X is selected from a group comprising beryllium, magnesium, calcium, strontium, barium and radium, n independently equals 1-10, Y is independently selected from a group comprising hydrogen, polymers, silicas and silica supported substrates, and Z is selected from a group comprising hydrogen, alkyls, aryls, a carboxyl group, carboxylate esters, a hydroxyl group, NH_2, HSO_3, halogens, a carbonyl group, organic groups, biological groups, polymers, silicas and silica supported substrates.

30. The method of claim 29, wherein the at least one metal and/or main group element may be any metal and/or main group element in or capable of being placed in a positive oxidation state.

31. The method of claim 29, wherein the at least one metal and/or main group element is selected from a group comprising yttrium, lanthanum, hafnium, vanadium, chromium, uranium, manganese, iron, cobalt, nickel, palladium, platinum, copper, silver, gold, zinc, cadmium, mercury, lead, tin, gallium, indium, thallium, boron, silicon, germanium, arsenic, antimony, selenium, tellurium, polonium, bismuth, molybdenum, thorium, plutonium, aluminum, barium, beryllium, magnesium, strontium, calcium, radium and mixtures thereof.

32. The method of claim 29, wherein the at least one metal and/or main group element remains bound to the chelate ligands or material supported chemical compounds at pH values from about 6 to about 8.

33. The method of claim 29, wherein at least one R^3 comprises a carboxyl group, methyl-ester or ethyl-ester.

34. A method for delivering a lipid-soluble heavy metal chelator to a lipid-containing tissue in a body, comprising delivering a hydrophilic heavy metal chelator complex according to claims 1 and 21 intravenously for uniform transport throughout the body;

whereby a dithiol linkage of the hydrophilic heavy metal chelator complex is reduced in the body, releasing a hydrophobic heavy metal chelator to partition into a lipid-containing tissue.

35. A method for delivering a hydrophobic heavy metal chelator which is excreted via the kidney, comprising delivering an ester-containing hydrophobic heavy metal chelator complex according to claims 1 and 21 to a lipid-containing tissue to bind a metal;

whereby the ester-containing aminothiol group is enzymatically converted to a carboxylic acid group by an esterase in the lipid-containing tissue to provide a hydrophilic heavy metal chelator which is excreted via the kidney.

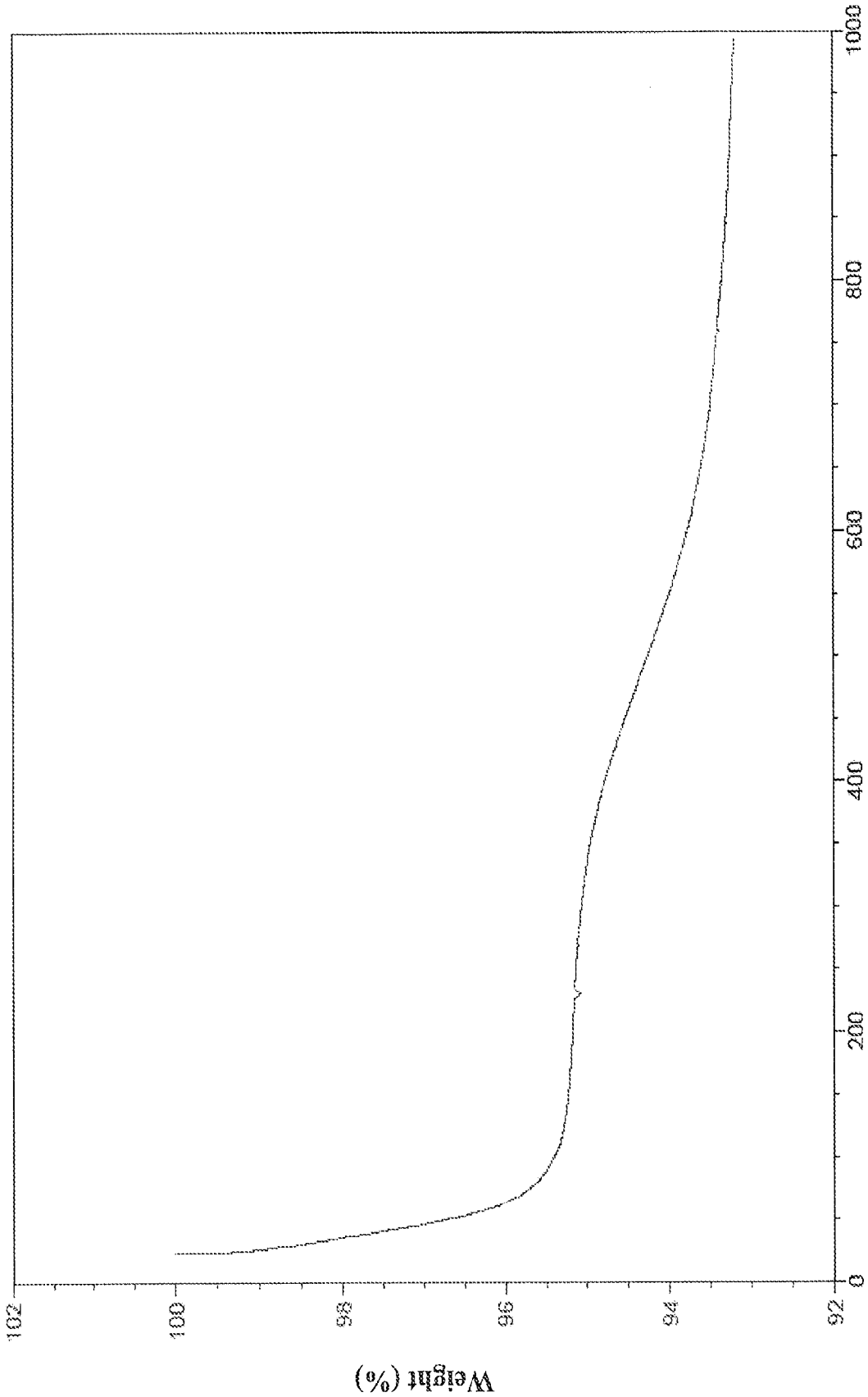


Figure 1

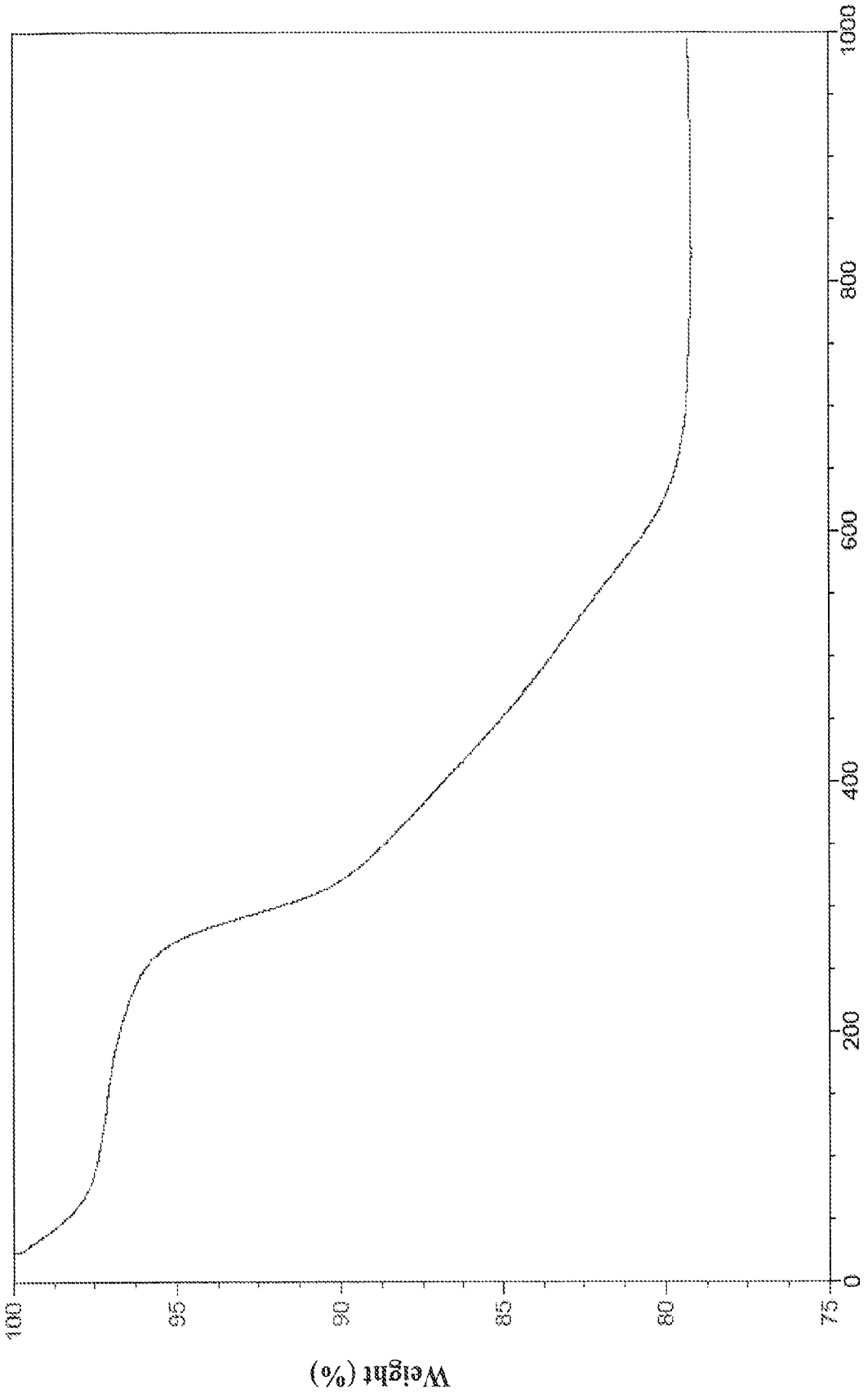


Figure 2

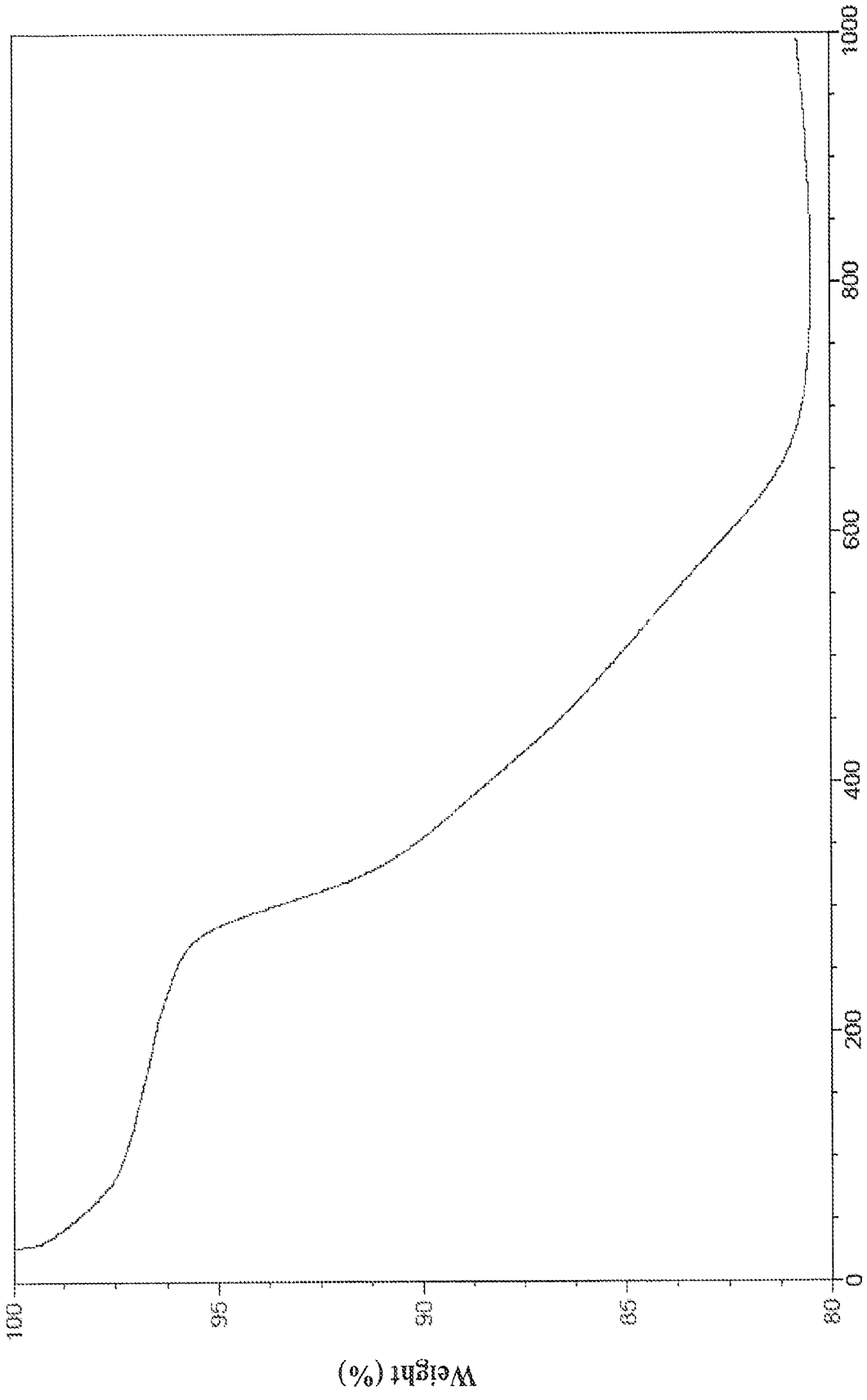


Figure 3

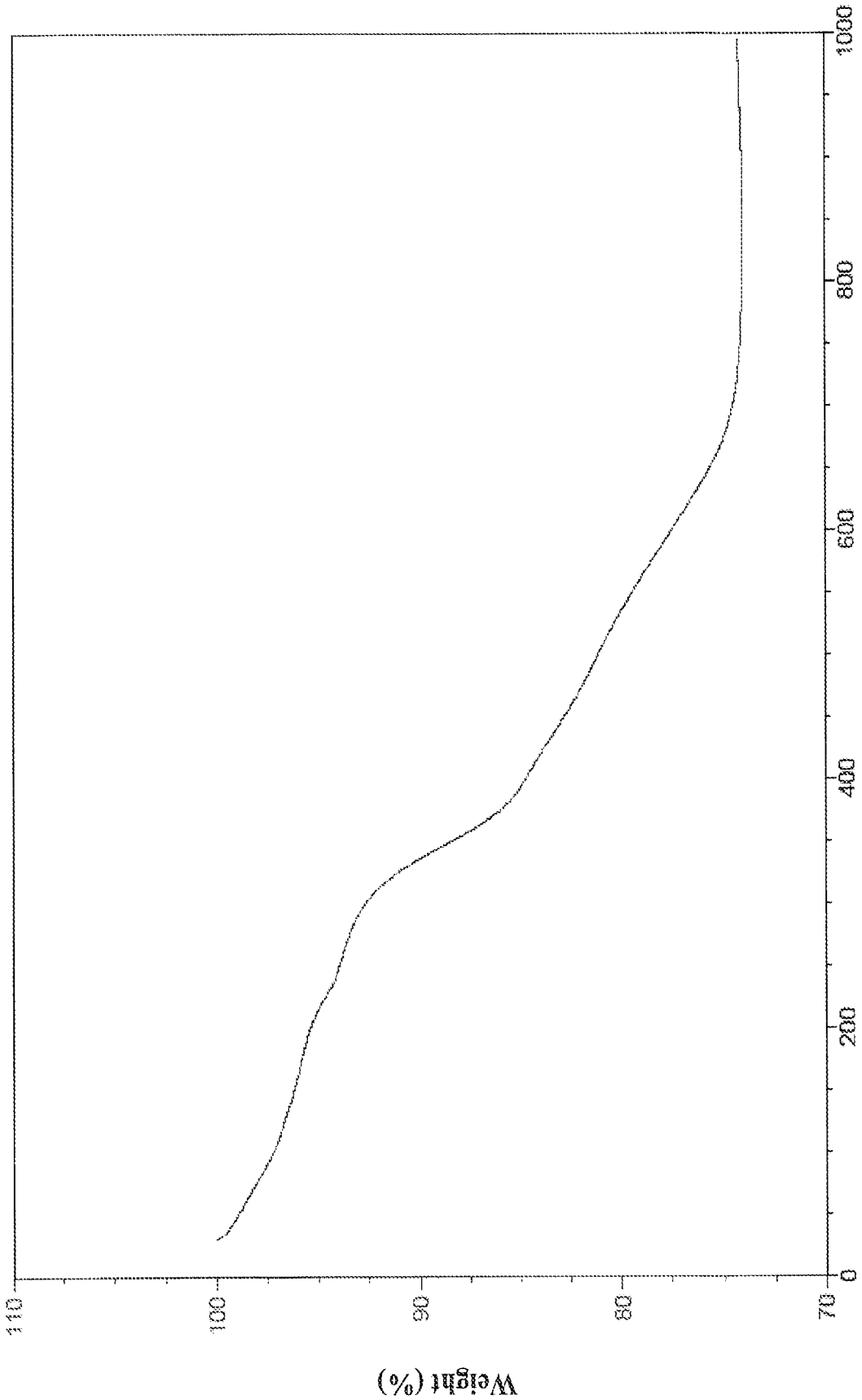


Figure 4

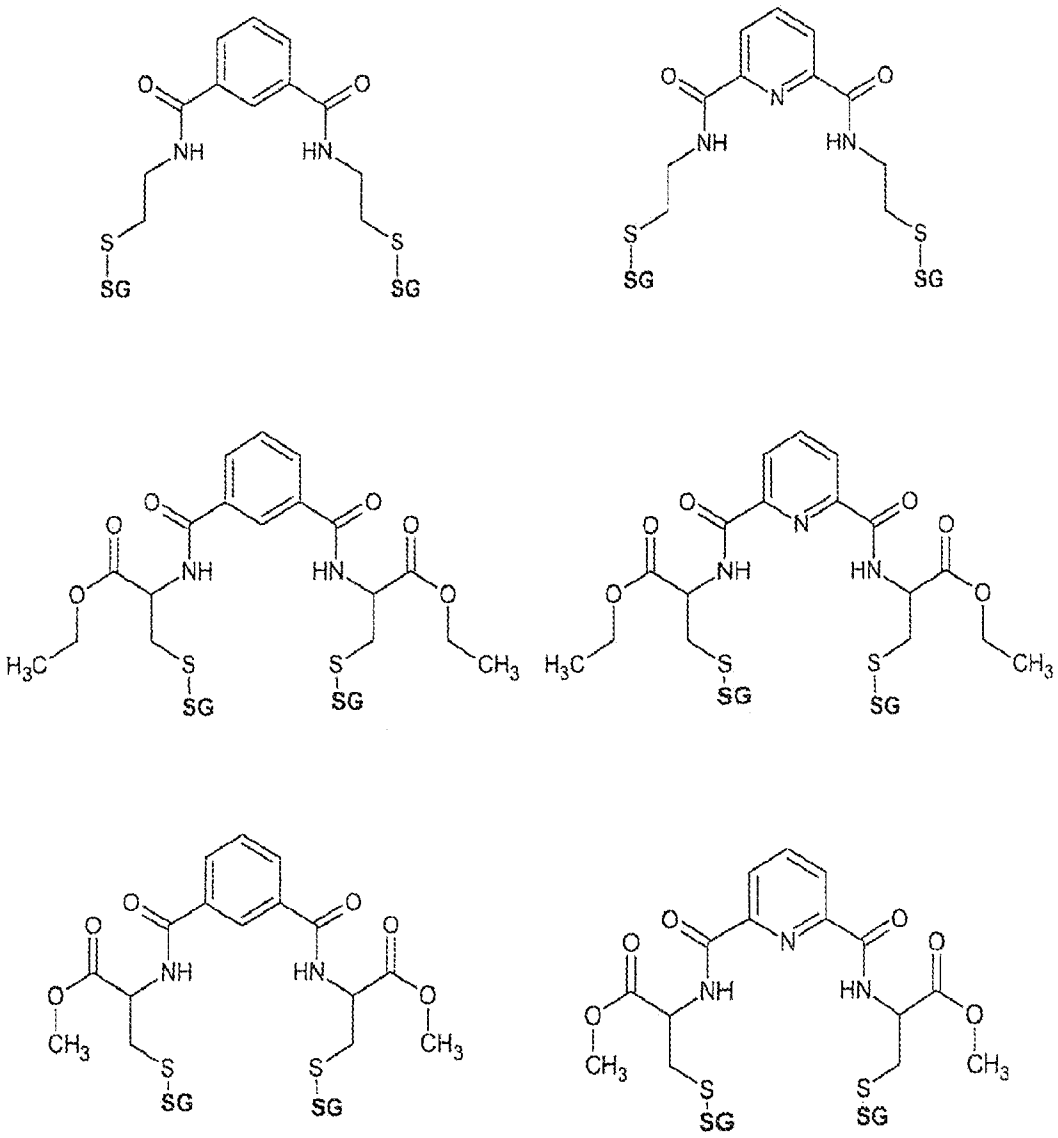


Fig. 5

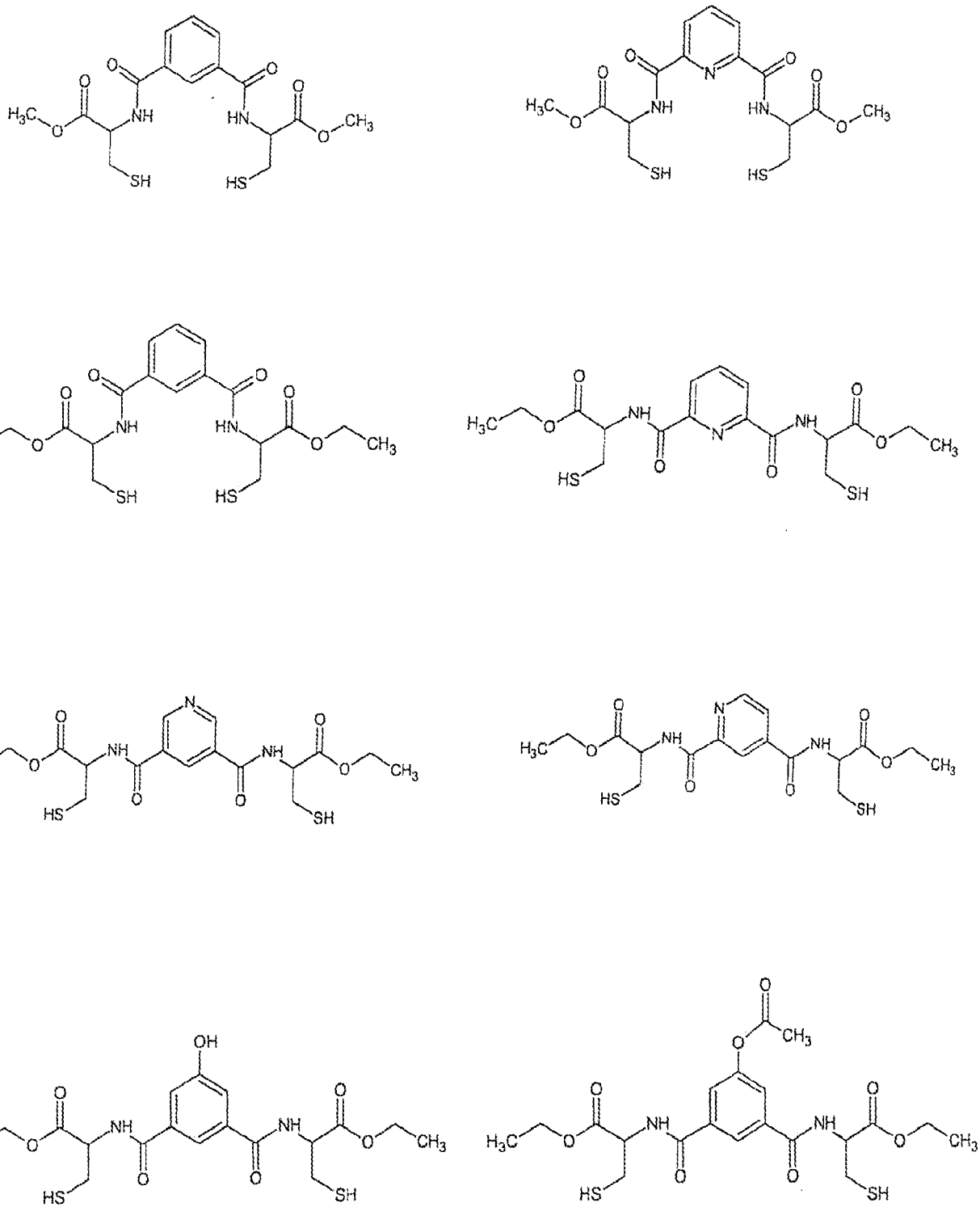
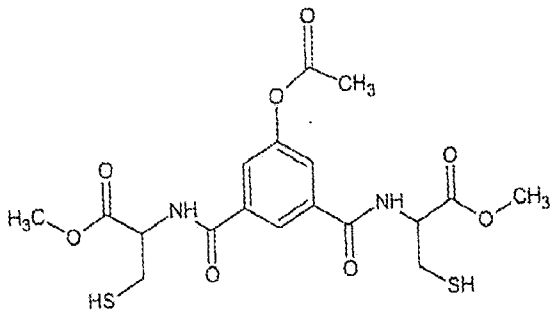
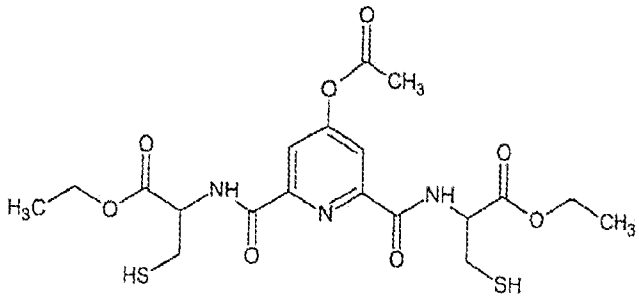
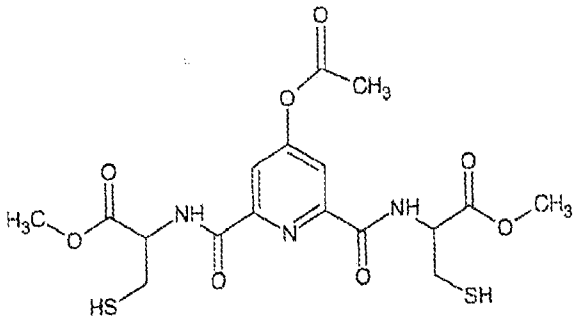
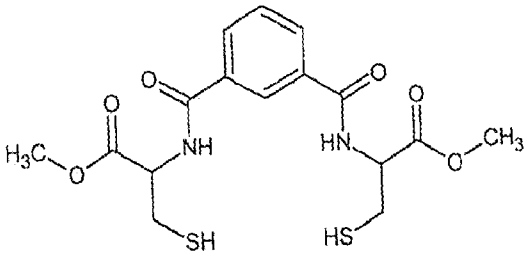


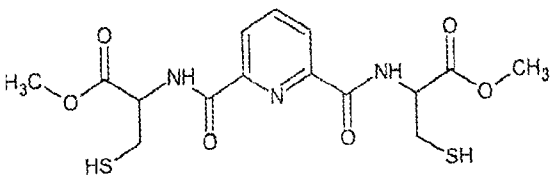
Fig. 6a

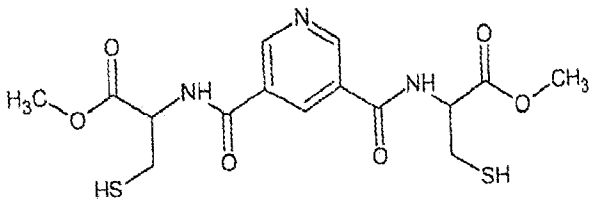


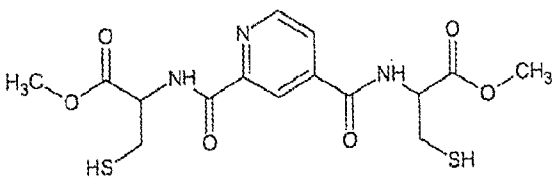












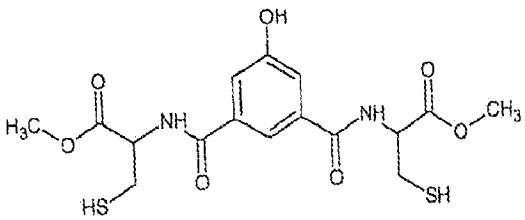


Fig. 6b