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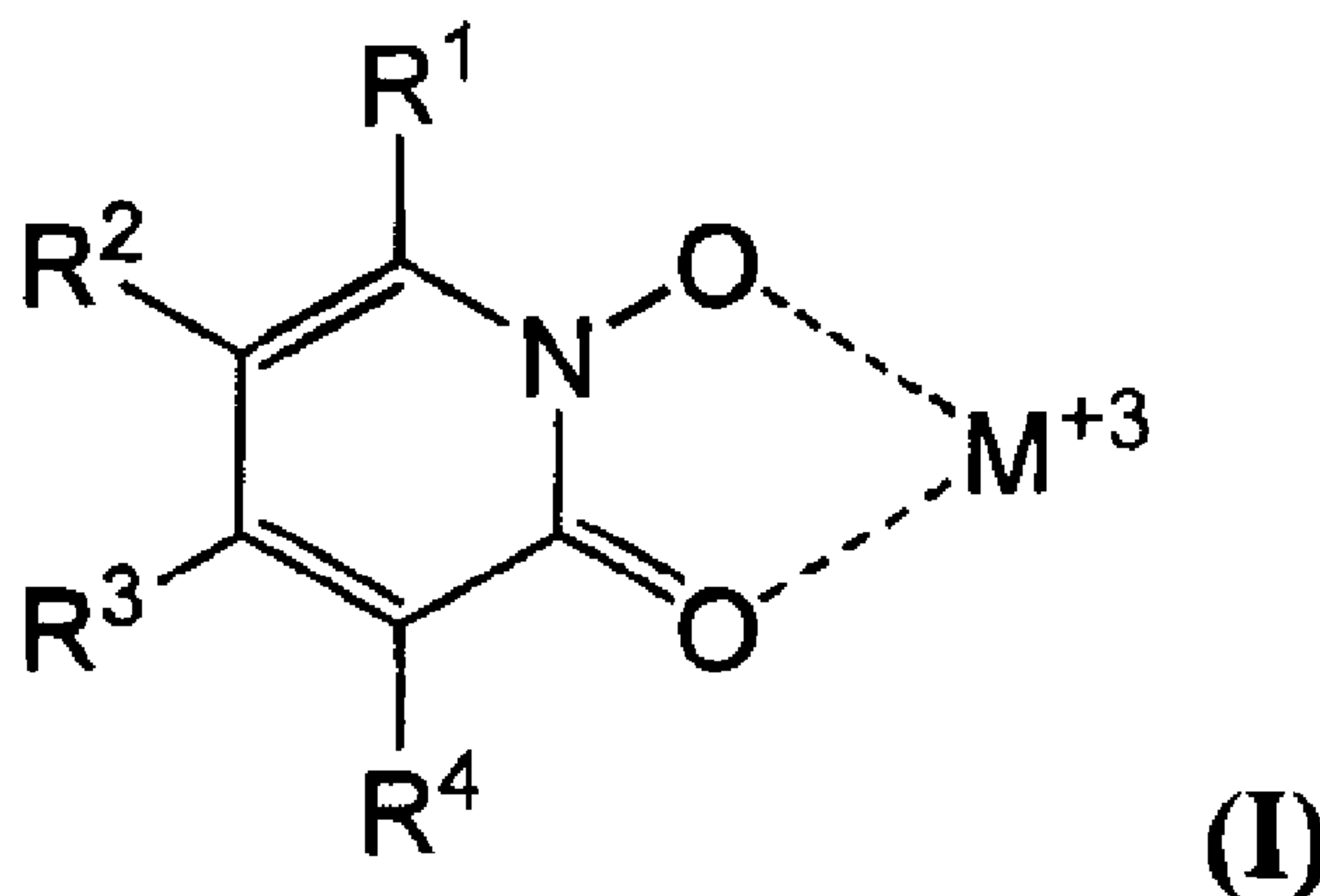
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(54) **Titre :** CHELATE LUMINESCENT DE 1-HYDROXY-2-PYRIDINONE ET DE LANTHANIDES
(54) **Title:** LUMINESCENT 1-HYDROXY-2-PYRIDINONE CHELATES OF LANTHANIDES



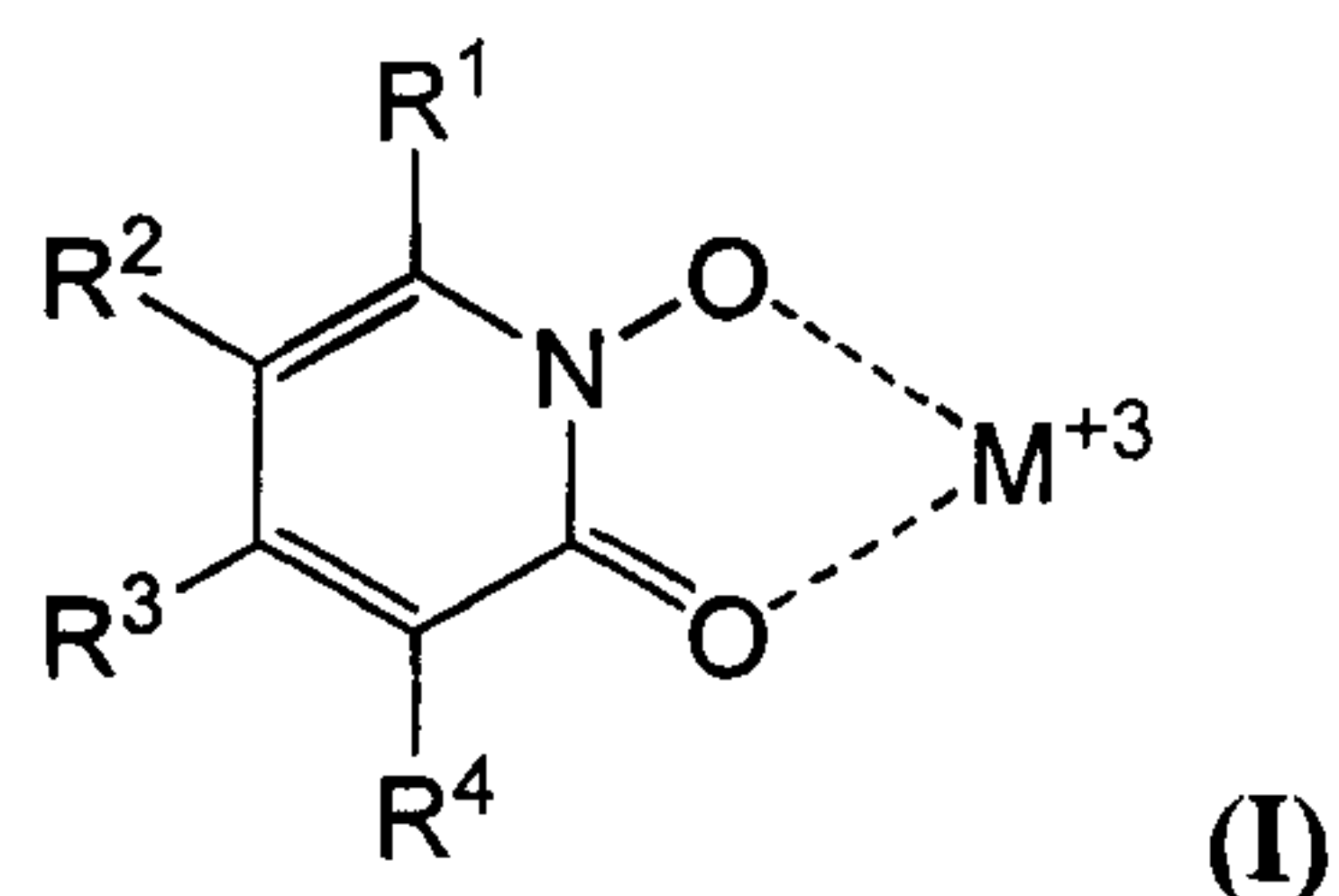
(57) **Abrégé/Abstract:**

A luminescent complex between a lanthanide ion and an organic ligand comprising the subunit of Formula I: (see formula I) wherein R^1 , R^2 , R^3 , and R^4 are members independently selected from H, an aryl group substituent, a linker to a scaffold moiety, and a linker to a functional moiety; wherein at least one of R^1 , R^2 , R^3 , and R^4 is a linker to a scaffold moiety; and M^{+3} is a lanthanide ion forming said luminescent complex with said organic ligand, wherein said lanthanide is a member selected from Neodymium (Nd), Samarium (Sm), Europium (Eu), Terbium (Tb), Dysprosium (Dy), and Ytterbium (Yb).



Abstract

A luminescent complex between a lanthanide ion and an organic ligand comprising the subunit of Formula I:



wherein R^1 , R^2 , R^3 , and R^4 are members independently selected from H, an aryl group substituent, a linker to a scaffold moiety, and a linker to a functional moiety; wherein at least one of R^1 , R^2 , R^3 , and R^4 is a linker to a scaffold moiety; and M^{+3} is a lanthanide ion forming said luminescent complex with said organic ligand, wherein said lanthanide is a member selected from Neodymium (Nd), Samarium (Sm), Europium (Eu), Terbium (Tb), Dysprosium (Dy), and Ytterbium (Yb).

**LUMINESCENT 1-HYDROXY-2-PYRIDINONE CHELATES OF
LANTHANIDES**

**STATEMENT AS TO RIGHTS TO INVENTIONS MADE UNDER
FEDERALLY SPONSORED RESEARCH AND DEVELOPMENT**

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FIELD

[0002] This disclosure relates to lanthanide complexes, useful as luminescent markers, as well as methods utilizing such complexes.

BACKGROUND

[0003] Luminescent metal complexes are valuable as probes and labels in a variety of applications such as diagnostic products and bioanalytical assay systems.

[0004] There is a continuing and expanding need for rapid, highly specific methods of detecting and quantifying chemical, biochemical and biological substances as analytes in research and diagnostic mixtures. Of particular value are methods for measuring small quantities of proteins, nucleic acids, peptides, pharmaceuticals, metabolites, microorganisms and other materials of diagnostic value. Examples of such materials include small molecular bioactive materials (*e.g.*, narcotics and poisons, drugs administered for therapeutic purposes, hormones), pathogenic microorganisms and viruses, antibodies, and enzymes and nucleic acids, particularly those implicated in disease states.

[0005] The presence of a particular analyte can often be determined by binding methods that exploit the high degree of specificity, which characterizes many biochemical and biological systems.

Frequently used methods are based on, for example, antigen-antibody systems, nucleic acid hybridization techniques, and protein-ligand systems. In these methods, the existence of a complex of diagnostic value is typically indicated by the presence or absence of an observable "label" which has been attached to one or more of the interacting materials. The specific labeling method chosen often dictates the usefulness and versatility of a particular system for detecting an analyte of interest.

Preferred labels are inexpensive, safe, and capable of being attached efficiently to a wide variety of chemical, biochemical, and biological materials without significantly altering the important binding

characteristics of those materials. The label should give a highly characteristic signal, and should be rarely, and preferably never, found in nature. The label should be stable and detectable in aqueous systems over periods of time ranging up to months. Detection of the label is preferably rapid, sensitive, and reproducible without the need for expensive, specialized facilities or the need for special precautions to protect personnel. Quantification of the label is preferably relatively independent of variables such as temperature and the composition of the mixture to be assayed.

[0006] A wide variety of labels have been developed, each with particular advantages and disadvantages. For example, radioactive labels are quite versatile, and can be detected at very low concentrations, such labels are, however, expensive, hazardous, and their use requires sophisticated equipment and trained personnel. Thus, there is wide interest in non-radioactive labels, particularly in labels that are observable by spectrophotometric, spin resonance, and luminescence techniques, and reactive materials, such as enzymes that produce such molecules.

[0007] Labels that are detectable using fluorescence spectroscopy are of particular interest, because of the large number of such labels that are known in the art. Moreover, the literature is replete with syntheses of fluorescent labels that are derivatized to allow their facile attachment to other molecules, and many such fluorescent labels are commercially available.

[0008] In addition to being directly detected, many fluorescent labels operate to quench or amplify the fluorescence of an adjacent second fluorescent label. Because of its dependence on the distance and the magnitude of the interaction between the quencher and the fluorophore, the quenching of a fluorescent species provides a sensitive probe of molecular conformation and binding, or other, interactions. An excellent example of the use of fluorescent reporter quencher pairs is found in the detection and analysis of nucleic acids.

[0009] An alternative detection scheme, which is theoretically more sensitive than autoradiography, is time-resolved fluorimetry. According to this method, a chelated lanthanide metal with a long radiative lifetime is attached to a molecule of interest. Pulsed excitation combined with a gated detection system allows for effective discrimination against short-lived background emission. For example, using this approach, the detection and quantification of DNA hybrids via an europium-labeled antibody has been demonstrated (Syvanen *et al.*, *Nucleic Acids Research* 14: 1017-1028 (1986)). In addition, biotinylated DNA was measured in microtiter wells using Eu-labeled streptavidin (Dahlen, *Anal. Biochem*, 164: 78-83 (1982)). A disadvantage, however, of these types of assays is that the label must be washed from the probe and its fluorescence developed in an enhancement solution. A further drawback has been the fact that the fluorescence produced has only been in the nanosecond (ns) range, a generally unacceptably

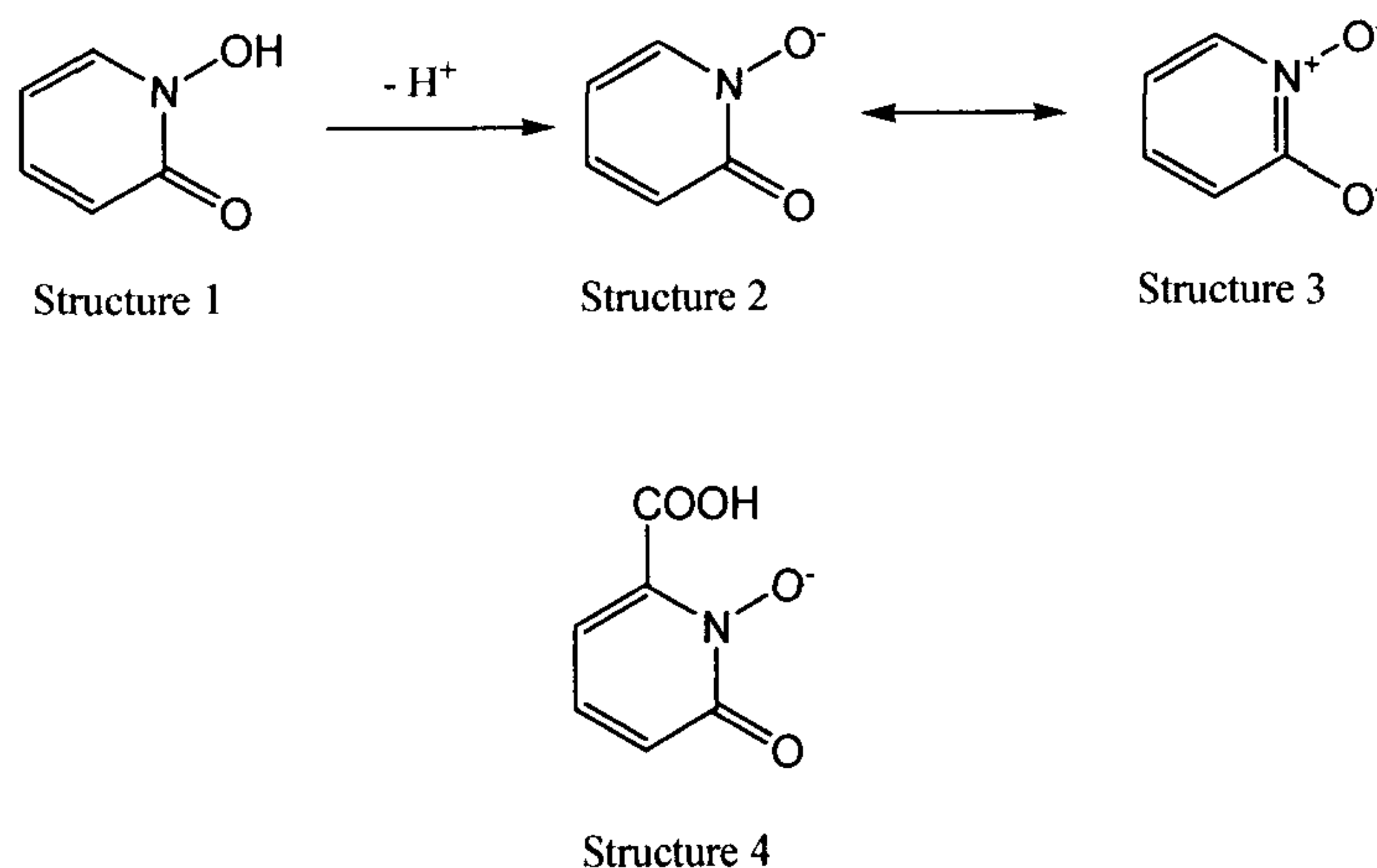
short period for adequate detection of the labeled molecules and for discrimination from background fluorescence.

[0010] In view of the predictable practical advantages it has been generally desired that the lanthanide chelates employed should exhibit a delayed luminescence with decay times of more than 10 μ s. The fluorescence of many of the known fluorescent chelates tends to be inhibited by water and require augmentation with e.g. fluoride or micelles. As water is generally present in an assay, particularly an immunoassay system, lanthanide complexes that undergo inhibition of fluorescence in the presence of water are viewed as somewhat unfavorable or impractical for many applications. Moreover, the short fluorescence decay times is considered a disadvantage of these compounds. This inhibition is due to the affinity of the lanthanide ions for coordinating water molecules. When the lanthanide ion has coordinated water molecules, the absorbed light energy (excitation energy) is transferred from the complex to the solvent rather than being emitted as fluorescence.

[0011] Thus, stable lanthanide chelates, particularly coordinatively saturated chelates having excellent luminescence properties are highly desirable. In the alternative, coordinatively unsaturated lanthanide chelates that exhibit acceptable luminescence in the presence of water are also advantageous. Such chelates that are derivatized to allow their conjugation to one or more components of an assay, find use in a range of different assay formats. The present invention provides these and other such compounds and assays using these compounds.

[0012] Derivatives of 1-hydroxy-2-pyridinone (Structure 1) are of particular interest, since the ligand and its mono-anion (Structure 2) have a zwitterionic resonance form (Structure 3) that is isoelectronic with the catechol dianion.

[0013] Further, the 1-hydroxy-2-pyridinone structure possesses synthetic advantages, since the 6-carboxylic acid derivative (Structure 4) can be made in a straightforward manner.



[0014] Since the 1,2-HOPO ligands are useful sequestering agents for hard metal ions, especially for the f-elements, effort has been directed towards improving the initial synthesis of complexing ligands based on 1,2-HOPO. The original synthesis of multidentate 1,2-HOPO ligands, reported a decade ago, involves several low yield steps, difficult purifications and the use of phosgene (White *et al.*, *J. Med. Chem.* 31: 11-18 (1988)). The use of phosgene gas is undesirable for a number of reasons: the procedure is tedious; phosgene is highly toxic and volatile; the yield of the amine conjugate is low (*e.g.*, yields of 3,4-LI-1,2-HOPO, and 3,4,3-LI-1,2-HOPO using phosgene were 34% and 15%, respectively); and the separation of the resulting product is difficult, often requiring the use of HPLC.

[0015] Uhler reported that, following benzyl protection of the N-hydroxyl group of 6-carboxy-1,2-HOPO, this protected species could be activated and coupled to an amine scaffold (Uhler, L.C. MIXED FUNCTIONALITY ACTINIDE SEQUESTERING AGENTS. Ph.D. thesis, University of California, Berkeley, 1992). Uhler activated the HOPO carboxyl group using NHS/DCC and HOBt/DCC (*see*, Bodansky, M.; Bodanszky, A., THE PRACTICE OF PEPTIDE SYNTHESIS 2nd Ed., Springer-Verlag Berlin Heidelberg 1994, pp 96-125). Uhler did not disclose the formation of an acid halide from the benzyl protected HOPO derivative.

[0016] Bailly *et al.* reported the multistep preparation of a benzyl protected 1,2-HOPO acid chloride and the use of the protected acid chloride to form amine conjugates of 1,2-HOPO (*C. R. Acad. Sci. Paris I, Serie II*: 241-245 (1998)). The procedure of Bailly *et al.* is cumbersome, requiring conversion of the carboxylic acid to the corresponding methyl ester, activation and protection of the N-hydroxyl group, saponification of the methyl ester, followed by the activation of the carboxylic acid as the acid chloride. Bailly *et al.* does not suggest that the hydroxy 1 group can be protected in the presence of the free acid at the 6-position.

[0017] Other related art includes U.S. Pat. No. 4,698,431, which discloses polyvalent 1,2-HOPO chelators having an amide or a carboxylic acid moiety in the 6-position. The chelating agents are useful in selectively removing certain cations from solution and are particularly useful as ferric ion and actinide chelators. U.S. Patent No. 5,892,029 and U.S. Patent No. 5,624,901 also set forth polyvalent 1,2-HOPO chelators. None of the patents discloses or suggests preparing a polyvalent chelator from a protected, acid halide intermediate.

[0018] U.S. Pat. No. 4,666,927. discloses a number of chelating agents having 1,2-HOPO, 3,2-HOPO, or 3,4-HOPO moieties incorporated within their structures that are linked through a number of possible combinations of linking groups, including -CONH- groups. However, U.S. Pat. No. 4,666,927

teaches against a HOPO moiety having a substitution ortho to the hydroxy or oxo group of the HOPO ring, and does not disclose or suggest an acyl halide 1,2-HOPO intermediate.

[0019] A need for luminescent complexes, which are stable under biological relevant conditions and at low concentrations, remains.

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BRIEF SUMMARY

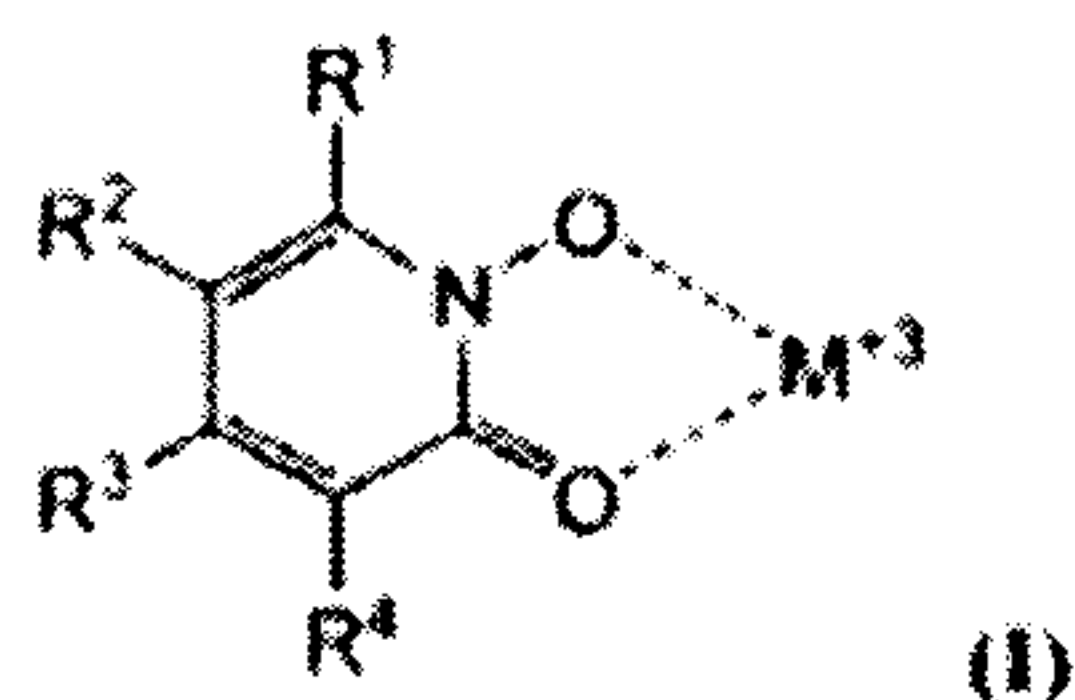
[0020] The present disclosure is directed toward new classes of chelating agents and metal complexes formed with these chelating agents and is exemplified by reference to the use of the chelating agents to complex lanthanide metal ions, particularly those lanthanide ions, which, when complexed by a chelating agent form a luminescent lanthanide chelate. The luminescent metal chelates incorporating a pyridinone, particularly a hydroxy-pyridinone subunit. An exemplary hydroxy-pyridinone subunit is 1-hydroxy-2-pyridinone. This disclosure provides luminescent complexes formed between lanthanides, e.g., Tb^{+3} and Eu^{+3} , and organic ligands that incorporate 1-hydroxy-2-pyridinone subunits as chelating agents. Also provided are complexes formed between actinides (e.g., ions of elements 89-103) and such a chelating agent.

15 [0021] Luminescent (including fluorescent, phosphorescent and emission arising from metal ions) markers find a wide variety of applications in science, medicine and engineering. In many situations, these markers or probes provide competitive replacements for radiolabels, chromogens, radiation-dense dyes, *etc.* Moreover, improvements in fluorometric instrumentation have increased attainable sensitivities and permitted quantitative analysis.

20 [0022] Lanthanide chelates in combination with time-resolved fluorescent spectroscopy is a widely used analytical, e.g., immunochemical tool. Lanthanide ions generally utilized in analytical procedures include Dy^{3+} , Sm^{3+} , Tb^{3+} , Er^{3+} and Eu^{3+} , Nd^{3+} , Tm^{3+} , Yb^{3+} . Other lanthanide ions, such as La^{3+} , Gd^{3+} and Lu^{3+} are useful as well.

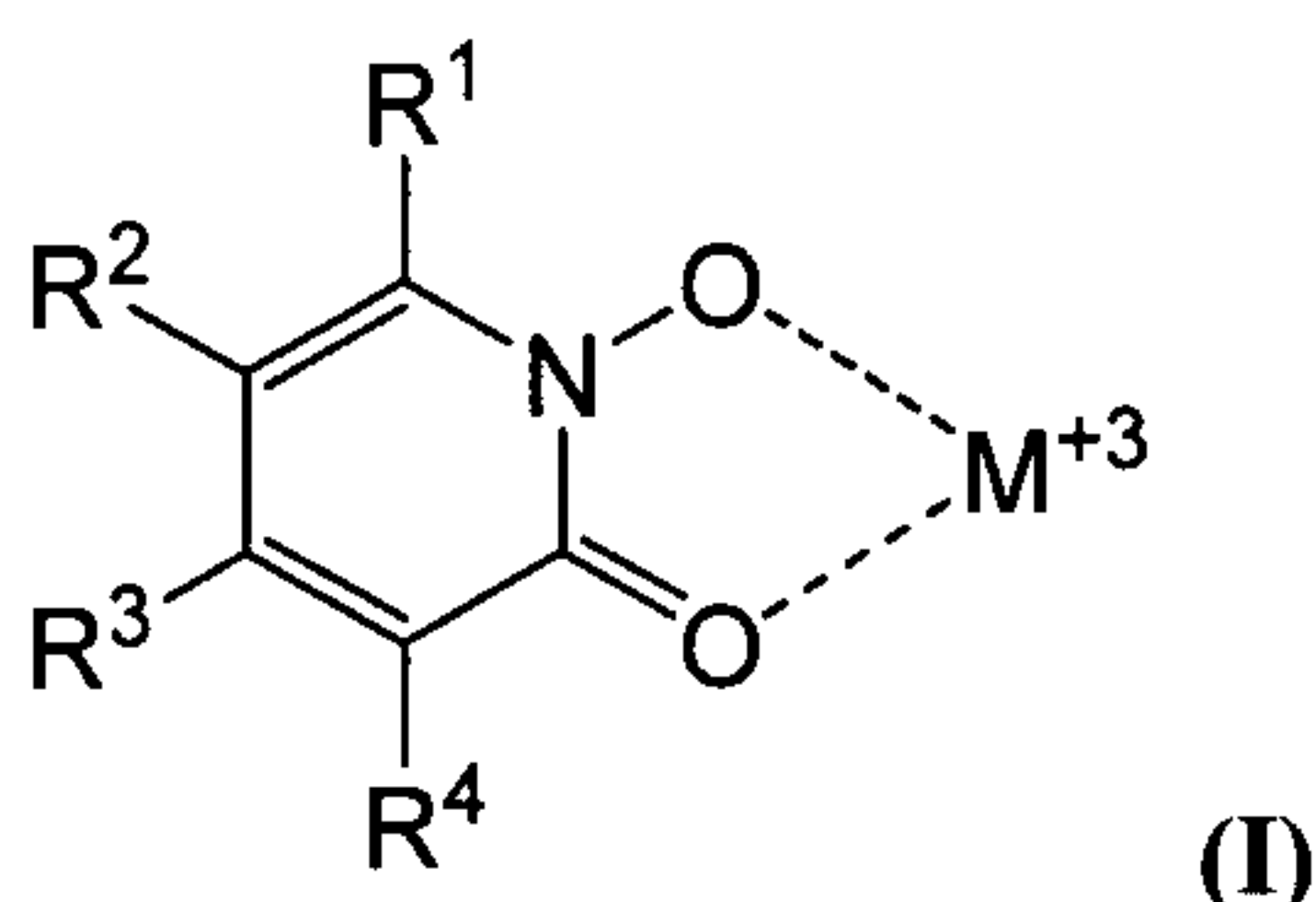
25 [0023] Unexpectedly, the inventors have discovered that chelates formed between a lanthanide ion and one or more organic ligands, incorporating a 1-hydroxy-2-pyridinone (1,2-HOPO) subunit, are luminescent and exhibit superior stability in aqueous solutions, including those with low pH. Moreover, these ligands complex actinides to form highly stable actinide ion complexes.

[0024] Thus in one aspect, this disclosure relates to a luminescent complex between a lanthanide ion and an organic ligand comprising the subunit of Formula 1:



wherein R^1 , R^2 , R^3 and R^4 are members independently selected from H, an aryl group substituent defined herein, a linker to a scaffold moiety and a linker to a functional moiety. M^{+3} is a metal ion, e.g., an actinide ion or a lanthanide ion, preferably forming the luminescent complex with one or more organic ligands.

[0025] Various embodiments of the claimed invention relate to a luminescent complex between a lanthanide ion and an organic ligand comprising the subunit of Formula I:



wherein

R^1 , R^2 , R^3 , and R^4 are members independently selected from H, an aryl group substituent, a linker to a scaffold moiety, and a linker to a functional moiety;

wherein the linker of said linker to the scaffold moiety is a member selected from $-C(O)NR^5-$, $-C(O)O-$, $-C(O)S-$, and $-C(O)CR^{20}R^{21}$, wherein R^5 , R^{20} , and R^{21} are members independently selected from H, substituted or unsubstituted alkyl, substituted or unsubstituted heteroalkyl, substituted or unsubstituted aryl, substituted or unsubstituted heteroaryl, and substituted or unsubstituted heterocycloalkyl;

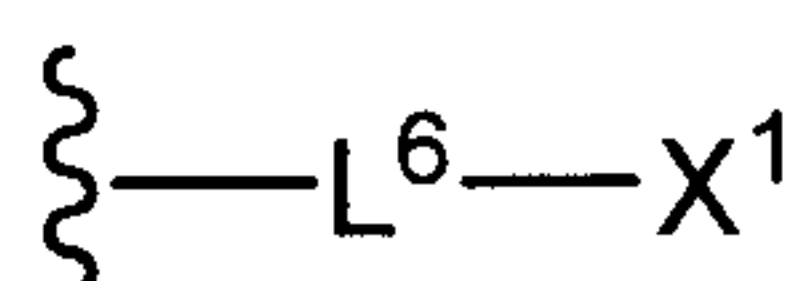
wherein said scaffold moiety is a member selected from substituted or unsubstituted alkyl and substituted or unsubstituted heteroalkyl;

wherein at least one of R^1 , R^2 , R^3 , and R^4 is said linker to the scaffold moiety;

M^{+3} is a lanthanide ion forming said luminescent complex with said organic ligand, wherein said lanthanide is a member selected from Neodymium (Nd), Samarium (Sm), Europium (Eu), Terbium (Tb), Dysprosium (Dy), and Ytterbium (Yb);

wherein said complex is substituted with at least one functional moiety;

wherein said functional moiety comprises the structure:



wherein

L^6 is a member selected from substituted or unsubstituted alkyl, substituted or unsubstituted heteroalkyl, substituted or unsubstituted heterocycloalkyl, substituted or unsubstituted aryl, and substituted or unsubstituted heteroaryl; and

X^1 is a reactive functional group or a targeting moiety;

wherein said reactive functional group is a member selected from $-OH$, $-SH$, $-NH_2$,

$-C(O)NHNH_2$ (hydrazide), maleimide, activated ester, aldehyde, ketone,

hydroxylamine, imidoester, isocyanate, isothiocyanate, sulfonylchloride, acylhalide,

$-COOH$, and $-COO^-$ or a salt thereof; and wherein said targeting moiety comprises a

member selected from a peptide, a protein, a fusion protein, an enzyme, an antibody, an

antibody fragment, an antigen, a nucleic acid, a carbohydrate, a lipid, and a

pharmacologically active molecule; and

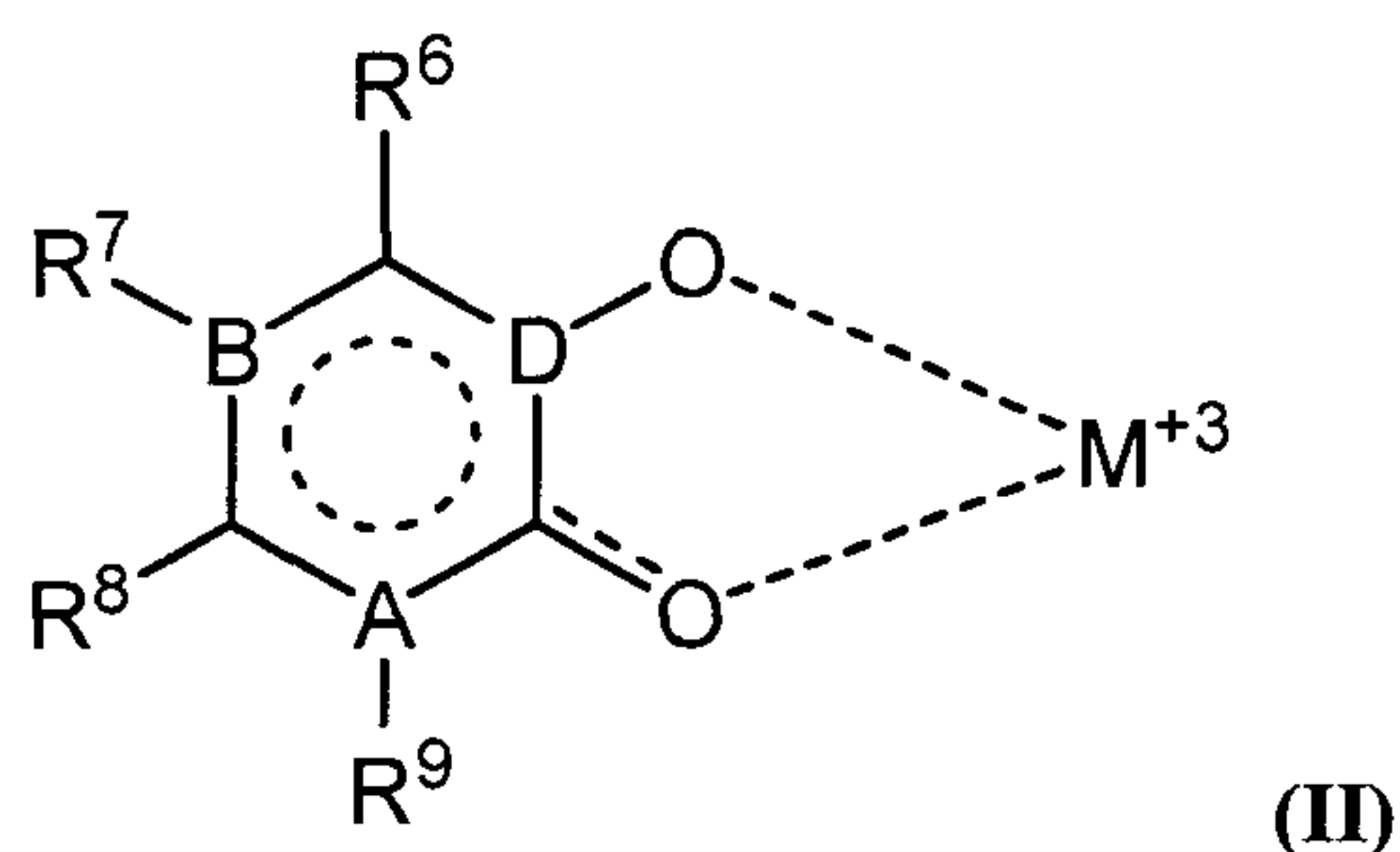
wherein “alkyl” is defined as comprising a straight, branched, or cyclic alkyl or a mono-, di- or

multivalent radical thereof, which is fully saturated, monounsaturated or polyunsaturated. Also claimed

is a mixture comprising such a luminescent complex and an analyte.

[0025A] In some embodiments, the organic ligand of such a luminescent complex comprises 8 or more donor oxygen atoms interacting with said lanthanide ion. In some embodiments, none of the donor oxygen atoms is part of a carboxylate group.

[0025B] In some embodiments, the luminescent complex may further comprise one or more chelating moieties, wherein each of said chelating moieties is complexed to said lanthanide ion and each of said chelating moieties has an independently selected structure according to Formula II:



wherein for each chelating moiety,

R^6 , R^7 , R^8 , and R^9 are members independently selected from H, substituted or

unsubstituted alkyl, substituted or unsubstituted heteroalkyl, substituted or

unsubstituted aryl, substituted or unsubstituted heteroaryl, substituted or

unsubstituted heterocycloalkyl, halogen, CN, CF_3 , $-C(O)R^{17}$, $-SO_2NR^{17}R^{18}$,

$-\text{NR}^{17}\text{R}^{18}$, $-\text{OR}^{17}$, $-\text{S}(\text{O})_2\text{R}^{17}$, $-\text{COOR}^{17}$, $-\text{S}(\text{O})_2\text{OR}^{17}$, $-\text{OC}(\text{O})\text{R}^{17}$,
 $-\text{C}(\text{O})\text{NR}^{17}\text{R}^{18}$, $-\text{NR}^{17}\text{C}(\text{O})\text{R}^{18}$, $-\text{NR}^{17}\text{SO}_2\text{R}^{18}$, $-\text{NO}_2$, a linker to a functional
 moiety, and a linker to a scaffold moiety,

wherein

zero or at least two of R^6 , R^7 , R^8 , and R^9 are joined to form a ring system which
 is a member selected from substituted or unsubstituted cycloalkyl,
 substituted or unsubstituted heterocycloalkyl, substituted or
 unsubstituted aryl, and substituted or unsubstituted heteroaryl,
 R^{17} and R^{18} are each members independently selected from H, substituted or
 unsubstituted alkyl, substituted or unsubstituted heteroalkyl, substituted
 or unsubstituted aryl, substituted or unsubstituted heteroaryl,
 substituted or unsubstituted heterocycloalkyl, a linker to a functional
 moiety, and a linker to a scaffold moiety; and R^{17} and R^{18} , together with
 the atoms to which they are attached, are joined to form a 5- to 7-
 membered ring or are not so joined;

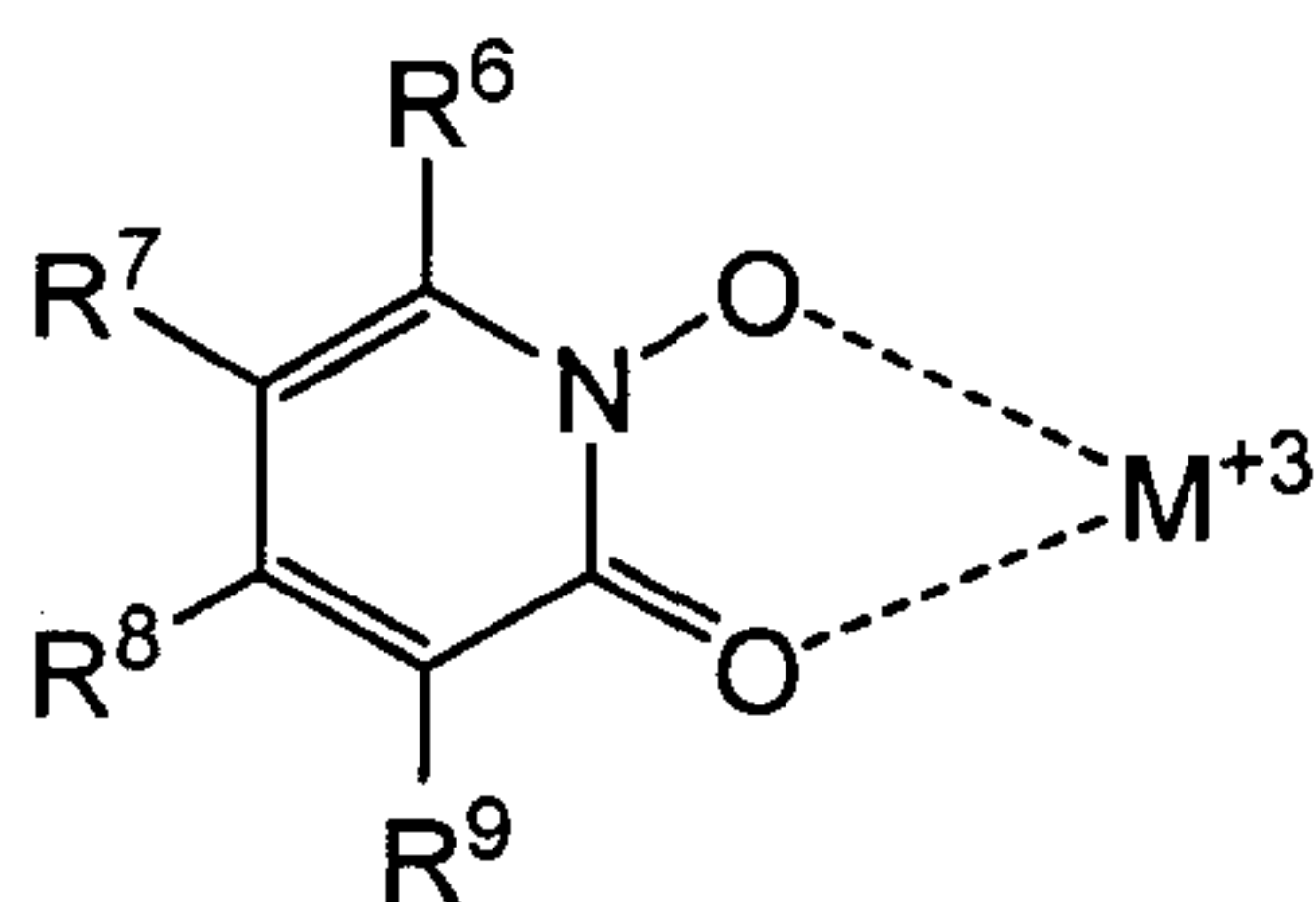
A and B are members independently selected from C, N, S, and O; and

D is a member selected from C and N,

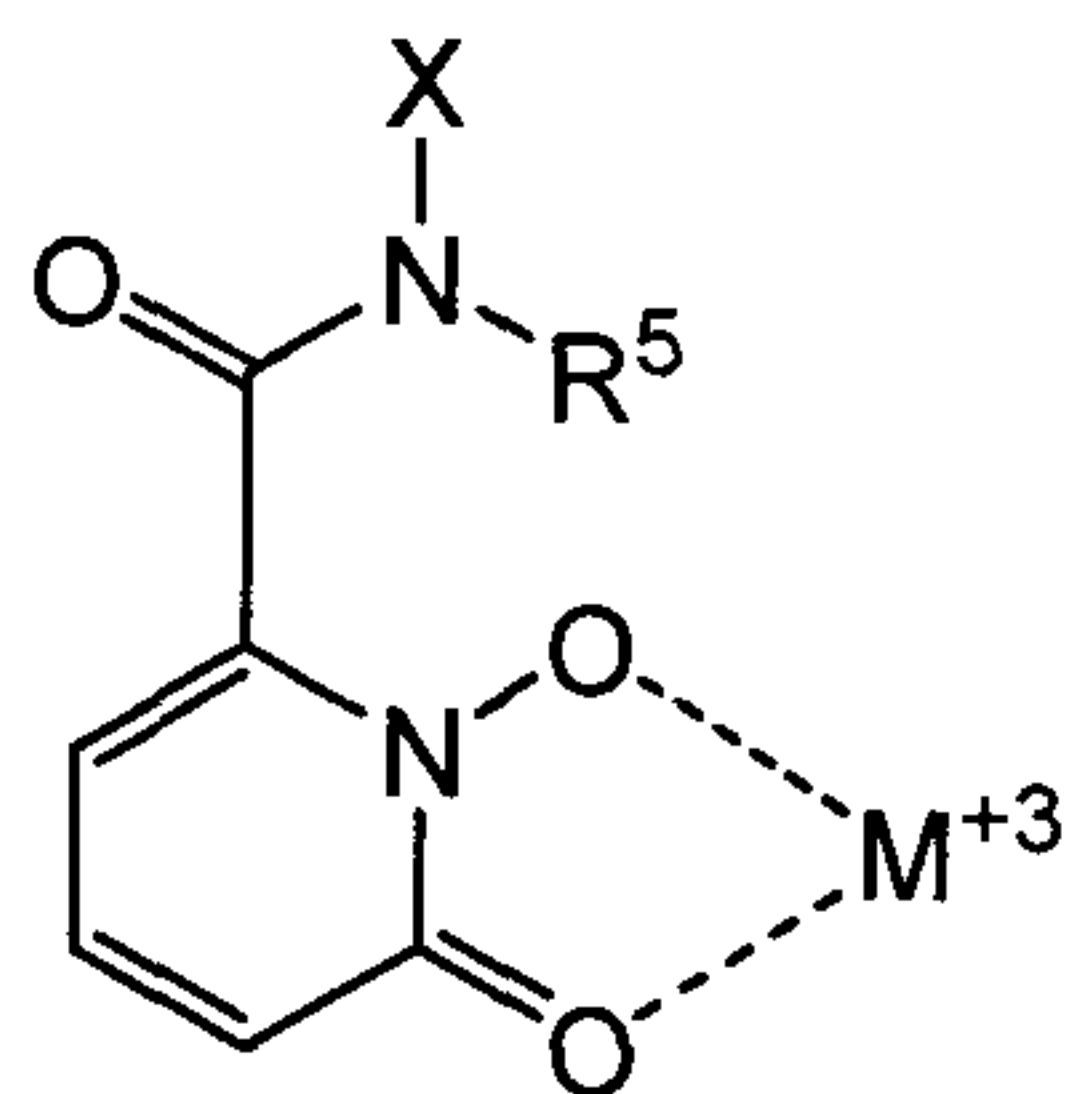
with the proviso that if A is O or S, R^9 is not present, and with the further proviso that if B is O
 or S, R^7 is not present;

wherein “alkyl” is defined as comprising a straight, branched, or cyclic alkyl or a mono-, di- or
 multivalent radical thereof, which is fully saturated, monounsaturated or
 polyunsaturated.

[0025C] In some embodiments, at least one of said chelating moieties of such a luminescent complex has the structure:



[0025D] In some embodiments, at least one of said chelating moieties of such a luminescent complex has the structure:

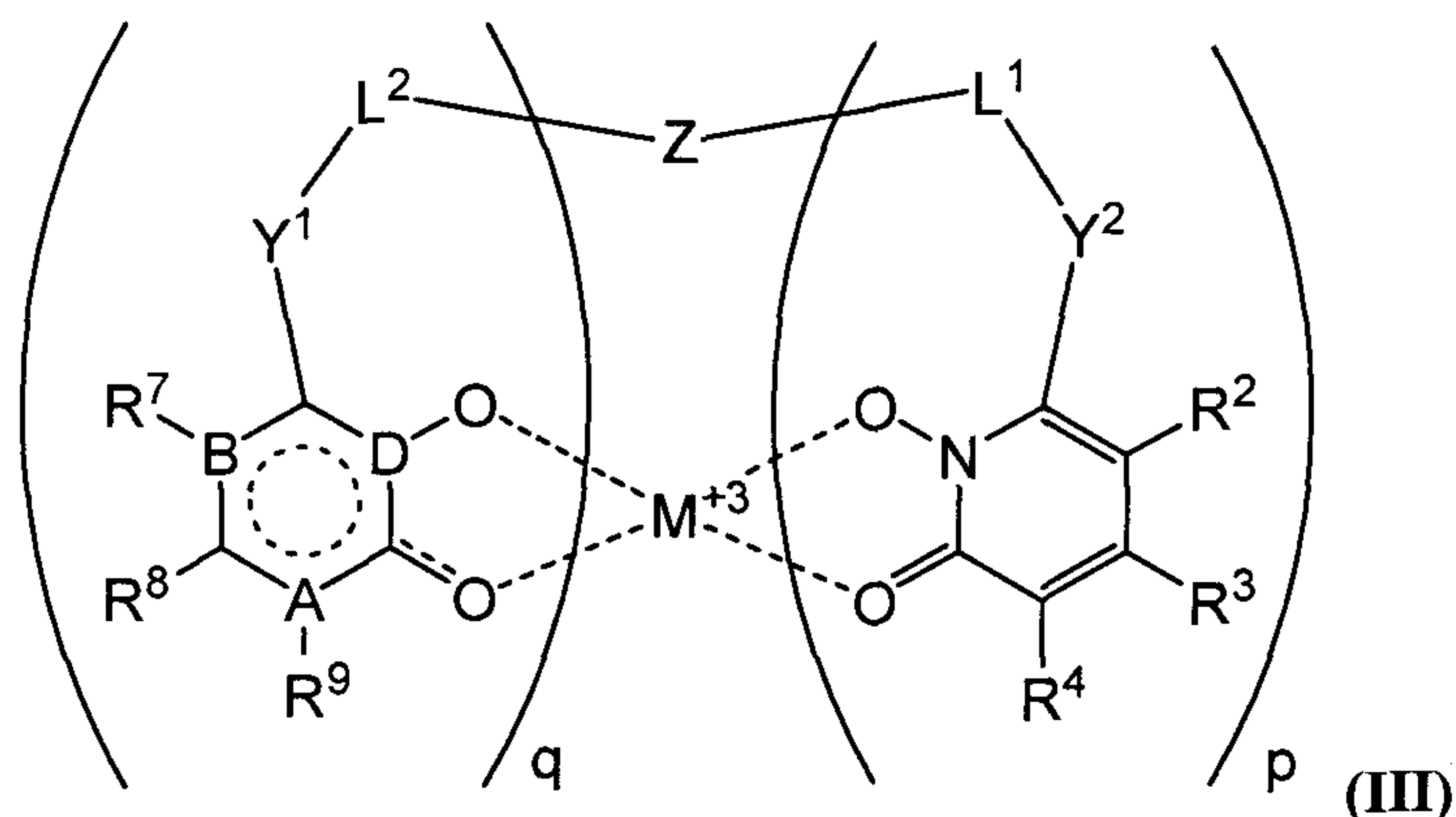


wherein

X is a scaffold moiety; and

R⁵ is a member selected from H, substituted or unsubstituted alkyl, substituted or unsubstituted heteroalkyl, substituted or unsubstituted aryl, substituted or unsubstituted heteroaryl, and substituted or unsubstituted heterocycloalkyl.

[0026] Various embodiments of the claimed invention relate to a luminescent complex having a structure according to Formula (III):



10 wherein

Z is a member selected from substituted or unsubstituted alkyl, substituted or unsubstituted heteroalkyl, substituted or unsubstituted aryl, substituted or unsubstituted heteroaryl, substituted or unsubstituted heterocycloalkyl, N, NR³⁰, O, S, and CR³¹R³²,

wherein

15 R³⁰, R³¹, and R³² are members independently selected from H, substituted or unsubstituted alkyl, substituted or unsubstituted heteroalkyl, substituted or unsubstituted aryl, substituted or unsubstituted heteroaryl, and substituted or unsubstituted heterocycloalkyl;

M⁺³ is a lanthanide ion, wherein said lanthanide is a member selected from Neodymium (Nd),
20 Samarium (Sm), Europium (Eu), Terbium (Tb), Dysprosium (Dy), and Ytterbium (Yb);
p is an integer selected from 1-3;

q is an integer selected from 0-2;

Y¹ and Y² are members independently selected from -C(O), -C(O)NR⁵-, -C(O)O-,
-C(O)S-, and -C(O)CR²⁰R²¹, wherein R⁵, R²⁰, and R²¹ are members independently
selected from H, substituted or unsubstituted alkyl, substituted or unsubstituted
heteroalkyl, substituted or unsubstituted aryl, substituted or unsubstituted heteroaryl,
substituted or unsubstituted heterocycloalkyl, and a functional moiety; and

L¹ and L² are members independently selected from a bond, substituted or unsubstituted alkyl,
substituted or unsubstituted heteroalkyl, substituted or unsubstituted aryl, substituted or
unsubstituted heteroaryl, and substituted or unsubstituted heterocycloalkyl,

each R², R³, and R⁴ are members independently selected from H, an aryl group substituent, a
linker to a scaffold moiety, and a linker to a functional moiety;

each R⁷, R⁸, and R⁹ are members independently selected from H, substituted or unsubstituted
alkyl, substituted or unsubstituted heteroalkyl, substituted or unsubstituted aryl,
substituted or unsubstituted heteroaryl, substituted or unsubstituted heterocycloalkyl,
halogen, CN, CF₃, -C(O)R¹⁷, -SO₂NR¹⁷R¹⁸, -NR¹⁷R¹⁸, -OR¹⁷, -S(O)₂R¹⁷, -COOR¹⁷,
-S(O)₂OR¹⁷, -OC(O)R¹⁷, -C(O)NR¹⁷R¹⁸, -NR¹⁷C(O)R¹⁸, -NR¹⁷SO₂R¹⁸, -NO₂, a
linker to a functional moiety, and a linker to a scaffold moiety,

wherein

zero of or at least two of R⁷, R⁸, and R⁹ are joined to form a ring system which is a
member selected from substituted or unsubstituted cycloalkyl, substituted or
unsubstituted heterocycloalkyl, substituted or unsubstituted aryl, and
substituted or unsubstituted heteroaryl,

R¹⁷ and R¹⁸ are each members independently selected from H, substituted or
unsubstituted alkyl, substituted or unsubstituted heteroalkyl, substituted or
unsubstituted aryl, substituted or unsubstituted heteroaryl, substituted or
unsubstituted heterocycloalkyl, a linker to a functional moiety, and a linker to a
scaffold moiety, and R¹⁷ and R¹⁸, together with the atoms to which they are
attached, are joined to form a 5- to 7-membered ring or are not so joined;

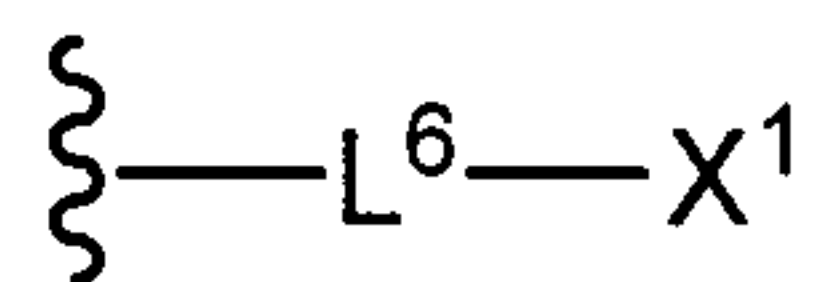
wherein each scaffold moiety is independently a member selected from substituted or
unsubstituted alkyl and substituted or unsubstituted heteroalkyl;

each A and B are members independently selected from C, N, S, and O; and

each D is a member selected from C and N,

with the proviso that if A is O or S, R⁹ is not present, and with the further proviso that if B is O or S, R⁷
is not present;

with the proviso that the sum of p and q is not greater than 4, and with the further proviso that if Z is O or S, the sum of p and q is not greater than 2; and
 wherein said complex is substituted with at least one functional moiety;
 wherein each functional moiety comprises the structure:



wherein

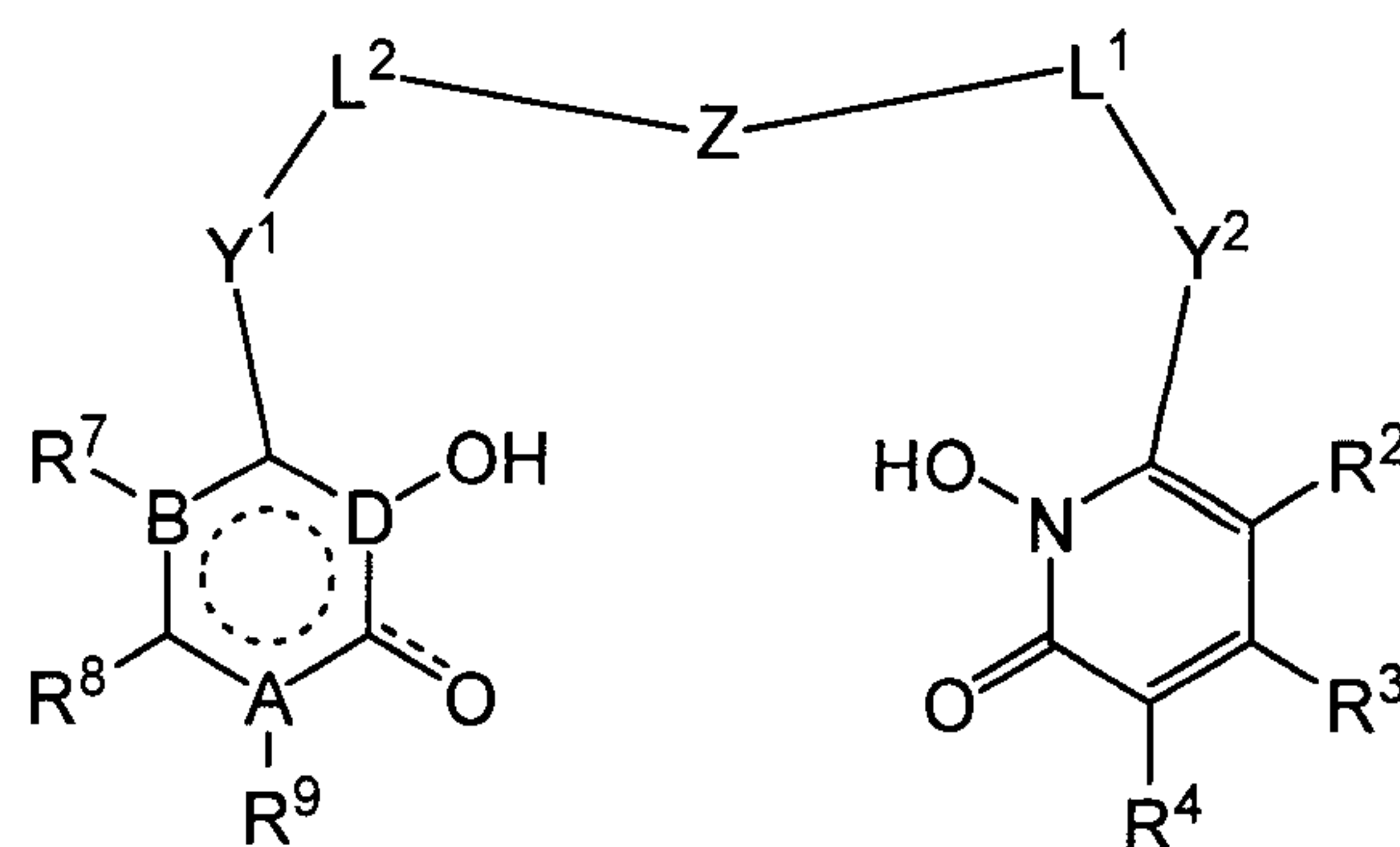
L^6 is a member selected from substituted or unsubstituted alkyl, substituted or unsubstituted heteroalkyl, substituted or unsubstituted heterocycloalkyl, substituted or unsubstituted aryl, and substituted or unsubstituted heteroaryl; and

X^1 is a reactive functional group or a targeting moiety;

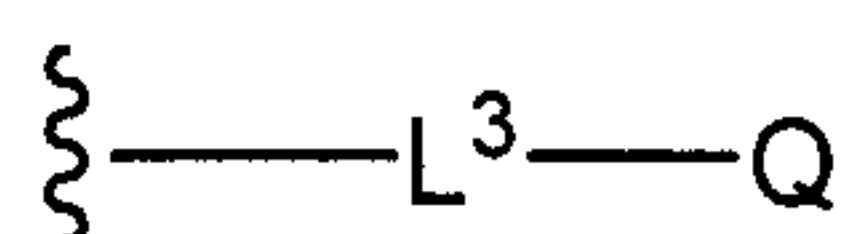
wherein said reactive functional group is a member selected from $-OH$, $-SH$, $-NH_2$, $-C(O)NHNH_2$ (hydrazide), maleimide, activated ester, aldehyde, ketone, hydroxylamine, imidoester, isocyanate, isothiocyanate, sulfonylchloride, acylhalide, $-COOH$, and $-COO^-$ or a salt thereof; and

wherein said targeting moiety comprises a member selected from a peptide, a protein, a fusion protein, an enzyme, an antibody, an antibody fragment, an antigen, a nucleic acid, a carbohydrate, a lipid, and a pharmacologically active molecule; and

wherein "alkyl" is defined as comprising a straight, branched, or cyclic alkyl or a mono-, di- or multivalent radical thereof, which is fully saturated, monounsaturated or polyunsaturated. In some embodiments, the organic ligand has the structure:



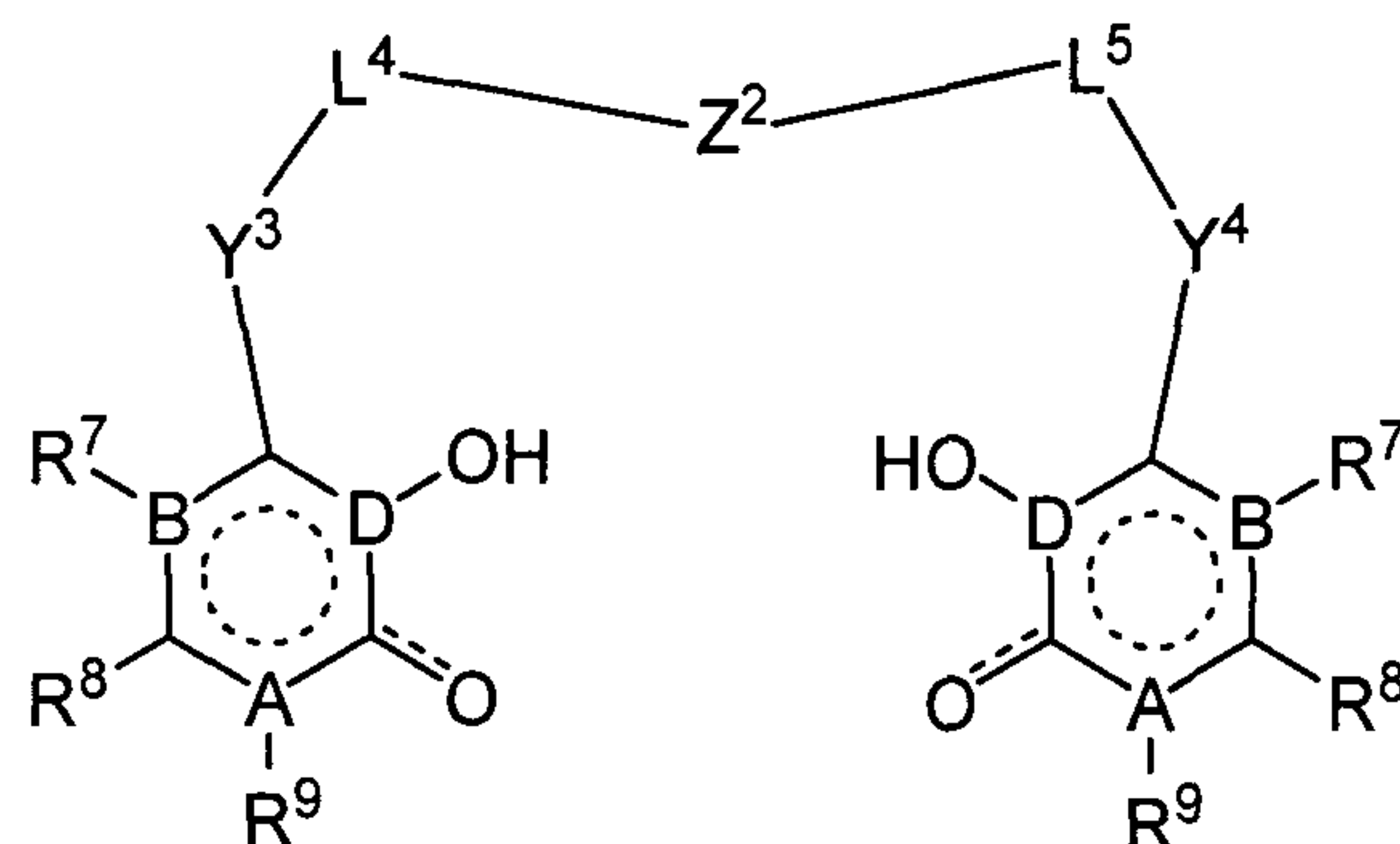
wherein at least one of Z, L^1 , and L^2 is substituted with a moiety having the structure:



wherein

L^3 is a member selected from a bond, substituted or unsubstituted alkyl, substituted or unsubstituted heteroalkyl, substituted or unsubstituted aryl, substituted or unsubstituted heteroaryl, and substituted or unsubstituted heterocycloalkyl;

Q has the structure:



wherein

Z^2 is a member selected from substituted or unsubstituted alkyl, substituted or unsubstituted heteroalkyl, substituted or unsubstituted aryl, substituted or unsubstituted heteroaryl, substituted or unsubstituted heterocycloalkyl, N, NR^{30} , O, S, and $CR^{31}R^{32}$,

wherein

R^{30} , R^{31} , and R^{32} are members independently selected from H, substituted or unsubstituted alkyl, substituted or unsubstituted heteroalkyl, substituted or unsubstituted aryl, substituted or unsubstituted heteroaryl, and substituted or unsubstituted heterocycloalkyl;

Y^3 and Y^4 are members independently selected from $-C(O)$, $-C(O)NR^5$, $-C(O)O-$, $-C(O)S-$, and $-C(O)CR^{20}R^{21}$, wherein R^5 , R^{20} , and R^{21} are members independently selected from H, substituted or unsubstituted alkyl, substituted or unsubstituted heteroalkyl, substituted or unsubstituted aryl, substituted or unsubstituted heteroaryl, substituted or unsubstituted heterocycloalkyl, and said functional moiety;

L^4 and L^5 are members independently selected from a bond, substituted or unsubstituted alkyl, substituted or unsubstituted heteroalkyl, substituted or unsubstituted aryl, substituted or unsubstituted heteroaryl, and substituted or unsubstituted heterocycloalkyl; and

one of Z^2 , L^4 , and L^5 is linked to L^3 . Also claimed is a mixture comprising such a luminescent complex and an analyte.

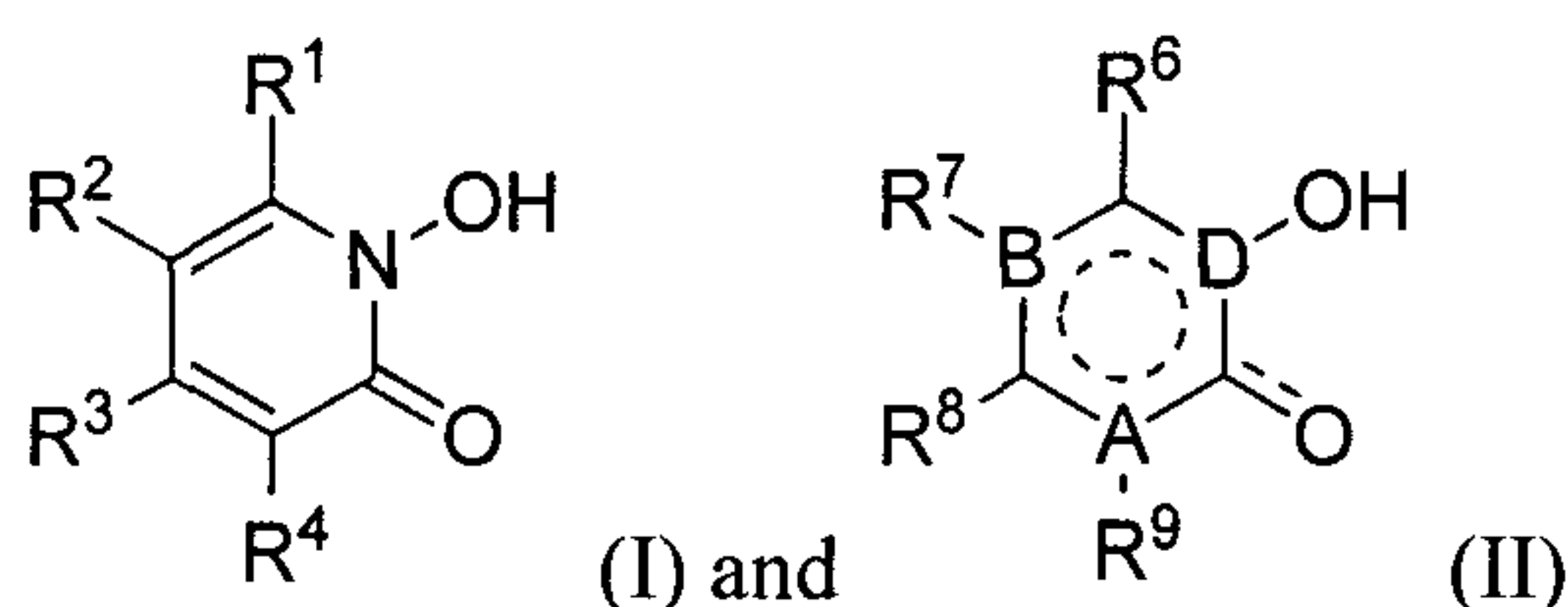
[0027] Various embodiments of the claimed invention relate to methods of detecting the presence of an analyte in a sample, said method comprising: (a) contacting said sample with a claimed luminescent complex; (b) exciting said complex; and (c) detecting luminescence from said complex.

[0027A] Various embodiments of the claimed invention relate to methods of detecting the presence of an analyte in a sample, said method comprising: (a) contacting said sample with a claimed luminescent complex and a luminescence modifying group, wherein energy can be transferred between said luminescent complex and said luminescence modifying group when said complex is excited; (b) exciting said complex; and (c) determining the luminescent property of said sample, wherein the presence of said analyte results in a change in said luminescent property.

[0027B] This disclosure also provides complexes comprising a compound and a metal ion.

[0027C] This disclosure also provides kits comprising a recognition molecule and a luminescent complex, wherein the recognition molecule is a member selected from an antibody, a protein, and a nucleic acid.

[0027D] This disclosure also provides a compound comprising two, four, or more than four chelating moieties independently selected from Formula (I) and Formula (II):



wherein the chelating moieties are covalently linked through a scaffold moiety;

wherein for each chelating moiety of Formula (I)

R^1 , R^2 , R^3 , and R^4 are members independently selected from H, an aryl group substituent, a linker to the scaffold moiety, and a linker to a functional moiety; and

for each chelating moiety according to Formula (II)

R^6 , R^7 , R^8 , and R^9 are members independently selected from H, substituted or unsubstituted alkyl, substituted or unsubstituted heteroalkyl, substituted or unsubstituted aryl, substituted or unsubstituted heteroaryl, substituted or unsubstituted heterocycloalkyl, halogen, CN, CF_3 , $-C(O)R^{17}$, $-SO_2NR^{17}R^{18}$, $-NR^{17}R^{18}$, $-OR^{17}$, $-S(O)_2R^{17}$, $-COOR^{17}$, $-S(O)_2OR^{17}$, $-OC(O)R^{17}$, -

C(O)NR¹⁷R¹⁸, -NR¹⁷C(O)R¹⁸, -NR¹⁷SO₂R¹⁸, -NO₂, a linker to a functional moiety, and a linker to a scaffold moiety,

wherein

none of or at least two of R⁶, R⁷, R⁸, and R⁹ are joined to form a ring system which is a member
 5 selected from substituted or unsubstituted cycloalkyl, substituted or unsubstituted heterocycloalkyl, substituted or unsubstituted aryl, and substituted or unsubstituted heteroaryl;

R¹⁷ and R¹⁸ are each members independently selected from H, substituted or unsubstituted alkyl, substituted or unsubstituted heteroalkyl, substituted or unsubstituted aryl, substituted or
 10 unsubstituted heteroaryl, substituted or unsubstituted heterocycloalkyl, a linker to a functional moiety, and a linker to a scaffold moiety; and R¹⁷ and R¹⁸, together with the atoms to which they are attached, are joined to form a 5- to 7-membered ring or are not so joined;

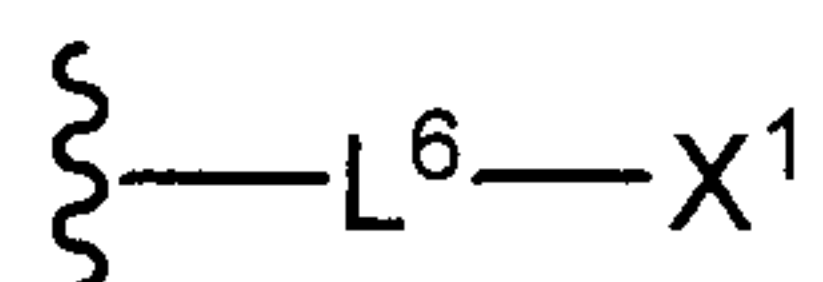
A and B are members independently selected from carbon, nitrogen, sulfur, and oxygen;

15 D is a member selected from carbon and nitrogen;

wherein if A is oxygen or sulfur, R⁹ is not present;

wherein if B is oxygen or sulfur, R⁷ is not present; and

wherein said compound is substituted with at least one functional moiety having the structure:



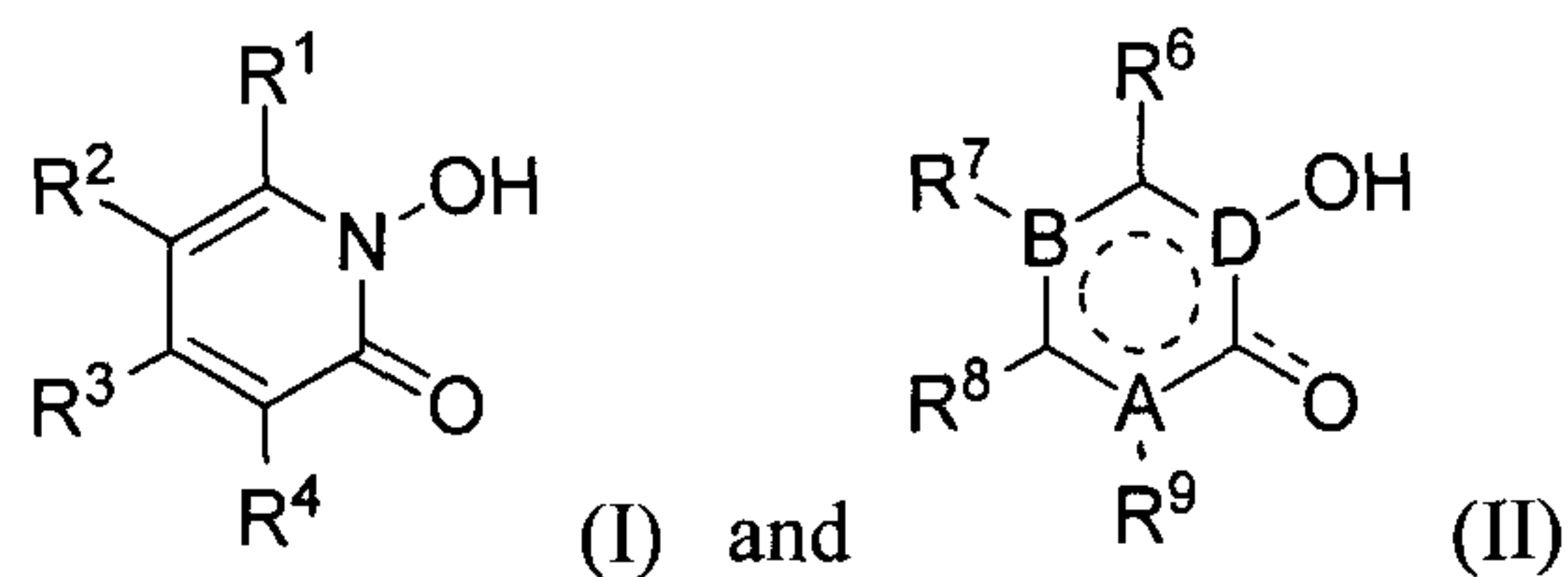
20 wherein

L⁶ is a linker group, which is a member selected from substituted or unsubstituted alkyl, substituted or unsubstituted heteroalkyl, substituted or unsubstituted heterocycloalkyl, substituted or unsubstituted aryl, and substituted or unsubstituted heteroaryl;

X¹ is a member selected from a reactive functional group and a targeting moiety; and

25 wherein "alkyl" is defined as comprising a straight, branched, or cyclic alkyl or a mono-, di- or multivalent radical thereof, which is fully saturated, monounsaturated or polyunsaturated.

[0027E] The present disclosure also provides complexes comprising a metal ion and a ligand, wherein said ligand comprises two or more chelating moieties independently selected from Formula (I) and Formula (II):



wherein the chelating moieties are covalently linked through a scaffold moiety;

wherein for each chelating moiety of Formula (I)

R^1 , R^2 , R^3 , and R^4 are members independently selected from H, an aryl group substituent, a linker to
5 the scaffold moiety, and a linker to a functional moiety; and

for each chelating moiety according to Formula (II)

R^6 , R^7 , R^8 , and R^9 are members independently selected from H, substituted or unsubstituted alkyl,
substituted or unsubstituted heteroalkyl, substituted or unsubstituted aryl, substituted or
unsubstituted heteroaryl, substituted or unsubstituted heterocycloalkyl, halogen, CN,
10 CF_3 , $-C(O)R^{17}$, $-SO_2NR^{17}R^{18}$, $-NR^{17}R^{18}$, $-OR^{17}$, $-S(O)_2R^{17}$, $-COOR^{17}$, $-S(O)_2OR^{17}$, $-OC(O)R^{17}$, $-$
 $C(O)NR^{17}R^{18}$, $-NR^{17}C(O)R^{18}$, $-NR^{17}SO_2R^{18}$, $-NO_2$, a linker to a functional moiety, and a linker
to a scaffold moiety,

wherein

zero of or at least two of R^6 , R^7 , R^8 and R^9 are joined to form a ring system which is a member
15 selected from substituted or unsubstituted cycloalkyl, substituted or unsubstituted
heterocycloalkyl, substituted or unsubstituted aryl, and substituted or unsubstituted
heteroaryl;

R^{17} and R^{18} are each members independently selected from H, substituted or unsubstituted alkyl,
substituted or unsubstituted heteroalkyl, substituted or unsubstituted aryl, substituted or
20 unsubstituted heteroaryl, substituted or unsubstituted heterocycloalkyl, a linker to a
functional moiety, and a linker to a scaffold moiety; and R^{17} and R^{18} , together with the
atoms to which they are attached, are joined to form a 5- to 7-membered ring or are not so
joined;

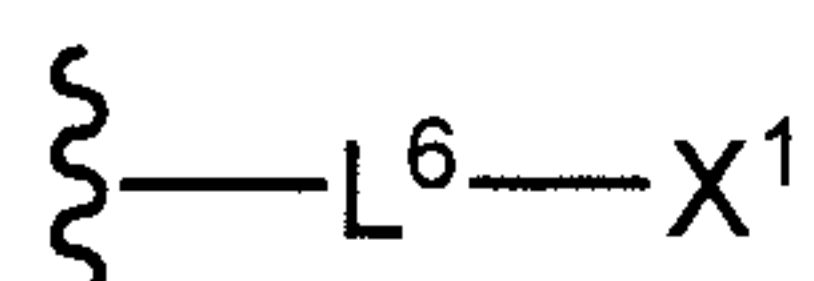
A and B are members independently selected from carbon, nitrogen, sulfur, and oxygen;

25 D is a member selected from carbon and nitrogen;

wherein if A is oxygen or sulfur, R^9 is not present;

wherein if B is oxygen or sulfur, R^7 is not present;

wherein said ligand is substituted with at least one functional moiety having the structure:



wherein

L⁶ is a linker group, which is a member selected from substituted or unsubstituted alkyl, substituted or unsubstituted heteroalkyl, substituted or unsubstituted heterocycloalkyl, substituted or unsubstituted aryl, and substituted or unsubstituted heteroaryl; and

5 X¹ is a member selected from a reactive functional group and a targeting moiety.

with the proviso that said targeting moiety is not a solid support;

with the proviso that the metal is not iron or gadolinium; and

wherein “alkyl” is defined as comprising a straight, branched, or cyclic alkyl or a mono-, di- or multivalent radical thereof, which is fully saturated, monounsaturated or polyunsaturated.

10

DETAILED DESCRIPTION

1. Introduction

[0028] The present disclosure provides a class of chelating agents of use to chelate metal ions, e.g., actinides and lanthanides, and are particularly preferred to form luminescent probes. The chelating
15 agents are based on 1,2-hydroxypyridinone-based ligands (“1,2-HOPO”). Exemplary chelating agents (and metal ion complexes) of the invention include 1,2-HOPO and other chelating moieties, e.g., maltol derivatives, hydroxypyrimidinone (HOPY) derivatives, hydroxy-*iso*-phthalic acid derivatives, catecholic acid derivatives, terephthalic acid derivatives (e.g., terephthalamidyl, TAM) and salicylic acid derivatives, preferably incorporated into a single ligand in which the subunits are linked by a scaffold
20 moiety, e.g., tris(2-aminoethyl)amine (TREN) and, preferably octadentate topology scaffolds, such as H22.

[0029] Selected complexes of this disclosure emit light or they can be used to absorb light emitted by a reporter fluorophore. The fluorophores of this disclosure can be used as small molecules in solution assays or they can be utilized as a label that is attached to an analyte or a species that interacts with, and
25 allows detection and/or quantification of an analyte.

[0030] Luminescent (e.g., fluorescent) labels have the advantage of requiring few precautions in their handling, and being amenable to high-throughput visualization techniques (optical analysis including digitization of the image for analysis in an integrated system comprising a computer). Preferred labels are typically characterized by high sensitivity, high stability, low background, long lifetimes, low
30 environmental sensitivity and high specificity in labeling.

[0031] The fluorophores of this disclosure can also be used in conjunction with other fluorophores or quenchers as components of energy transfer probes. Many fluorescent labels are useful in

combination with the chelators of the invention. Many such labels are commercially available from, for example, the SIGMA chemical company (Saint Louis, MO), Molecular Probes (Eugene, OR), R&D systems (Minneapolis, MN), Pharmacia LKB Biotechnology (Piscataway, NJ), CLONTECH Laboratories, Inc. (Palo Alto, CA), Chem Genes Corp., Aldrich Chemical Company (Milwaukee, WI), Glen Research, Inc., GIBCO BRL Life Technologies, Inc. (Gaithersburg, MD), Fluka Chemica- Biochemika Analytika (Fluka Chemie AG, Buchs, Switzerland), and Applied Biosystems (Foster City, CA), as well as many other commercial sources known to one of skill. Furthermore, those of skill in the art will recognize how to select an appropriate fluorophore for a particular application and, if not readily available commercially, will be able to synthesize the necessary fluorophore *de novo* or synthetically modify commercially available fluorescent compounds to arrive at the desired fluorescent label.

[0032] In addition to small molecule fluorophores, naturally occurring fluorescent proteins and engineered analogues of such proteins are useful with the complexes of the present invention. Such proteins include, for example, green fluorescent proteins of cnidarians (Ward *et al.*, *Photochem. Photobiol.* 35:803-808 (1982); Levine *et al.*, *Comp. Biochem. Physiol.*, 72B:77-85 (1982)), yellow fluorescent protein from *Vibrio fischeri* strain (Baldwin *et al.*, *Biochemistry* 29:5509-15 (1990)), Peridinin-chlorophyll from the dinoflagellate *Symbiodinium* sp. (Morris *et al.*, *Plant Molecular Biology* 24:673:77 (1994)), phycobiliproteins from marine cyanobacteria, such as *Synechococcus*, *e.g.*, phycoerythrin and phycocyanin (Wilbanks *et al.*, *J. Biol. Chem.* 268:1226-35 (1993)), and the like.

[0033] Compounds disclosed herein can be used as probes, as tools for separating particular ions from other solutes, as probes in microscopy, enzymology, clinical chemistry, molecular biology and medicine, as diagnostic agents and as components of optical amplifiers of light, waveguides and the like. Furthermore, compounds disclosed herein can be incorporated into inks and dyes, such as those used in the printing of currency or other negotiable instruments.

[0034] Complexes disclosed herein emit fluorescence upon excitation using any manner known in the art, including, for example, with light or electrochemical energy (*see*, for example, Kulmala *et al.*, *Analytica Chimica Acta* 386: 1 (1999)). The luminescence can, in the case of chiral compounds of the invention, be circularly polarized (*see*, for example, Riehl *et al.*, *Chem. Rev.* 86: 1 (1986)).

[0035] The chelating agents and their metal ion complexes, *e.g.*, luminescent complexes, and methods discussed in the following sections are generally representative of compositions

of this disclosure and the methods in which such compositions can be used. Many of the chelating agents are shown in the sections that follow in their complexed form (e.g., complexed with M^{+3}). These formulae are not limited to the metal ion complexes, but merely recite one form of the chelating agent, i.e., complexed. The formulae are equally representative of the uncomplexed chelating agents, unless
5 the chelating agent is designated as being complexed with a specific metal ion or as having a specific property imparted to the complex by chelation of the metal ion (e.g., luminescence). The following discussion is intended as illustrative of selected aspects and embodiments and it should not be interpreted as limiting in scope.

2. Definitions

10 [0036] Unless defined otherwise, all technical and scientific terms used herein generally have the same meaning as commonly understood by one of ordinary skill in the art to which this invention belongs. Generally, the nomenclature used herein and the laboratory procedures in molecular biology, organic chemistry and nucleic acid chemistry and hybridization described below are those well known and commonly employed in the art. Standard techniques are used for nucleic acid and peptide synthesis.

15 The nomenclature used herein and the laboratory procedures in analytical chemistry, and organic synthetic described below are those known and employed in the art. Standard techniques, or modifications thereof, are used for chemical syntheses and chemical analyses.

[0037] "Analyte", as used herein, means any compound or molecule of interest for which a diagnostic test is performed, such as a biopolymer or a small molecular bioactive material. An analyte can be, for
20 example, a protein, peptide, a lipid, a carbohydrate, polysaccharide, glycoprotein, hormone, receptor, antigen, antibody, virus, substrate, metabolite, transition state analog, cofactor, inhibitor, drug, dye, nutrient, growth factor, lipid etc., without limitation.

[0038] As used herein, "energy transfer" refers to the process by which the light emission of a luminescent group is altered by a luminescence-modifying group. When the luminescence-modifying
25 group is a quenching group then the light emission from the luminescent group is attenuated (quenched). Energy transfer mechanisms include luminescence resonance energy transfer by dipole-dipole interaction (e.g., in longer range energy transfer) or electron transfer (e.g., across shorter distances). While energy transfer is often based on spectral overlapping of the emission spectrum of the luminescent group and the absorption spectrum of the

luminescence-modifying group, (in addition to distance between the groups) it has been demonstrated that spectral overlap is not necessarily required for energy transfer to occur (see e.g., Latva et al., U.S. Patent No.: 5,988,146). It is to be understood that any reference to "energy transfer" in the instant application encompasses all mechanistically-distinct phenomena.

5 [0039] "Energy transfer pair" is used to refer to a group of molecules that participate in energy transfer. Such complexes may comprise, for example, two luminescent groups, which may be different from one-another and one quenching group, two quenching groups and one luminescent group, or multiple luminescent groups and multiple quenching groups. In cases where there are multiple luminescent groups and/or multiple quenching groups, the individual groups may be
10 different from one another. Typically, one of the molecules acts as a luminescent group, and another acts as a luminescence-modifying group. The preferred energy transfer pair of the invention comprises a luminescent group and a quenching group of the invention. There is no limitation on the identity of the individual members of the energy transfer pair in this application. All that is required is that the spectroscopic properties of the energy transfer pair as a whole change
15 in some measurable way if the distance between the individual members is altered by some critical amount.

[0040] As used herein, "luminescence-modifying group" refers to a molecule that can alter in any way the luminescence emission from a luminescent group. A luminescence-modifying group generally accomplishes this through an energy transfer mechanism. Depending on the identity of
20 the luminescence-modifying group, the luminescence emission can undergo a number of alterations, including, but not limited to, attenuation, complete quenching, enhancement, a shift in wavelength, a shift in polarity, and a change in luminescence lifetime. One example of a luminescence-modifying group is a fluorescence-modifying group. Another exemplary luminescence-modifying group is a quenching group.

25 [0041] As used herein, "quenching group" refers to any luminescence-modifying group that can attenuate at least partly the light emitted by a luminescent group. This attenuation is referred to herein as "quenching". Hence, excitation of the luminescent group in the presence of the quenching group leads to an emission signal that is less intense than expected, or even completely absent. Quenching typically occurs through energy transfer between the luminescent group and the
30 quenching group.

[0042] "Fluorescence resonance energy transfer" or "FRET" is used interchangeably with FET, and refers to an energy transfer phenomenon in which the light emitted by an excited fluorescent group is absorbed at least partially by a fluorescence-modifying group of the invention. If the fluorescence-modifying group is a quenching group, then that group will preferably not radiate a substantial fraction of the absorbed light as light of a different wavelength, and will preferably dissipate it as heat. FRET depends on energy transfer between the fluorescent group and the fluorescence-modifying group. FRET also depends on the distance between the quenching group and the fluorescent group.

[0043] "Moiety" refers to a radical of a molecule that is attached to another portion of the molecule.

[0044] As used herein, "nucleic acid" means DNA, RNA, single-stranded, double-stranded, or more highly aggregated hybridization motifs, and any chemical modifications thereof. Modifications include, but are not limited to, those providing chemical groups that incorporate additional charge, polarizability, hydrogen bonding, electrostatic interaction, and fluxionality to the nucleic acid ligand bases or to the nucleic acid ligand as a whole. Such modifications include, but are not limited to, peptide nucleic acids, phosphodiester group modifications (e.g., phosphorothioates, methylphosphonates), 2'-position sugar modifications, 5-position pyrimidine modifications, 8-position purine modifications, modifications at exocyclic amines, substitution of 4-thiouridine, substitution of 5-bromo or 5-iodo-uracil; backbone modifications, methylations, unusual base-pairing combinations such as the isobases, isocytidine and isoguanidine and the like. Modifications can also include 3' and 5' modifications such as capping with a fluorophore or another moiety.

[0045] "Peptide" refers to a polymer in which the monomers are amino acids and are joined together through amide bonds, alternatively referred to as a polypeptide. When the amino acids are alpha-amino acids, either the L-optical isomer or the D-optical isomer can be used. Additionally, unnatural amino acids, for example, beta.-alanine, phenylglycine and homoarginine are also included. Commonly encountered amino acids that are not gene-encoded may also be used in the present invention. All of the amino acids used in the present invention may be either the D- or L-isomer. The L-isomers are generally preferred. The term "peptide" or "polypeptide", as used herein, refers to naturally occurring as well as synthetic peptides. In addition, peptidomimetics are also useful in the present invention. For a general

review, see, Spatola, A. F., in CHEMISTRY AND BIOCHEMISTRY OF AMINO ACIDS, PEPTIDES AND PROTEINS, B. Weinstein, eds., Marcel Dekker, New York, p. 267 (1983).

[0046] Where substituent groups are specified by their conventional chemical formulae, written from left to right, they optionally equally encompass the chemically identical substituents, which would result from writing the structure from right to left, *e.g.*, -CH₂O- is intended to also recite -OCH₂-.

[0047] The term “alkyl,” by itself or as part of another substituent, means, unless otherwise stated, a straight or branched chain, or cyclic hydrocarbon radical, or combination thereof, which may be fully saturated, mono- or polyunsaturated and can include di- and multivalent radicals, having the number of carbon atoms designated (*i.e.* C₁-C₁₀ means one to ten carbons). Examples of saturated hydrocarbon radicals include, but are not limited to, groups such as methyl, ethyl, n-propyl, isopropyl, n-butyl, t-butyl, isobutyl, sec-butyl, cyclohexyl, (cyclohexyl)methyl, cyclopropylmethyl, homologs and isomers of, for example, n-pentyl, n-hexyl, n-heptyl, n-octyl, and the like. An unsaturated alkyl group is one having one or more double bonds or triple bonds. Examples of unsaturated alkyl groups include, but are not limited to, vinyl, 2-propenyl, crotyl, 2-isopentenyl, 2-(butadienyl), 2,4-pentadienyl, 3-(1,4-pentadienyl), ethynyl, 1- and 3-propynyl, 3-butylnyl, and the higher homologs and isomers. The term “alkyl,” unless otherwise noted, is also meant to include those derivatives of alkyl defined in more detail below, such as “heteroalkyl” with the difference that the heteroalkyl group, in order to qualify as an alkyl group, is linked to the remainder of the molecule through a carbon atom. Alkyl groups that are limited to hydrocarbon groups are termed “homoalkyl”.

[0048] The term “alkenyl” by itself or as part of another substituent is used in its conventional sense, and refers to a radical derived from an alkene, as exemplified, but not limited by, substituted or unsubstituted vinyl and substituted or unsubstituted propenyl. Typically, an alkenyl group will have from 1 to 24 carbon atoms, with those groups having from 1 to 10 carbon atoms being generally preferred.

[0049] The term “alkylene” by itself or as part of another substituent means a divalent radical derived from an alkane, as exemplified, but not limited, by -CH₂CH₂CH₂CH₂-, and further includes those groups described below as “heteroalkylene.” Typically, an alkyl (or alkylene) group will have from 1 to 24 carbon atoms, with those groups having 10 or fewer

carbon atoms being preferred in the present invention. A "lower alkyl" or "lower alkylene" is a shorter chain alkyl or alkylene group, generally having eight or fewer carbon atoms.

[0050] The terms "alkoxy," "alkylamino" and "alkylthio" (or thioalkoxy) are used in their conventional sense, and refer to those alkyl groups attached to the remainder of the molecule via an oxygen atom, an amino group, or a sulfur atom, respectively.

[0051] The term "heteroalkyl," by itself or in combination with another term, means, unless otherwise stated, a stable straight or branched chain, or cyclic hydrocarbon radical, or combinations thereof, consisting of the stated number of carbon atoms and at least one heteroatom selected from the group consisting of O, N, Si and S, and wherein the nitrogen and sulfur atoms may optionally be oxidized and the nitrogen heteroatom may optionally be quaternized. The heteroatom(s) O, N and S and Si may be placed at any interior position of the heteroalkyl group or at the position at which the alkyl group is attached to the remainder of the molecule. Examples include, but are not limited to, -CH₂-CH₂-O-CH₃, -CH₂-CH₂-NH-CH₃, -CH₂-CH₂-N(CH₃)-CH₃, -CH₂-S-CH₂-CH₃, -CH₂-CH₂-S(O)-CH₃, -CH₂-CH₂-S(O)₂-CH₃, -CH=CH-O-CH₃, -Si(CH₃)₃, -CH₂-CH=N-OCH₃, and -CH=CH-N(CH₃)-CH₃. Up to two heteroatoms may be consecutive, such as, for example, -CH₂-NH-OCH₃ and -CH₂-O-Si(CH₃)₃. Similarly, the term "heteroalkylene" by itself or as part of another substituent means a divalent radical derived from heteroalkyl, as exemplified, but not limited by, -CH₂-CH₂-S-CH₂-CH₂- and -CH₂-S-CH₂-CH₂-NH-CH₂-. For heteroalkylene groups, heteroatoms can also occupy either or both of the chain termini (e.g., alkyleneoxy, alkylenedioxy, alkyleneamino, alkylenediamino, and the like). Still further, for alkylene and heteroalkylene linking groups, no orientation of the linking group is implied by the direction in which the formula of the linking group is written. For example, the formula -CO₂R' represents both -C(O)OR' and -OC(O)R'.

[0052] The terms "cycloalkyl" and "heterocycloalkyl", by themselves or in combination with other terms, represent, unless otherwise stated, cyclic versions of "alkyl" and "heteroalkyl", respectively. Additionally, for heterocycloalkyl, a heteroatom can occupy the position at which the heterocycle is attached to the remainder of the molecule. A "cycloalkyl" or "heterocycloalkyl" substituent may be attached to the remainder of the molecule directly or through a linker, wherein the linker is preferably alkylene. Examples of cycloalkyl include, but are not limited to, cyclopentyl, cyclohexyl, 1-cyclohexenyl, 3-

cyclohexenyl, cycloheptyl, and the like. Examples of heterocycloalkyl include, but are not limited to, 1-(1,2,5,6-tetrahydropyridyl), 1-piperidinyl, 2-piperidinyl, 3-piperidinyl, 4-morpholinyl, 3-morpholinyl, tetrahydrofuran-2-yl, tetrahydrofuran-3-yl, tetrahydrothien-2-yl, tetrahydrothien-3-yl, 1-piperazinyl, 2-piperazinyl, and the like.

5 **[0053]** The terms “halo” or “halogen,” by themselves or as part of another substituent, mean, unless otherwise stated, a fluorine, chlorine, bromine, or iodine atom. Additionally, terms such as “haloalkyl,” are meant to include monohaloalkyl and polyhaloalkyl. For example, the term “halo(C₁-C₄)alkyl” is mean to include, but not be limited to, trifluoromethyl, 2,2,2-trifluoroethyl, 4-chlorobutyl, 3-bromopropyl, and the like.

10 **[0054]** The term “aryl” means, unless otherwise stated, a polyunsaturated, aromatic, substituent that can be a single ring or multiple rings (preferably from 1 to 3 rings), which are fused together or linked covalently. The term “heteroaryl” refers to aryl groups (or rings) that contain from one to four heteroatoms selected from N, O, S, Si and B, wherein the nitrogen and sulfur atoms are optionally oxidized, and the nitrogen atom(s) are optionally quaternized.

15 A heteroaryl group can be attached to the remainder of the molecule through a heteroatom. Non-limiting examples of aryl and heteroaryl groups include phenyl, 1-naphthyl, 2-naphthyl, 4-biphenyl, 1-pyrrolyl, 2-pyrrolyl, 3-pyrrolyl, 3-pyrazolyl, 2-imidazolyl, 4-imidazolyl, pyrazinyl, 2-oxazolyl, 4-oxazolyl, 2-phenyl-4-oxazolyl, 5-oxazolyl, 3-isoxazolyl, 4-isoxazolyl, 5-isoxazolyl, 2-thiazolyl, 4-thiazolyl, 5-thiazolyl, 2-furyl, 3-furyl, 2-thienyl, 3-

20 thienyl, 2-pyridyl, 3-pyridyl, 4-pyridyl, 2-pyrimidyl, 4-pyrimidyl, 5-benzothiazolyl, purinyl, 2-benzimidazolyl, 5-indolyl, 1-isoquinolyl, 5-isoquinolyl, 2-quinoxaliny, 5-quinoxaliny, 3-quinolyl, and 6-quinolyl. Substituents for each of the above noted aryl and heteroaryl ring systems are selected from the group of acceptable substituents described below.

25 **[0055]** For brevity, the term “aryl” when used in combination with other terms (*e.g.*, aryloxy, arylthioxy, arylalkyl) optionally includes both aryl and heteroaryl rings as defined above. Thus, the term “arylalkyl” optionally includes those radicals in which an aryl group is attached to an alkyl group (*e.g.*, benzyl, phenethyl, pyridylmethyl and the like) including those alkyl groups in which a carbon atom (*e.g.*, a methylene group) has been replaced by, for example, an oxygen atom (*e.g.*, phenoxymethyl, 2-pyridyloxymethyl, 3-(1-

30 naphthyloxy)propyl, and the like).

[0056] Each of the above terms (*e.g.*, “alkyl,” “heteroalkyl,” “aryl” and “heteroaryl”) optionally include both substituted and unsubstituted forms of the indicated radical. Preferred substituents for each type of radical are provided below.

[0057] Substituents for the alkyl and heteroalkyl radicals (including those groups often referred to as alkylene, alkenyl, heteroalkylene, heteroalkenyl, alkynyl, cycloalkyl, heterocycloalkyl, cycloalkenyl, and heterocycloalkenyl) are generically referred to as “alkyl group substituents,” and they can be one or more of a variety of groups selected from, but not limited to: substituted or unsubstituted aryl, substituted or unsubstituted heteroaryl, substituted or unsubstituted heterocycloalkyl, -OR', =O, =NR', =N-OR', -NR'R'', -SR', -halogen, -SiR'R''R''', -OC(O)R', -C(O)R', -CO₂R', -CONR'R'', -OC(O)NR'R'', -NR''C(O)R', -NR'-C(O)NR''R''', -NR''C(O)₂R', -NR-C(NR'R''R''')=NR''', -NR-C(NR'R'')=NR'', -S(O)R', -S(O)₂R', -S(O)₂NR'R'', -NRSO₂R', -CN and -NO₂ in a number ranging from zero to (2m'+1), where m' is the total number of carbon atoms in such radical. R', R'', R''' and R'''' each preferably independently refer to hydrogen, substituted or unsubstituted heteroalkyl, substituted or unsubstituted aryl, *e.g.*, aryl substituted with 1-3 halogens, substituted or unsubstituted alkyl, alkoxy or thioalkoxy groups, or arylalkyl groups. When a compound of the invention includes more than one R group, for example, each of the R groups is independently selected as are each R', R'', R''' and R'''' groups when more than one of these groups is present. When R' and R'' are attached to the same nitrogen atom, they can be combined with the nitrogen atom to form a 5-, 6-, or 7-membered ring. For example, -NR'R'' is meant to include, but not be limited to, 1-pyrrolidinyl and 4-morpholinyl. From the above discussion of substituents, one of skill in the art will understand that the term “alkyl” is meant to include groups including carbon atoms bound to groups other than hydrogen groups, such as haloalkyl (*e.g.*, -CF₃ and -CH₂CF₃) and acyl (*e.g.*, -C(O)CH₃, -C(O)CF₃, -C(O)CH₂OCH₃, and the like).

[0058] Similar to the substituents described for the alkyl radical, substituents for the aryl and heteroaryl groups are generically referred to as “aryl group substituents.” The substituents are selected from, for example: substituted or unsubstituted alkyl, substituted or unsubstituted aryl, substituted or unsubstituted heteroaryl, substituted or unsubstituted heterocycloalkyl, -OR', =O, =NR', =N-OR', -NR'R'', -SR', -halogen, -SiR'R''R''', -OC(O)R', -C(O)R', -CO₂R', -CONR'R'', -OC(O)NR'R'', -NR''C(O)R', -NR'-C(O)NR''R''', -NR''C(O)₂R', -NR-C(NR'R''R''')=NR''', -NR-C(NR'R'')=NR'', -S(O)R', -S(O)₂R', -S(O)₂NR'R'', -NRSO₂R', -CN and -NO₂, -R', -N₃, -CH(Ph)₂, fluoro(C₁-C₄)alkoxy, and

fluoro(C₁-C₄)alkyl, in a number ranging from zero to the total number of open valences on the aromatic ring system; and where R', R'', R''' and R'''' are preferably independently selected from hydrogen, substituted or unsubstituted alkyl, substituted or unsubstituted heteroalkyl, substituted or unsubstituted aryl and substituted or unsubstituted heteroaryl.

- 5 When a compound of the invention includes more than one R group, for example, each of the R groups is independently selected as are each R', R'', R''' and R'''' groups when more than one of these groups is present.

[0059] Two of the substituents on adjacent atoms of the aryl or heteroaryl ring may optionally be replaced with a substituent of the formula -T-C(O)-(CRR')_q-U-, wherein T and
 10 U are independently -NR-, -O-, -CRR'- or a single bond, and q is an integer of from 0 to 3. Alternatively, two of the substituents on adjacent atoms of the aryl or heteroaryl ring may optionally be replaced with a substituent of the formula -A-(CH₂)_r-B-, wherein A and B are independently -CRR'-, -O-, -NR-, -S-, -S(O)-, -S(O)₂-, -S(O)₂NR'- or a single bond, and r is an integer of from 1 to 4. One of the single bonds of the new ring so formed may optionally
 15 be replaced with a double bond. Alternatively, two of the substituents on adjacent atoms of the aryl or heteroaryl ring may optionally be replaced with a substituent of the formula - (CRR')_s-X-(CR''R''')_d-, where s and d are independently integers of from 0 to 3, and X is -O-, -NR'-, -S-, -S(O)-, -S(O)₂-, or -S(O)₂NR'-. The substituents R, R', R'' and R''' are preferably independently selected from hydrogen or substituted or unsubstituted (C₁-C₆)alkyl.

- 20 [0060] As used herein, the term "acyl" describes a substituent containing a carbonyl residue, C(O)R. Exemplary species for R include H, halogen, substituted or unsubstituted alkyl, substituted or unsubstituted aryl, substituted or unsubstituted heteroaryl, and substituted or unsubstituted heterocycloalkyl.

[0061] As used herein, the term "fused ring system" means at least two rings, wherein each
 25 ring has at least 2 atoms in common with another ring. "Fused ring systems may include aromatic as well as non aromatic rings. Examples of "fused ring systems" are naphthalenes, indoles, quinolines, chromenes and the like.

[0062] As used herein, the term "heteroatom" includes oxygen (O), nitrogen (N), sulfur (S) and silicon (Si), boron (B) and phosphorus (P).

- 30 [0063] The symbol "R" is a general abbreviation that represents a substituent group, e.g., one that is selected from substituted or unsubstituted alkyl, substituted or unsubstituted

heteroalkyl, substituted or unsubstituted aryl, substituted or unsubstituted heteroaryl, and substituted or unsubstituted heterocycloalkyl groups.

[0064] The term "pharmaceutically acceptable salts" includes salts of the active compounds which are prepared with relatively nontoxic acids or bases, depending on the particular substituents found on the compounds described herein. When compounds of the present disclosure contain relatively acidic functionalities, base addition salts can be obtained by contacting the neutral form of such compounds with a sufficient amount of the desired base, either neat or in a suitable inert solvent. Examples of pharmaceutically acceptable base addition salts include sodium, potassium, calcium, ammonium, organic amino, or magnesium salt, or a similar salt. When compounds of the present invention contain relatively basic functionalities, acid addition salts can be obtained by contacting the neutral form of such compounds with a sufficient amount of the desired acid, either neat or in a suitable inert solvent. Examples of pharmaceutically acceptable acid addition salts include those derived from inorganic acids like hydrochloric, hydrobromic, nitric, carbonic, monohydrogencarbonic, phosphoric, monohydrogenphosphoric, dihydrogenphosphoric, sulfuric, monohydrogensulfuric, hydriodic, or phosphorous acids and the like, as well as the salts derived from relatively nontoxic organic acids like acetic, propionic, isobutyric, maleic, malonic, benzoic, succinic, suberic, fumaric, lactic, mandelic, phthalic, benzenesulfonic, p-tolylsulfonic, citric, tartaric, methanesulfonic, and the like. Also included are salts of amino acids such as arginate and the like, and salts of organic acids like glucuronic or galactunoric acids and the like (see, for example, Berge *et al.*, *Journal of Pharmaceutical Science*, 66: 1-19 (1977)). Certain specific compounds of the present invention contain both basic and acidic functionalities that allow the compounds to be converted into either base or acid addition salts.

[0065] The neutral forms of the compounds are preferably regenerated by contacting the salt with a base or acid and isolating the parent compound in the conventional manner. The parent form of the compound differs from the various salt forms in certain physical properties, such as solubility in polar solvents, but otherwise the salts are equivalent to the parent form of the compound for the purposes of the present disclosure.

[0066] In addition to salt forms, the present disclosure provides compounds, which are in a prodrug form. Prodrugs of the compounds described herein are those compounds that readily undergo chemical changes under physiological conditions to provide the compounds of the present disclosure.

Additionally, prodrugs can be converted to the compounds by chemical or biochemical methods in an *ex vivo* environment. For example, prodrugs can be slowly converted when placed in a transdermal patch reservoir with a suitable enzyme or chemical reagent.

[0067] Certain compounds of the present disclosure can exist in unsolvated forms as well as solvated forms, including hydrated forms. In general, the solvated forms are equivalent to unsolvated forms and are encompassed within the scope of the present disclosure. Certain compounds of the present disclosure may exist in multiple crystalline or amorphous forms. In general, all physical forms are equivalent for the uses contemplated by the present disclosure and are intended to be within its scope.

[0068] Certain compounds of the present disclosure possess asymmetric carbon atoms (optical centers) or double bonds; the racemates, diastereomers, geometric isomers and individual isomers are encompassed within the scope of the present disclosure.

[0069] Compounds disclosed herein may be prepared as a single isomer (*e.g.*, enantiomer, cis-trans, positional, diastereomer) or as a mixture of isomers. In a preferred embodiment, the compounds are prepared as substantially a single isomer. Methods of preparing substantially isomerically pure compounds are known in the art. For example, enantiomerically enriched mixtures and pure enantiomeric compounds can be prepared by using synthetic intermediates that are enantiomerically pure in combination with reactions that either leave the stereochemistry at a chiral center unchanged or result in its complete inversion. Alternatively, the final product or intermediates along the synthetic route can be resolved into a single stereoisomer. Techniques for inverting or leaving unchanged a particular stereocenter, and those for resolving mixtures of stereoisomers are well known in the art and it is well within the ability of one of skill in the art to choose and appropriate method for a particular situation. *See*, generally, Furniss *et al.* (eds.), VOGEL'S ENCYCLOPEDIA OF PRACTICAL ORGANIC CHEMISTRY 5TH ED., Longman Scientific and Technical Ltd., Essex, 1991, pp. 809-816; and Heller, *Acc. Chem. Res.* 23: 128 (1990).

[0070] The graphic representations of racemic, ambiscalemic and scalemic or enantiomerically pure compounds used herein are taken from Maehr, *J. Chem. Ed.*, 62: 114-120 (1985); solid and broken wedges are used to denote the absolute configuration of a chiral element; wavy lines indicate disavowal of any stereochemical implication which the bond it represents could generate; solid and broken bold lines are geometric descriptors indicating the

relative configuration shown but not implying any absolute stereochemistry; and wedge outlines and dotted or broken lines denote enantiomerically pure compounds of indeterminate absolute configuration.

[0071] The terms “enantiomeric excess” and diastereomeric excess” are used interchangeably herein. Compounds with a single stereocenter are referred to as being present in “enantiomeric excess,” those with at least two stereocenters are referred to as being present in “diastereomeric excess.”

[0072] The compounds of the present invention may also contain unnatural proportions of atomic isotopes at one or more of the atoms that constitute such compounds. For example, the compounds may be radiolabeled with radioactive isotopes, such as for example tritium (^3H), iodine-125 (^{125}I) or carbon-14 (^{14}C). All isotopic variations of the compounds of the present invention, whether radioactive or not, are intended to be encompassed within the scope of the present invention.

[0073] “Reactive functional group,” as used herein refers to groups including, but not limited to, olefins, acetylenes, alcohols, phenols, ethers, oxides, halides, aldehydes, ketones, carboxylic acids, esters, amides, cyanates, isocyanates, thiocyanates, isothiocyanates, amines, hydrazines, hydrazones, hydrazides, diazo, diazonium, nitro, nitriles, mercaptans, sulfides, disulfides, sulfoxides, sulfones, sulfonic acids, sulfinic acids, acetals, ketals, anhydrides, sulfates, sulfenic acids isonitriles, amidines, imides, imidates, nitrones, hydroxylamines, oximes, hydroxamic acids thiohydroxamic acids, allenes, ortho esters, sulfites, enamines, ynamines, ureas, pseudoureas, semicarbazides, carbodiimides, carbamates, imines, azides, azo compounds, azoxy compounds, and nitroso compounds. Reactive functional groups also include those used to prepare bioconjugates, e.g., N-hydroxysuccinimide esters, maleimides and the like. Methods to prepare each of these functional groups are well known in the art and their application or modification for a particular purpose is within the ability of one of skill in the art (*see*, for example, Sandler and Karo, eds. ORGANIC FUNCTIONAL GROUP PREPARATIONS, Academic Press, San Diego, 1989).

[0074] “Non-covalent protein binding groups” are moieties that interact with an intact or denatured polypeptide in an associative manner. The interaction may be either reversible or irreversible in a biological milieu. The incorporation of a “non-covalent protein binding group” into a chelating agent or complex of the invention provides the agent or complex with the ability to interact with a polypeptide in a non-covalent manner. Exemplary non-covalent

interactions include hydrophobic-hydrophobic and electrostatic interactions. Exemplary “non-covalent protein binding groups” include anionic groups, e.g., phosphate, thiophosphate, phosphonate, carboxylate, boronate, sulfate, sulfone, sulfonate, thiosulfate, and thiosulfonate.

5 [0075] As used herein, “linking member” or “linking moiety” refers to a covalent chemical bond that preferentially includes at least one heteroatom. Exemplary linking moieties include –C(O)NH-, -C(O)O-, -NH-, -S-, -O-, and the like.

10 [0076] The term “targeting moiety” is intended to mean any moiety attached to the complexes of the invention. The targeting moiety can be a small molecule, which is intended to include both non-peptides and peptides. The targeting group can also be a macromolecule, which includes saccharides, lectins, receptors, ligands for receptors, proteins such as BSA, antibodies, solid supports and so forth. The targeting group can also be a polymer, such as a plastic surface, a poly-ethyleneglycol derivative and the like.

15 [0077] The symbol $\sim$, whether utilized as a bond or displayed perpendicular to a bond indicates the point at which the displayed moiety is attached to the remainder of the molecule, solid support, etc.

3. Compositions

Chelating Agents and Complexes

20 [0078] In one embodiment, this disclosure provides organic ligand contains at least one 1-hydroxy-2-pyridinone (1,2-HOPO) subunit as a chelating moiety. The HOPO subunit is optionally covalently linked to a scaffold moiety. In an exemplary embodiment, the chelate complexes a lanthanide ion and forms a luminescent lanthanide complex of the invention. Alternatively, the metal ion is an actinide or other metal ion (e.g., transition metal ion).

25 [0079] Throughout this specification, the chelating subunits are exemplified as being complexed with a metal ion having a +3 charge. The chemical formulae showing this representation are intended to also encompass the unmetallated chelating agents as well as complexes in which the metal ion has a charge other than +3, e.g., U^{6+} or Pu^{4+} .

30 [0080] Chelates and complexes disclosed herein can contain any number of “free chelating moieties” and “linked chelating moieties”, wherein a “linked chelating moiety” is covalently linked to at least one other chelating moiety through a scaffold moiety and wherein a “free chelating moiety” is not covalently linked to another chelating moiety through a scaffold moiety.

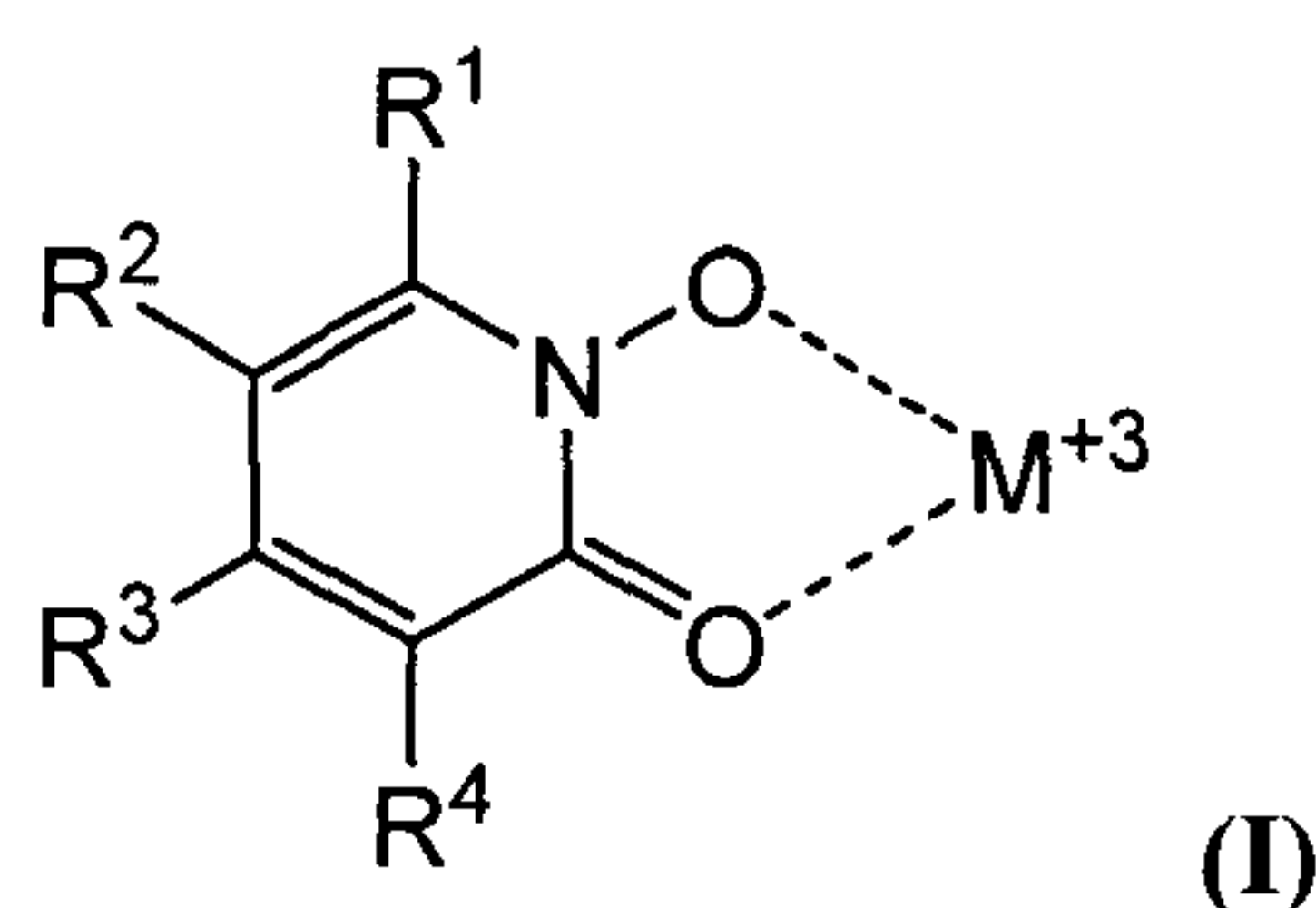
[0081] In one exemplary embodiment, a complex is formed between a metal ion (e.g., a lanthanide ion or actinide ion) and one organic ligand having four or more chelating moieties that are linked through a scaffold moiety. In another exemplary embodiment, the complex is formed between a lanthanide ion and two organic ligands, wherein each organic ligand is composed of two chelating moieties that are covalently linked through a scaffold moiety. In yet another exemplary embodiment, the complex is formed utilizing an organic ligand containing two chelating moieties that are linked through a scaffold moiety as well as two “free chelating moieties”. Other permutations of “linked-“ and “free chelating moieties” are encompassed within the scope of the present disclosure.

[0082] In addition, the complexes between the metal ion and the organic ligands may be charged or uncharged. For instance, in those complexes wherein the overall electric charge is negative, the negative charge may be “offset” by a cation, such as a quaternary amine (e.g., NMe_4^+).

[0083] Preferred complexes include those in which the organic ligand complexes the metal ion through oxygen atoms. Even more preferred is a chelate that complexes metal ions only through oxygen atoms. A further preferred complex includes an organic ligand that has 8 donor oxygen atoms that are coordinated to the metal ion, e.g., lanthanide ion.

[0084] Currently preferred metal ions include, but are not limited to Fe^{3+} , Gd^{3+} , Eu^{3+} , Tb^{3+} , Am^{3+} , Pu^{4+} , Np^{4+} , Np^{5+} and U^{6+} ions.

[0085] One embodiment provides a metal complex, e.g., a luminescent complex between a metal ion, e.g., a lanthanide ion or actinide ion, and an organic ligand that includes a chelating moiety of Formula (I):



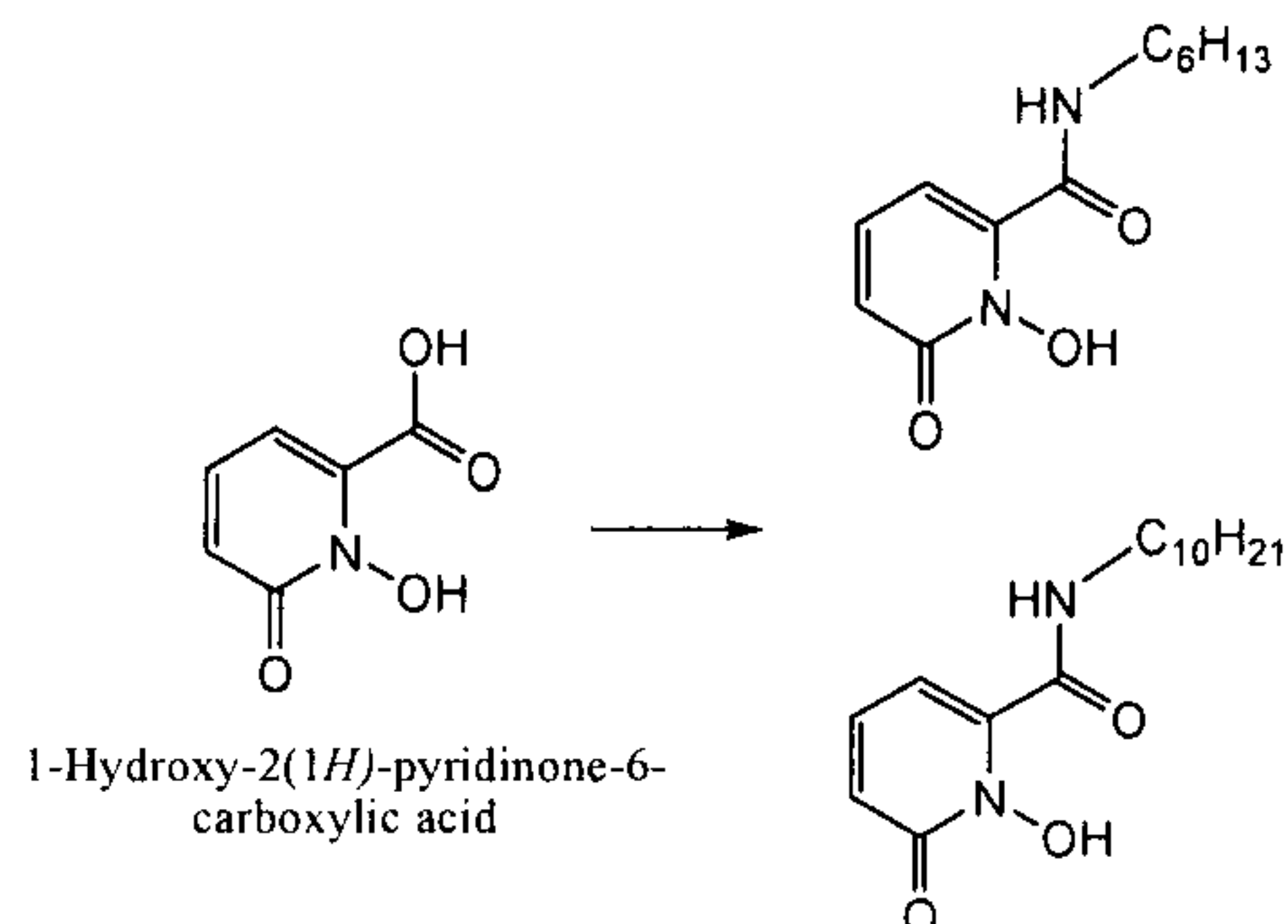
[0086] In Formula (I), R^1 , R^2 , R^3 and R^4 are members independently selected from H, an aryl group substituent as defined herein and a linker to a scaffold or functional moiety. M^{+3} is metal ion, e.g., a lanthanide ion forming the complex, e.g., the luminescent complex, with the organic ligand.

[0087] Complexes of this disclosure can contain one or more chelating moieties, each optionally based on 1-hydroxy-2-pyridinone (1,2-HOPO) subunits of Formula (I).

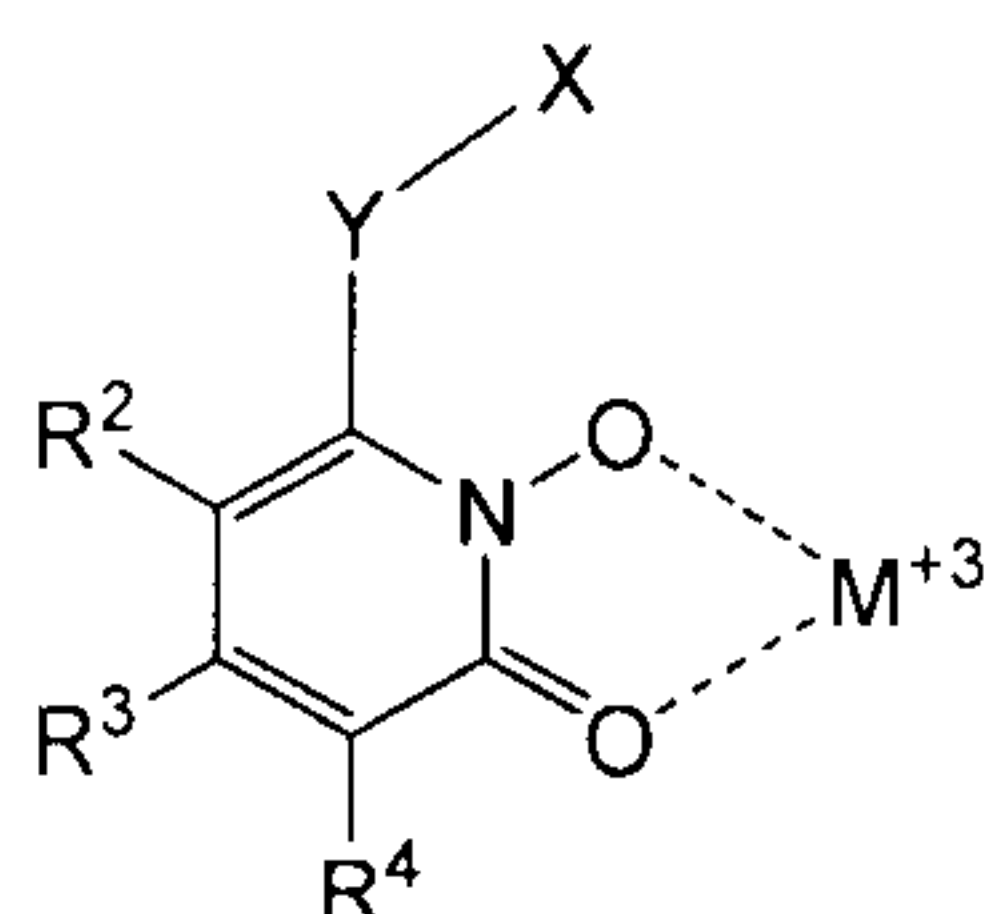
[0088] In one exemplary embodiment, in Formula (I), R^1 , R^2 , R^3 , and R^4 are members independently selected from H, substituted or unsubstituted alkyl, substituted or unsubstituted heteroalkyl, substituted or unsubstituted aryl, substituted or unsubstituted heteroaryl, substituted or unsubstituted heterocycloalkyl, halogen, CN, CF_3 , $-C(O)R^{17}$, $-SO_2NR^{17}R^{18}$, $-NR^{17}R^{18}$, $-OR^{17}$, $-S(O)_2R^{17}$, $-COOR^{17}$, $-S(O)_2OR^{17}$, $-OC(O)R^{17}$, $-C(O)NR^{17}R^{18}$, $-NR^{17}C(O)R^{18}$, $-NR^{17}SO_2R^{18}$, $-NO_2$, a linker to a functional moiety and a linker to a scaffold moiety. At least two of R^1 , R^2 , R^3 and R^4 are optionally joined to form a ring system which is a member selected from substituted or unsubstituted cycloalkyl, substituted or unsubstituted heterocycloalkyl, substituted or unsubstituted aryl and substituted or unsubstituted heteroaryl. R^{17} and R^{18} are each members independently selected from H, substituted or unsubstituted alkyl, substituted or unsubstituted heteroalkyl, substituted or unsubstituted aryl, substituted or unsubstituted heteroaryl and substituted or unsubstituted heterocycloalkyl, a linker to a functional moiety and a linker to a scaffold moiety. R^{17} and R^{18} , together with the atoms to which they are attached, are optionally joined to form a 5- to 7-membered ring.

[0089] Exemplary linker moieties include a bond ("zero-order"), $-C(O)NR^5$ -, $-C(O)O$ -, $-C(O)S$ -, and $-C(O)CR^{20}R^{21}$, wherein R^5 , R^{20} and R^{21} are members independently selected from H, substituted or unsubstituted alkyl, substituted or unsubstituted heteroalkyl, substituted or unsubstituted aryl, substituted or unsubstituted heteroaryl and substituted or unsubstituted heterocycloalkyl. Preferred linkers include C_1 - C_{10} , preferably, C_1 - C_6 substituted or unsubstituted alkyl or substituted or unsubstituted heteroalkyl moieties.

[0090] In one exemplary embodiment, the organic ligand is an amide derived from 1-hydroxy-2-pyridinone-6-carboxylic acid. Exemplary amides include those in which R^1 is $-C(O)NR^{17}R^{18}$. In another exemplary embodiment, R^{17} is H and R^{18} is substituted or unsubstituted alkyl. Two exemplary amides are shown below. Both the hexylamide and the decylamide showed strong luminescence under long-wave UV light when mixed with an aqueous solution of a lanthanide ion.

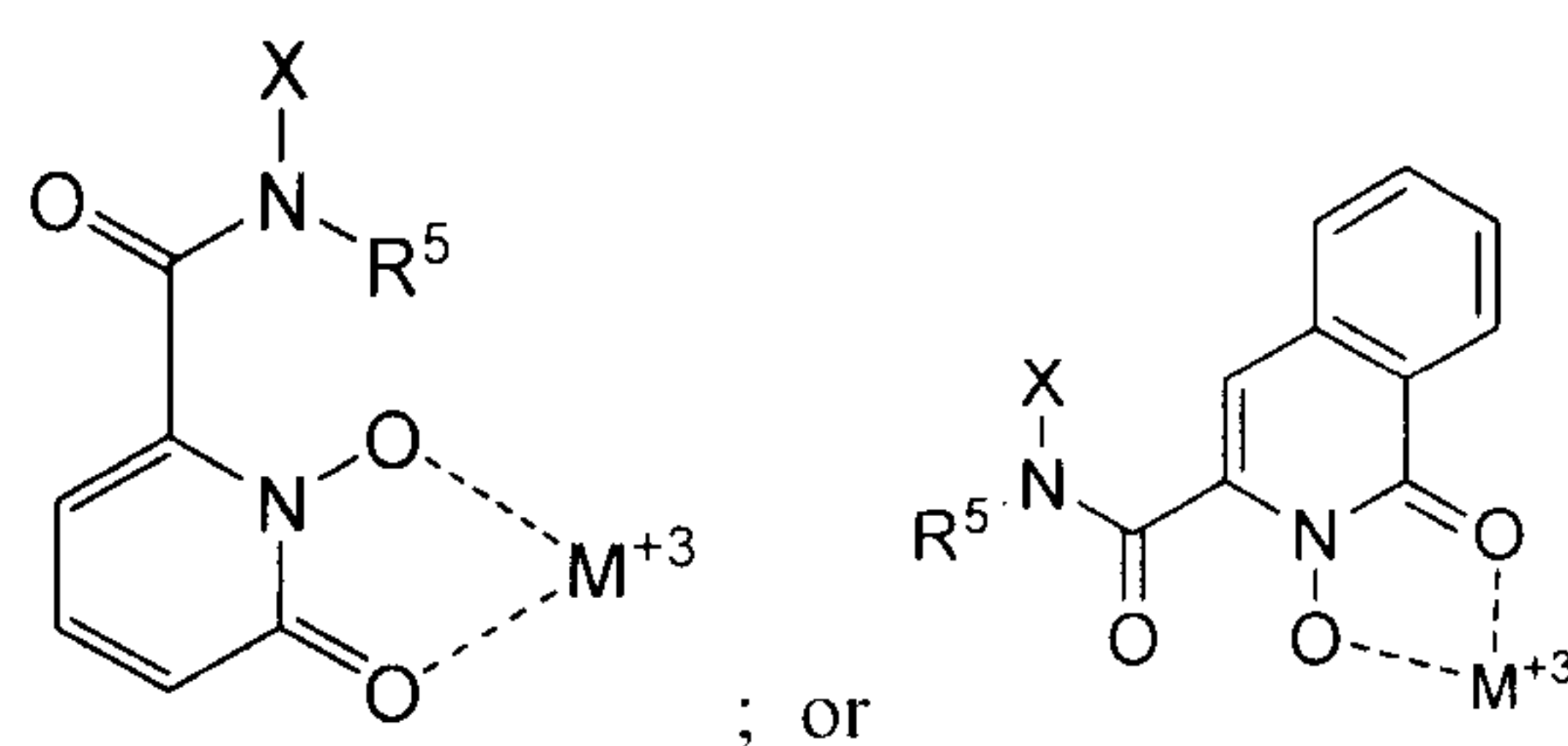


[0091] In another exemplary embodiment, the 1,2-HOPO subunit is covalently linked to a scaffold moiety and the chelating moiety of Formula (I) has the structure:



5 wherein X is a scaffold moiety, and Y is a linker moiety. Exemplary linker moieties include a bond (“zero-order”), $-C(O)NR^5$, $-C(O)O-$, $-C(O)S-$, and $-C(O)CR^{20}R^{21}$, wherein R^5 , R^{20} and R^{21} are members independently selected from H, substituted or unsubstituted alkyl, substituted or unsubstituted heteroalkyl, substituted or unsubstituted aryl, substituted or unsubstituted heteroaryl and substituted or unsubstituted heterocycloalkyl.

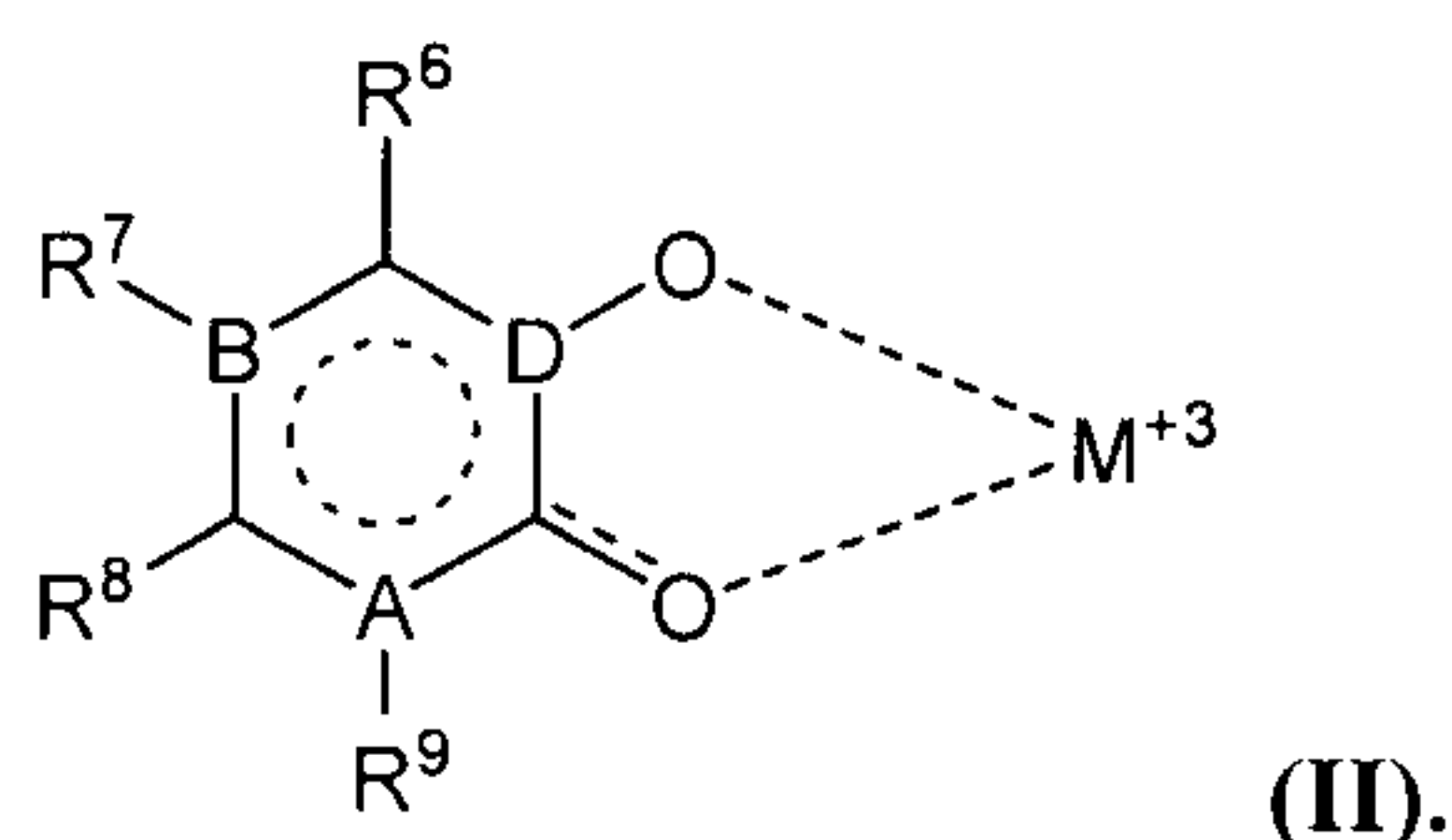
10 [0092] In yet another embodiment, the hydroxypyridinone subunit of the complex has the structure:



15 wherein X and R^5 are as defined above. The heterocycle or the aryl ring are optionally functionalized with one or more substituent defined herein as an “aryl group substituent” or an “alkyl group substituent.”

[0093] In a further embodiment, the chelating agents and their complexes, e.g., luminescent complexes, of the invention contain one or more chelating moieties that, in addition to a 1,2-

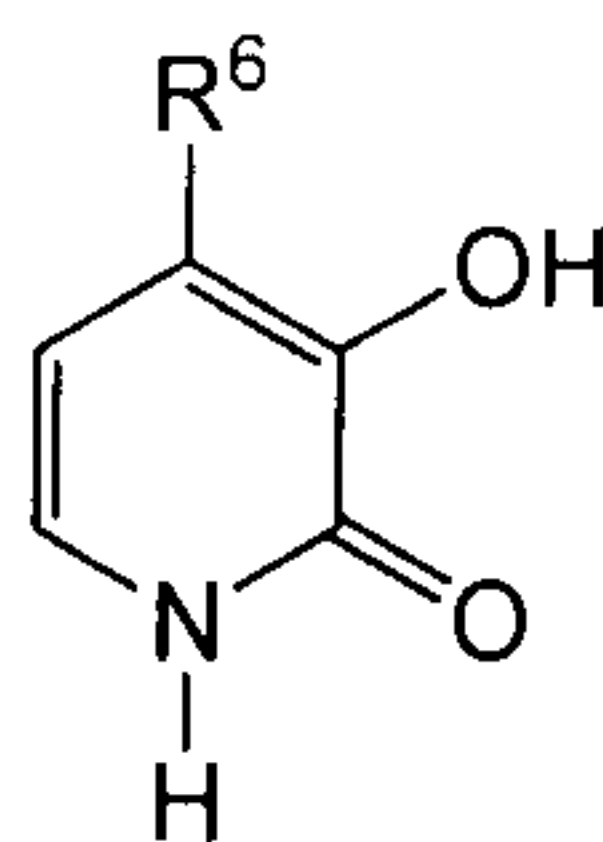
HOPO moiety, include a structure distinct from the 1,2-HOPO derivatives discussed above. In a preferred embodiment, each of those chelating moieties is independently selected from a structure according to Formula (II):



- 5 [0094] In Formula (II), the chelating agent is shown in the form of its complex. It will be apparent to those of skill in the art that Formula (II) also discloses the uncomplexed chelating agent. In one exemplary embodiment, in Formula (II), each R^6 , R^7 , R^8 , and R^9 in each chelating moiety are members independently selected from H, substituted or unsubstituted alkyl, substituted or unsubstituted heteroalkyl, substituted or unsubstituted aryl, substituted or
- 10 unsubstituted heteroaryl, substituted or unsubstituted heterocycloalkyl, halogen, CN, CF_3 , $-C(O)R^{17}$, $-SO_2NR^{17}R^{18}$, $-NR^{17}R^{18}$, $-OR^{17}$, $-S(O)_2R^{17}$, $-COOR^{17}$, $-S(O)_2OR^{17}$, $-OC(O)R^{17}$, $-C(O)NR^{17}R^{18}$, $-NR^{17}C(O)R^{18}$, $-NR^{17}SO_2R^{18}$, $-NO_2$, a linker to a functional moiety, and a linker to a scaffold moiety. At least two of R^6 , R^7 , R^8 and R^9 are optionally joined to form a ring system which is a member selected from substituted or unsubstituted
- 15 cycloalkyl, substituted or unsubstituted heterocycloalkyl, substituted or unsubstituted aryl and substituted or unsubstituted heteroaryl. R^{17} and R^{18} are each members independently selected from H, substituted or unsubstituted alkyl, substituted or unsubstituted heteroalkyl, substituted or unsubstituted aryl, substituted or unsubstituted heteroaryl and substituted or unsubstituted heterocycloalkyl, a linker to a functional moiety and a linker to a scaffold
- 20 moiety. R^{17} and R^{18} , together with the atoms to which they are attached, are optionally joined to form a 5- to 7-membered ring.

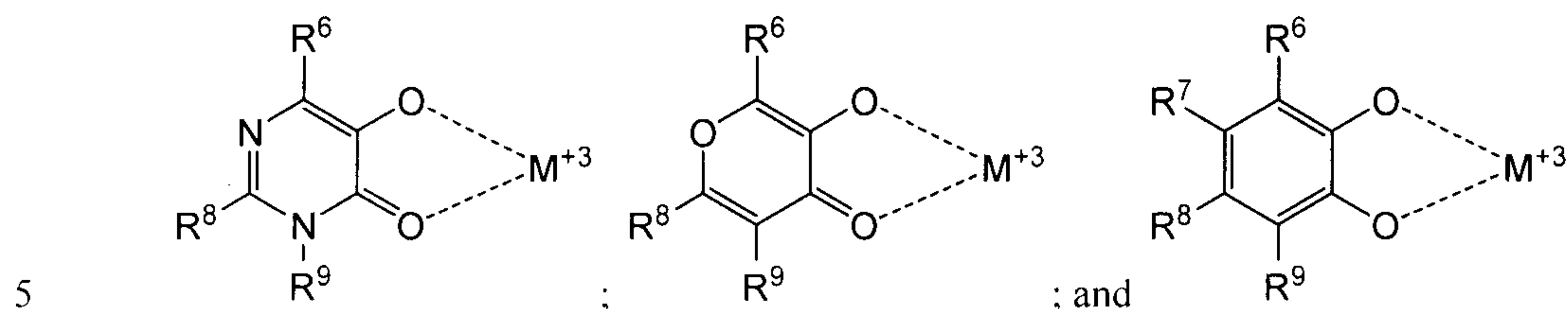
[0095] A and B in Formula (II) are members independently selected from carbon, nitrogen, sulfur and oxygen. D is a member selected from carbon and nitrogen. If A is oxygen or sulfur, R^9 is preferably not present; and if B is oxygen or sulfur, R^7 is preferably not present.

- 25 [0096] The chelating moiety of Formula (II) is preferably not 3-hydroxy-2-pyridinone:

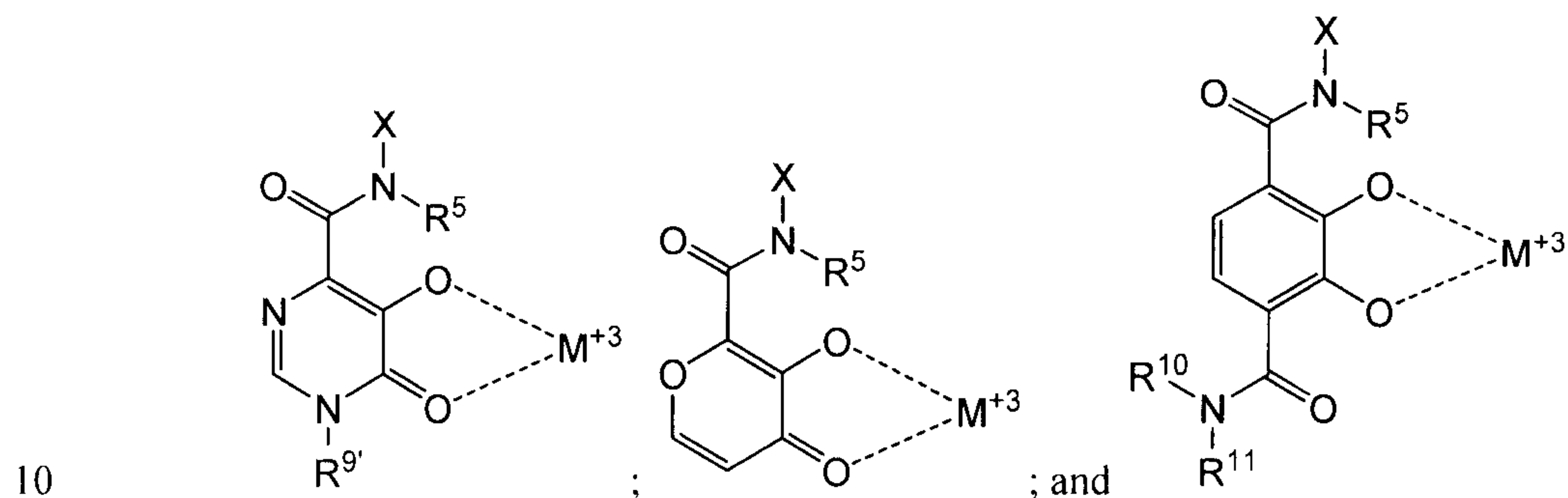


or this moiety complexed with a metal ion.

[0097] In one exemplary embodiment, the chelating moieties of Formula (II) are members independently selected from the following structures.



[0098] Similar to Formula (II), these structures should be interpreted as disclosing both the complexed and uncomplexed chelating agents. In another exemplary embodiment, R^6 in Formula (II) represents a linker to a scaffold moiety. Exemplary chelating moieties according to this aspect have the following structures:



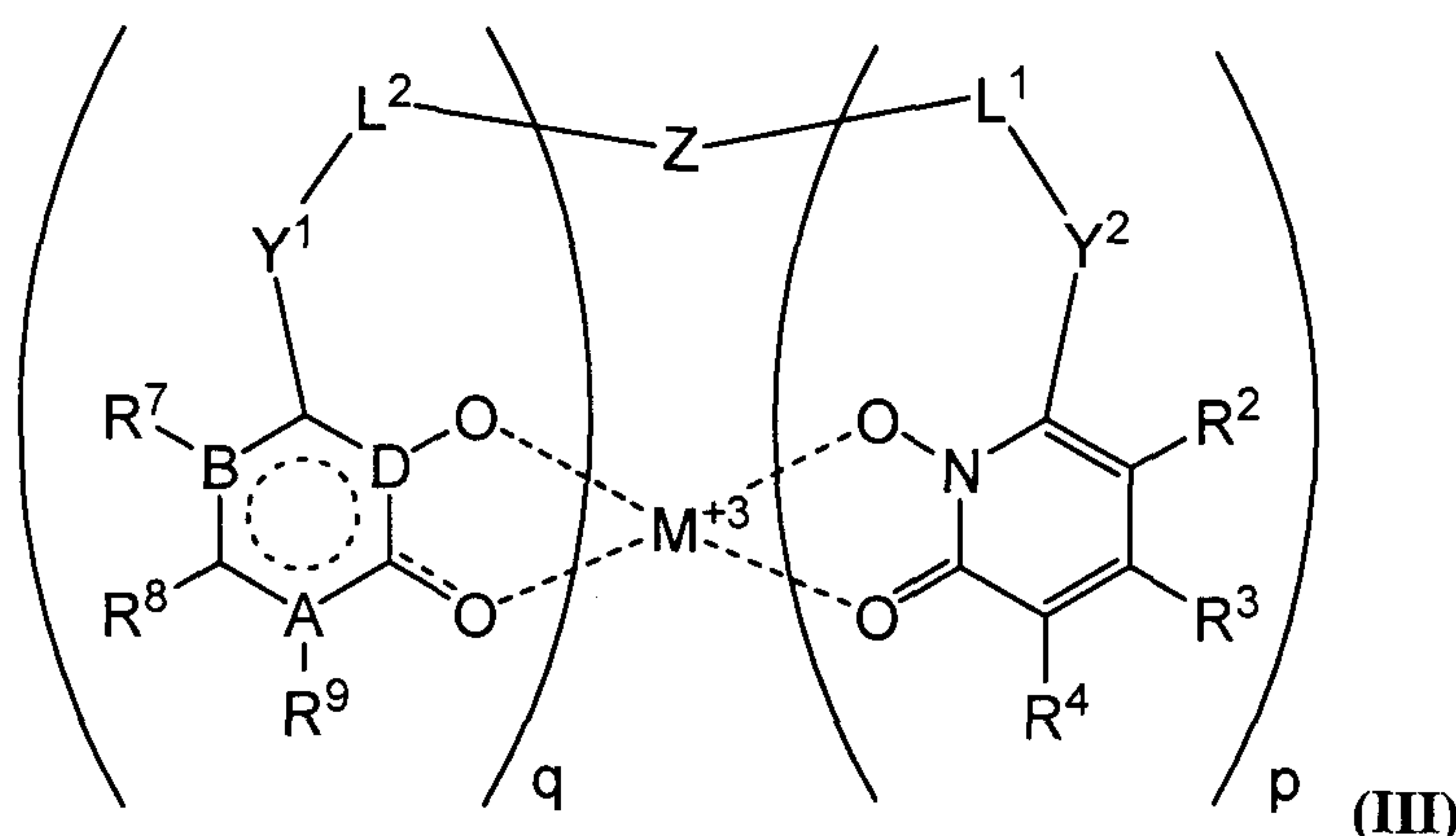
wherein X is a scaffold moiety. R^5 and R^{10} are members independently selected from H, substituted or unsubstituted alkyl, substituted or unsubstituted heteroalkyl, substituted or unsubstituted aryl, substituted or unsubstituted heteroaryl, substituted or unsubstituted heterocycloalkyl. R^{11} is a member selected from H, substituted or unsubstituted alkyl, substituted or unsubstituted heteroalkyl, substituted or unsubstituted aryl, substituted or unsubstituted heteroaryl, substituted or unsubstituted heterocycloalkyl, and a functional moiety. R^9 in the pyrimidinone is a member selected from substituted or unsubstituted alkyl, substituted or unsubstituted heteroalkyl, substituted or unsubstituted aryl, substituted or

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unsubstituted heteroaryl, and substituted or unsubstituted heterocycloalkyl and is preferably a member selected from C₁-C₆ alkyl.

[0099] In one embodiment, two or more of the chelating moieties, which are independently selected from Formula (I) and Formula (II) can be covalently linked through a scaffold moiety. This is, for example, the case when at least one of R¹, R², R³ and R⁴ in Formula (I) is covalently linked to a scaffold moiety, wherein the scaffold moiety is covalently linked to at least one chelating moiety of Formula (II).

[0100] Thus, in an exemplary embodiment the luminescent complex has a structure according to Formula (III):



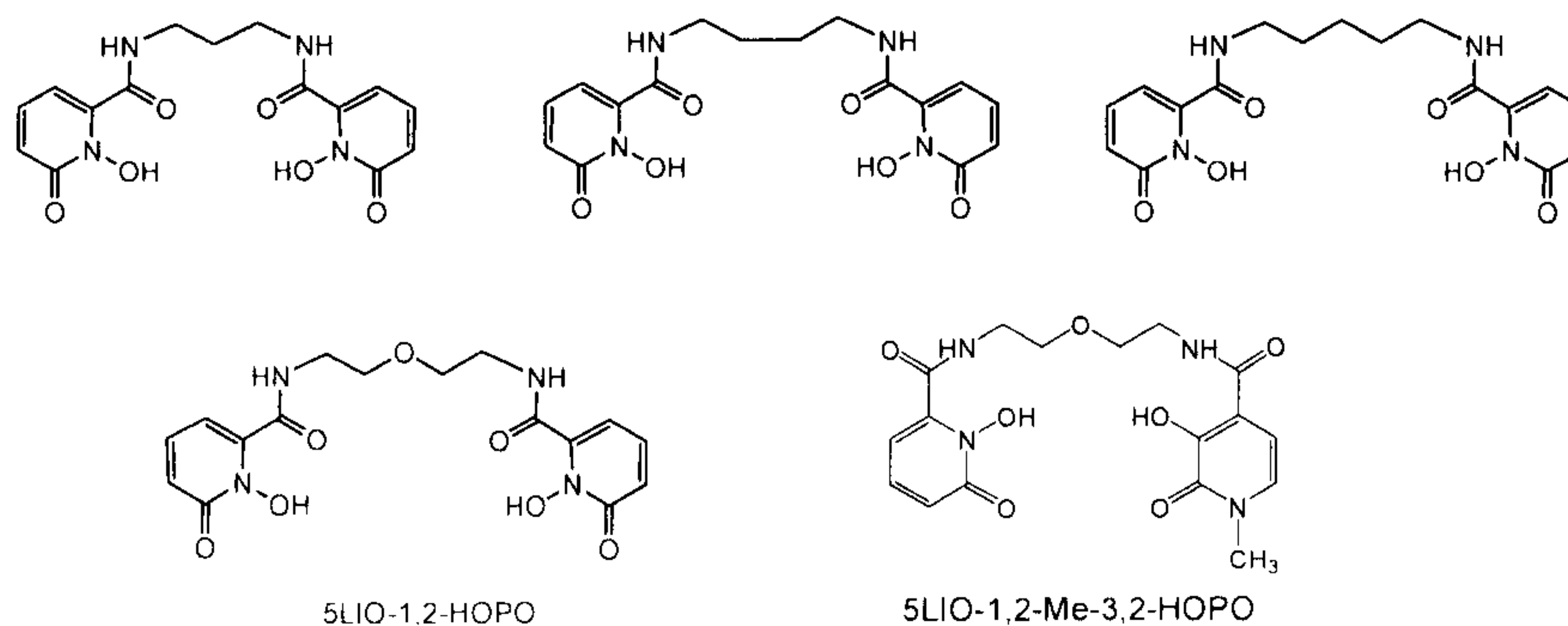
[0101] In Formula (III) Z is a member selected from substituted or unsubstituted alkyl, substituted or unsubstituted heteroalkyl, substituted or unsubstituted aryl, substituted or unsubstituted heteroaryl, substituted or unsubstituted heterocycloalkyl, N, NR³⁰, O and S. In an exemplary embodiment, Z is CR³¹R³². R³⁰, R³¹ and R³² are members independently selected from H, substituted or unsubstituted alkyl, substituted or unsubstituted heteroalkyl, substituted or unsubstituted aryl, substituted or unsubstituted heteroaryl, substituted or unsubstituted heterocycloalkyl and a linker to a functional moiety. In another exemplary embodiment, Z is substituted with a chelating moiety. The integer p is selected from 1-3 and q is an integer selected from 0-2. The sum of p and q is preferably not greater than 4, and if Z is O or S, the sum of p and q is preferably 2. Y¹ and Y² are linker moieties. In one exemplary embodiment, each of Y¹ and Y² is a member independently selected from -C(O)NR⁵-, -C(O)O-, -C(O)S-, and -C(O)CR²⁰R²¹, wherein R⁵, R²⁰ and R²¹ are members independently selected from H, substituted or unsubstituted alkyl, substituted or unsubstituted heteroalkyl, substituted or unsubstituted aryl, substituted or unsubstituted heteroaryl, substituted or unsubstituted heterocycloalkyl and a functional moiety.

[0102] L^1 and L^2 are linker groups, and each L^1 and L^2 is a member independently selected from a bond, substituted or unsubstituted alkyl, substituted or unsubstituted heteroalkyl, substituted or unsubstituted aryl, substituted or unsubstituted heteroaryl and substituted or unsubstituted heterocycloalkyl. At least one of Z, Y^1 , Y^2 , L^1 and L^2 is optionally substituted with a functional moiety. In an exemplary embodiment, Z is O and L^1 and L^2 are each ethyl.

[0103] In one exemplary embodiment, Z is NR^{30} (e.g., when the sum of p and q is 2), wherein R^{30} is a member selected from substituted or unsubstituted alkyl, substituted or unsubstituted heteroalkyl, substituted or unsubstituted aryl, substituted or unsubstituted heteroaryl, substituted or unsubstituted heterocycloalkyl and a linker to a functional moiety.

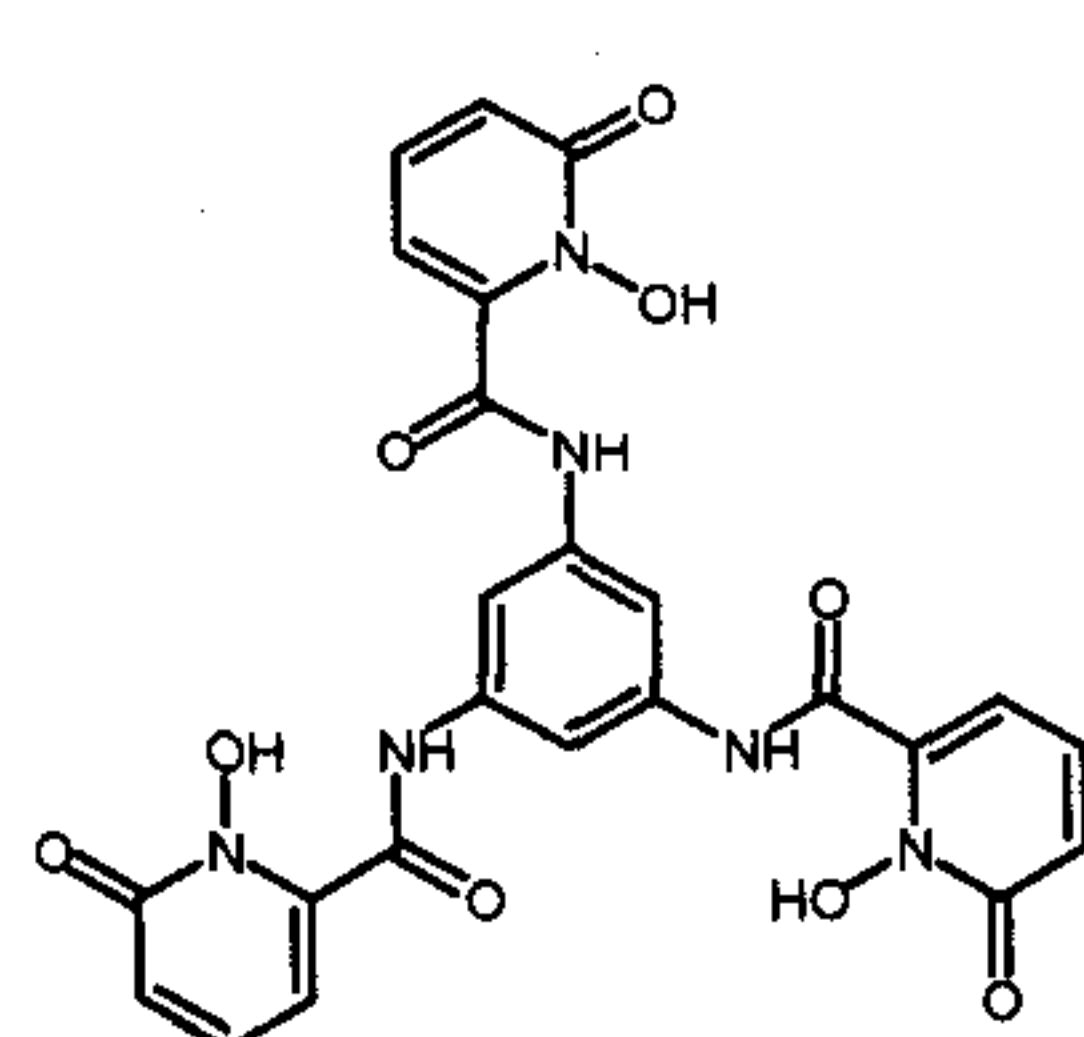
10 Tetradentate Ligands

[0104] In one embodiment, the organic ligand is a tetradentate ligand. Exemplary tetradentate ligands include:

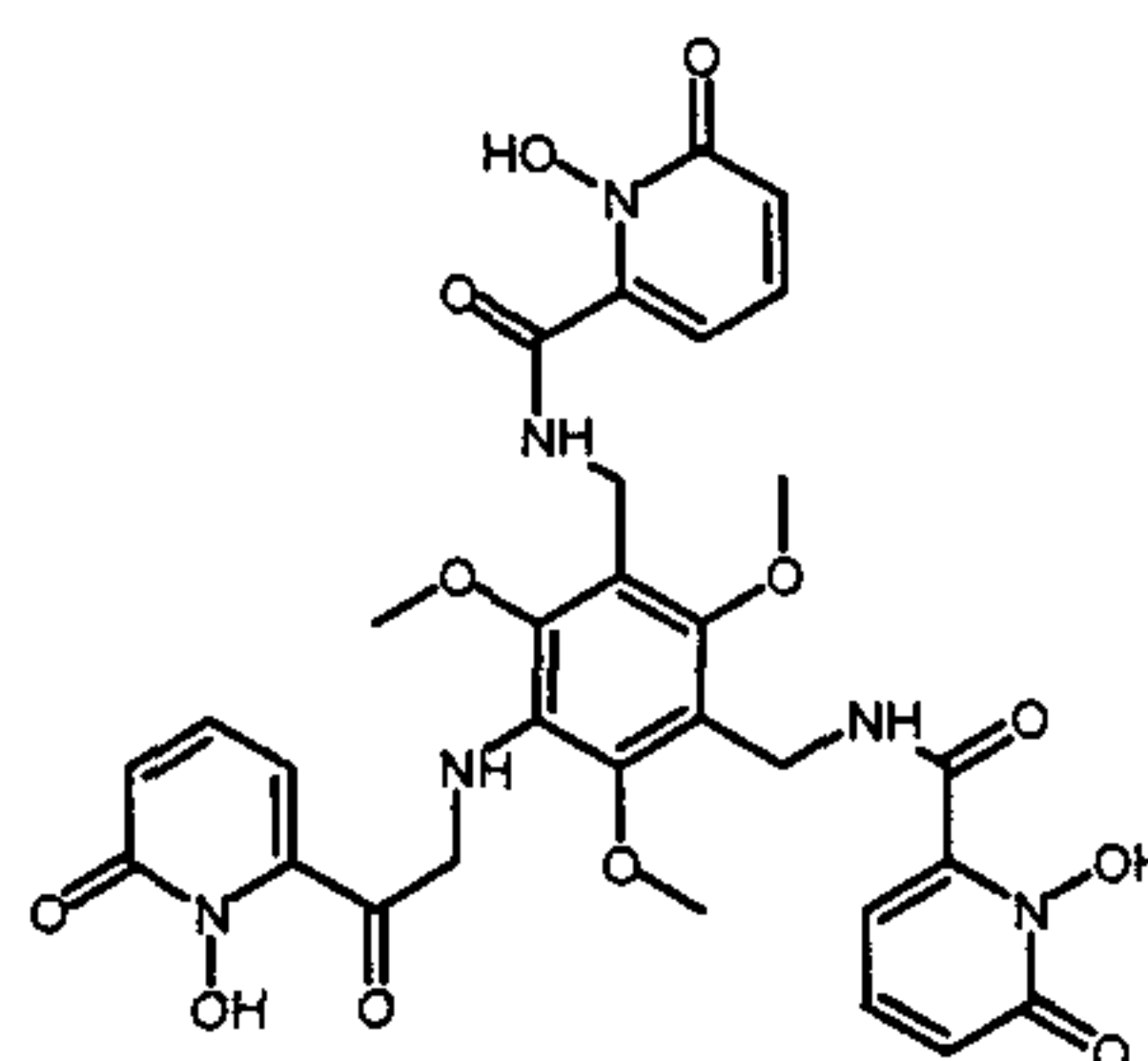


Hexadentate Ligands

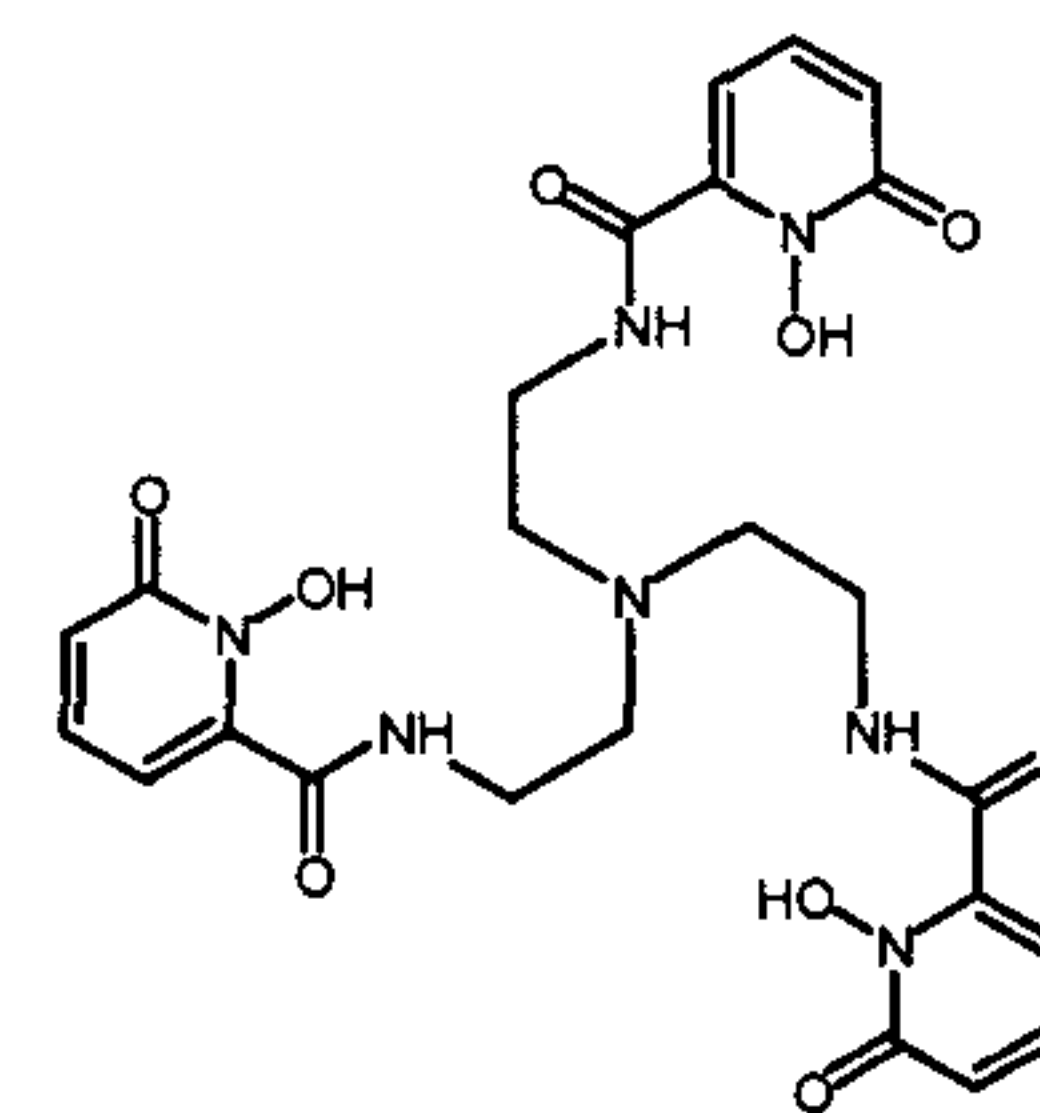
15 [0105] In another exemplary embodiment, the organic ligand is a hexadentate ligand. Exemplary hexadentate ligands include rigid and flexible structures:



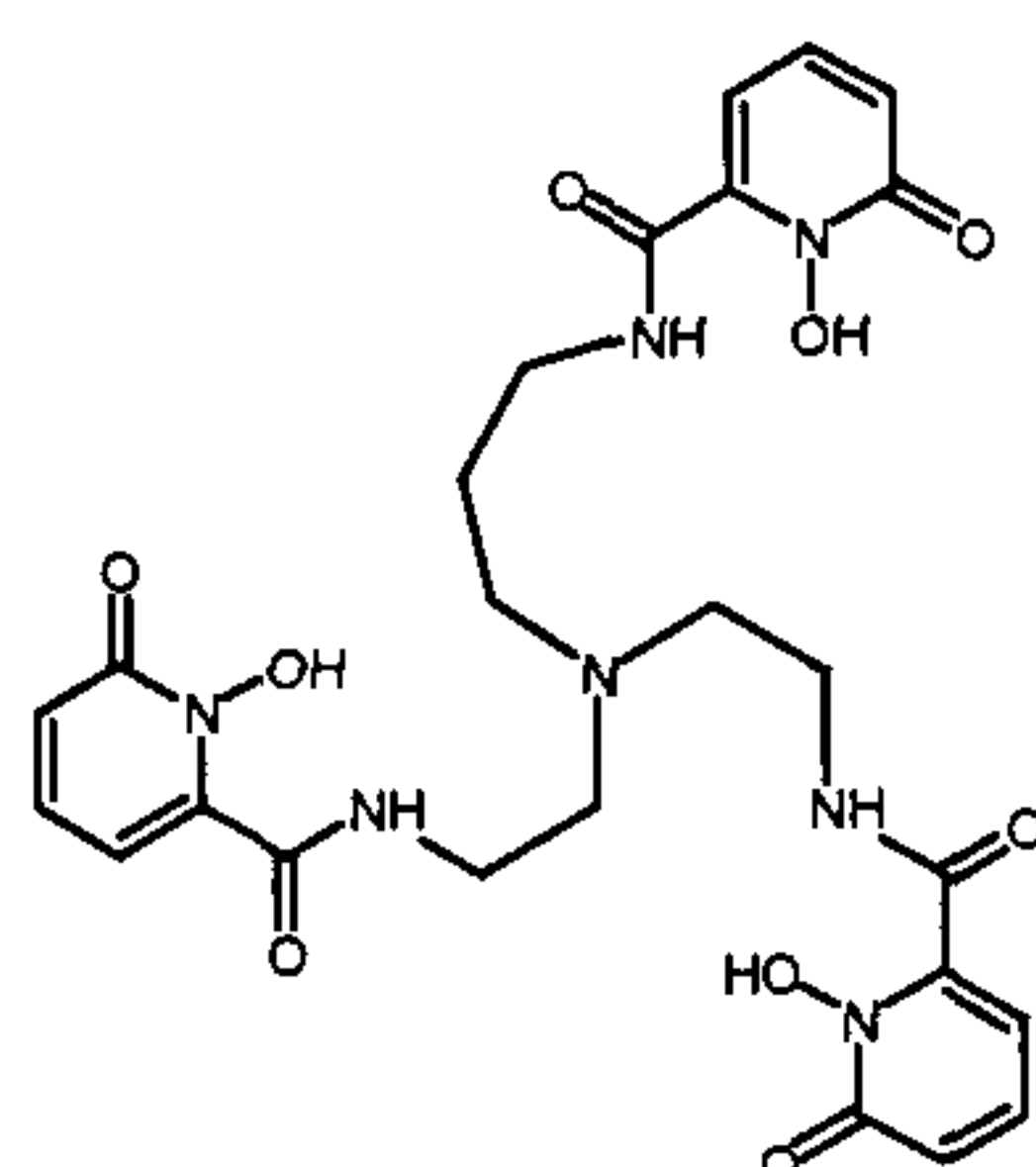
Benzene-1,3,5-tris-1,2-HOPO



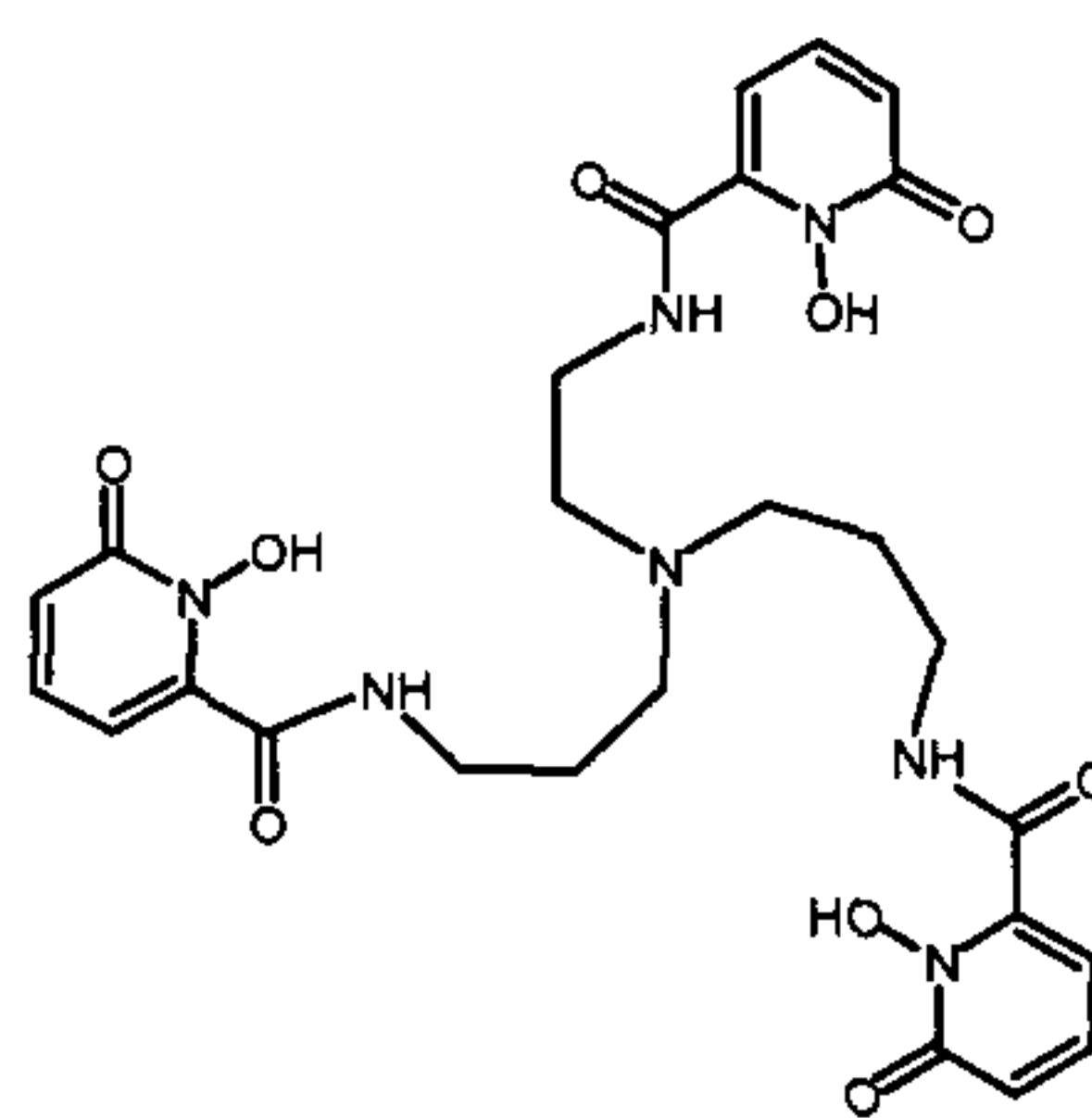
MeOMe-1,2-HOPO



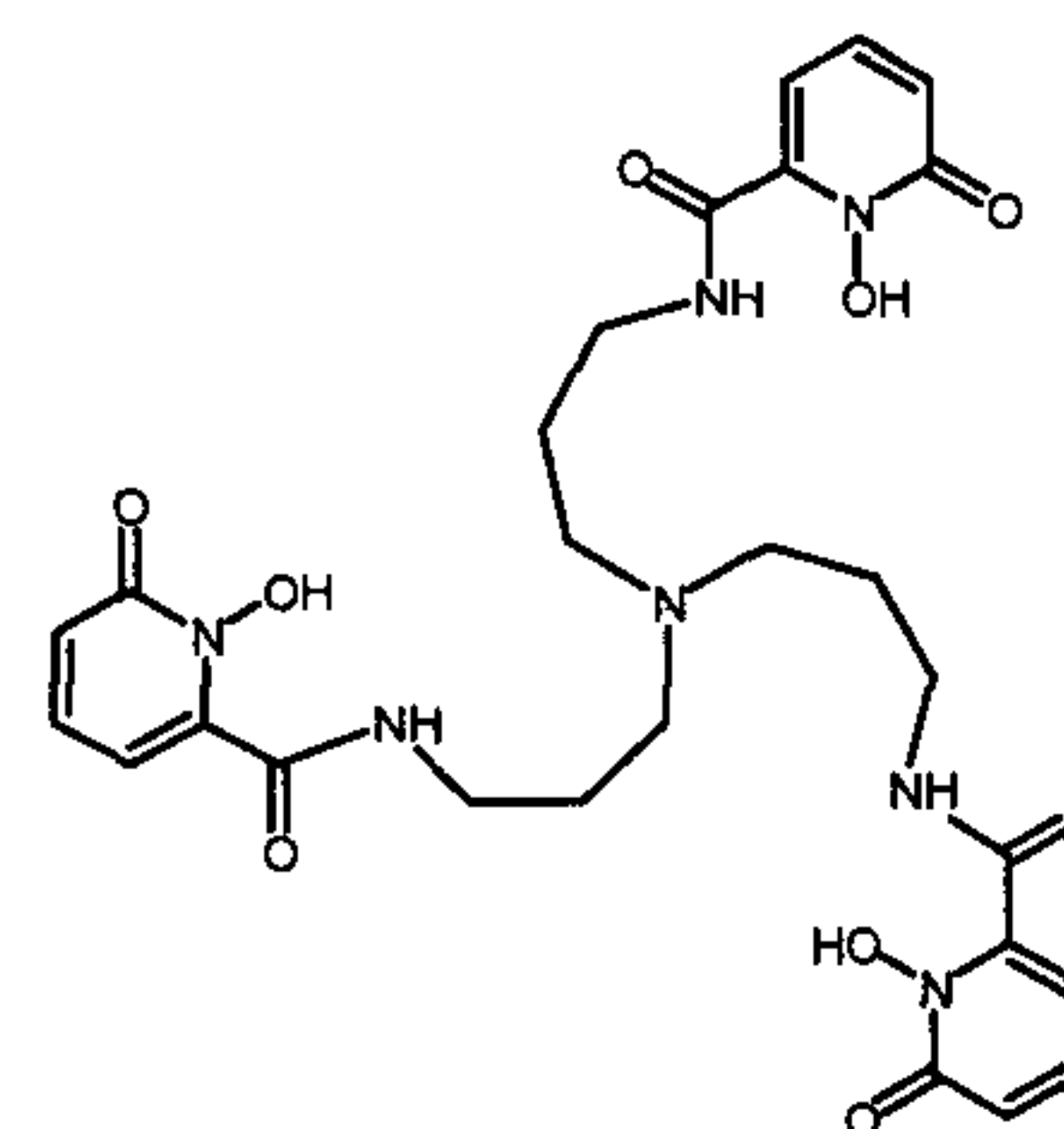
TREN-1,2-HOPO



TR223-1,2-HOPO



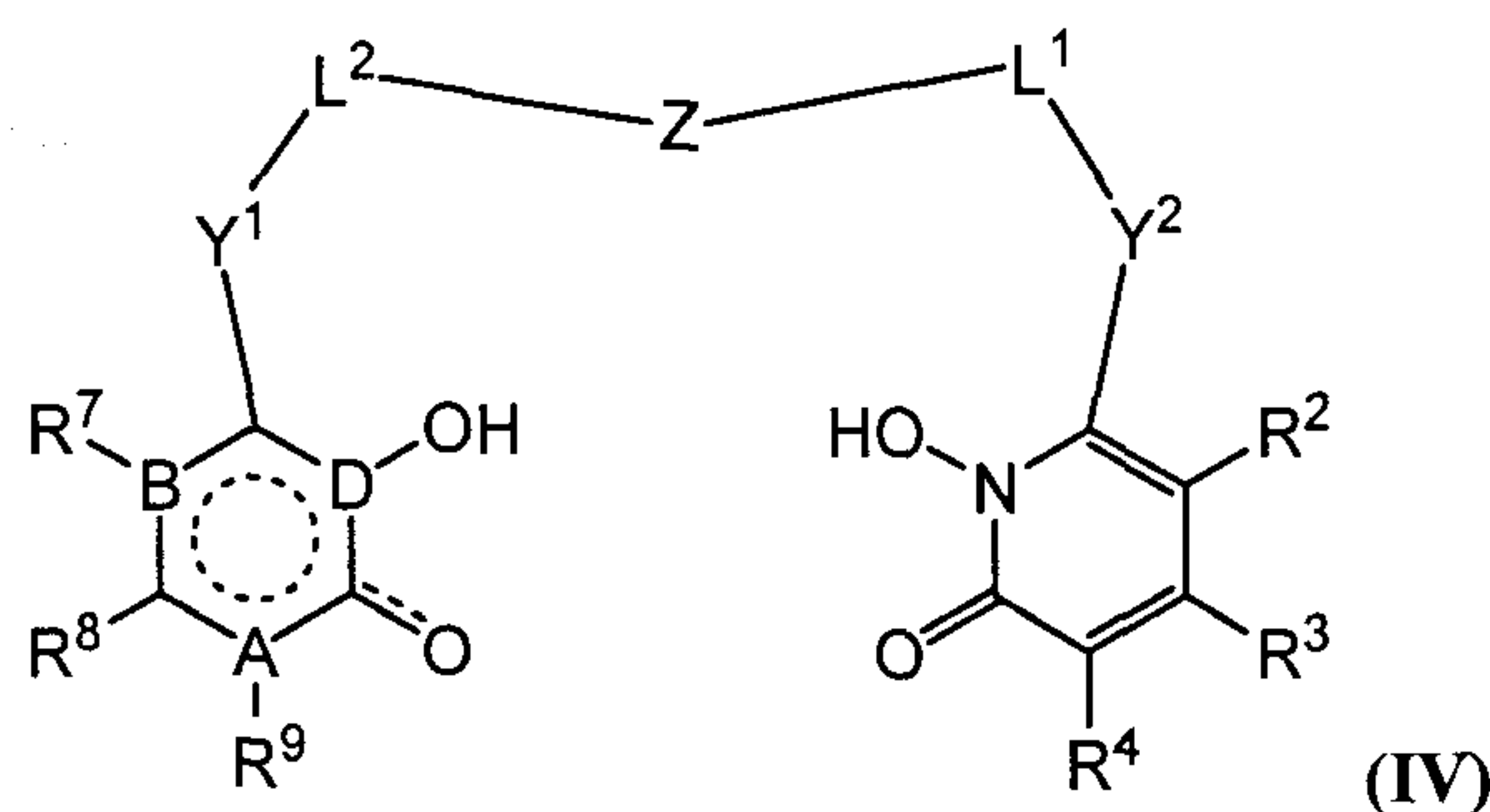
TR332-1,2-HOPO



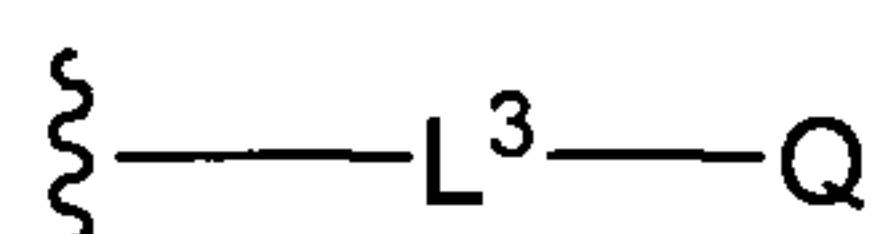
TRPN-1,2-HOPO

Octadentate Ligands

[0106] In another embodiment, the luminescent complex includes an octadentate ligand having a structure according to Formula (IV):

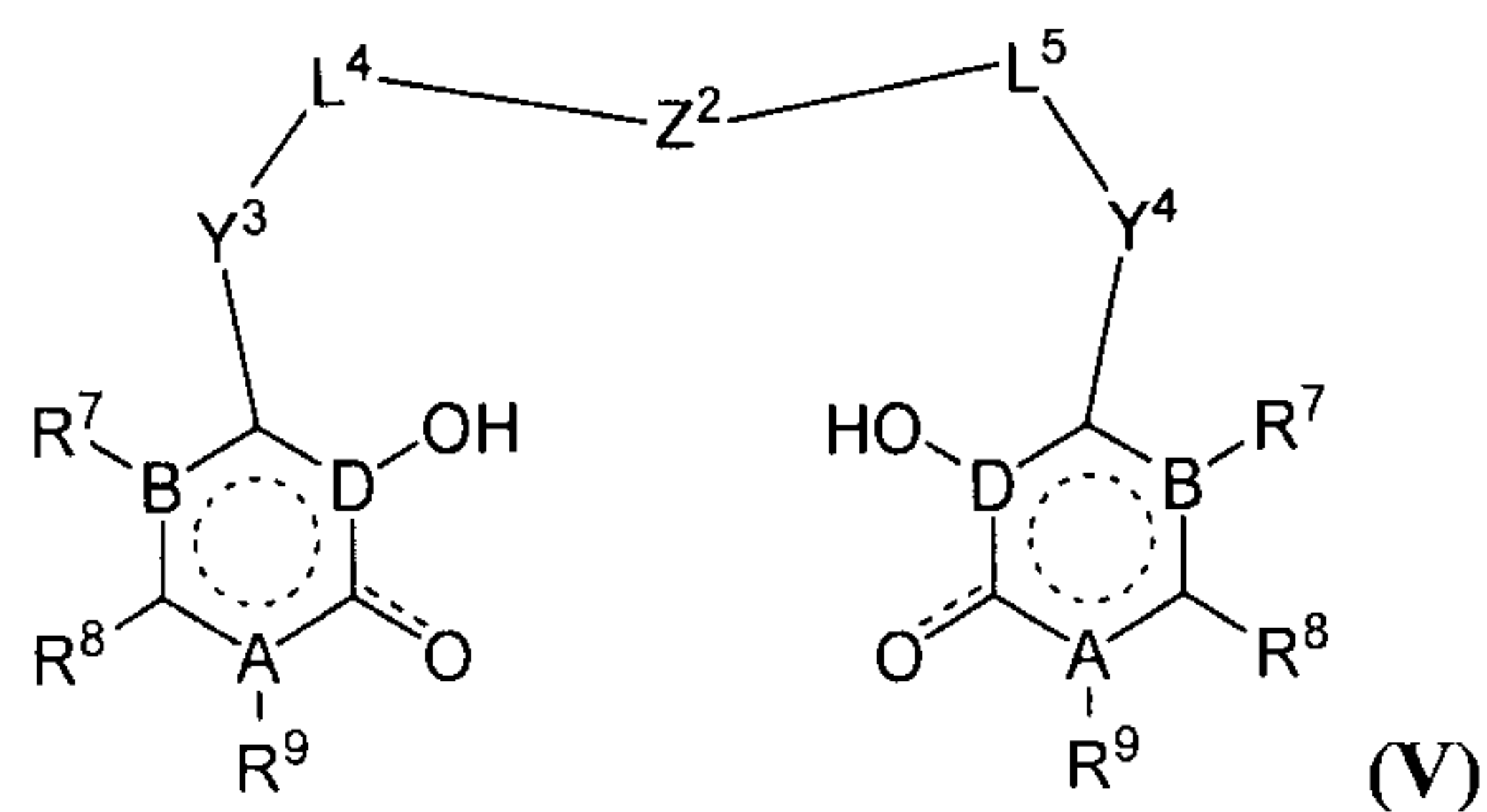


wherein Z, L¹, L², Y¹, Y², R², R³, R⁴, R⁷, R⁸, R⁹, A, B and D are as defined above for Formula (I), Formula (II) and Formula (III). In Formula (IV) at least one of Z, Y¹, Y², L¹ and L² is substituted with a moiety having the structure:



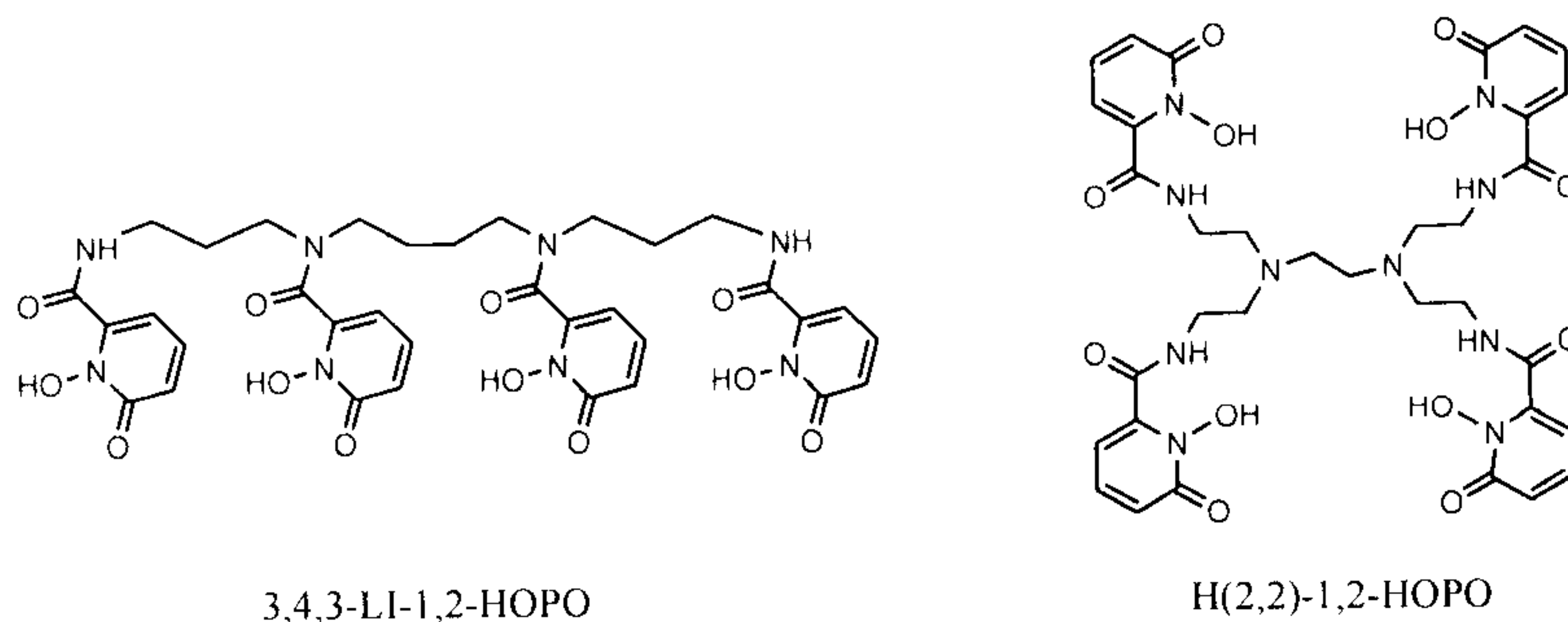
[0107] L³ is a linker group, which is a member selected from a bond, substituted or unsubstituted alkyl, substituted or unsubstituted heteroalkyl, substituted or unsubstituted aryl, substituted or unsubstituted heteroaryl and substituted or unsubstituted heterocycloalkyl. In an exemplary embodiment L³ is substituted with one or more groups that include a chelating moiety. In another embodiment, L³ is chosen to increase the water solubility of the complex. Accordingly, in one example, L³ includes an ether group or a polyether moiety. In a preferred embodiment, L³ includes 2 to 10 linear atoms, and more preferably 2 to 8 linear atoms.

[0108] Q has the structure of Formula (V):

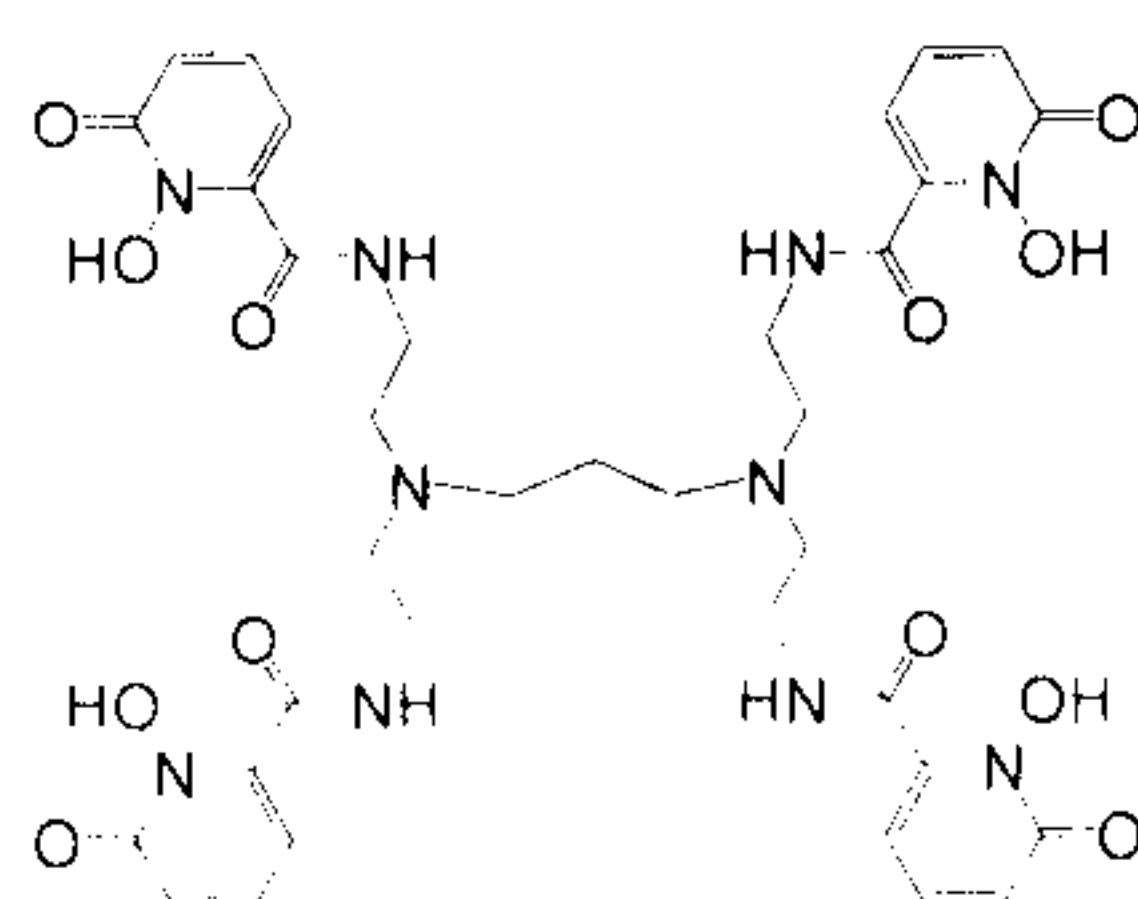


wherein Z^2 is a member selected from substituted or unsubstituted alkyl, substituted or unsubstituted heteroalkyl, substituted or unsubstituted aryl, substituted or unsubstituted heteroaryl, substituted or unsubstituted heterocycloalkyl, N, NR^{30} , O and S. In an exemplary embodiment, Z^2 is $CR^{31}R^{32}$. R^{30} , R^{31} and R^{32} are as defined above. In another exemplary embodiment, Z^2 is substituted with a chelating moiety. Y^3 and Y^4 are linker moieties, which are members independently selected from $-C(O)-$, $-C(O)NR^5-$, $-C(O)O-$, $-C(O)S-$, and $-C(O)CR^{20}R^{21}$, wherein R^5 , R^{20} and R^{21} are as defined above. L^4 and L^5 are linker groups, which are members independently selected from a bond, substituted or unsubstituted alkyl, substituted or unsubstituted heteroalkyl, substituted or unsubstituted aryl, substituted or unsubstituted heteroaryl and substituted or unsubstituted heterocycloalkyl. In Formula (V), at least one of Z^2 , Y^3 , Y^4 , L^4 and L^5 is linked to L^3 . At least one of the chelating moieties of Formula (V) is preferably a 1,2-HOPO unit.

[0109] Exemplary octadentate ligands include those with linear as well as tetrapodal topology:

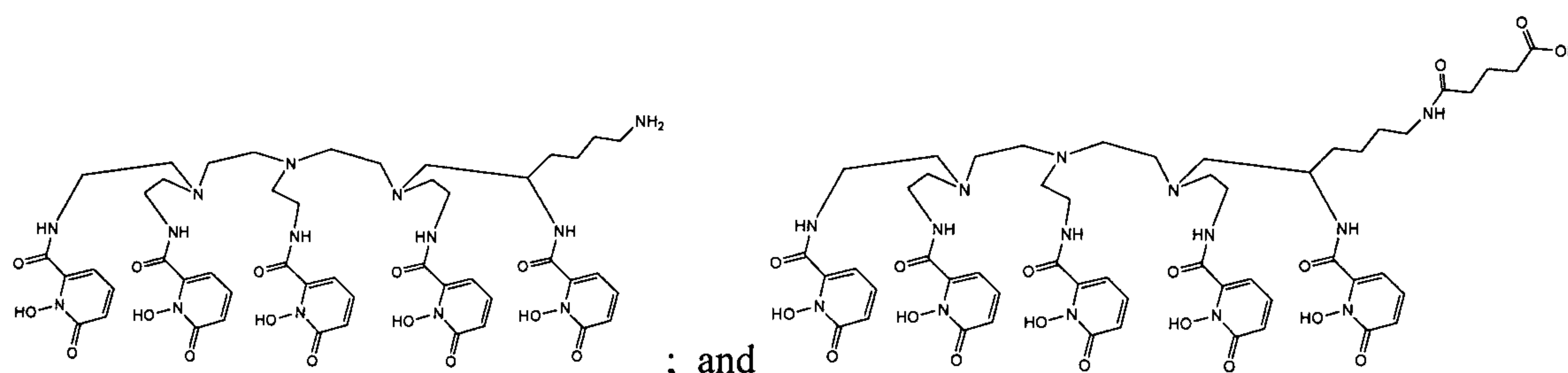


H(5O,2)-1,2-HOPO



H(4,2)-1,2-HOPO

5 **[0113]** Exemplary decadentate ligands include the following molecules, which also carry exemplary functional moieties:



[0114] The scaffold moiety can be any moiety useful for covalently linking two or more chelating moieties. In one embodiment, the scaffold moiety is a member selected from substituted or unsubstituted alkyl and substituted or unsubstituted heteroalkyl. Exemplary scaffold moieties include linear or branched ethers and amines.

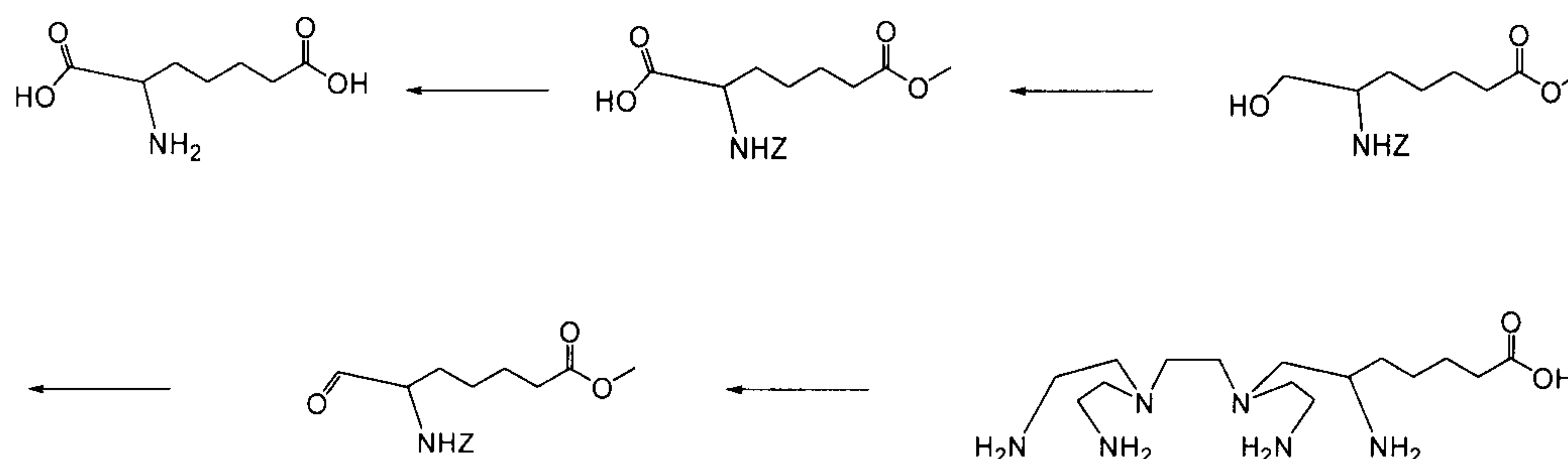
Chemical structures of various substituted compounds, where X represents a substituent group. The structures are arranged in four rows:

- Row 1: 1,2-dihaloethane, 1,2-dihalo-1,2-dimethylcyclohexane, 1,1'-dihalo-2,2'-diphenyl, 2,3-dihalo-2,3-dimethylbutane, 2,3-dihalo-2,3-dimethylpentane, and a legend box showing X = 2-hydroxy-1,2,3,4-tetrahydropyridin-5-yl.
- Row 2: 1,3-dihalo-2-methylbutane, 1,5-dihalo-2-methylhexane, 1,3-bis(halo)propan-2-amine, and 1,3-bis(halo)propan-2-amine with a substituent R.
- Row 3: 1,2-dihalo-1,2-diphenyl, 1,3-dihalo-1,3-diphenyl, 1,4-dihalo-1,4-diphenyl, 1,2-bis(halo)-1,2-diphenyl, 1,4-bis(halo)-1,4-diphenyl, and 2,6-bis(halo)pyridine.
- Row 4: 1,3,5-trihalo-1,3,5-triphenyl, 1,2-bis(halo)-1,2-diphenyl, 1,2-bis(halo)-1,2-diphenyl, 1,2-bis(halo)-1,2-diphenyl, and 1,4-bis(halo)-1,4-diphenyl.

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hereinabove. In each of the scaffold structures, and the 1,2-HOPO structure set forth above, the aryl moiety or alkyl moiety can be substituted with one or more "aryl group substituent" or "alkyl group substituent" as defined herein.

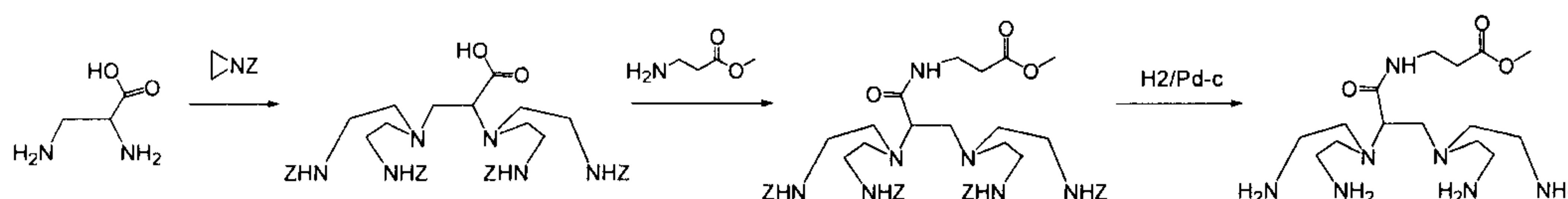
5 [0117] Other scaffold moieties that include functional moieties (or a linker to a functional moiety) include linkers prepared by the following exemplary methods.



Scheme 1.1. Reverse synthetic scheme for carboxyl functionalized H22 cap-amine.

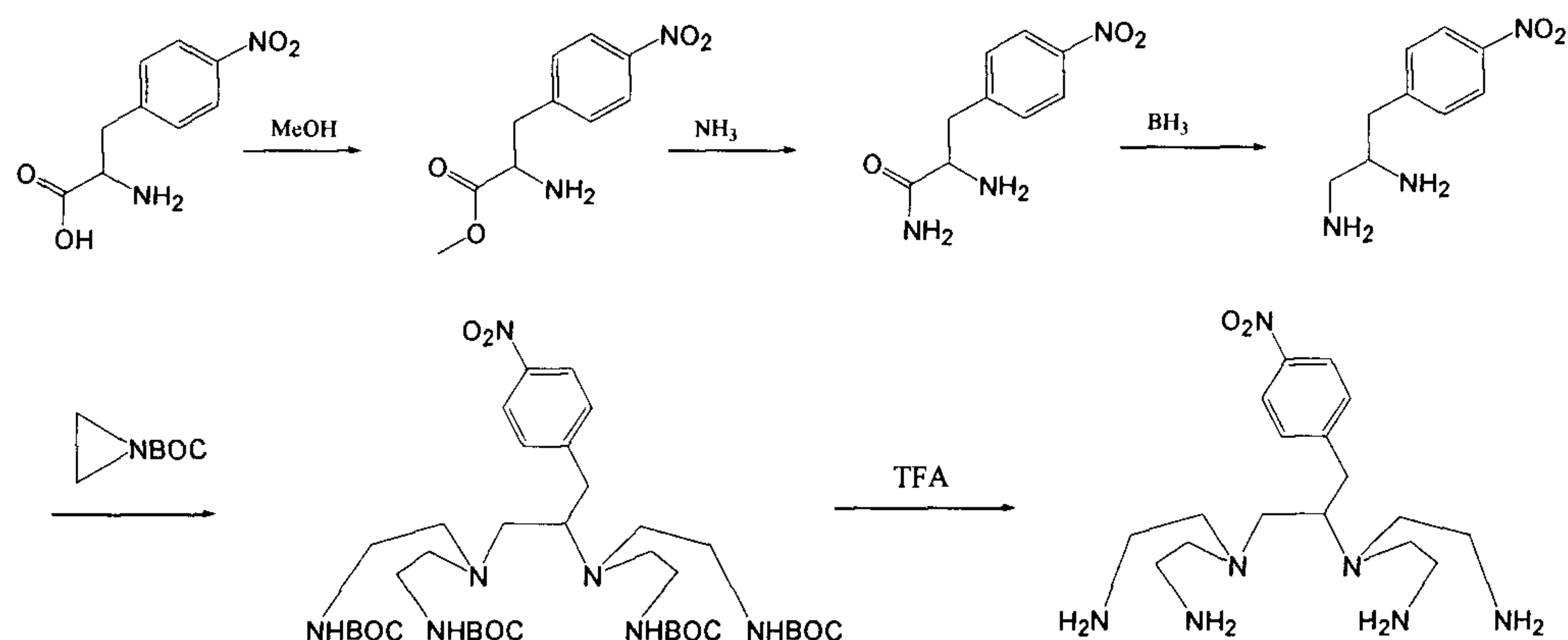
10 [0118] Other functionalize scaffolds include those in which the chiral carbon is placed on the central ethylene bridge of H22-amine. An exemplary route to such a scaffold initiates with 2,3-Diaminopropionic acid, as its carboxyl group is connected directly to the amine backbone to give a very rigid geometry, extended carboxyl chain is needed to provide flexibility for eventual protein conjugating. A synthetic scheme to the scaffold is shown in scheme 1.2.

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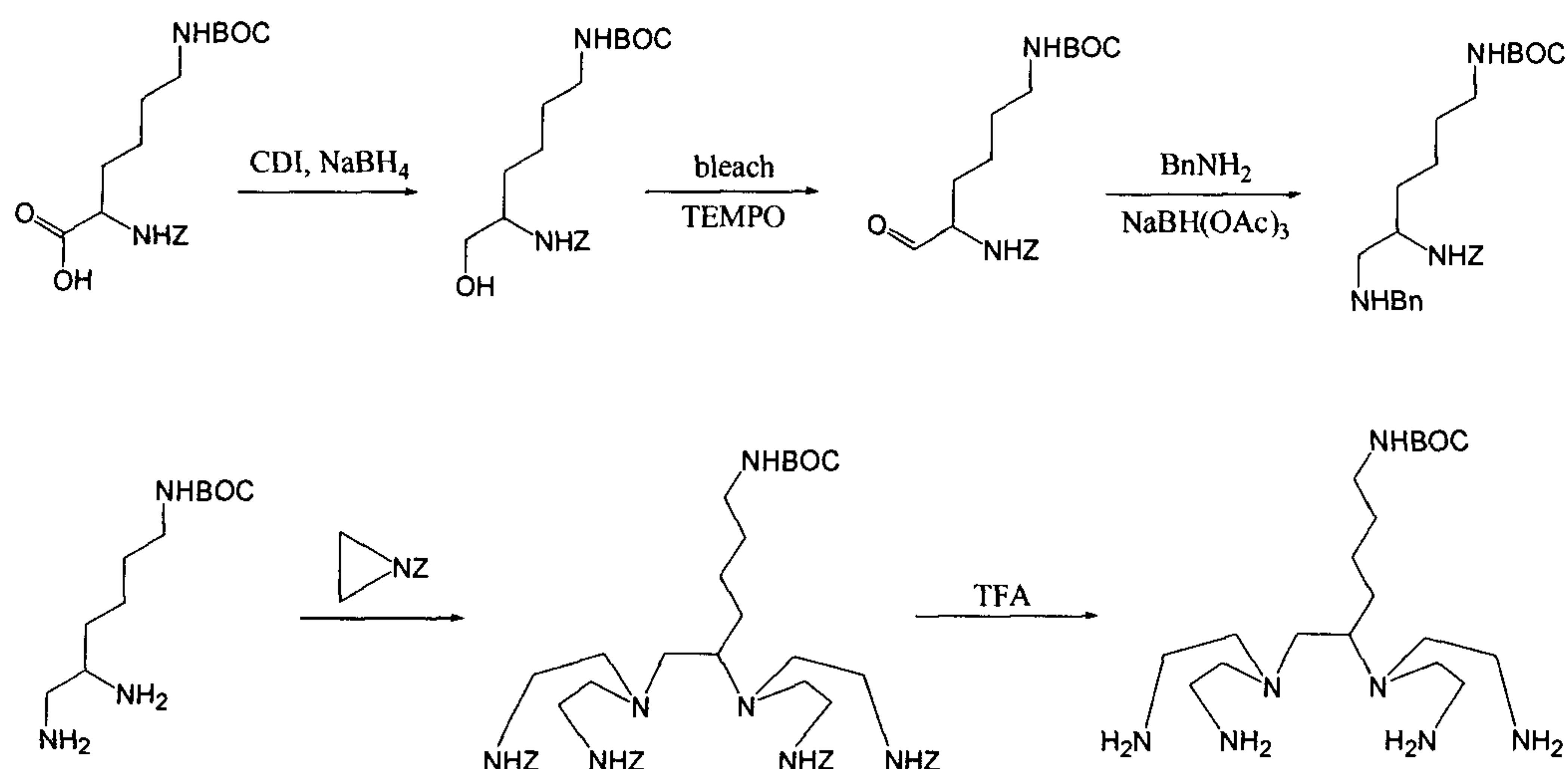


Scheme 1.2

20 [0119] Variations on this synthesis include the use of a nitrophenylalanine or a BOC-amino group, which are optionally converted to carboxyl groups. Synthetic routes to these scaffolds are shown in Schemes 1.3 and 1.4.



Scheme 1.3



Scheme 1.4

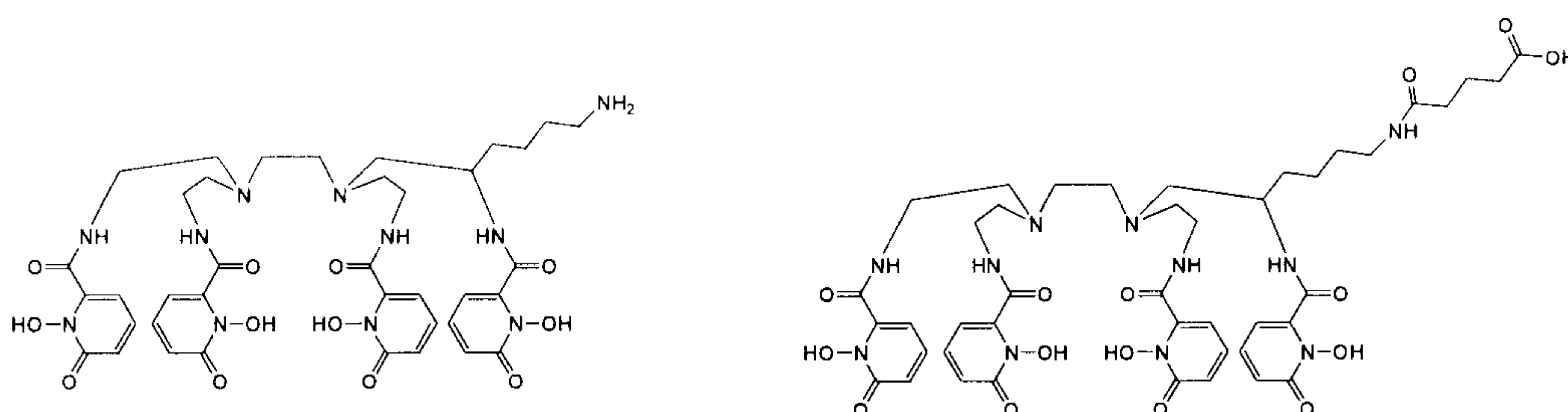
5 *Functional Moiety*

[0120] In one exemplary embodiment, complexes disclosed herein are derivatized with at least one functional moiety. The term “functional moiety” includes any substituent group, which is useful to link a complex of the invention to another molecule. Such linkage can be either covalent or non-covalent. Hence, the functional moiety may contain a reactive functional group. “Functional moiety” also includes any substituent group that includes a targeting moiety, such as a polypeptide, a ligand to a receptor, an antibody and the like.

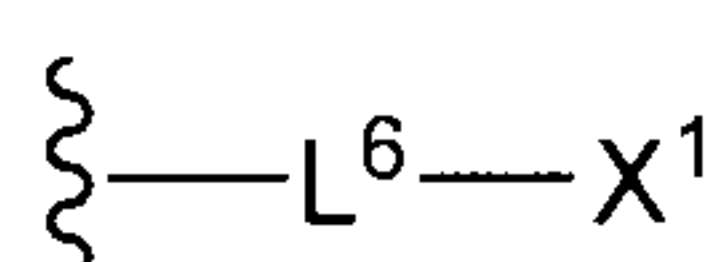
[0121] The functional moiety is preferably attached, so that the resulting functionalized ligand will be able to undergo formation of stable metal ion complexes. In one exemplary embodiment, the functional moiety can be attached to the scaffold moiety, for instance, to

one of the linker groups, such as L^1 or L^2 in Formula (III). In another exemplary embodiment, the functional moiety is attached to one of the chelating moieties of Formula (I) or Formula (II). For example, the functional moiety can be part of R^{11} in a TAM moiety. The functional moiety can also be attached to any other linker moiety (e.g., R^5 may include a functional moiety) or linker group within the complex. In another example, a functional moiety is attached to at least one of L^1 , L^2 , L^3 , L^4 or L^5 in Formula (IV) and/or Formula (V).

[0122] Exemplary organic ligands including a functional moiety are shown below:



[0123] In an exemplary embodiment, the functional moiety has the structure:



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wherein L^6 is a linker moiety, which is a member selected from substituted or unsubstituted alkyl, substituted or unsubstituted heteroalkyl, substituted or unsubstituted aryl, substituted or unsubstituted heteroaryl and substituted or unsubstituted heterocycloalkyl. X^1 is a member selected from a reactive functional group and a targeting moiety.

15 **Reactive Functional Groups**

[0124] In one embodiment, the functional moiety includes a reactive functional group, which can be used to covalently attach the ligand to a targeting moiety, such as a protein, a small molecule, a lipid, a carbohydrate and the like. Alternatively, the reactive functional group can be used to link the ligand to a nano-particle of any kind. Reactive groups and classes of reactions useful in practicing the present invention are generally those that are well known in the art of bioconjugate chemistry. Currently favored classes of reactions available with reactive functional groups of the invention are those which proceed under relatively mild conditions. These include, but are not limited to nucleophilic substitutions (e.g., reactions of amines and alcohols with acyl halides and activated esters), electrophilic substitutions (e.g., enamine reactions) and additions to carbon-carbon and carbon-heteroatom multiple bonds (e.g., Michael reactions and Diels-Alder reactions). These and other useful reactions are

20

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discussed, for example, in: March, ADVANCED ORGANIC CHEMISTRY, 3rd Ed., John Wiley & Sons, New York, 1985; Hermanson, BIOCONJUGATE TECHNIQUES, Academic Press, San Diego, 1996; and Feeney et al., MODIFICATION OF PROTEINS; Advances in Chemistry Series, Vol. 198, American Chemical Society, Washington, D.C., 1982.

5 a) *Amines and Amino-Reactive Groups*

[0125] In one embodiment, the reactive functional group is a member selected from amines, such as a primary or secondary amine, hydrazines, hydrazides, and sulfonylhydrazides. Amines can, for example, be acylated, alkylated or oxidized. Useful non-limiting examples of amino-reactive groups include N-hydroxysuccinimide (NHS) esters, sulfur-NHS esters,
10 imidoesters, isocyanates, isothiocyanates, acylhalides, arylazides, p-nitrophenyl esters, aldehydes, sulfonyl chlorides, thiazolides and carboxyl groups.

[0126] NHS esters and sulfur-NHS esters react preferentially with the primary (including aromatic) amino groups of the reaction partner. The imidazole groups of histidines are known to compete with primary amines for reaction, but the reaction products are unstable
15 and readily hydrolyzed. The reaction involves the nucleophilic attack of an amine on the acid carboxyl of an NHS ester to form an amide, releasing the N-hydroxysuccinimide.

[0127] Imidoesters are the most specific acylating reagents for reaction with the amine groups of e.g., a protein. At a pH between 7 and 10, imidoesters react only with primary amines. Primary amines attack imidates nucleophilically to produce an intermediate that
20 breaks down to amidine at high pH or to a new imidate at low pH. The new imidate can react with another primary amine, thus crosslinking two amino groups, a case of a putatively monofunctional imidate reacting bifunctionally. The principal product of reaction with primary amines is an amidine that is a stronger base than the original amine. The positive charge of the original amino group is therefore retained. As a result, imidoesters do not affect
25 the overall charge of the conjugate.

[0128] Isocyanates (and isothiocyanates) react with the primary amines of the conjugate components to form stable bonds. Their reactions with sulfhydryl, imidazole, and tyrosyl groups give relatively unstable products.

[0129] Acylazides are also used as amino-specific reagents in which nucleophilic amines of
30 the reaction partner attack acidic carboxyl groups under slightly alkaline conditions, e.g. pH 8.5.

[0130] Arylhalides such as 1,5-difluoro-2,4-dinitrobenzene react preferentially with the amino groups and tyrosine phenolic groups of the conjugate components, but also with its sulfhydryl and imidazole groups.

[0131] p-Nitrophenyl esters of carboxylic acids are also useful amino-reactive groups.

5 Although the reagent specificity is not very high, α - and ϵ -amino groups appear to react most rapidly.

[0132] Aldehydes react with primary amines of the conjugate components (*e.g.*, ϵ -amino group of lysine residues). Although unstable, Schiff bases are formed upon reaction of the protein amino groups with the aldehyde. Schiff bases, however, are stable, when conjugated
10 to another double bond. The resonant interaction of both double bonds prevents hydrolysis of the Schiff linkage. Furthermore, amines at high local concentrations can attack the ethylenic double bond to form a stable Michael addition product. Alternatively, a stable bond may be formed by reductive amination.

[0133] Aromatic sulfonyl chlorides react with a variety of sites of the conjugate components,
15 but reaction with the amino groups is the most important, resulting in a stable sulfonamide linkage.

[0134] Free carboxyl groups react with carbodiimides, soluble in both water and organic solvents, forming pseudoureas that can then couple to available amines yielding an amide linkage. Yamada *et al.*, *Biochemistry* 1981, 20: 4836-4842, *e.g.*, teach how to modify a
20 protein with carbodiimides.

b) *Sulfhydryl and Sulfhydryl-Reactive Groups*

[0135] In another embodiment, the reactive functional group is a member selected from a sulfhydryl group (which can be converted to disulfides) and sulfhydryl-reactive groups. Useful non-limiting examples of sulfhydryl-reactive groups include maleimides, alkyl
25 halides, acyl halides (including bromoacetamide or chloroacetamide), pyridyl disulfides, and thiophthalimides.

[0136] Maleimides react preferentially with the sulfhydryl group of the conjugate components to form stable thioether bonds. They also react at a much slower rate with primary amino groups and the imidazole groups of histidines. However, at pH 7 the
30 maleimide group can be considered a sulfhydryl-specific group, since at this pH the reaction rate of simple thiols is 1000-fold greater than that of the corresponding amine.

[0137] Alkyl halides react with sulfhydryl groups, sulfides, imidazoles, and amino groups. At neutral to slightly alkaline pH, however, alkyl halides react primarily with sulfhydryl groups to form stable thioether bonds. At higher pH, reaction with amino groups is favored.

[0138] Pyridyl disulfides react with free sulfhydryl groups via disulfide exchange to give mixed disulfides. As a result, pyridyl disulfides are relatively specific sulfhydryl-reactive groups.

[0139] Thiophthalimides react with free sulfhydryl groups to also form disulfides.

c) *Other Reactive Functional Groups*

[0140] Other exemplary reactive functional groups include:

- 10 (i) carboxyl groups and various derivatives thereof including, but not limited to, N-hydroxybenztriazole esters, acid halides, acyl imidazoles, thioesters, p-nitrophenyl esters, alkyl, alkenyl, alkynyl and aromatic esters;
- (ii) hydroxyl groups, which can be converted to esters, ethers, aldehydes, etc.;
- 15 (iii) haloalkyl groups, wherein the halide can be displaced with a nucleophilic group such as, for example, an amine, a carboxylate anion, thiol anion, carbanion, or an alkoxide ion, thereby resulting in the covalent attachment of a new group at the site of the halogen atom;
- (iv) dienophile groups, which are capable of participating in Diels-Alder reactions such as, for example, maleimido groups;
- 20 (v) aldehyde or ketone groups, such that subsequent derivatization is possible via formation of carbonyl derivatives such as, for example, imines, hydrazones, semicarbazones or oximes, or via such mechanisms as Grignard addition or alkyllithium addition;
- (vi) alkenes, which can undergo, for example, cycloadditions, acylation, Michael addition, etc;
- 25 (vii) epoxides, which can react with, for example, amines and hydroxyl groups;
- (ix) phosphoramidites and other standard functional groups useful in nucleic acid synthesis and
- (x) any other functional group useful to form a covalent bond between the
- 30 functionalized ligand and a molecular entity or a surface.

d) *Functional Groups with Non-specific Reactivities*

[0141] In addition to the use of site-specific reactive moieties, the present invention contemplates the use of non-specific reactive groups to link the ligand to a targeting moiety. Non-specific groups include photoactivatable groups, for example.

5 [0142] Photoactivatable groups are ideally inert in the dark and are converted to reactive species in the presence of light. In one embodiment, photoactivatable groups are selected from precursors of nitrenes generated upon heating or photolysis of azides. Electron-deficient nitrenes are extremely reactive and can react with a variety of chemical bonds including N-H, O-H, C-H, and C=C. Although three types of azides (aryl, alkyl, and acyl
10 derivatives) may be employed, arylazides are presently preferred. The reactivity of arylazides upon photolysis is better with N-H and O-H than C-H bonds. Electron-deficient arylnitrenes rapidly ring-expand to form dehydroazepines, which tend to react with nucleophiles, rather than form C-H insertion products. The reactivity of arylazides can be increased by the presence of electron-withdrawing substituents such as nitro or hydroxyl
15 groups in the ring. Such substituents push the absorption maximum of arylazides to longer wavelength. Unsubstituted arylazides have an absorption maximum in the range of 260-280 nm, while hydroxy and nitroarylazides absorb significant light beyond 305 nm. Therefore, hydroxy and nitroarylazides are most preferable since they allow to employ less harmful photolysis conditions for the affinity component than unsubstituted arylazides.

20 [0143] In another preferred embodiment, photoactivatable groups are selected from fluorinated arylazides. The photolysis products of fluorinated arylazides are arylnitrenes, all of which undergo the characteristic reactions of this group, including C-H bond insertion, with high efficiency (Keana *et al.*, *J. Org. Chem.* 55: 3640-3647, 1990).

[0144] In another embodiment, photoactivatable groups are selected from benzophenone
25 residues. Benzophenone reagents generally give higher crosslinking yields than arylazide reagents.

[0145] In another embodiment, photoactivatable groups are selected from diazo compounds, which form an electron-deficient carbene upon photolysis. These carbenes undergo a variety of reactions including insertion into C-H bonds, addition to double bonds (including aromatic
30 systems), hydrogen attraction and coordination to nucleophilic centers to give carbon ions.

[0146] In still another embodiment, photoactivatable groups are selected from diazopyruvates. For example, the p-nitrophenyl ester of p-nitrophenyl diazopyruvate reacts

with aliphatic amines to give diazopyruvic acid amides that undergo ultraviolet photolysis to form aldehydes. The photolyzed diazopyruvate-modified affinity component will react like formaldehyde or glutaraldehyde forming intraprotein crosslinks.

[0147] It is well within the abilities of a person skilled in the art to select a reactive functional group, according to the reaction partner. As an example, an activated ester, such as an NHS ester will be useful to label a protein *via* lysine residues. Sulfhydryl reactive groups, such as maleimides can be used to label proteins *via* amino acid residues carrying an SH-group (e.g., cystein). Antibodies may be labeled by first oxidizing their carbohydrate moieties (e.g., with periodate) and reacting resulting aldehyde groups with a hydrazine containing ligand.

[0148] The reactive functional groups can be chosen such that they do not participate in, or interfere with, the reactions necessary to assemble the reactive ligand. Alternatively, a reactive functional group can be protected from participating in the reaction by means of a protecting group. Those of skill in the art understand how to protect a particular functional group so that it does not interfere with a chosen set of reaction conditions. For examples of useful protecting groups, see, for example, Greene et al., PROTECTIVE GROUPS IN ORGANIC SYNTHESIS, John Wiley & Sons, New York, 1991.

Targeting Moieties

[0149] Exemplary targeting moieties include small-molecule ligands, lipids, linear and cyclic peptides, polypeptides (e.g., EPO, insulin etc.), proteins, such as enzymes and receptors and fusion proteins. Other targeting moieties include antibodies and antibody fragments (e.g., those generated to recognize small-molecules and receptor ligands), antigens, nucleic acids (e.g. RNA and cDNA), carbohydrate moieties (e.g., polysaccharides), lipids and pharmacologically active molecules, such as toxins, pharmaceutical drugs and drugs of abuse (e.g. steroids).

[0150] Additional targeting moieties are selected from solid supports and polymeric surfaces (e.g., polymeric beads and plastic sample reservoirs, such as plastic well-plates), sheets, fibers and membranes. Targeting moieties also include particles (e.g., nano-particles) and drug-delivery vehicles.

[0151] In one embodiment, the targeting moiety includes at least one unit of a macrocyclic compound. In another exemplary embodiment, the compound has a dendrimeric structure and encompasses several ligands covalently linked to

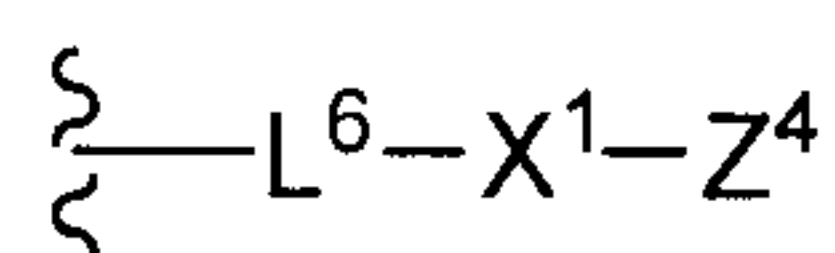
each other. In a further exemplary embodiment, according to this aspect, a complex based on such dendrimer includes at least two metal ions.

[0152] In another exemplary embodiment, the Linker moiety L^6 or the targeting moiety include a polyether, such as polyethylene glycol (PEG) and derivatives thereof. In one
5 example, the polyether has a molecular weight between about 50 to about 10,000 daltons.

[0153] In one exemplary embodiment, the targeting moiety is a protein containing a lipid recognition motif. Exemplary lipid binding proteins include those that bind to phosphatidylinositol, phosphatidylinositol phosphates or other biological lipids.

[0154] In another exemplary embodiment, the targeting moiety is substituted with a
10 luminescence modifying group that allows luminescence energy transfer between a complex of the invention and the luminescence modifying group when the complex is excited.

[0155] In one example, the functional moiety has the structure:

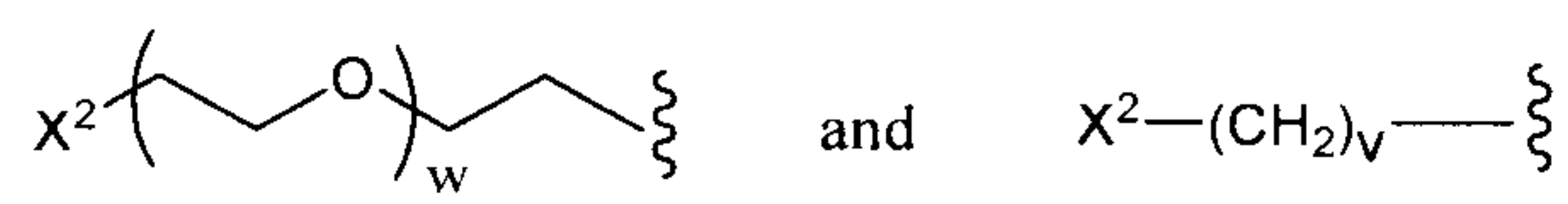


wherein L^6 is a linker moiety, which is a member selected from substituted or unsubstituted
15 alkyl, substituted or unsubstituted heteroalkyl, substituted or unsubstituted aryl, substituted or unsubstituted heteroaryl and substituted or unsubstituted heterocycloalkyl. X^1 is a targeting moiety and Z^4 is a luminescence modifying group allowing luminescence energy transfer between said complex and said luminescence modifying group when said complex is excited.

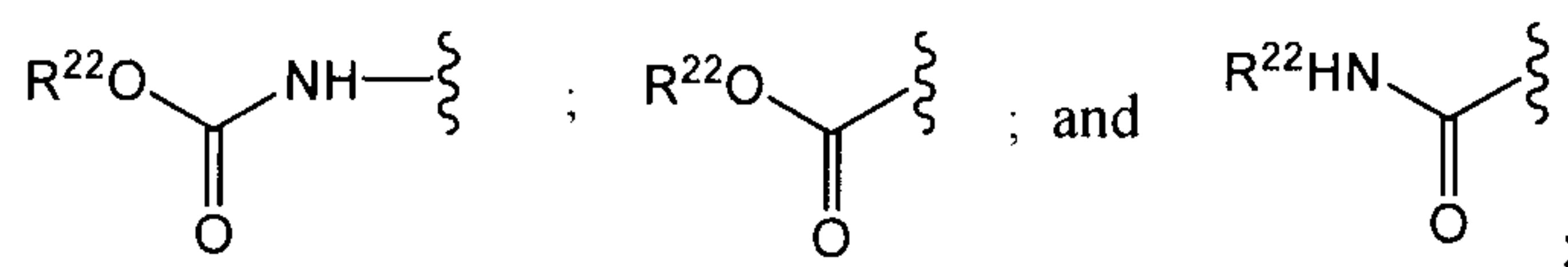
Linker Moiety L^6

[0156] In one preferred embodiment, the linker moiety L^6 of the functional moiety is long
20 enough to avoid side reactions during synthesis (e.g. intra-molecular reactions, such as intra-molecular peptide bond formation), to allow coupling of the organic ligand or complex of the invention to a targeting moiety and to allow the targeting moiety to fulfill its intended function. Useful linkers include those with about 2 to about 50 linear atoms, preferably about
25 4 to about 20 linear atoms.

[0157] In one exemplary embodiment the linker moiety includes an aliphatic carbon chain or a poly-ethyleneglycol (PEG) chain. Thus, the functional moiety includes a structure which is a member selected from:

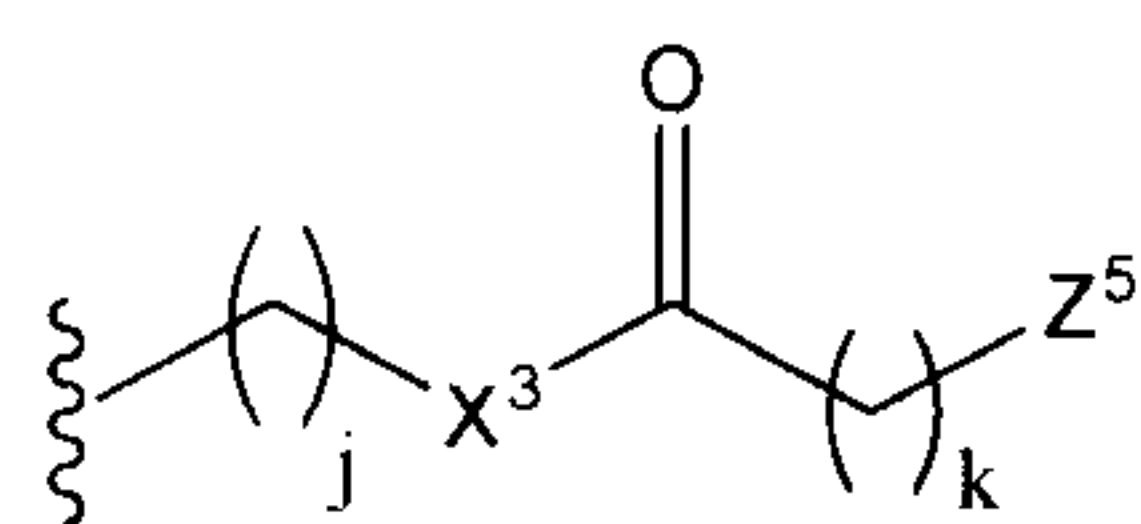


[0158] Exemplary X^2 groups include OH, alkoxy, and one of the following structures:



wherein R^{22} is a member selected from H, substituted or unsubstituted alkyl, substituted or unsubstituted heteroalkyl, substituted or unsubstituted aryl, substituted or unsubstituted heteroaryl and substituted or unsubstituted heterocycloalkyl. The integer v is selected from 1 to 20, and w is an integer from 1 to 1,000.

[0159] In another exemplary embodiment, the functional moiety has the structure:



wherein Z^5 is a member selected from H, OR^{23} , SR^{23} , NHR^{23} , OCOR^{24} , OC(O)NHR^{24} , NHC(O)OR^{23} , $\text{OS(O)}_2\text{OR}^{23}$, and C(O)R^{24} . R^{23} is a member selected from H, substituted or unsubstituted alkyl, and substituted or unsubstituted heteroalkyl. R^{24} is a member selected from H, OR^{25} , $\text{NR}^{25}\text{NH}_2$, SH, C(O)R^{25} , NR^{25}H , substituted or unsubstituted alkyl and substituted or unsubstituted heteroalkyl. R^{25} is a member selected from H, substituted or unsubstituted alkyl and substituted or unsubstituted heteroalkyl. X^3 is a member selected from O, S and NR^{26} , wherein R^{26} is a member selected from H, substituted or unsubstituted alkyl and substituted or unsubstituted heteroalkyl. The integers j and k are members independently selected from 1 to 20.

[0160] In linker arms with multiple reactive functional groups, a particular functional group can be chosen such that it does not participate in, or interfere with, the reaction controlling the attachment of the functionalized spacer component to another ligand component. Alternatively, the reactive functional group can be protected from participating in the reaction by the presence of a protecting group. Those of skill in the art understand how to protect a particular functional group from interfering with a chosen set of reaction conditions. For examples of useful protecting groups, See Greene *et al.*, PROTECTIVE GROUPS IN ORGANIC SYNTHESIS, John Wiley & Sons, New York, 1991.

[0161] In one embodiment, the linker attaches the ligand to a targeting group essentially irreversibly via a "stable bond" between the components. A "stable bond", as used herein, is a bond, which maintains its chemical integrity over a wide range of conditions (*e.g.*, amide,

carbamate, carbon-carbon, ether, *etc.*). In another embodiment the linker attaches two or more components by a "cleaveable bond". A "cleaveable bond", as used herein, is a bond which is designed to undergo scission under selected conditions. Cleaveable bonds include, but are not limited to, disulfide, imine, carbonate and ester bonds.

5 [0162] In an exemplary embodiment, the complex includes a water-soluble polymer as a scaffold moiety, or as a targeting moiety. Exemplary water-soluble polymers include polylysine, polyethylene glycol (PEG) or polydextran (Dresser, T. R. *et al.*, *J. Magn. Reson. Imaging* 1994, 4: 467)

[0163] Thus, in another embodiment, this disclosure provides a complex (e.g., of Formula III),
10 wherein at least one of R¹, R², R³, and R⁴ comprise a moiety derived from polyethylene glycol (PEG). PEG is used in biotechnology and biomedical applications. The use of this agent has been reviewed (POLY-ETHYLENE GLYCOL CHEMISTRY: BIOTECHNICAL AND BIOMEDICAL APPLICATIONS, J. M. Harris, Ed., Plenum Press, New York, 1992). Modification of enzymes (Chiu *et al.*, *J. Bioconjugate Chem.*, 4: 290-295 (1993)), RGD peptides (Braatz *et al.*, *Bioconjugate Chem.*, 4: 262-
15 267 (1993)), liposomes (Zalipsky, *S. Bioconjugate Chem.*, 4: 296-299 (1993)), and CD4-IgG glycoprotein (Chamow *et al.*, *Bioconjugate Chem.*, 4: 133-140 (1993)) are some of the recent advances in the use of polyethylene glycol. Surfaces treated with PEG have been shown to resist protein deposition and have improved resistance to thrombogenicity when coated on blood contacting biomaterials (Merrill, "Poly(ethylene oxide) and Blood Contact: A Chronicle of One
20 Laboratory," in POLY(ETHYLENE GLYCOL) CHEMISTRY: BIOTECHNICAL AND BIOMEDICAL APPLICATIONS, Harris, Ed., Plenum Press, New York, (1992), pp. 199-220).

[0164] Many routes are available for attaching a ligand or complex as disclosed herein onto a polymeric or oligomeric species. See, for example, Dunn, R.L., *et al.*, Eds. POLYMERIC DRUGS AND DRUG DELIVERY SYSTEMS, ACS Symposium Series Vol. 469, American Chemical Society,
25 Washington, D.C. 1991; Herren *et al.*, *J. Colloid and Interfacial Science* 115: 46-55 (1987); Nashabeh *et al.*, *J. Chromatography* 559: 367-383 (1991); Balachandar *et al.*, *Langmuir* 6: 1621-1627 (1990); and Burns *et al.*, *Biomaterials* 19: 423-440 (1998).

[0165] Many activated derivatives of PEG are available commercially and in the literature. It is well within the abilities of one of skill to choose, and synthesize if necessary, an appropriate
30 activated PEG derivative with which to prepare a substrate useful in the present subject matter. See, Abuchowski *et al. Cancer Biochem. Biophys.*, 7: 175-186 (1984); Abuchowski *et al.*, *J. Biol.*

Chem., 252: 3582-3586 (1977); Jackson *et al.*, *Anal. Biochem.*, 165: 114-127 (1987); Koide *et al.*, *Biochem Biophys. Res. Commun.*, 111: 659-667 (1983)), tresylate (Nilsson *et al.*, *Methods Enzymol.*, 104: 56-69 (1984); Delgado *et al.*, *Biotechnol. Appl. Biochem.*, 12: 119-128 (1990)); N-hydroxysuccinimide derived active esters (Buckmann *et al.*, *Makromol. Chem.*, 182: 1379-1384 (1981); Joppich *et al.*, *Makromol. Chem.*, 180: 1381-1384 (1979); Abuchowski *et al.*, *Cancer Biochem. Biophys.*, 7: 175-186 (1984); Katreet *al. Proc. Natl. Acad. Sci. U.S.A.*, 84: 1487-1491 (1987); Kitamura *et al.*, *Cancer Res.*, 51: 4310-4315 (1991); Boccu *et al.*, *Z. Naturforsch.*, 38C: 94-99 (1983), carbonates (Zalipsky *et al.*, POLY(ETHYLENE GLYCOL) CHEMISTRY: BIOTECHNICAL AND BIOMEDICAL APPLICATIONS, Harris, Ed., Plenum Press, New York, 1992, pp. 347-370; Zalipsky *et al.*, *Biotechnol. Appl. Biochem.*, 15: 100-114 (1992); Veronese *et al.*, *Appl. Biochem. Biotech.*, 11: 141-152 (1985)), imidazolyl formates (Beauchamp *et al.*, *Anal. Biochem.*, 131: 25-33 (1983); Berger *et al.*, *Blood*, 71: 1641-1647 (1988)), 4-dithiopyridines (Woghiren *et al.*, *Bioconjugate Chem.*, 4: 314-318 (1993)), isocyanates (Byun *et al.*, *ASAIO Journal*, M649-M-653 (1992)) and epoxides (U.S. Pat. No. 4,806,595, issued to Noishiki *et al.*, (1989). Other linking groups include the urethane linkage between amino groups and activated PEG. See, Veronese, *et al.*, *Appl. Biochem. Biotechnol.*, 11: 141-152 (1985).

[0166] In another aspect, the present disclosure provides a metal complex as set forth above, which is attached to a dendrimer via a reactive functional group. Similar to the linker group discussed above, the dendrimer will have at least two reactive functional groups. In one embodiment, one or more fully assembled ligand is attached to the dendrimer. Alternatively, the dendrimer is selected such that it serves as the linker and the chelate is formed directly on the dendrimer.

[0167] In one embodiment, complexes as disclosed herein non-covalently bind to macromolecules within a cell, tissue or body (Lauffer, R. B., *Magn. Reson. Med.* 1991, 22, 339). The binding causes an increased concentration and retention of the luminescent complex in the localized region of the biomolecule. The art is replete with examples of metal complexes designed to bind selected targets in vivo. For example, the complex MS-325 forms a noncovalent adduct with the blood protein human serum albumin (HSA) (Parmalee, D. J. W. et al., *Invest. Radiol.* 1997, 32, 741; Lauffer, R. B. P. et al., *Radiology* 1998, 207, 529). Lanthanide complexes have also been designed to target other macromolecules. For example, Gd-BOPTA was designed to target hepatocytes in order to facilitate hepatobiliary imaging (Cavanga, F. M. et al., *Invest. Radiol.* 1997, 32, 780).

Luminescence Modifying Groups (Donor and Acceptor Moieties)

[0168] Luminescent compounds of this disclosure can be used with a wide range of energy donor and acceptor molecules to construct luminescence energy transfer pairs, e.g., fluorescence energy transfer (FET) probes. Fluorophores useful in conjunction with complexes disclosed herein are
5 known to those of skill in the art. *See*, for example, Cardullo *et al.*, *Proc. Natl. Acad. Sci. USA* 85: 8790-8794 (1988); Dexter, D.L., *J. of Chemical Physics* 21: 836- 850 (1953); Hochstrasser *et al.*, *Biophysical Chemistry* 45: 133-141 (1992); Selvin, P., *Methods in Enzymology* 246: 300-334 (1995); Steinberg, I. *Ann. Rev. Biochem.*, 40: 83- 114 (1971); Stryer, L. *Ann. Rev. Biochem.*, 47: 819-846 (1978); Wang *et al.*, *Tetrahedron Letters* 31: 6493-6496 (1990); Wang *et al.*, *Anal. Chem.*
10 67: 1197-1203 (1995).

[0169] A non-limiting list of exemplary donor or acceptor moieties that can be used in conjunction with the luminescent complexes of this disclosure, is provided in Table 1.

TABLE 1

Suitable Moieties Useful as Donors or Acceptors in FET Pairs	
	4-acetamido-4'-isothiocyanatostilbene-2,2'-disulfonic acid
	acridine and derivatives:
	acridine
5	acridine isothiocyanate
	5-(2'-aminoethyl)aminonaphthalene-1-sulfonic acid (EDANS)
	4-amino-N-[3-vinylsulfonyl]phenyl]naphthalimide-3,5 disulfonate
	N-(4-anilino-1-naphthyl)maleimide
	anthranilamide
10	BODIPY
	Brilliant Yellow
	coumarin and derivatives:
	coumarin
	7-amino-4-methylcoumarin (AMC, Coumarin 120)
15	7-amino-4-trifluoromethylcoumarin (Coumarin 151)
	cyanine dyes
	cyanosine
	4',6-diaminidino-2-phenylindole (DAPI)
	5', 5''-dibromopyrogallol-sulfonaphthalein (Bromopyrogallol Red)
20	7-diethylamino-3-(4'-isothiocyanatophenyl)-4-methylcoumarin
	diethylenetriamine pentaacetate
	4,4'-diisothiocyanatodihydro-stilbene-2,2'-disulfonic acid
	4,4'-diisothiocyanatostilbene-2,2'-disulfonic acid
	5-[dimethylamino]naphthalene-1-sulfonyl chloride (DNS, dansylchloride)
25	4-(4'-dimethylaminophenylazo)benzoic acid (DABCYL)
	4-dimethylaminophenylazophenyl-4'-isothiocyanate (DABITC)
	eosin and derivatives:
	eosin
	eosin isothiocyanate
30	erythrosin and derivatives:
	erythrosin B
	erythrosin isothiocyanate
	ethidium
	fluorescein and derivatives:
35	5-carboxyfluorescein (FAM)
	5-(4,6-dichlorotriazin-2-yl)amino fluorescein (DTAF)
	2',7'-dimethoxy-4',5'-dichloro-6-carboxyfluorescein (JOE)
	fluorescein
	fluorescein isothiocyanate
40	QFITC (XRITC)
	fluorescamine
	IR144
	IR1446
	Malachite Green isothiocyanate
45	4-methylumbelliferone
	ortho cresolphthalein
	nitrotyrosine
	pararosaniline
	Phenol Red
50	B-phycoerythrin

TABLE 1, continued

Suitable Moieties Useful as Donors or Acceptors in FET Pairs	
	o-phthaldialdehyde
	pyrene and derivatives:
5	pyrene
	pyrene butyrate
	succinimidyl 1-pyrene butyrate
	quantum dots
	Reactive Red 4 (Cibacron™ Brilliant Red 3B-A)
	rhodamine and derivatives:
10	6-carboxy-X-rhodamine (ROX)
	6-carboxyrhodamine (R6G)
	lissamine rhodamine B sulfonyl chloride rhodamine (Rhod)
	rhodamine B
	rhodamine 123
15	rhodamine X isothiocyanate
	sulforhodamine B
	sulforhodamine 101
	sulfonyl chloride derivative of sulforhodamine 101 (Texas Red)
	N,N,N',N'-tetramethyl-6-carboxyrhodamine (TAMRA)
20	tetramethyl rhodamine
	tetramethyl rhodamine isothiocyanate (TRITC)
	riboflavin
	rosolic acid
25	lanthanide chelate derivatives

[0170] There is practical guidance available in the literature for selecting appropriate donor-acceptor pairs for particular probes, as exemplified by the following references: Pesce *et al.*, Eds., FLUORESCENCE SPECTROSCOPY (Marcel Dekker, New York, 1971); White *et al.*,
 30 FLUORESCENCE ANALYSIS: A PRACTICAL APPROACH (Marcel Dekker, New York, 1970). The literature also includes references providing exhaustive lists of fluorescent and chromogenic molecules and their relevant optical properties, for choosing reporter-quencher pairs (*see*, for example, Berlman, HANDBOOK OF FLUORESCENCE SPECTRA OF AROMATIC MOLECULES, 2nd Edition (Academic Press, New York, 1971); Griffiths, COLOUR AND CONSTITUTION OF
 35 ORGANIC MOLECULES (Academic Press, New York, 1976); Bishop, Ed., INDICATORS (Pergamon Press, Oxford, 1972); Haugland, HANDBOOK OF FLUORESCENT PROBES AND RESEARCH CHEMICALS (Molecular Probes, Eugene, 1992) Pringsheim, FLUORESCENCE AND PHOSPHORESCENCE (Interscience Publishers, New York, 1949); and the like. Further, there is extensive guidance in the literature for derivatizing reporter and quencher molecules for
 40 covalent attachment via readily available reactive groups that can be added to a molecule.

[0171] The diversity and utility of chemistries available for conjugating fluorophores to other molecules and surfaces is exemplified by the extensive body of literature on preparing

nucleic acids derivatized with fluorophores. *See*, for example, Haugland (*supra*); Ullman *et al.*, U.S. Pat. No. 3,996,345; Khanna *et al.*, U.S. Pat. No. 4,351,760. Thus, it is well within the abilities of those of skill in the art to choose an energy exchange pair for a particular application and to conjugate the members of this pair to a probe molecule, such as, for
5 example, a small molecular bioactive material, nucleic acid, peptide or other polymer.

[0172] In a FET pair, it is generally preferred that an absorbance band of the acceptor substantially overlap a fluorescence emission band of the donor. When the donor (fluorophore) is a component of a probe that utilizes fluorescence resonance energy transfer (FRET), the donor fluorescent moiety and the quencher (acceptor) of the invention are
10 preferably selected so that the donor and acceptor moieties exhibit fluorescence resonance energy transfer when the donor moiety is excited. One factor to be considered in choosing the fluorophore-quencher pair is the efficiency of fluorescence resonance energy transfer between them. Preferably, the efficiency of FRET between the donor and acceptor moieties is at least 10%, more preferably at least 50% and even more preferably at least 80%. The
15 efficiency of FRET can easily be empirically tested using the methods both described herein and known in the art.

[0173] The efficiency of FRET between the donor-acceptor pair can also be adjusted by changing ability of the donor and acceptor to dimerize or closely associate. If the donor and acceptor moieties are known or determined to closely associate, an increase or decrease in
20 association can be promoted by adjusting the length of a linker moiety, or of the probe itself, between the two fluorescent entities. The ability of donor-acceptor pair to associate can be increased or decreased by tuning the hydrophobic or ionic interactions, or the steric repulsions in the probe construct. Thus, intramolecular interactions responsible for the association of the donor-acceptor pair can be enhanced or attenuated. Thus, for example, the
25 association between the donor-acceptor pair can be increased by, for example, utilizing a donor bearing an overall negative charge and an acceptor with an overall positive charge.

[0174] In addition to fluorophores that are attached directly to a probe, the fluorophores can also be attached by indirect means. In this embodiment, a ligand molecule (*e.g.*, biotin) is preferably covalently bound to the probe species. The ligand then binds to another molecules
30 (*e.g.*, streptavidin) molecule, which is either inherently detectable or covalently bound to a signal system, such as a fluorescent compound of the invention, or an enzyme that produces a fluorescent compound by conversion of a non-fluorescent compound. Useful enzymes of

interest as labels include, for example, hydrolases, particularly phosphatases, esterases and glycosidases, or oxidotases, particularly peroxidases. Fluorescent compounds include fluorescein and its derivatives, rhodamine and its derivatives, dansyl, umbelliferone, *etc.*, as discussed above. For a review of various labeling or signal producing systems that can be used, *see*, U.S. Patent No. 4,391,904.

[0175] Means of detecting fluorescent labels are well known to those of skill in the art. Thus, for example, fluorescent labels can be detected by exciting the fluorophore with the appropriate wavelength of light and detecting the resulting fluorescence. The fluorescence can be detected visually, by means of photographic film, by the use of electronic detectors such as charge coupled devices (CCDs) or photomultipliers and the like. Similarly, enzymatic labels may be detected by providing the appropriate substrates for the enzyme and detecting the resulting reaction product.

IV. Methods

[0176] Complexes of this disclosure are useful as probes in a variety of biological assay systems and diagnostic applications. An overview of assay systems, such as competitive assay formats, immunological assays, microarrays, membrane binding assays and enzyme activity assays, is given e.g., in U.S. Patent No. 6,864,103 to Raymond et al.. It is within the ability of one of skill in the art to select and prepare a probe that includes a complex as disclosed herein, and which is suitable for a selected assay system. In an exemplary embodiment, the luminescent probe molecule is used to detect the presence or absence of an analyte in a sample.

[0177] Thus, in a second aspect, this disclosure provides mixtures that contain a luminescent complex and an analyte.

[0178] In a third aspect, this disclosure provides a method of detecting the presence or absence of an analyte in a sample. The method comprises (a) contacting the sample and a composition including a complex as disclosed herein; (b) exciting said complex; and (c) detecting luminescence from the complex.

[0179] In a fourth aspect, this disclosure provides a method of detecting the presence or absence of an analyte in a sample. The method comprises (a) contacting the sample and a composition including a complex as disclosed herein, and a luminescence modifying group, wherein energy can be transferred between the complex and the luminescence modifying group when the complex is excited, and wherein the complex and the luminescence modifying group can be part of the same

molecule or be part of different molecules; and (b) exciting said complex; and (c) determining the luminescent property of the sample, wherein the presence or absence of the analyte is indicated by the luminescent property of the sample. In one example, the presence or absence of the analyte results in a change of the luminescent property of the sample.

5 [0180] In an exemplary embodiment, the analyte is detected using a competition assay format. For example, the analyte, if present in the sample, displaces a targeting moiety of a complex as disclosed herein from a binding site located on a recognition molecule, by binding to the binding site.

10 [0181] Hence, in another aspect, this disclosure provides a kit including a recognition molecule and a complex as disclosed herein. Exemplary recognition molecules include biomolecules, such as whole cells, cell-membrane preparations, antibodies, antibody fragments, proteins (e.g., cell-surface receptors, such as G-protein coupled receptors), protein domains, peptides, nucleic acids and the like. Alternatively the kit may contain a lanthanide ion and an organic ligand, which form a luminescent complex when contacted with each other.

15 Analytes

[0182] Compounds, complexes and methods disclosed herein can be used to detect any analyte or class of analytes in any sample. A sample may contain e.g., a biological fluid or tissue. Other samples can e.g., include solutions of synthetic molecules or extracts from a plant or microorganism (e.g., for drug screening efforts). Exemplary analytes are pharmaceutical drugs,
20 drugs of abuse, synthetic small molecules, biological marker compounds, hormones, infectious agents, toxins, antibodies, proteins, lipids, organic and inorganic ions, carbohydrates and the like. (see e.g., U.S. Patent No.: 6,864,103 to Raymond *et al.* for additional examples of analytes).

Synthesis

[0183] The following section and the Examples appended hereto set forth exemplary synthetic
25 routes to compounds of this disclosure.

1-Hydroxy-2-pyridinone (1,2-HOPO) Complexes

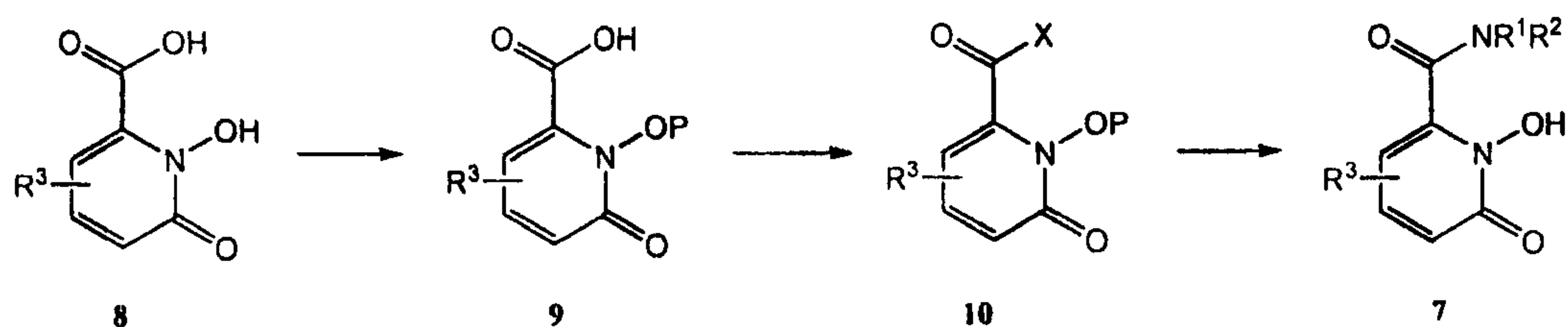
[0184] Useful 1,2-HOPO ligands and their metal chelates may be synthesized using art recognized methods. In one example, the ligands are synthesized

utilizing a reactive 1,2-HOPO intermediate prepared from the corresponding acid as described, e.g., in Appendix B.

[0185] Once the ligand is formed and purified, the metal complex is synthesized by any of a wide range of art-recognized methods, including, for example, by incubating a salt of the
5 ligand with a metal salt, such as a lanthanide salt (e.g., lanthanide trihalide, lanthanide triacetate). The reaction of the ligand with the metal ion is carried out either before or after coupling the ligand to a targeting moiety in order to generate a complex of the invention.

[0186] For example, 1,2-HOPO derivatives in which the carboxylic acid is activated as an acid halide and the N-hydroxyl group is protected can be used to prepare the organic ligands
10 that form the complexes of the invention.

[0187] An exemplary method of preparing a 1,2-HOPO chelator is outlined in Scheme 1:

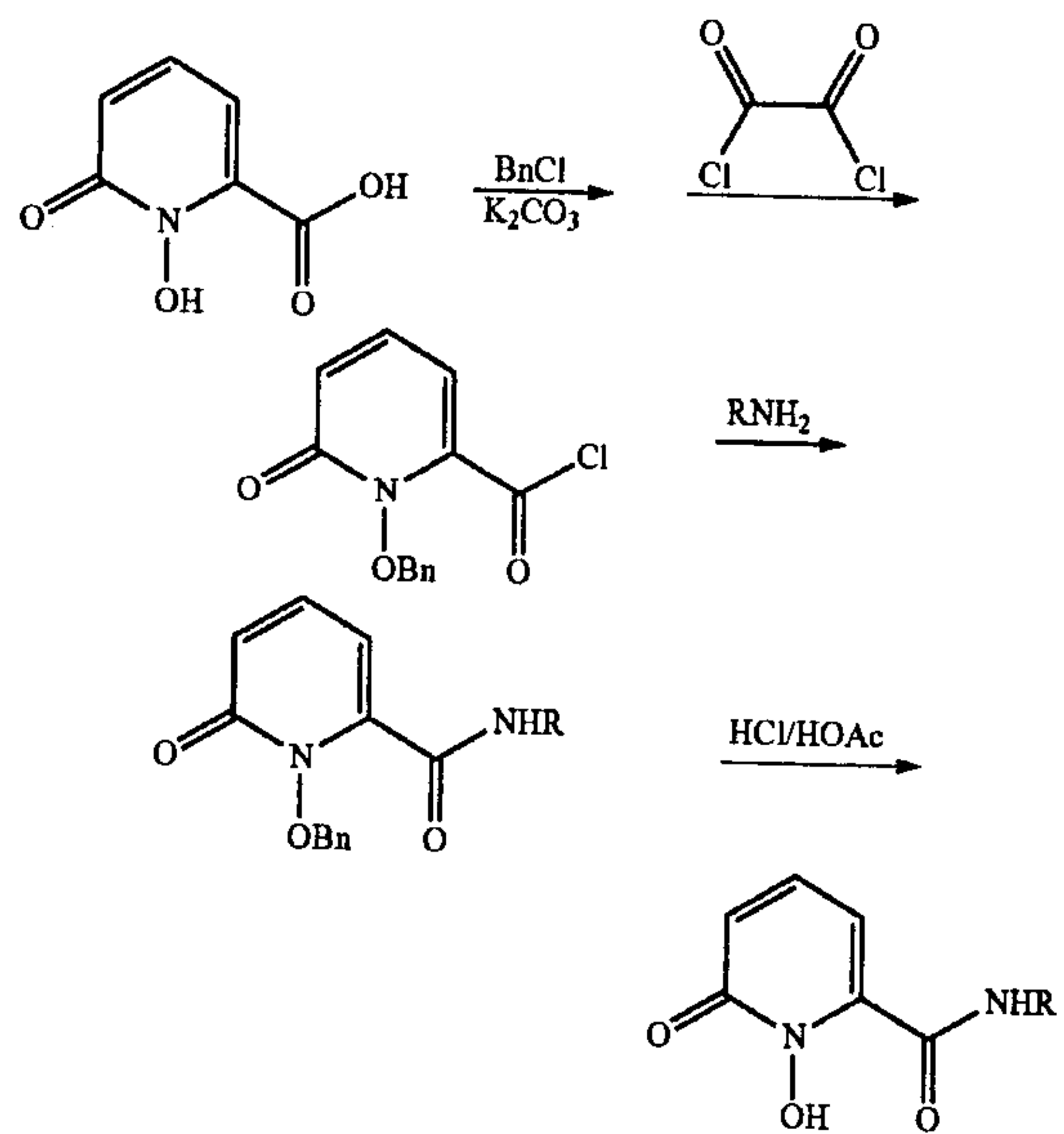


Scheme 1

R^1 and R^2 represent members independently selected from the group described herein as aryl
15 group substituents. The symbol R^3 represents a member selected from the group of H, C_1 - C_4 substituted or unsubstituted alkyl, and substituted or unsubstituted aryl.

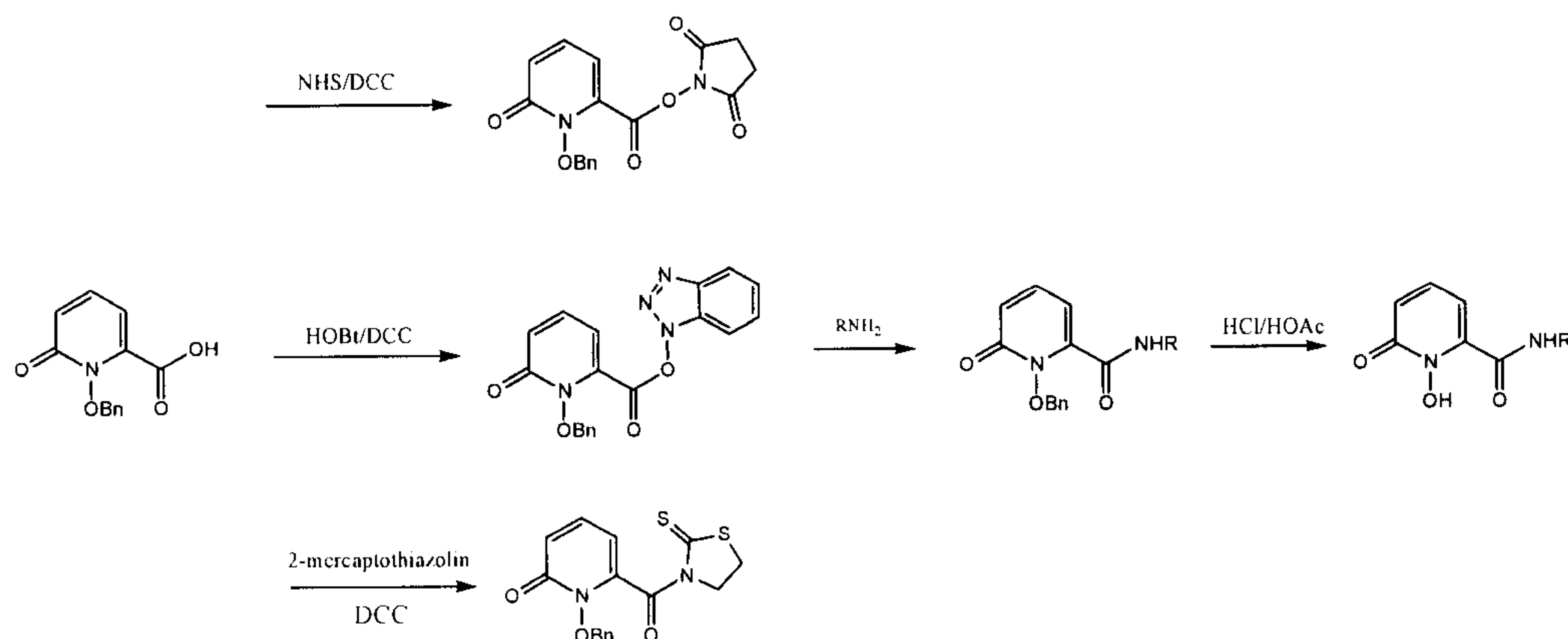
[0188] The method includes contacting compounds of structure 8 with a protecting agent, thereby forming the protected compounds of structure 9, in which P is a protecting group. Compounds according to structure 9 are then contacted with an agent that converts the
20 carboxylic acid to the corresponding acid halide, thereby forming compounds of structure 10, which are then contacted with HNR^1R^2 and subsequently deprotected thereby forming the chelators according to structure 7.

[0189] An example of this method according to Scheme 1 is:



O=C(O)c1ccc(=O)[nH]1 + c1ccn(c1)C(=O)n2ccnc2 >> [O=C(O)c1ccc(=O)[nH]1C(=O)n2ccnc2] >> O=C(NR)c1ccc(=O)[nH]1

[0193] The protected 1,2-HOPO acid **9** can also be activated by forming various activated esters or amides. An exemplary reaction sequence is shown below in Scheme 2:

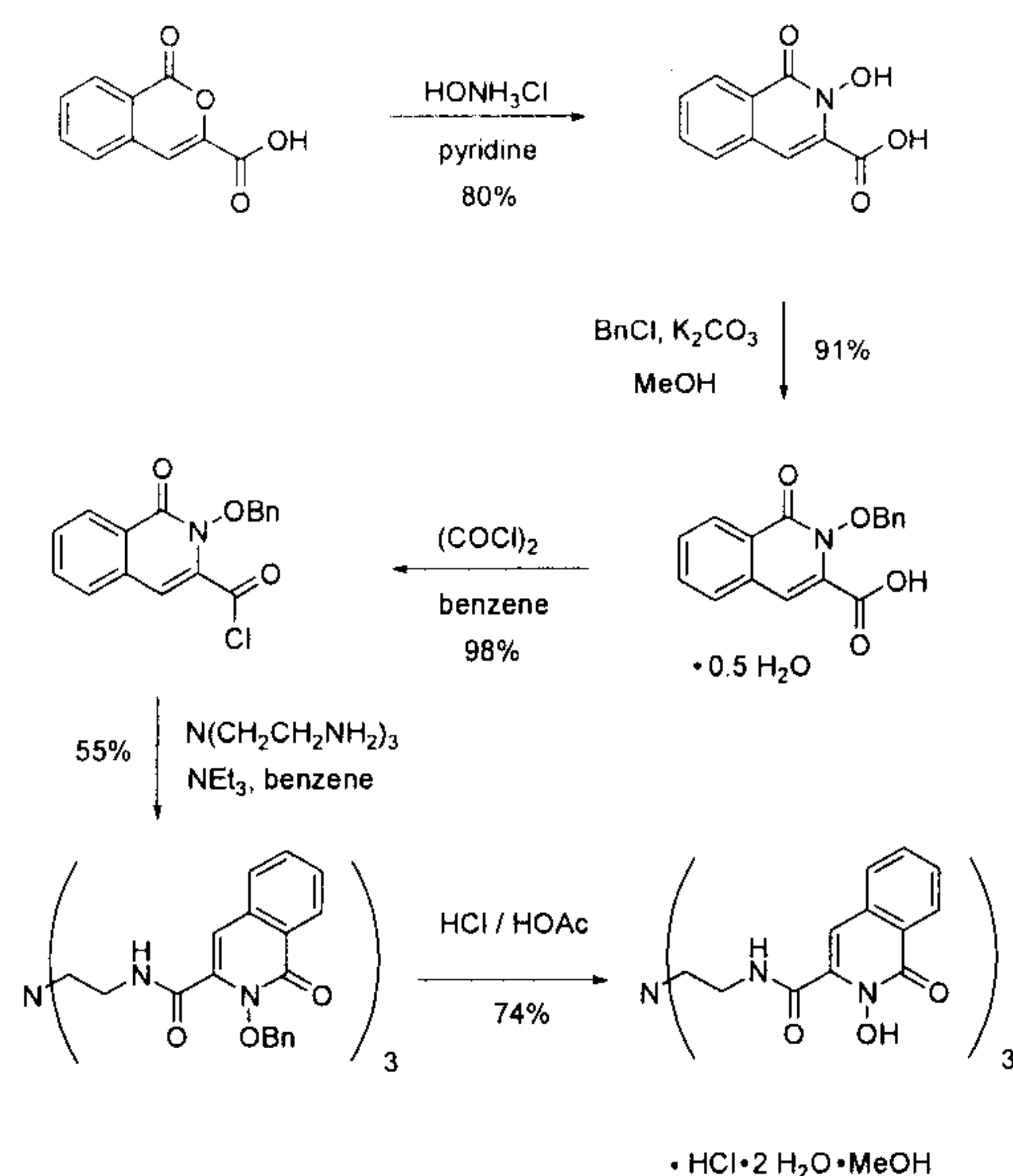


[0194] Benzyl protected 1,2-HOPO-6-carboxylic acid (1,2-HOPOBn acid) is a versatile compound for synthesizing 1,2-HOPO ligands. It can be converted to various activated

intermediates and then coupled to a variety of amines, sulfhydryls, alcohols and other nucleophilic groups. For example, 1,2-HOPO-6-carboxylic acid reacts with 2-mercaptothiazoline in the presence of DCC (dicyclohexyl carbodiimide) and DMAP (1,4-Dimethylaminopyridine) to give 1,2-HOPO thiazolide, which selectively reacts with aliphatic primary amines, like its 3,2-HOPO analogue, 3,2-HOPO-thiazolide. The protected HOPO-acid can also be converted to the corresponding N-hydroxysuccinimide or other activated esters and coupled to various backbones that include nucleophilic moieties. In most cases, the active esters are not isolated, but are coupled with amines or other nucleophilic moieties *in situ*.

[0195] Protecting agents and protecting groups useful in practicing the present invention are generally those known in the art to be of use in protecting hydroxyl moieties (*see*, for example, Greene, PROTECTIVE GROUPS IN ORGANIC SYNTHESIS, 2nd Edition, Wiley-Interscience, 1991). A presently preferred protecting group is the benzyl group. Preferred protecting agents include, but are not limited to, benzyl halides, benzyl sulfonates, and benzyl triflates.

[0196] The chelating agent 1,2HOIQO is prepared and attached to an exemplary scaffold by the scheme set forth below:

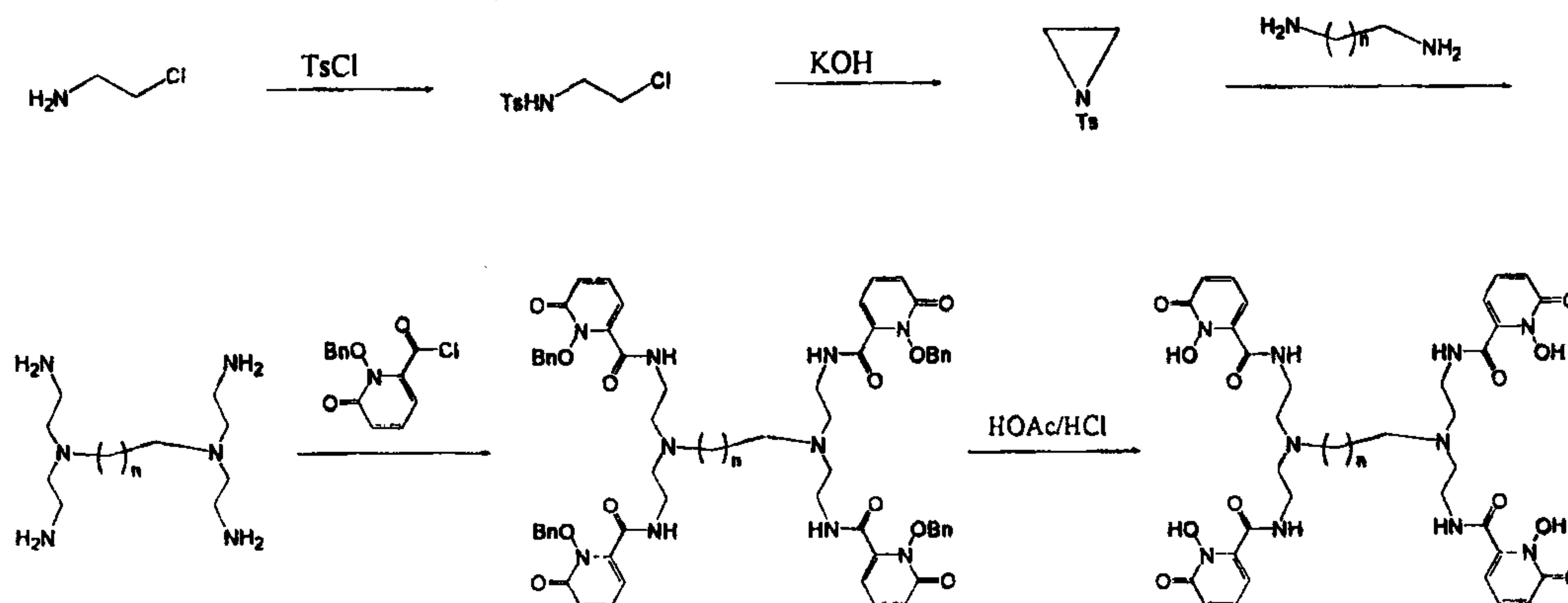


[0197] As will be apparent to those of skill in the art, if the synthesis is initiated with a starting material functionalized on the phenyl ring or the heterocycle, a similarly functionalized chelating moiety will result. The scaffold set forth above is purely exemplary

and it is understood that any of the scaffolds set forth herein, or art recognized scaffolds are equally applicable.

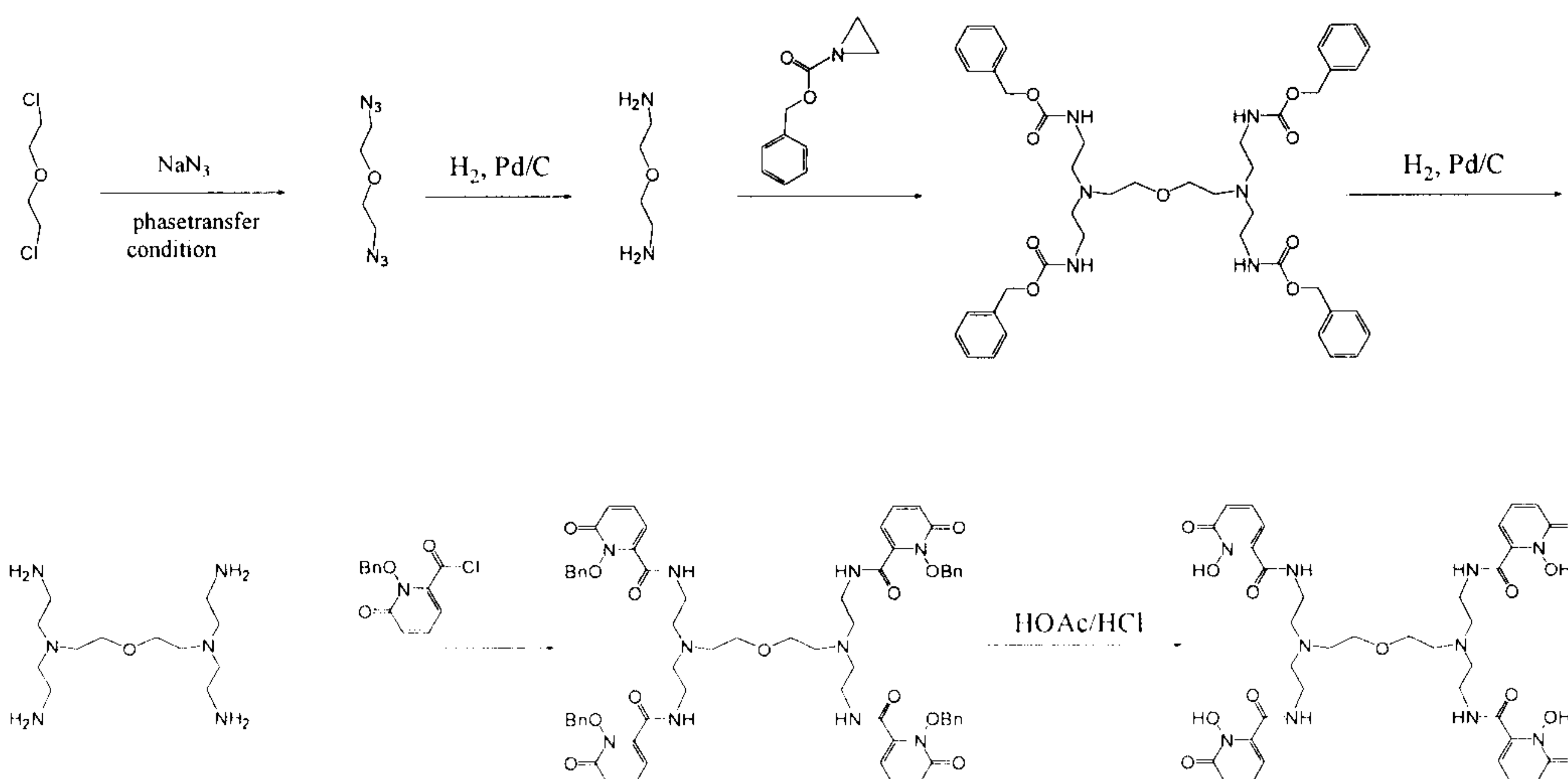
[0198] Any nucleophilic species that reacts with the material according to structure **10** is useful in practicing the present invention. In a preferred embodiment, the nucleophilic species is an amine, $\text{NR}^{17}\text{R}^{18}$. In a further preferred embodiment, $\text{NR}^{17}\text{R}^{18}$ is a polyamine. Preferred polyamines include 1,3-diaminopropane, spermidine, and spermine. Representative amine species to which compound **10** can be conjugated include, but are not limited to, those set forth in U.S. Patent No. 4,698,431, U.S. Patent No. 5,624,901 and U.S. Patent No. 5,892,029.

[0199] An exemplary synthetic route for the synthesis of octadentate, tetrapodal 1,2-HOPO ligands is outlined in Schemes 3 to 5:



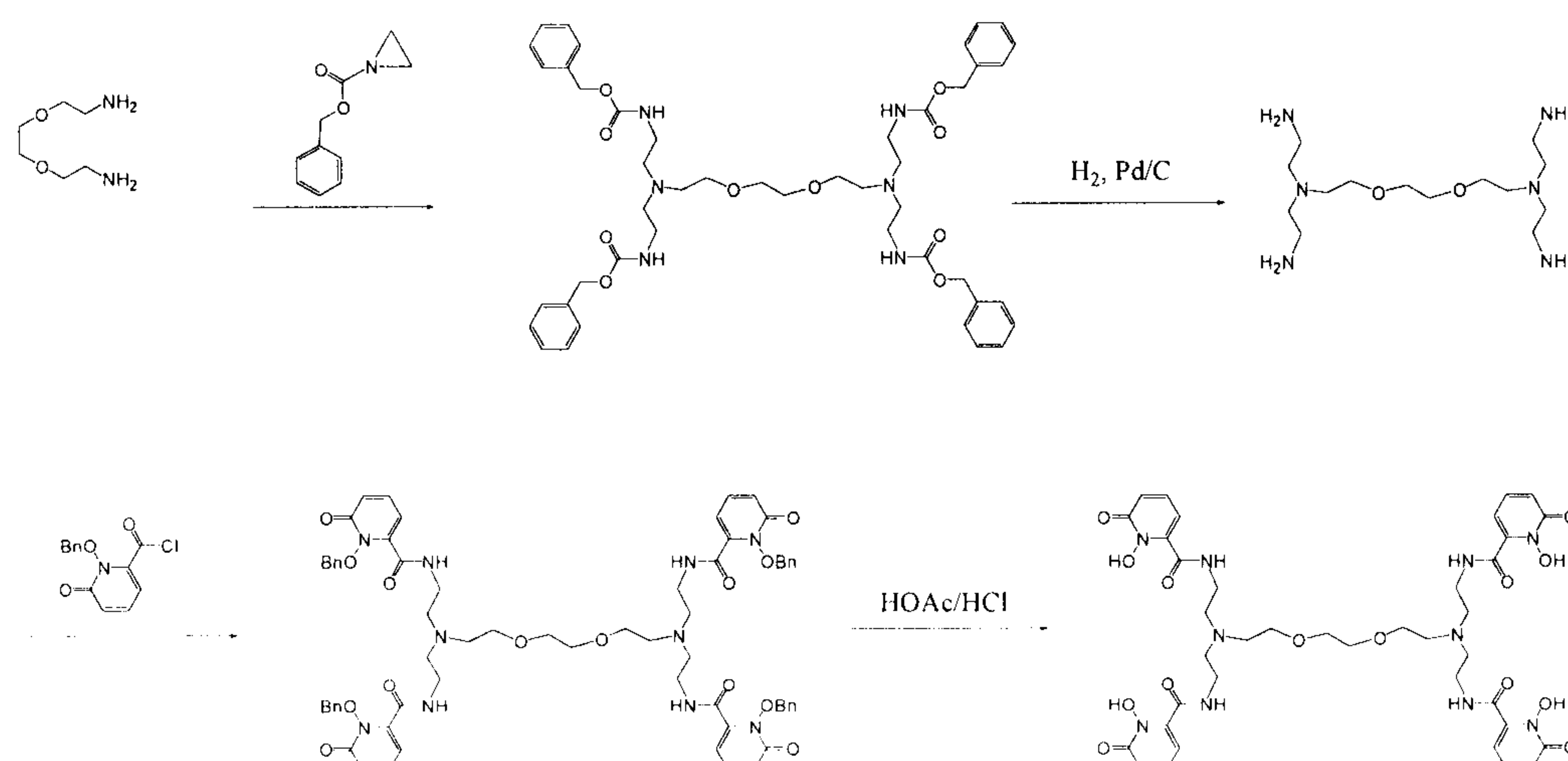
Scheme 3

[0200] In Scheme 3, H(2,2)-, H(3,2)- and H(4,2)-1,2-HOPO ligands are synthesized via an aziridine intermediate, which is opened using the appropriate diamine, wherein the integer n is selected from 1 to 10, preferably 1 to 7.



Scheme 4

[0201] Scheme 4 outlines the synthesis of H(5O,2)-1,2-HOPO.

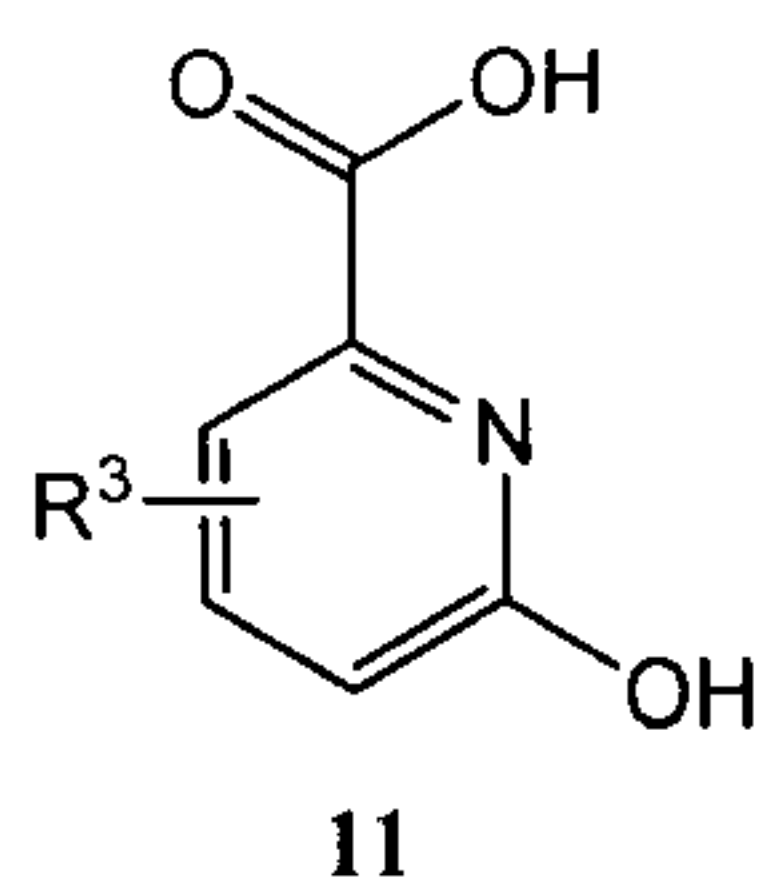


5 Scheme 5

[0202] Scheme 5 outlines the synthesis of H(8O2,2)-1,2-HOPO.

[0203] The carboxylic acid starting material according to structure 8 may be prepared by any method known in the art. In a preferred embodiment, the carboxylic acid is prepared by a method that includes contacting a trifluoroacetic acid solution of a hydroxyl-containing compound having a structure according to structure 11:

10



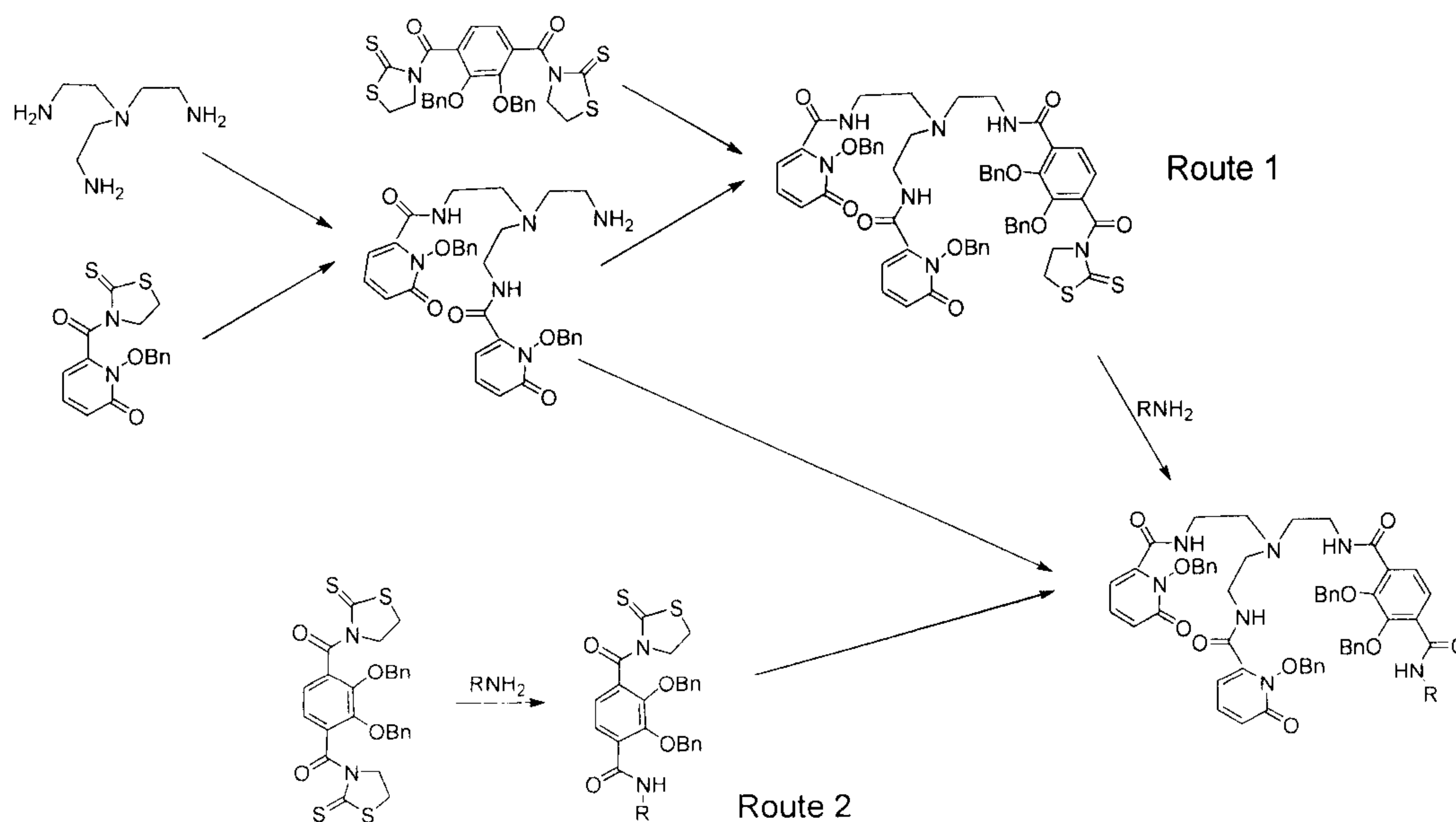
with a mixture comprising acetic anhydride and hydrogen peroxide, thereby forming a precipitate of an N-hydroxyamide compound having a structure according to structure **9**.

Other starting materials for the preparation of **8** include 6-chloro-picolinic acid and 6-bromo-picolinic acid.

[0204] Mixed ligands that include at least one 1,2-HOPO subunit in combination with another complexing moiety can also be prepared using art recognized methods.

Functionalization of 1-Hydroxy-2-Pyridinonate Chelating Agents

[0205] TAM moieties conveniently contain a second amide group, which can be functionalized either prior to or following connection with the scaffold moiety (e.g., TREN in Scheme 6 or the octadentate scaffold H(2,2)).



Scheme 6

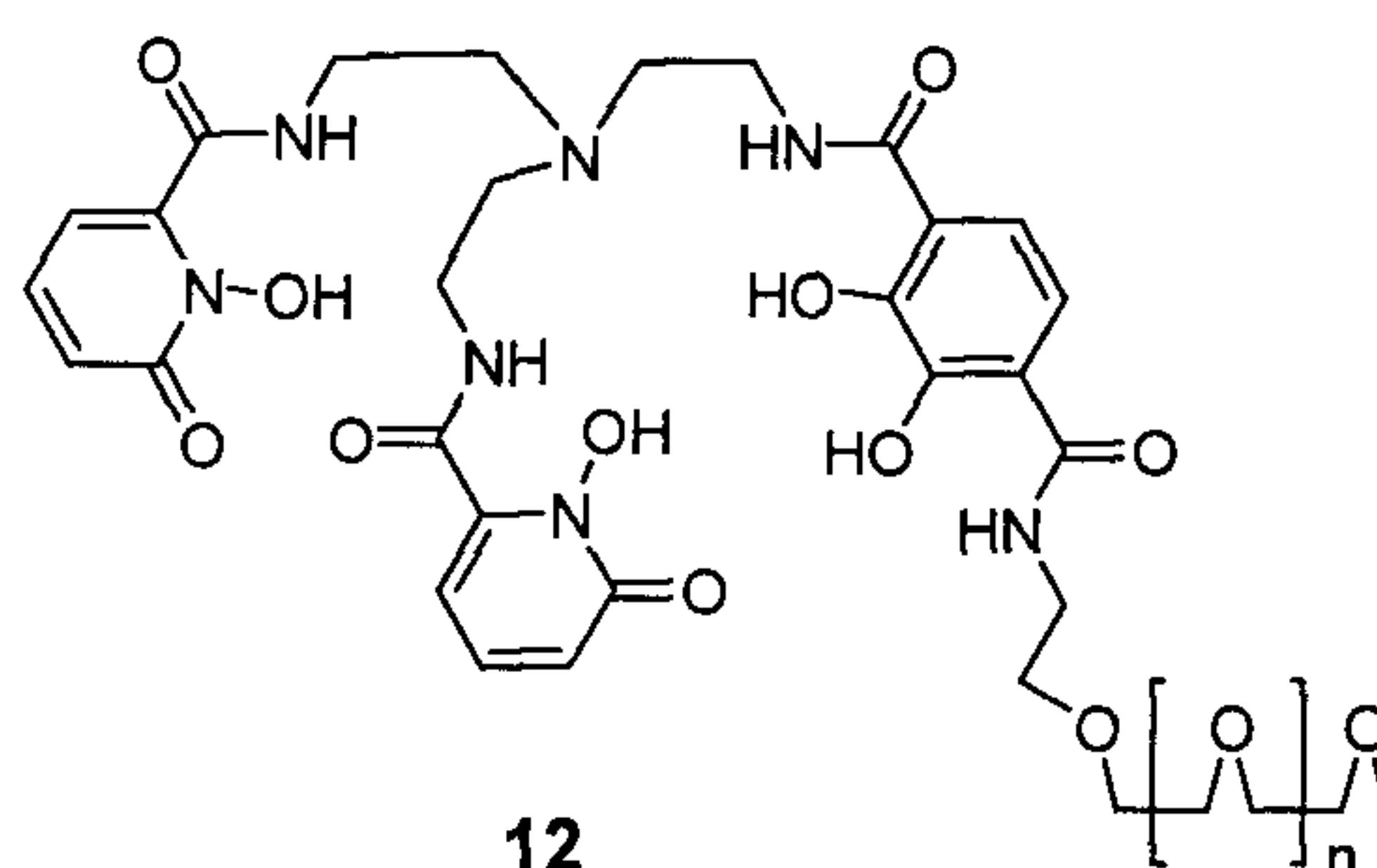
[0206] A series of TREN-HOPO-TAM derivatives are synthesized using either route. The choice of route may depend on the choice of amine RNH_2 .

[0207] The use of benzyl (Bn) protecting groups on TAM is generally preferable to the methyl groups previously reported (Cohen, S. M. et al., *Inorg. Chem.* 2000, 39, 4339), since

the deprotection conditions are less severe, making the method amenable to a greater range of primary amines (RNH_2).

Synthesis of Chelating Agents Containing PEG Functionalization

[0208] In another embodiment, this disclosure provides poly(ethylene glycol) (PEG) functionalized chelates. In an exemplary embodiment, this disclosure provides derivatives of TREN-1,2-HOPO-TAM
 5 12. The PEG group increases the rather low solubility of the parent complexes.



[0209] Also included in the present disclosure is a method of preparing a chelating agent having a polymeric backbone and at least one functionality to which a chelating ligand of the invention is
 10 bonded. Examples of suitable polymers include, but are not limited to, poly(styrene-divinylbenzene), agarose (manufactured by Bio-Rad Corp., Richmond, CA, under the name "Affi-Gel"), and polyacrylamide. Those of skill in the art will appreciate that the method is not limited by the identity of the backbone species, and that numerous amine-, hydroxyl- and sulfhydryl-containing compounds are useful as backbones in practicing the method.

Evaluation of Ligands and Complexes

[0210] The present disclosure generally utilizes art recognized methods to characterize the new ligands and their metal complexes. For example, the basicity of the ligands can be assessed by determining the protonation constants ($\text{p}K_a$'s) by potentiometric titrations.

[0211] Methods of determining stability constant measurements include, but are not limited to those set
 20 forth in, Johnson, A. R. et al., *Inorg. Chem.* 2000, 39: 2652-2660; and Cohen, S. M. et al., *Inorg. Chem.* 2000, 39: 5747.

[0212] The Bjerrum method can be used for metal complex stability measurements (pH titrations of ligand and metal + ligand). Competition titrations with DTPA can be performed to determine the stability of very stable complexes where direct pH titration methods are inappropriate.

25 Spectrophotometric techniques can be used to monitor metal-ligand complexation reactions which give rise to changes in the Vis/UV spectra relative to the parent metal and ligand species. With digitally-

recording automated spectrophotometric titrators, factor analysis of the Vis/UV spectra readily determined the species in solution, their individual spectra and the equilibrium constants, which interrelate them.

[0213] The emissive properties of Eu(III) and/or Tb(III), are used to reflect the rates of emissive decay in distinct sites that the metal ion occupies. Hence, luminescence titration of the Eu(III) and Tb(III) complexes of the ligands with HSA is a good method for determining biomolecule affinity (Feig, A. L. P. et al., *Chem. & Biol.* 1999, 6, 801; Chaudhuri, D. H. et al., *Biochem.* 1997, 36, 9674; Cronce, D. T. H. et al., *Biochem.* 1992, 31, 7963.

[0214] The following examples are provided to illustrate selected embodiments of this disclosure and are not to be construed as limiting the scope of the claimed invention.

EXAMPLES

2-Bromopyridine-6-carboxylic Acid

[0215] A 9.7-g (0.048-mol) portion of 6-bromopyridine-2-carboxylic acid was added to a solution of 125 mL of $\text{CF}_3\text{CO}_2\text{H}$ and 18 mL of 30% H_2O_2 and heated to 80 °C for 6.5 h. The reaction mixture was concentrated to ca. 25 mL by rotary evaporation and then added to 1 L of water. The product immediately precipitated as a finely divided, white crystalline solid. It was isolated by filtration, washed with water, and dried in vacuum. This yielded 10.2 g (97%) of product, mp 180 °C dec. ^1H NMR(300MHz, $\text{DMSO}-d_6$): δ 7.70(t, 1H), 8.24(dd, 1H), 8.29(dd, 1H). Anal. Calcd for $\text{C}_6\text{H}_4\text{BrNO}_3$: C, 33.05; H, 1.85; Br, 36.65; N, 6.43. Found: C, 33.30; H, 1.88; Br, 36.37; N, 6.52.

1-Hydroxy-6-carboxy-2(1H)pyridinone

[0216] A 10.1-g (0.046 mol) portion of 2-bromopyridine-6-carboxylic acid was dissolved in 175 mL of a 10% aqueous KOH solution, and the resulting solution was maintained at 80 °C overnight and then cooled in an ice bath and treated with 85 mL of concentrated HCl. The white suspended solid was isolated by filtration, washed with dilute HCl followed by three 15 mL portions of water, and then dried in vacuo yielding 6.21 g (86.4%), mp 216 °C dec.

[0217] An alternative route is described below: Acetic anhydride (100 ml) was mixed with 30% hydrogen peroxide solution (25 ml) with cooling; the mixture was stirred for 3 hr until a homogenous peracetic acid solution formed. To a solution of 6-hydroxy-picolinic acid

(Fluka, 25 g, 0.18 mol) in a mixture of trifluoroacetic acid (150 mL) and glacial acetic acid (100 mL), the above peracetic acid solution was added slowly with stirring. (CAUTION! any solid particle in the mixture will caused vigorous oxygen release and lead to out of control of the reaction). The mixture stirred at room temperature for one 1 hr, and heated slowly to 75 °C and kept at 80 °C (oil bath temperature) for 10 hr. White precipitate formed during this period, it was collected by filtration, washed with cold methanol, and dried in a vacuum oven, yield 20.5 g (0.132 mol, 73%). mp 176-177 °C.

[0218] ¹H NMR(300MHz, DMSO-*d*₆): δ 6.634(dd, J_{ortho} = 7 Hz, J_{meta} = 1.5 Hz, 1H), 6.710(dd, J_{ortho}=9.2 Hz, J_{meta}= 1.5 Hz, 1H), 7.437(dd, J_{ortho}=9, J_{meta}= 7 Hz, 1H). ¹³C NMR(75 MHz, DMSO-*d*₆): δ 106.9, 120.6, 135.0, 137.3, 157.4, 163.3. IR (KBr pellet) ν 1734 (br, C=O), 1616(m, C=O) cm⁻¹. Anal. Calcd (Found) for C₆H₅NO₄ (F.W. 155.15): C, 46.46 (46.31); H, 3.25 (3.45), N, 9.03 (9.12).

1-Benzyloxy-6-carboxy-2(1H)-pyridinone (1,2-HOPOBn acid)

[0219] 1-Hydroxy-6-carboxy-2(1H)-pyridinone (15.5 g, 0.1 mol) and anhydrous potassium carbonate (27.6 g, 0.2 mol) were mixed with benzyl chloride (15.2 g, 0.12 mol) in methanol (250 mL). The mixture was refluxed for 16 h, filtered, and the filtrate evaporated to dryness. The residue was dissolved in water (50 mL) and acidified with 6 N HCl to pH 2. The white precipitate was isolated by filtration, washed with cold water, and dried in vacuum, to yield 22.3 g (91 %) of 1-Benzyloxy-6-carboxy-2(1H)-pyridinone, mp 176-177 °C.

[0220] ¹H NMR(300MHz, CDCl₃): δ 5.269(s, 2H), 6.546(dd, J=1.6 Hz, J= 6.7 Hz, 1H), 6.726(dd, J=1.6Hz, J=9.2 Hz, 1H), 7.39-7.51(m, 6H). ¹³C NMR(75 MHz, DMSO-*d*₆): δ 77.9, 106.0, 124.1, 128.5, 129.1, 129.6, 133.8, 138.7, 140.5, 157.7, 161.7. Anal. Calcd (Found) for C₁₃H₁₁NO₄: C, 63.66 (63.75); H, 4.53 (4.55), N, 5.71 (5.52).

1,2-HOPOBn acid chloride

[0221] To a suspension of 1,2-HOPOBn acid (5.0 g, 20 mmol) in toluene or benzene (50-70 mL), excess of oxalyl chloride (2.0 g) was added with stirring. A lot of gas bubbles evolved and the suspension turned to be clear upon the addition of a drop of DMF as catalyst. The mixture was then warmed to 40° C (oil bath temperature) for 4-6 hr, and the solvent was moved on a rotovap to leave pale yellow oil. The residual solvent and oxalyl chloride were removed in a vacuum line (0.1 mm Hg) when the oil solidified as pale yellow crystalline

solid, raw yield 5.0 g (95%). It is generally used directly for next step reaction without further purification.

[0222] ^1H NMR(300MHz, CDCl_3): δ 5.32(s, 2H), 6.88(d, 1H), 6.94(d, 1H), 7.3-7.4(m, 4H), 7.49(m, 2H). ^{13}C NMR(75 MHz, CDCl_3): δ 78.5, 112.3, 128.4, 128.6, 129.4, 130.3,
5 132.7, 136.4, 140.2, 158.1, 158.8.

1-Benzoyloxy-6-(2-thioxothiazolidin-1-yl)-carbonyl-2(1H)-pyridinone (1,2-HOPOBn-thiazolide)

[0223] To a solution of 1-benzyloxy-6-carboxy-2(1H)-pyridinone (4.90 g, 20 mmol), 2-mercaptothiazoline (2.62 g, 22 mmol), and a catalytic amount of 4-dimethyl-aminopyridine (DMAP) in dry THF (50 mL), was added N,N'-dicyclohexylcarbodiimide (DCC) (4.6 g, 22 mmol). After stirring overnight, the dicyclohexylurea (DCU) solids are removed by filtration the yellow filtrate is removed by rotary evaporation to give a yellow solid. Crystallization from isopropanol-methylene chloride gives the title compound (5.80 g,
15 83.7%) as a pale yellow powder, m.p.: 135-7 °C.

[0224] ^1H NMR (300 MHz, CDCl_3): δ 3.156(t, J=7.4 Hz, 2H), 4.450(t, J=7.4 Hz, 2H), 5.321(s, 2H), 6.176(dd, J=1.6 Hz, J=6.8 Hz, 1H), 6.776(dd, J=1.6 Hz, J=9.2 Hz, 1H), 7.27-7.47(m, 6H). ^{13}C NMR(75 MHz, CDCl_3): δ 28.9, 54.4, 78.9, 124.2, 128.6, 129.3, 129.8, 133.6, 137.8, 141.5, 158.1, 159.6. Anal for $\text{C}_{17}\text{H}_{16}\text{N}_2\text{O}_3\text{S}_2$ Calcd. (Found): C, 55.47(55.36); H, 4.07(4.17); N, 8.08(7.83); S, 18.51(18.41).
20

1-Hydroxy-6-N-octylcarboxamide-2(1H)-pyridinone (Octyl-1,2-HOPO)

[0225] Lipophilic bidentate 1,2-HOPO ligand with long aliphatic chains were synthesized as raw models of lanthanide and actinide extractants. The general procedure for synthesizing such extractants is given below.

[0226] 1,2-HOPO acid (1.00g, 6.45 mmol) and 1,1'-carbonyldiimidazole (CDI) (1.05 g, 6.47 mmol) were stirred in dry DMF (40 mL) under N_2 for 2 hr. Octylamine (0.84 g, 6.46 mmol) was added to the above solution, and the mixture stirred overnight. DMF was then removed by rotary evaporation, the residue taken up in dichloromethane (50 mL). It was extracted three times with 0.1 NaOH (3 x 25 mL) and the combined aqueous phase reduced
30 in volume to 20 mL by rotary evaporation. The concentrated solution was acidified with 1 M HCl to pH 2, upon which a white precipitated immediately. It was collected by filtration, washed with cold water and dried in vacuo to give a beige solid (1.10 g, 63.1%).

[0227] ^1H NMR(300MHz, CDCl_3): δ 0.878(t, 3H, CH_3), 1.27-1.39(m, 10H, CH_2 , 1.653(qint, 2H, CH_2), 3.49(qint, 2H, CH_2), 7.06(d, 1H, arom H), 7.45(d, 1H, arom H), 9.65(s, 1H, NH). ^{13}C NMR(300MHz, CDCl_3): δ 14.1, 22.6, 27.1, 29.2, 31.8, 113.9, 115.0, 133.0, 137.0, 156.4, 158.7. MS(FAB+): 266(MH^+). Anal. Calcd (Found) for $\text{C}_{14}\text{H}_{22}\text{N}_2\text{O}_3$: C, 63.13 (62.71); H, 8.32 (8.47), N, 10.52 (10.63).

[0228] Preliminary extraction study indicated octyl-1,2-HOPO exhibits high specificity extractant for Pu(IV) over a wide range of acidity and ionic strength.

Carbostyryl-124-1,2-HOPOBn (CS124-1,2-HOPOBn)

[0229] To a solution of carbostyryl (0.174 g, 1 mmol) and dry triethylamine (0.4 ml, 4 mmol) in DMAA (20 mL) cooling with an ice bath, a solution of raw 1,2-HOPOBn acid chloride (0.58 g, 2.2 mmol) in dry CH_2Cl_2 (35 mL) was added dropwisely with stirring. The mixture was heated at room temperature overnight, until TLC indicated the reaction was complete. The volatiles were removed under vacuo, and the residue was loaded on a flash silica column. Elution with 2-6% methanol in methylene chloride allows the separation of the benzyl-protected precursor CS124-1,2-HOPOBn) (0.27g, 67% based on CS-124) as a thick pale yellow oil.

[0230] ^1H NMR (300MHz, CDCl_3): δ 2.39(s, 3H), 5.29(s, 4H), 6.31(s, 1H), 6.55(dd, 1H), 6.73(dd, 1H), 7.25-7.45(m, 5H), 7.55(d, 1H), 7.69(d, 1H), 7.89(d, 1H), 11.16(s, 1H), 11.66(s, 1H). ^{13}C NMR (300MHz, CDCl_3): δ 18.1, 79.2, 105.1, 106.1, 114.6, 117.2, 120.4, 123.8, 126.3, 129.2, 129.8, 130.3, 134.4, 139.8, 140.2, 144.1, 148.4, 158.1, 159.6, 162.7.

Carbostyryl-124-1,2-HOPO (CS124-1,2-HOPO)

[0231] Since the 1,2-HOPO moiety is reductively sensitive to hydrogenation, most benzyl protected 1,2-HOPO ligands were deprotected under strong acidic conditions. CS124-1,2-HOPOBn (0.4 g, 1 mmol) was dissolved in concentrated HCl (12 M)/glacial acetic acid (1:1, 20 mL), and stirred at room temperature for 2 days. Removal of the solvent gives a beige residue, which was stirred with methanol to form a white slurry which was filtered to give CS124-1,2-HOPO (0.37 g, 93%) as a white powder.

[0232] ^1H NMR (300 MHz, CDCl_3): δ 2.38(s, 3H), 6.30(s, 1H), 6.46(dd, 1H), 6.63(dd, 1H), 7.36(dd, 1H), 7.45(dd, 1H), 7.68(d, 1H), 7.88(d, 1H), 11.09(s, 1H), 11.64(s, 1H).

^{13}C NMR (75 MHz, CDCl_3): δ 18.6, 104.0, 105.5, 114.5, 116.7, 118.8, 120.2, 125.7, 137.7, 139.3, 140.2, 142.1, 148.7, 157.6, 159.1, 162.1. MS(ES^-): 310.1(M^-).

2,2-Dimethyl-3LI-1,2-HOPOBn

[0233] To a solution of 1,2-HOPOBn-thiazolide (1.22 g, 4 mmol) in dry methylene chloride (30 mL), was added neat 2,2-dimethyl-1,3-propanediamine (184 mg, 1.8 mmol). The mixture was stirred overnight, solvent removed and loaded onto a flash silica column. Elution with 2-6% methanol in methylene chloride allows the separation of the benzyl-protected precursor: 2,2-Dimethyl-3LI-1,2-HOPO-Bn (940 mg, 84.6%) as thick pale yellow oil.

[0234] ^1H NMR(300MHz, CDCl_3): δ 0.844(s, 6H), 3.027(d, br, 4H), 5.301(s, 4H), 6.307(dd, 2H), 6.635(dd, 2H), 7.246(dd, 2H), 7.21-7.37(m, 6H), 7.43-7.46(m, 4H), 7.650(t, 2H, $J=6.6$ Hz). ^{13}C NMR(75 MHz, CDCl_3): δ 23.2, 36.5, 45.9, 53.2, 81.5, 104.7, 122.7, 128.0, 128.7, 129.3, 133.0, 137.9, 143.1, 158.1, 160.9.

2,2-Dimethyl-3LI-1,2-HOPO

[0235] 2,2-Dimethyl-3LI-1,2-HOPO-Bn (557 mg, 1 mmol) was dissolved in concentrated HCl (12 M)/glacial acetic acid (1:1, 20 mL), and was stirred at room temperature for 2 days. Filtration followed by removal of the solvent gives a beige residue, which was washed with ether to give 2,2-Dimethyl-3LI-1,2-HOPO (412 mg, 92.1%) as a beige powder, m.p. 115-117 °C.

[0236] ^1H NMR(300MHz, $\text{DMSO}-d_6$): δ 0.892(s, 6H), 3.114(d, 4H), 6.314(dd, 2H), 6.573(dd, 2H), 7.394(dd, 2H), 8.730(t, 2H, $J=6.6$ Hz). Anal for $\text{C}_{17}\text{H}_{18}\text{N}_4\text{O}_6 \cdot 3\text{HCl} \cdot \text{H}_2\text{O}$ (485.34) Calcd. (Found): C, 42.07(41.95); H, 5.40(5.67); N, 11.54(11.29).

4LI-1,2-HOPOBn

[0237] The benzyl protected 4LI-1,2-HOPOBn was prepared following the procedure for 2,2-dimethyl-3LI-1,2-HOPO-Bn, except 1,4-butanediamine (160 mg, 1.8 mmol) was used instead of 2,2-dimethyl-1,3-propanediamine. Separation and purification of the benzyl-protected precursor was performed as described above to give the desired product as pale yellow oil (77% based on amine).

[0238] ^1H NMR (300MHz, CDCl_3): δ 1.42(s,br,4H), 3.16(d, br, 4H), 5.27 (s, 4H), 6.35(dd, 2H), 6.63(dd, 2H), 6.86(t,br, 2H), 7.24-7.46(m, 12H).

4LI-1,2-HOPO

[0239] 4LI-1,2-HOPOBn was deprotected following the procedure of 2,2-dimethyl-3LI-1,2-HOPO, except 4LI-1,2-HOPOBn (543 mg, 1 mmol) was used instead of 2,2-dimethyl-3LI-1,2-HOPOBn. Separation and purification of the deprotected product are performed as
5 described above to afford a beige solid (452 mg, 92.2%).

[0240] ^1H NMR (300MHz, DMSO-*d*₆): δ 1.52(s, br, 4H), 3.21(d, br, 4H), 6.26(dd, 2H), 6.55(dd, 2H), 7.38(dd, 2H), 8.74(t, 2H, $J=5.6$ Hz). Anal for $\text{C}_{16}\text{H}_{18}\text{N}_4\text{O}_6 \cdot 3\text{HCl} \cdot \text{H}_2\text{O}$, Calcd. (Found): C, 39.23(39.52); H, 3.73(3.69); N, 11.43(11.27).

5LI-1,2-HOPOBn

10 [0241] The benzyl protected 5LI-1,2-HOPOBn was prepared following the procedure for 2,2-dimethyl-3LI-1,2-HOPO-Bn, except 1,5-pentanediamine (184 mg, 1.8 mmol) was used instead of 2,2-dimethyl-1,3-propanediamine. Separation and purification of the protected precursor was performed as described above to give a pale yellow oil (0.9 g, 90% based on amine).

15 [0242] ^1H NMR (300MHz, CDCl_3): δ 1.18(qin, 2H), 1.39(qin, 4H), 3.17(q, 4H), 5.26(s, 4H), 6.32(dd, 2H), 6.62(dd, 2H), 6.78(t, 2H), 7.26-7.45(m, 12H). ^{13}C NMR (75 MHz, CDCl_3): δ 23.4, 27.9, 39.3, 79.1, 105.9, 123.2, 128.4, 129.2, 129.9, 133.2, 138.5, 142.9, 158.5, 160.3.

5LI-1,2-HOPO

20 [0243] 5LI-1,2-HOPO was deprotected following the procedure for 2,2-dimethyl-3LI-1,2-HOPO, except 5LI-1,2-HOPOBn (557 mg, 1 mmol) was used instead of 2,2-dimethyl-3LI-1,2-HOPOBn. Separation and purification of the deprotected product was performed as described above to yield the desired product as a beige solid (344 mg, 91%).

25 [0244] ^1H NMR (300MHz, DMSO-*d*₆): δ 1.35(qin, 2H), 1.46 (qin, 4H), 3.18(q, 4H), 6.26(dd, 2H), 6.55(dd, 2H), 7.37 (dd, 2H), 8.73(t, 2H, $J=5.6$). MS(FAB⁺): 377(MH⁺). Anal for $\text{C}_{17}\text{H}_{20}\text{N}_4\text{O}_6 \cdot 2\text{HCl} \cdot \text{H}_2\text{O}$ (467.32), Calcd. (Found): 43.69(43.75), 5.17(4.93), 11.98(11.65).

 $\text{C}_5\text{H}_6\text{N}[\text{Eu}(\text{5LI-1,2-HOPO})_2]$

30 [0245] A solution of europium chloride hexahydrate (37 mg, 0.1 mmol) in methanol (1 mL) was added to a solution of 5LI-1,2-HOPO $\cdot 2\text{HCl} \cdot \text{H}_2\text{O}$ (94 mg, 0.20 mmol) in methanol (5 mL) while stirring. The mixture was refluxed for 6 hr. under nitrogen, during which time the complex deposits as a white precipitate. This solid was isolated by filtration, rinsed with

cold methanol, and dried to give the pyridinium salt of title complex (80 mg, 82 %) as a white solid.

Anal. For $\text{EuC}_{34}\text{H}_{36}\text{N}_8\text{O}_{12}\cdot\text{C}_5\text{H}_6\text{N}$, Calcd. (Found): C, 47.76 (47.45); H, 4.32 (4.22); N, 12.85 (12.67). MS(ES⁻): 900.1 (M⁻).

- 5 [0246] Crystals of Eu5LI-1,2-HOPO suitable for X-ray diffraction are prepared by vapor diffusion of ether into a wet methanol solution of the complex with excess of dimethylamine. The ORTEP diagram and crystallographic data have been mentioned in introduction section.

3-Oxapentane-1,5-diamine (5LIO-amine)

- 10 [0247] This amine was available from Aldrich as hydrochloride salt form at high cost. However the following modified literature procedure was quite easy to preparation good amount of the free amine.

- [0248] A mixture of 34.7 g (0.5mol) of NaN_3 and catalytical amount of KI (1 g) in 75 mL of H_2O and 6.8 g (0.02 mol) of cetylpyridinium chloride in 42.9 g (0.3 mol) of 1,5-dichloro-
15 3-oxapentan we refluxed and stirred for 20 h. The reaction mixture was filtered, the organic phase of the filtrate separated and the aqueous phase extracted with dichloromethane three times. The combined organic solution was extracted with 10 % solution of $\text{Na}_2\text{S}_2\text{O}_3$ to removed any iodine in the organic phase. The organic phase was then loaded onto a flash silica gel plug to remove the pyridinium salt and residual water. Evaporation under vacuo
20 at 25 °C affords 45 g of crude diazide. It was dissolved in 60 mL of 95% ethanol and hydrogenated at 25 °C (cooling with a water bath) and 50 atm in the presence of 10% Pd/C (1.5 g). Filtration of the catalyst, evaporation of the solvent, and distillation gave 25 g (80%) of 5LIO-amine: bp 48-50 °C (1 torr)].

[0249] ^1H NMR (300MHz, CDCl_3): δ 1.33(s,br, 4H), 2.83(t, 4H), 3.45(t, 4H).

25 **5LIO-1,2-HOPOBn**

- [0250] To a solution of 1,2-HOPO(Bn)-thiazolide (644 mg, 2.1 mmol) in dry methylene chloride (20 mL), was added neat 5LIO-amine (104 mg, 1.0 mmol). The mixture was stirred overnight, after which time the solvent was removed and the residue was loaded onto a flash silica column. Elution with 2-6% methanol in methylene chloride allowed for the
30 separation and isolation of the benzyl-protected 5LIO-1,2-HOPO(Bn) to give a pale yellow oil (447 mg, 85 % based on amine).

[0251] ^1H NMR (500MHz, CDCl_3): δ 3.22(s, 8H, CH_2), 5.24(s, 4H, benzyl CH_2), 6.26(dd, $J = 7, 1.2$ Hz, 2H, HOPO H), 6.31(d, 2H, $J = 9.0$ Hz, HOPO H), 7.24(dd, 2H, $J = 9.0, 2$ Hz, ArH), 7.26-7.45(m, 12H, ArH), 7.74(s,br, 2H, amideH). ^{13}C NMR (125 MHz, CDCl_3): δ 38.8, 68.1, 78.2, 104.7, 121.7, 127.7, 128.3, 129.0, 132.9, 138.3, 143.2, 157.8, 160.0.

5 MS(FAB⁺): 559.2 (MH⁺).

5LIO-1,2-HOPO

[0252] 5LIO-1,2-HOPOBn (558 mg, 1 mmol) was dissolved in concentrated HCl (12 M)/glacial acetic acid (1:1, 20 mL), and was stirred at room temperature for 2 days. Filtration followed by removal of the solvent gave a beige residue, which was dissolved in a
10 minimum amount of methanol and then mixed with diethyl ether while stirring, 5LIO-1,2-HOPO precipitated, and was collected by filtration and dried under vacuum at 80°C affording a white powder as product (340 mg, 90%).

[0253] ^1H NMR (500MHz, $\text{DMSO}-d_6$): δ 3.37(q, 4H, $J = 6.0$ Hz, CH_2), 3.52(t, 4H, $J = 6.0$ Hz, CH_2), 6.29(dd, 2H, $J = 7.0, 1.5$ Hz, HOPO H), 6.57(dd, 2H, $J = 9.0, 2.0$ Hz, HOPO H),
15 7.32(dd, 2H, $J = 9.0, 2.0$ Hz, HOPO H), 8.82(t, 2H, $J = 5.5$ Hz, amide H). ^{13}C NMR (300MHz, CDCl_3): δ 39.2, 68.0, 108.4, 120.2, 138.6, 139.7, 159.2, 161.7. MS(FAB⁺): 379(MH⁺). Anal for $\text{C}_{16}\text{H}_{18}\text{N}_4\text{O}_7$ (378.34), Calcd. (Found): 50.79(50.60), 4.80(4.99), 14.80(14.50).

$\text{C}_5\text{H}_6\text{N}[\text{Eu}-5\text{LIO}-1,2-\text{HOPO}]\cdot\text{H}_2\text{O}$

20 [0254] A solution of europium chloride hexahydrate (37 mg, 0.1 mmol) in methanol (1 mL) was added to a solution of 5LIO-1,2-HOPO (76 mg, 0.20 mmol) in methanol (5 mL) while stirring. The clear solution became turbid after 2 drops of dry pyridine was added. The mixture was refluxed for 6 hr. under nitrogen, during which time the complex deposits as a white precipitate. This solid was isolated by filtration, rinsed with cold methanol, and dried
25 to give the pyridinium salt of title complex (63 mg, 63 %) as a white solid.
Anal. for $\text{EuC}_{32}\text{H}_{32}\text{N}_8\text{O}_{14}\cdot\text{C}_5\text{H}_6\text{N}\cdot\text{H}_2\text{O}$, Calcd. (Found): C, 44.32 (44.15); H, 4.02 (4.08); N, 12.57 (12.40). MS(ES⁻): 905.1 (M⁻).

[0255] Crystals of Eu5LIO-1,2-HOPO suitable for X-ray diffraction are prepared by vapor diffusion of ether into a methanol solution of the above complex with 1 equivalent of
30 tetramethylammonium hydroxide.

o-Phenylene-1,2-HOPOBn

- [0256] To a mixture of o-phenylenediamine (0.11 g, 1 mmol) and 30% potassium carbonate solution (5 mL) in CH₂Cl₂ (20 mL) cooling with an ice bath, a solution of raw 1,2-HOPOBn acid chloride (0.64 g, 2.4 mmol) in dry CH₂Cl₂ (35 mL) was added dropwise within 1 hr with vigorous stirring. The mixture was warmed to room temperature with stirring, until
- 5 TLC indicated the reaction was complete. The organic phase was separated loaded on a flash silica column. Elution with 2-4% methanol in methylene chloride allows the separation of the benzyl-protected precursor o-phenylene-1,2-HOPOBn (0.44g, 79% based on the free amine) as a thick pale yellow oil which was solidified upon standing overnight.
- [0257] ¹H NMR (300MHz, CDCl₃): δ 5.19(s, 4H), 6.32(dd, 2H), 7.13-7.30(m, 14H),
- 10 7.61(m, 2H), 9.02(s, 2H). ¹³C NMR (300MHz, CDCl₃): δ 79.3, 106.4, 123.5, 124.5, 126.4, 128.4, 128.7, 129.2, 132.7, 138.4, 142.6, 158.4, 158.8. MS(FAB⁺): 562.2(MH⁺).

o-Phenylene-1,2-HOPO

- [0258] o-Phenylene-1,2-HOPOBn was deprotected under strong acidic condition as mentioned for CS124-1,2-HOPOBn, yield 90 %.
- 15 [0259] ¹H NMR (300MHz, CDCl₃): δ 6.67(m, 4H), 7.30(dd, 2H), 7.47(dd, 2H), 7.69(dd, 2H), 10.52(s, 2H). ¹³C NMR (75 MHz, CDCl₃): δ 106.0, 120.0, 125.5, 126.4, 130.2, 137.2, 141.5, 157.7, 159.1. MS(FAB⁺): 383.3(MH⁺). Anal for C₁₈H₁₄N₄O₆ (Mr. 382.33), Calcd.(Found): C, 56.55(56.35); H, 3.69(3.57); N, 14.65(14.48).

m-Phenylene-1,2-HOPOBn

- 20 [0260] The benzyl protected m-phenylene-1,2-HOPOBn was prepared following the procedure for o-phenylene-1,2-HOPO-Bn, except m-phenylenediamine (160 mg, 1.8 mmol) was used instead of o-phenylenediamine. Separation and purification of the benzyl-protected precursor was performed as described for that of o-phenylene-1,2-HOPOBn to give the desired product as pale yellow oil (95% based on amine).
- 25 [0261] ¹H NMR (300MHz, CDCl₃): δ 5.28(s, 4H), 6.58(d, 2H), 6.71(d, 2H), 7.15-7.30(m, 14H), 7.44(d, 2H), 7.92(s, 1H), 9.26(s, 2H). ¹³C NMR (300MHz, CDCl₃): δ 79.0, 106.3, 112.0, 116.6, 122.9, 128.1, 128.8, 129.3, 129.6, 132.6, 138.1, 138.3, 142.9, 158.0, 158.7. MS(FAB⁺): 562.2(MH⁺).

m-Phenylene-1,2-HOPO

- 30 [0262] 1,3-Phenylene-Bis(1,2-HOPO) was prepared following the acidic deprotection procedure of 2,2-dimethyl-3LI-1,2-HOPO as a beige solid (158 mg, 82.6%).

¹H NMR (300MHz,DMSO-*d*₆): δ 6.43(d, 2H), 6.61(d, 2H), 7.34(m, 1H), 7.43(m, 4H), 8.13(s, 1H), 10.91(s, 2H), 11.85(s, br, 2H). MS(FAB⁺): 383.3(MH⁺). Anal for C₁₈H₁₄N₄O₆ (Mr. 382.33), Calcd.(Found): C, 56.55(56.26); H, 3.69(3.61); N, 14.65(14.45).

2-Aminomethylaniline-1,2-HOPOBn (o-BnPhen-1,2-HOPOBn)

5 [0263] The benzyl protected o-BnPhen-1,2-HOPOBn was prepared following the procedure for o-phenylene-1,2-HOPO-Bn, except 2-Aminomethyl-aniline (122 mg, 1.0 mmol) was used instead of o-phenylenediamine. Separation and purification of the benzyl-protected precursor was performed as described for that of o-phenylene-1,2-HOPOBn to give the desired product as pale yellow oil which was solidified upon standing (85% based on
10 amine).

[0264] ¹H NMR (500MHz, CDCl₃): δ 4.32(d, 2H), 4.79(s, 2H), 5.37(s, 2H), 6.33(dd, 1H), 6.40(d, 2H), 6.69(dd, 1H), 6.84(d, 2H), 7.08(m,3H), 7.19-7.31(m, 6H), 7.38(d, 1H), 7.44(m, 3H), 8.01(d,1H),8.26(s, 1H),10.29(s, 1H). ¹³C NMR (125MHz, CDCl₃): δ 39.7, 78.3, 78.8, 104.7, 106.4, 122.7, 123.0, 124.2, 125.9, 127.9, 128.3, 128.6, 129.3, 129.6, 129.8, 130.8,
15 132.1, 132.9, 134.5, 137.7, 137.8, 141.3, 143.0, 157.9, 158.1, 158.9, 160.4. MS(FAB⁺): 577(MH⁺).

2-Aminomethylaniline-1,2-HOPO (o-BnPhen-1,2-HOPO)

[0265] o-BnPhen-1,2-HOPO) was prepared following the acidic deprotection procedure of CS124-1,2-HOPO. A beige solid was obtained as product, yield 86%.

20 [0266] ¹H NMR (500MHz, CDCl₃): δ 4.49(s, 2H), 6.36(dd, 1H), 6.58(t, 2H), 6.66(d, 1H), 7.26(t, 1H), 7.32(t,3H), 7.39-7.52(m, 4H), 9.28(t, 1H),10.62(s, 1H). ¹³C NMR (125MHz, CDCl₃): δ 104.0, 104.5, 119.7, 125.5, 126.4, 127.5, 127.7, 132.6, 134.2, 137.2, 142.1, 157.5, 157.6, 159.2, 160.8. MS(FAB⁺): 397.1 (MH⁺).
Anal for C₁₉H₁₆N₄O₆ (Mr. 396.11), Calcd.(Found): C, 57.58(57.29); H, 4.07(4.01); N,
25 14.14(13.82).

3-Aminomethylaniline-1,2-HOPOBn (m-BnPhen-1,2-HOPOBn)

[0267] The benzyl protected o-BnPhen-1,2-HOPOBn was prepared following the procedure for o-phenylene-1,2-HOPO-Bn, except 3-Aminomethyl-aniline (122 mg, 1.0 mmol) was used instead of o-phenylenediamine. Separation and purification of the benzyl-protected
30 precursor was performed as described for that of o-phenylene-1,2-HOPOBn to give the

desired product as pale yellow oil which was solidified upon standing (87% based on amine).

[0268] ^1H NMR (300MHz, CDCl_3): δ 4.43(d, 2H), 5.20(s, 2H), 6.43(dd, 2H), 6.52(m, 2H), 7.04(d, 1H), 7.10-7.31(m, 13H), 7.53(s,br, 3H), 9.50(s, 1H). ^{13}C NMR (125MHz, CDCl_3):
 5 δ 43.0, 78.7, 105.7, 118.9, 122.7, 123.6, 128.0, 128.7, 128.8, 128.9, 129.3, 129.6, 132.7, 137.7, 138.0, 138.2, 142.6, 142.8, 158.0, 158.3, 160.1. MS(FAB+): 577(MH^+).

3-Aminomethylaniline-1,2-HOPO (m-BnPhen-1,2-HOPO)

[0269] m-BnPhen-1,2-HOPO) was prepared following the acidic deprotection procedure of CS124-1,2-HOPO. A beige solid was obtained as product, yield 86%.

10 [0270] ^1H NMR (500MHz, CDCl_3): δ 4.41(s, 2H), 6.36(d, 1H), 6.42(d, 1H), 6.60(t, 2H), 7.10(d, 1H), 7.32(t, 1H), 7.32(t,3H), 7.39-7.47(m, 2H), 7.56(d, 1H), 7.47(s, 1H), 9.34(t, 1H), 10.83(s, 1H). ^{13}C NMR (125MHz, CDCl_3): δ 42.4, 103.6, 103.9, 118.3, 119.6, 119.9, 123.2, 129.0, 137.4, 137.6, 138.4, 139.5, 142.2, 142.3, 157.5, 157.6, 158.7, 160.5.
 MS(FAB+): 397.1 (MH^+). Anal for $\text{C}_{19}\text{H}_{16}\text{N}_4\text{O}_6$ (Mr. 396.35), Calcd.(Found): C,
 15 57.58(57.36); H, 4.07(4.02); N, 14.14(13.93).

o-Aminomethyl-benzylamine-1,2-HOPOBn (o-diBnPhen-1,2-HOPOBn)

[0271] The benzyl protected o-diBnPhen-1,2-HOPOBn was prepared following the procedure for o-phenylene-1,2-HOPO-Bn, except 2-Aminomethylbenzylamine was used instead of o-phenylenediamine. Separation and purification of the benzyl-protected
 20 precursor was performed as described for that of o-phenylene-1,2-HOPOBn to give the desired product as pale yellow oil which was solidified upon standing (83% based on amine).

[0272] ^1H NMR (500MHz, CDCl_3): δ 4.44(d, 4H), 5.08(s, 4H), 6.19(m, 4H), 7.04(dd, 2H), 7.10-7.15(m, 2H), 7.20-7.40(m, 12H), 7.83(d, 2H). ^{13}C NMR (125MHz, CDCl_3): δ 40.5,
 25 78.5, 105.3, 122.5, 127.8, 128.0, 128.7, 129.4, 132.8, 135.0, 142.5, 158.0, 159.9.
 MS(FAB+): 591(MH^+).

o-Aminomethyl-benzylamine-1,2-HOPO (o-diBnPhen-1,2-HOPO)

[0273] o-diBnPhen-1,2-HOPO was prepared following the acidic deprotection procedure of CS124-1,2-HOPO. A beige solid was obtained as product, yield 90%.

[0274] ^1H NMR (500MHz, DMSO- d_6): δ 4.50(s, 2H), 6.35(dd, 2H), 6.58(dd, 2H), 6.66(d, 1H), 7.26(dd, 2H), 7.38(m, 4H), 9.26(t, 2H). ^{13}C NMR (125MHz, CDCl_3): δ 103.9, 119.6, 127.3, 127.9, 135.9, 137.4, 142.3, 157.6, 160.5. MS(FAB+): 397.1 (MH^+).
 Anal for $\text{C}_{19}\text{H}_{16}\text{N}_4\text{O}_6 \cdot 0.7 \text{H}_2\text{O}$ (Mr. 422.73), Calcd.(Found): C, 56.82 (57.02); H, 4.62(4.59); N, 13.25(12.88).

TREN-1,2-HOPOBn

[0275] The benzyl protected TREN-1,2-HOPOBn was prepared following the procedure for 2,2-dimethyl-3LI-1,2-HOPO-Bn, except tris(2-aminoethyl)amine (TREN) was used instead of 2,2-dimethyl-1,3-propanediamine. Separation and purification of the benzyl-protected precursor are performed as described above to give pale yellow oil (89% based on amine).

[0276] ^1H NMR (300MHz, CDCl_3): δ 2.329(s, br, 6H), 2.992(d, br, 4H), 5.234(s, 4H), 6.086(dd, 6H), 6.365(dd, 6H), 6.785(t, 6H), 7.131(dd, 6H) 7.27-7.35(m, 12H). ^{13}C NMR (300MHz, CDCl_3): δ 37.5, 52.9, 79.0, 105.0, 122.8, 128.3, 129.0, 129.6 133.2, 138.4, 142.9, 158.1, 160.4.

TREN-1,2-HOPO

[0277] TREN-1,2-HOPO was prepared following the procedure for 2,2-dimethyl-3LI-1,2-HOPO, except TREN-1,2-HOPOBn (827 mg, 1 mmol) was used instead 2,2-dimethyl-3LI-1,2-HOPOBn. Separation and purification of the deprotected product was performed as described above affording a beige solid (502 mg, 90.1%).

[0278] ^1H NMR (300MHz, DMSO- d_6): δ 1.35(qin, 2H), 1.47(qin, 4H), 3.18(q, 4H), 6.26(dd, 2H), 6.55(dd, 2H), 7.37 (dd, 2H), 8.73(t, 2H, $J=5.6$ Hz). MS(FAB+): 558(MH^+).
 Anal for $\text{C}_{24}\text{H}_{27}\text{N}_7\text{O}_9 \cdot \text{HCl} \cdot \text{H}_2\text{O}$, Calcd. (Found): 47.10(47.34), 4.94(4.79), 16.02(15.95).

Europium Complex with TREN-1,2-HOPO

[0279] To a solution of TREN-1,2-HOPO (61 mg, 0.10 mmol) in methanol (10 mL), was added a solution of europium chloride hexahydrate (36 mg, 0.1 mmol) in methanol (10 mL) while stirring. The clear solution becomes turbid after 2 drops of dry pyridine are added. The mixture was refluxed overnight under nitrogen, during which time the complex deposits as a white precipitate. This was filtered, rinsed with cold methanol, and dried to give the title complex (63 mg, 89%) as a white solid. Anal. for $\text{EuC}_{24}\text{H}_{24}\text{N}_7\text{O}_9 \cdot \text{H}_2\text{O}$, Calcd. (Found): C, 39.79 (40.01); H, 3.62 (3.47); N, 13.53 (13.26).

Crystals of this compound suitable for X-ray diffraction are prepared by vapor diffusion of ether into a DMF solution. The chemical formula was $\text{Eu}(\text{C}_{24}\text{H}_{24}\text{N}_7\text{O}_9 \cdot \text{C}_3\text{H}_7\text{NO})_2 \cdot 2\text{C}_3\text{H}_7\text{NO} \cdot \text{C}_4\text{H}_{10}\text{O}$. The ORTEP diagram and crystallographic data and parameters for Eu-TREN-1,2-HOPO are given in introduction section.

5 **1,3,5-Tris(bromomethyl)-2,4,6-trimethoxybenzene (MeOMETribromide)**

[0280] To a solution of 1,3,5-trimethoxybenzene (5.0 g, 30 mmol) and paraformaldehyde (3.0 g, 99 mmol) in 10 mL of acetic acid was added 22 mL of hydrogen bromide (30 wt % in HOAc). The mixture was heated at 60-70 °C in a round bottom flask equipped with a condenser cooled with ice water for 3 hrs. The mixture then was poured in 100 mL of water.

10 The precipitate was filtered and dried. Flash chromatography using hexane/ethyl acetate (20/1) as the eluent gave the product as white powder. Yield, 1.7 g (13 %); mp 126 °C. ^1H NMR (300MHz, CDCl_3) δ 4.14 (s, 9H), 4.60 (s, 6H).

1,3,5-Tris-azidomethyl-2,4,6-trimethoxy-benzene (MeOMETriazide)

[0281] The MeOME-triazide was prepared in high yield from the corresponding
15 tetrabromide by nucleophilic substitution with azide anion. The triazide was handled with great care due to the high N:C ratio of this compound. In a typical preparation, MeOMETribromide (0.9 g, 2mmol) was mixed with excess of sodium azide (1.0 g, 15 mmol) in dry DMF (20 mL). The mixture was stirred at 40 °C overnight, the solvent was removed under reduced pressure at room temperature and the oily residue solidified after
20 stirring with cold water. It was then washed thoroughly with water and air dried. Yield 0.60 g (90%).

[0282] ^1H NMR (500 MHz, CDCl_3) δ 3.92 (s, 9H, methoxy CH_3), 4.45 (s, 6H, ArCH_2).
 ^{13}C NMR (125 MHz, CDCl_3) δ 44.1, 63.2, 119.8, 160.3.

1,3,5-Bis-aminomethyl-2,4,6-trimethoxy-benzylamine (MeOMETriaamine)

25 [0283] To a solution of MeOMETriazide (0.6 g, 2 mmol) in methanol (20 mL) was added palladium on carbon (10%) catalyst (50 mg). The mixture was hydrogenated at room temperature in a Parr bomb at 500 psi overnight. The catalyst was then removed by filtration (fine glass frit) and the filtrate was evaporated under reduced pressure, yield 0.41 g (90%). The MeOMETriaamine was directly used for the next amidation reaction.

30 [0284] ^1H NMR (500 MHz, CDCl_3) δ 1.70 (s, 6H, ArCH_2), 3.81 (s, 9H, methoxy CH).
 ^{13}C NMR (125 MHz, CDCl_3) δ 35.4, 61.7, 126.1, 156.4.

MeOME-1,HOPOBn

[0285] To a mixture of o- MeOMETriaamine (0.13 g, 0.5 mmol) and 30% potassium carbonate solution (5 mL) in CH₂Cl₂ (20 mL) cooling with an ice bath, a solution of raw 1,2-HOPOBn acid chloride (from 0.5 g of 1,2-HOPOBn acid, 2 mmol) in dry CH₂Cl₂ (15 mL) was added dropwise within 1 hr with vigorous stirring. The mixture was warmed to room temperature with stirring, until TLC indicated the reaction was complete. The organic phase was separated loaded on a flash silica column. Elution with 2-5% methanol in methylene chloride allows the separation of the benzyl-protected precursor o-phenylene-1,2-HOPOBn (0.34g, 74% based on the free amine) as a thick pale yellow oil which was solidified upon standing overnight.

[0286] ¹H NMR (300MHz, CDCl₃): δ 3.61(s, 9H, CH₃), 4.57(d, 6H, ArCH₂), 5.25(s, 6H), 6.40(dd, 3H), 6.74(dd, 3H), 6.95(t, 3H, amide H), 7.20-7.36(m, 15H), 7.38(d, 3H). MS(FAB⁺): 937(MH⁺).

MeOME-1,2-HOPO

MeOME-1,2-HOPO was prepared following the acidic deprotection procedure of 2,2-dimethyl-3LI-1,2-HOPO as a beige solid, yield 83%.

[0287] ¹H NMR (500MHz,DMSO-*d*₆): δ 3.80(s, 9H), 6.49(d, 6H, ArCH₂), 6.38(d, 3H), 6.59(dd, 3H), 7.37(dd, 3H), 9.06(t, 3H, amideH). ¹³C NMR (125 MHz,DMSO-*d*₆) δ 33.5, 62.3, 105.1, 118.9, 120.5, 136.6, 141.5, 157.3, 159.1, 159.8. MS(FAB⁺): 667(MH⁺). Anal for C₃₀H₃₀N₆O₁₂·H₂O (Mr. 684.606), Calcd.(Found): C, 52.63(52.66); H, 4.71(4.64); N, 12.27(12.42).

H(2,2)-1,2-HOPOBn

[0288] The benzyl protected H(2,2)-1,2-HOPOBn was prepared following the procedure for 2,2-dimethyl-3LI-1,2-HOPOBn, except H(2,2) amine (or PENTEN, 198 mg, 0.9 mmol) was used instead of 2,2-dimethyl-1,3-propanediamine. Separation and purification of the benzyl-protected precursor was performed as described above affording a pale yellow oil (893 mg, 87% based on amine).

[0289] ¹H NMR(300MHz, CDCl₃): δ 1.77(s, 2H), 2.20(t, 8H), 3.02(d, br, 8H), 5.28(s, 8H), 6.15(dd, 4H), 6.59(dd, 4H), 7.21(dd, 4H), 7.30-7.34(m, 20H), 7.47-7.51(m, 8H). ¹³C NMR (300MHz, CDCl₃): δ 37.2, 51.8, 52.6, 79.0, 105.0, 123.1, 128.3, 129.2, 130.0, 133.2, 138.1, 142.8, 158.2, 160.5.

H(2,2)-1,2-HOPO

[0290] H(2,2)-1,2-HOPO was prepared following the procedure for 2,2-dimethyl-3LI-1,2-HOPO, except H(2,2)-1,2-HOPOBn (856 mg, 0.75 mmol) was used instead of 2,2-dimethyl-3LI-1,2-HOPOBn. Separation and purification of the deprotected product was
 5 performed as described above yield a beige solid (529 mg, 81%).

[0291] ^1H NMR (300MHz, DMSO- d_6): δ 3.15(s, br, 8H), 3.55(s, br, 4H), 3.62(s, br, 8H), 6.42(d, 2H), 6.59(dd, 2H), 7.40(dd, 2H), 9.05(t, 2H, $J=5.6$ Hz). Anal for $\text{C}_{34}\text{H}_{40}\text{N}_{10}\text{O}_{12}\cdot 2\text{HCl}\cdot \text{H}_2\text{O}$, Calcd.(Found): C, 46.84(46.75); H, 5.08(5.10); N, 16.07(16.05).

H(3,2)-1,2-HOPOBn

10 [0292] The benzyl protected H(3,2)-1,2-HOPOBn was prepared following the procedure for H(2,2)-1,2-HOPOBn, except N,N,N',N'-Tetrakis-(2-amino-ethyl)-propane-1,3-diamine, (H(3,2) amine 220 mg, 0.9 mmol) was used instead of H(2,2)-amine. Separation and purification of the benzyl-protected precursor was performed as described above affording a pale yellow oil (0.73 g, 71% based on amine).

15 [0293] ^1H NMR(500MHz, CDCl_3): δ 1.03(s, 2H), 1.87(s, 4H), 2.13(s, 8H), 3.08(s, br, 8H), 5.22(s, 8H), 6.15(d, 4H), 6.52(d, 4H), 7.15(t, 4H), 7.30-7.34(m, 12H), 7.44(d, 8H), 7.49(s, 4H). ^{13}C NMR (125MHz, CDCl_3): δ 24.2, 37.3, 51.0, 52.3, 78.8, 105.0, 122.9, 128.1, 128.9, 129.7, 133.1, 138.0, 142.8, 158.1, 160.4. MS(FAB+, DTT/DTE): 1155.6 (MH+).

H(3,2)-1,2-HOPO

20 [0294] H(3,2)-1,2-HOPO was prepared following the strong acidic deprotection procedure for H(2,2)-1,2-HOPO, except H(2,2)-1,2-HOPOBn (0.87 g, 0.75mmol) was used instead of H(2,2)-1,2-HOPOBn. Separation and purification of the deprotected product was performed as described above yield a beige solid (0.52 g, 87%).

[0295] ^1H NMR (500MHz, DMSO- d_6): δ 1.67(s, br, 2H), 2.70-2.85(m, 12H), 3.07(s, br, 4H), 5.97(dd, 4H), 6.02(dd, 4H), 6.67(dd, 4H). ^1H NMR (500MHz, CD_3OD): δ 20.5, 36.3, 51.7, 54.7, 109.9, 121.5, 138.8, 140.7, 160.3, 163.8. Anal for $\text{C}_{35}\text{H}_{42}\text{N}_{10}\text{O}_{12}\cdot 2\text{HCl}\cdot 1.5\text{H}_2\text{O}$ (894.714), Calcd.(Found): C, 46.98(47.19); H, 5.29(5.22); N, 15.66(15.55). MS(ES $^-$, MeOH): 793 (M $^-$).

25

H(4,2)-1,2-HOPOBn

30 [0296] The benzyl protected H(4,2)-1,2-HOPOBn was prepared following the procedure for H(2,2)-1,2-HOPOBn, except N,N,N',N'-Tetrakis-(2-amino-ethyl)-butane-1,4-diamine,

(H(4,2) amine 234 mg, 0.9 mmol) was used instead of H(2,2)-amine. Separation and purification of the benzyl-protected precursor was performed as described above affording a pale yellow oil (0.72 g, 68% based on amine).

[0297] ^1H NMR(500MHz, CDCl_3): δ 0.85(s, 4H), 1.95(s, 4H), 2.29(s, 8H), 3.15(s, br, 8H), 5.24(s, 8H), 6.18(s, 4H), 6.50(dd, 4H), 7.14(m, 4H), 7.30-7.34(m, 12H), 7.43-7.50(m, 12H). ^{13}C NMR (125MHz, CDCl_3): δ 23.9, 37.4, 52.1, 53.0, 78.8, 105.0, 122.9, 128.1, 128.9, 129.7, 133.1, 137.8, 142.9, 158.1, 160.3. MS(FAB+, DTT/DTE): 1169.5 (MH+).

H(4,2)-1,2-HOPO

[0298] H(4,2)-1,2-HOPO was prepared following the strong acidic deprotection procedure for H(2,2)-1,2-HOPO,. Separation and purification of the deprotected product was performed as described above yield a beige solid (0.42 g, 90%).

[0299] ^1H NMR (500MHz, $\text{DMSO}-d_6$): δ 1.81(s, br, 4H), 3.15(s, 4H), 3.25(s, 8H), 3.55(s, 8H), 6.43(d, 4H), 6.59(d, 4H), 7.40(dd, 4H), 9.13(t, 4H), 10.96(s, br, 4H). ^1H NMR (100MHz, CD_3OD): δ 22.1, 36.3, 49.8, 54.3, 109.7, 121.7, 139.1, 140.9, 160.3, 163.7. Anal for $\text{C}_{36}\text{H}_{44}\text{N}_{10}\text{O}_{12}\cdot 2\text{HCl}\cdot 2.5\text{H}_2\text{O}$ (926.76), Calcd.(Found): C, 46.66(46.82); H, 5.54(5.23); N, 15.11(14.89). MS(ES^- , MeOH): 807.3 (M $^-$).

H(5O,2)-CBZ

[0300] Several approaches were tried to synthesize the N,N,N',N'-Tetrakis-(2-amino-ethyl)-3-oxapentane-1,5-diamine [H(5O,2)-amine]. It was found that the reaction of 5LIO-amine with CBZ-aziridine provides clean H(5O,2)-CBZ.

5LIO-amine (0.21 g, 2 mmol) and Cbz-aziridine (1.77 g, 10 mmol) were mixed in *tert*-butanol (30 mL) at room temperature under N_2 . The mixture was stirred under a N_2 atmosphere at 80°C for 16 hrs, when TLC showed the completeness of the reaction. The volatile were removed under vacuum and the residue was dissolved in dichloromethane. The appropriate fractions of a gradient flash silica gel column (1-7% methanol in dichloromethane) were collected and evaporated to dryness to give a pale beige thick oil, yield: 1.28 g, 79%.

[0301] ^1H NMR(300MHz, CDCl_3): δ 2.53(s, br, 12H), 3.17(s, br, 4H), 3.83(s, br, 8H), 5.04(s, 8H), 7.29(s, br, 20H). ^{13}C NMR (300MHz, CDCl_3): δ 38.8, 53.0, 53.6, 69.3, 128.0, 128.1, 128.4, 136.6, 156.4. MS(FAB+, DTT/DTE): 813.5 (MH+).

H(5O,2)-amine

[0302] H(5O,2)CBZ (0.83 g, 1 mmol) and 0.1 g of Pd/C catalyst (palladium, 10 wt. & on activated carbon (Aldrich)) were combined in methanol (25 mL). The mixture was hydrogenated (500 psi pressure, room temperature) overnight in a Parr bomb. After removing the catalyst by filtration, and the filtrate was evaporated to dryness to leave pale yellow oil as product, yield 0.23 g (84%).

[0303] ¹H NMR (500 MHz, DMSO-*d*₆): δ: 0.84 (t, 4H), 0.90 (t, 8H), 1.10 (t, 8H), 1.66 (t, 4H). ¹³C NMR (500 MHz, CDCl₃) δ: 38.6, 53.4, 53.9, 70.1.

H(5O,2)-1,2-HOPOBn

[0304] The benzyl protected H(5O,2)-1,2-HOPOBn was prepared following the procedure for H(2,2)-1,2-HOPOBn, except H(5O,2) amine (140 mg, 0.5 mmol) was used instead of H(2,2)-amine. Separation and purification were performed as described for H(2,2)-1,2-HOPOBn affording a pale yellow oil (0.42 g, 71% based on amine).

[0305] ¹H NMR(300MHz, CDCl₃): δ 2.14(s,br, 4H), 2.32(s,br, 8H), 2.83(s,br, 4H), 3.06(s, br, 8H), 5.15(s, 8H), 6.05(s, 4H), 6.34(s, 4H), 7.04(s, 4H), 7.20(s,br, 12H), 7.32(s,br, 8H). 7.63(s,br, 4H). ¹³C NMR (300MHz, CDCl₃): δ 37.3, 52.0, 52.7, 78.8, 104.8, 122.9, 128.1, 128.9, 129.7, 133.1, 138.0, 143.0, 158.1, 160.3. MS(FAB+, DTT/DTE): 1185.6 (MH⁺).

H(5O,2)-1,2-HOPO

[0306] H(2,2)-1,2-HOPOBn was deprotected following the procedure for H(2,2)-1,2-HOPO. Separation and purification of the deprotected product was performed as described above yield a beige solid (81%).

[0307] ¹H NMR (500MHz,DMSO-*d*₆): δ 3.40(s, br, 8H), 3.52(s, br, 4H), 3.70(s, br, 8H), 3.86(s, br, 4H), 6.41(d, 4H), 6.60(d, 4H), 7.40(dd, 4H), 9.11(t, 2H, J=5.6 Hz), 10.48(s, 4H). MS(FAB+, DTT/DTE): 824.3 (MH⁺). Anal for C₃₆H₄₄N₁₀O₁₃·2HCl·H₂O, Calcd.(Found): C, 47.22(47.54); H, 5.28(5.35); N, 15.30(14.95).

H(8O2,2)-CBZ

[0308] H(8O2,2)-CBZ was prepared following the procedure for H(5O,2)CBZ, except 2-[2-(2-Amino-ethoxy)-ethoxy]-ethylamine (0.15 g, 1 mmol) was used instead of 5LIO-amine. Separation and purification of the deprotected product was performed as described for H(5O,2)-amine yielding pale yellow oil, yield: 0.64 g, 74%.

[0309] ^1H NMR(300MHz, CDCl_3): δ 2.53(s,br, 12H), 3.16(s,br, 8H), 3.23(s, br, 4H), 3.35(s, br, 4H), 5.03(s, 8H), 7.28(s,br, 20H). ^{13}C NMR (300MHz, CDCl_3): δ 38.8, 52.6, 53.6, 66.3, 69.2, 69.9, 127.8, 128.0, 128.3, 136.6, 156.5. MS(FAB+, DTT/DTE): 857.5 (MH+).

5 **H(8O2,2)-amine**

[0310] H(8O,2)CBZ (0.86 g, 1 mmol) and 0.1 g of Pd/C catalyst (palladium, 10 wt. & on activated carbon (Aldrich)) were combined in methanol (25 mL). The mixture was hydrogenated (500 psi pressure, room temperature) overnight in a Parr bomb. After removing the catalyst by filtration, and the filtrate was evaporated to dryness to leave pale
10 yellow oil as product, yield 0.27 g (85%).

[0311] ^1H NMR(300 MHz, D_2O) δ 2.49 (t, 4H), 2.54 (t, 8H), 2.78 (t, 8H), 3.34 (t, 4H), 3.40 (t, 4H). ^{13}C NMR(500 MHz, CDCl_3) δ 36.9, 51.3, 51.7, 68.1, 69.3. MS(FAB+): 321.3 (MH+).

H(8O2,2)-1,2-HOPOBn

15 [0312] The benzyl protected H(8O2,2)-1,2-HOPOBn was prepared following the procedure for H(2,2)-1,2-HOPOBn, except H(8O2,2) amine (0.16 g, 0.5 mmol) was used instead of H(2,2)-amine. Separation and purification were performed as described for H(2,2)-1,2-HOPOBn affording a pale yellow oil (0.41 g, 68% based on amine).

[0313] ^1H NMR(300MHz, CDCl_3): δ 2.31(s,br, 4H), 2.42(s,br, 8H), 2.63(s,br, 4H),
20 2.85(s,br, 4H), 3.14(s, br, 8H), 5.32(s, 8H), 6.20(d, 4H), 6.48(d, 4H), 7.08(s, 4H), 7.34(s,br, 16H), 7.50(s,br, 8H). ^{13}C NMR (300MHz, CDCl_3): δ 37.4, 52.2, 53.0, 68.8, 69.0, 79.0, 104.9, 123.0, 129.1, 130.1, 133.3, 138.2, 143.2, 158.2, 160.4. MS(FAB+, NBA): 1229.7 (MH+).

H(8O2,2)-1,2-HOPO

25 [0314] H(8O2,2)-1,2-HOPOBn was deprotected following the procedure for H(2,2)-1,2-HOPO. Separation and purification of the deprotected product was performed as described above yield a beige solid (81%).

[0315] ^1H NMR (500MHz, $\text{DMSO}-d_6$): δ 3.36(s, br, 8H), 3.47(s, br, 4H), 3.62(s, br, 4H),
3.67(q, br, 8H), 3.85(s, br, 4H), 6.43(dd, 4H), 6.60(dd, 4H), 7.41(dd, 4H), 9.11(t, 2H, J=5.6
30 Hz), 10.56(s, 4H). ^{13}C NMR (125MHz, CD_3OD): δ 36.4, 49.3, 55.0, 66.0, 71.5, 110.2,

121.0, 139.0, 141.1, 159.9, 163.2. MS(FAB+, NBA): 869 (MH⁺). Anal for C₃₈H₄₈N₁₀O₁₄·2HCl·2.5H₂O (986.81), Calcd.(Found): C, 46.25(46.69); H, 5.62(5.71); N, 14.19(13.89).

BocLys-H(2,2)-1,2-HOPOBn

5 **[0316]** To a solution of lysH(2,2)-amine {[5-Amino-6-((2-amino-ethyl)-{2-[bis-(2-amino-ethyl)-amino]-ethyl}-amino)-hexyl]-carbamic acid tert-butyl ester} (200 mg, 0.5 mmol) in dichloromethane (20 mL) 2 mL of 40% potassium carbonate solution was added. The mixture was cooled with an ice bath and vigorously stirred. A solution of raw 1,2-HOPOBn acid chloride (from 0.75 g 1,2-HOPOBn acid, 3 mmol) in dichloromethane (20 mL) was
 10 added slowly via a teflon tube equipped with a glass capillary tip over a period of 1 hr. The reaction mixture was allowed to warm to room temperature and stirred overnight. The mixture was then washed with 1 M HCL (20 mL), and saline (20 mL) successively and loaded onto a flash silica column. Elution with 2-8% methanol in methylene chloride allows the separation of the benzyl-protected precursor LysH(2,2)-1,2-HOPOBn as beige
 15 foam, yield 70%.

[0317] ¹H NMR (300MHz, DMSO-d₆): δ 1.15(s,br, 4H), 1.41(s, 9H, BocH), 1.9-2.8(m, 14H), 2.8-3.3(m, 8H), 3.79(s,br, 1H), 4.90-5.40(m, 8H), 6.03(s, 1H), 6.17(d, 3H), 6.53(d, 1H), 6.60(d, 3H), 6.94(d, 1H), 7.0-7.4(m, 19H), 7.4-7.5(m, 8H), 7.71(s, 1H, NH). ¹³C
 20 NMR (125MHz, CDCl₃): δ 22.8, 28.2, 29.3, 31.9, 37.4, 37.5, 39.8, 48.7, 51.5, 51.9, 52.8, 53.3, 53.7, 59.0, 78.6, 79.0, 104.6, 105.0, 123/1, 128.3, 129.1, 129.7, 129.9, 130.0, 133.2, 133.3, 137.9, 138.1, 142.9, 143.1, 155.9, 158.1, 158.2160.5, 160.7. MS(FAB+, NBA): 1312 (MH⁺).

Lys-H(2,2)-1,2-HOPO

[0318] BocLysH(2,2)-1,2-HOPOBn was deprotected following the procedure for H(2,2)-
 25 1,2-HOPO. Separation and purification of the deprotected product was performed as described above yield a beige solid (81%).

[0319] ¹H NMR (300MHz,DMSO-d₆): δ 1.2-1.7(m, br, 6H), 2.74(s, br, 3H), 3.05(s, br, 3H), 3.15(s, br, 5H), 3.55(s, br, 3H), 3.61(s, br, 6H), 4.15(s,br, 1H), 6.30-6.45(m, 4H), 6.60(d, 4H), 7.39(m, 5H), 7.88(s,br, 3H), 8.85(s,br, 1H), 9.00(s,br, 1H), 9.06(s,br, 2H).
 30 MS(FAB+, NBA): 851 (MH⁺). Anal for C₃₈H₄₉N₁₁O₁₂·2HCl·H₂O·2CH₃OH, Calcd.(Found): C, 47.72(47.60); H, 6.11(6.17); N, 15.30(15.34)

LysEtGlutar-H(2,2)-1,2-HOPOBn

[0320] To a cooled solution of BocLysH(2,2)-1,2-HOPOBn (260 mg, 0.2 mmol) in 2 mL dichloromethane (with an ice bath) 2 mL of trifluoroacetic acid was added neatly. The mixture was stirred for 4 hrs then evaporated to dryness at room temperature. TLC confirms the BOC group was deprotected completely. The residue was dissolved in dry THF (20 mL), dry triethylamine (0.5 mL) was added while cooling with an ice bath. To this cold mixture, excess of ethyl glutarate N-hydroxysuccinimide ester (100 mg, 0.4 mmol) was added under nitrogen. The mixture was stirred for 4 hrs and the volatiles were removed under vacuum. The residue was dissolved in dichloromethane and loaded onto a flash silica column. Elution with 2-8% methanol in methylene chloride allows the separation of the benzyl-protected precursor LysEtGlutarH(2,2)-1,2-HOPOBn as beige foam, yield 70%.

[0321] ¹H NMR (300MHz, DMSO-d₆): δ 1.09(s,br, 4H), 1.20(t, 3H), 1.25(t, 4H), 1.84(t, 2H), 2.02(m, 2H), 2.17(t, 6H), 2.28(t, 6H), 2.98-3.1(m, 8H), 3.78(s,br, 1H), 4.05(q, 2H), 5.10-5.40(m, 8H), 6.03(s, 1H), 6.16(d, 3H), 6.45(s, 1H), 6.51(d, 1H), 6.58(d, 3H), 7.15(dd, 1H), 7.18-7.40(m, 18H), 7.40-7.51(m, 8H), 8.00(s, 1H, NH). ¹³C NMR (125MHz, CDCl₃): δ 14.4, 21.2, 23.2, 25.5, 28.9, 31.9, 33.7, 35.5, 37.7, 38.2, 39.0, 46.0, 49.1, 50.4, 52.1, 53.2, 54.5, 59.9, 60.6, 79.4, 105.1, 105.6, 123.3, 123.5, 128.8, 129.6, 130.3, 130.4, 130.6, 133.7, 133.8, 138.7, 143.4, 143.7, 143.8, 158.7, 158.8, 161.0, 161.2, 161.5, 173.0, 173.5.. MS(FAB+, NBA): 1354 (MH⁺).

LysGlutar-H(2,2)-1,2-HOPO

[0322] The deprotection of LysEtGlutar-H(2,2)-1,2-HOPOBn was performed in two steps. The first step was the saponification. The hydrolyzed LysGlutar-H(2,2)-1,2-HOPOBn was then deprotected under strong acidic condition as mentioned for LysH(2,2)-1,2-HOPOBn.

[0323] To a cooled solution of LysEtGlutar-H(2,2)-1,2-HOPOBn (0.27 g, 0.2 mmol) in 5 mL methanol (with an ice bath) 2 mL of KOH solution (1 M) was added. The mixture was stirred for 4 hrs when TLC confirms the hydrolysis of ester was complete. The mixture was evaporated to dryness at room temperature and the residue was dissolved in water (10 mL). The hydrolyzed LysGlutar-H(2,2)-1,2-HOPOBn was precipitated upon acidification with HCl (1 M), it was collected, rinse with cold water and further deprotected under strong acidic condition as mentioned above yield a beige solid (71%). ¹H NMR (300MHz, DMSO-d₆): δ 1.37(s,br, 4H), 1.67(t, 7H), 1.84(t, 2H), 2.03(m, 2H), 2.17(t, 6H), 2.28(t, 6H),

2.98-3.1(m, 8H), 3.78(s,br, 1H), 4.05(q, 2H), 6.41(m, 4H), 6.60(m, 4H), 7.39(m, 4H), 7.78(t, 1H), 8.83(m, 1H), 8.80(m, 1H), 9.05(t, 2H). MS(FAB+, NBA): 966.4 (MH⁺). Anal for C₄₃H₅₅N₁₁O₁₅·HCl·4H₂O (1074.48), Calcd.(Found): C, 48.07(48.34); H, 6.00(6.09); N, 14.34(14.00)

5 **3,4,3-LI-1,2-HOPOBn**

[0324] To a solution of spermine (1.01 g, 5 mmol) in dichloromethane (50 mL) 10 mL of 40% potassium carbonate was added. The mixture was cooled with an ice bath and vigorously stirred. A solution of raw 1,2-HOPOBn acid chloride (from 5.4 g 1,2-HOPOBn acid, 25 mmol) in dichloromethane (50 mL) was added slowly via a Teflon tube equipped with a glass capillary tip over a period of 1 hr. The reaction mixture was allowed to warm to room temperature and stirred overnight. The mixture was then washed with 1 M NaOH (100 mL), 1 M HCL (100 mL), and saline (100 mL) successively. The organic phase was loaded onto a flash silica column. Elution with 2-6% methanol in methylene chloride allows the separation of the benzyl-protected precursor 3,4,3-LI-1,2-HOPOBn as white foam, yield 80%.

[0325] ¹H NMR (400MHz, DMSO-d₆): δ 0.4-1.8(m, 16H), 2.8-3.6(m, 24H), 4.8-5.1(m, 2H), 4.88-5.05(m, 2H), 5.15-5.30(m, 4H), 5.30-5.45(m, 2H), 6.00-6.46(m, 4H), 6.55-6.70(m, 4H), 7.25-7.55(m, 24H), 8.72-8.95(m, 2H, NH).. MS(FAB+): 1111.5(MH⁺).

3,4,3-LI-1,2-HOPO

20 [0326] The precursor 3,4,3-LI-1,2-HOPOBn was deprotected with 1:1 HCl(37%)/glacial HOAc for 2 days. The deprotection time could be reduced to few hours if elevated temperature (up to 50 °C) was used. All the volatiles were removed in vacuo, the residue was dissolved in minimum amount of methanol and precipitated with ether. The product was filtered and dried under vacuum, yield 91%.

25 [0327] ¹H NMR (400MHz, DMSO-d₆): δ 0.4-1.7(m, 16H), 2.8-3.6(m, 24H), 6.1-6.25(m, 6H), 6.25-6.35(m, 2H), 6.45-6.55(m, 8H), 7.31-7.42(m, 4H), 8.822(q, 1H). 8.912(q, 1H). MS(FAB+): 751(MH⁺). Anal for C₃₄H₃₈N₈O₁₂·H₂O·2HCl (841.68), Calcd. (found): C, 48.52 (48.16); H, 5.03(4.82); N, 13.31 (13.23).

Synthesis of 1,2-HOPO Functional Polystyrene resin

30 [0328] 1,2-HOPO acid (700 mg) and CDI were stirred in DMF under nitrogen for 2 hr. The dien Merrifield resin (Suzuki, T.M.; Yokoyama, T. Polyhedron 1984, 3, 939-945.) was

added, and the suspension stirred for 4 days. The resin was collected by filtration and washed with methanol (3 x 50 mL) and acetone (3 x 50 mL), then dried in vacuo at 70 °C, yield 60%. The resin was then treated with 10 mL concentrated sulfuric acid containing catalytic amount of silver sulfate (50 mg) for 4 hr. The sulfonated resin was collected by
 5 filtration, washed with anhydrous dioxane (3 x 50 mL), methanol (3 x 50 mL), and water (4 x 50 mL) successively. The product was then dried in vacuo at 70 °C for 4 hr. IR(KBr pellet) ν 1653 (s, C=O) cm^{-1} . Anal. Found: C, 80.15; H, 7.32, N, 5.39.

Synthesis of Functional Water Soluble Polymer Bearing 1,2-HOPO Units:

[0329] To a solution of 1.7 g commercially available water soluble polyamine polymer, PEI
 10 (average molecular weight = 30 K Dalton) in dry DMF (50 mL), was added 3.46 g of 1,2-HOPOBn-thiazolide. The solution was stirred at room temperature for 24 h. The solvent was removed and the residue was dissolved in 50 mL of water containing 1 mL of glacial acetic acid. The solution was extracted with methylene chloride 3 times to remove the byproducts and evaporated to dryness. The residue was dissolved in 20 mL of a 1:1 mixture
 15 of glacial acetic acid and hydrochloric acid (37%). The mixture was stirred at room temperature for 2 days, and evaporated to dryness, Yield: 85% to 90%. Initial testing indicated this water-soluble polymer shows strong affinity towards lanthanide and actinides ions.

[0330]

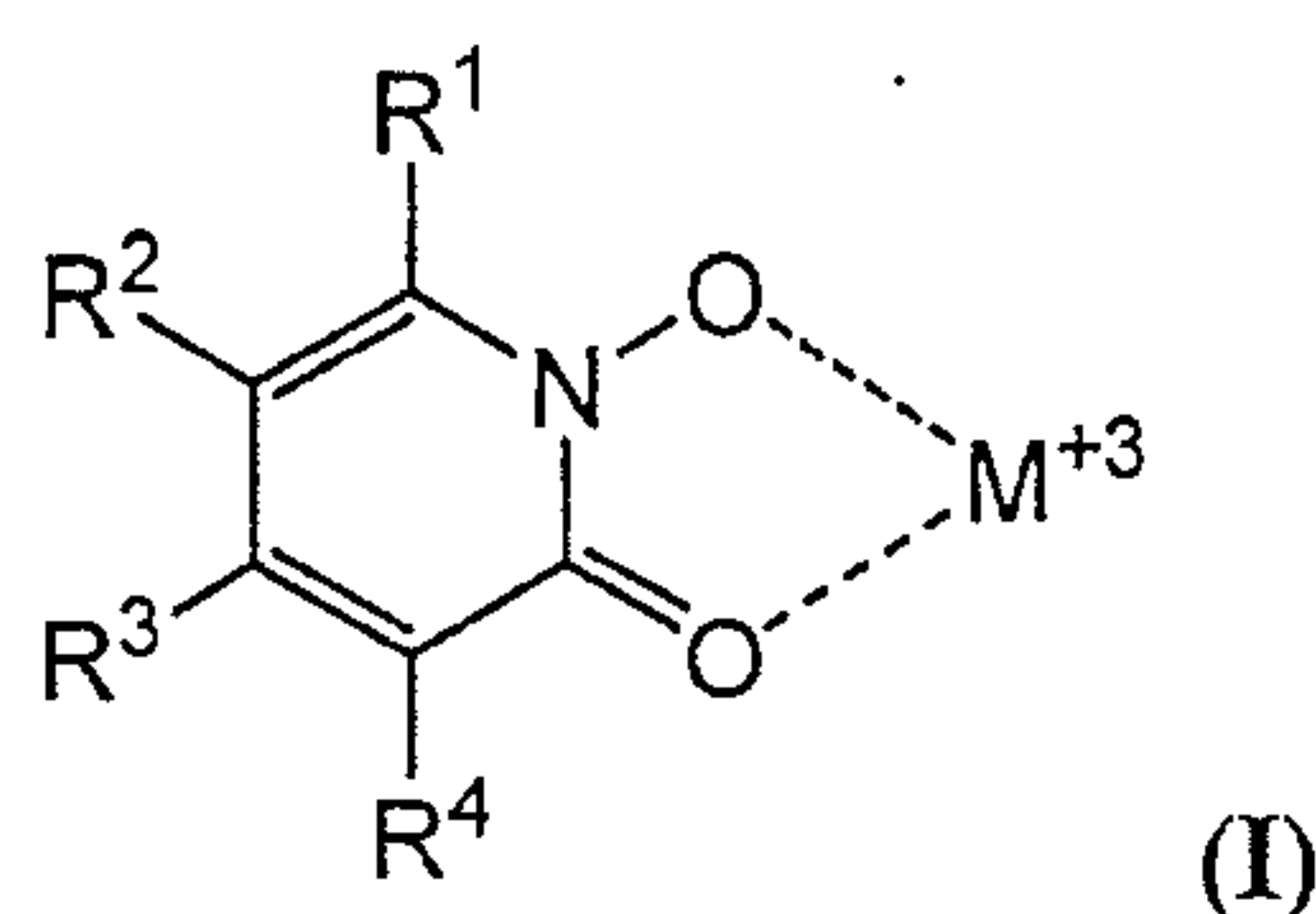
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By their citation of various references in this document, Applicants do not admit any particular reference is "prior art" to their invention.

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CLAIMS

1. A luminescent complex between a lanthanide ion and an organic ligand comprising the subunit of Formula I:

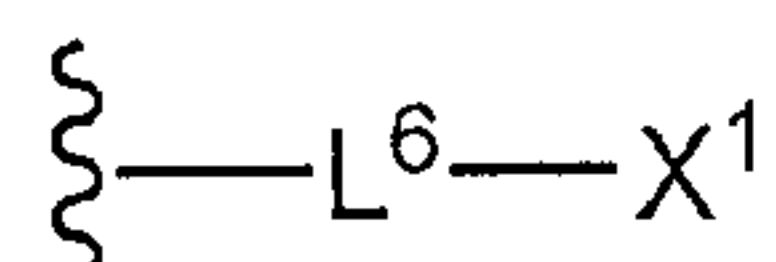


wherein

R^1 , R^2 , R^3 , and R^4 are members independently selected from H, an aryl group substituent, a linker to a scaffold moiety, and a linker to a functional moiety; wherein the linker of said linker to the scaffold moiety is a member selected from $-C(O)NR^5-$, $-C(O)O-$, $-C(O)S-$, and $-C(O)CR^{20}R^{21}$, wherein R^5 , R^{20} , and R^{21} are members independently selected from H, substituted or unsubstituted alkyl, substituted or unsubstituted heteroalkyl, substituted or unsubstituted aryl, substituted or unsubstituted heteroaryl, and substituted or unsubstituted heterocycloalkyl; wherein said scaffold moiety is a member selected from substituted or unsubstituted alkyl and substituted or unsubstituted heteroalkyl; wherein at least one of R^1 , R^2 , R^3 , and R^4 is said linker to the scaffold moiety; M^{+3} is a lanthanide ion forming said luminescent complex with said organic ligand, wherein said lanthanide is a member selected from Neodymium (Nd), Samarium (Sm), Europium (Eu), Terbium (Tb), Dysprosium (Dy), and Ytterbium (Yb);

wherein said complex is substituted with at least one functional moiety;

wherein said functional moiety comprises the structure:



wherein

L^6 is a member selected from substituted or unsubstituted alkyl, substituted or unsubstituted heteroalkyl, substituted or unsubstituted heterocycloalkyl, substituted or unsubstituted aryl, and substituted or unsubstituted heteroaryl; and

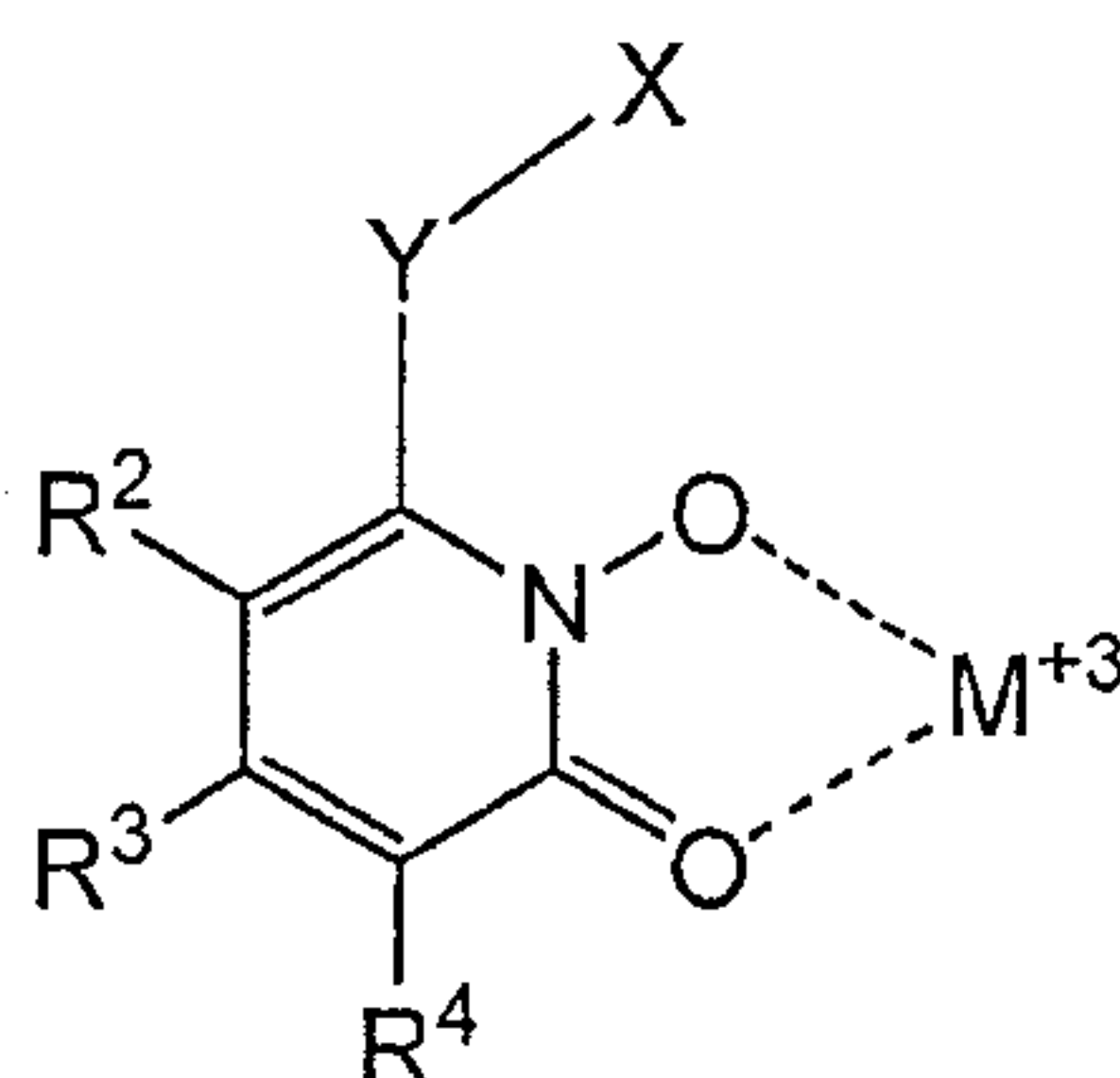
X^1 is a reactive functional group or a targeting moiety;

wherein said reactive functional group is a member selected from $-OH$, $-SH$, $-NH_2$, $-C(O)NHNH_2$ (hydrazide), maleimide, activated ester, aldehyde, ketone, hydroxylamine, imidoester, isocyanate, isothiocyanate, sulfonylchloride, acylhalide, $-COOH$, and $-COO^-$ or a salt thereof; and

wherein said targeting moiety comprises a member selected from a peptide, a protein, a fusion protein, an enzyme, an antibody, an antibody fragment, an antigen, a nucleic acid, a carbohydrate, a lipid, and a pharmacologically active molecule; and

wherein "alkyl" is defined as comprising a straight, branched, or cyclic alkyl or a mono-, di- or multivalent radical thereof, which is fully saturated, monounsaturated or polyunsaturated.

2. The luminescent complex according to claim 1, wherein said subunit of Formula I has the structure:

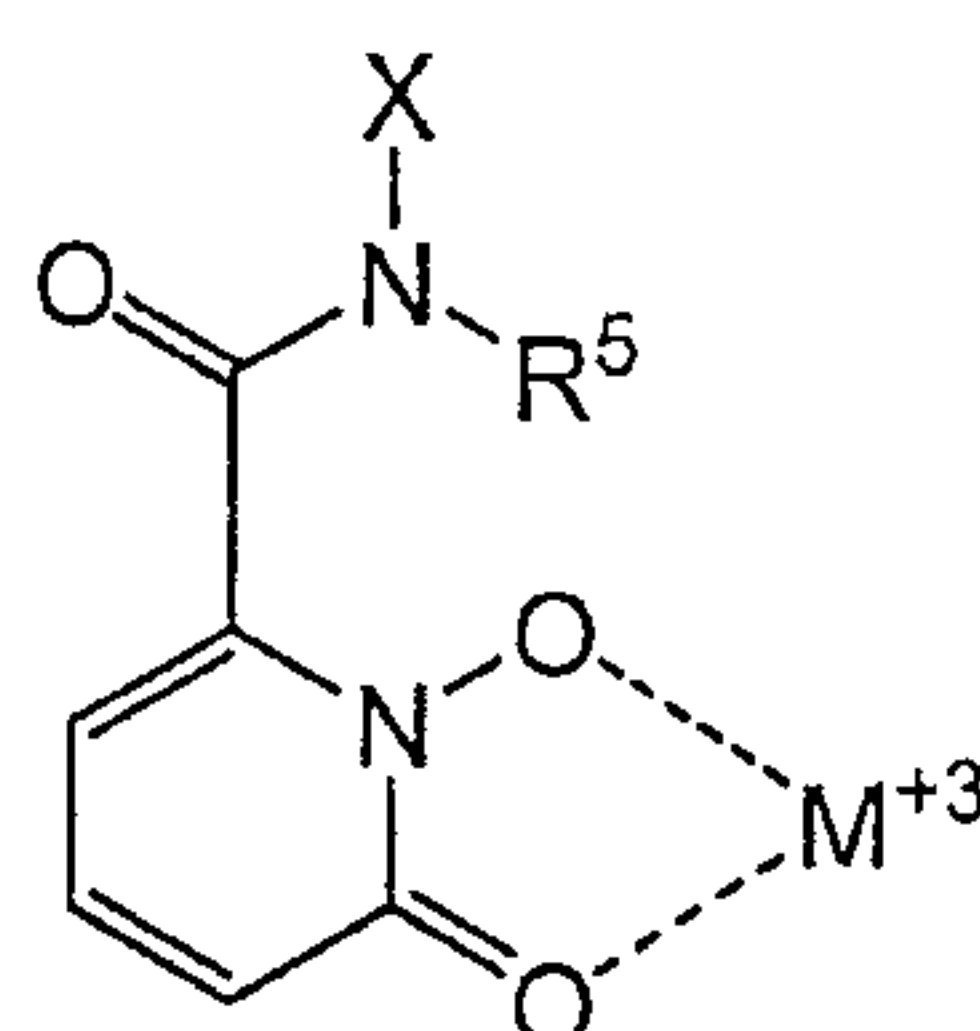


wherein

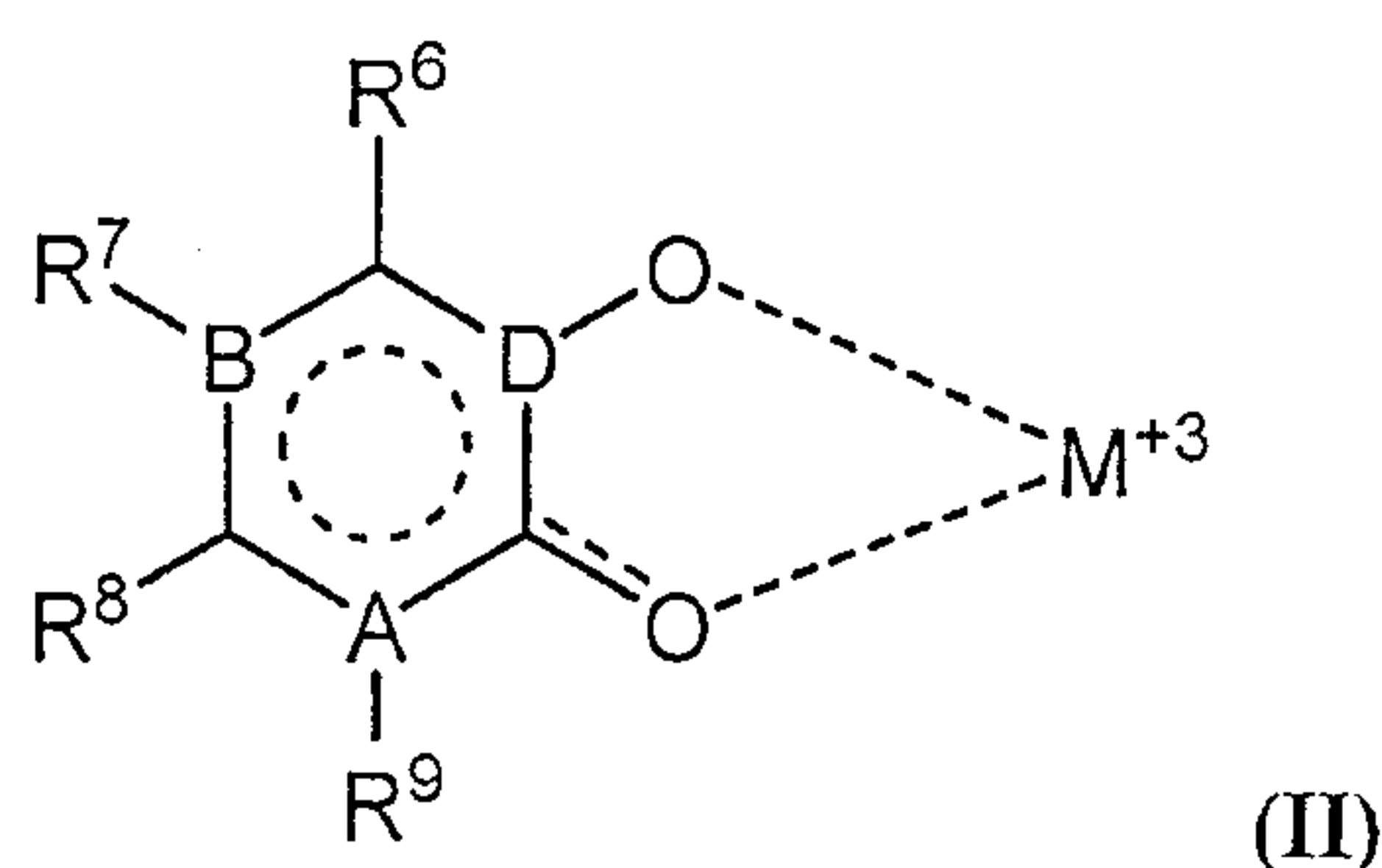
X is said scaffold moiety; and

Y is said linker to the scaffold moiety.

3. The luminescent complex according to claim 2, wherein said subunit of Formula I has the structure:



4. The luminescent complex according to claim 1, 2 or 3, further comprising one or more chelating moieties, wherein each of said chelating moieties is complexed to said lanthanide ion and each of said chelating moieties has an independently selected structure according to Formula II:



wherein for each chelating moiety,

R^6 , R^7 , R^8 , and R^9 are members independently selected from H, substituted or unsubstituted alkyl, substituted or unsubstituted heteroalkyl, substituted or unsubstituted aryl, substituted or unsubstituted heteroaryl, substituted or unsubstituted heterocycloalkyl, halogen, CN, CF_3 , $-C(O)R^{17}$, $-SO_2NR^{17}R^{18}$, $-NR^{17}R^{18}$, $-OR^{17}$, $-S(O)_2R^{17}$, $-COOR^{17}$, $-S(O)_2OR^{17}$, $-OC(O)R^{17}$, $-C(O)NR^{17}R^{18}$, $-NR^{17}C(O)R^{18}$, $-NR^{17}SO_2R^{18}$, $-NO_2$, a linker to a functional moiety as defined in claim 1, and a linker to a scaffold moiety;

wherein

zero or at least two of R^6 , R^7 , R^8 , and R^9 are joined to form a ring system which is a member selected from substituted or unsubstituted cycloalkyl, substituted or unsubstituted heterocycloalkyl,

substituted or unsubstituted aryl, and substituted or unsubstituted heteroaryl;

R^{17} and R^{18} are each members independently selected from H, substituted or unsubstituted alkyl, substituted or unsubstituted heteroalkyl, substituted or unsubstituted aryl, substituted or unsubstituted heteroaryl, substituted or unsubstituted heterocycloalkyl, a linker to a functional moiety, and a linker to a scaffold moiety; and R^{17} and R^{18} , together with the atoms to which they are attached, are joined to form a 5- to 7-membered ring or are not so joined;

A and B are members independently selected from C, N, S, and O; and

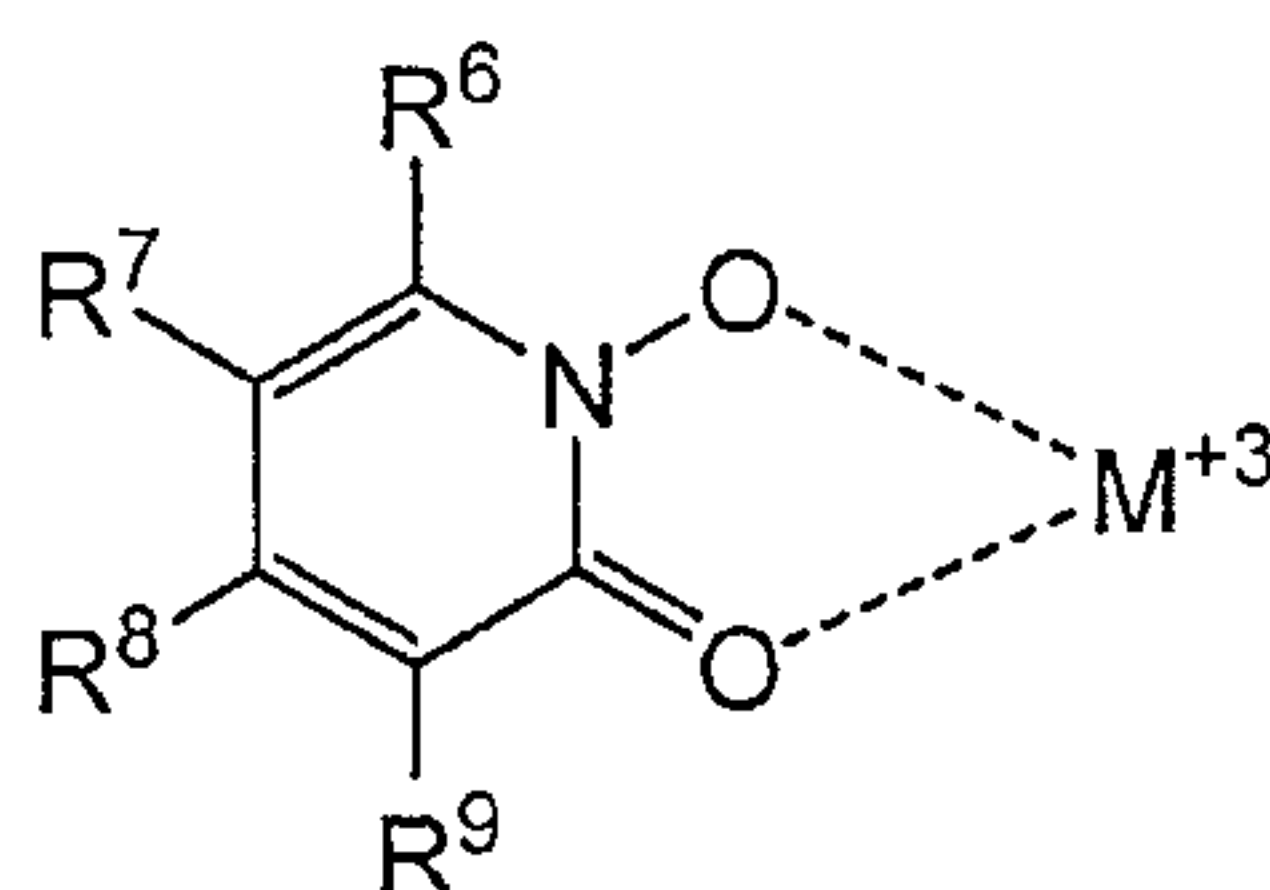
D is a member selected from C and N,

with the proviso that if A is O or S, R^9 is not present, and with the further proviso that if

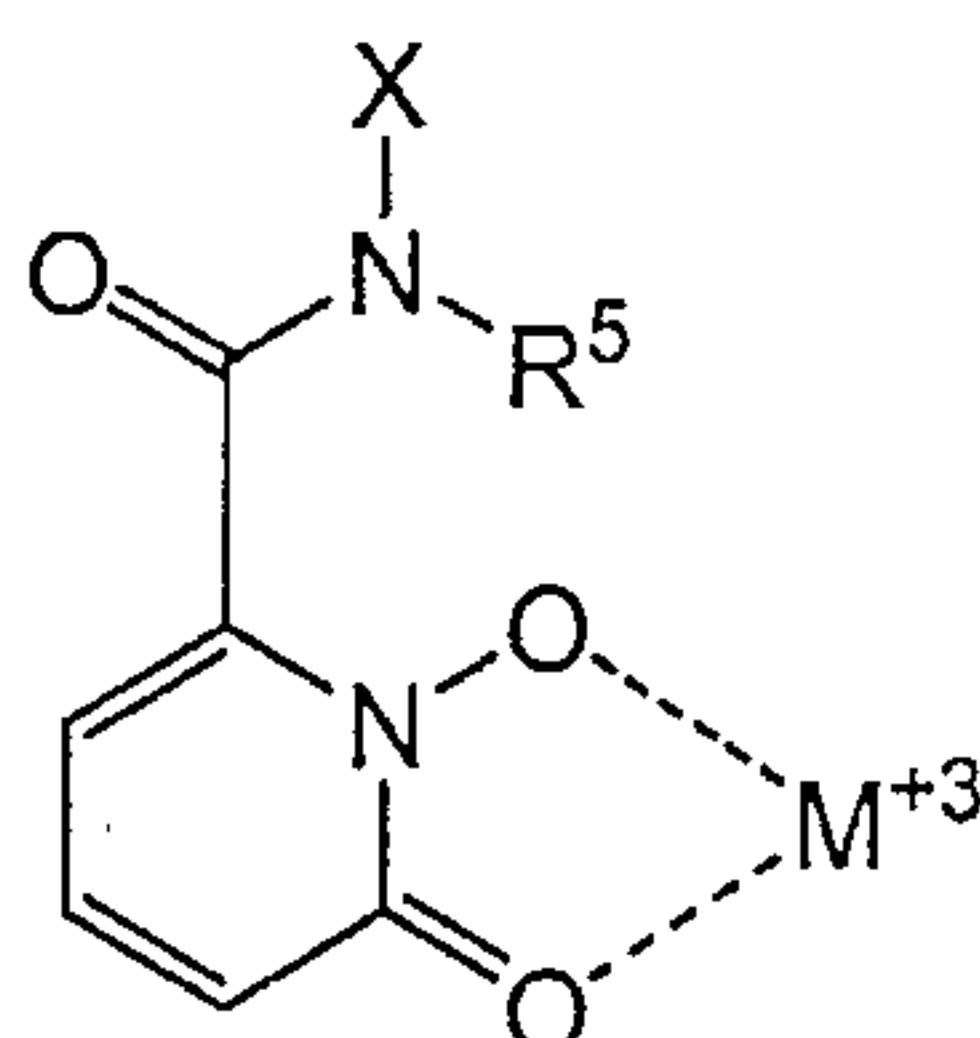
B is O or S, R^7 is not present; and

wherein "alkyl" is as defined in claim 1.

5. The luminescent complex according to claim 4, wherein at least one of said chelating moieties has the structure:



6. The luminescent complex according to claim 5, wherein the at least one of said chelating moieties has the structure:

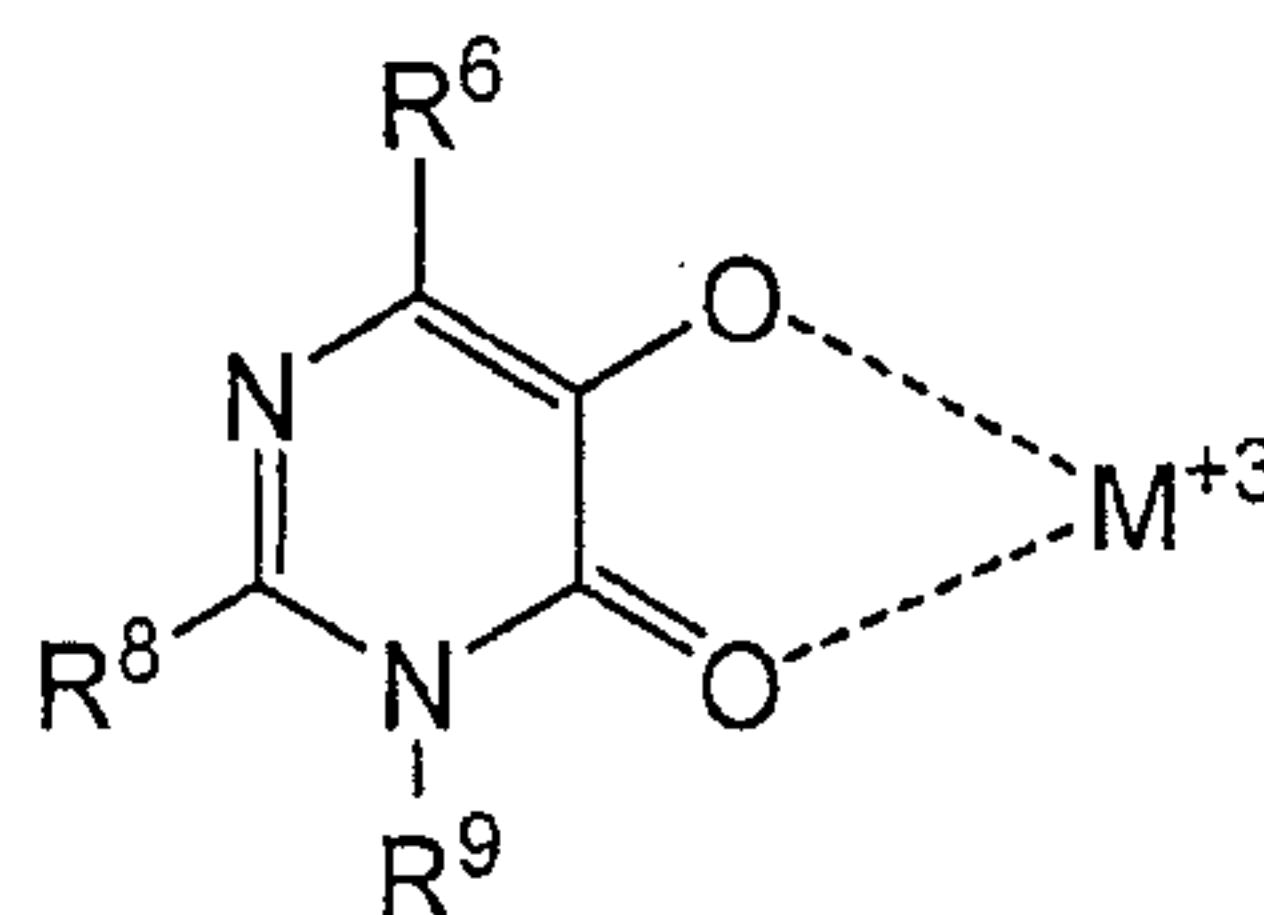


wherein

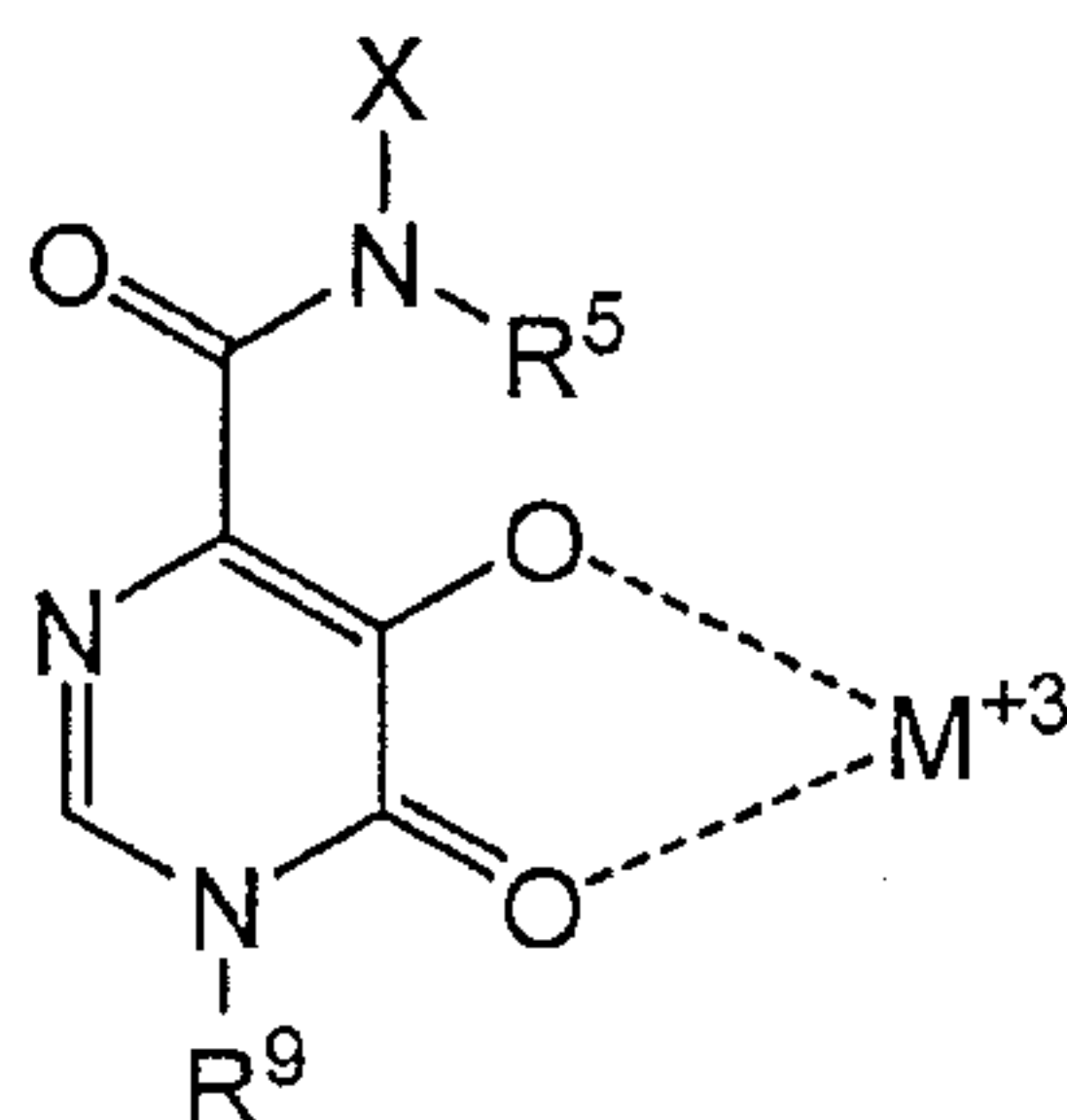
X is said scaffold moiety; and

R^5 is a member selected from H, substituted or unsubstituted alkyl, substituted or unsubstituted heteroalkyl, substituted or unsubstituted aryl, substituted or unsubstituted heteroaryl, and substituted or unsubstituted heterocycloalkyl.

7. The luminescent complex according to claim 4, wherein at least one of said chelating moieties has the structure:



8. The luminescent complex according to claim 7, wherein the at least one of said chelating moieties has the structure:

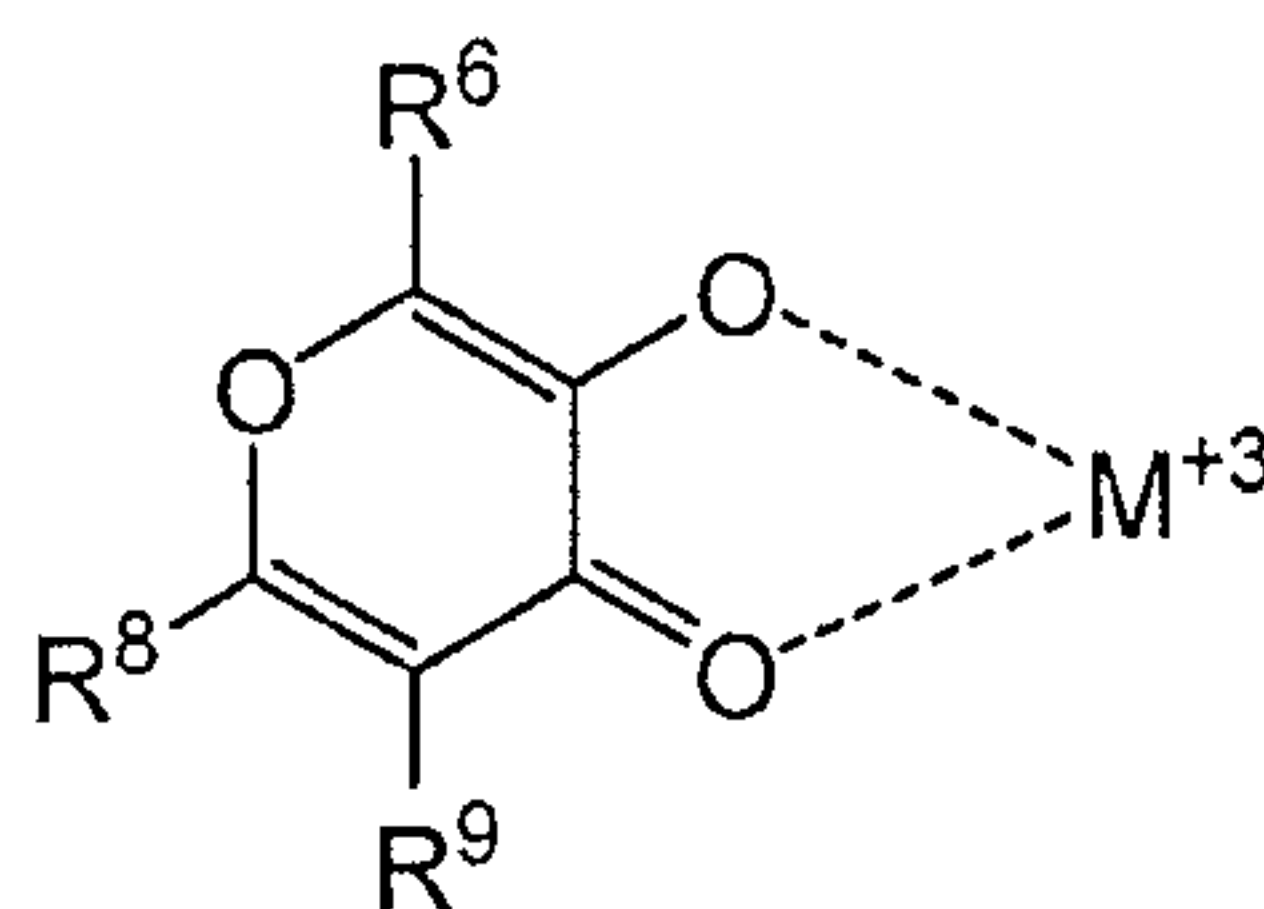


wherein

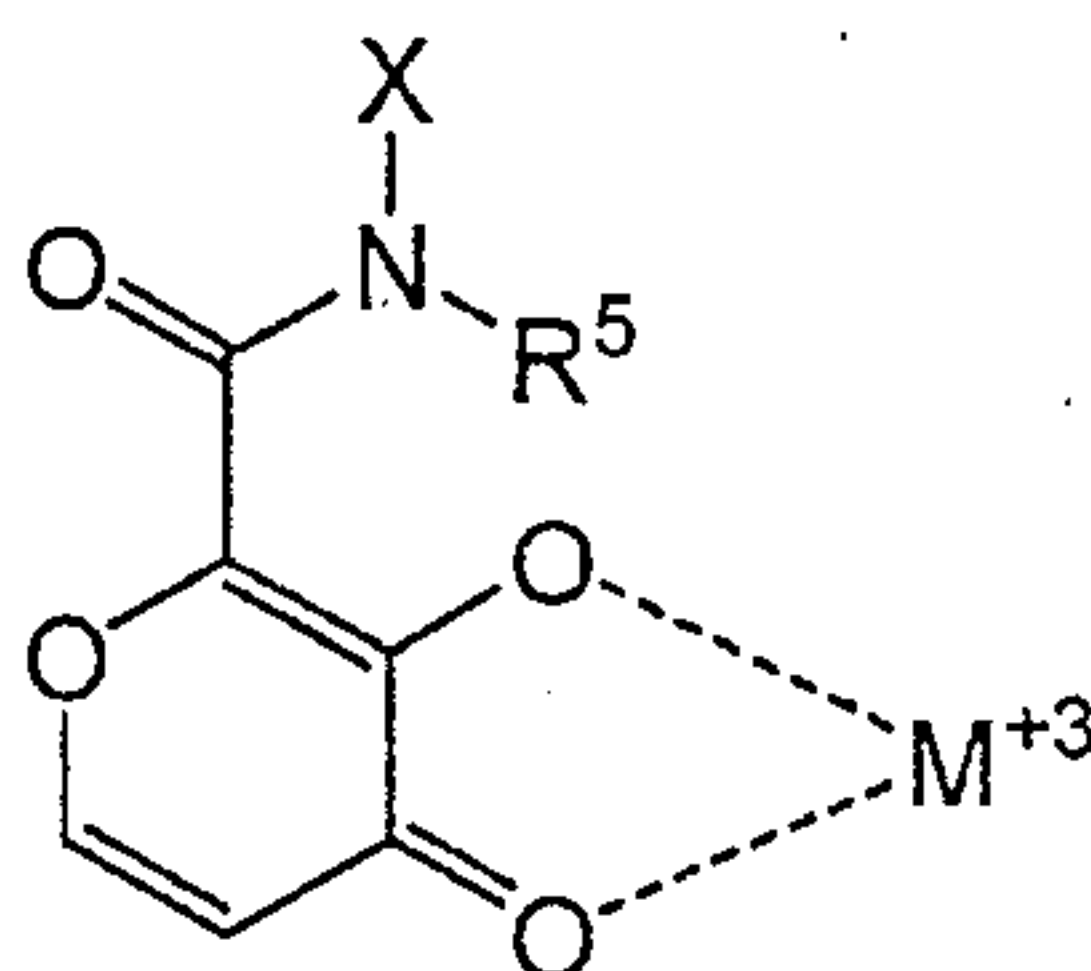
X is said scaffold moiety; and

R^5 is a member selected from H, substituted or unsubstituted alkyl, substituted or unsubstituted heteroalkyl, substituted or unsubstituted aryl, substituted or unsubstituted heteroaryl, and substituted or unsubstituted heterocycloalkyl.

9. The luminescent complex according to claim 4, wherein at least one of said chelating moieties has the structure:



10. The luminescent complex according to claim 9, wherein the at least one of said chelating moieties has the structure:

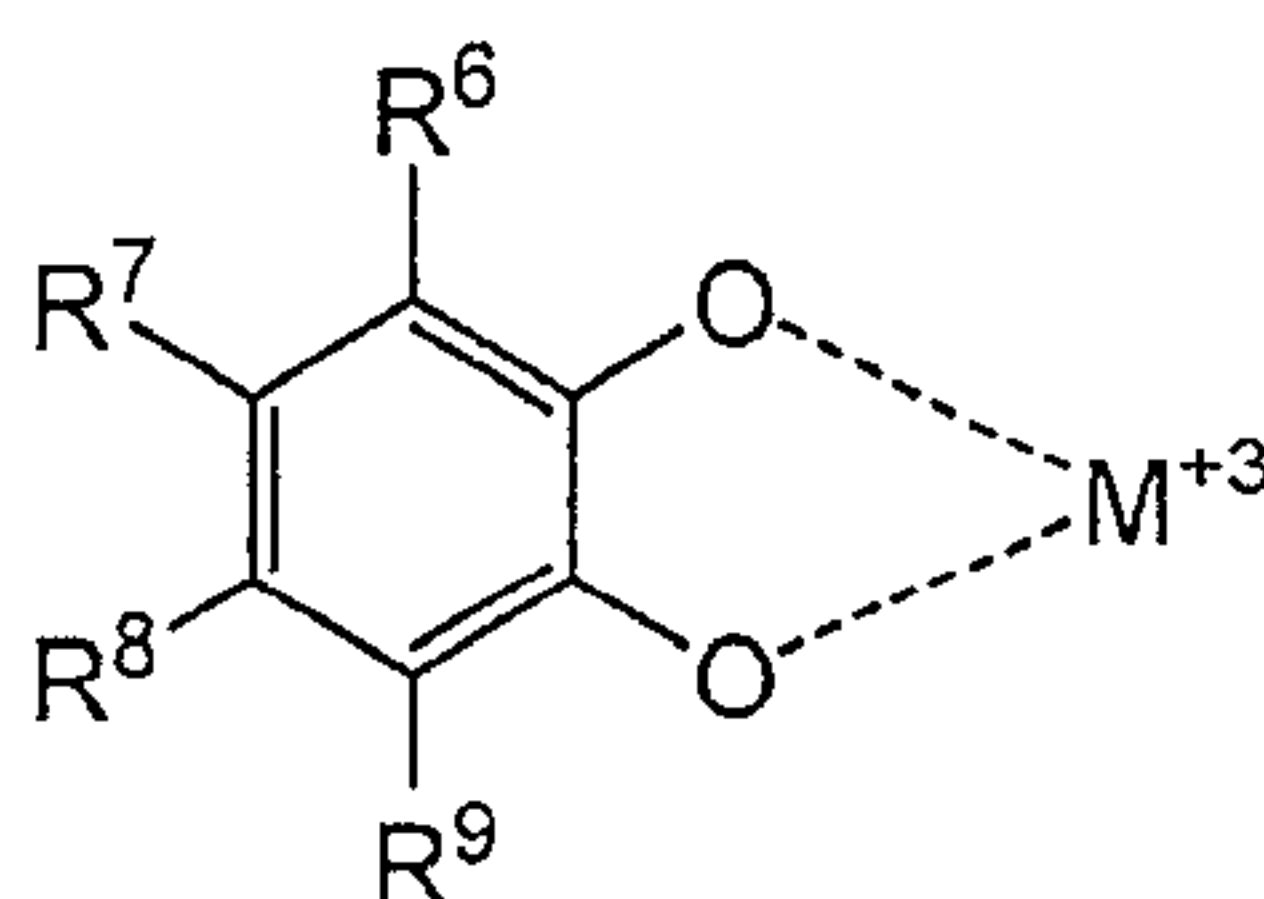


wherein

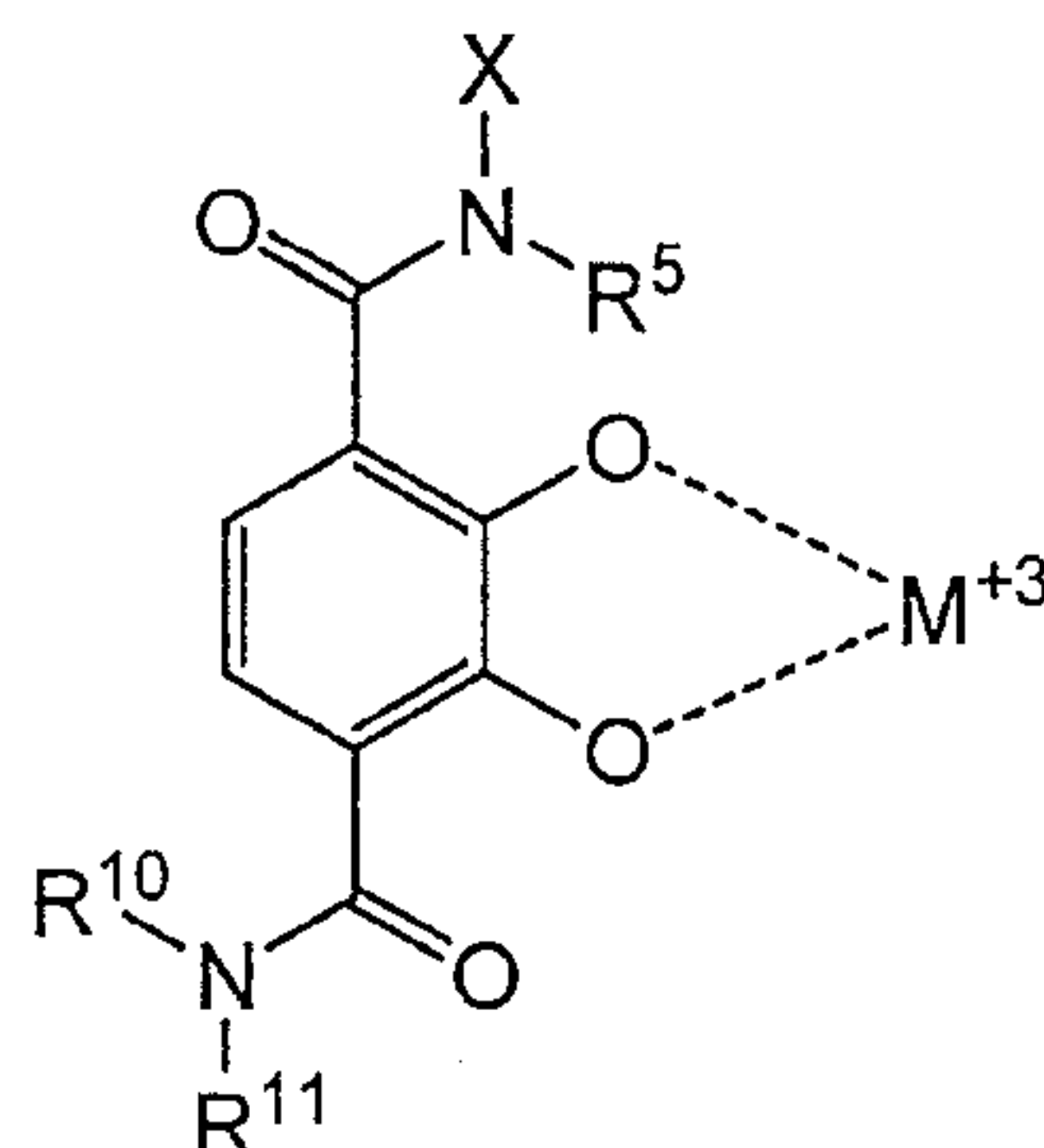
X is said scaffold moiety; and

R⁵ is a member selected from H, substituted or unsubstituted alkyl, substituted or unsubstituted heteroalkyl, substituted or unsubstituted aryl, substituted or unsubstituted heteroaryl, and substituted or unsubstituted heterocycloalkyl.

11. The luminescent complex according to claim 4, wherein at least one of said chelating moieties has the structure:



12. The luminescent complex according to claim 11, wherein the at least one of said chelating moieties has the structure:



wherein

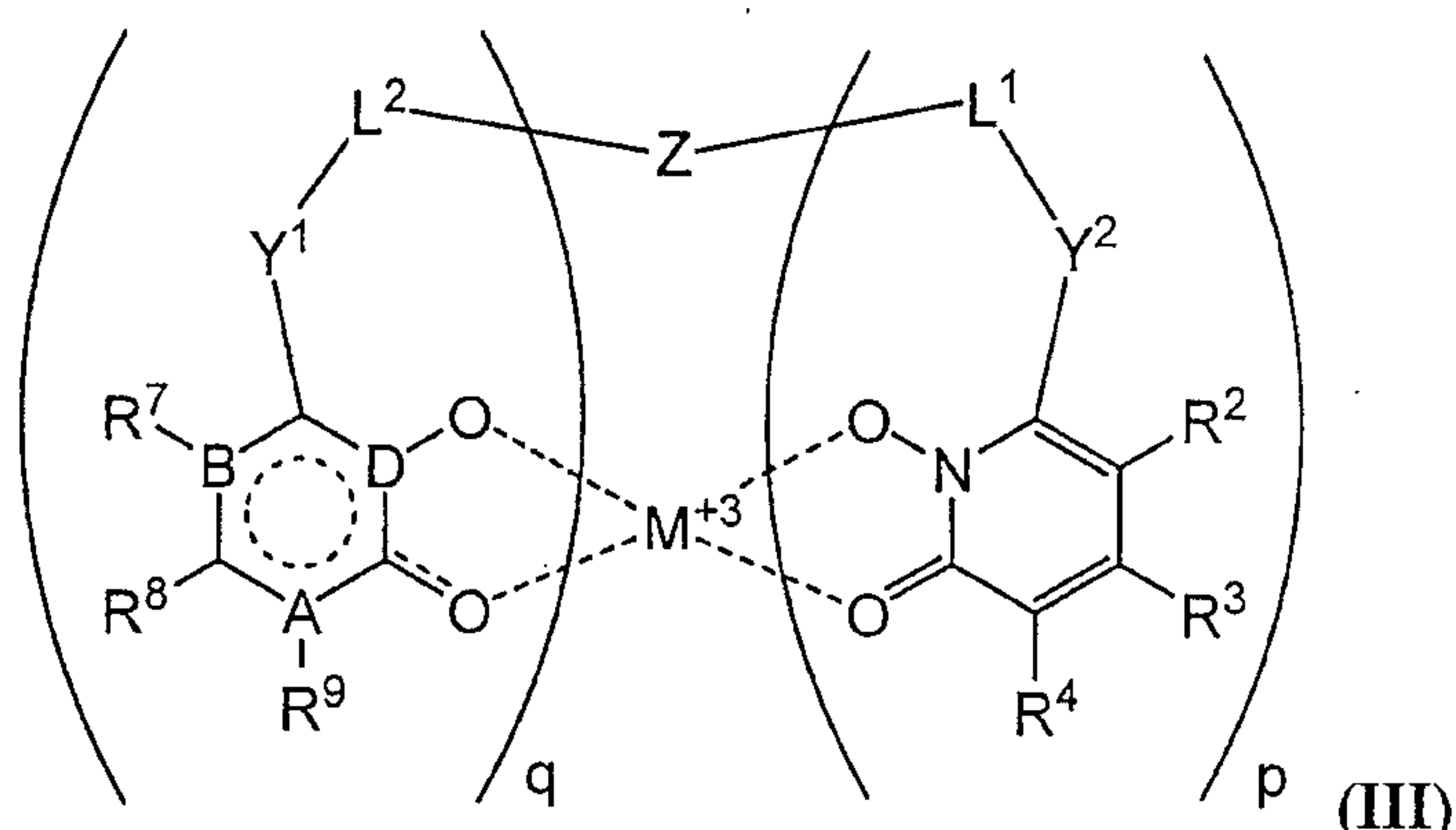
X is said scaffold moiety;

R^5 and R^{10} are members independently selected from H, substituted or unsubstituted alkyl, substituted or unsubstituted heteroalkyl, substituted or unsubstituted aryl, substituted or unsubstituted heteroaryl, and substituted or unsubstituted heterocycloalkyl; and

R^{11} is a member selected from H, substituted or unsubstituted alkyl, substituted or unsubstituted heteroalkyl, substituted or unsubstituted aryl, substituted or unsubstituted heteroaryl, substituted or unsubstituted heterocycloalkyl, and a functional moiety.

13. The luminescent complex according to claim 4, 5, 7, 8, 9, or 11, wherein R^9 is H or C_1 - C_6 alkyl.
14. The luminescent complex according to any one of claims 4 to 13, wherein at least one of R^1 , R^2 , R^3 , and R^4 in Formula I is covalently linked to a scaffold moiety, wherein said scaffold moiety is covalently linked to at least one of said chelating moieties of Formula II.
15. The luminescent complex according to any one of claims 1 to 14, wherein each linker to the functional moiety is independently a bond, or a member selected from $-C(O)NR^5-$, $-C(O)O-$, $-C(O)S-$, and $-C(O)CR^{20}R^{21}$, wherein R^5 , R^{20} , and R^{21} are members independently selected from H, substituted or unsubstituted alkyl, substituted or unsubstituted heteroalkyl, substituted or unsubstituted aryl, substituted or unsubstituted heteroaryl, and substituted or unsubstituted heterocycloalkyl.

16. The luminescent complex according to any one of claims 1 to 15, wherein said organic ligand comprises 8 or more donor oxygen atoms interacting with said lanthanide ion.
17. The luminescent complex according to claim 16, wherein none of the donor oxygen atoms is part of a carboxylate group.
18. A luminescent complex having a structure according to Formula (III):



wherein

Z is a member selected from substituted or unsubstituted alkyl, substituted or unsubstituted heteroalkyl, substituted or unsubstituted aryl, substituted or unsubstituted heteroaryl, substituted or unsubstituted heterocycloalkyl, N, NR^{30} , O, S, and $\text{CR}^{31}\text{R}^{32}$,

wherein

R^{30} , R^{31} , and R^{32} are members independently selected from H, substituted or unsubstituted alkyl, substituted or unsubstituted heteroalkyl, substituted or unsubstituted aryl, substituted or unsubstituted heteroaryl, and substituted or unsubstituted heterocycloalkyl;

M^{+3} is a lanthanide ion, wherein said lanthanide is a member selected from Neodymium (Nd), Samarium (Sm), Europium (Eu), Terbium (Tb), Dysprosium (Dy), and Ytterbium (Yb);

p is an integer selected from 1-3;

q is an integer selected from 0-2;

Y^1 and Y^2 are members independently selected from $-\text{C}(\text{O})$, $-\text{C}(\text{O})\text{NR}^5$, $-\text{C}(\text{O})\text{O}-$,

-C(O)S-, and $-C(O)CR^{20}R^{21}$, wherein R^5 , R^{20} , and R^{21} are members independently selected from H, substituted or unsubstituted alkyl, substituted or unsubstituted heteroalkyl, substituted or unsubstituted aryl, substituted or unsubstituted heteroaryl, substituted or unsubstituted heterocycloalkyl, and a functional moiety; and

L^1 and L^2 are members independently selected from a bond, substituted or unsubstituted alkyl, substituted or unsubstituted heteroalkyl, substituted or unsubstituted aryl, substituted or unsubstituted heteroaryl, and substituted or unsubstituted heterocycloalkyl,

each R^2 , R^3 , and R^4 are members independently selected from H, an aryl group substituent, a linker to a scaffold moiety, and a linker to a functional moiety;

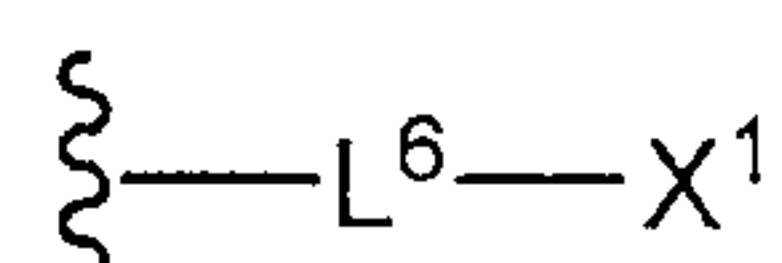
each R^7 , R^8 , and R^9 are members independently selected from H, substituted or unsubstituted alkyl, substituted or unsubstituted heteroalkyl, substituted or unsubstituted aryl, substituted or unsubstituted heteroaryl, substituted or unsubstituted heterocycloalkyl, halogen, CN, CF_3 , $-C(O)R^{17}$, $-SO_2NR^{17}R^{18}$, $-NR^{17}R^{18}$, $-OR^{17}$, $-S(O)_2R^{17}$, $-COOR^{17}$, $-S(O)_2OR^{17}$, $-OC(O)R^{17}$, $-C(O)NR^{17}R^{18}$, $-NR^{17}C(O)R^{18}$, $-NR^{17}SO_2R^{18}$, $-NO_2$, a linker to a functional moiety, and a linker to a scaffold moiety,

wherein

zero of or at least two of R^7 , R^8 , and R^9 are joined to form a ring system which is a member selected from substituted or unsubstituted cycloalkyl, substituted or unsubstituted heterocycloalkyl, substituted or unsubstituted aryl, and substituted or unsubstituted heteroaryl,

R^{17} and R^{18} are each members independently selected from H, substituted or unsubstituted alkyl, substituted or unsubstituted heteroalkyl, substituted or unsubstituted aryl, substituted or unsubstituted heteroaryl, substituted or unsubstituted heterocycloalkyl, a linker to a functional moiety, and a linker to a scaffold moiety, and R^{17} and R^{18} , together with the atoms to which they are attached, are joined to form a 5- to 7-membered ring or are not so joined;

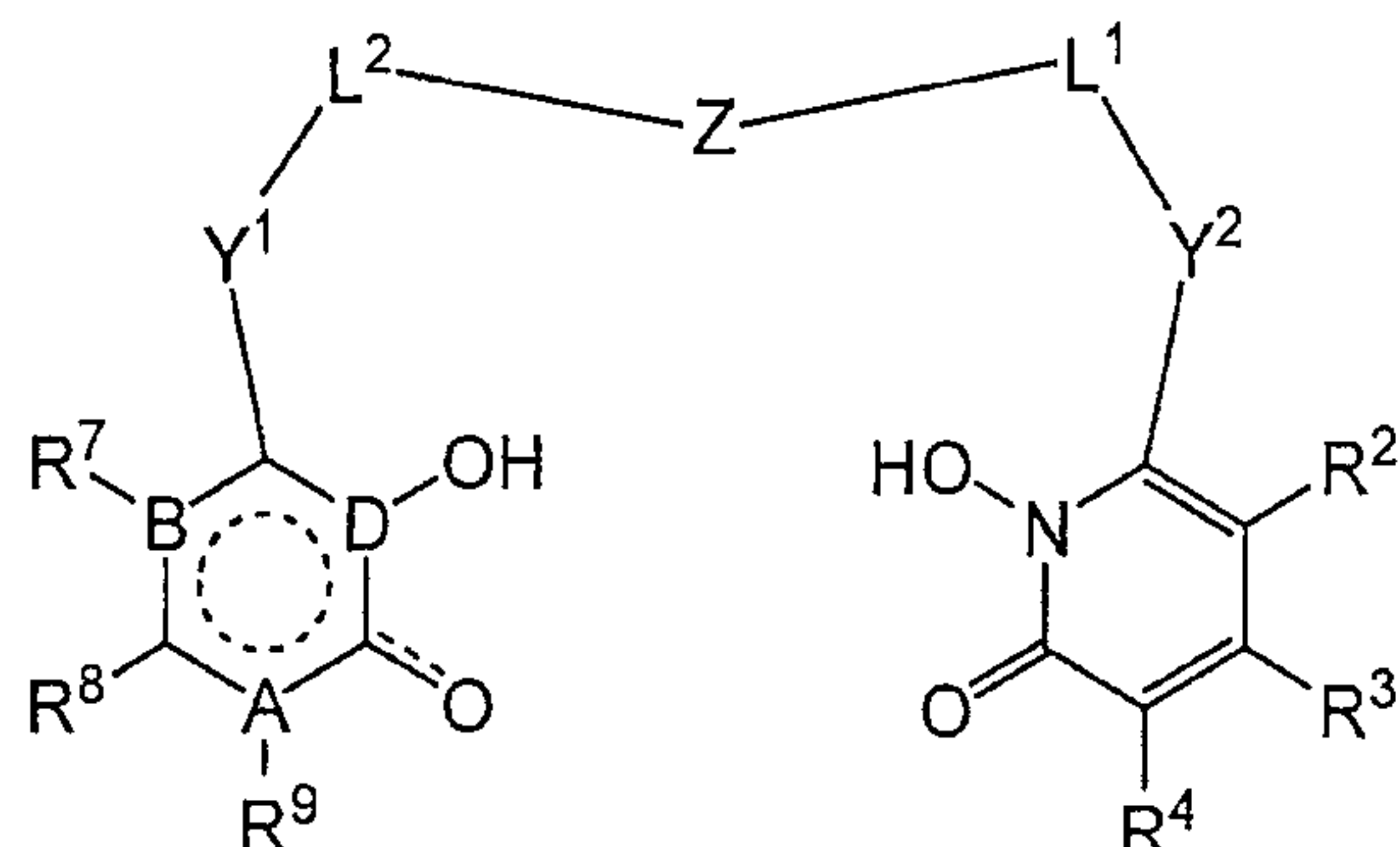
wherein each scaffold moiety is independently a member selected from substituted or unsubstituted alkyl and substituted or unsubstituted heteroalkyl;
 each A and B are members independently selected from C, N, S, and O; and
 each D is a member selected from C and N,
 with the proviso that if A is O or S, R⁹ is not present, and with the further proviso that if B is O or S, R⁷ is not present;
 with the proviso that the sum of p and q is not greater than 4, and with the further proviso that if Z is O or S, the sum of p and q is not greater than 2; and
 wherein said complex is substituted with at least one functional moiety;
 wherein each functional moiety comprises the structure:



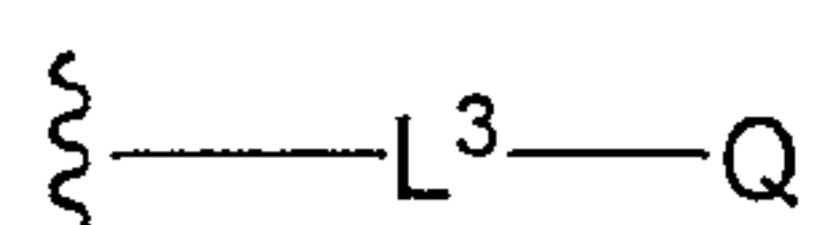
wherein

L⁶ is a member selected from substituted or unsubstituted alkyl, substituted or unsubstituted heteroalkyl, substituted or unsubstituted heterocycloalkyl, substituted or unsubstituted aryl, and substituted or unsubstituted heteroaryl; and
 X¹ is a reactive functional group or a targeting moiety;
 wherein said reactive functional group is a member selected from —OH, —SH, —NH₂, —C(O)NHNH₂ (hydrazide), maleimide, activated ester, aldehyde, ketone, hydroxylamine, imidoester, isocyanate, isothiocyanate, sulfonylchloride, acylhalide, —COOH, and —COO[−] or a salt thereof; and
 wherein said targeting moiety comprises a member selected from a peptide, a protein, a fusion protein, an enzyme, an antibody, an antibody fragment, an antigen, a nucleic acid, a carbohydrate, a lipid, and a pharmacologically active molecule;
 and
 wherein “alkyl” is defined as comprising a straight, branched, or cyclic alkyl or a mono-, di- or multivalent radical thereof, which is fully saturated, monounsaturated or polyunsaturated.

19. The luminescent complex according to claim 18, wherein the organic ligand has the structure:



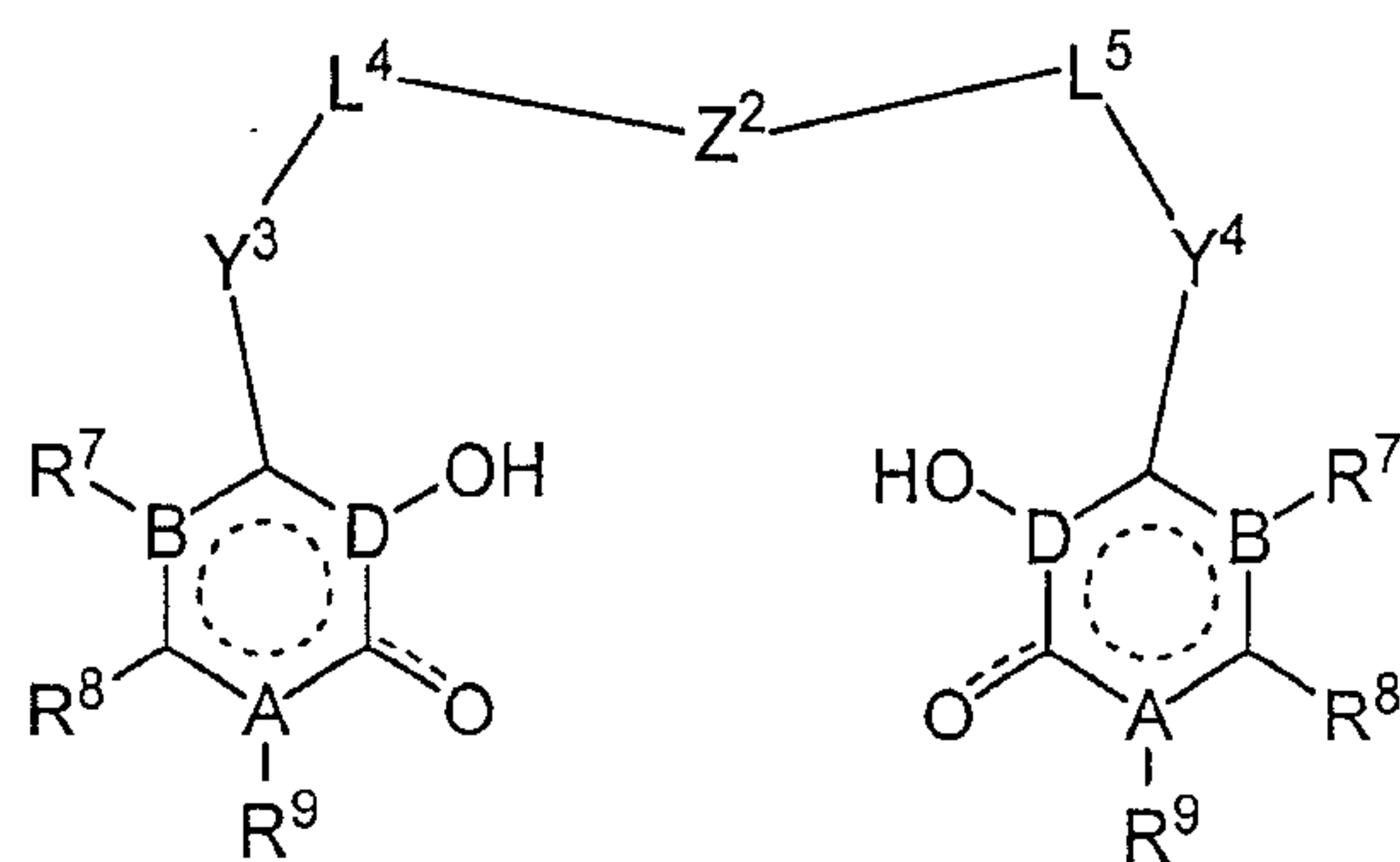
wherein at least one of Z, L¹, and L² is substituted with a moiety having the structure:



wherein

L³ is a member selected from a bond, substituted or unsubstituted alkyl, substituted or unsubstituted heteroalkyl, substituted or unsubstituted aryl, substituted or unsubstituted heteroaryl, and substituted or unsubstituted heterocycloalkyl;

Q has the structure:



wherein

Z² is a member selected from substituted or unsubstituted alkyl, substituted or unsubstituted heteroalkyl, substituted or unsubstituted aryl, substituted or unsubstituted heteroaryl, substituted or unsubstituted heterocycloalkyl, N, NR³⁰, O, S, and CR³¹R³²,

wherein

R^{30} , R^{31} , and R^{32} are members independently selected from H, substituted or unsubstituted alkyl, substituted or unsubstituted heteroalkyl, substituted or unsubstituted aryl, substituted or unsubstituted heteroaryl, and substituted or unsubstituted heterocycloalkyl;

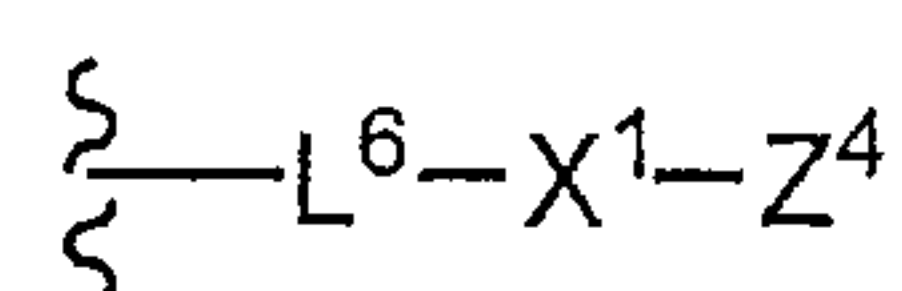
Y^3 and Y^4 are members independently selected from $-C(O)$, $-C(O)NR^5$, $-C(O)O-$, $-C(O)S-$, and $-C(O)CR^{20}R^{21}$, wherein R^5 , R^{20} , and R^{21} are members independently selected from H, substituted or unsubstituted alkyl, substituted or unsubstituted heteroalkyl, substituted or unsubstituted aryl, substituted or unsubstituted heteroaryl, substituted or unsubstituted heterocycloalkyl, and said functional moiety;

L^4 and L^5 are members independently selected from a bond, substituted or unsubstituted alkyl, substituted or unsubstituted heteroalkyl, substituted or unsubstituted aryl, substituted or unsubstituted heteroaryl, and substituted or unsubstituted heterocycloalkyl; and one of Z^2 , L^4 , and L^5 is linked to L^3 .

20. The luminescent complex according to claim **18** or **19**, wherein Z is O and L^1 and L^2 are each ethyl.

21. The luminescent complex according to any one of claims **1** to **20**, wherein said functional moiety comprises a luminescence modifying group allowing luminescence energy transfer between said complex and said luminescence modifying group when said complex is excited.

22. The luminescent complex according to any one of claims **1** to **20**, wherein said functional moiety has the structure:

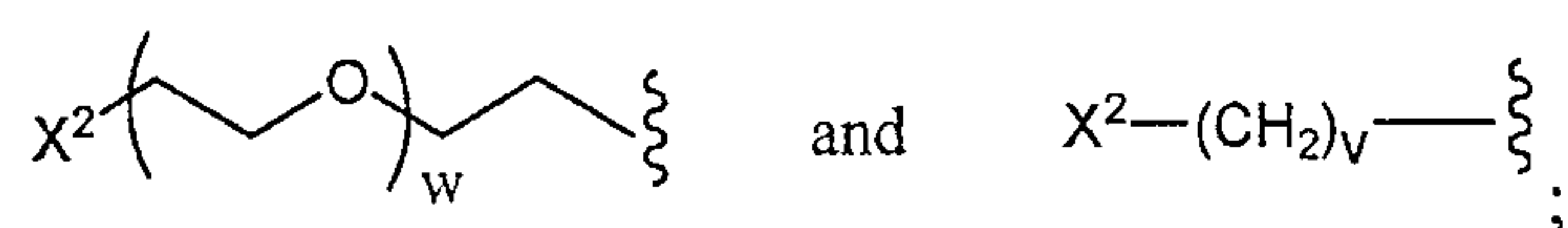


wherein

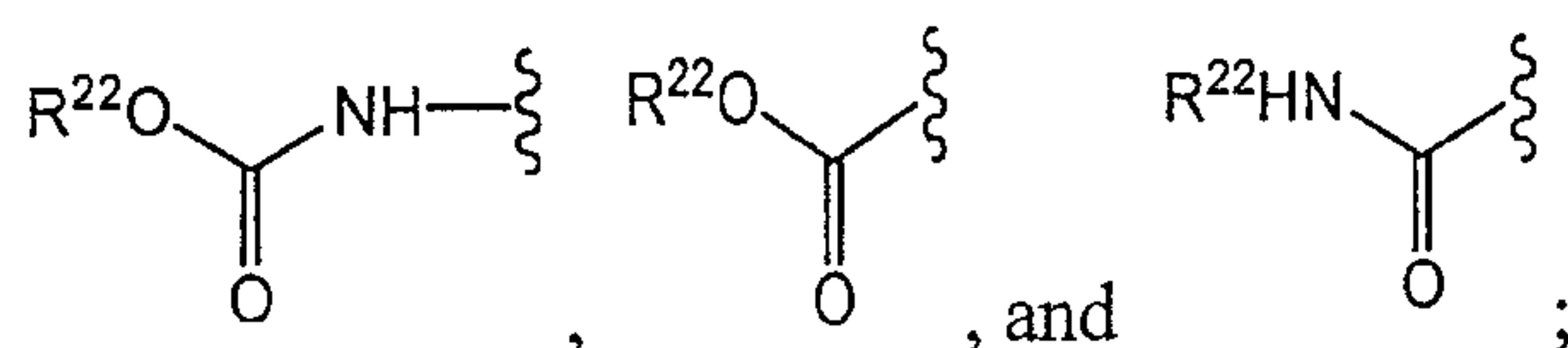
X¹ is said targeting moiety; and

Z^4 is a luminescence modifying group allowing luminescence energy transfer between said complex and said luminescence modifying group when said complex is excited.

23. The luminescent complex according to any one of claims 1 to 20, wherein said functional moiety is a member selected from:



wherein X^2 is a member selected from OH, alkoxy,



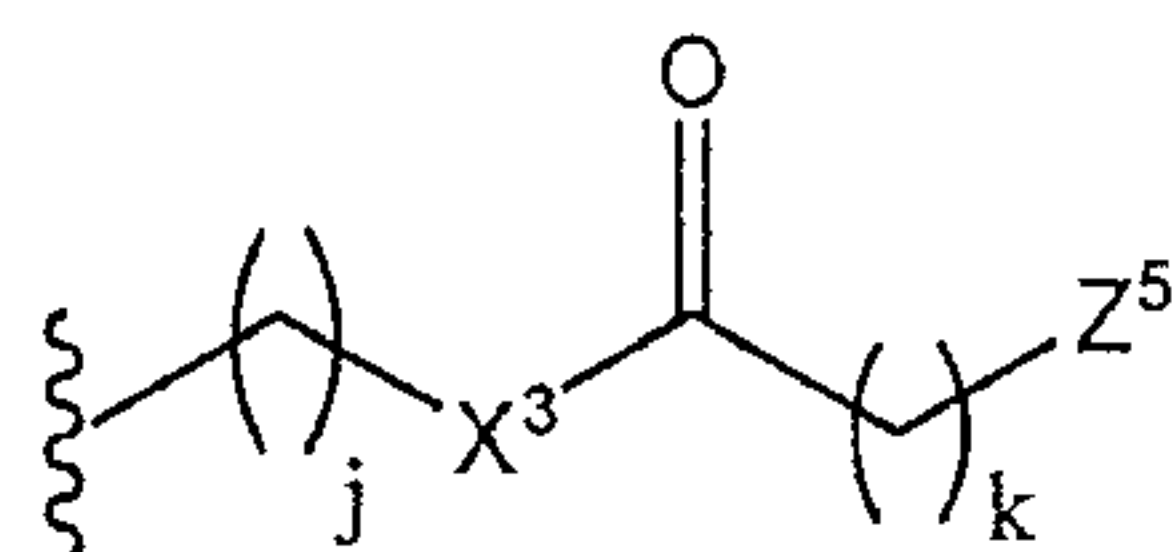
wherein R²² is a member selected from H, substituted or unsubstituted alkyl, and substituted or unsubstituted aryl;

v is an integer from 1 to 20; and

w is an integer from 1 to 1,000; and

wherein “alkyl” is defined as comprising a straight, branched, or cyclic alkyl or a mono-, di- or multivalent radical thereof, which is fully saturated, monounsaturated or polyunsaturated.

24. The luminescent complex according to any one of claims 1 to 20, wherein said functional moiety has the structure:



wherein,

Z^5 is a member selected from H, OR^{23} , SR^{23} , NHR^{23} , $OCOR^{24}$, $OC(O)NHR^{24}$, $NHC(O)OR^{23}$, $OS(O)_2OR^{23}$, and $C(O)R^{24}$;

R^{23} is a member selected from H, substituted or unsubstituted alkyl, and substituted or unsubstituted heteroalkyl;

R^{24} is a member selected from H, OR^{25} , $NR^{25}NH_2$, SH, $C(O)R^{25}$, $NR^{25}H$, substituted or unsubstituted alkyl, and substituted or unsubstituted heteroalkyl;

R^{25} is a member selected from H and substituted or unsubstituted alkyl;

X^3 is a member selected from O, S, and NR^{26}

wherein

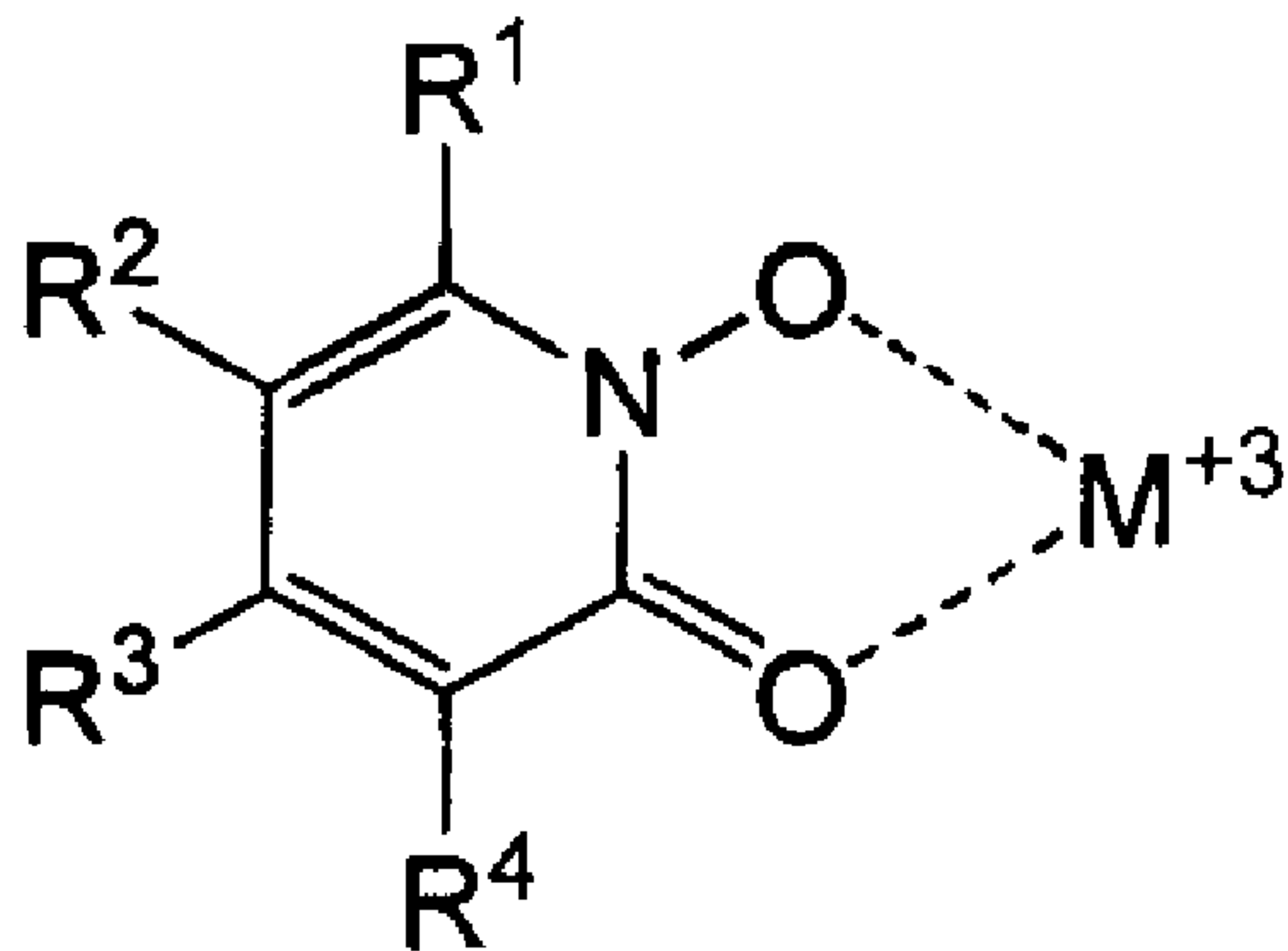
R^{26} is a member selected from H, substituted or unsubstituted alkyl, and substituted or unsubstituted heteroalkyl; and

j and k are members independently selected from the group consisting of integers from 1 to 20; and

wherein “alkyl” is defined as comprising a straight, branched, or cyclic alkyl or a mono-, di- or multivalent radical thereof, which is fully saturated, monounsaturated or polyunsaturated.

25. The luminescent complex according to any one of claims 1 to 20, wherein said functional moiety comprises a polyether.
26. The luminescent complex according to claim 25, wherein said polyether is a member selected from polyethylene glycol (PEG) and derivatives thereof.
27. The luminescent complex according to claim 25 or 26, wherein said polyether has a molecular weight of about 50 to about 10,000 daltons.
28. A mixture comprising a luminescent complex as defined in any one of claims 1 to 27 and an analyte.
29. A method of detecting the presence of an analyte in a sample, said method comprising:
 - (a) contacting said sample with a luminescent complex as defined in any one of claims 1 to 27;
 - (b) exciting said complex; and
 - (c) detecting luminescence from said complex.

30. A method of detecting the presence of an analyte in a sample, said method comprising:
- (a) contacting said sample with a luminescent complex as defined in any one of claims 1 to 27, and a luminescence modifying group, wherein energy can be transferred between said luminescent complex and said luminescence modifying group when said complex is excited;
 - (b) exciting said complex; and
 - (c) determining the luminescent property of said sample, wherein the presence of said analyte results in a change in said luminescent property.
31. The method according to claim 30, wherein said luminescent complex and said luminescence modifying group are part of the same molecule or part of different molecules.
32. The method according to claim 30 or claim 31, wherein said analyte, if present in said sample, displaces the luminescent complex from an antibody binding site, by binding to said binding site.



(I)