

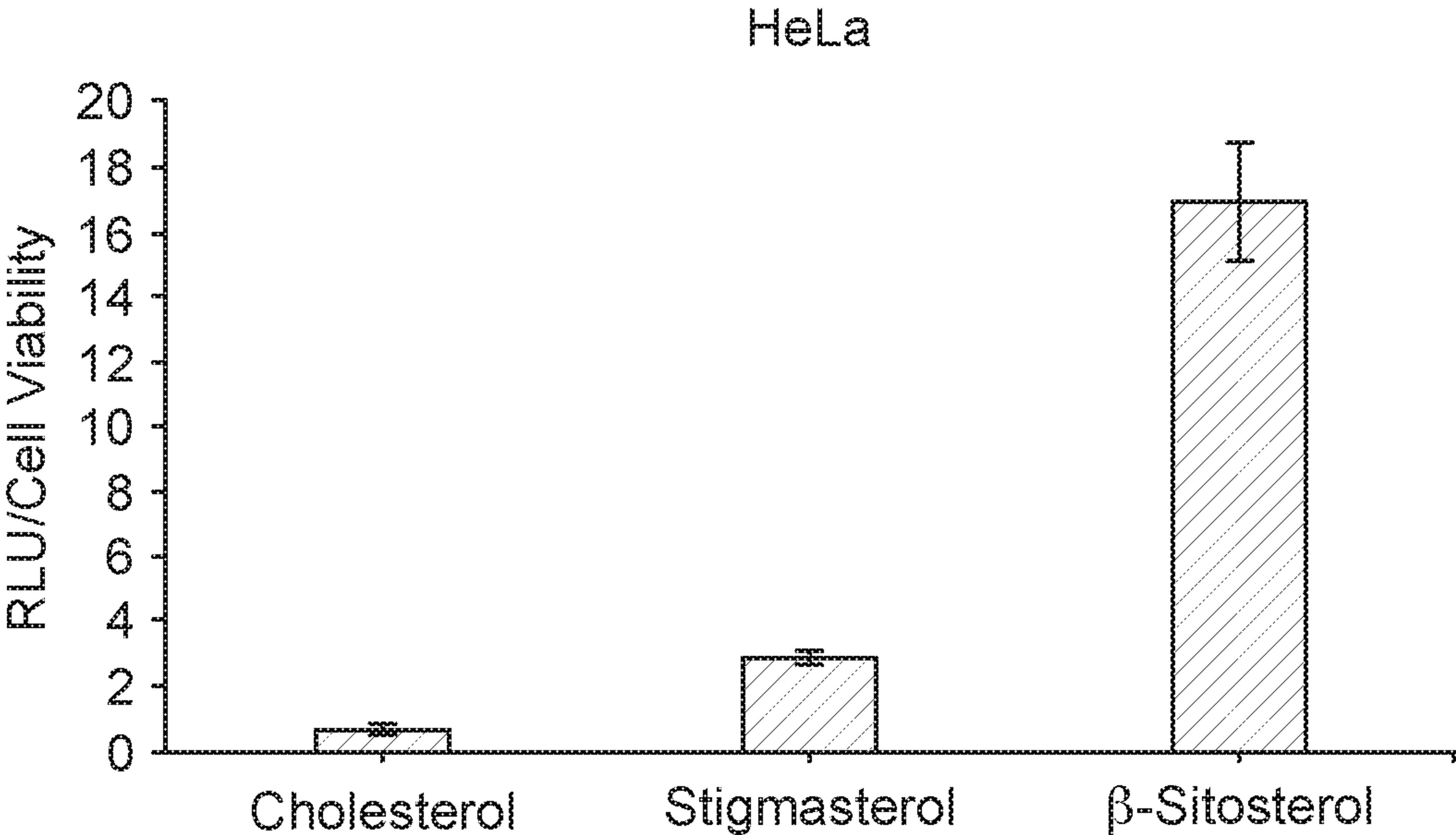


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(54) Titre : FORMULATION DE NANOPARTICULES LIPIDIQUES
(54) Title: LIPID NANOPARTICLE FORMULATION

Fig. 1A



(57) **Abrégé/Abstract:**
The disclosure features novel lipids and compositions involving the same. Nanoparticle compositions include an ionizable lipid, a phospholipid, a first sterol or a tocopherol, and optionally a second sterol different from the first sterol. Nanoparticle compositions further including therapeutic and/or prophylactics such as RNA are useful in the delivery of therapeutic and/or prophylactics to mammalian cells or organs to, for example, regulate polypeptide, protein, or gene expression.

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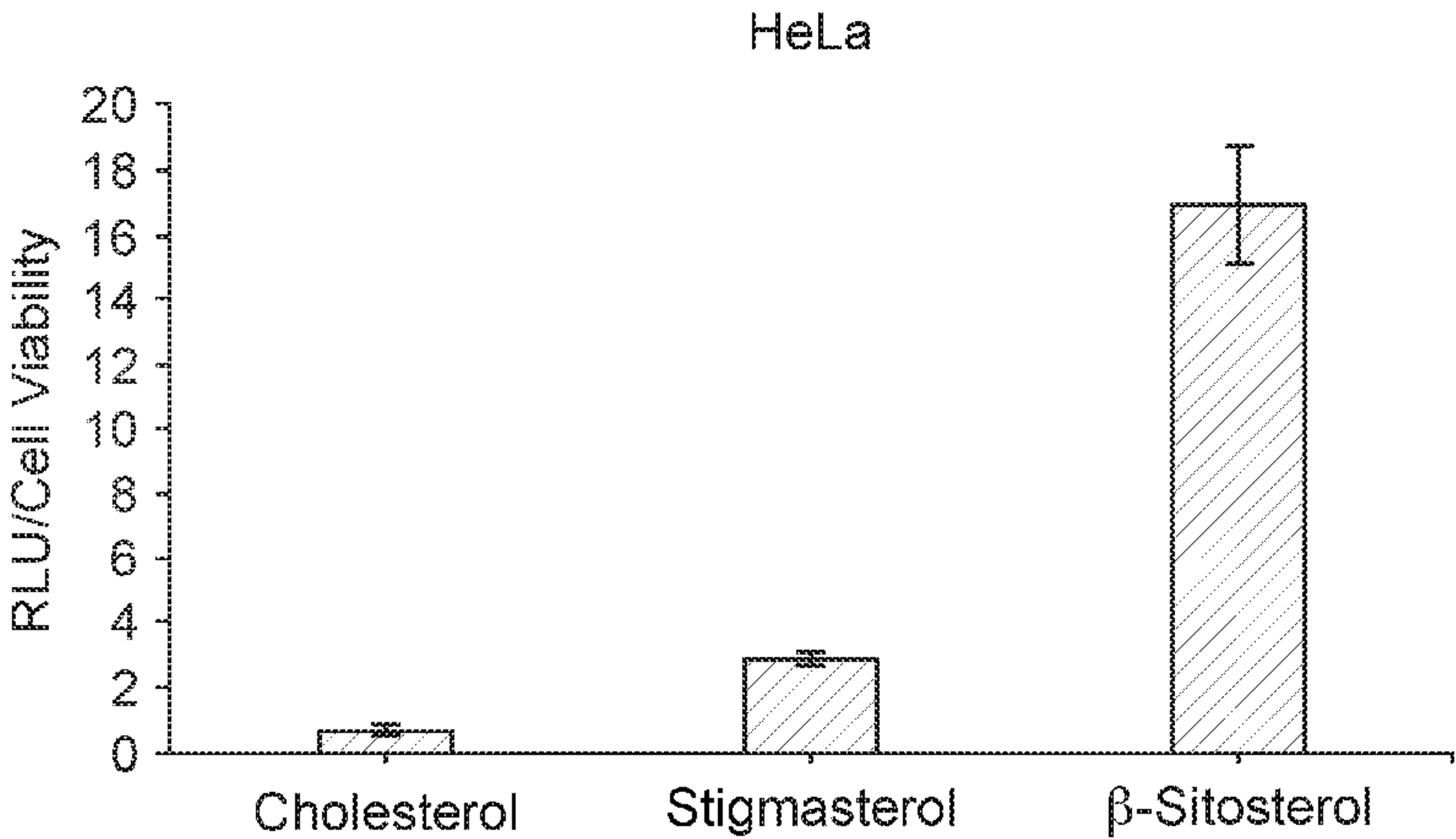
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(54) Title: LIPID NANOPARTICLE FORMULATION

Fig. 1A



(57) Abstract: The disclosure features novel lipids and compositions involving the same. Nanoparticle compositions include an ionizable lipid, a phospholipid, a first sterol or a tocopherol, and optionally a second sterol different from the first sterol. Nanoparticle compositions further including therapeutic and/or prophylactics such as RNA are useful in the delivery of therapeutic and/or prophylactics to mammalian cells or organs to, for example, regulate polypeptide, protein, or gene expression.

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LIPID NANOPARTICLE FORMULATION

Related Applications

[0001] This application claims priority to, and the benefit of, U.S. Provisional Application Nos. 62/471,949, filed March 15, 2017; and 62/475,166, filed March 22, 2017; the entire contents of each of which are incorporated herein by reference.

Incorporation-by-Reference of Sequence Listing

[0002] The present application is being filed along with a Sequence Listing in electronic format. The Sequence Listing is provided as a file entitled “MRNA036001WOSequenceListing.txt” created on February 26, 2018, which is 661 bytes in size. The information in the electronic format of the sequence listing is incorporated herein by reference in its entirety.

Background of the Disclosure

[0003] The effective targeted delivery of biologically active substances such as small molecule drugs, proteins, and nucleic acids represents a continuing medical challenge. In particular, the delivery of nucleic acids to cells is made difficult by the relative instability and low cell permeability of such species. Thus, there exists a need to develop methods and compositions to facilitate the delivery of therapeutic and/or prophylactics such as nucleic acids to cells.

[0004] Lipid-containing nanoparticle compositions, liposomes, and lipoplexes have proven effective as transport vehicles into cells and/or intracellular compartments for biologically active substances such as small molecule drugs, proteins, and nucleic acids. Such compositions generally include one or more “cationic” and/or amino (ionizable) lipids, phospholipids including polyunsaturated lipids, structural lipids (*e.g.*, sterols), and/or lipids containing polyethylene glycol (PEG lipids). Cationic and/or ionizable lipids include, for example, amine-containing lipids that can be readily protonated. Though a variety of such lipid-containing nanoparticle compositions have been demonstrated, improvements in safety, efficacy, and specificity are still lacking.

Summary of the Disclosure

[0005] The present disclosure provides novel nanoparticle compositions and methods involving the same.

[0006] In one aspect, the disclosure provides a nanoparticle composition comprising a lipid component comprising

an ionizable lipid,

a phospholipid,

a first sterol or a tocopherol, and

optionally a second sterol different from the first sterol wherein the molar ratio between the first and second sterols is between about 1:100 and 100:1, or the molar ratio between the tocopherol and second sterol is between about 1:100 and 100:1.

[0007] In another aspect, the disclosure provides a nanoparticle composition comprising:

an ionizable lipid;

a phospholipid;

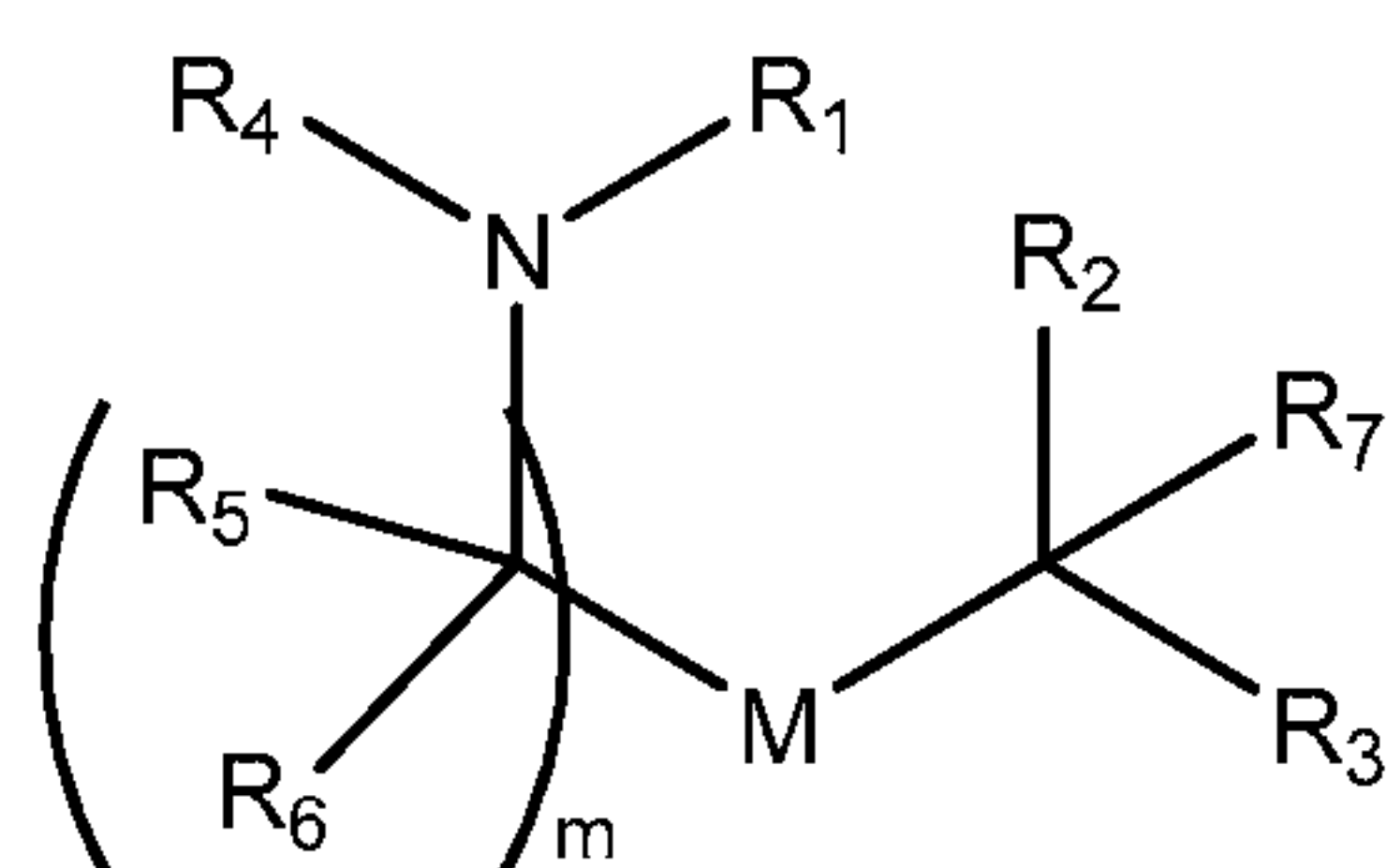
a surfactant;

a nucleic acid moiety; and

a cholesterol derivative.

[0008] In certain embodiments, the composition includes a second sterol. For example, the molar ratio between the first and second sterols is between about 1:10 and 10:1, or between about 1:5 and 5:1, or between about 1:3 and 3:1, or between about 1:2 and 2:1, or about 1:1. For example, the molar ratio between the tocopherol and second sterol is between about 1:10 and 10:1, or between about 1:5 and 5:1, or between about 1:3 and 3:1, or between about 1:2 and 2:1, or about 1:1. For example, the first sterol is cholesterol and the second sterol is a cholesterol derivative (e.g., a phytosterol). For example, the composition comprises a tocopherol and a second sterol which is cholesterol or a cholesterol derivative or a combination thereof.

[0009] In certain embodiments, the ionizable lipid is a compound of Formula (I):



(I) or its N-oxide,

or a salt or isomer thereof, wherein:

R₁ is selected from the group consisting of C₅₋₃₀ alkyl, C₅₋₂₀ alkenyl, -R*YR'', -YR'', and -R''M'R';

R₂ and R₃ are independently selected from the group consisting of H, C₁₋₁₄ alkyl, C₂₋₁₄ alkenyl, -R*YR'', -YR'', and -R*OR'', or R₂ and R₃, together with the atom to which they are attached, form a heterocycle or carbocycle;

R₄ is selected from the group consisting of hydrogen, a C₃₋₆ carbocycle, -(CH₂)_nQ, -(CH₂)_nCHQR, -CHQR, -CQ(R)₂, and unsubstituted C₁₋₆ alkyl, where Q is selected from a carbocycle, heterocycle, -OR, -O(CH₂)_nN(R)₂, -C(O)OR, -OC(O)R, -CX₃, -CX₂H, -CXH₂, -CN, -N(R)₂, -C(O)N(R)₂, -N(R)C(O)R, -N(R)S(O)₂R, -N(R)C(O)N(R)₂, -N(R)C(S)N(R)₂, -N(R)R₈, -N(R)S(O)₂R₈, -O(CH₂)_nOR, -N(R)C(=NR₉)N(R)₂, -N(R)C(=CHR₉)N(R)₂, -OC(O)N(R)₂, -N(R)C(O)OR, -N(OR)C(O)R, -N(OR)S(O)₂R, -N(OR)C(O)OR, -N(OR)C(O)N(R)₂, -N(OR)C(S)N(R)₂, -N(OR)C(=NR₉)N(R)₂, -N(OR)C(=CHR₉)N(R)₂, -C(=NR₉)N(R)₂, -C(=NR₉)R, -C(O)N(R)OR, and -C(R)N(R)₂C(O)OR, and each n is independently selected from 1, 2, 3, 4, and 5;

each R₅ is independently selected from the group consisting of C₁₋₃ alkyl, C₂₋₃ alkenyl, and H;

each R₆ is independently selected from the group consisting of C₁₋₃ alkyl, C₂₋₃ alkenyl, and H;

M and M' are independently selected from -C(O)O-, -OC(O)-, -OC(O)-M''-C(O)O-, -C(O)N(R')-, -N(R')C(O)-, -C(O)-, -C(S)-, -C(S)S-, -SC(S)-, -CH(OH)-, -P(O)(OR')O-, -S(O)₂-, -S-S-, an aryl group, and a heteroaryl group, in which M'' is a bond, C₁₋₁₃ alkyl or C₂₋₁₃ alkenyl;

R₇ is selected from the group consisting of C₁₋₃ alkyl, C₂₋₃ alkenyl, and H;

R₈ is selected from the group consisting of C₃₋₆ carbocycle and heterocycle;

R₉ is selected from the group consisting of H, CN, NO₂, C₁₋₆ alkyl, -OR, -S(O)₂R, -S(O)₂N(R)₂, C₂₋₆ alkenyl, C₃₋₆ carbocycle and heterocycle;

each R is independently selected from the group consisting of C₁₋₃ alkyl, C₂₋₃ alkenyl, and H;

each R' is independently selected from the group consisting of C₁₋₁₈ alkyl, C₂₋₁₈ alkenyl, -R*YR'', -YR'', and H;

each R'' is independently selected from the group consisting of C₃₋₁₅ alkyl and C₃₋₁₅ alkenyl;

each R* is independently selected from the group consisting of C₁₋₁₂ alkyl and C₂₋₁₂ alkenyl;

each Y is independently a C₃₋₆ carbocycle;

each X is independently selected from the group consisting of F, Cl, Br, and I; and m is selected from 5, 6, 7, 8, 9, 10, 11, 12, and 13.

[0010] For example, when R_4 is $-(CH_2)_nQ$, $-(CH_2)_nCHQR$, $-CHQR$, or $-CQ(R)_2$, then (i) Q is not $-N(R)_2$ when n is 1, 2, 3, 4 or 5, or (ii) Q is not 5, 6, or 7-membered heterocycloalkyl when n is 1 or 2. For example, R_1 is different from $-(CHR_5R_6)_m-M-CR_2R_3R_7$.

[0011] In another aspect, the disclosure features a pharmaceutical composition comprising the nanoparticle composition described herein and a pharmaceutically acceptable carrier. For example, the pharmaceutical composition is refrigerated or frozen for storage and/or shipment (e.g., being stored at a temperature of 4 °C or lower, such as a temperature between about -150 °C and about 0 °C or between about -80 °C and about -20 °C (e.g., about -5 °C, -10 °C, -15 °C, -20 °C, -25 °C, -30 °C, -40 °C, -50 °C, -60 °C, -70 °C, -80 °C, -90 °C, -130 °C or -150 °C). For example, the pharmaceutical composition is a solution that is refrigerated for storage and/or shipment at, for example, about -20° C, -30 °C, -40 °C, -50 °C, -60 °C, -70 °C, or -80 °C.

[0012] In another aspect, the disclosure provides a method of delivering a therapeutic and/or prophylactic (e.g., an mRNA) to a cell (e.g., a mammalian cell). This method includes the step of administering to a subject (e.g., a mammal, such as a human) a nanoparticle composition of the disclosure, in which administering involves contacting the cell with the nanoparticle composition, whereby the therapeutic and/or prophylactic is delivered to the cell.

[0013] In another aspect, the disclosure provides a method of specifically delivering a therapeutic and/or prophylactic (e.g., an mRNA) to a mammalian organ (e.g., a liver, spleen, lung, or femur). This method includes the step of administering to a subject (e.g., a mammal, such as a human) a nanoparticle composition including of the disclosure, in which administering involves contacting the organ with the nanoparticle composition, whereby the therapeutic and/or prophylactic is delivered to the organ.

[0014] In yet another aspect, the disclosure provides a method of producing a polypeptide of interest in a cell (e.g., a mammalian cell). The method includes the step of contacting the cell with a nanoparticle composition of the disclosure, whereby the mRNA is capable of being translated in the cell to produce the polypeptide.

[0015] In still another aspect, the disclosure provides a method of treating a disease or disorder in a subject (e.g., a mammal, e.g., a human) in need thereof. The method includes the step of administering to the subject a therapeutically effective amount of a nanoparticle composition of the

disclosure. In some embodiments, the disease or disorder is characterized by dysfunctional or aberrant protein or polypeptide activity. For example, the disease or disorder is selected from the group consisting of rare diseases, infectious diseases, cancer and proliferative diseases, genetic diseases (*e.g.*, cystic fibrosis), autoimmune diseases, diabetes, neurodegenerative diseases, cardio- and reno-vascular diseases, and metabolic diseases. In some embodiments, the disease or disorder is characterized by overexpression of a polypeptide. In some embodiments, the disease or disorder is characterized by underexpression of a polypeptide. In some embodiments, a nanoparticle of the disclosure comprises a nucleic acid capable of silencing or decreasing the expression of a target polypeptide. In some embodiments, a nanoparticle of the disclosure comprises a nucleic acid capable of expressing or increasing the expression of a target polypeptide.

[0016] In some embodiments, the method further comprises, prior to the contacting or administering step, pretreating said subject with one or more additional compounds, wherein pretreating comprises administering said one or more additional compounds to said subject.

[0017] In still another aspect, the disclosure provides a nanoparticle composition for use in the treatment of a disease or disorder in a subject (*e.g.*, a mammal, *e.g.*, a human) in need thereof. The nanoparticle composition includes a nanoparticle of the disclosure. In some embodiments, the disease or disorder is characterized by dysfunctional or aberrant protein or polypeptide activity. For example, the disease or disorder is selected from the group consisting of rare diseases, infectious diseases, cancer and proliferative diseases, genetic diseases (*e.g.*, cystic fibrosis), autoimmune diseases, diabetes, neurodegenerative diseases, cardio- and reno-vascular diseases, and metabolic diseases. In some embodiments, the disease or disorder is characterized by overexpression of a polypeptide. In some embodiments, the disease or disorder is characterized by underexpression of a polypeptide.

[0018] In still another aspect, the disclosure provides a nanoparticle composition for use in the manufacture of a medicament for the treatment of a disease or disorder in a subject (*e.g.*, a mammal, *e.g.*, a human) in need thereof. The nanoparticle composition includes a nanoparticle of the disclosure. In some embodiments, the disease or disorder is characterized by dysfunctional or aberrant protein or polypeptide activity. For example, the disease or disorder is selected from the group consisting of rare diseases, infectious diseases, cancer and proliferative diseases, genetic diseases (*e.g.*, cystic fibrosis), autoimmune diseases, diabetes, neurodegenerative diseases, cardio- and reno-vascular diseases, and metabolic diseases. In some embodiments, the disease or disorder

is characterized by overexpression of a polypeptide. In some embodiments, the disease or disorder is characterized by underexpression of a polypeptide.

[0019] In another aspect, the disclosure provides the use of a nanoparticle composition in the manufacture of a medicament for the treatment of a disease or disorder in a subject (*e.g.*, a mammal, *e.g.* a human) in need thereof. The nanoparticle composition includes a nanoparticle composition of the disclosure. In some embodiments, the disease or disorder is characterized by dysfunctional or aberrant protein or polypeptide activity. For example, the disease or disorder is selected from the group consisting of rare diseases, infectious diseases, cancer and proliferative diseases, genetic diseases (*e.g.*, cystic fibrosis), autoimmune diseases, diabetes, neurodegenerative diseases, cardio- and reno-vascular diseases, and metabolic diseases. In some embodiments, the disease or disorder is characterized by overexpression of a polypeptide. In some embodiments, the disease or disorder is characterized by underexpression of a polypeptide.

[0020] In some embodiments the subject has been pretreated with one or more additional compounds, wherein pretreating comprises administering said one or more additional compounds to said subject.

[0021] In another aspect, the disclosure features a method for the enhanced delivery of a therapeutic and/or prophylactic (*e.g.*, an mRNA) to a target tissue (*e.g.*, a liver, spleen, lung, or femur). This method includes administering to a subject (*e.g.*, a mammal) a nanoparticle composition of the disclosure, the administering including contacting the target tissue with the nanoparticle composition, whereby the therapeutic and/or prophylactic is delivered to the target tissue.

[0022] In another aspect, the disclosure features a method for transfecting a cell, comprising contacting the cell with a lipid nanoparticle of the disclosure, and incubating the cell for a time period sufficient to transfection to proceed. In some embodiments, the time period sufficient for transfection to proceed is between about 1h and about 48h. In other embodiments, the time period sufficient for transfection to proceed is between about 1h and about 5h, between about 6h and about 12h, between about 13h and about 24h, between about 25h and about 36h, or between about 37h and about 48h. In further embodiments the time period sufficient for transfection to proceed is about 1h, about 5h, about 10h, about 15h, about 20h, about 25h, about 30h, about 35h, about 40h, or about 45h. In even further embodiments, the time period sufficient for transfection to proceed is about 2h, about 6h, about 12h, about 18h, about 24h, about 36h, about 42h, or about 48h.

[0023] In another aspect, the disclosure features a method for making a lipid nanoparticle of the disclosure, comprising:

introducing a first stream comprising the nucleic acid in a first solvent into a device;

introducing a second stream comprising the cationic lipid, the phospholipid, the surfactant and the cholesterol derivative in a second solvent into the device;

flowing the first and second streams into a mixing region of the device for a time period sufficient for the first and second streams to mix to form a third stream comprising the lipid nanoparticles. In some embodiments, the time period sufficient for the first and second streams to mix is between about 1h and about 48h. In other embodiments, the time period sufficient for the first and second streams to mix is between about 1h and about 5h, between about 6h and about 12h, between about 13h and about 24h, between about 25h and about 36h, or between about 37h and about 48h. In further embodiments the time period sufficient for the first and second streams to mix is about 1h, about 5h, about 10h, about 15h, about 20h, about 25h, about 30h, about 35h, about 40h, or about 45h. In even further embodiments, the time period sufficient for the first and second streams to mix is about 2h, about 6h, about 12h, about 18h, about 24h, about 36h, about 42h, or about 48h. In some embodiments, the volume ratio of the second stream to the first stream is 1:3.

[0024] In another aspect, the disclosure features a method for modulating the expression of a target polynucleotide or polypeptide, comprising contacting a cell with the lipid nanoparticle of the disclosure, comprising a nucleic acid that is capable of modulating the expression of a target polynucleotide or polypeptide. In some embodiments, a nanoparticle of the disclosure comprises a nucleic acid capable of modulating the expression of a target polynucleotide or polypeptide.

Brief Description of the Drawings

[0025] The patent or application file contains at least one drawing executed in color. Copies of this patent or patent application publication with color drawing(s) will be provided by the Office upon request and payment of the necessary fee.

[0026] The above and further features will be more clearly appreciated from the following detailed description when taken in conjunction with the accompanying drawings.

[0027] Figures 1A and 1B are a pair of graphs illustrating transfection efficiency results from Luciferase/Cell Viability Assay of (Figure 1A) Hela cells and (Figure 1B) HepG2 cells upon treatment with nanoparticles containing cholesterol, beta-sitosterol and stigmasterol.

[0028] Figures 2A and 2B are a pair of graphs illustrating expression of green fluorescent protein (eGFP) in HeLa cells induced by lipid nanoparticles of the disclosure, comprising Compound 18, cholesterol and/or a cholesterol derivative. The particles were formulated with an acetate buffer. Cell uptake and expression levels for particles containing cholesterol but not cholesterol derivative are shown as control. Figure 2A shows the eGFP expression by formulations of the disclosure over the course of 16 h. Figure 2B shows the AUC of eGFP expression for each formulation.

[0029] Figures 3A and B are a pair of graphs illustrating expression of green fluorescent protein (eGFP) in HeLa cells vs. cell uptake of lipid nanoparticles of the disclosure, comprising Compound 18, cholesterol and/or a cholesterol derivative, with an acetate buffer. Lipid uptake was determined via tetramethylrhodamine (TRITC) labeling, more specifically, using 1,2-dioleoyl-*sn*-glycero-3-phosphoethanolamine-N-(lissamine rhodamine B sulfonyl) (ammonium salt). Figure 3A shows the eGFP expression vs. cell uptake over the course of 16 h. Figure 3B shows the AUC for each formulation. The right axis of each graph measures eGFP expression and the left axis measures lipid uptake.

[0030] Figures 4A and 4B are a pair of graphs illustrating expression of green fluorescent protein (eGFP) in Hep3b cells vs. cell uptake of lipid nanoparticles of the disclosure, comprising Compound 18, cholesterol and/or a cholesterol derivative, with an acetate buffer. Lipid uptake was determined via TRITC labeling, more specifically, using 1,2-dioleoyl-*sn*-glycero-3-phosphoethanolamine-N-(lissamine rhodamine B sulfonyl) (ammonium salt). Figure 4A shows the eGFP expression vs. cell uptake over the course of 16 h. Figure 4B shows the AUC for each formulation. The right axis of each graph measures eGFP expression and the left axis measures lipid uptake.

[0031] Figures 5A and 5B are a pair of graphs illustrating expression of green fluorescent protein (eGFP) in AML12 cells vs. cell uptake of lipid nanoparticles of the disclosure, comprising Compound 18, cholesterol and/or a cholesterol derivative, with an acetate buffer. Lipid uptake was determined via TRITC labeling, more specifically, using 1,2-dioleoyl-*sn*-glycero-3-phosphoethanolamine-N-(lissamine rhodamine B sulfonyl) (ammonium salt). Figure 5A shows the eGFP expression vs. cell uptake over the course of 16 h. Figure 5B shows the AUC for each formulation. The right axis of each graph measures eGFP expression and the left axis measures lipid uptake.

[0032] Figures 6A and 6B are a pair of graphs showing activated B-cell frequencies in the human peripheral blood mononuclear cells (PBMCs) dosed with the compositions of the disclosure, comprising Compound 18, cholesterol and/or a cholesterol derivative, with an acetate buffer.

Lipopolysaccharide (LPS) and cell culture medium alone are used as controls. Figure 6A shows the percentage of CD19⁺ cells. Figure 6B shows the percentage of CD19⁺ CD69⁺ CD86⁺ cells.

[0033] Figure 7A illustrates structure of different cholesterol derivatives: (1.a) cholesterol structure, (1.b) IUPAC nomenclature (1989) of cholesterol ring system. (2.a) vitamin D-3, (2.b) vitamin D-2, (2.c) calcipotriol [Section 2 includes 9,10-Secosteroids], (3.a) stigmasterol, (3.b) beta-sitosterol [Section 3 includes phytosterols with C-20 to C-27 side chain modification], (4.a) betulin, (4.b) lupeol, (4.c) ursolic Acid, (4.d) oleanolic acid [Section 4 includes phytosterols with C-20 to C-27 side chain modification with an additional ring]. In all the structures, the red color indicates the structural variation in comparison with cholesterol. The β -sitosterol is 70% pure and contains mixture of campesterol, stigmasterol and sitostanol. In Figures 7B-7H, 8A-8C, and 9A-9F, eLNP refers to lipid nanoparticles with cholesterol replaced with cholesterol derivatives while LNP, unless otherwise specified, refers to lipid nanoparticles with cholesterol.

[0034] Figure 7B is a graph showing that β -sitosterol lipid nanoparticles (eLNPs) outperform other cholesterol derivative-eLNPs with respect to size (determined by DLS, mean of 36-45 scans), mRNA encapsulation efficiency (determined by RiboGreen assay, $N = 2$), and transfection efficiency (compared by adding 200 ng mRNA using each eLNP, normalized to transfection with cholesterol LNPs, $N = 3$). β -sitosterol is 70% pure and is a mixture of campesterol, stigmasterol and sitostanol.

[0035] Figure 7C is a graph illustrating transfection efficiency results from a study in HeLa cells of Luciferase activity normalized to cell viability 24 hours after transfection with 0-400 ng *Luciferase* mRNA using LNP (blue) or eLNP (red). Data shown as mean $\pm$ SD; $N = 3$.

[0036] Figure 7D is a graph illustrating data in Figure 8c, expressed as a fold-increase ratio (eLNP/LNP). Data shown as mean $\pm$ SD; $N = 3$. β -sitosterol is 97% pure.

[0037] Figure 7E is a graph illustrating mean cellular uptake of LNPs vs eLNPs; determined by transfection of cyanine 5-labelled mRNA (0-400 ng mRNA/well) using LNP vs β -sitosterol-eLNP. Uptake area defined as perinuclear space identified using Hoescht nuclear stain. Cyanine 5 fluorescence is normalized to number of nuclei. Data shown as mean $\pm$ SD; $N = 3$.

[0038] Figure 7F illustrates structures of other phytosterol analogues. All are C-24 alkyl and alkenyl substituents of cholesterol. In all the structures, the red color indicates the structural variation in comparison with cholesterol. Size and E.eff refers to the size and encapsulation efficiency of the lipid nanoparticles as formed.

[0039] Figure 7G is a graph illustrating transfection efficiency results from a study in HeLa cells of Luciferase activity normalized to cell viability 24 hours after transfection with 0-400 ng *Luciferase* mRNA using LNP (blue), β -sitosterol-eLNP (red), campesterol-eLNP (yellow), fucosterol-eLNP (grey), or sitostanol-eLNP (green). Data shown as mean $\pm$ SD; $N = 3$.

[0040] Figure 7H is a graph illustrating cholesterol and β -sitosterol-conjugate LNP characterizations. Upon acetylation, a loss of function is observed with both cholesterol and β -sitosterol LNPs, however conjugation of amino acids at this site can partially restore functionality. Shown: Size (determined by DLS, mean of 36-45 scans), mRNA encapsulation efficiency (determined by RiboGreen assay, $N = 2$), and transfection efficiency (compared by adding 200 ng mRNA using each eLNP, normalized to transfection with cholesterol LNPs, $N = 3$). The letters in the names of compounds stands for H=Histidine, R=Arginine, G=Glycine, S=Serine, C= Cysteine, Ac=Acetyl. The data suggest that OH group is essential for cholesterol mediated gene delivery.

[0041] Figure 8A is a graph showing results from a study in 6 distinct fibroblast cell lines cultured from human patients with lysosomal storage disorders. Luciferase activity normalized to cell viability 24 hours after transfection with 0-600 ng *Luciferase* mRNA using LNP (blue) or β -sitosterol eLNP (red). Data shown as mean $\pm$ SD; $N = 3$.

[0042] Figure 8B is a graph showing results from a study in 3 macrophage cell lines – RAW264.7 and J774A.1 cells (mouse), and peripheral blood macrophages from an apparently healthy human patient. Luciferase activity normalized to cell viability 24 hours after transfection with 0-200 ng *Luciferase* mRNA using LNP (blue) or β -sitosterol eLNP (red). Data shown as mean $\pm$ SD; $N = 3$.

[0043] Figure 8C is a graph showing results from a study in hepatocyte HepG2 cells. Luciferase activity normalized to cell viability 24 hours after transfection with 0-50 ng *Luciferase* mRNA using LNP (blue) or β -sitosterol eLNP (red). Data shown as mean $\pm$ SD; $N = 3$.

[0044] Figure 9A is a graph illustrating luciferase activity in HeLa cells transfected with mRNA-lipoplexes at a dose of 50 ng mRNA in the presence of bioactive lipids (black) normalized to mRNA-lipoplex only control (red), which was set at 100%. Data represented as mean $\pm$ SEM; $n =$

3. Compound# 2 (MK-571) in bioactive lipid library demonstrates the most favorable bioactivity, inducing approximately 40% enhancement of protein expression over the control.

[0045] Figure 9B is a graph illustrating luciferase activity in HeLa cells transfected with mRNA-lipoplexes at a dose of 50 ng mRNA in the presence of varying concentrations of MK-571 (blue) relative to mRNA-lipoplex only control (red). Data represented as mean $\pm$ SD; n = 3. MK-571 is capable of doubling the protein expression at a concentration of 5 μ M.

[0046] Figure 9C is a graph illustrating luciferase activity in HeLa cells transfected with mRNA-lipoplexes at a dose of 50 ng mRNA in the presence of varying concentrations of Arachidonic Acid (blue) relative to mRNA-lipoplex only control (red). Data represented as mean $\pm$ SD; n = 3. Treating cells with free Arachidonic Acid failed to elicit improvement in protein expression.

[0047] Figure 9D is a graph illustrating luciferase activity at increasing doses of mRNA in HeLa cells transfected using LNPs, with and without 24 hr pre-incubation with MK-571 (5 μ M). Data represented as mean $\pm$ SD; n = 3. MK-571 is able to enhance transfection at all doses of mRNA.

[0048] Figure 9E is a graph illustrating luciferase activity at increasing doses of mRNA in HeLa cells transfected using LNPs and MK-571 loaded LNPs. Data represented as mean $\pm$ SD; n = 3. Similar to the observations made using lipoplexes and free MK-571, LNP delivered MK-571 increases the protein expression two-fold.

[0049] Figure 9F is a graph illustrating luciferase activity in HeLa cells transfected with mRNA-lipoplexes at a dose of 50 ng mRNA in the presence of varying concentrations of MK-571 or its analogues, Montelukast, Pranlukast, and Zafirlukast relative to mRNA-lipoplex only control. Data represented as mean $\pm$ SD; n = 3. Pranlukast and Zafirlukast demonstrate a similar activity to MK-571 in enhancing protein expression.

Detailed Description

[0050] The disclosure relates to novel lipid nanoparticle compositions including a novel sterol, or a mixture of sterols, in particular, a mixture of cholesterol and cholesterol derivative (e.g., total or partial replacement of cholesterol in nanoparticle compositions). Without wishing to be bound by theory, total or partial replacement of cholesterol may disrupt intracellular lipid transport by modulating binding with Niemann-Pick C1 (NPC1, a late endosomal membrane protein that mediates intracellular cholesterol trafficking in mammals) to enhance cell uptake of the lipid nanoparticles, e.g., to increase the amount of mRNAs delivered to cytoplasm which would be available for translation. Additionally or alternatively, total or partial replacement of cholesterol may disrupt intracellular lipid transport by modulating binding with NPC1 to enhance expression of a protein of interest. It is possible that cholesterol derivatives are more effective in binding to the NPC1 nucleotide domain that binds OH group of the sterols and may cause endosomal escape to the endoplasmic reticulum. Blockage of OH group causes decrease in efficacy. However absence of NPC1 still led to enhanced delivery possibly due to activation of compensatory pathways in the endo/lysosomal system (see, e.g., Fig. 7H and Fig. 8A). It is possible that the cholesterol derivative can change binding affinity with different endolysosomal proteins like Npc1, LIMP2, LAMPA and B.

[0051] The disclosure also provides methods of delivering a therapeutic and/or prophylactic to a mammalian cell, specifically delivering a therapeutic and/or prophylactic to a mammalian organ, producing a polypeptide of interest in a mammalian cell, and treating a disease or disorder in a mammal in need thereof. For example, a method of producing a polypeptide of interest in a cell involves contacting a nanoparticle composition comprising an mRNA with a mammalian cell, whereby the mRNA may be translated to produce the polypeptide of interest. For example, the production of the polypeptide of interest is increased (e.g., by at least 10%, 20%, 30%, 40%, 50%, or 100%) by using a combination of first and second sterols (e.g., cholesterol and a cholesterol derivative such as stigmasterol, β -sitosterol, or those disclosed herein) as compared to administering a corresponding composition which comprises either the first sterol or the second sterol but not both. In another example, the production of the polypeptide of interest is increased (e.g., by at least 10%, 20%, 30%, 40%, 50%, or 100%) by using a cholesterol derivative (such as stigmasterol, β -sitosterol, or those disclosed herein) as compared to administering a corresponding composition which comprises cholesterol or a combination of cholesterol and the cholesterol derivative. A

method of delivering a therapeutic and/or prophylactic to a mammalian cell or organ may involve administration of a nanoparticle composition including the therapeutic and/or prophylactic to a subject, in which the administration involves contacting the cell or organ with the composition, whereby the therapeutic and/or prophylactic is delivered to the cell or organ. For example, the delivery efficiency is increased (e.g., by at least 10%, 20%, 30%, 40%, 50%, or 100%) by using a combination of first and second sterols (e.g., cholesterol and a cholesterol derivative such as stigmasterol, β -sitosterol, or those disclosed herein) as compared to administering a corresponding composition which comprises either the first sterol or the second sterol but not both. In another example, the delivery efficiency is increased (e.g., by at least 10%, 20%, 30%, 40%, 50%, or 100%) by using a cholesterol derivative (such as stigmasterol, β -sitosterol, or those disclosed herein) as compared to administering a corresponding composition which comprises cholesterol or a combination of cholesterol and the cholesterol derivative.

Sterols

[0052] The disclosure provides a nanoparticle composition comprising a lipid component comprising

an ionizable lipid,

a phospholipid,

a first sterol or a tocopherol, and

optionally a second sterol different from the first sterol wherein the molar ratio between the first and second sterols is between about 1:100 and 100:1, or the molar ratio between the tocopherol and second sterol is between about 1:100 and 100:1.

[0053] The disclosure also provides a nanoparticle composition comprising:

an ionizable lipid;

a phospholipid;

a surfactant;

a nucleic acid moiety; and

a cholesterol derivative.

[0054] The term "sterol" refers to a subgroup of steroids also known as steroid alcohols. Sterols are usually divided into two classes: (1) plant sterols also known as "phytosterols", and (2) animal sterols also known as "zoosterols."

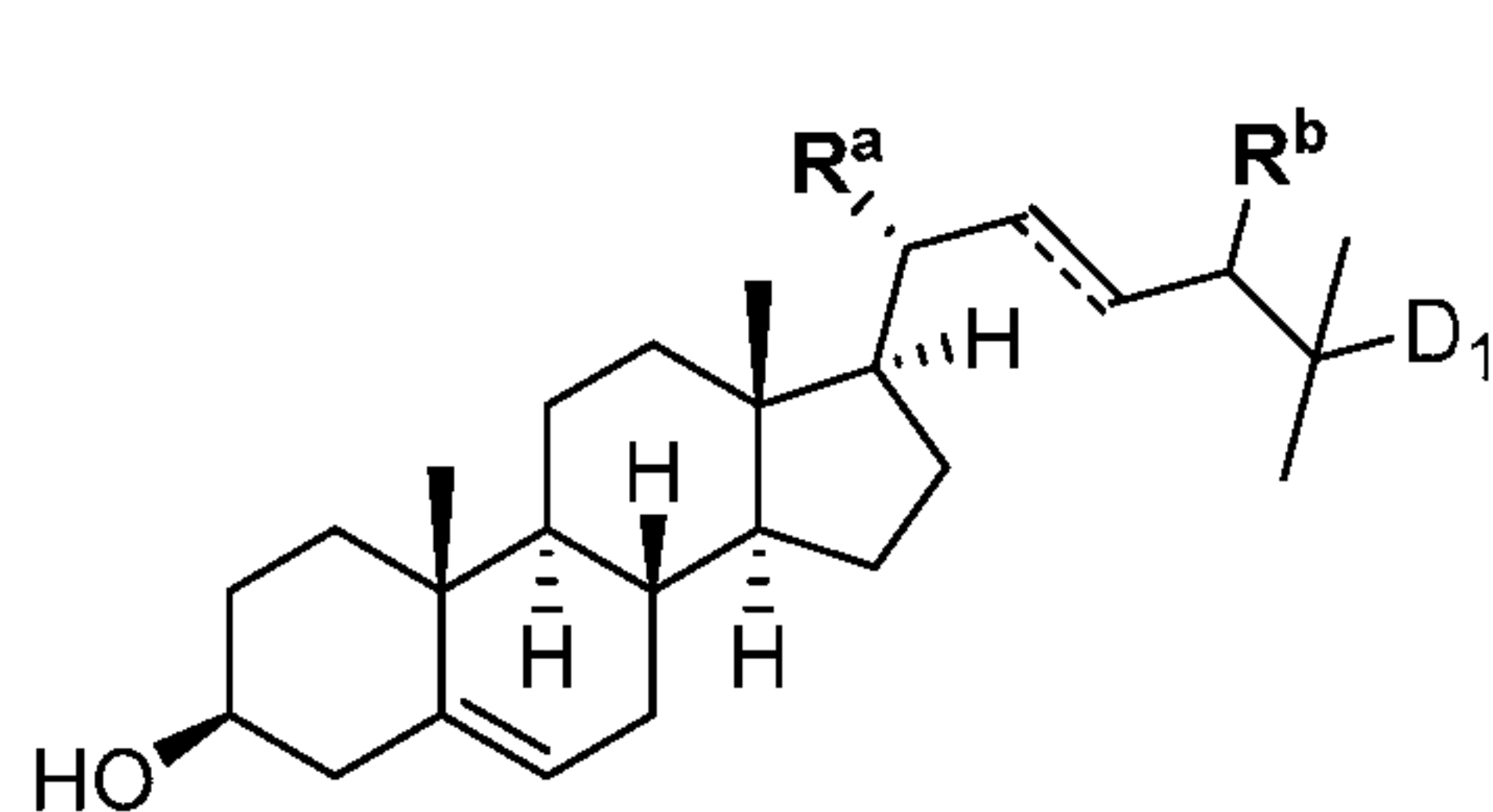
[0055] In certain embodiments, the composition includes a second sterol. For example, the molar ratio between the first and second sterols is between about 1:10 and 10:1, or between about 1:5 and 5:1, or between about 1:3 and 3:1, or between about 1:2 and 2:1, or about 1:1. For example, the molar ratio between the tocopherol and second sterol is between about 1:10 and 10:1, or between about 1:5 and 5:1, or between about 1:3 and 3:1, or between about 1:2 and 2:1, or about 1:1. For example, the first sterol is cholesterol and the second sterol is a cholesterol derivative (e.g., a phytosterol). For example, the composition comprises a tocopherol (α -tocopherol, β -tocopherol, γ -tocopherol, δ -tocopherol, or a salt or ester thereof, such as α -tocopherol hemisuccinate) and a second sterol which is cholesterol or a cholesterol derivative or a combination thereof.

[0056] In certain embodiments, the cholesterol derivative is a phytosterol, e.g., β -sitosterol, campesterol, stigmasterol, fucosterol, or stigmastanol.

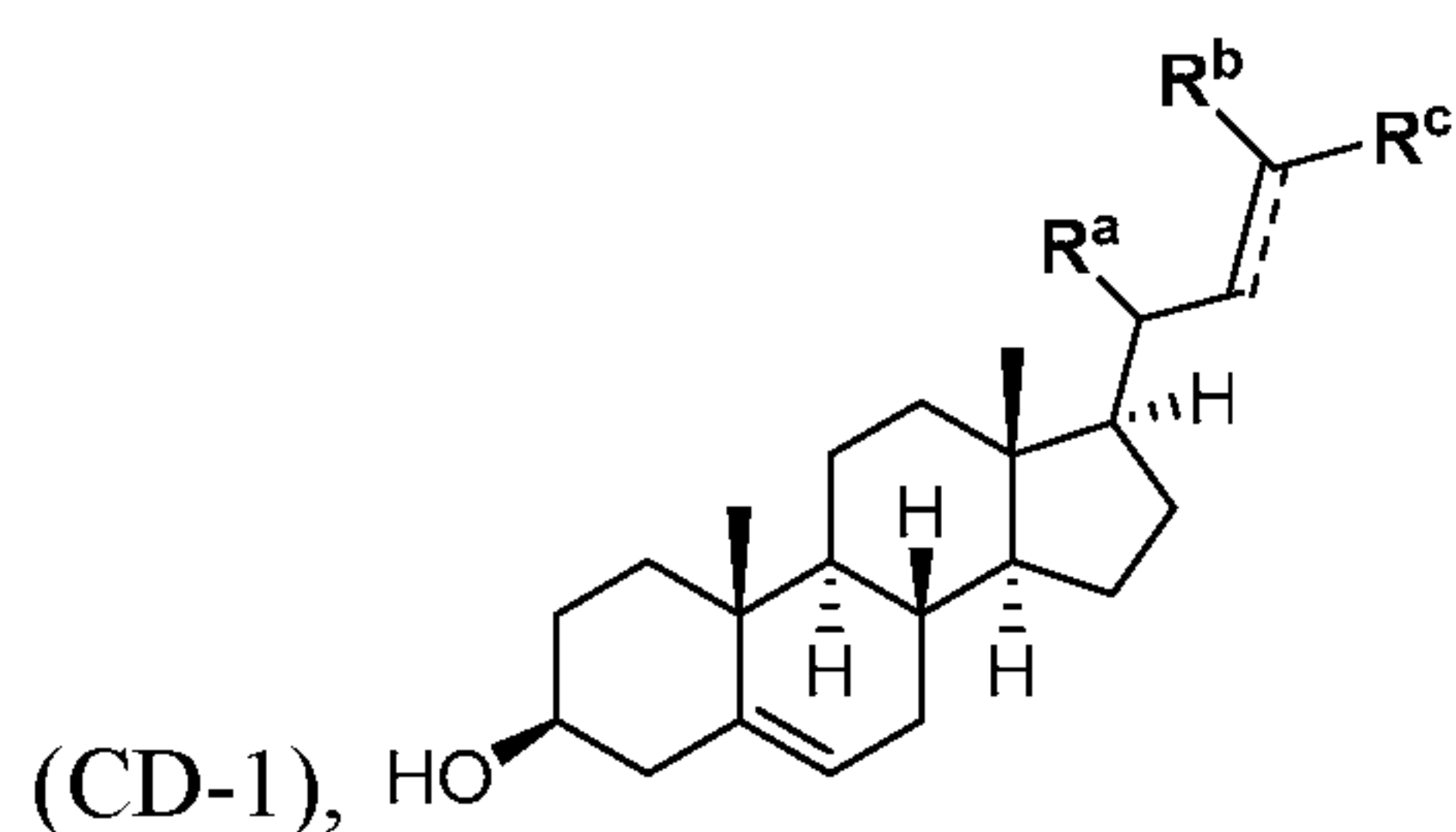
[0057] In certain embodiments, the cholesterol derivative is dihydrocholesterol, ent-cholesterol, epi-cholesterol, desmosterol, cholestanol, cholestanone, cholestenone, cholesteryl-2'-hydroxyethyl ether, cholesteryl-4'-hydroxybutyl ether, 3β -[N-(N'-dimethylaminoethyl)carbamoyl cholesterol (DC-Chol), 24(S)-hydroxycholesterol, 25-hydroxycholesterol, 25(R)-27-hydroxycholesterol, 22-oxacholesterol, 23-oxacholesterol, 24-oxacholesterol, cycloartenol, 22-ketosterol, 20-hydroxysterol, 7-hydroxycholesterol, 19-hydroxycholesterol, 22-hydroxycholesterol, 25-hydroxycholesterol, 7-dehydrocholesterol, 5α -cholest-7-en- 3β -ol, 3,6,9-trioxaoctan-1-ol-cholesteryl-3e-ol, dehydroergosterol, dehydroepiandrosterone, lanosterol, dihydrolanosterol, lanostenol, lumisterol, sitocalciferol, calcipotriol, coprostanol, cholecalciferol, lupeol, ergocalciferol, 22-dihydroergocalciferol, ergosterol, brassicasterol, tomatidine, tomatine, ursolic acid, cholic acid, chenodeoxycholic acid, zymosterol, diosgenin, fucosterol, fecosterol, or fecosterol, or a salt or ester thereof, e.g., sodium cholate.

[0058] In certain embodiments, cholesterol refers to cholesterol itself or a salt or ester thereof, e.g., cholesterol succinic acid, cholesterol sulfate, cholesterol hemisuccinate, cholesterol phthalate, cholesterol phosphate, cholesterol valerate, cholesterol acetate, cholesteryl oleate, cholesteryl linoleate, cholesteryl myristate, cholesteryl palmitate, cholesteryl arachidate, and cholesteryl phosphorylcholine.

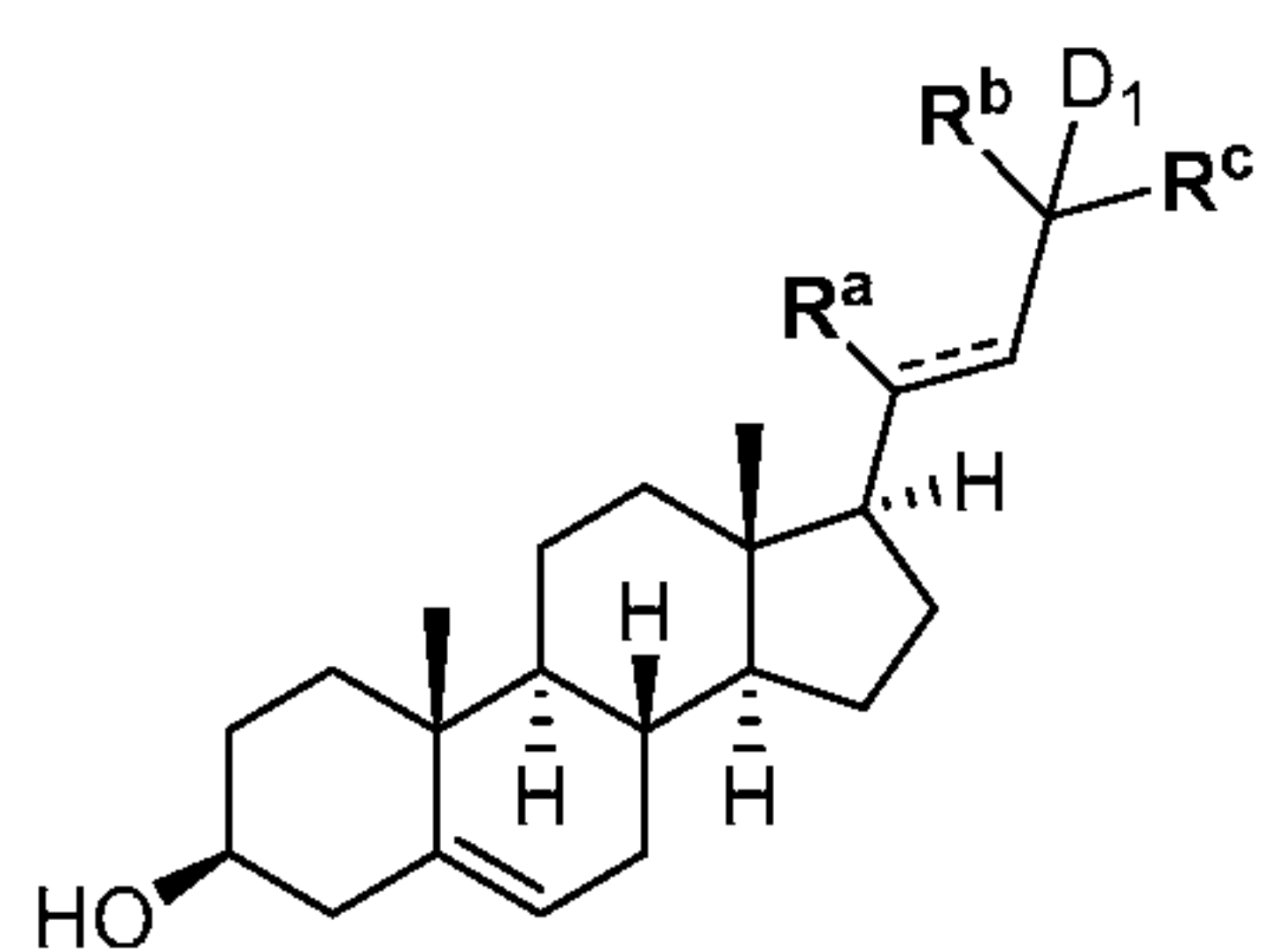
[0059] In certain embodiments, the cholesterol derivative is a compound of any of Formula (CD-1) through (CD6):



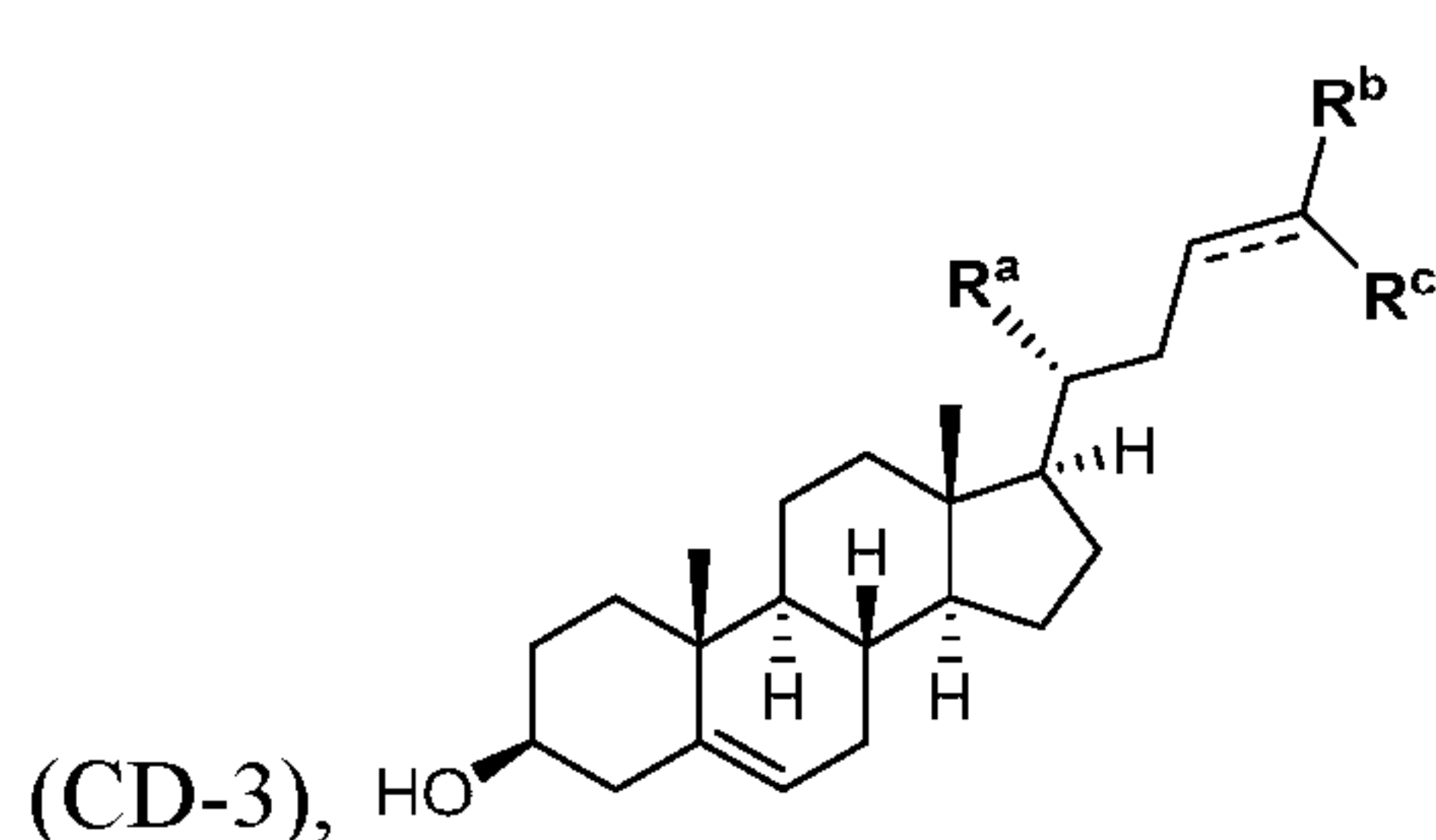
(CD-1),



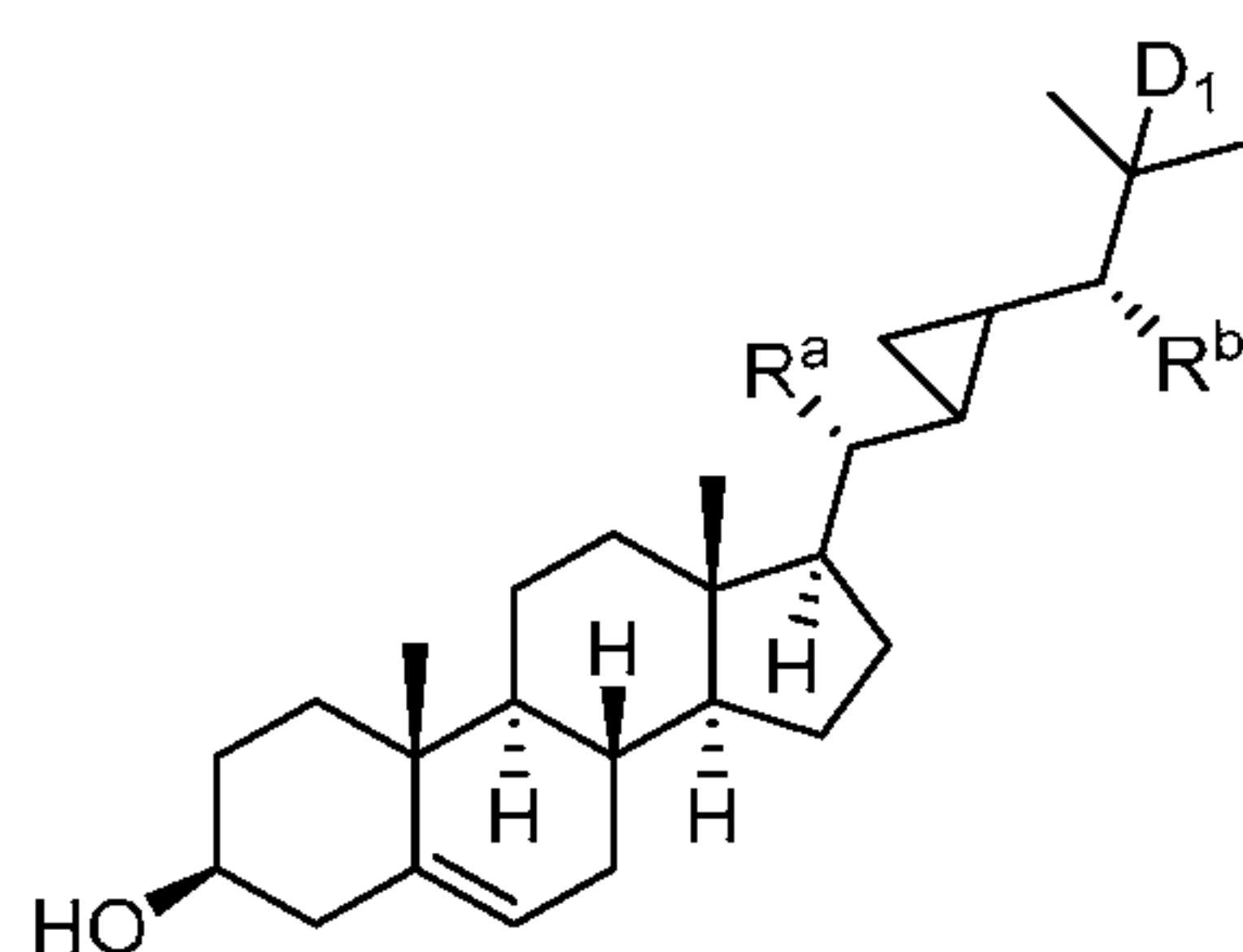
(CD-2),



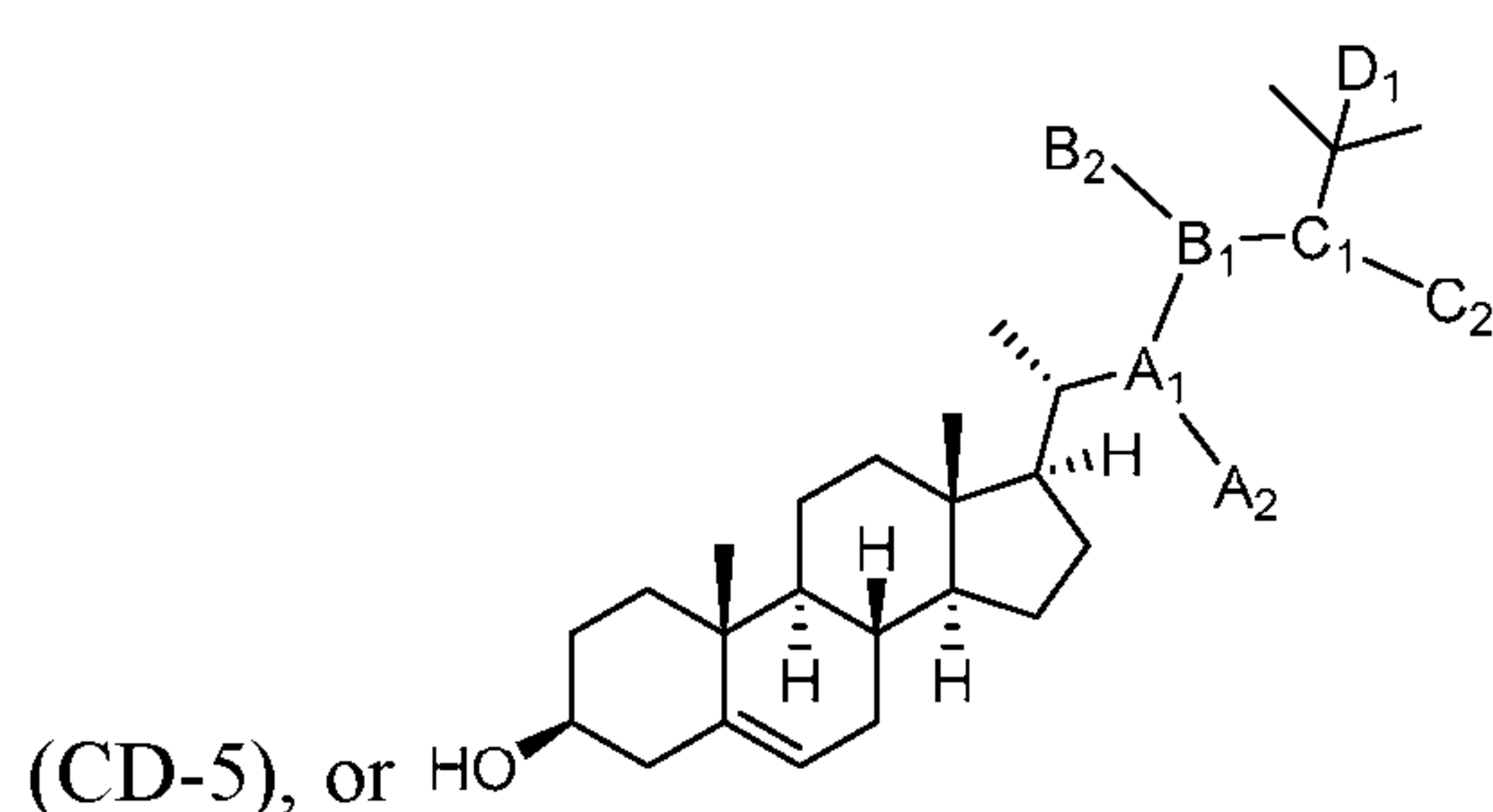
(CD-3),



(CD-4),

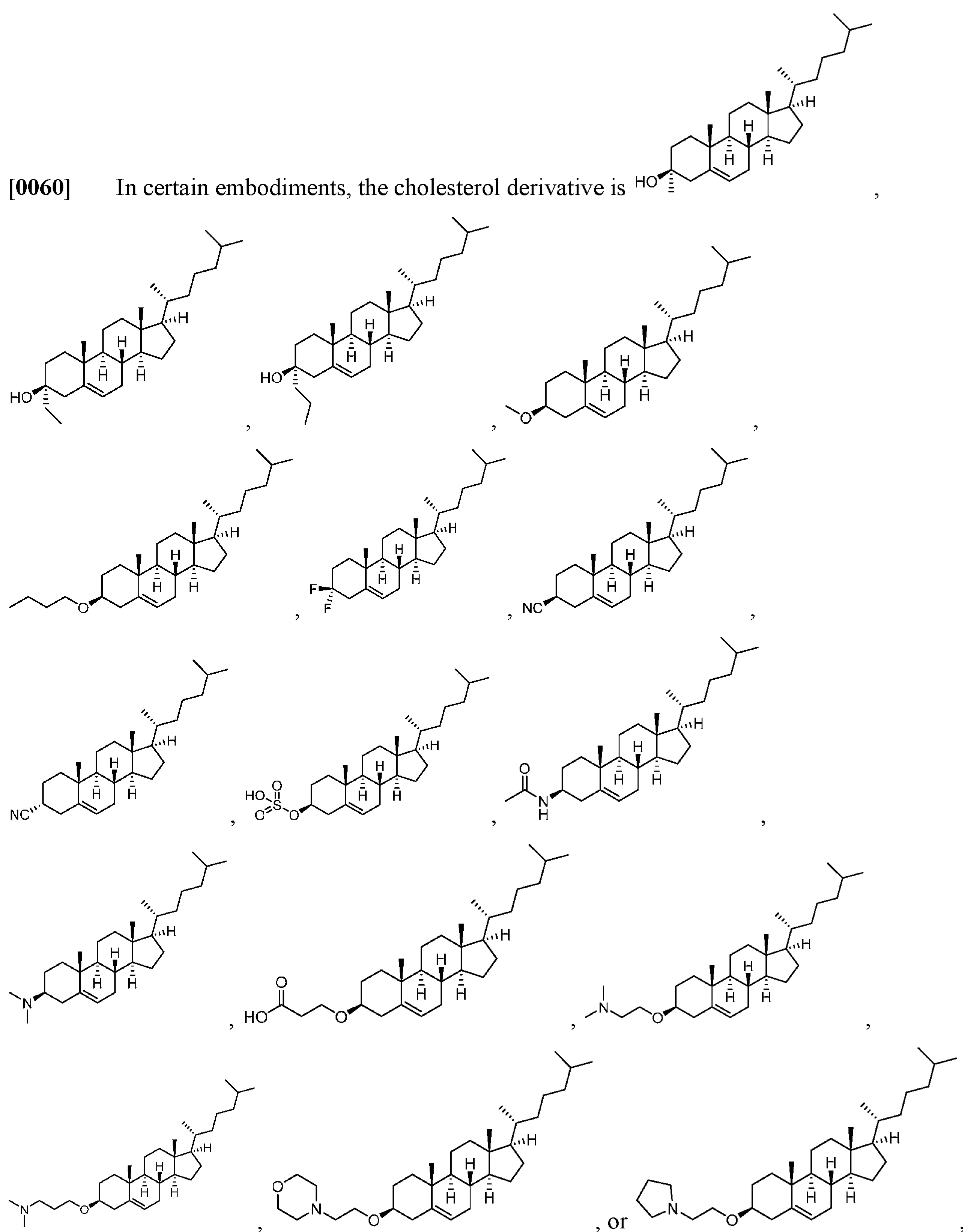


(CD-5), or



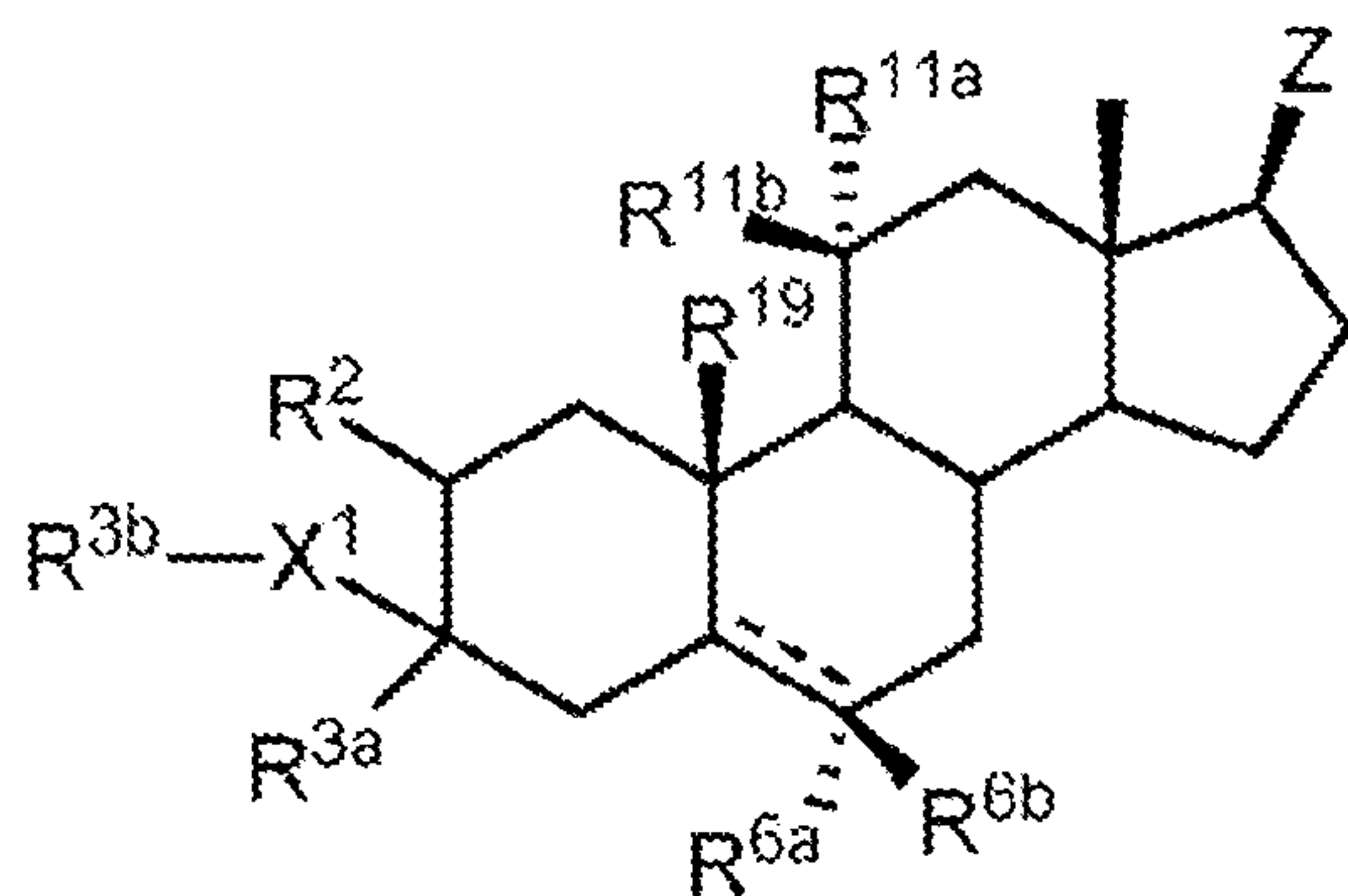
(CD-6), or a salt or isomer

thereof, in which ----- denotes a carbon-carbon single or double bond; R^a is C_{1-6} alkyl optionally substituted with OH or halo; each of R^b and R^c independently is H or C_{1-6} alkyl optionally substituted with OH or halo; each of A_1 , B_1 , C_1 is independently CH, CF, O, or S and when one of A_1 , B_1 , C_1 is O or S, the other two are independently CH or CF; and each of A_2 , B_2 , C_2 , D_1 is independently H, OH, or F.



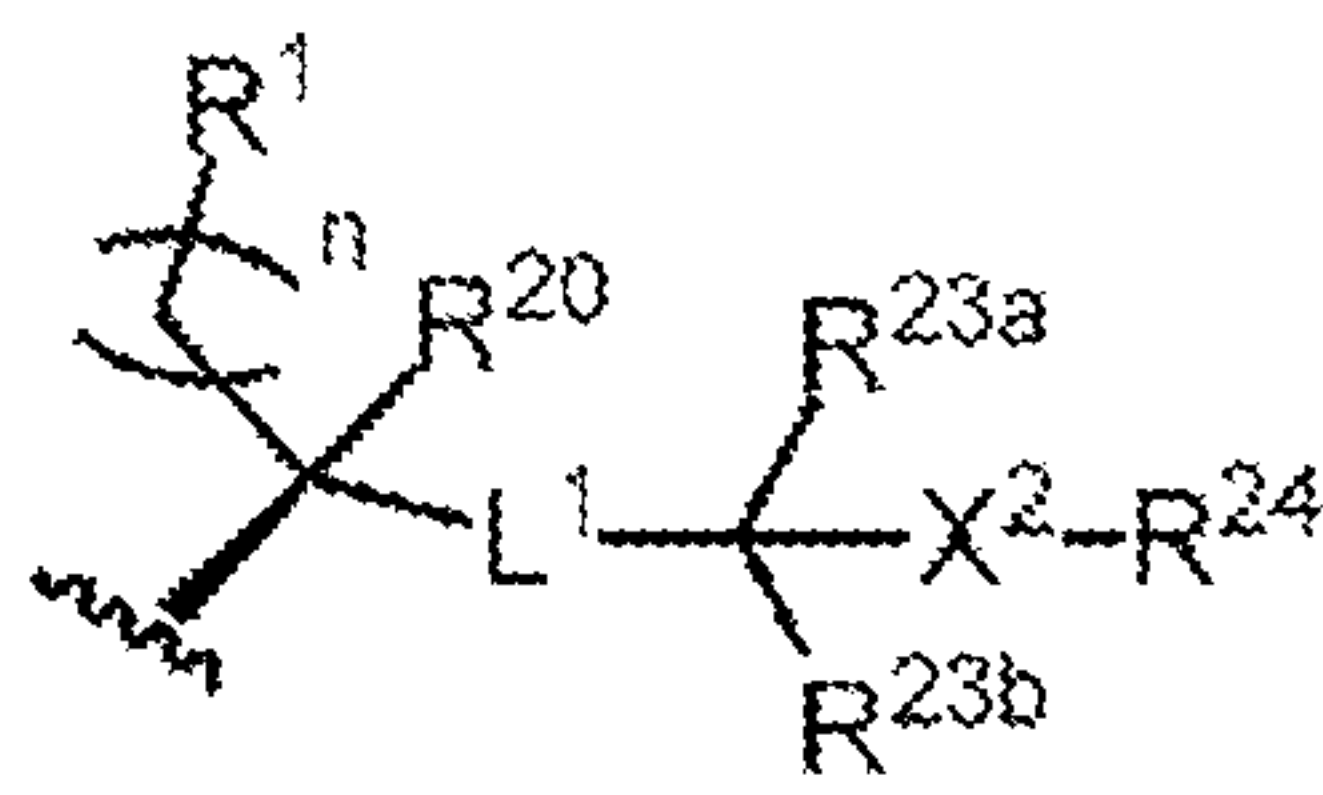
or a salt or isomer thereof.

[0061] In certain embodiments, the cholesterol derivative is a compound of Formula (CD-7):

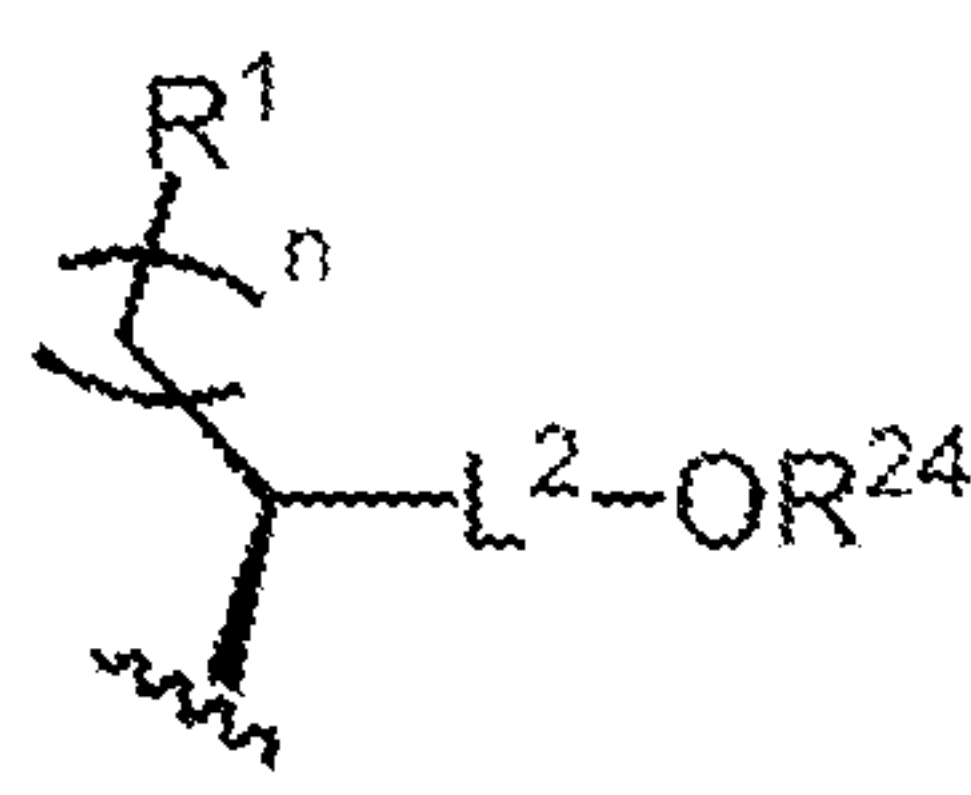


(CD-7), or a salt or isomer thereof, wherein

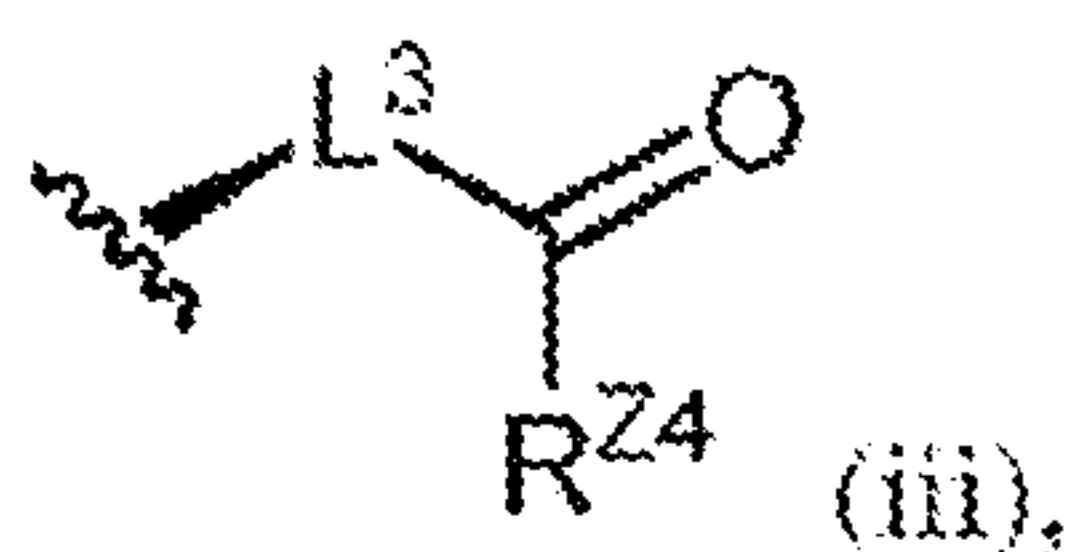
Z is a group of the formula (i), (ii), (iii), (iv), or (v)



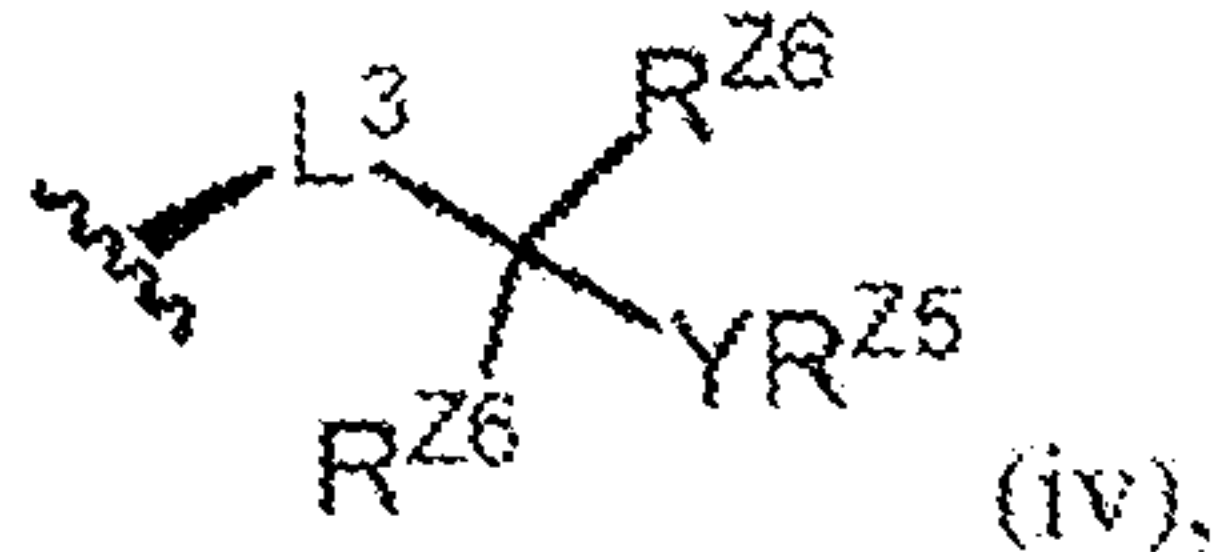
(i),



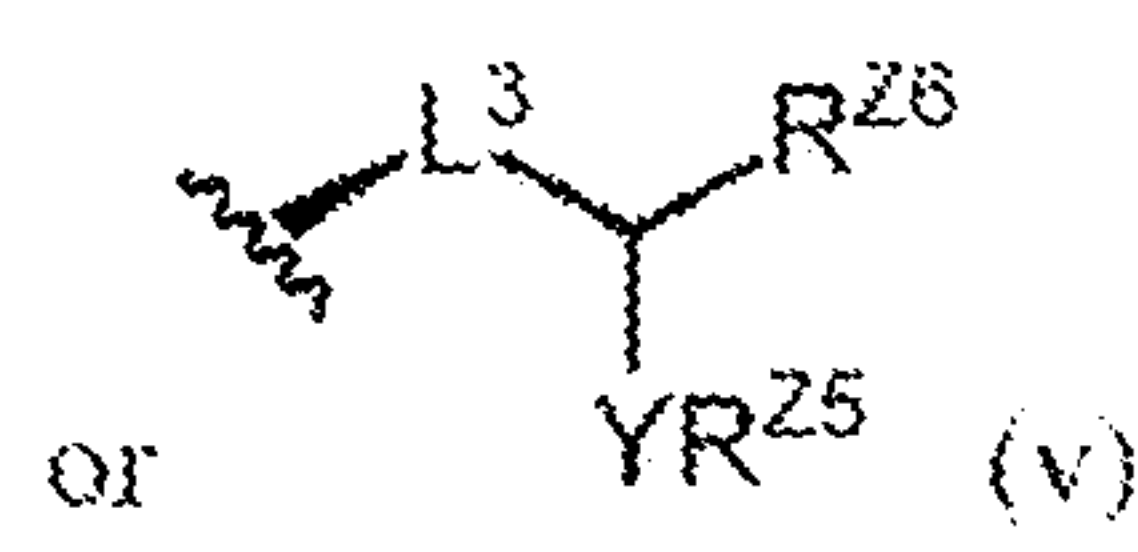
(ii),



(iii),



(iv),



(v)

L^1 and L^2 are selected from a group consisting of a bond, a substituted or unsubstituted C_1 - C_6 alkylene, a substituted or unsubstituted C_2 - C_6 alkenylene, substituted or unsubstituted C_2 - C_6 alkynylene, a substituted or unsubstituted hetero C_1 - C_6 alkylene, a substituted or unsubstituted hetero C_2 - C_6 alkenylene, and a substituted or unsubstituted hetero C_2 - C_6 alkynylene;

L^3 is a substituted or unsubstituted C_1 - C_6 alkylene, a substituted or unsubstituted C_2 - C_6 alkenylene, substituted or unsubstituted C_2 - C_6 alkynylene, a substituted or unsubstituted hetero C_1 - C_6 alkylene, a substituted or unsubstituted hetero C_2 - C_6 alkenylene, or a substituted or unsubstituted hetero C_2 - C_6 alkynylene;

each instance of X^1 and X^2 is independently -O-, -S-, or -NH-;

R^1 is hydrogen or substituted or unsubstituted alkyl;

R^{3b} is hydrogen;

R^{3a} is hydrogen, substituted or unsubstituted alkyl, substituted or unsubstituted alkenyl, or substituted or unsubstituted alkynyl;

each instance of R^2 , R^{11a} and R^{11b} is independently hydrogen or $-OR^{B1}$, wherein R^{B1} is hydrogen or substituted or unsubstituted alkyl, or R^{11a} and R^{11b} are joined to form an oxo ($=O$) group;

each of R^{6a} and R^{6b} is independently hydrogen, halo, or substituted or unsubstituted alkyl, and ----- represents a single or double bond, provided if a double bond is present, then one of R^{6a} and R^{6b} is absent, and provided if a single bond is present, then the hydrogen at C5 is in the alpha or beta position;

each instance of R^{19} and R^{20} is independently hydrogen or $-CH_3$;

each instance of R^{23a} and R^{23b} is independently hydrogen, halogen, or substituted or unsubstituted alkyl, or R^{23a} and R^{23b} are joined together to form substituted or unsubstituted C_3 - C_6 cycloalkyl;

R^{24} is hydrogen or substituted or unsubstituted alkyl;

Y is $-O-$, $-S-$ or $-NR^{Z5}-$;

R^{Z4} is independently substituted or unsubstituted alkyl, substituted or unsubstituted alkenyl, substituted or unsubstituted alkynyl, substituted or unsubstituted carbocyclyl, substituted or unsubstituted heterocyclyl, substituted or unsubstituted aryl, substituted or unsubstituted heteroaryl, $-OR^{Z5}$, $-SR^{Z5}$, or $-N(R^{Z5})_2$;

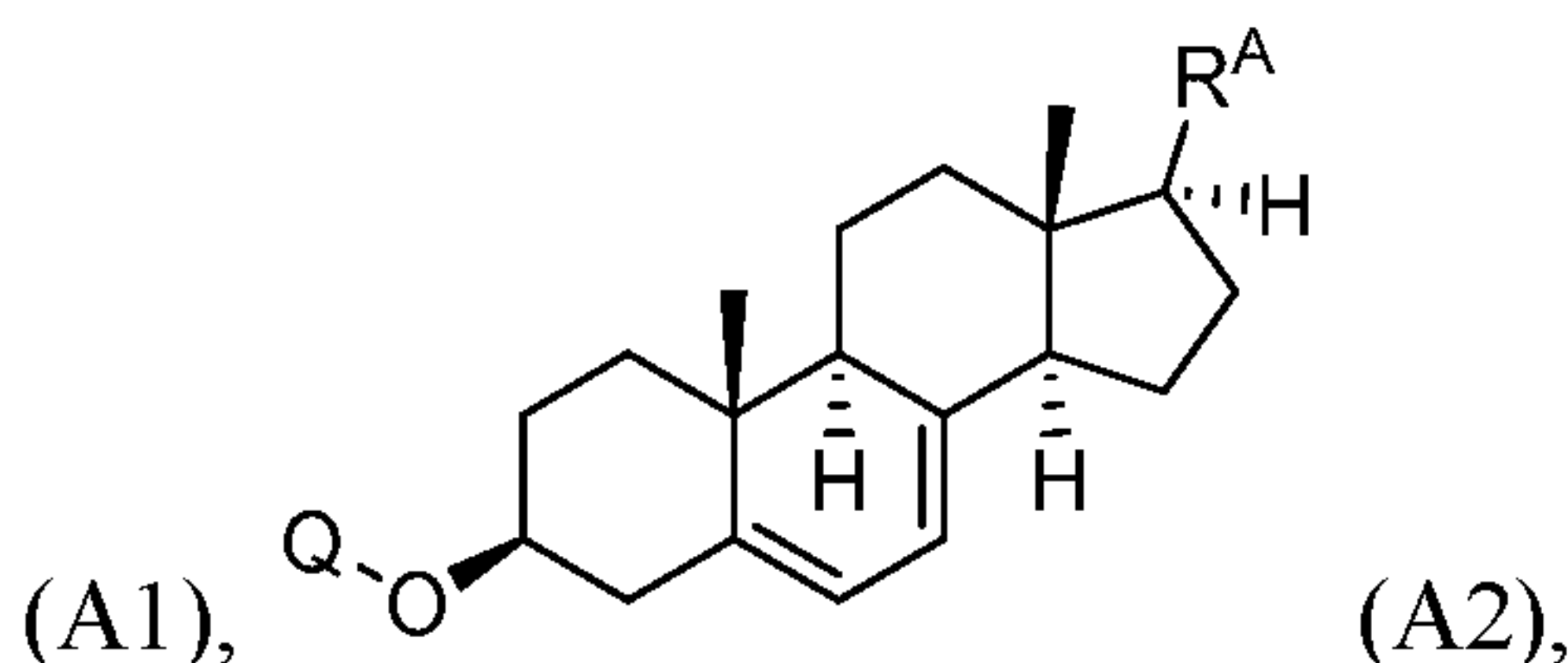
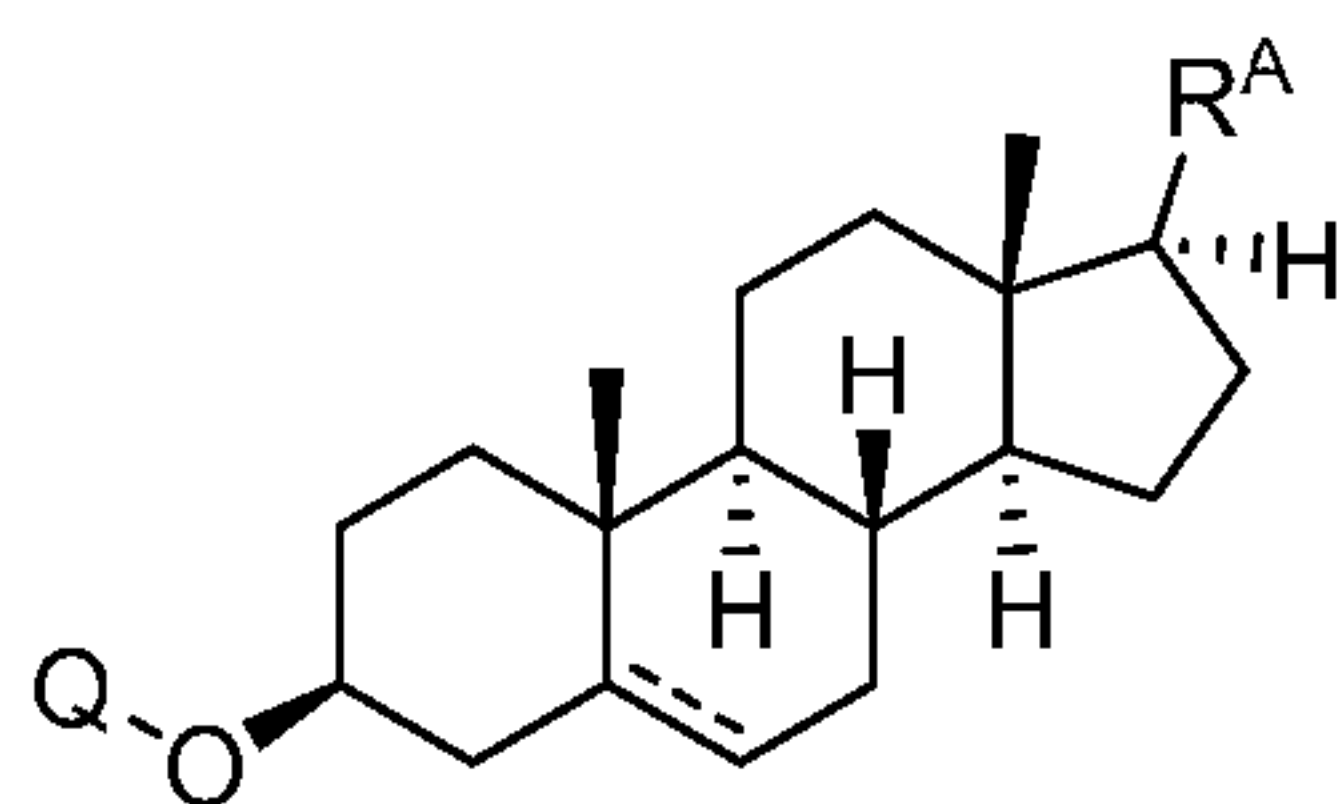
each instance of R^{Z5} is independently hydrogen or substituted or unsubstituted alkyl;

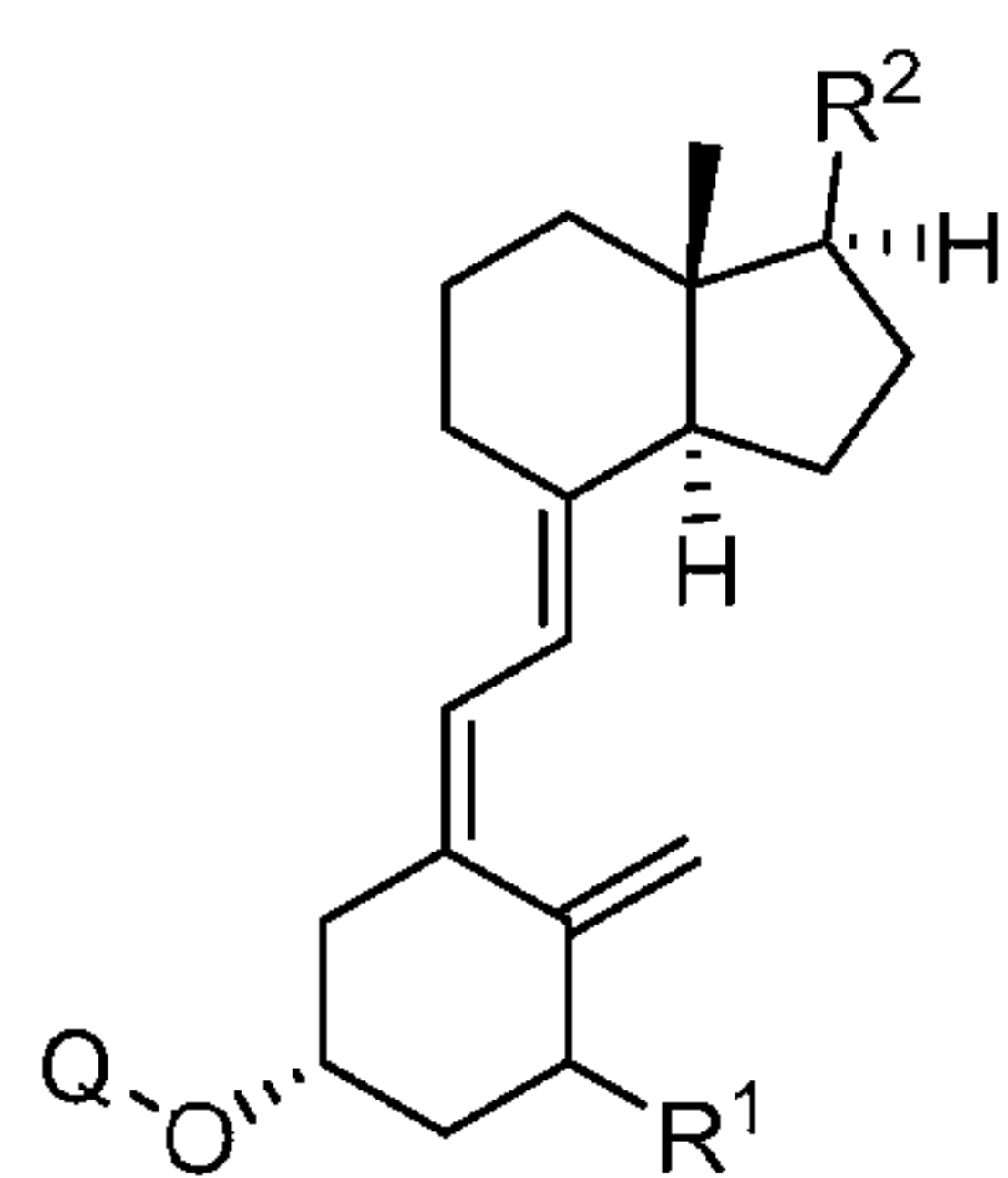
each instance of R^{Z6} is independently hydrogen or substituted or unsubstituted alkyl, or two R^{Z6} groups are joined to form a C_3 - C_6 carbocyclic ring; and

the subscript n is 0 or 1.

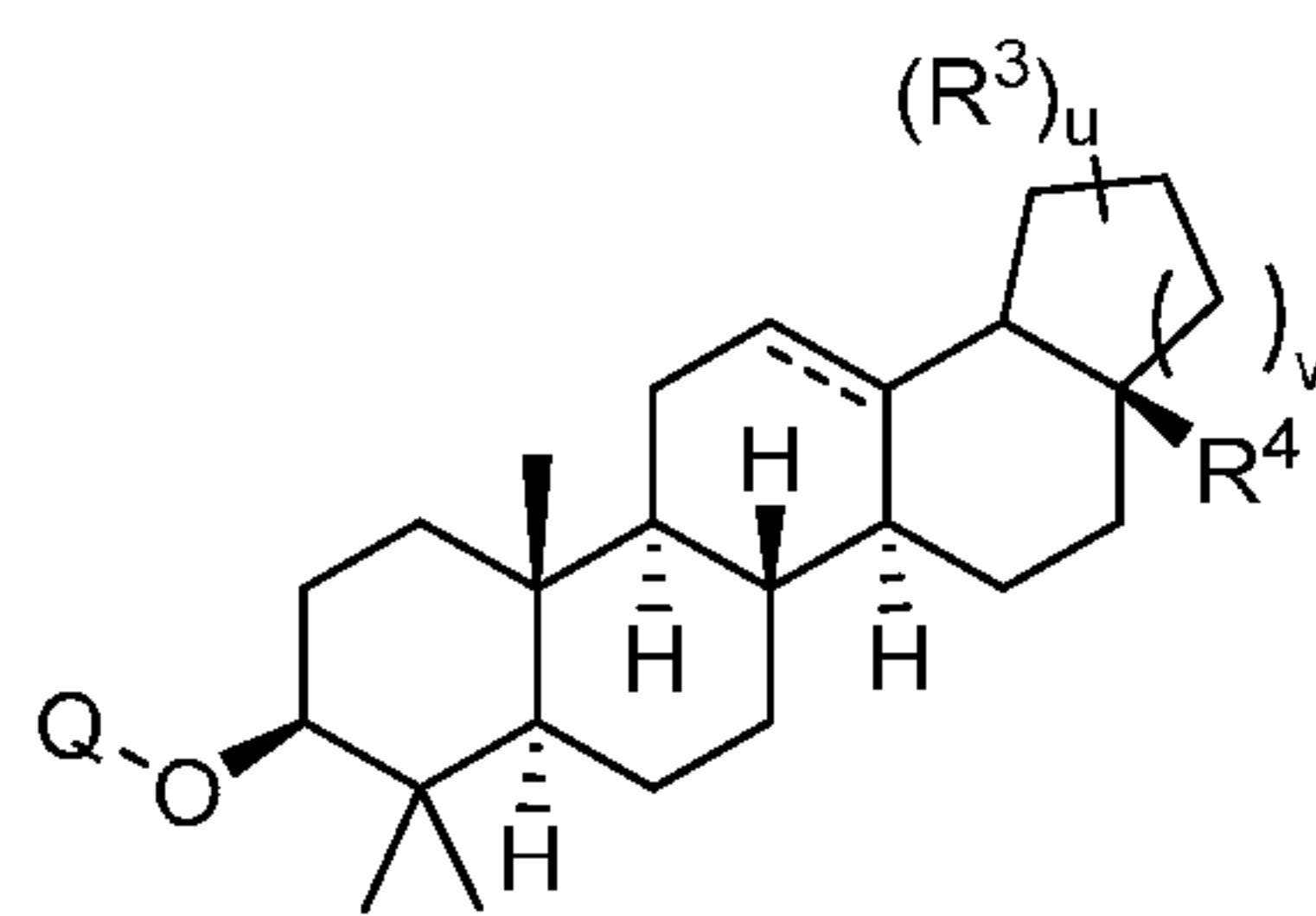
[0062] Other examples of cholesterol derivatives are described in e.g., US Patent No. 4,125,544 and WO2013/036835, the contents of which are each incorporated herein by reference in their entireties.

[0063] In yet other embodiments, the cholesterol derivative is of any of Formulae (A1)-(A4):



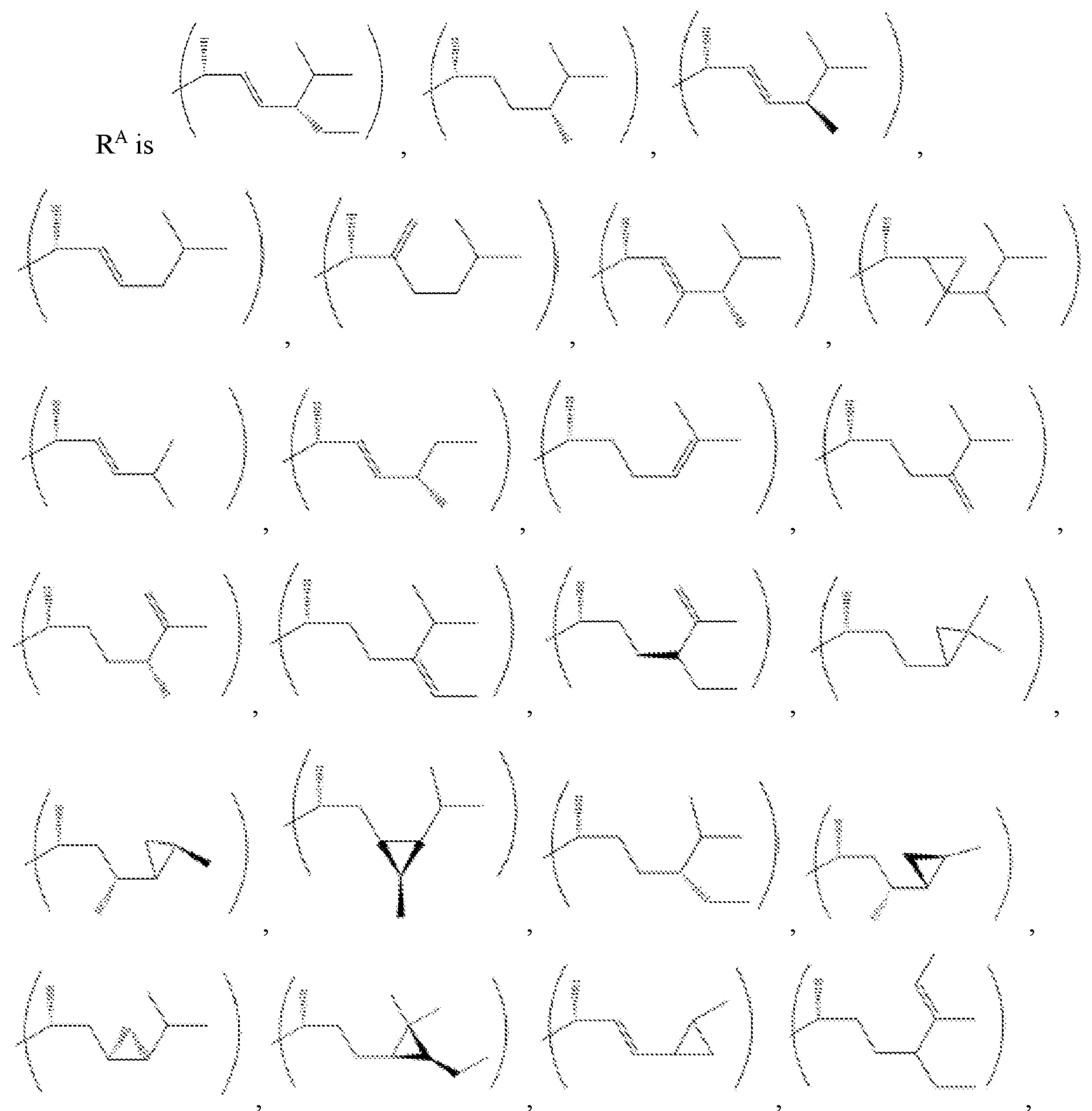


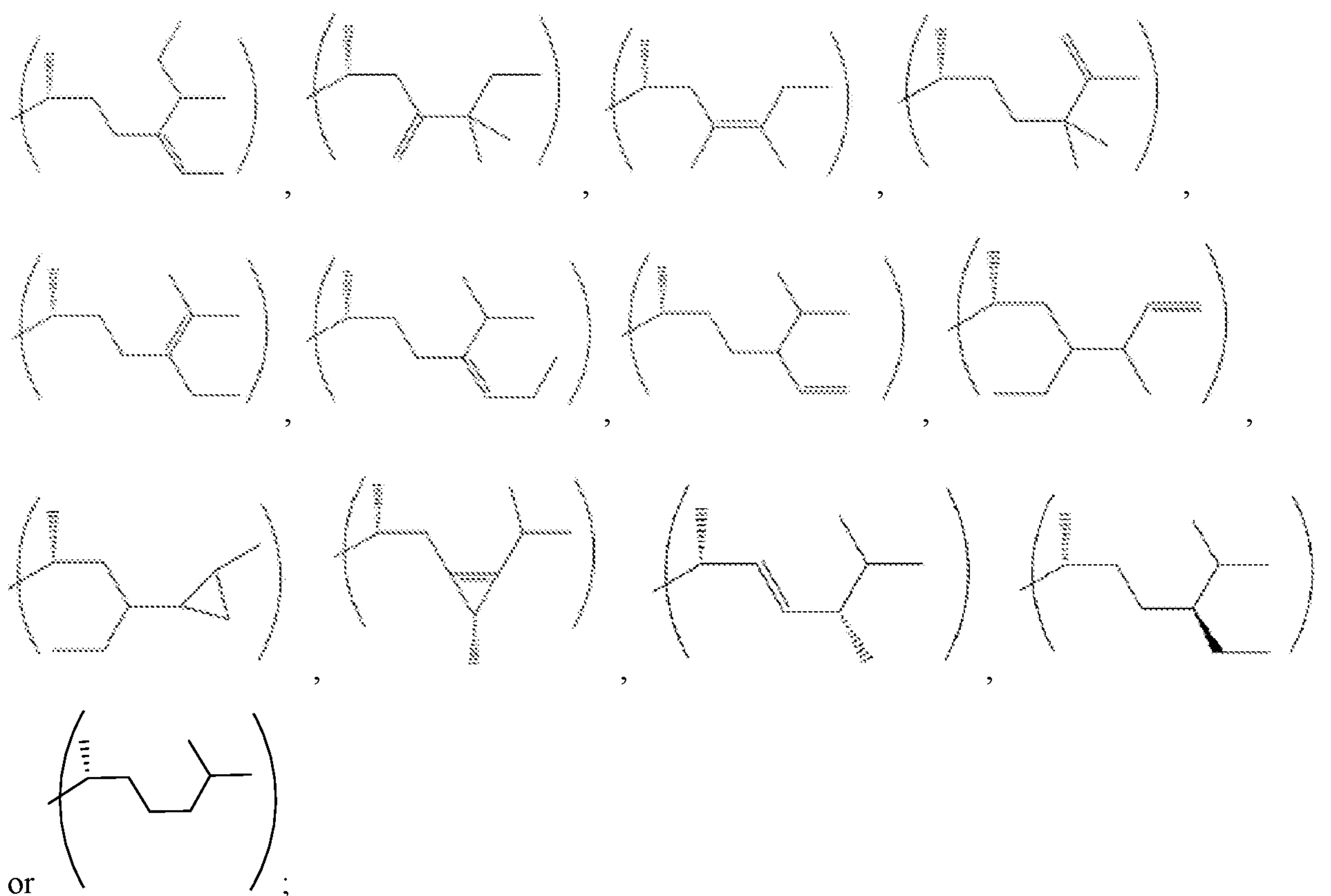
(A3), or



(A4); or a salt or isomer

thereof,

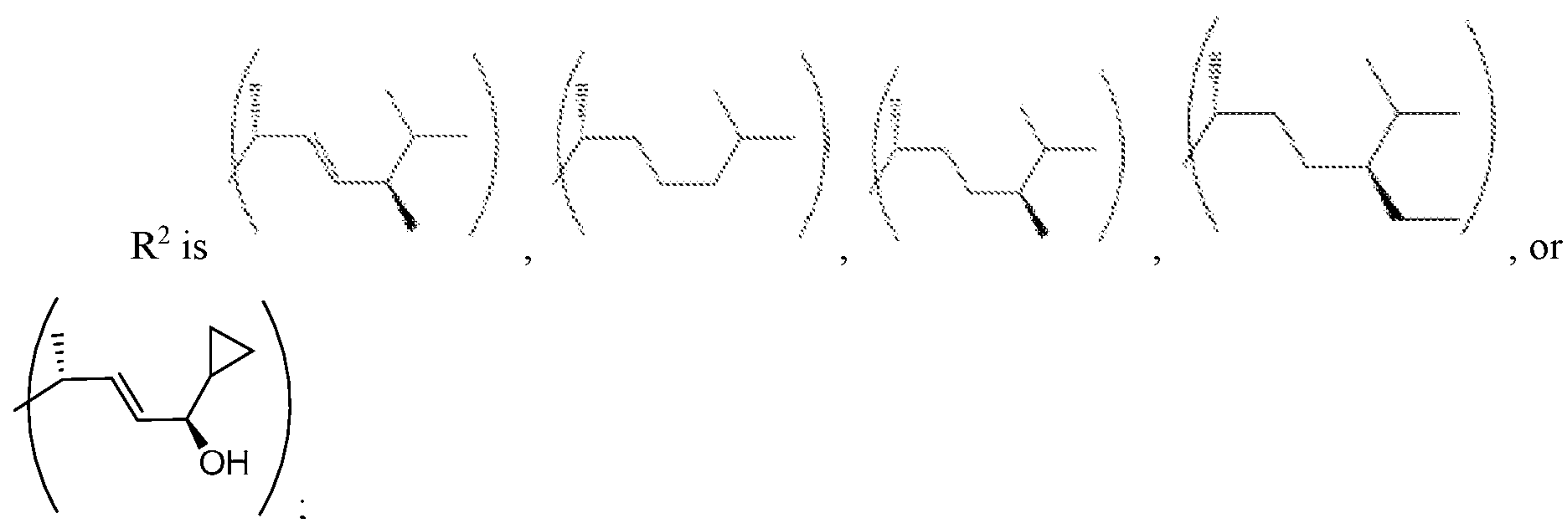
wherein ----- denotes a carbon-carbon single or double bond;



u is 1 or 2;

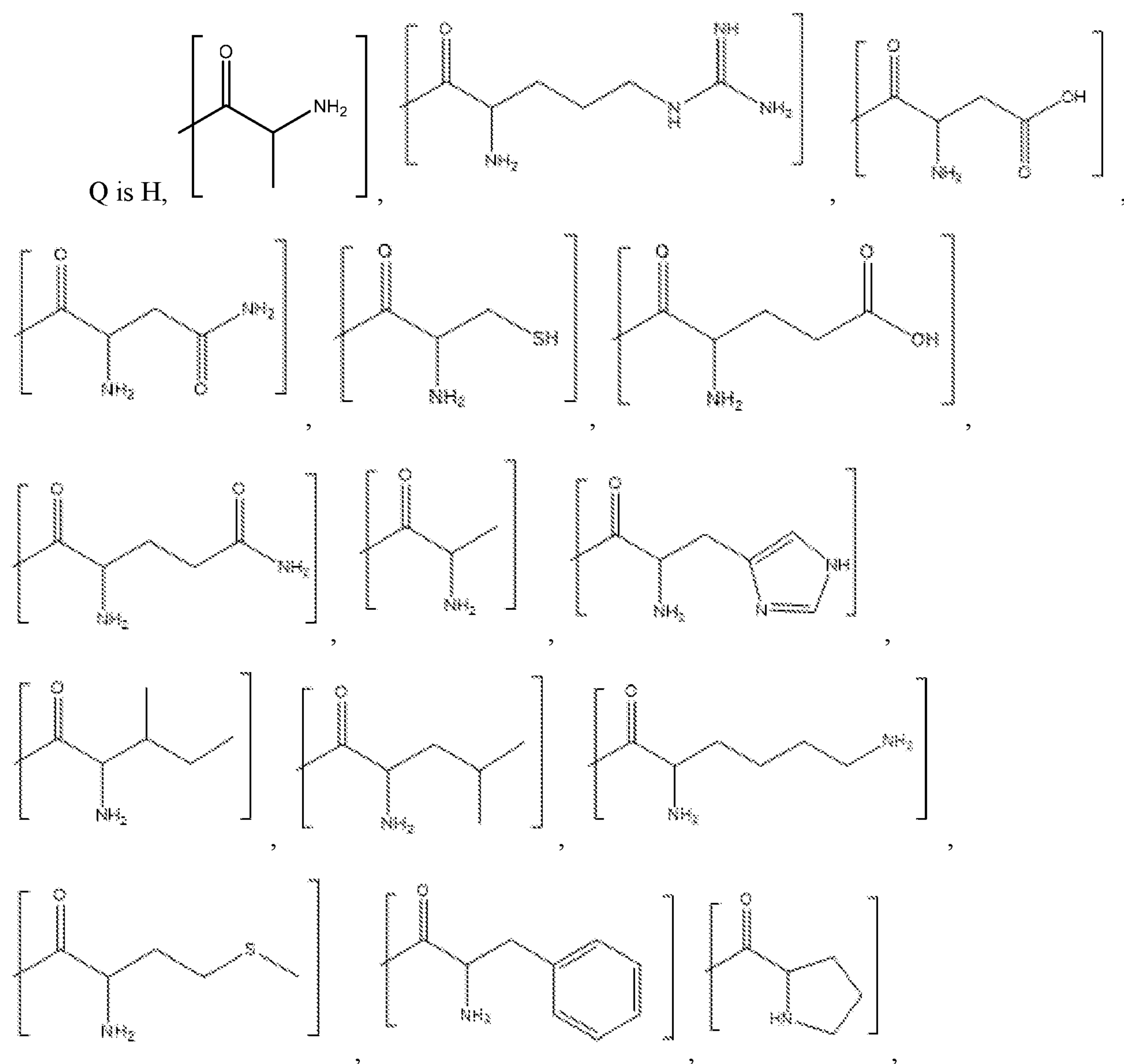
v is 1 or 2;

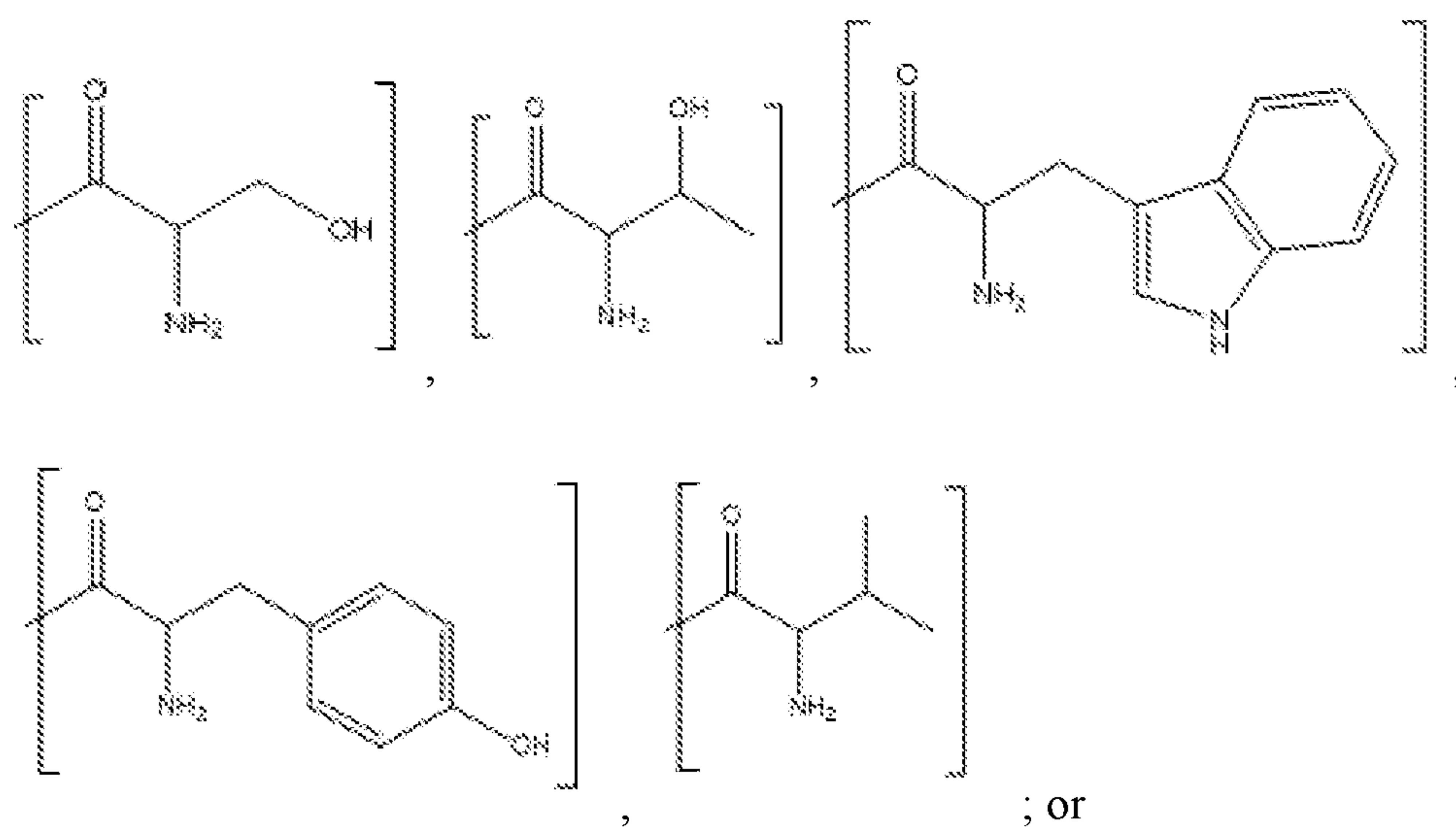
R¹ is H or OH;



each R³ independently is CH₃, or ;

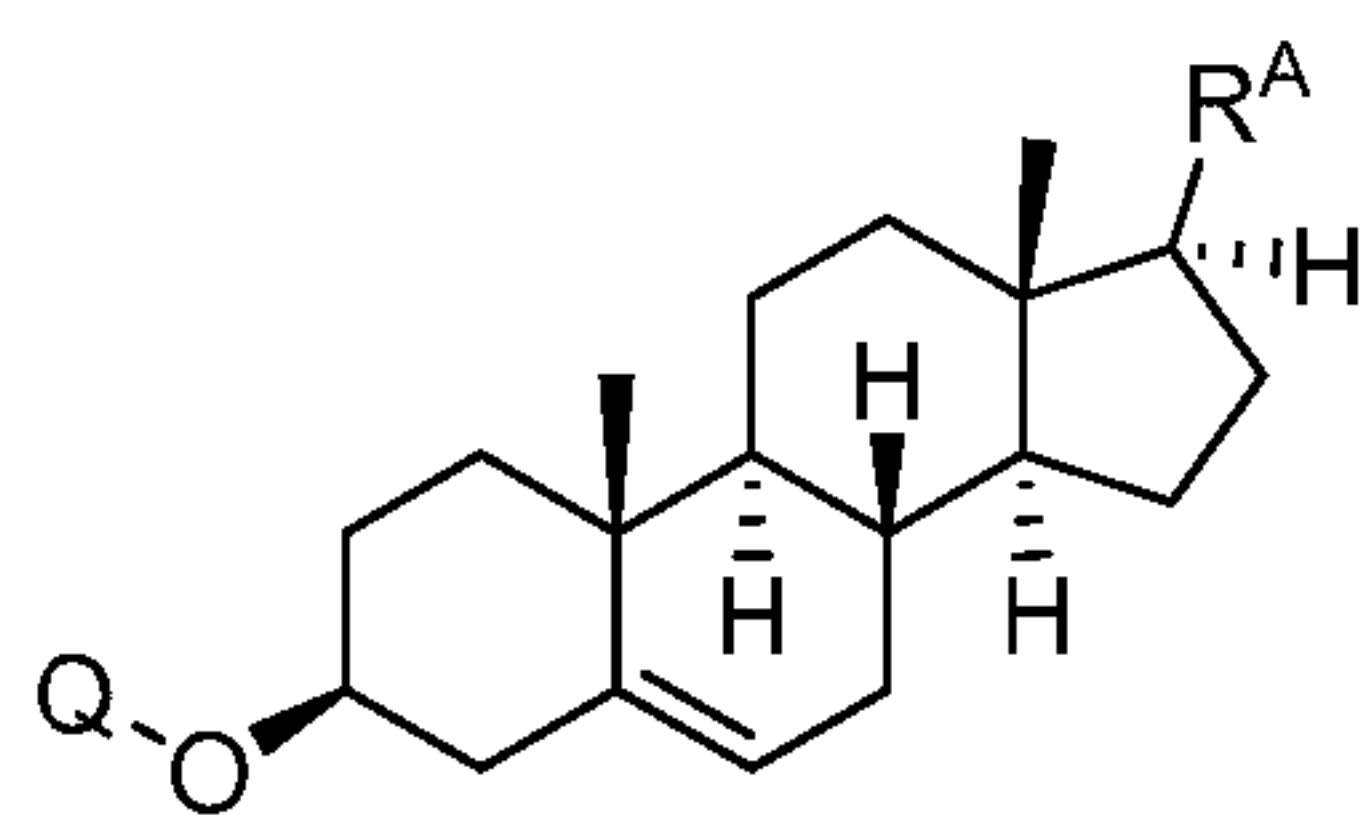
R⁴ is CH₃, CH₂OH, or CO₂H; and



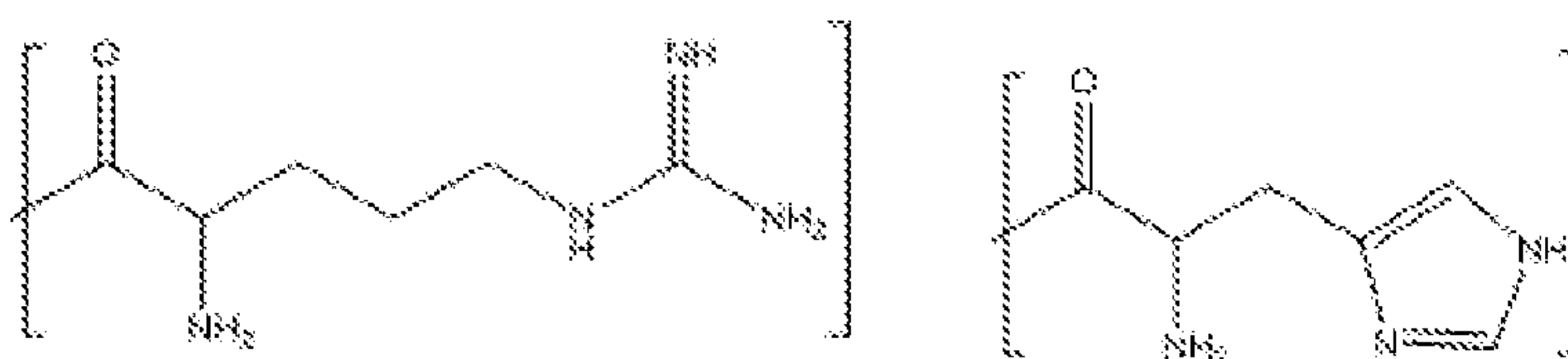


Q is $\left[\begin{array}{c} \text{O} \\ \parallel \\ \text{---} \end{array} \right]$, where R^5 is C_{1-25} alkyl, C_{2-25} alkenyl, C_{2-25} alkynyl, or glycoside.

[0064] In some embodiments, when the cholesterol derivative has a formula



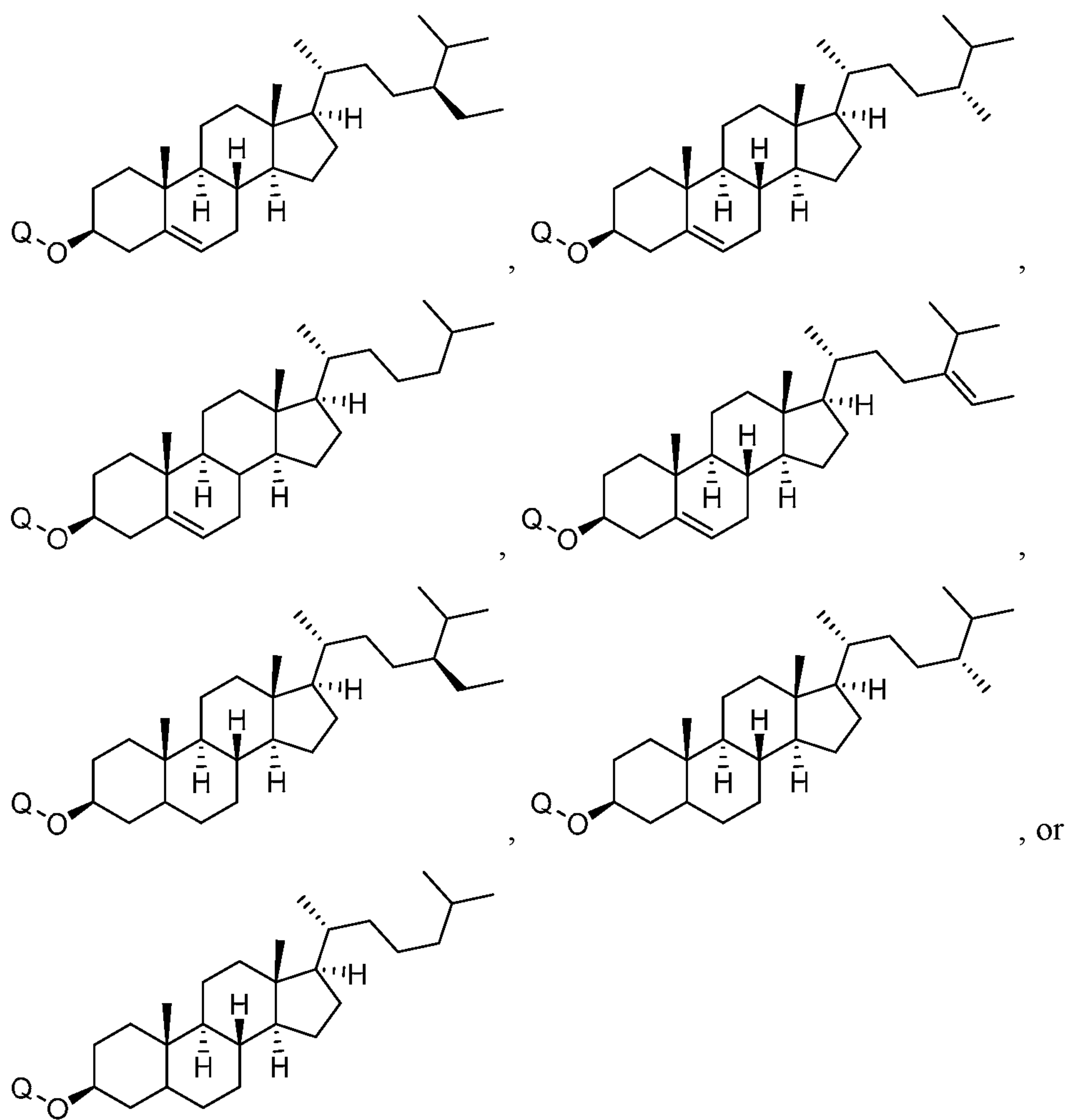
then Q is not H.



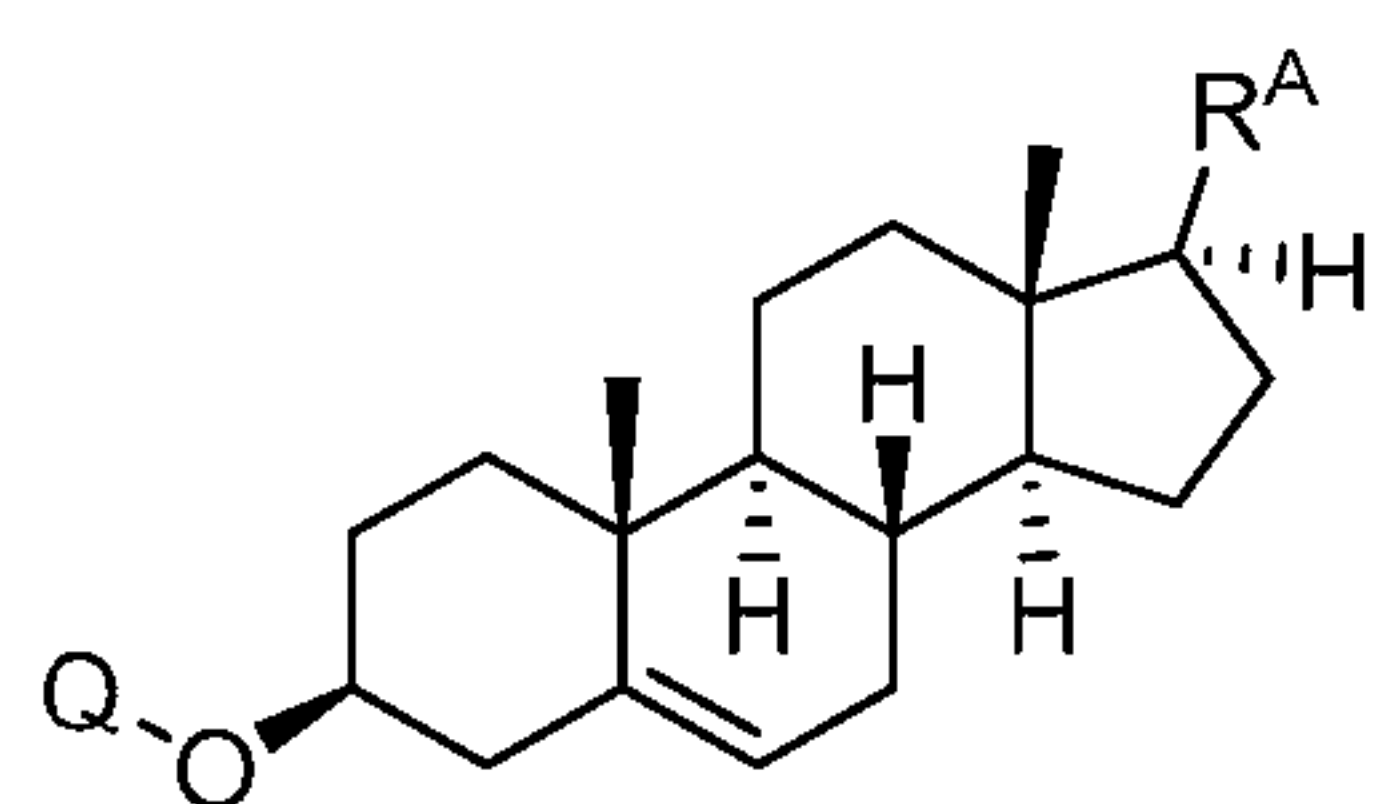
[0065] For example, Q is

or

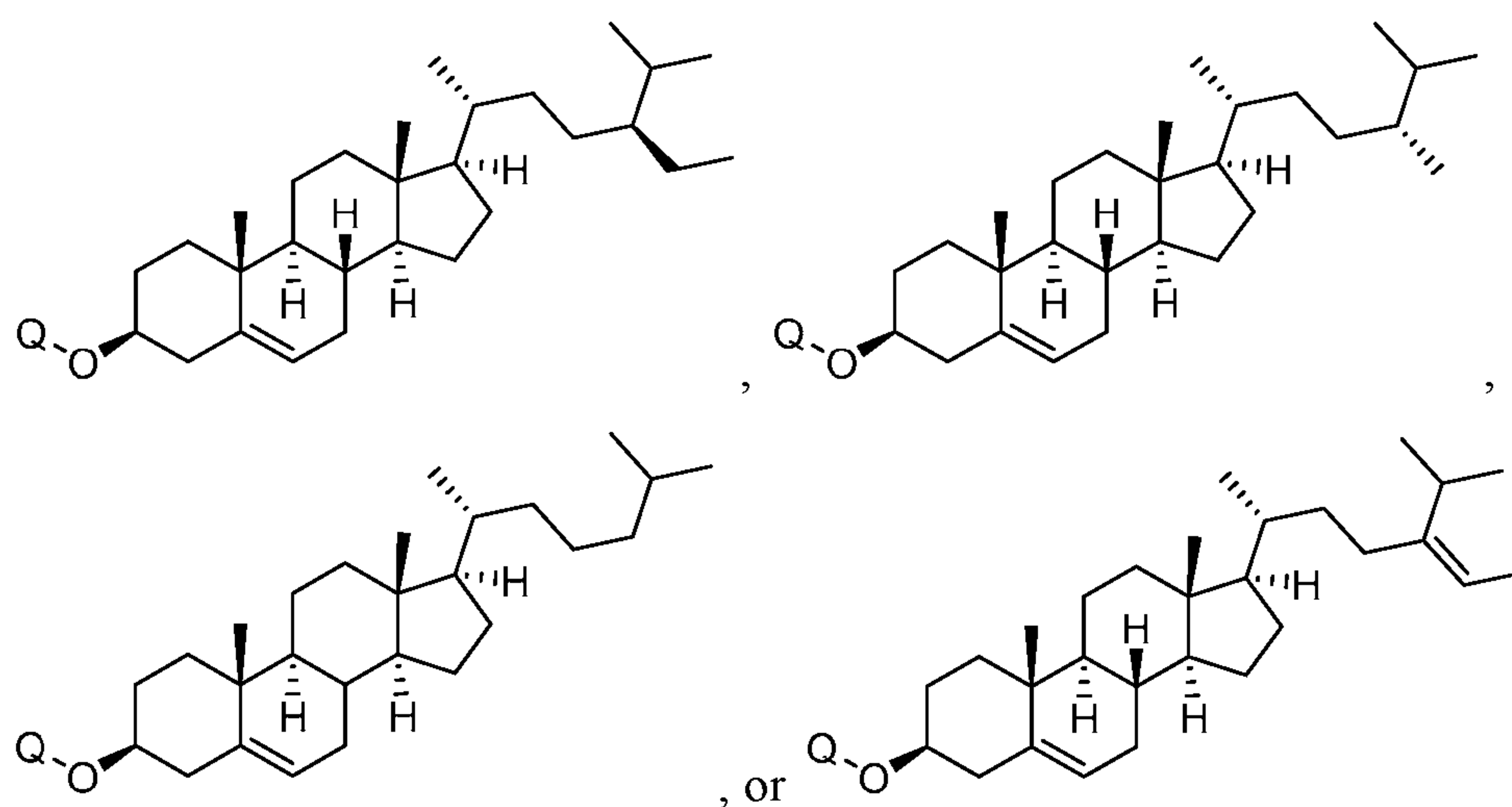
[0066] For example, the cholesterol derivative has a formula:



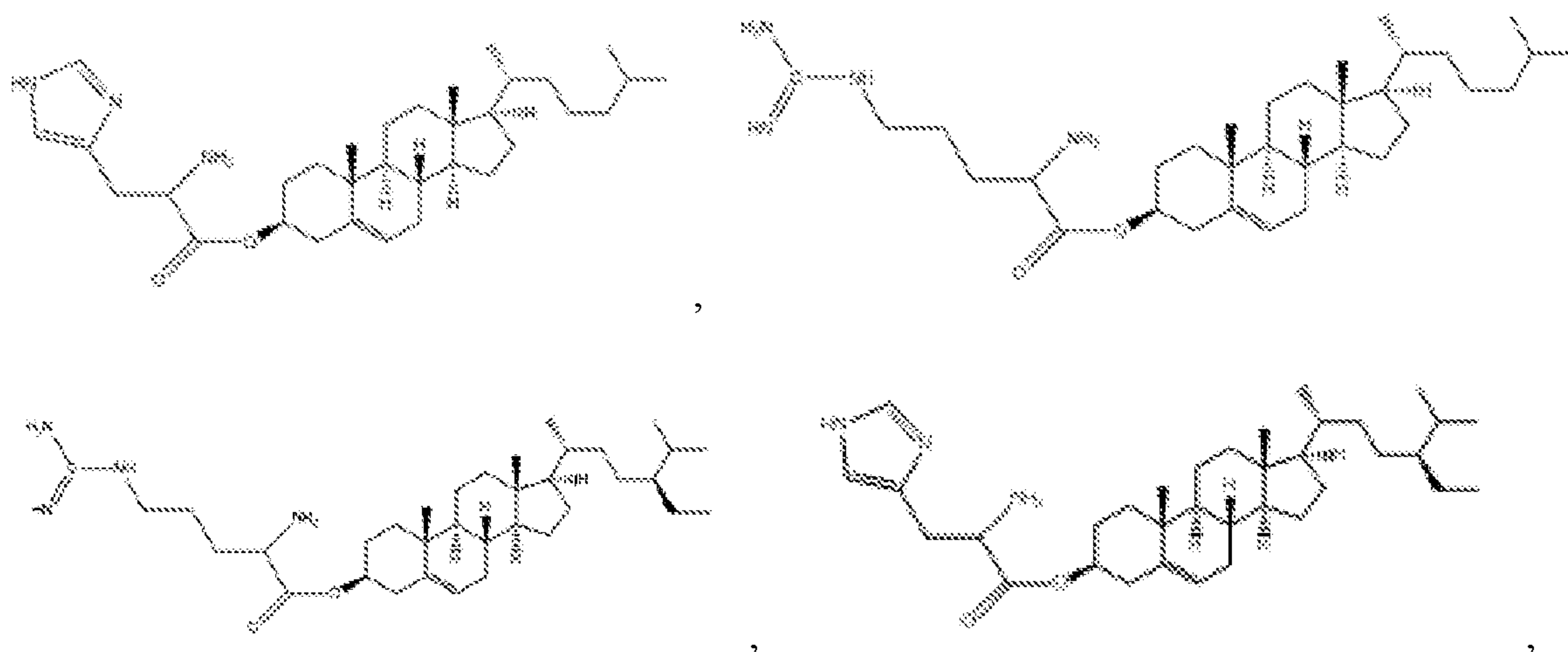
[0067] For example, the cholesterol derivative has a formula:

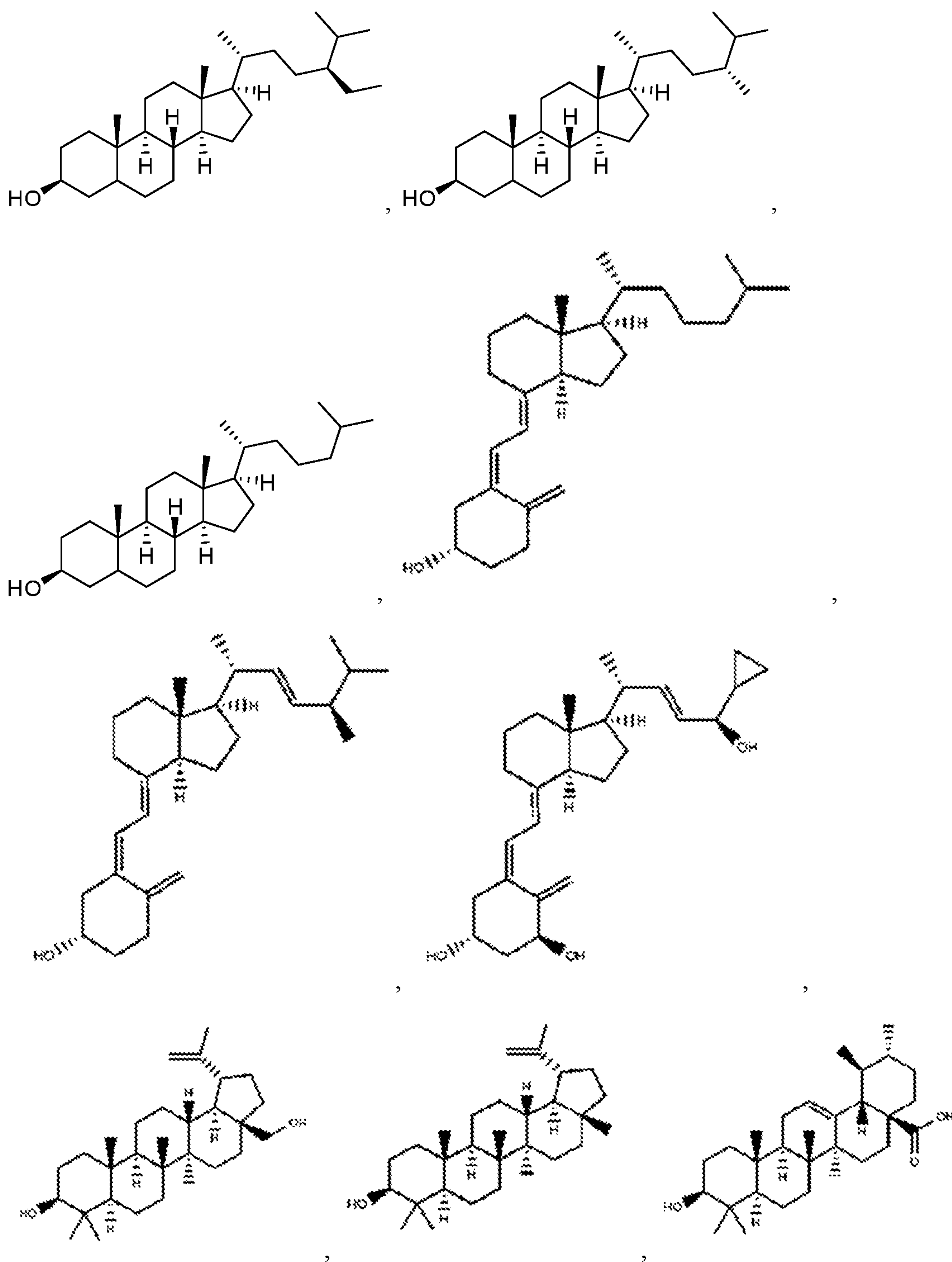


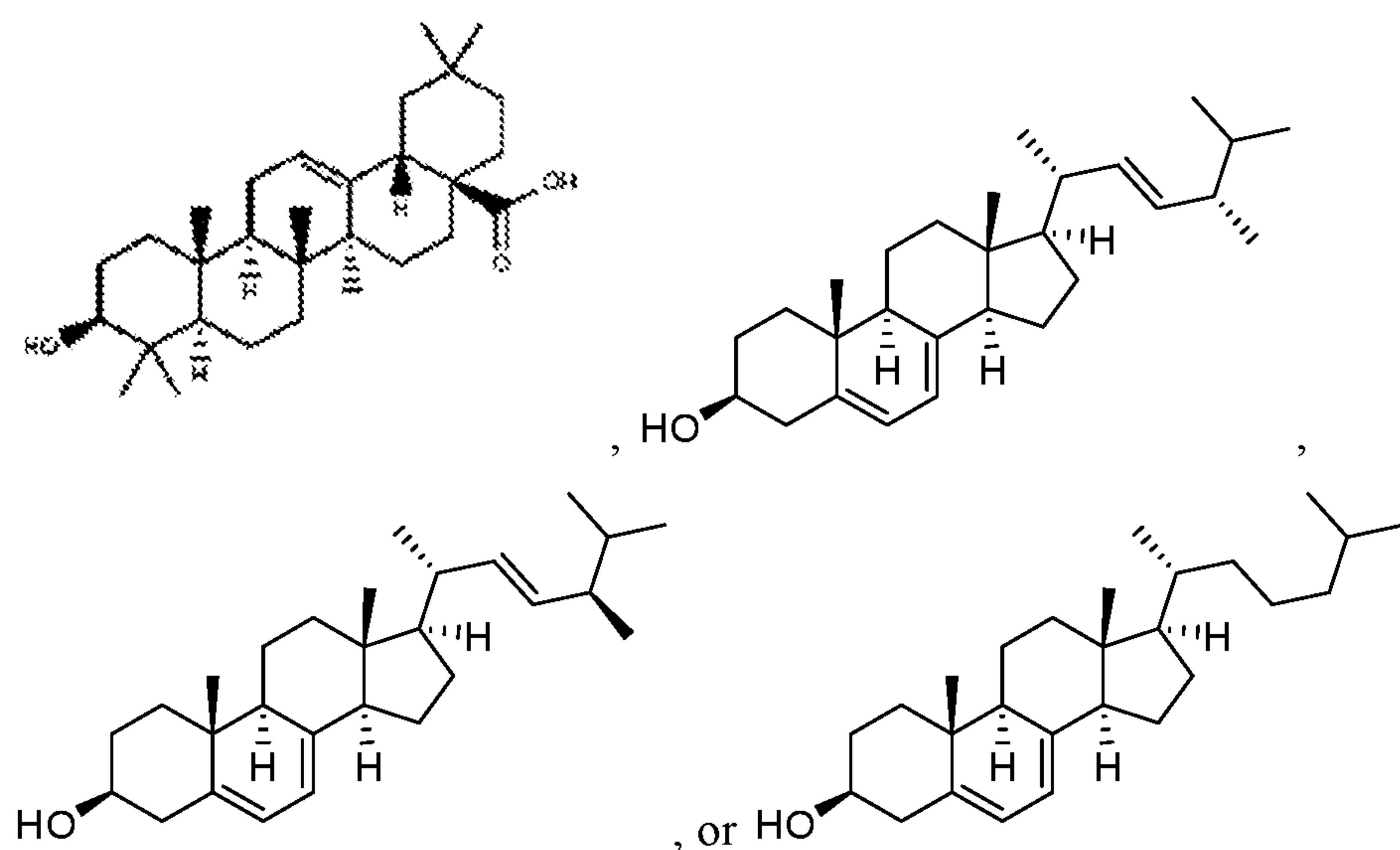
[0068] For example, the cholesterol derivative has a formula:



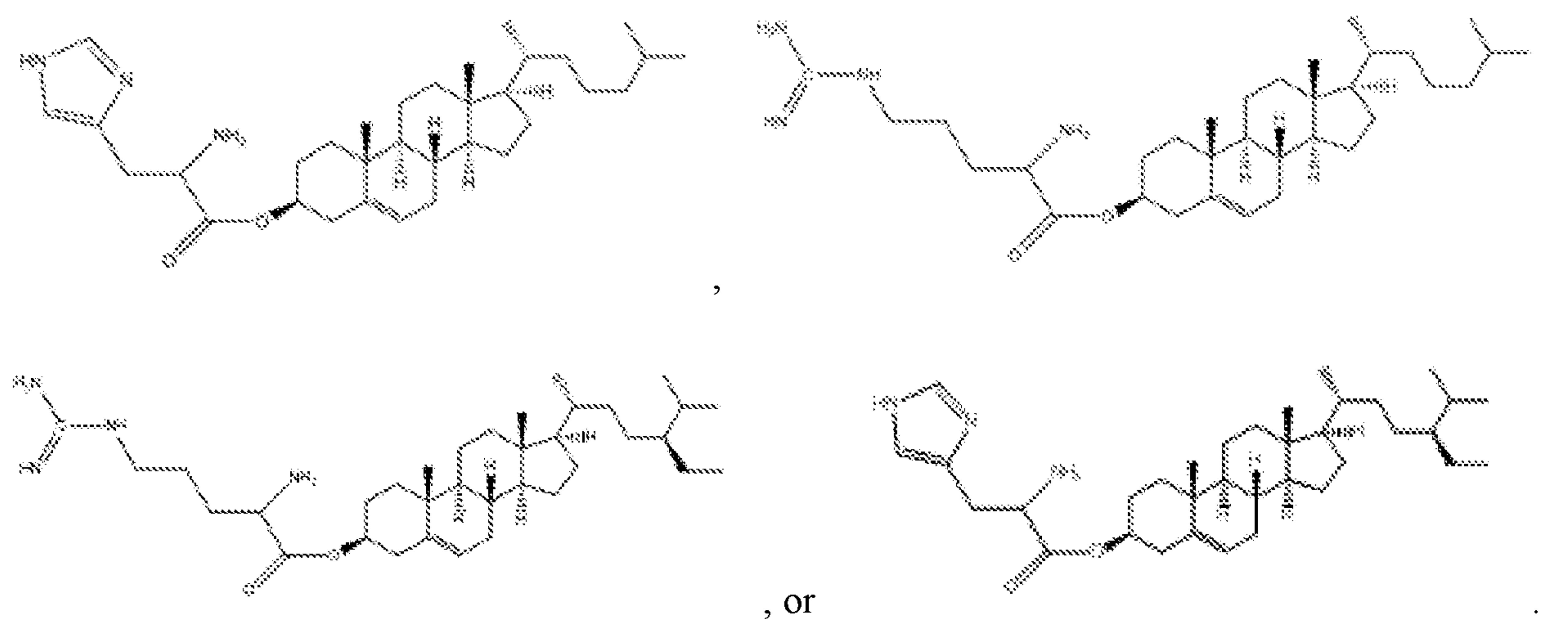
[0069] For example, the cholesterol derivative has a formula of any of the following:



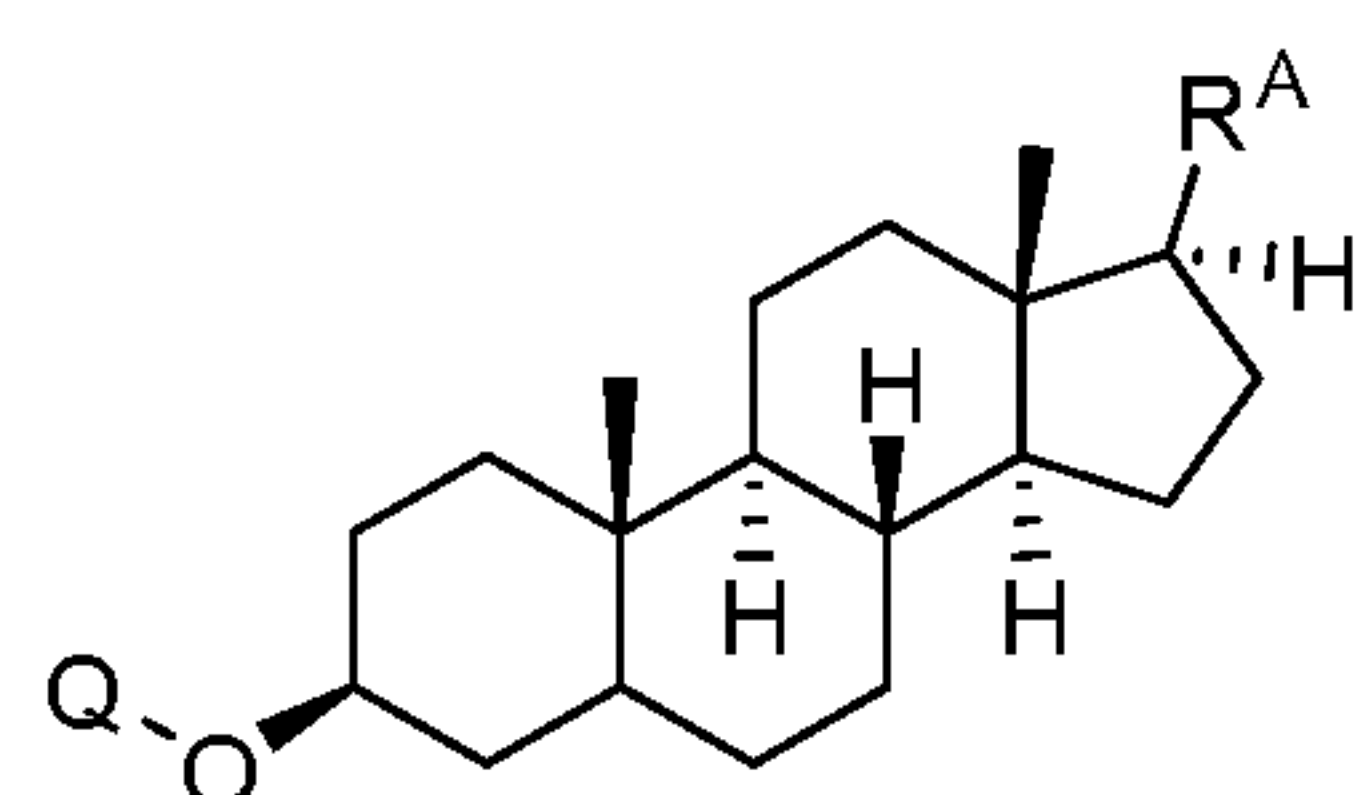




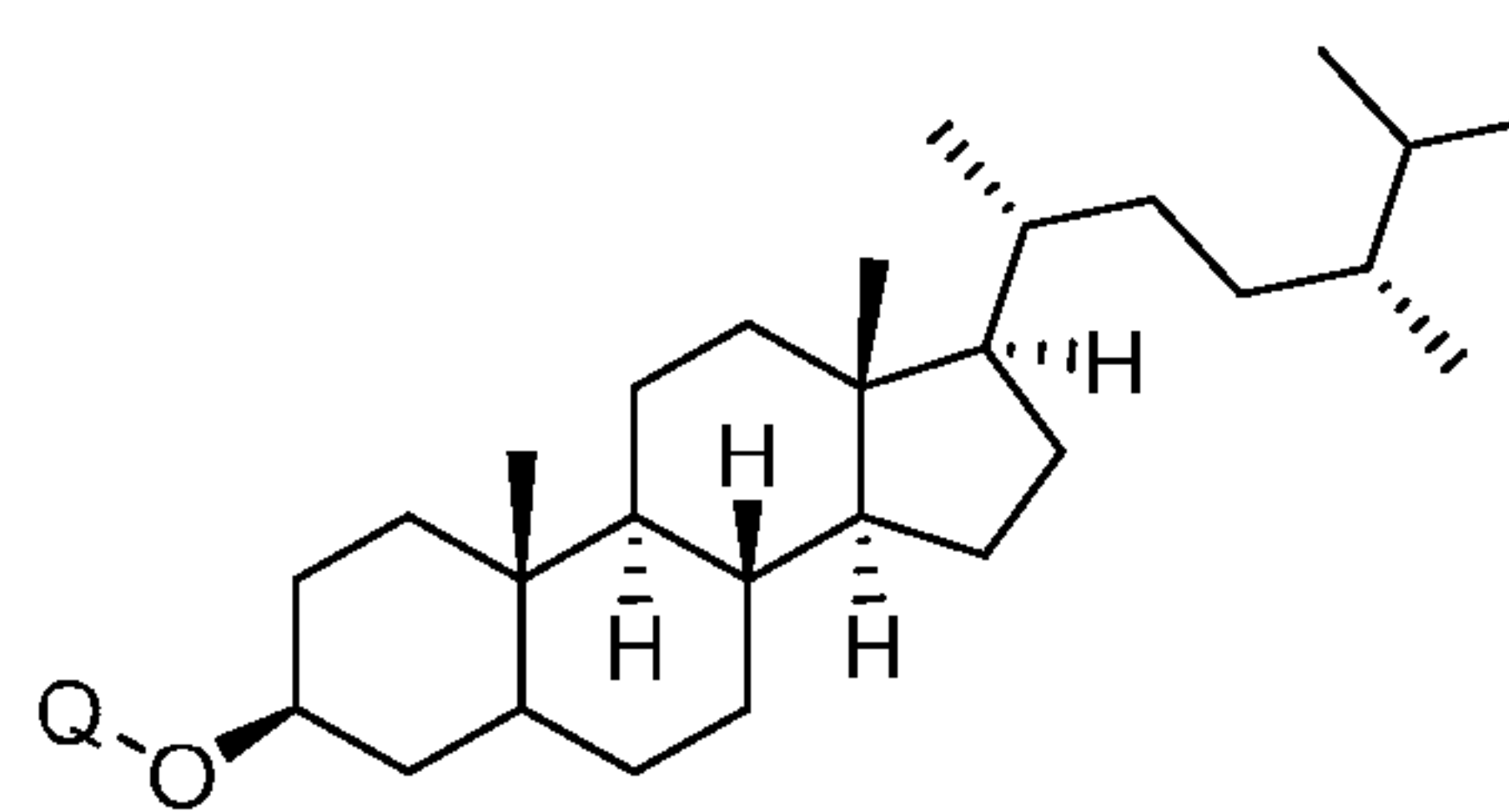
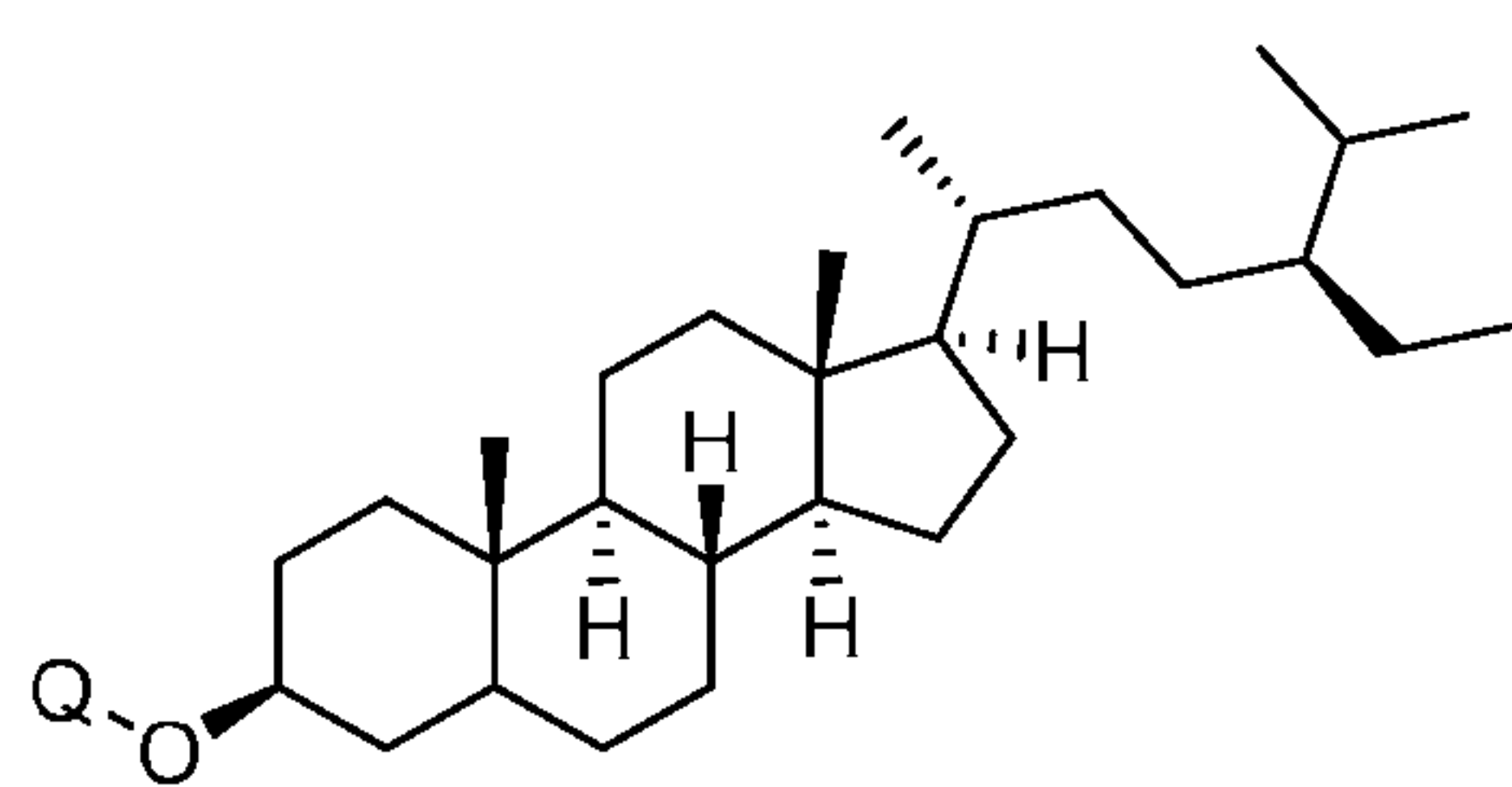
[0070] For example, the cholesterol derivative has a formula:



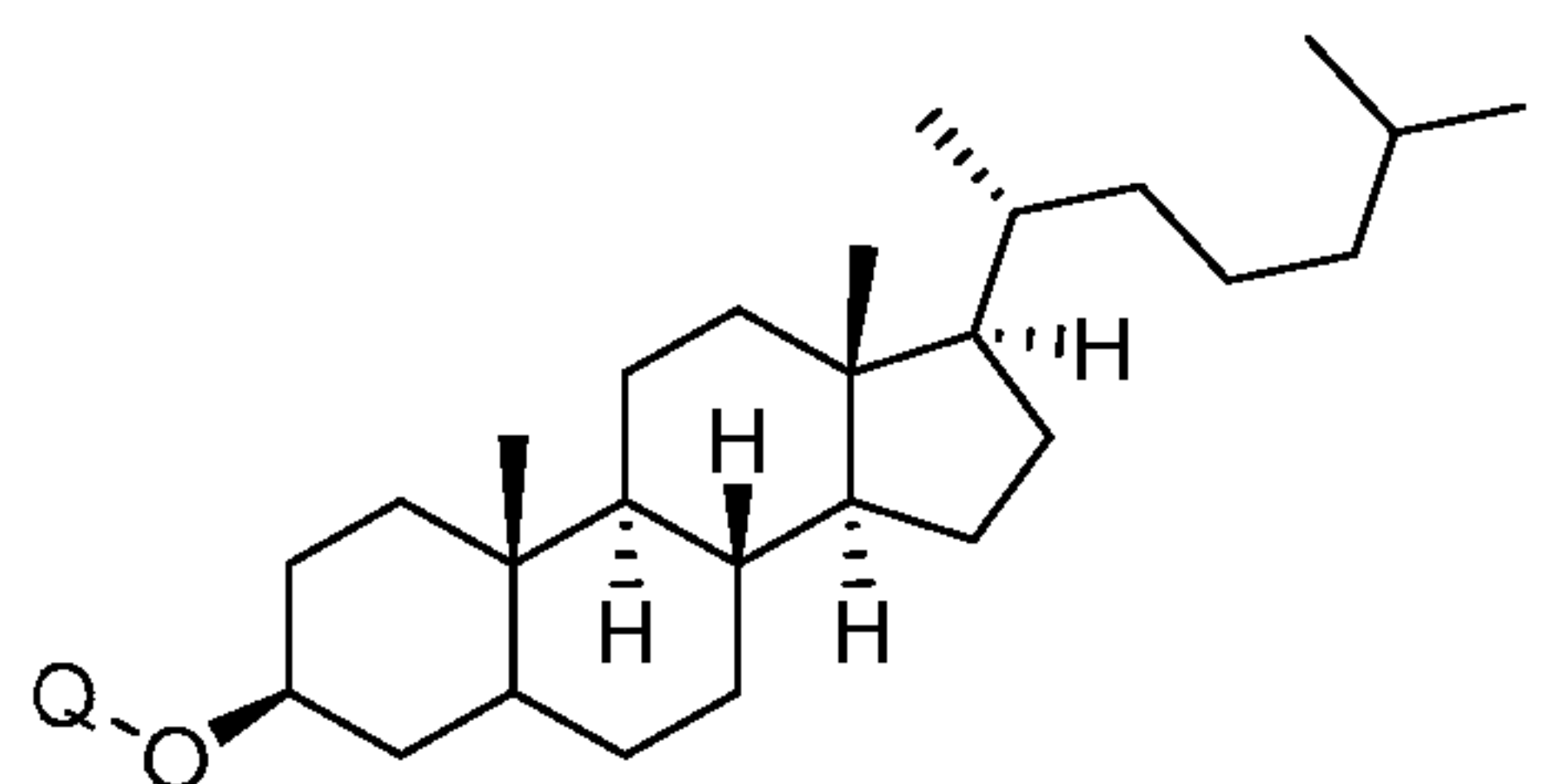
[0071] For example, the cholesterol derivative has a formula:



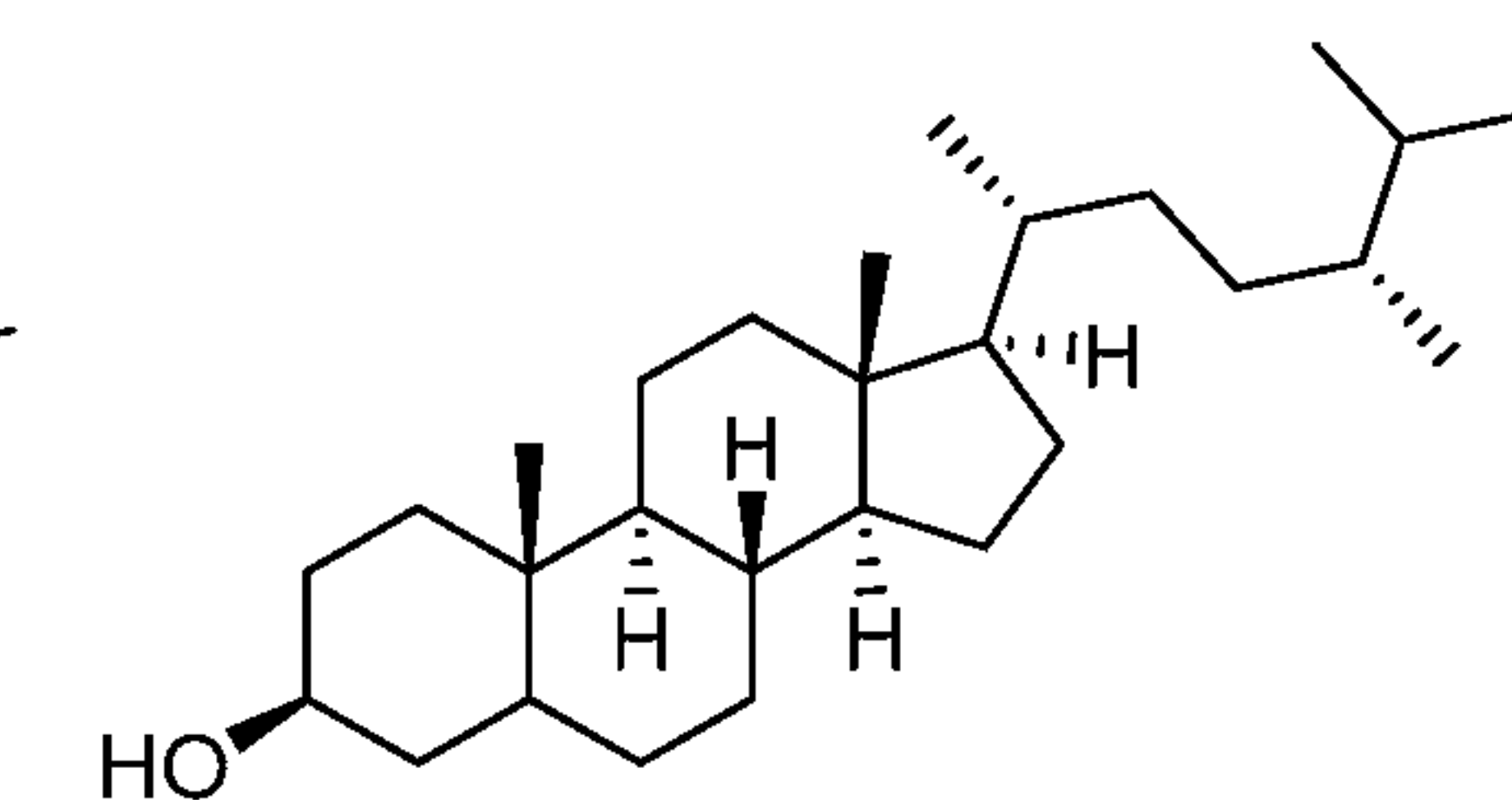
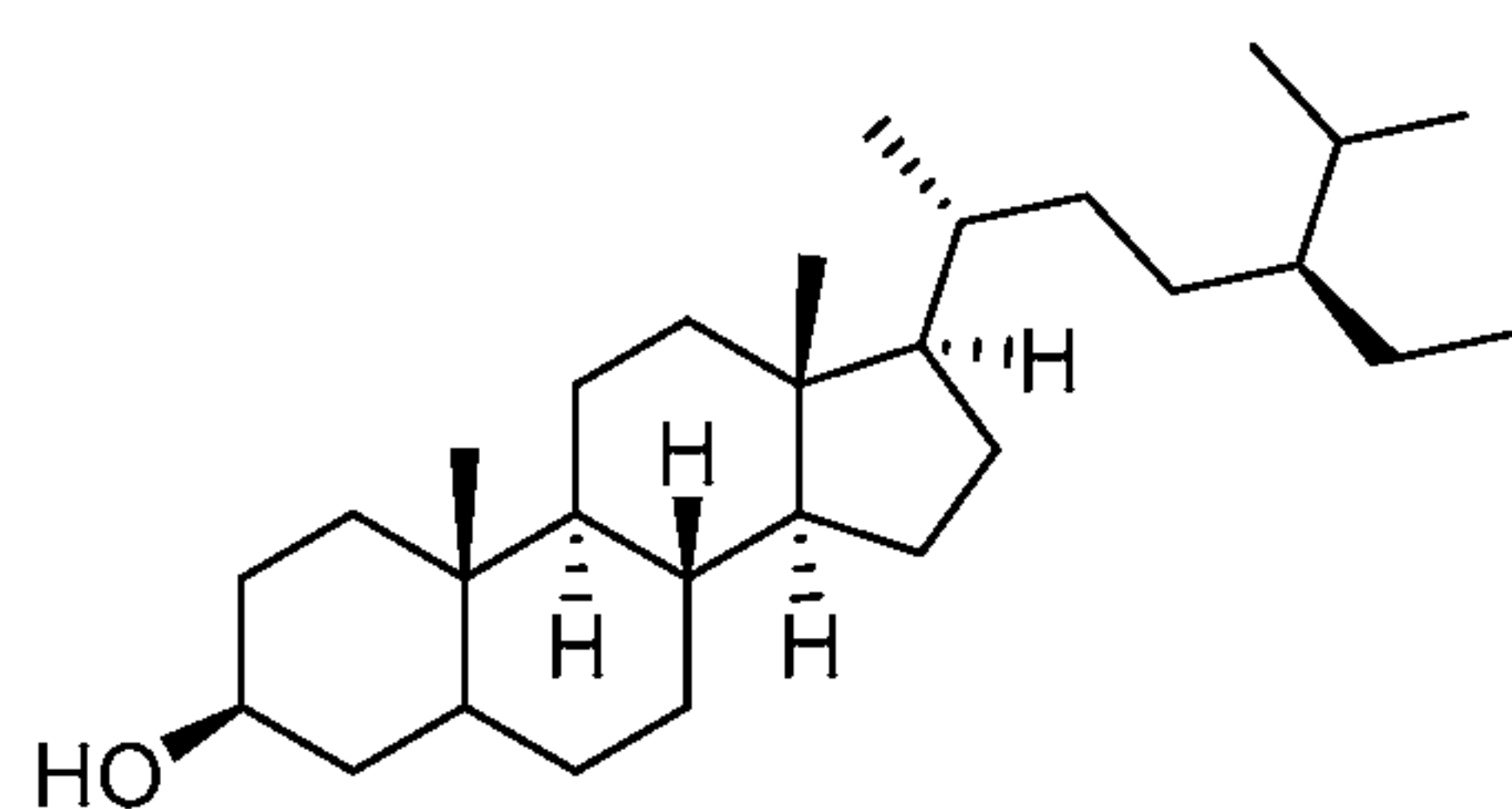
[0072] For example, the cholesterol derivative has a formula:



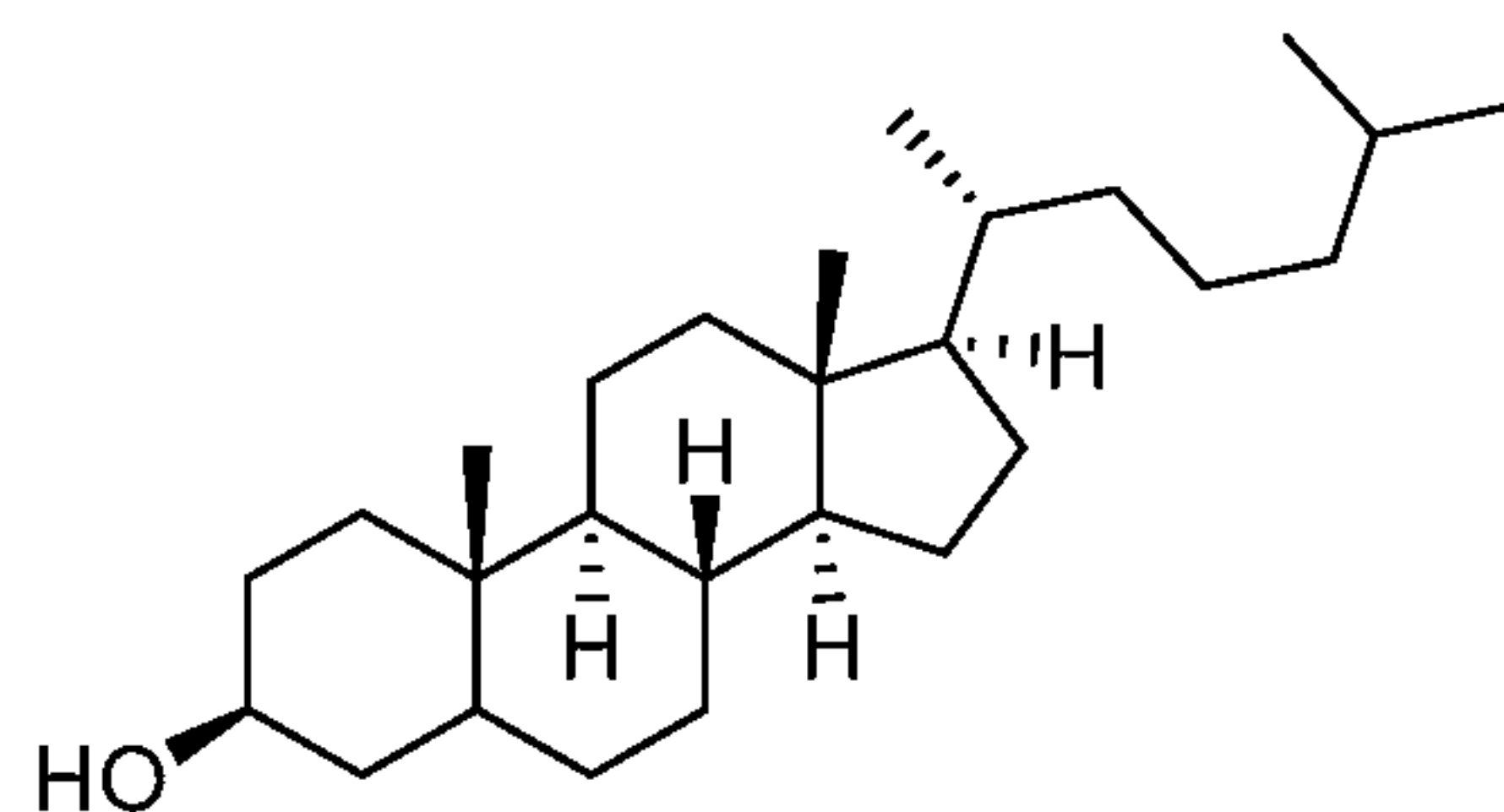
or



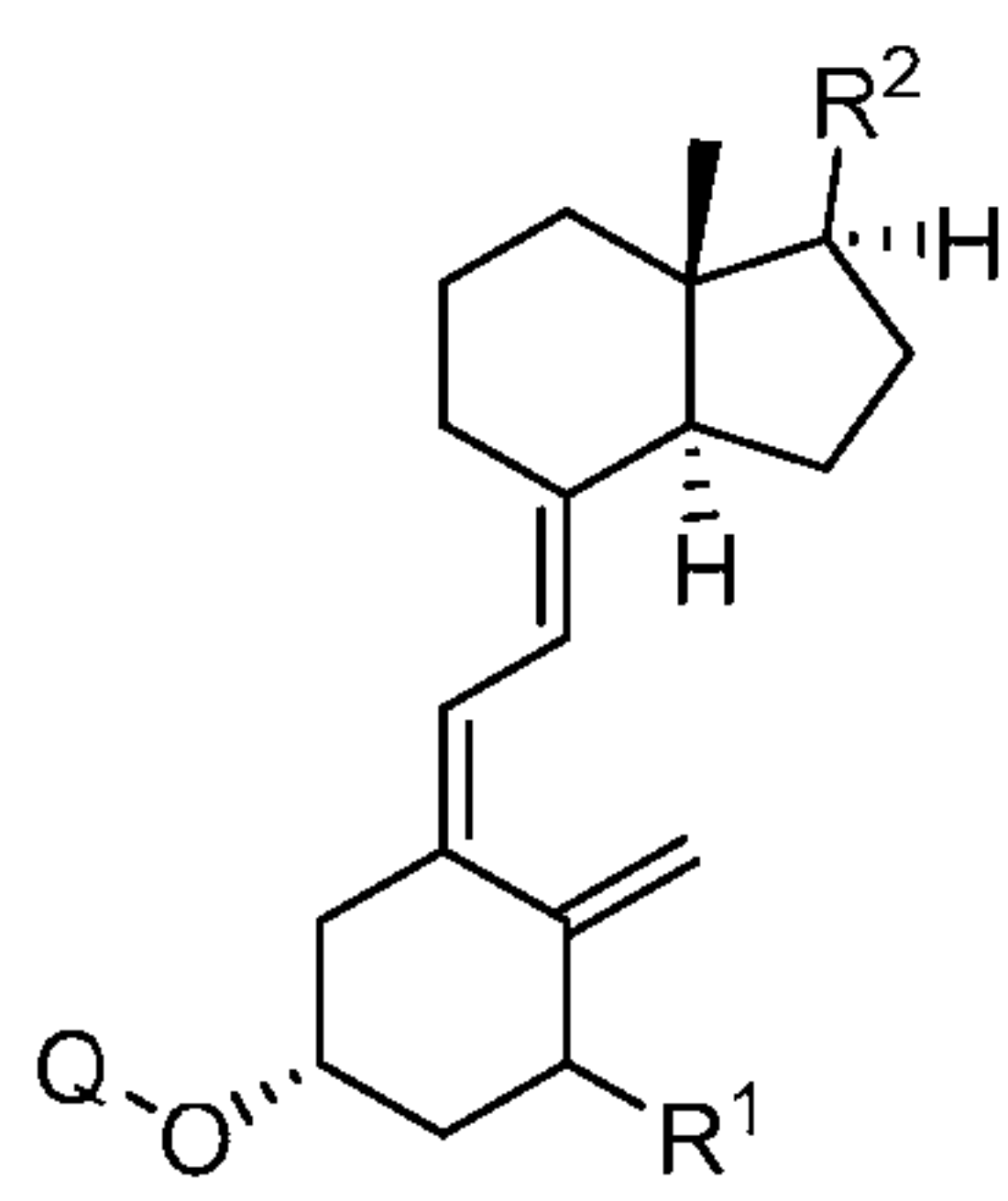
[0073] For example, the cholesterol derivative has a formula:



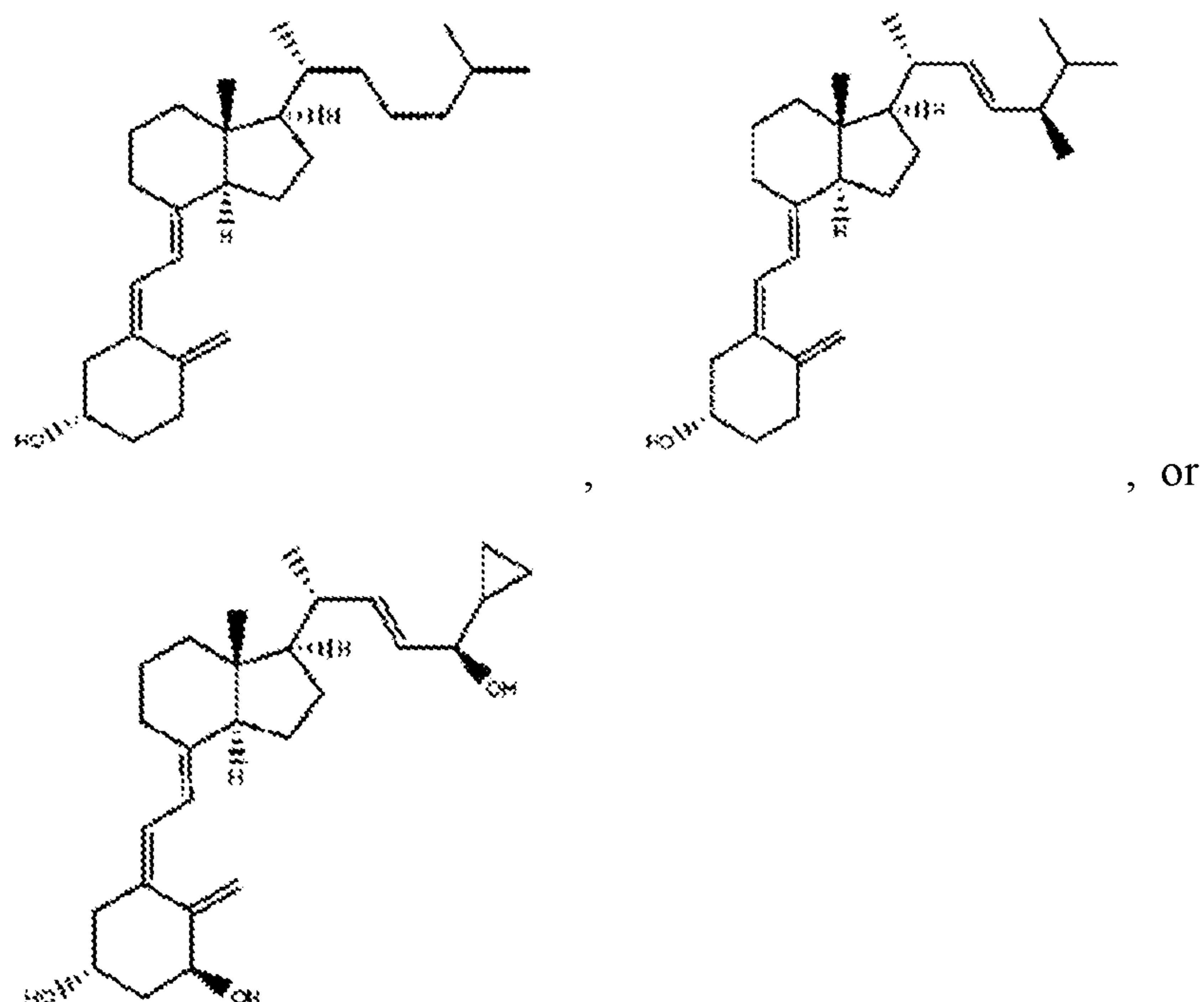
, or



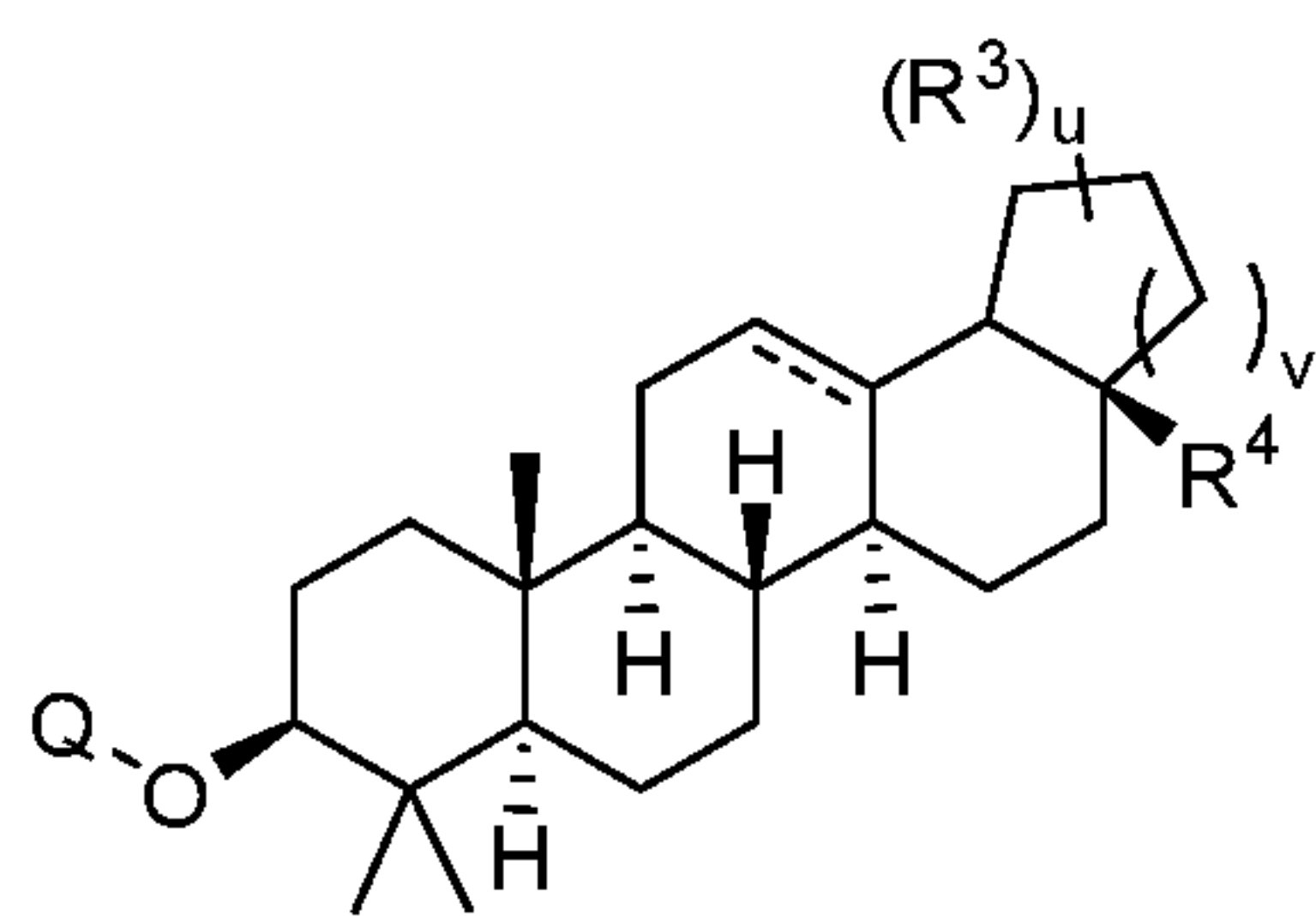
[0074] For example, the cholesterol derivative has a formula:



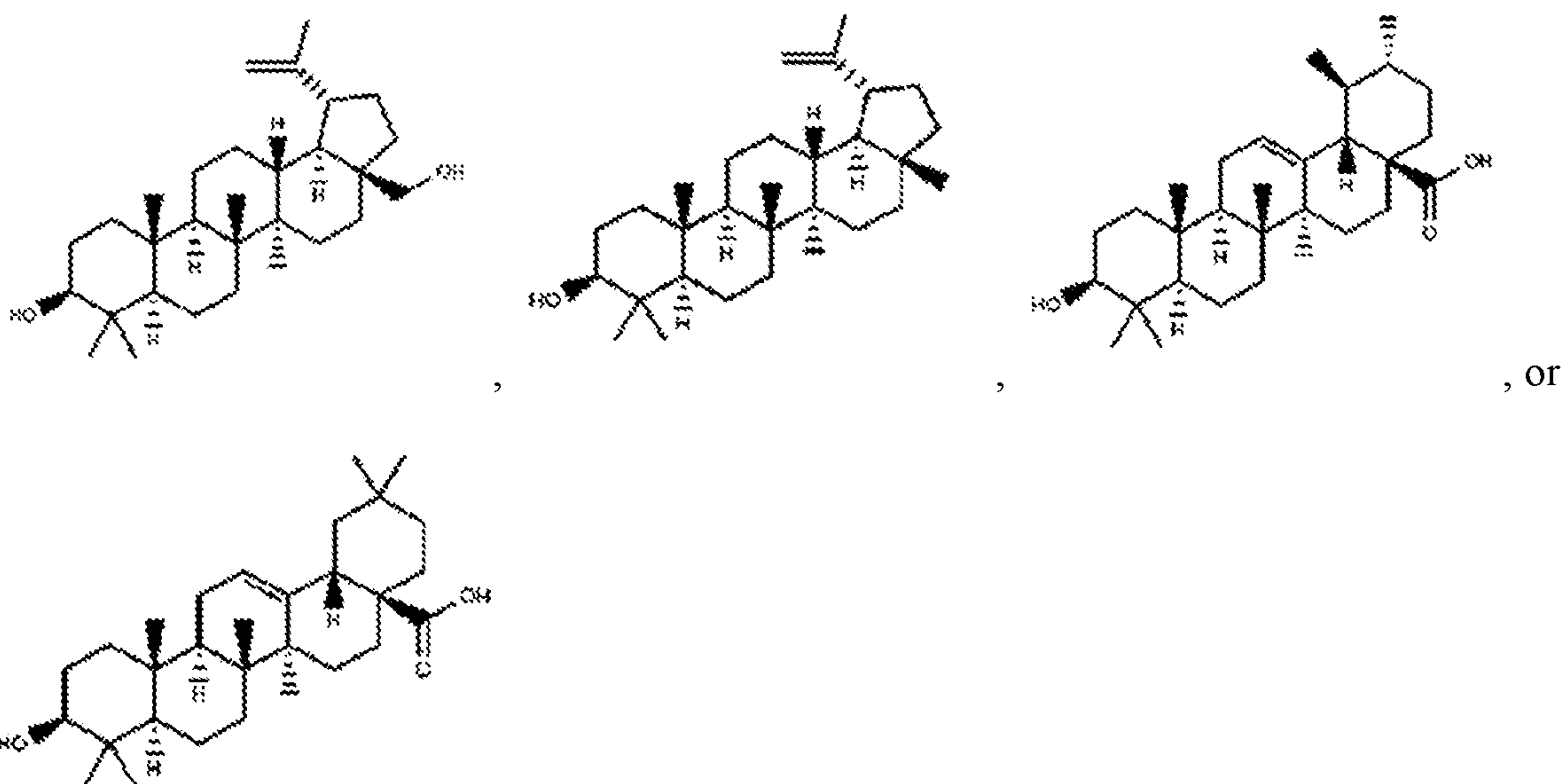
[0075] For example, the cholesterol derivative has a formula:



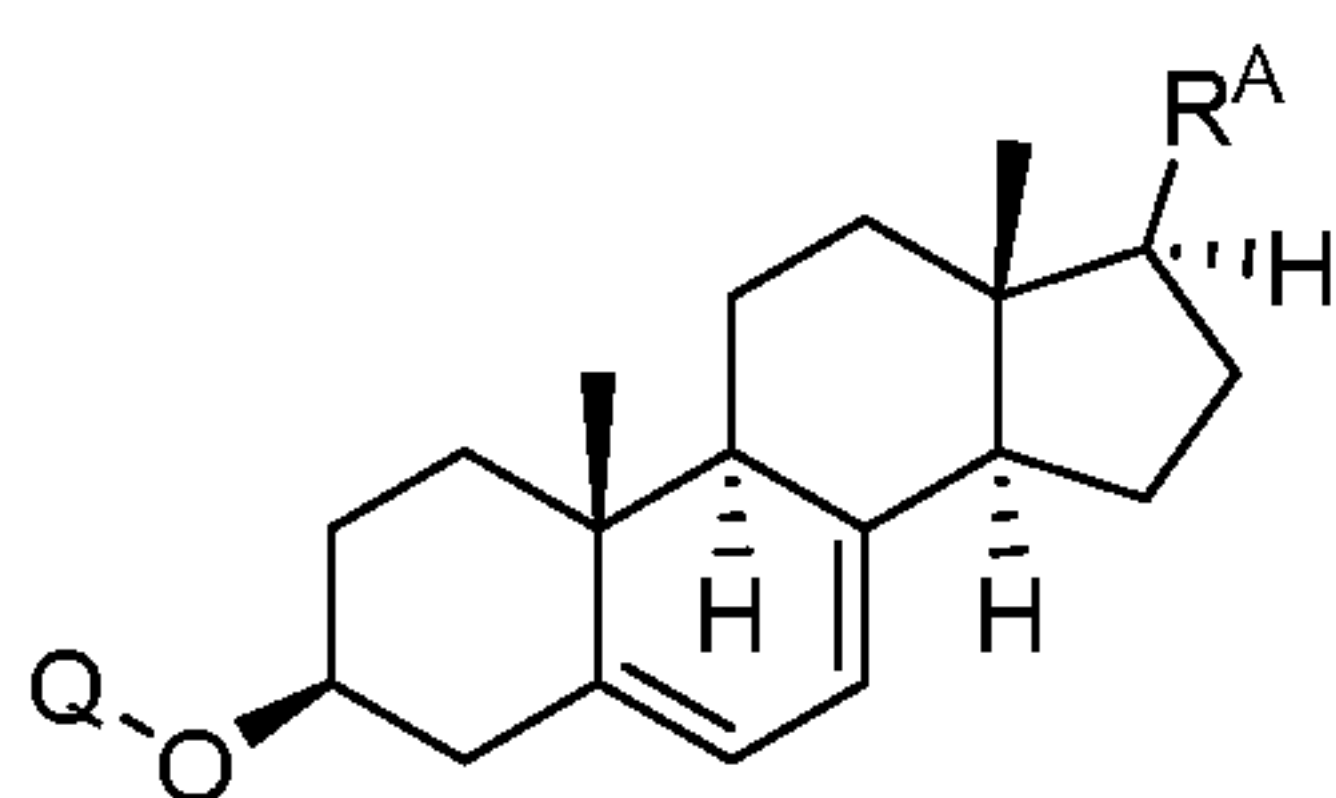
[0076] For example, the cholesterol derivative has a formula:



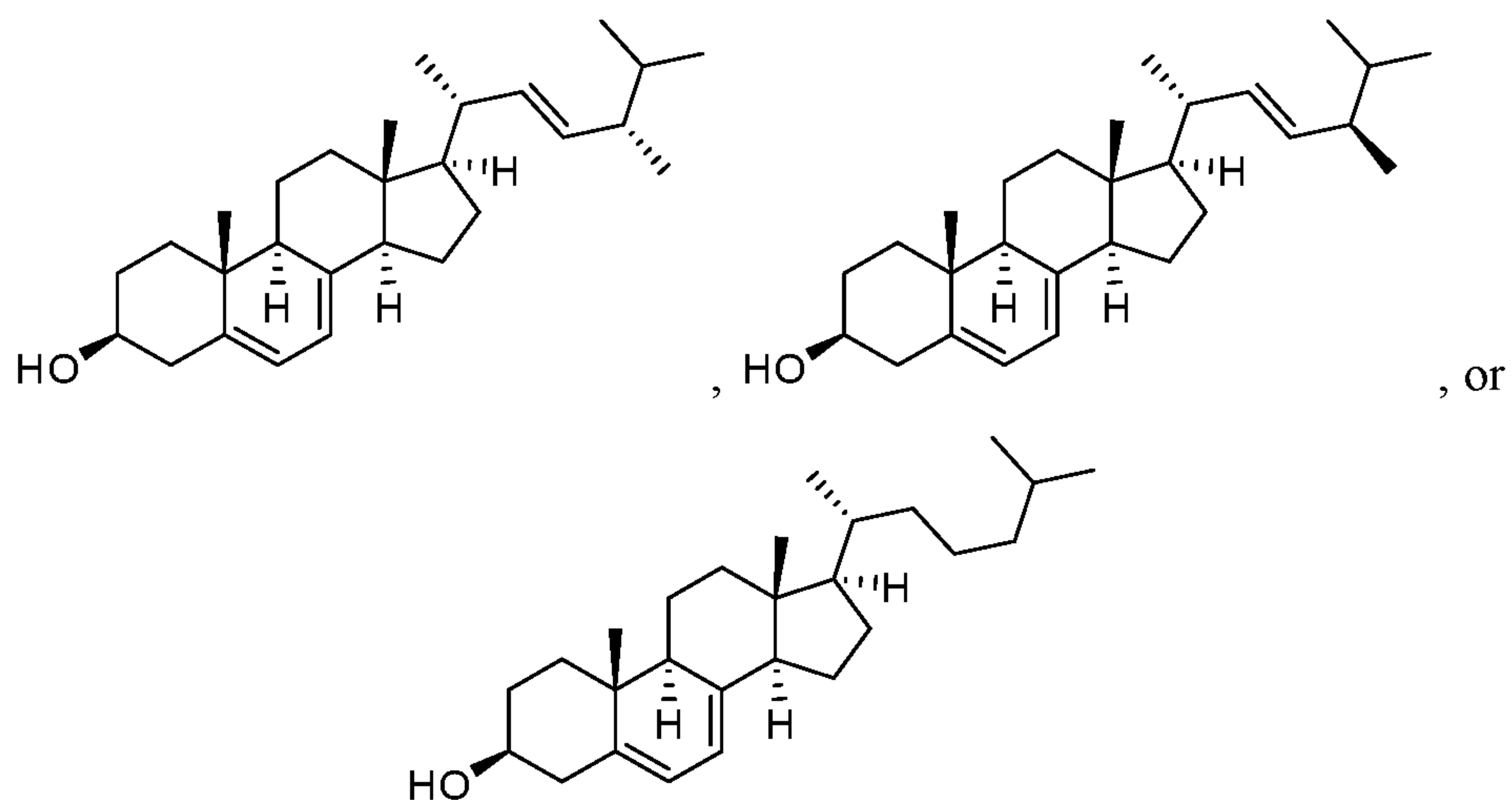
[0077] For example, the cholesterol derivative has a formula:



[0078] For example, the cholesterol derivative has a formula:



[0079] For example, the cholesterol derivative has a formula:

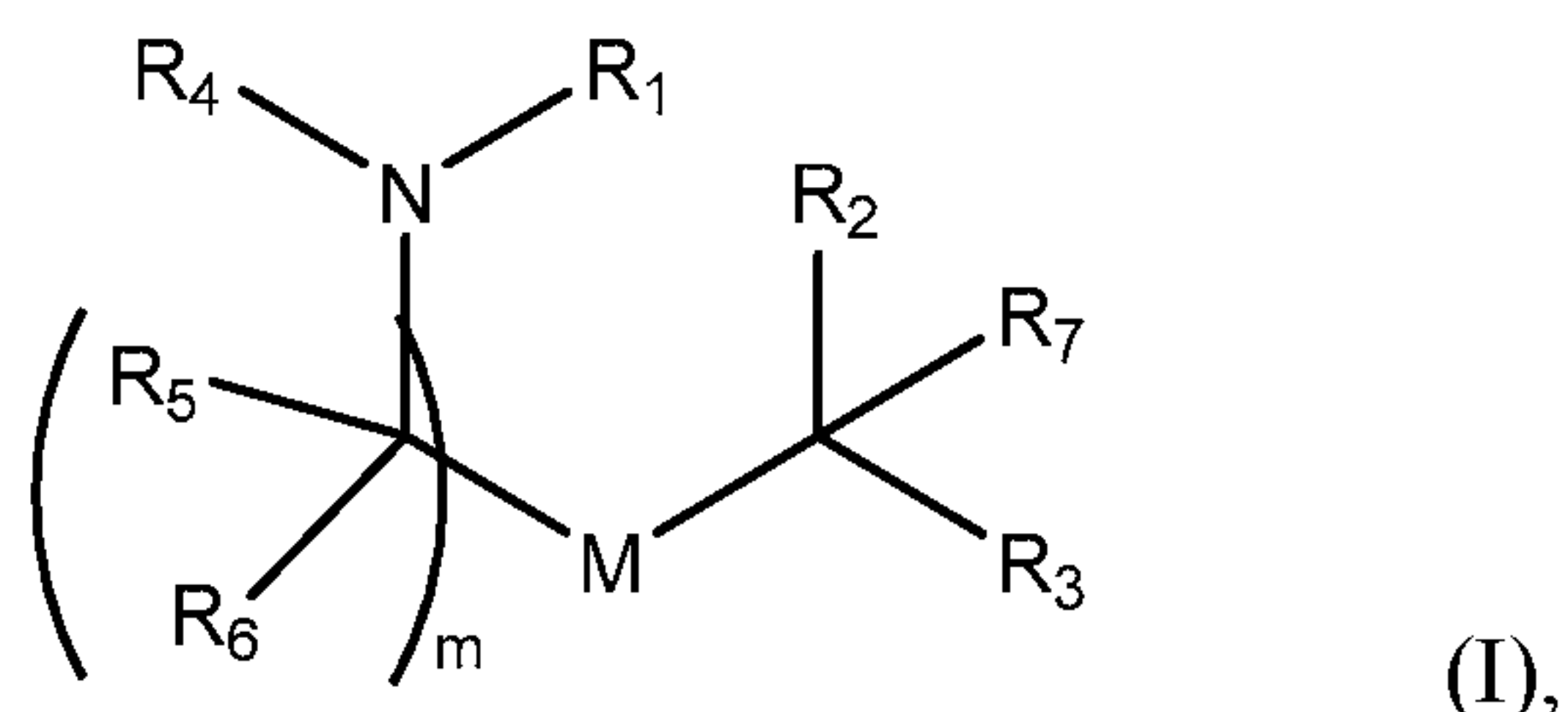


[0080] In other embodiments, the first sterol is a cholesterol derivative and the second sterol is absent. For example, the first sterol is selected from any of Formulae (A1)-(A4) and any species disclosed herein that are encompassed by Formulae (A1)-(A4).

Ionizable Lipids

[0081] The present disclosure provides ionizable lipids including a central amine moiety and at least one biodegradable group. The lipids described herein may be advantageously used in lipid nanoparticle compositions for the delivery of therapeutic and/or prophylactics to mammalian cells or organs. For example, the lipids described herein have little or no immunogenicity. For example, the lipid compound of any of Formula (I), (IA), (IB), (II), (IIa), (IIb), (IIc), (IId), (IId), (IId), (IId), (IId), (IId) or (IId) has a lower immunogenicity as compared to a reference lipid (*e.g.*, MC3, KC2, or DLinDMA). For example, a formulation comprising a lipid disclosed herein and a therapeutic or prophylactic agent has an increased therapeutic index as compared to a corresponding formulation which comprise a reference lipid (*e.g.*, MC3, KC2, or DLinDMA) and the same therapeutic or prophylactic agent.

[0082] In a first aspect of the invention, the compounds described herein are of Formula (I):



or their N-oxides, or salts or isomers thereof, wherein:

R₁ is selected from the group consisting of C₅₋₃₀ alkyl, C₅₋₂₀ alkenyl, -R*YR'', -YR'', and -R''M'R';

R₂ and R₃ are independently selected from the group consisting of H, C₁₋₁₄ alkyl, C₂₋₁₄ alkenyl, -R*YR'', -YR'', and -R*OR'', or R₂ and R₃, together with the atom to which they are attached, form a heterocycle or carbocycle;

R₄ is selected from the group consisting of hydrogen, a C₃₋₆ carbocycle, -(CH₂)_nQ, -(CH₂)_nCHQR, -CHQR, -CQ(R)₂, and unsubstituted C₁₋₆ alkyl, where Q is selected from a carbocycle, heterocycle, -OR, -O(CH₂)_nN(R)₂, -C(O)OR, -OC(O)R, -CX₃, -CX₂H, -CXH₂, -CN, -N(R)₂, -C(O)N(R)₂, -N(R)C(O)R, -N(R)S(O)₂R, -N(R)C(O)N(R)₂, -N(R)C(S)N(R)₂, -N(R)R₈, -N(R)S(O)₂R₈, -O(CH₂)_nOR, -N(R)C(=NR₉)N(R)₂, -N(R)C(=CHR₉)N(R)₂, -OC(O)N(R)₂,

-N(R)C(O)OR, -N(OR)C(O)R, -N(OR)S(O)₂R, -N(OR)C(O)OR, -N(OR)C(O)N(R)₂,
 -N(OR)C(S)N(R)₂, -N(OR)C(=NR₉)N(R)₂, -N(OR)C(=CHR₉)N(R)₂, -C(=NR₉)N(R)₂, -C(=NR₉)R,
 -C(O)N(R)OR, and -C(R)N(R)₂C(O)OR, and each n is independently selected from 1, 2, 3, 4, and 5;

each R₅ is independently selected from the group consisting of C₁₋₃ alkyl, C₂₋₃ alkenyl, and H;

each R₆ is independently selected from the group consisting of C₁₋₃ alkyl, C₂₋₃ alkenyl, and H;

M and M' are independently selected from -C(O)O-, -OC(O)-, -OC(O)-M'-C(O)O-,
 -C(O)N(R')-, -N(R')C(O)-, -C(O)-, -C(S)-, -C(S)S-, -SC(S)-, -CH(OH)-, -P(O)(OR')O-, -S(O)₂-, -S
 -S-, an aryl group, and a heteroaryl group, in which M' is a bond, C₁₋₁₃ alkyl or C₂₋₁₃ alkenyl;

R₇ is selected from the group consisting of C₁₋₃ alkyl, C₂₋₃ alkenyl, and H;

R₈ is selected from the group consisting of C₃₋₆ carbocycle and heterocycle;

R₉ is selected from the group consisting of H, CN, NO₂, C₁₋₆ alkyl, -OR, -S(O)₂R,
 -S(O)₂N(R)₂, C₂₋₆ alkenyl, C₃₋₆ carbocycle and heterocycle; each R is independently selected from
 the group consisting of C₁₋₃ alkyl, C₂₋₃ alkenyl, , and H;

each R' is independently selected from the group consisting of C₁₋₁₈ alkyl, C₂₋₁₈
 alkenyl, -R*YR'', -YR'', and H;

each R'' is independently selected from the group consisting of C₃₋₁₅ alkyl and
 C₃₋₁₅ alkenyl;

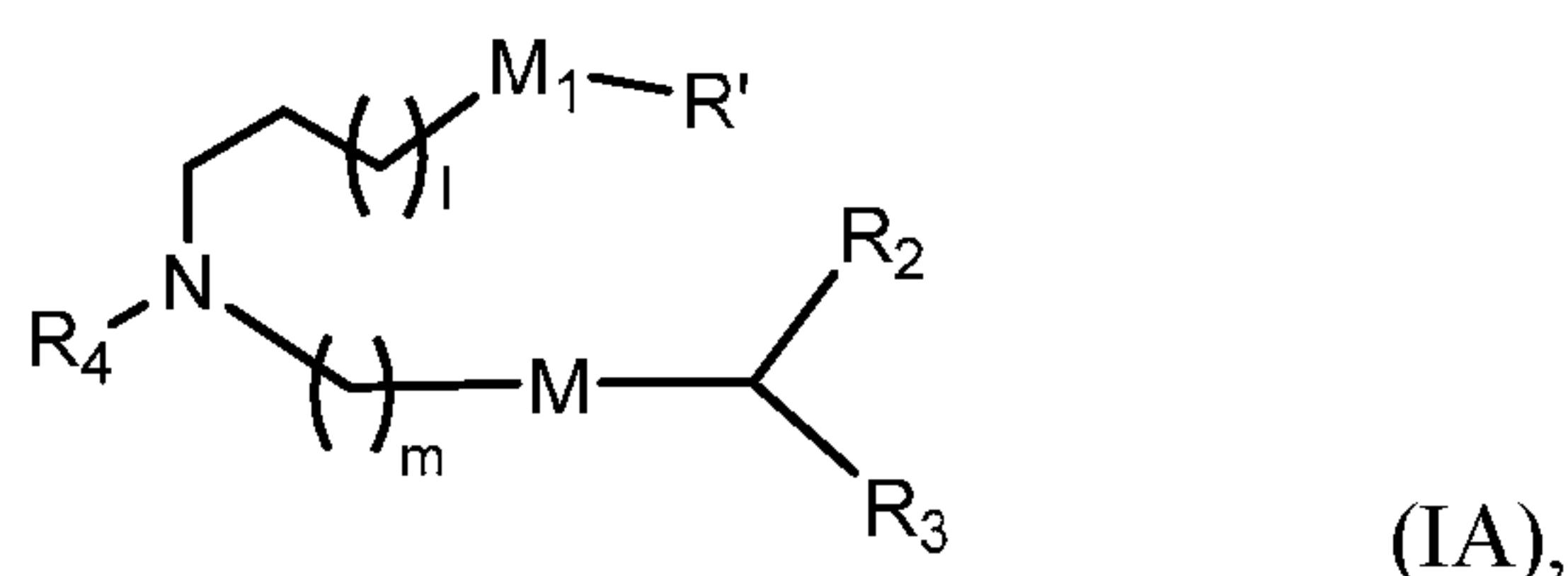
each R* is independently selected from the group consisting of C₁₋₁₂ alkyl and
 C₂₋₁₂ alkenyl;

each Y is independently a C₃₋₆ carbocycle;

each X is independently selected from the group consisting of F, Cl, Br, and I; and

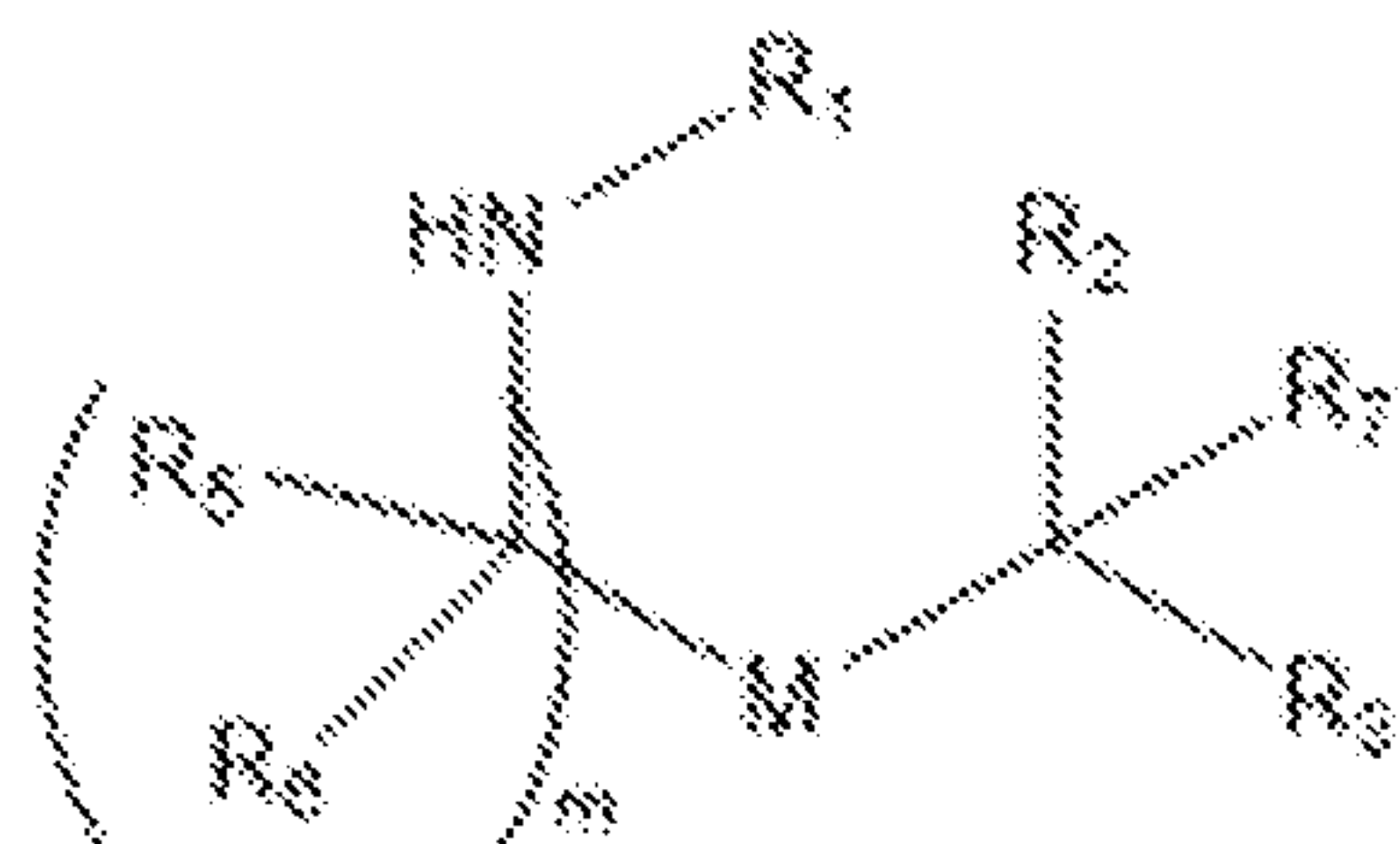
m is selected from 5, 6, 7, 8, 9, 10, 11, 12, and 13; and wherein when R₄
 is -(CH₂)_nQ, -(CH₂)_nCHQR, -CHQR, or -CQ(R)₂, then (i) Q is not -N(R)₂ when n is 1, 2, 3, 4 or 5,
 or (ii) Q is not 5, 6, or 7-membered heterocycloalkyl when n is 1 or 2.

[0083] In certain embodiments, a subset of compounds of Formula (I) includes those of
 Formula (IA):



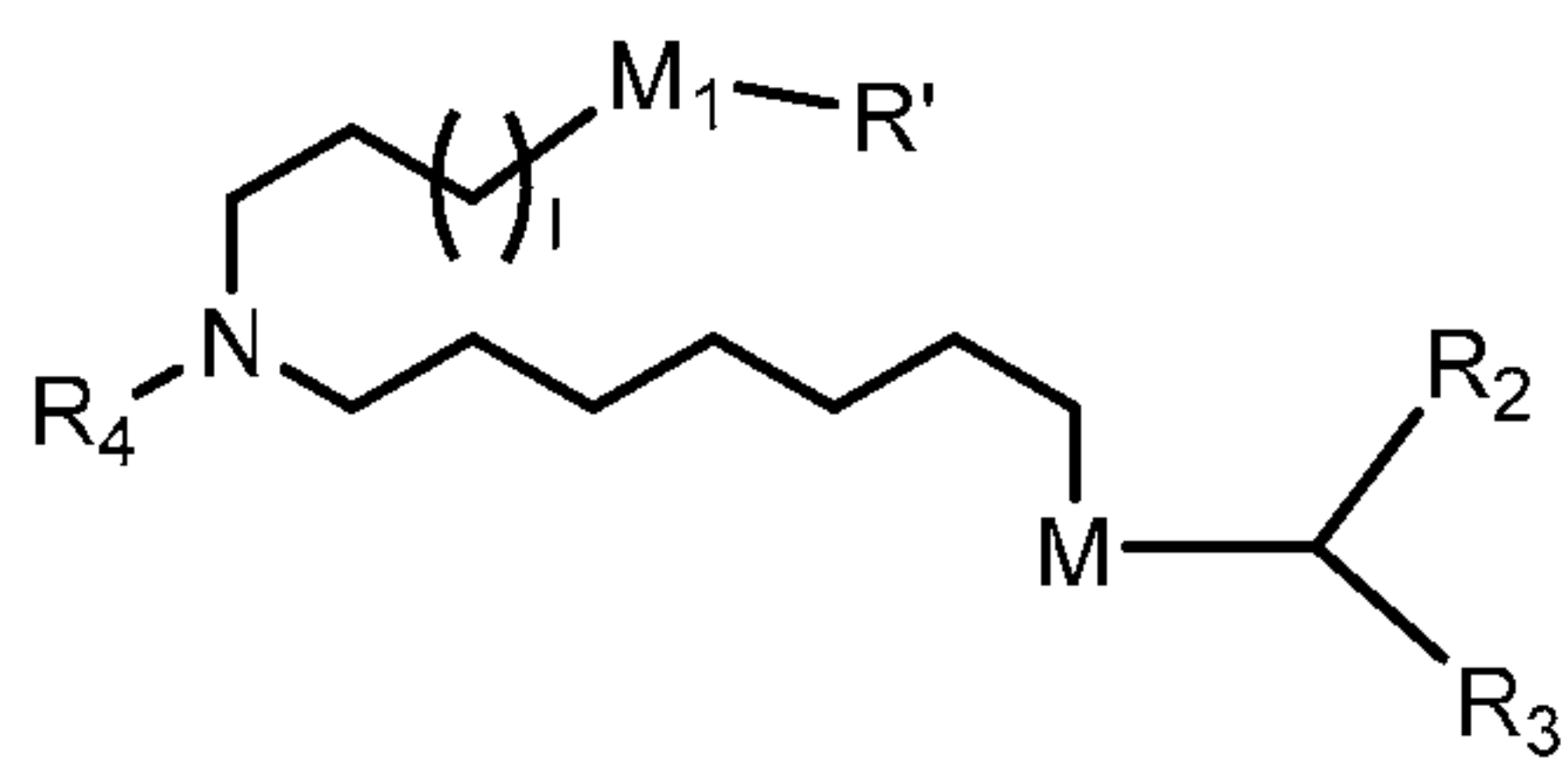
or its N-oxide, or a salt or isomer thereof, wherein l is selected from 1, 2, 3, 4, and 5; m is selected from 5, 6, 7, 8, and 9; M_1 is a bond or M' ; R_4 is hydrogen, unsubstituted C_{1-3} alkyl, or $-(CH_2)_nQ$, in which Q is OH, $-NHC(S)N(R)_2$, $-NHC(O)N(R)_2$, $-N(R)C(O)R$, $-N(R)S(O)_2R$, $-N(R)R_8$, $-N(R)S(O)_2R_8$, $-NHC(=NR_9)N(R)_2$, $-NHC(=CHR_9)N(R)_2$, $-OC(O)N(R)_2$, $-N(R)C(O)OR$, heteroaryl or heterocycloalkyl; M and M' are independently selected from $-C(O)O-$, $-OC(O)-$, $-OC(O)-M''-C(O)O-$, $-C(O)N(R')$, $-P(O)(OR')O-$, $-S-S-$, an aryl group, and a heteroaryl group; and R_2 and R_3 are independently selected from the group consisting of H, C_{1-14} alkyl, and C_{2-14} alkenyl. For example, m is 5, 7, or 9. For example, Q is OH, $-NHC(S)N(R)_2$, or $-NHC(O)N(R)_2$. For example, Q is $-N(R)C(O)R$, or $-N(R)S(O)_2R$.

[0084] In certain embodiments, a subset of compounds of Formula (I) includes those of Formula (IB):



or its N-oxide, or a salt or isomer thereof, in which all variables are as defined herein. For example, m is selected from 5, 6, 7, 8, and 9; R_4 is hydrogen, unsubstituted C_{1-3} alkyl, or $-(CH_2)_nQ$, in which Q is OH, $-NHC(S)N(R)_2$, $-NHC(O)N(R)_2$, $-N(R)C(O)R$, $-N(R)S(O)_2R$, $-N(R)R_8$, $-N(R)S(O)_2R_8$, $-NHC(=NR_9)N(R)_2$, $-NHC(=CHR_9)N(R)_2$, $-OC(O)N(R)_2$, $-N(R)C(O)OR$, heteroaryl or heterocycloalkyl; M and M' are independently selected from $-C(O)O-$, $-OC(O)-$, $-OC(O)-M''-C(O)O-$, $-C(O)N(R')$, $-P(O)(OR')O-$, $-S-S-$, an aryl group, and a heteroaryl group; and R_2 and R_3 are independently selected from the group consisting of H, C_{1-14} alkyl, and C_{2-14} alkenyl. For example, m is 5, 7, or 9. For example, Q is OH, $-NHC(S)N(R)_2$, or $-NHC(O)N(R)_2$. For example, Q is $-N(R)C(O)R$, or $-N(R)S(O)_2R$.

[0085] In certain embodiments, a subset of compounds of Formula (I) includes those of Formula (II):



(II) or its N-oxide, or a salt or isomer thereof, wherein l

is selected from 1, 2, 3, 4, and 5; M₁ is a bond or M'; R₄ is hydrogen, unsubstituted C₁₋₃ alkyl, or -(CH₂)_nQ, in which n is 2, 3, or 4, and Q is

OH, -NHC(S)N(R)₂, -NHC(O)N(R)₂, -N(R)C(O)R, -N(R)S(O)₂R, -N(R)R₈, -N(R)S(O)₂R₈, -NHC(=NR₉)N(R)₂, -NHC(=CHR₉)N(R)₂, -OC(O)N(R)₂, -N(R)C(O)OR, heteroaryl or heterocycloalkyl; M and M' are independently selected

from -C(O)O-, -OC(O)-, -OC(O)-M''-C(O)O-, -C(O)N(R')-, -P(O)(OR')O-, -S-S-, an aryl group, and a heteroaryl group; and R₂ and R₃ are independently selected from the group consisting of H, C₁₋₁₄ alkyl, and C₂₋₁₄ alkenyl.

[0086] The compounds of any one of formula (I) or (IA) include one or more of the following features when applicable.

[0087] In some embodiments, M₁ is M'.

[0088] In some embodiments, M and M' are independently -C(O)O- or -OC(O)-.

[0089] In some embodiments, at least one of M and M' is -C(O)O- or -OC(O)-.

[0090] In some embodiments, at least one of M and M' is -OC(O)-M''-C(O)O-.

[0091] In some embodiments, at least one of M and M' is -OC(O)-.

[0092] In certain embodiments, M is -OC(O)- and M' is -C(O)O-. In some embodiments, M is -C(O)O- and M' is -OC(O)-. In certain embodiments, M and M' are each -OC(O)-. In some embodiments, M and M' are each -C(O)O-.

[0093] In some embodiments, M and M' are independently -S-S-.

[0094] In some embodiments, at least one of M and M' is -S-S-.

[0095] In some embodiments, one of M and M' is -C(O)O- or -OC(O)- and the other is -S-S-.

For example, M is -C(O)O- or -OC(O)- and M' is -S-S- or M' is -C(O)O- or -OC(O)- and M is -S-S-.

[0096] In some embodiments, l is 1, 3, or 5.

[0097] In some embodiments, R₄ is hydrogen.

[0098] In some embodiments, R₄ is not hydrogen.

[0099] In some embodiments, R_4 is unsubstituted methyl or $-(CH_2)_nQ$, in which Q is OH, $-NHC(S)N(R)_2$, $-NHC(O)N(R)_2$, $-N(R)C(O)R$, or $-N(R)S(O)_2R$.

[00100] In some embodiments, Q is OH.

[00101] In some embodiments, Q is $-NHC(S)N(R)_2$.

[00102] In some embodiments, Q is $-NHC(O)N(R)_2$.

[00103] In some embodiments, Q is $-N(R)C(O)R$.

[00104] In some embodiments, Q is $-N(R)S(O)_2R$.

[00105] In some embodiments, Q is $-O(CH_2)_nN(R)_2$.

[00106] In some embodiments, Q is $-O(CH_2)_nOR$.

[00107] In some embodiments, Q is $-N(R)R_8$.

[00108] In some embodiments, Q is $-N(R)S(O)_2R_8$.

[00109] In some embodiments, Q is $-NHC(=NR_9)N(R)_2$.

[00110] In some embodiments, Q is $-NHC(=CHR_9)N(R)_2$.

[00111] In some embodiments, Q is $-OC(O)N(R)_2$.

[00112] In some embodiments, Q is $-N(R)C(O)OR$.

[00113] In some embodiments, n is 2.

[00114] In some embodiments, n is 3.

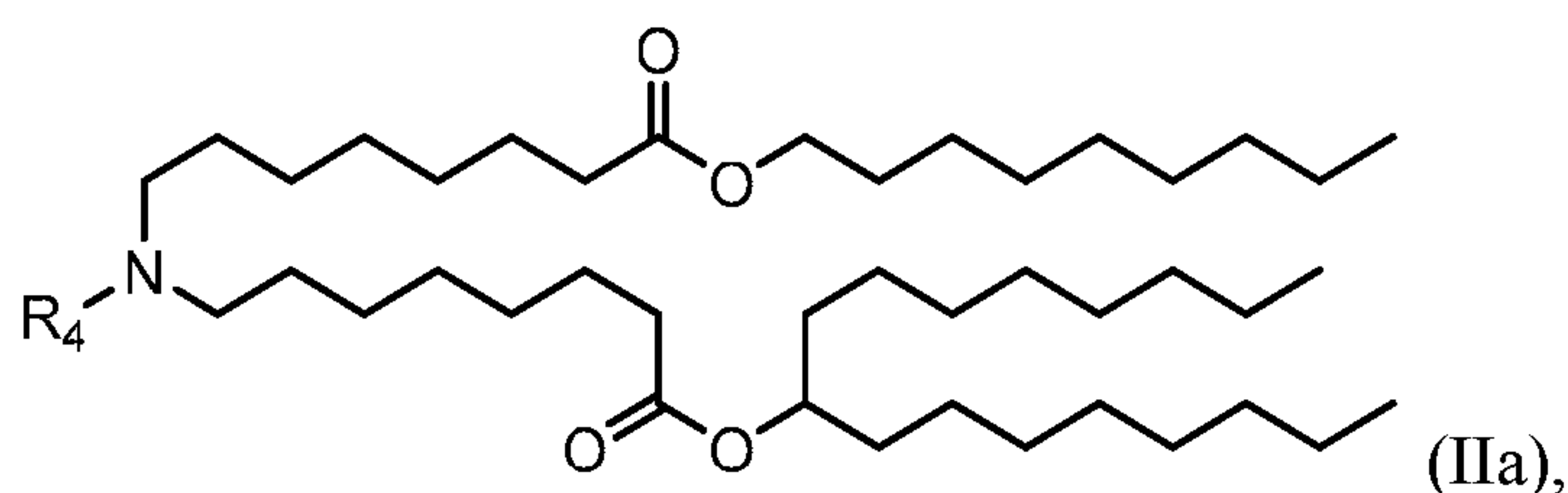
[00115] In some embodiments, n is 4.

[00116] In some embodiments, M_1 is absent.

[00117] In some embodiments, R' is C_{1-18} alkyl, C_{2-18} alkenyl, $-R^*YR''$, or $-YR''$.

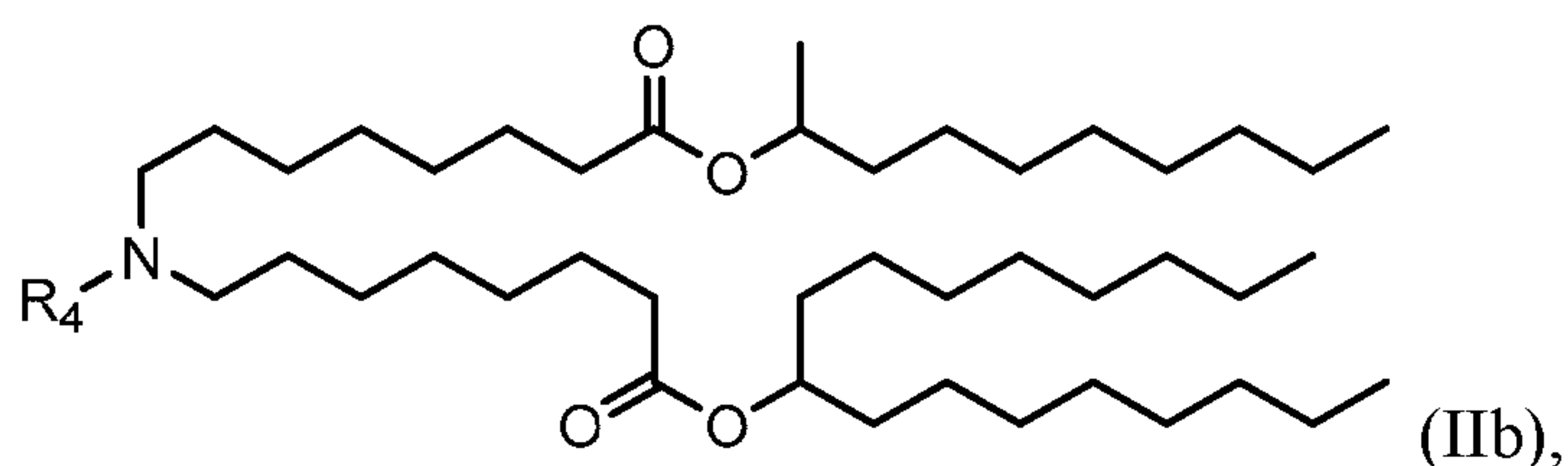
[00118] In some embodiments, R_2 and R_3 are independently C_{3-14} alkyl or C_{3-14} alkenyl.

[00119] In one embodiment, the compounds of Formula (I) are of Formula (IIa),



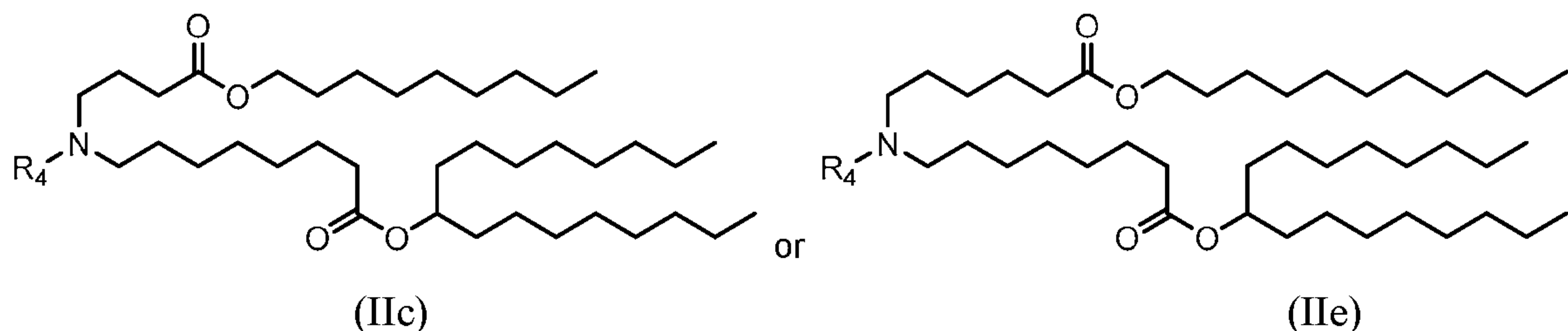
or their N-oxides, or salts or isomers thereof, wherein R_4 is as described herein.

[00120] In another embodiment, the compounds of Formula (I) are of Formula (IIb),



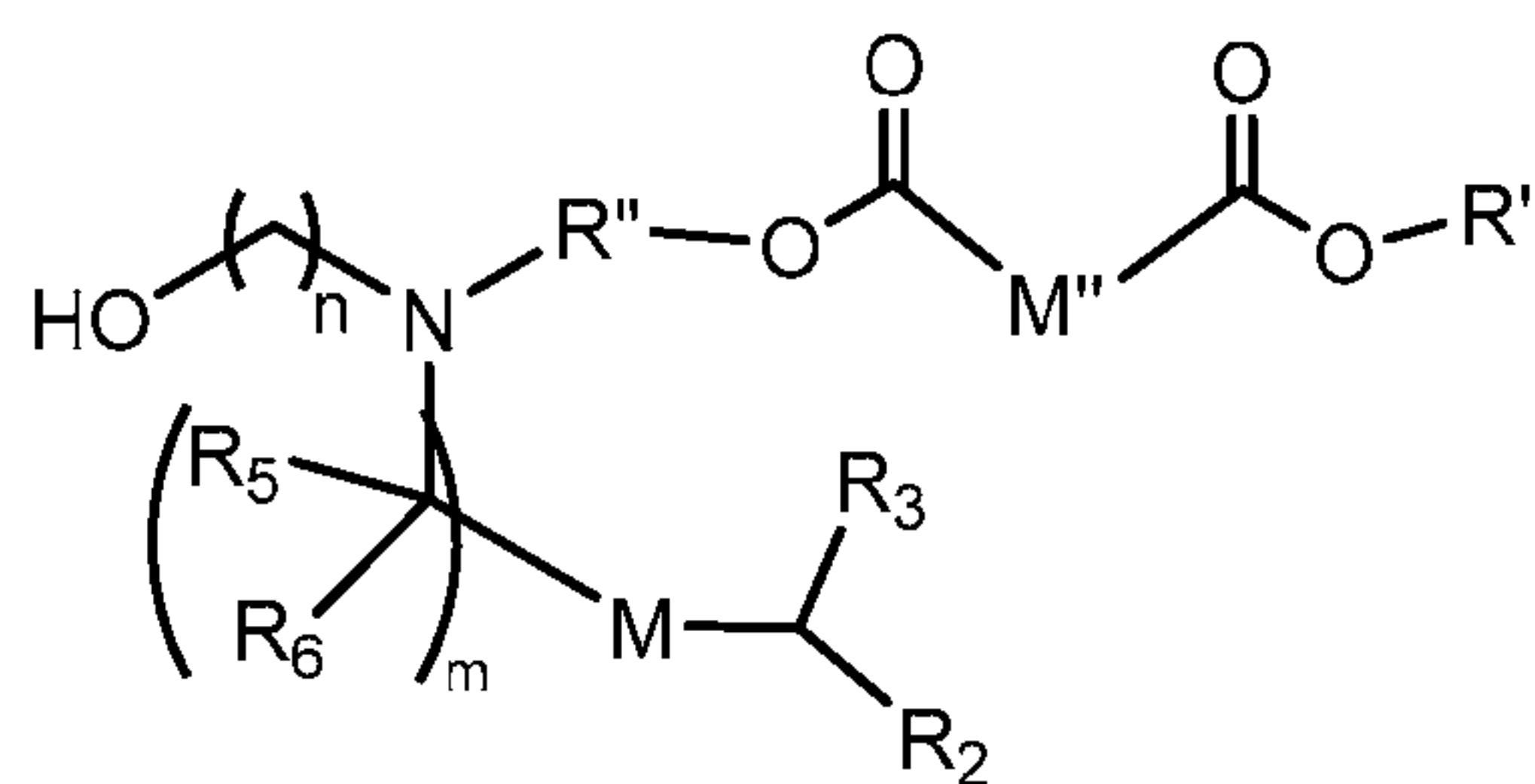
or their N-oxides, or salts or isomers thereof, wherein R₄ is as described herein.

[00121] In another embodiment, the compounds of Formula (I) are of Formula (IIc) or (Ile):



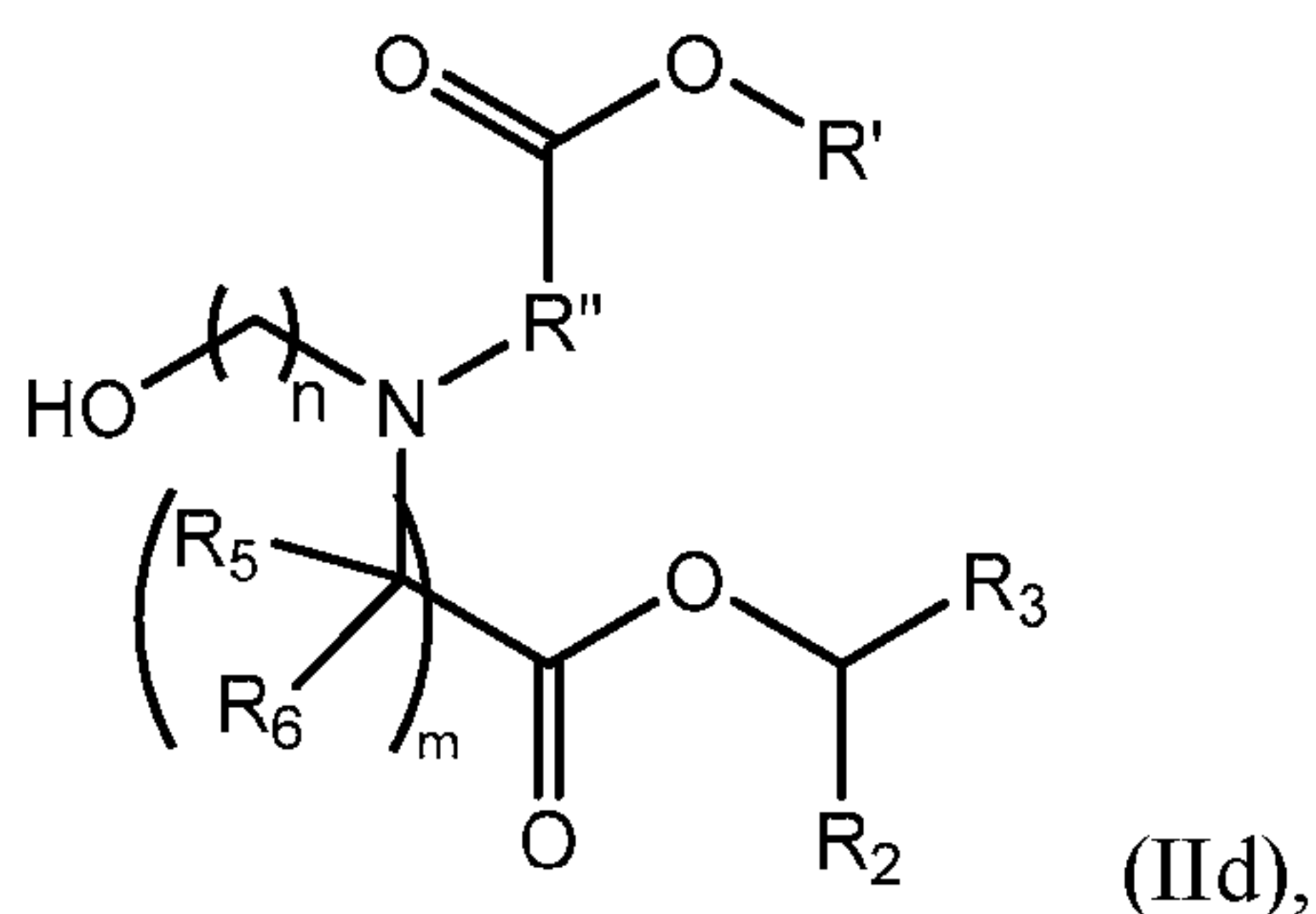
or their N-oxides, or salts or isomers thereof, wherein R₄ is as described herein.

[00122] In another embodiment, the compounds of Formula (I) are of Formula (IIf):



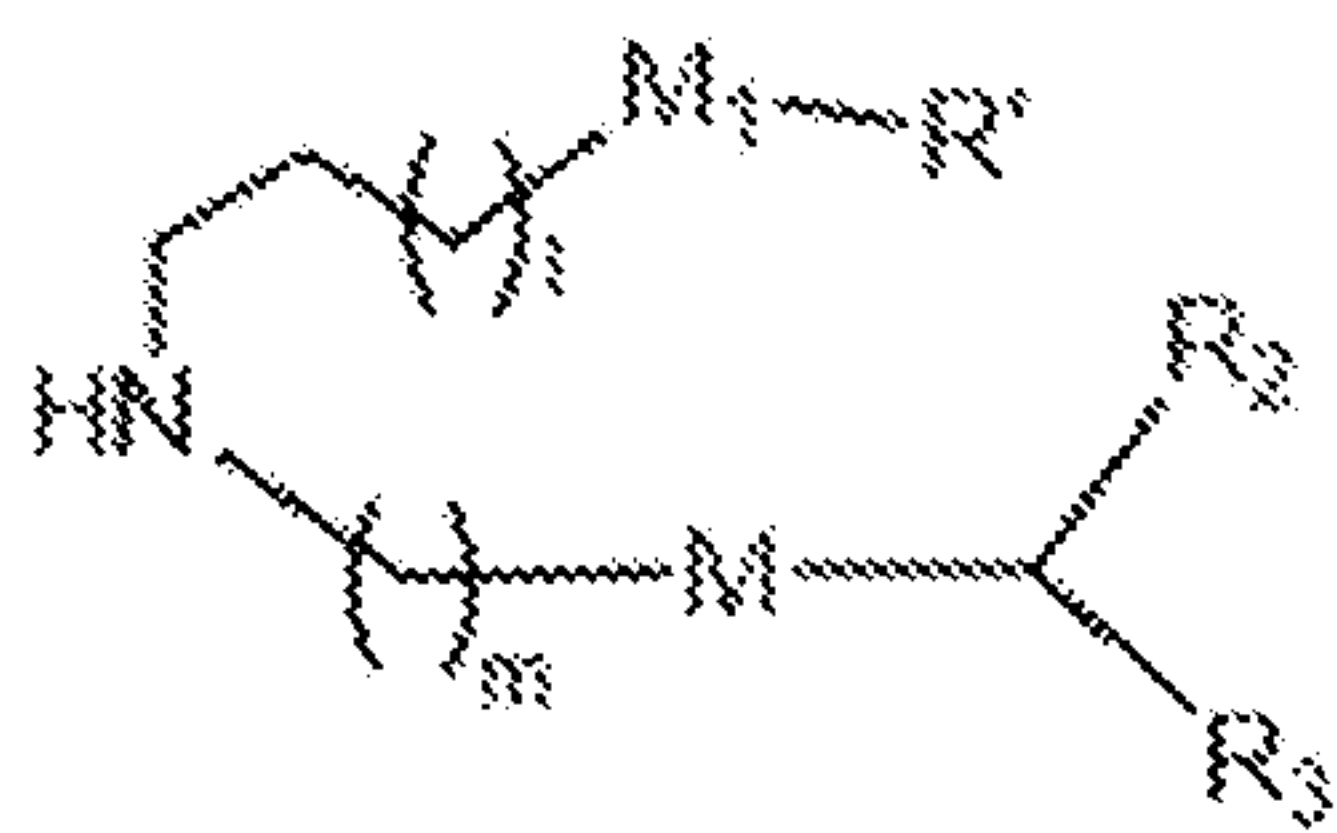
thereof, wherein M is -C(O)O- or -OC(O)-, M' is C₁₋₆ alkyl (e.g., C₁₋₄ alkyl) or C₂₋₆ alkenyl (e.g., C₂₋₄ alkenyl), R₂ and R₃ are independently selected from the group consisting of C₅₋₁₄ alkyl and C₅₋₁₄ alkenyl, and n is selected from 2, 3, and 4.

[00123] In a further embodiment, the compounds of Formula (I) are of Formula (IIId),



or their N-oxides, or salts or isomers thereof, wherein n is 2, 3, or 4; and m, R', R'', and R₂ through R₆ are as described herein. For example, each of R₂ and R₃ may be independently selected from the group consisting of C₅₋₁₄ alkyl and C₅₋₁₄ alkenyl.

[00124] In another embodiment, the compounds of Formula (I) are of Formula (IIg):



(IIg) or their N-oxides, or salts or isomers thereof, wherein l is selected from 1, 2, 3, 4, and 5; m is selected from 5, 6, 7, 8, and 9; M₁ is a bond or M'; M and M' are independently selected from -C(O)O-, -OC(O)-, -OC(O)-M''-C(O)O-, -C(O)N(R')-, -P(O)(OR')O-, -S-S-, an aryl group, and a heteroaryl group; and R₂ and R₃ are independently selected from the group consisting of H, C₁₋₁₄ alkyl, and C₂₋₁₄ alkenyl. For example, M'' is C₁₋₆ alkyl (e.g., C₁₋₄ alkyl) or C₂₋₆ alkenyl (e.g., C₂₋₄ alkenyl). For example, R₂ and R₃ are independently selected from the group consisting of C₅₋₁₄ alkyl and C₅₋₁₄ alkenyl.

[00125] The compounds of any one of formulae (I), (IA), (II), (IIa), (IIb), (IIc), (IId), (IIe), and (IIf) include one or more of the following features when applicable.

[00126] In some embodiments, R₄ is selected from the group consisting of a C₃₋₆ carbocycle, -(CH₂)_nQ, -(CH₂)_nCHQR, -CHQR, and -CQ(R)₂, where Q is selected from a C₃₋₆ carbocycle, 5- to 14- membered aromatic or non-aromatic heterocycle having one or more heteroatoms selected from N, O, S, and P, -OR, -O(CH₂)_nN(R)₂, -C(O)OR, -OC(O)R, -CX₃, -CX₂H, -CXH₂, -CN, -N(R)₂, -C(O)N(R)₂, -N(R)C(O)R, -N(R)S(O)₂R, -N(R)C(O)N(R)₂, -N(R)S(O)₂R₈, -N(R)C(S)N(R)₂, and -C(R)N(R)₂C(O)OR, and each n is independently selected from 1, 2, 3, 4, and 5.

[00127] In another embodiment, R₄ is selected from the group consisting of a C₃₋₆ carbocycle, -(CH₂)_nQ, -(CH₂)_nCHQR, -CHQR, and -CQ(R)₂, where Q is selected from a C₃₋₆ carbocycle, a 5- to 14-membered heteroaryl having one or more heteroatoms selected from N, O, and S, -OR, -O(CH₂)_nN(R)₂, -C(O)OR, -OC(O)R, -CX₃, -CX₂H, -CXH₂, -CN, -C(O)N(R)₂, -N(R)C(O)R, -N(R)S(O)₂R, -N(R)S(O)₂R₈, -N(R)C(O)N(R)₂, -N(R)C(S)N(R)₂, -C(R)N(R)₂C(O)OR, and a 5- to 14-membered heterocycloalkyl having one or more heteroatoms selected from N, O, and S which is substituted with one or more substituents selected from oxo (=O), OH, amino, and C₁₋₃ alkyl, and each n is independently selected from 1, 2, 3, 4, and 5.

[00128] In another embodiment, R₄ is selected from the group consisting of a C₃₋₆ carbocycle, -(CH₂)_nQ, -(CH₂)_nCHQR, -CHQR, and -CQ(R)₂, where Q is selected from a C₃₋₆

carbocycle, a 5- to 14-membered heterocycle having one or more heteroatoms selected from N, O, and S, -OR, -O(CH₂)_nN(R)₂, -C(O)OR, -OC(O)R, -CX₃, -CX₂H, -CXH₂, -CN, -C(O)N(R)₂, -N(R)C(O)R, -N(R)S(O)₂R, -N(R)S(O)₂R₈, -N(R)C(O)N(R)₂, -N(R)C(S)N(R)₂, -C(R)N(R)₂C(O)OR, and each n is independently selected from 1, 2, 3, 4, and 5; and when Q is a 5- to 14-membered heterocycle and (i) R₄ is -(CH₂)_nQ in which n is 1 or 2, or (ii) R₄ is -(CH₂)_nCHQR in which n is 1, or (iii) R₄ is -CHQR, and -CQ(R)₂, then Q is either a 5- to 14-membered heteroaryl or 8- to 14-membered heterocycloalkyl.

[00129] In another embodiment, R₄ is selected from the group consisting of a C₃₋₆ carbocycle, -(CH₂)_nQ, -(CH₂)_nCHQR, -CHQR, and -CQ(R)₂, where Q is selected from a C₃₋₆ carbocycle, a 5- to 14-membered heteroaryl having one or more heteroatoms selected from N, O, and S, -OR, -O(CH₂)_nN(R)₂, -C(O)OR, -OC(O)R, -CX₃, -CX₂H, -CXH₂, -CN, -C(O)N(R)₂, -N(R)C(O)R, -N(R)S(O)₂R, -N(R)S(O)₂R₈, -N(R)C(O)N(R)₂, -N(R)C(S)N(R)₂, -C(R)N(R)₂C(O)OR, and each n is independently selected from 1, 2, 3, 4, and 5.

[00130] In another embodiment, R₄ is -(CH₂)_nQ, where Q is -N(R)S(O)₂R₈ and n is selected from 1, 2, 3, 4, and 5. In a further embodiment, R₄ is -(CH₂)_nQ, where Q is -N(R)S(O)₂R₈, in which R₈ is a C₃₋₆ carbocycle such as C₃₋₆ cycloalkyl, and n is selected from 1, 2, 3, 4, and 5. For example, R₄ is -(CH₂)₃NHS(O)₂R₈ and R₈ is cyclopropyl. In another embodiment, R₄ is unsubstituted C₁₋₄ alkyl, e.g., unsubstituted methyl.

[00131] In certain embodiments, the disclosure provides a compound having the Formula (I), wherein R₄ is -(CH₂)_nQ or -(CH₂)_nCHQR, where Q is -N(R)₂, and n is selected from 3, 4, and 5.

[00132] In certain embodiments, the disclosure provides a compound having the Formula (I), wherein R₄ is selected from the group consisting of -(CH₂)_nQ, -(CH₂)_nCHQR, -CHQR, and -CQ(R)₂, where Q is -N(R)₂, and n is selected from 1, 2, 3, 4, and 5.

[00133] In certain embodiments, the disclosure provides a compound having the Formula (I), wherein R₂ and R₃ are independently selected from the group consisting of C₂₋₁₄ alkyl, C₂₋₁₄ alkenyl, -R*YR'', -YR'', and -R*OR'', or R₂ and R₃, together with the atom to which they are attached, form a heterocycle or carbocycle, and R₄ is -(CH₂)_nQ or -(CH₂)_nCHQR, where Q is -N(R)₂, and n is selected from 3, 4, and 5.

[00134] In certain embodiments, R₂ and R₃ are independently selected from the group consisting of C₂₋₁₄ alkyl, C₂₋₁₄ alkenyl, -R*YR'', -YR'', and -R*OR'', or R₂ and R₃, together with the atom to which they are attached, form a heterocycle or carbocycle.

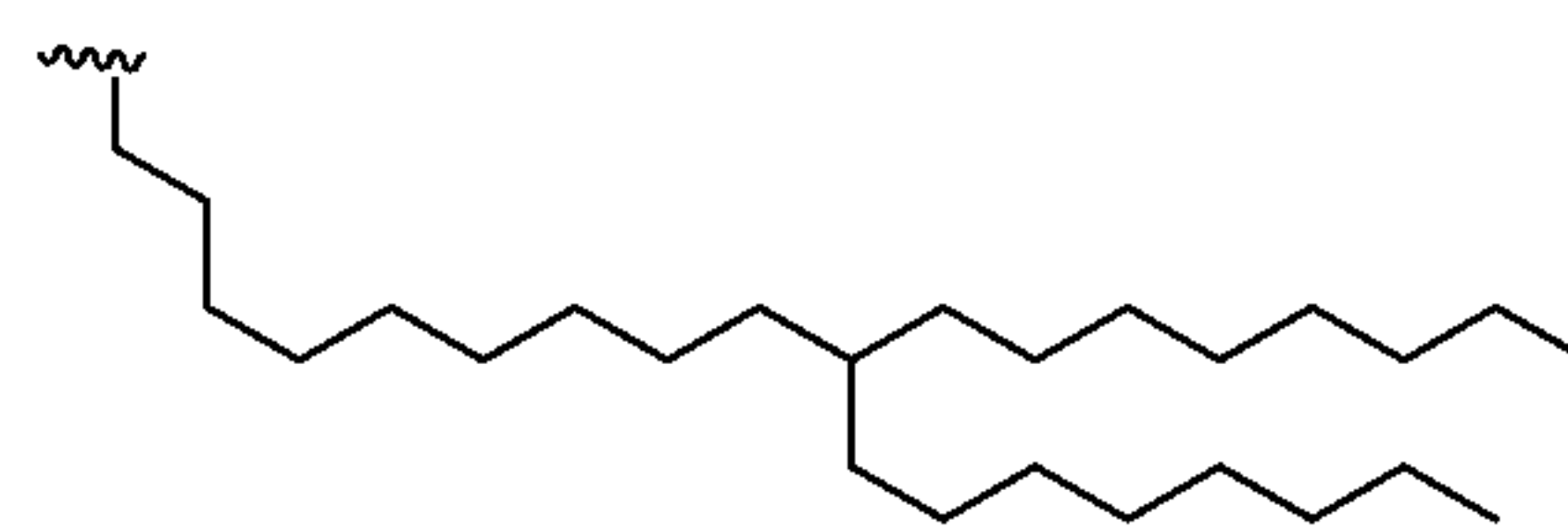
[00135] In some embodiments, R_1 is selected from the group consisting of C_{5-20} alkyl and C_{5-20} alkenyl.

[00136] In other embodiments, R_1 is selected from the group consisting of $-R^*YR''$, $-YR''$, and $-R''M'R'$.

[00137] In certain embodiments, R_1 is selected from $-R^*YR''$ and $-YR''$. In some embodiments, Y is a cyclopropyl group. In some embodiments, R^* is C_8 alkyl or C_8 alkenyl. In certain embodiments, R'' is C_{3-12} alkyl. For example, R'' may be C_3 alkyl. For example, R'' may be C_{4-8} alkyl (e.g., C_4 , C_5 , C_6 , C_7 , or C_8 alkyl). In some embodiments, R_1 is C_{5-20} alkyl. In some embodiments, R_1 is C_6 alkyl. In some embodiments, R_1 is C_8 alkyl. In other embodiments, R_1 is C_9 alkyl. In certain embodiments, R_1 is C_{14} alkyl. In other embodiments, R_1 is C_{18} alkyl.

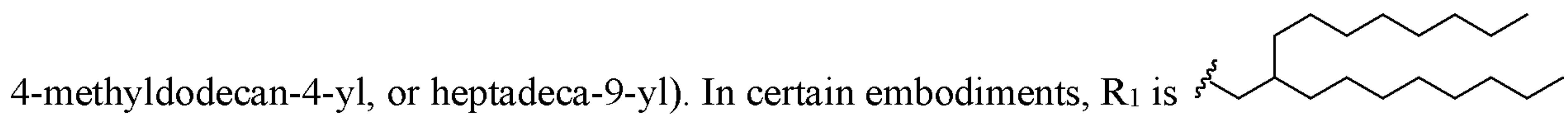
[00138] In some embodiments, R_1 is C_{21-30} alkyl. In some embodiments, R_1 is C_{26} alkyl. In

some embodiments, R_1 is C_{28} alkyl. In certain embodiments, R_1 is

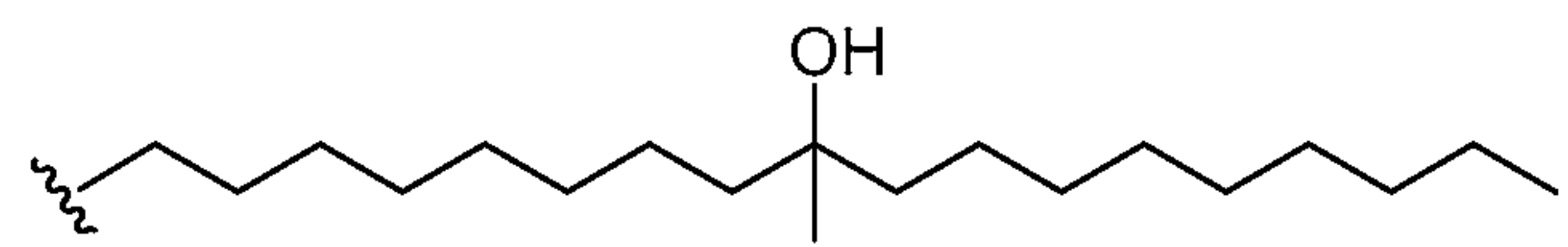


[00139] In some embodiments, R_1 is C_{5-20} alkenyl. In certain embodiments, R_1 is C_{18} alkenyl. In some embodiments, R_1 is linoleyl.

[00140] In certain embodiments, R_1 is branched (e.g., decan-2-yl, undecan-3-yl, dodecan-4-yl, tridecan-5-yl, tetradecan-6-yl, 2-methylundecan-3-yl, 2-methyldecan-2-yl, 3-methylundecan-3-yl, 4-methyldodecan-4-yl, or heptadeca-9-yl). In certain embodiments, R_1 is

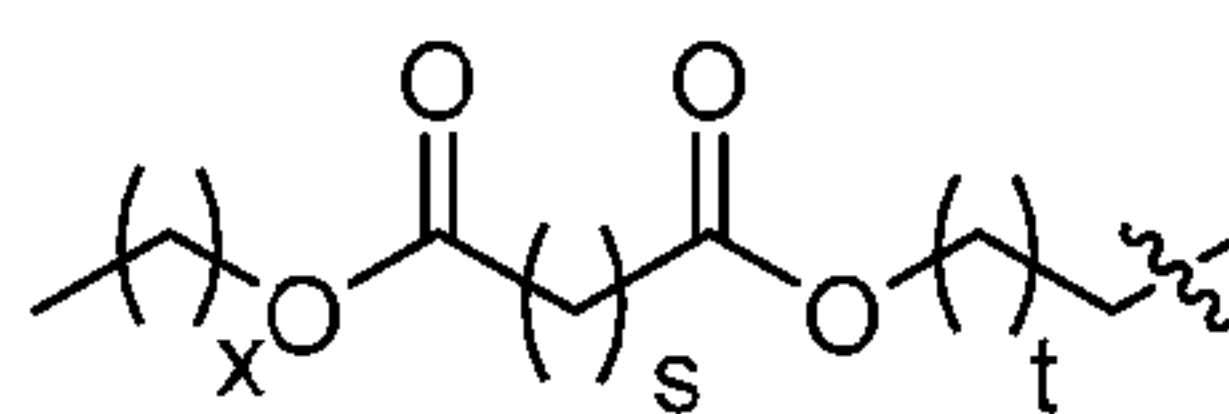


[00141] In certain embodiments, R_1 is unsubstituted C_{5-20} alkyl or C_{5-20} alkenyl. In certain embodiments, R' is substituted C_{5-20} alkyl or C_{5-20} alkenyl (e.g., substituted with a C_{3-6} carbocycle such as 1-cyclopropylnonyl or substituted with OH or alkoxy). For example, R_1 is



[00142] In other embodiments, R_1 is $-R''M'R'$. In certain embodiments, M'

is $-OC(O)-M''-C(O)O-$. For example, R_1 is $-(CH_2)_xO-C(=O)-(CH_2)_s-C(=O)O-(CH_2)_t-$, wherein x is an integer between 1 and 13 (e.g., selected from 3, 4, 5, and 6), s is an integer between 1 and 13 (e.g., selected from 1, 2, and 3), and t is an integer between 2 and 14 (e.g., selected from 4, 5, and 6). For



example, x is selected from 3, 4, 5, and 6, s is selected from 1, 2, and 3, and t is selected from 4, 5, and 6.

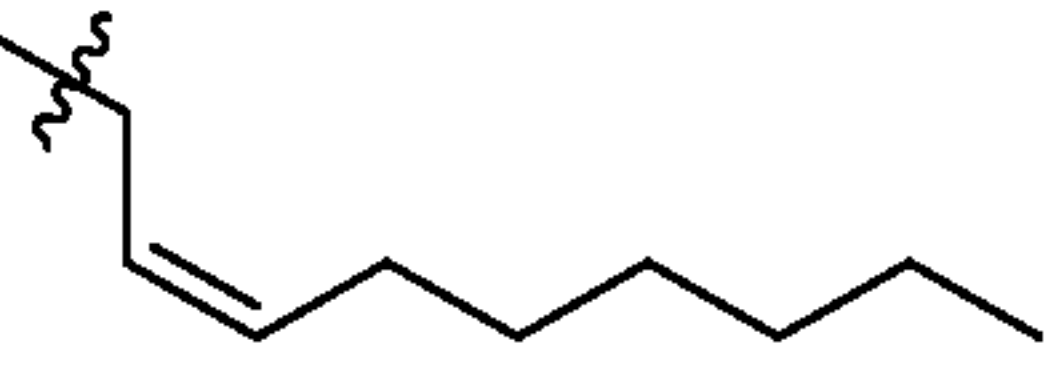
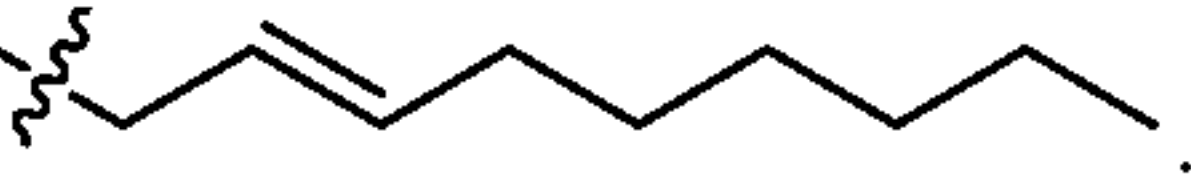
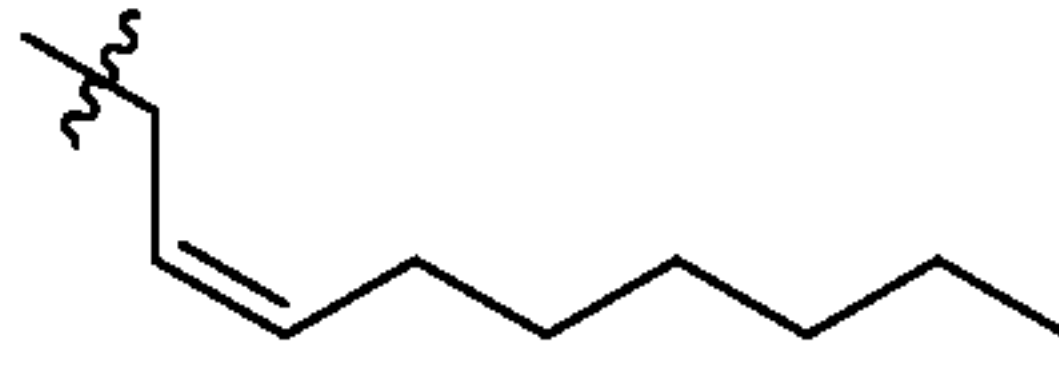
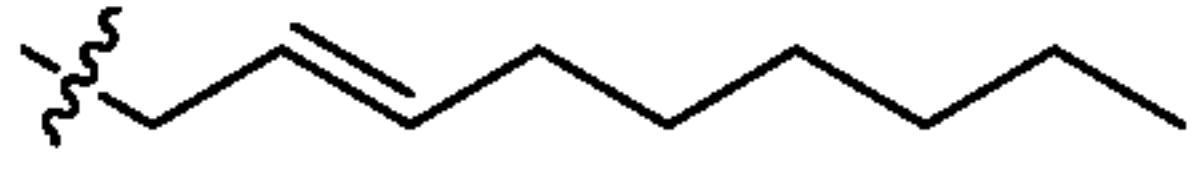
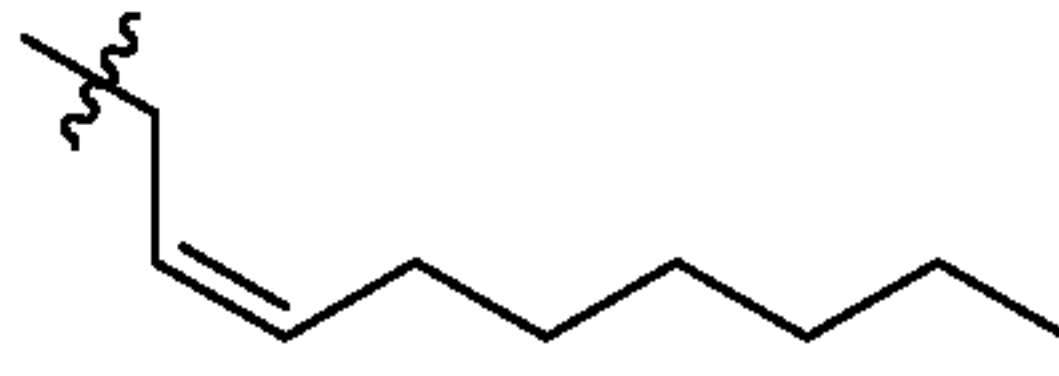
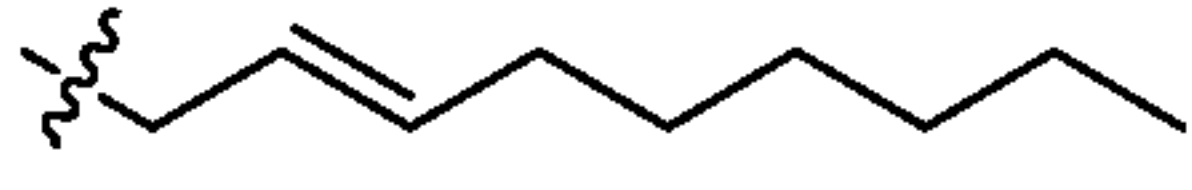
[00143] In other embodiments, R_1 is different from $-(CHR_5R_6)_m-M-CR_2R_3R_7$.

[00144] In some embodiments, R' is selected from $-R^*YR''$ and $-YR''$. In some embodiments, Y is C_{3-8} cycloalkyl. In some embodiments, Y is C_{6-10} aryl. In some embodiments, Y is a cyclopropyl group. In some embodiments, Y is a cyclohexyl group. In certain embodiments, R^* is C_1 alkyl.

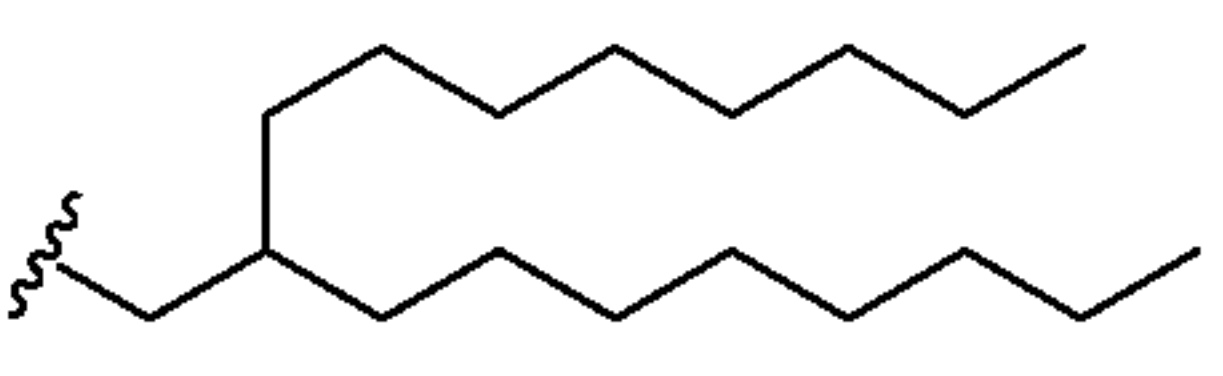
[00145] In some embodiments, R'' is selected from the group consisting of C_{3-12} alkyl and C_{3-12} alkenyl. In some embodiments, R'' adjacent to Y is C_1 alkyl. In some embodiments, R'' adjacent to Y is C_{4-9} alkyl (*e.g.*, C_4 , C_5 , C_6 , C_7 or C_8 or C_9 alkyl).

[00146]

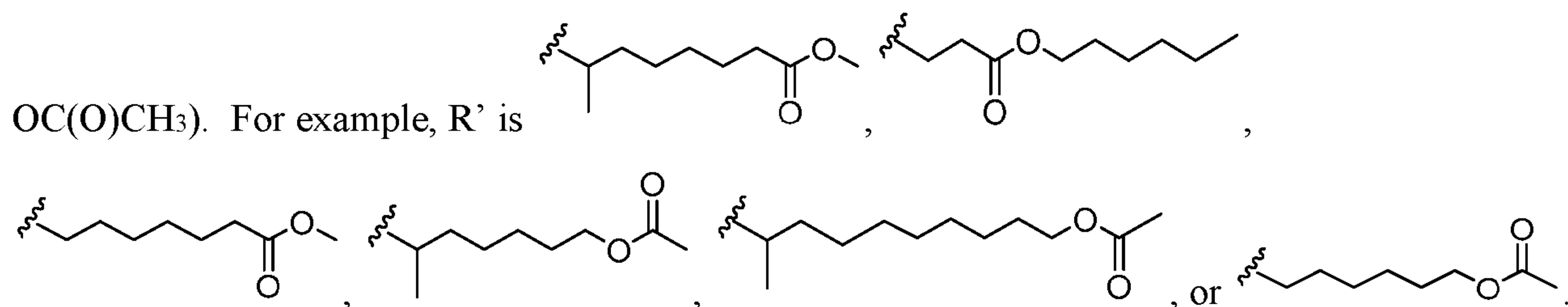
[00147] In some embodiments, R' is selected from C_4 alkyl and C_4 alkenyl. In certain embodiments, R' is selected from C_5 alkyl and C_5 alkenyl. In some embodiments, R' is selected from C_6 alkyl and C_6 alkenyl. In some embodiments, R' is selected from C_7 alkyl and C_7 alkenyl. In some embodiments, R' is selected from C_9 alkyl and C_9 alkenyl.

[00148] In some embodiments, R' is  or . In some embodiments, R' is  or  and M' is $-OC(O)-$. In other embodiments, R' is  or  and M' is $-C(O)O-$.

[00149] In other embodiments, R' is selected from C_{11} alkyl and C_{11} alkenyl. In other embodiments, R' is selected from C_{12} alkyl, C_{12} alkenyl, C_{13} alkyl, C_{13} alkenyl, C_{14} alkyl, C_{14} alkenyl, C_{15} alkyl, C_{15} alkenyl, C_{16} alkyl, C_{16} alkenyl, C_{17} alkyl, C_{17} alkenyl, C_{18} alkyl, and C_{18} alkenyl. In certain embodiments, R' is linear C_{4-18} alkyl or C_{4-18} alkenyl. In certain embodiments, R' is branched (*e.g.*, decan-2-yl, undecan-3-yl, dodecan-4-yl, tridecan-5-yl, tetradecan-6-yl, 2-methylundecan-3-yl, 2-methyldecan-2-yl, 3-methylundecan-3-yl, 4-methyldodecan-4-yl or

heptadeca-9-yl). In certain embodiments, R' is .

[00150] In certain embodiments, R' is unsubstituted C_{1-18} alkyl. In certain embodiments, R' is substituted C_{1-18} alkyl (*e.g.*, C_{1-15} alkyl substituted with, *e.g.*, an alkoxy such as methoxy, or a C_{3-6} carbocycle such as 1-cyclopropylnonyl, or $C(O)O$ -alkyl or $OC(O)$ -alkyl such as $C(O)OCH_3$ or



[00151] In some embodiments, R'' is selected from the group consisting of C₃₋₁₅ alkyl and C₃₋₁₄ alkenyl (e.g., C₃₋₁₄ alkyl and C₃₋₁₄ alkenyl). In some embodiments, R'' is C₃ alkyl, C₄ alkyl, C₅ alkyl, C₆ alkyl, C₇ alkyl, or C₈ alkyl. In some embodiments, R'' is C₉ alkyl, C₁₀ alkyl, C₁₁ alkyl, C₁₂ alkyl, C₁₃ alkyl, C₁₄ alkyl, or C₁₅ alkyl.

[00152] In some embodiments, M' is -C(O)O-. In some embodiments, M' is -OC(O)-. In some embodiments, M' is -OC(O)-M''-C(O)O-.

[00153] In other embodiments, M' is an aryl group or heteroaryl group. For example, M' may be selected from the group consisting of phenyl, oxazole, and thiazole.

[00154] In some embodiments, M is -C(O)O-. In some embodiments, M is -OC(O)-. In some embodiments, M is -C(O)N(R')-. In some embodiments, M is -P(O)(OR')O-. In some embodiments, M is -OC(O)-M''-C(O)O-.

[00155] In other embodiments, M is an aryl group or heteroaryl group. For example, M may be selected from the group consisting of phenyl, oxazole, and thiazole.

[00156] In some embodiments, M is the same as M'. In other embodiments, M is different from M'.

[00157] In some embodiments, M'' is a bond. In some embodiments, M'' is C₁₋₁₃ alkyl or C₂₋₁₃ alkenyl. In some embodiments, M'' is C₁₋₆ alkyl or C₂₋₆ alkenyl. In certain embodiments, M'' is linear alkyl or alkenyl. In certain embodiments, M'' is branched, e.g., -CH(CH₃)CH₂-.

[00158] In some embodiments, each R₅ is H. In certain such embodiments, each R₆ is also H.

[00159] In some embodiments, R₇ is H. In other embodiments, R₇ is C₁₋₃ alkyl (e.g., methyl, ethyl, propyl, or i-propyl).

[00160] In some embodiments, R₂ and R₃ are independently C₅₋₁₄ alkyl or C₅₋₁₄ alkenyl.

[00161] In some embodiments, R₂ and R₃ are the same. In some embodiments, R₂ and R₃ are C₈ alkyl. In certain embodiments, R₂ and R₃ are C₂ alkyl. In other embodiments, R₂ and R₃ are C₃ alkyl. In some embodiments, R₂ and R₃ are C₄ alkyl. In certain embodiments, R₂ and R₃ are C₅ alkyl. In other embodiments, R₂ and R₃ are C₆ alkyl. In some embodiments, R₂ and R₃ are C₇ alkyl.

[00162] In other embodiments, R_2 and R_3 are different. In certain embodiments, R_2 is C_8 alkyl. In some embodiments, R_3 is C_{1-7} (*e.g.*, C_1 , C_2 , C_3 , C_4 , C_5 , C_6 , or C_7 alkyl) or C_9 alkyl.

[00163] In some embodiments, R_7 and R_3 are H.

[00164] In certain embodiments, R_2 is H.

[00165] In some embodiments, m is 5, 7, or 9.

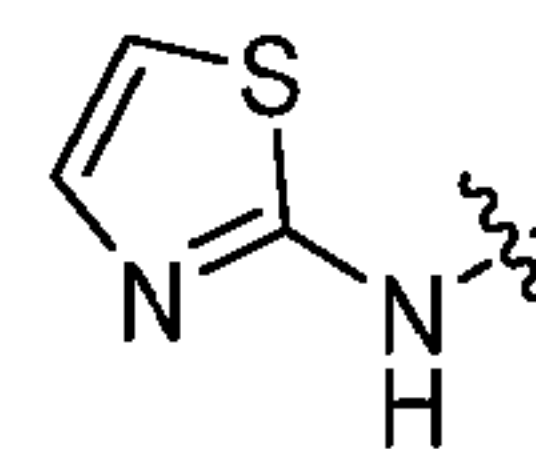
[00166] In some embodiments, R_4 is selected from $-(CH_2)_nQ$ and $-(CH_2)_nCHQR$.

[00167] In some embodiments, Q is selected from the group consisting of $-OR$, $-OH$, $-O(CH_2)_nN(R)_2$, $-OC(O)R$, $-CX_3$, $-CN$, $-N(R)C(O)R$, $-N(H)C(O)R$, $-N(R)S(O)_2R$, $-N(R)S(O)_2R_8$, $-N(H)S(O)_2R$, $-N(R)C(O)N(R)_2$, $-N(H)C(O)N(R)_2$, $-N(H)C(O)N(H)(R)$, $-N(R)C(S)N(R)_2$, $-N(H)C(S)N(R)_2$, $-N(H)C(S)N(H)(R)$, $-C(R)N(R)_2C(O)OR$, a carbocycle, and a heterocycle.

[00168] In certain embodiments, Q is $-N(R)R_8$, $-N(R)S(O)_2R_8$, $-O(CH_2)_nOR$, $-N(R)C(=NR_9)N(R)_2$, $-N(R)C(=CHR_9)N(R)_2$, $-OC(O)N(R)_2$, or $-N(R)C(O)OR$.

[00169] In certain embodiments, Q is $-N(OR)C(O)R$, $-N(OR)S(O)_2R$, $-N(OR)C(O)OR$, $-N(OR)C(O)N(R)_2$, $-N(OR)C(S)N(R)_2$, $-N(OR)C(=NR_9)N(R)_2$, or $-N(OR)C(=CHR_9)N(R)_2$.

[00170] In certain embodiments, Q is thiourea or an isostere thereof, *e.g.*,
or $-NHC(=NR_9)N(R)_2$.



[00171] In certain embodiments, Q is $-C(=NR_9)N(R)_2$. For example, when Q is $-C(=NR_9)N(R)_2$, n is 4 or 5. For example, R_9 is $-S(O)_2N(R)_2$.

[00172] In certain embodiments, Q is $-C(=NR_9)R$ or $-C(O)N(R)OR$, *e.g.*, $-CH(=N-OCH_3)$, $-C(O)NH-OH$, $-C(O)NH-OCH_3$, $-C(O)N(CH_3)-OH$, or $-C(O)N(CH_3)-OCH_3$.

[00173] In certain embodiments, Q is $-OH$.

[00174] In certain embodiments, Q is a substituted or unsubstituted 5- to 10- membered heteroaryl, *e.g.*, Q is a triazole, an imidazole, a pyrimidine, a purine, 2-amino-1,9-dihydro-6*H*-purin-6-one-9-yl (or guanine-9-yl), adenine-9-yl, cytosine-1-yl, or uracil-1-yl, each of which is optionally substituted with one or more substituents selected from alkyl, OH, alkoxy, $-alkyl-OH$, $-alkyl-O-alkyl$, and the substituent can be further substituted. In certain embodiments, Q is a substituted 5- to 14-membered heterocycloalkyl, *e.g.*, substituted with one or more substituents selected from oxo ($=O$), OH, amino, mono- or di-alkylamino, and C_{1-3} alkyl. For example, Q is 4-

methylpiperazinyl, 4-(4-methoxybenzyl)piperazinyl, isoindolin-2-yl-1,3-dione, pyrrolidin-1-yl-2,5-dione, or imidazolidin-3-yl-2,4-dione.

[00175] In certain embodiments, Q is -NHR₈, in which R₈ is a C₃₋₆ cycloalkyl optionally substituted with one or more substituents selected from oxo (=O), amino (NH₂), mono- or di-alkylamino, C₁₋₃ alkyl and halo. For example, R₈ is cyclobutenyl, e.g., 3-(dimethylamino)-cyclobut-3-ene-4-yl-1,2-dione. In further embodiments, R₈ is a C₃₋₆ cycloalkyl optionally substituted with one or more substituents selected from oxo (=O), amino (NH₂), mono- or di-alkylamino, C₁₋₃ alkyl and halo, wherein the mono- or di-alkylamino and C₁₋₃ alkyl are further substituted. For example R₈ is cyclobutenyl substituted with one or more of oxo, amino, and alkylamino, wherein the alkylamino is further substituted, e.g., with one or more of amino, mono- or di-alkylamino, and halo. For example, R₈ is 3-(((dimethylamino)ethyl)amino)cyclobut-3-enyl-1,2-dione.

[00176] In certain embodiments, Q is -NHR₈, in which R₈ is a heteroaryl optionally substituted with one or more substituents selected from amino (NH₂), mono- or di-alkylamino, C₁₋₃ alkyl and halo. For example, R₈ is thiazole or imidazole.

[00177] In certain embodiments, Q is -NHC(=NR₉)N(R)₂ in which R₉ is CN, C₁₋₆ alkyl, NO₂, -S(O)₂N(R)₂, -OR, -S(O)₂R, or H. For example, Q is -NHC(=NR₉)N(CH₃)₂, -NHC(=NR₉)NHCH₃, -NHC(=NR₉)NH₂. In some embodiments, Q is -NHC(=NR₉)N(R)₂ in which R₉ is CN and R is C₁₋₃ alkyl substituted with mono- or di-alkylamino, e.g., R is ((dimethylamino)ethyl)amino. In some embodiments, Q is -NHC(=NR₉)N(R)₂ in which R₉ is C₁₋₆ alkyl, NO₂, -S(O)₂N(R)₂, -OR, -S(O)₂R, or H and R is C₁₋₃ alkyl substituted with mono- or di-alkylamino, e.g., R is ((dimethylamino)ethyl)amino.

[00178] In certain embodiments, Q is -NHC(=CHR₉)N(R)₂, in which R₉ is NO₂, CN, C₁₋₆ alkyl, -S(O)₂N(R)₂, -OR, -S(O)₂R, or H. For example, Q is -NHC(=CHR₉)N(CH₃)₂, -NHC(=CHR₉)NHCH₃, or -NHC(=CHR₉)NH₂.

[00179] In certain embodiments, Q is -OC(O)N(R)₂, -N(R)C(O)OR, -N(OR)C(O)OR, such as -OC(O)NHCH₃, -N(OH)C(O)OCH₃, -N(OH)C(O)CH₃, -N(OCH₃)C(O)OCH₃, -N(OCH₃)C(O)CH₃, -N(OH)S(O)₂CH₃, or -NHC(O)OCH₃.

[00180] In certain embodiments, Q is -N(R)C(O)R, in which R is alkyl optionally substituted with C₁₋₃ alkoxy or S(O)_tC₁₋₃ alkyl, in which t is 0, 1, or 2.

[00181] In certain embodiments, Q is an unsubstituted or substituted C₆₋₁₀ aryl (such as phenyl) or C₃₋₆ cycloalkyl.

[00182] In some embodiments, n is 1. In other embodiments, n is 2. In further embodiments, n is 3. In certain other embodiments, n is 4. For example, R_4 may be $-(CH_2)_2OH$. For example, R_4 may be $-(CH_2)_3OH$. For example, R_4 may be $-(CH_2)_4OH$. For example, R_4 may be benzyl. For example, R_4 may be 4-methoxybenzyl.

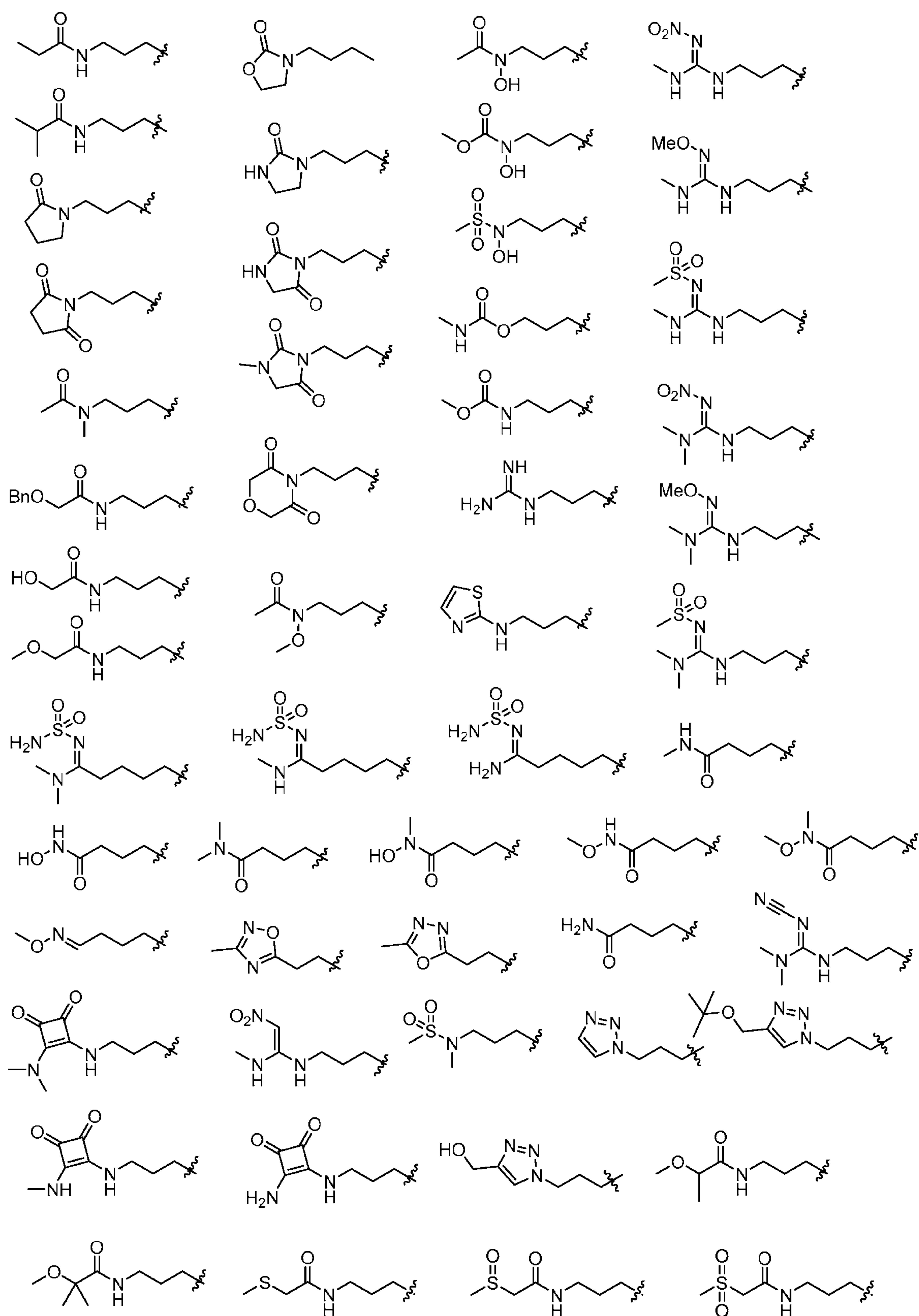
[00183] In some embodiments, R_4 is a C_{3-6} carbocycle. In some embodiments, R_4 is a C_{3-6} cycloalkyl. For example, R_4 may be cyclohexyl optionally substituted with *e.g.*, OH, halo, C_{1-6} alkyl, etc. For example, R_4 may be 2-hydroxycyclohexyl.

[00184] In some embodiments, R is H.

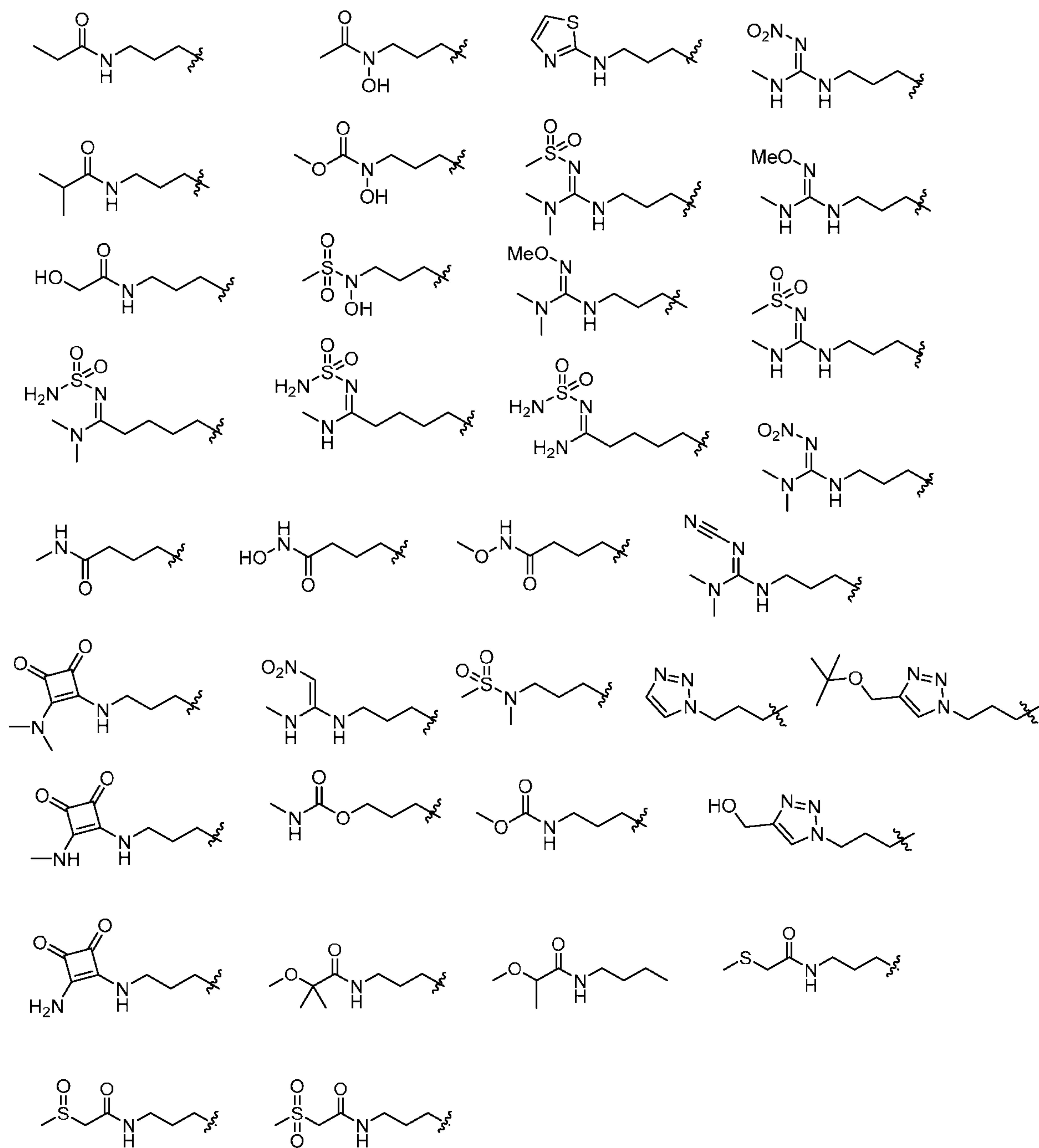
[00185] In some embodiments, R is C_{1-3} alkyl substituted with mono- or di-alkylamino, *e.g.*, R is ((dimethylamino)ethyl)amino. In some embodiments, R is unsubstituted C_{1-3} alkyl or unsubstituted C_{2-3} alkenyl. For example, R_4 may be $-CH_2CH(OH)CH_3$, $-CH(CH_3)CH_2OH$, or $-CH_2CH(OH)CH_2CH_3$.

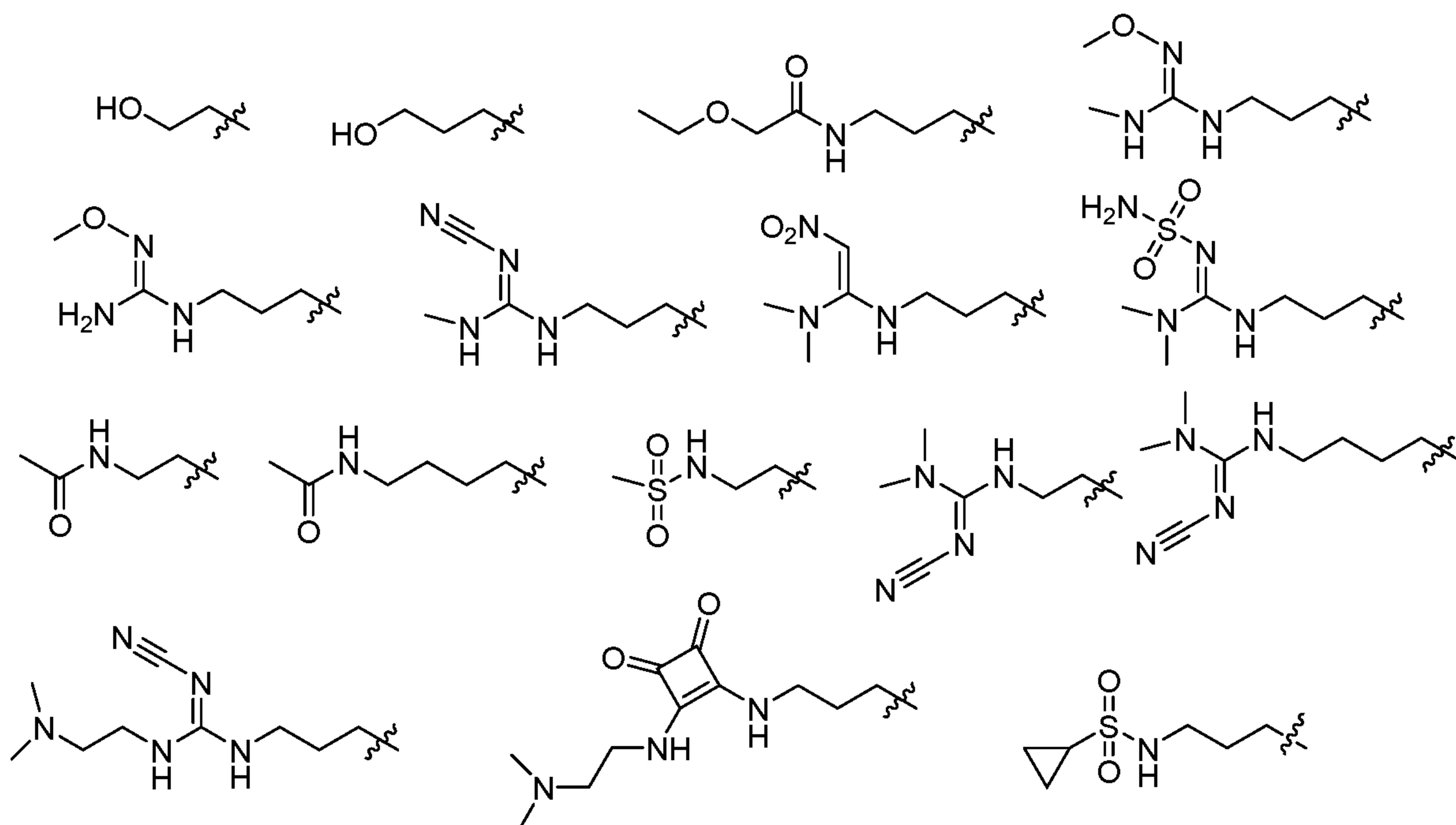
[00186] In some embodiments, R is substituted C_{1-3} alkyl, *e.g.*, CH_2OH . For example, R_4 may be $-CH_2CH(OH)CH_2OH$, $-(CH_2)_3NHC(O)CH_2OH$, $-(CH_2)_3NHC(O)CH_2OBn$, $-(CH_2)_2O(CH_2)_2OH$, $-(CH_2)_3NHCH_2OCH_3$, $-(CH_2)_3NHCH_2OCH_2CH_3$, CH_2SCH_3 , $CH_2S(O)CH_3$, $CH_2S(O)_2CH_3$, or $-CH(CH_2OH)_2$.

[00187] In some embodiments, R_4 is selected from any of the following groups:









[00189] In some embodiments the compound of any of the formulae described herein is suitable for making a nanoparticle composition for intramuscular administration.

[00190] In some embodiments, R₂ and R₃, together with the atom to which they are attached, form a heterocycle or carbocycle. In some embodiments, R₂ and R₃, together with the atom to which they are attached, form a 5- to 14- membered aromatic or non-aromatic heterocycle having one or more heteroatoms selected from N, O, S, and P. In some embodiments, R₂ and R₃, together with the atom to which they are attached, form an optionally substituted C₃₋₂₀ carbocycle (*e.g.*, C₃₋₁₈ carbocycle, C₃₋₁₅ carbocycle, C₃₋₁₂ carbocycle, or C₃₋₁₀ carbocycle), either aromatic or non-aromatic. In some embodiments, R₂ and R₃, together with the atom to which they are attached, form a C₃₋₆ carbocycle. In other embodiments, R₂ and R₃, together with the atom to which they are attached, form a C₆ carbocycle, such as a cyclohexyl or phenyl group. In certain embodiments, the heterocycle or C₃₋₆ carbocycle is substituted with one or more alkyl groups (*e.g.*, at the same ring atom or at adjacent or non-adjacent ring atoms). For example, R₂ and R₃, together with the atom to which they are attached, may form a cyclohexyl or phenyl group bearing one or more C₅ alkyl substitutions. In certain embodiments, the heterocycle or C₃₋₆ carbocycle formed by R₂ and R₃, is substituted with a carbocycle groups. For example, R₂ and R₃, together with the atom to which they are attached, may form a cyclohexyl or phenyl group that is substituted with cyclohexyl. In some

embodiments, R₂ and R₃, together with the atom to which they are attached, form a C₇₋₁₅ carbocycle, such as a cycloheptyl, cyclopentadecanyl, or naphthyl group.

[00191] In some embodiments, R₄ is selected from -(CH₂)_nQ and -(CH₂)_nCHQR. In some embodiments, Q is selected from the group consisting of -OR, -OH, -O(CH₂)_nN(R)₂, -OC(O)R, -CX₃, -CN, -N(R)C(O)R, -N(H)C(O)R, -N(R)S(O)₂R, -N(H)S(O)₂R, -N(R)S(O)₂R₈, -N(R)C(O)N(R)₂, -N(H)C(O)N(R)₂, -N(H)C(O)N(H)(R), -N(R)C(S)N(R)₂, -N(H)C(S)N(R)₂, -N(H)C(S)N(H)(R), and a heterocycle. In other embodiments, Q is selected from the group consisting of an imidazole, a pyrimidine, and a purine.

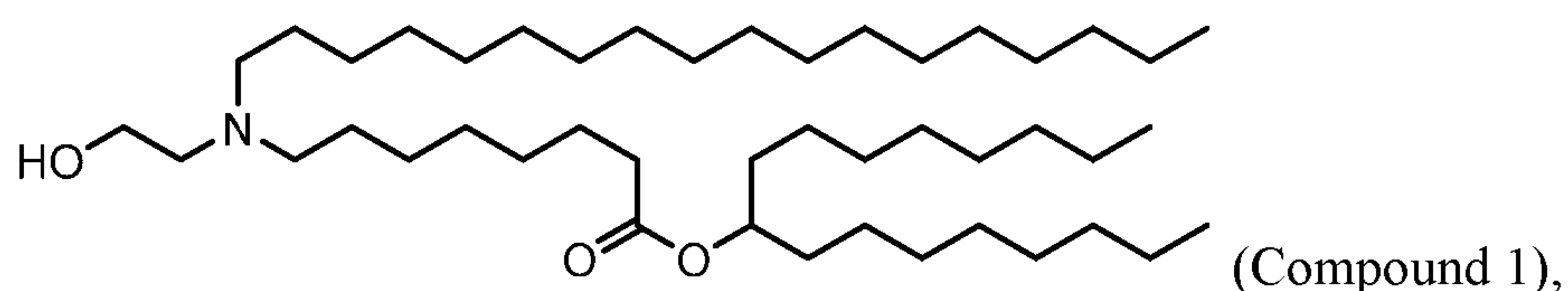
[00192] In some embodiments, R₂ and R₃, together with the atom to which they are attached, form a heterocycle or carbocycle. In some embodiments, R₂ and R₃, together with the atom to which they are attached, form a C₃₋₆ carbocycle, such as a phenyl group. In certain embodiments, the heterocycle or C₃₋₆ carbocycle is substituted with one or more alkyl groups (*e.g.*, at the same ring atom or at adjacent or non-adjacent ring atoms). For example, R₂ and R₃, together with the atom to which they are attached, may form a phenyl group bearing one or more C₅ alkyl substitutions.

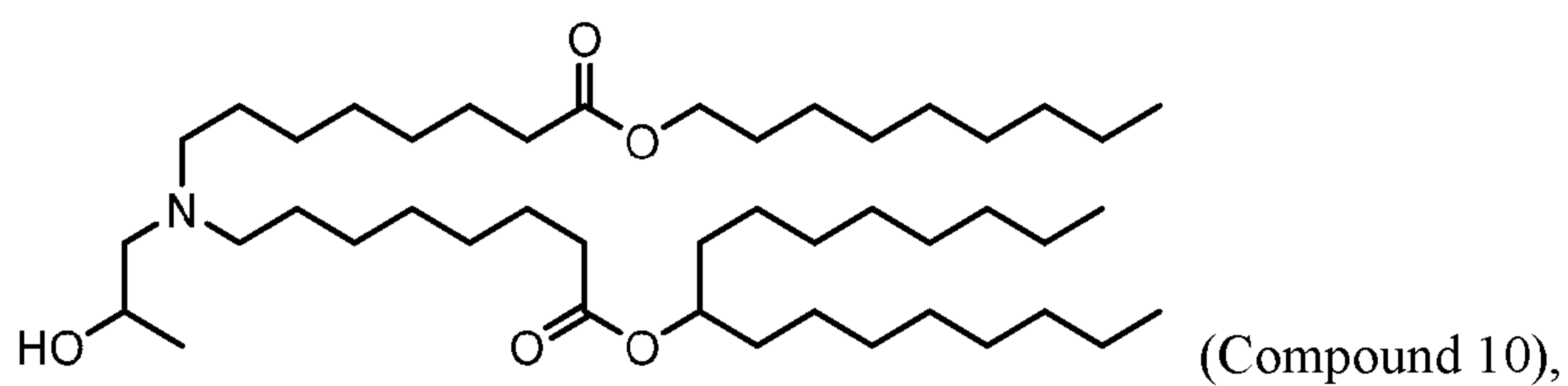
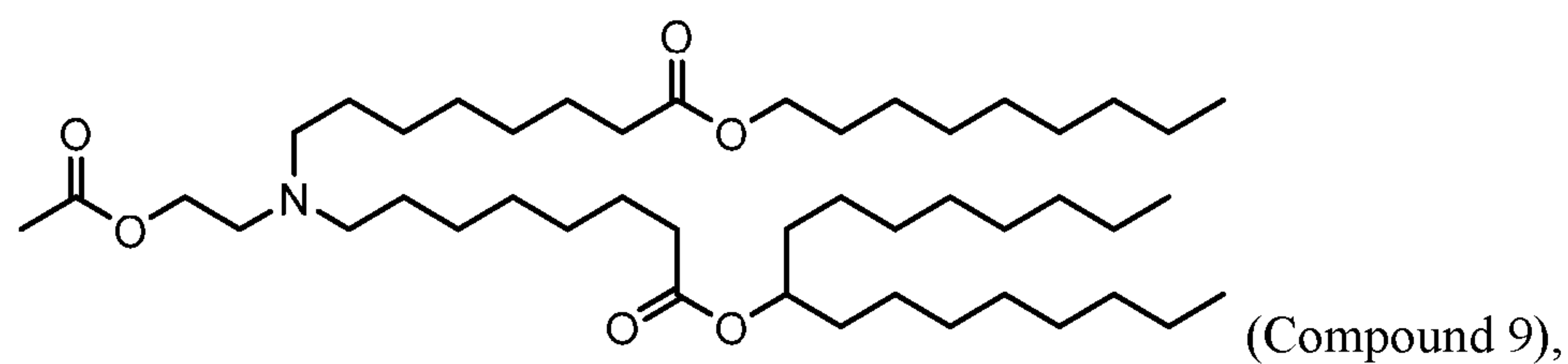
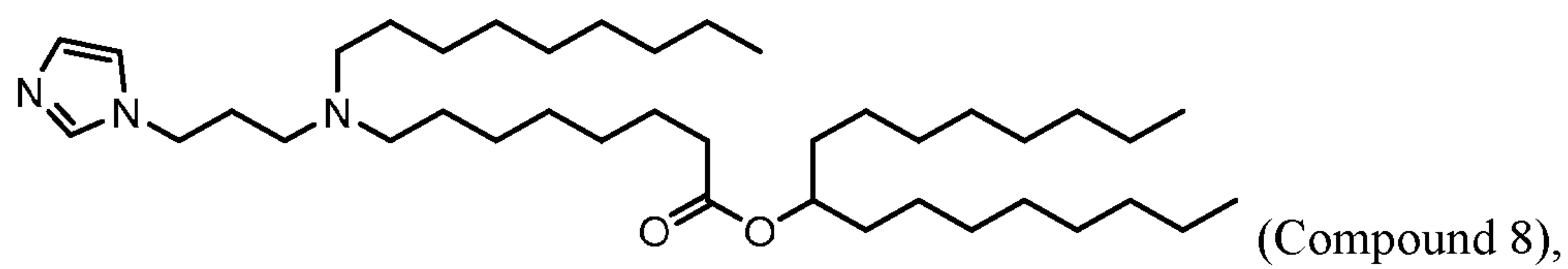
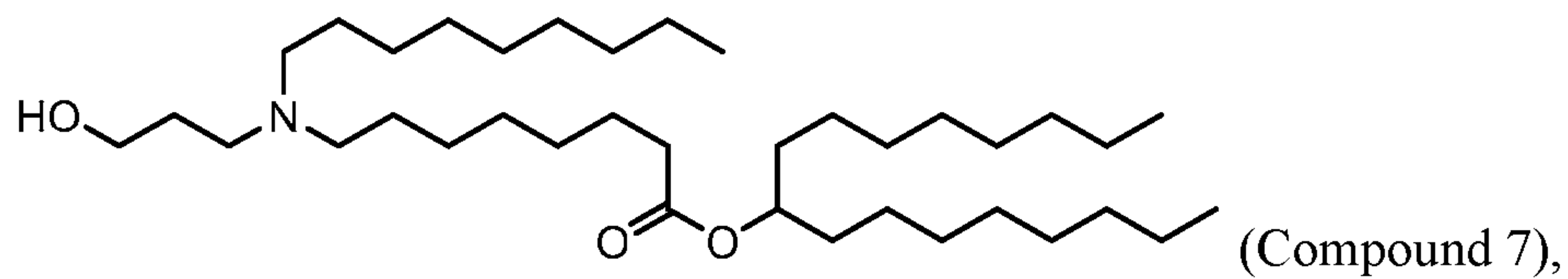
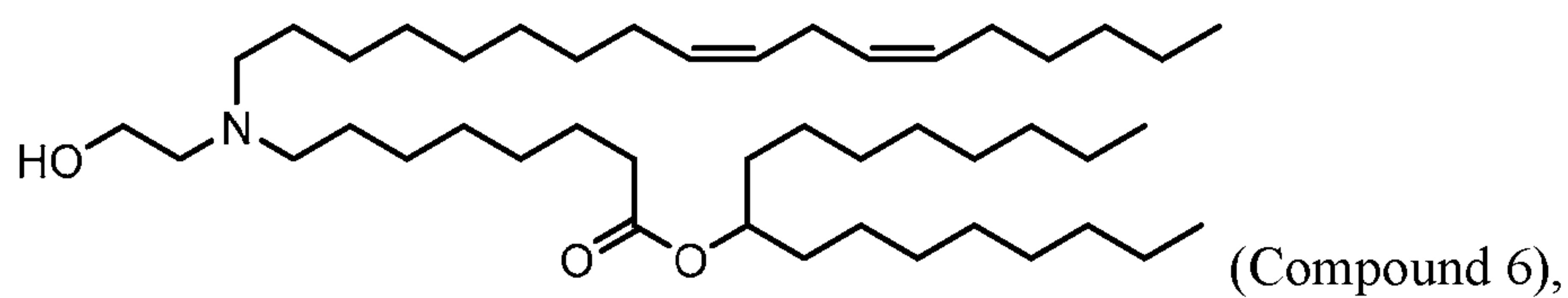
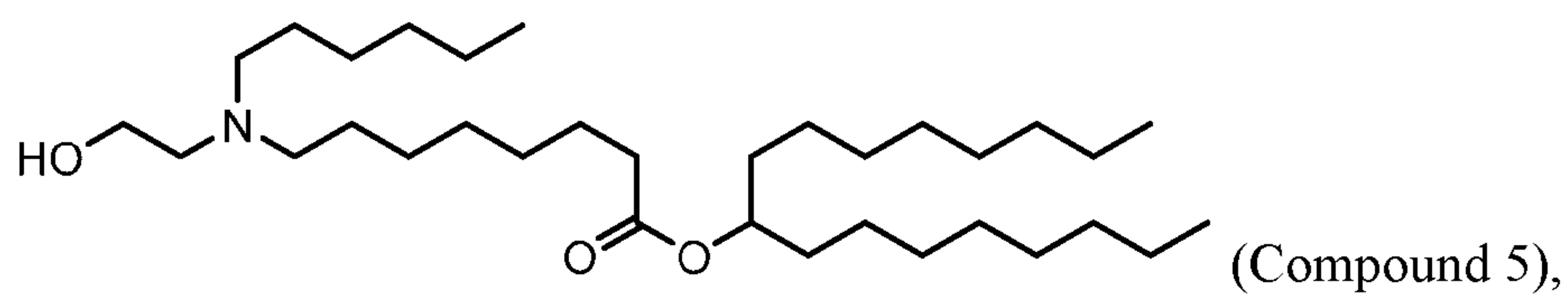
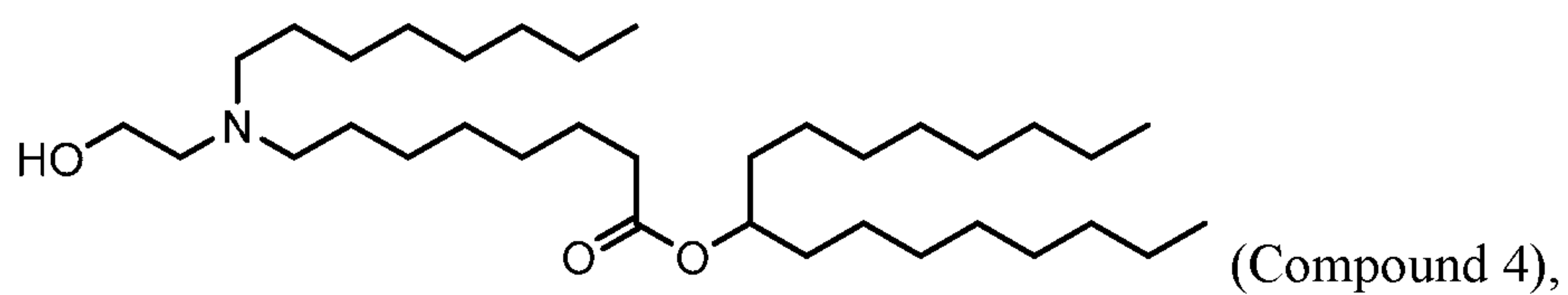
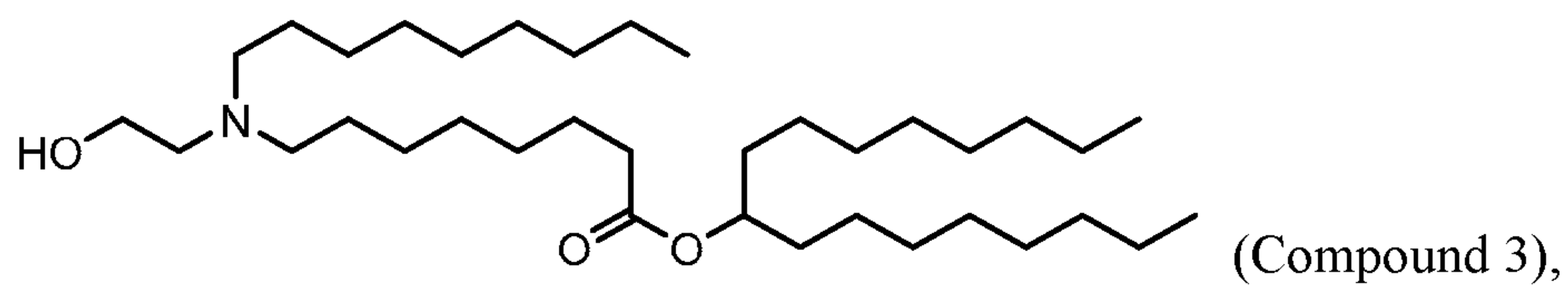
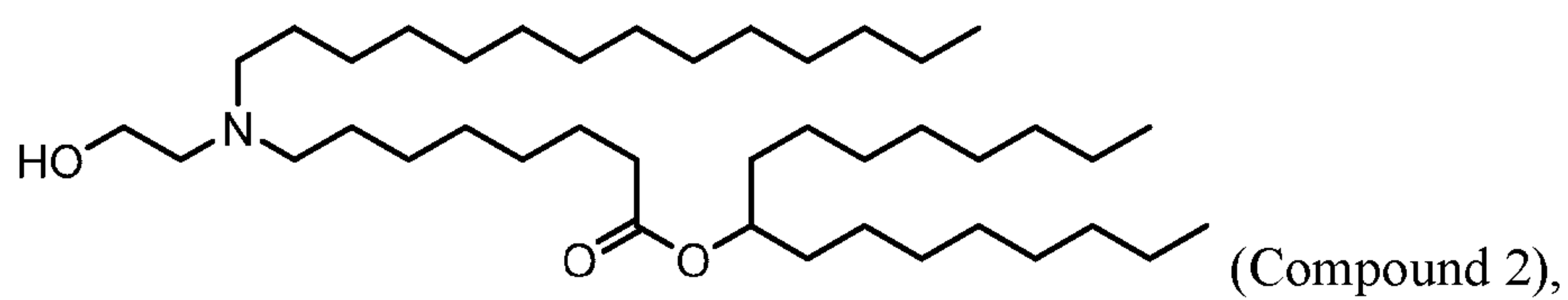
[00193] In some embodiments, at least one occurrence of R₅ and R₆ is C₁₋₃ alkyl, *e.g.*, methyl. In some embodiments, one of the R₅ and R₆ adjacent to M is C₁₋₃ alkyl, *e.g.*, methyl, and the other is H. In some embodiments, one of the R₅ and R₆ adjacent to M is C₁₋₃ alkyl, *e.g.*, methyl and the other is H, and M is -OC(O)- or -C(O)O-.

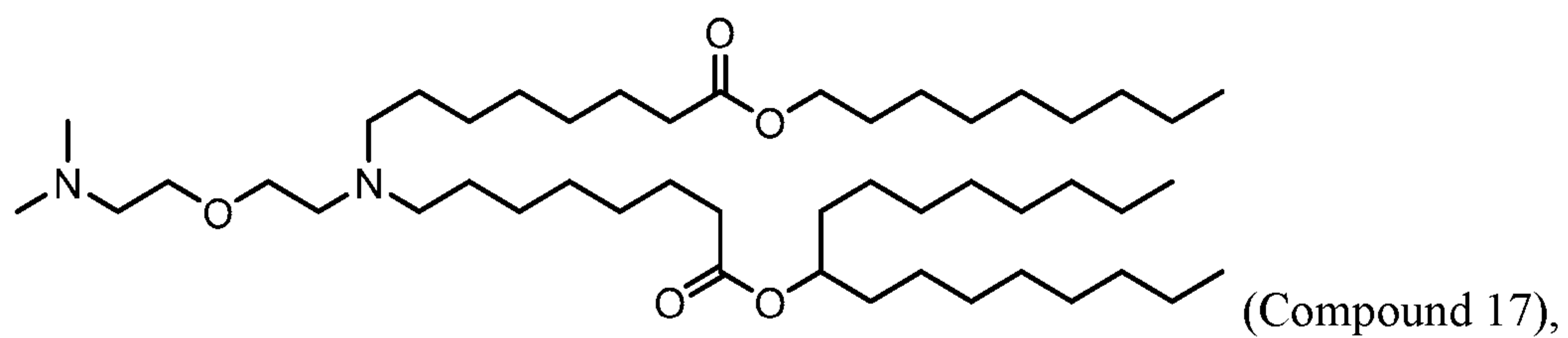
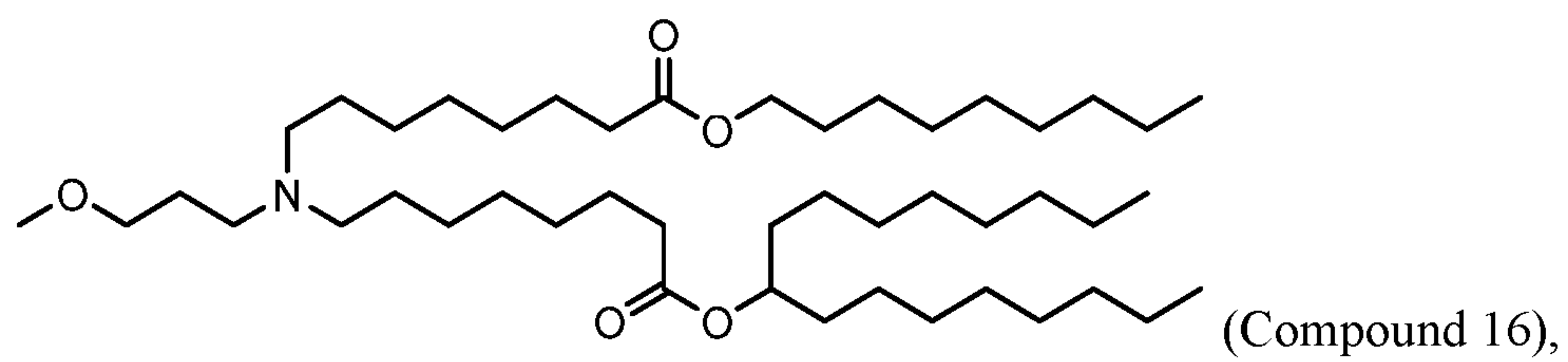
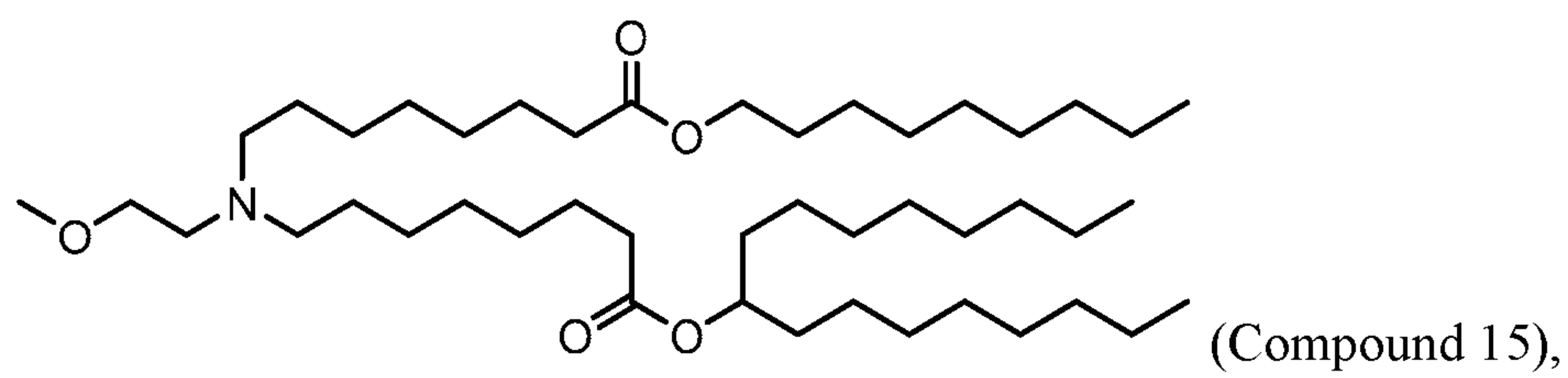
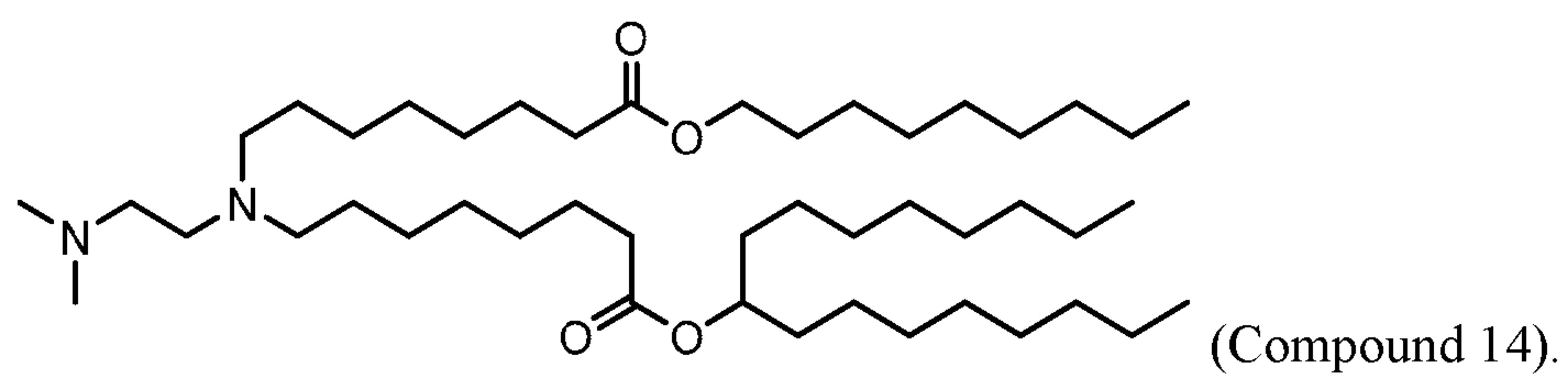
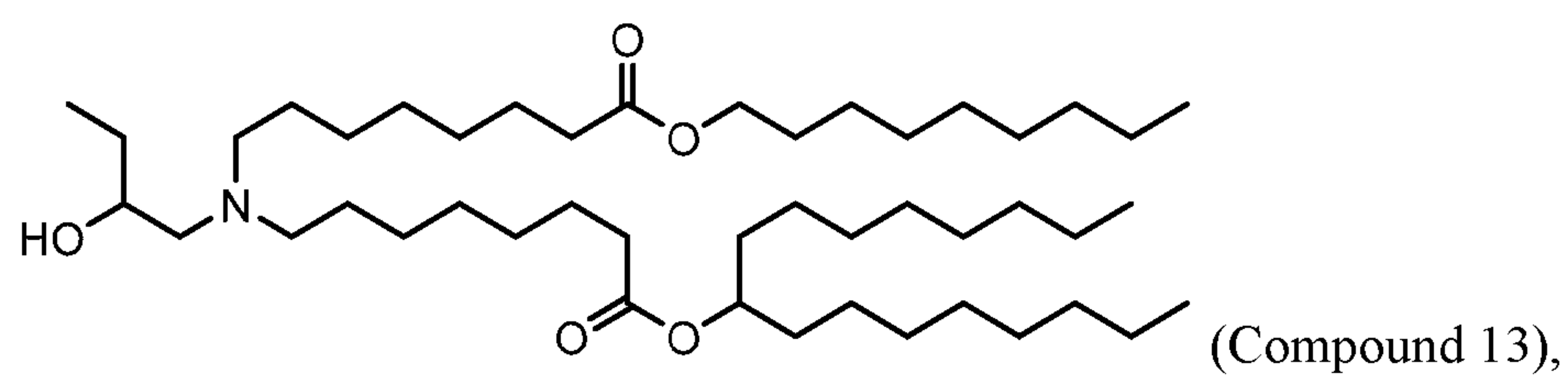
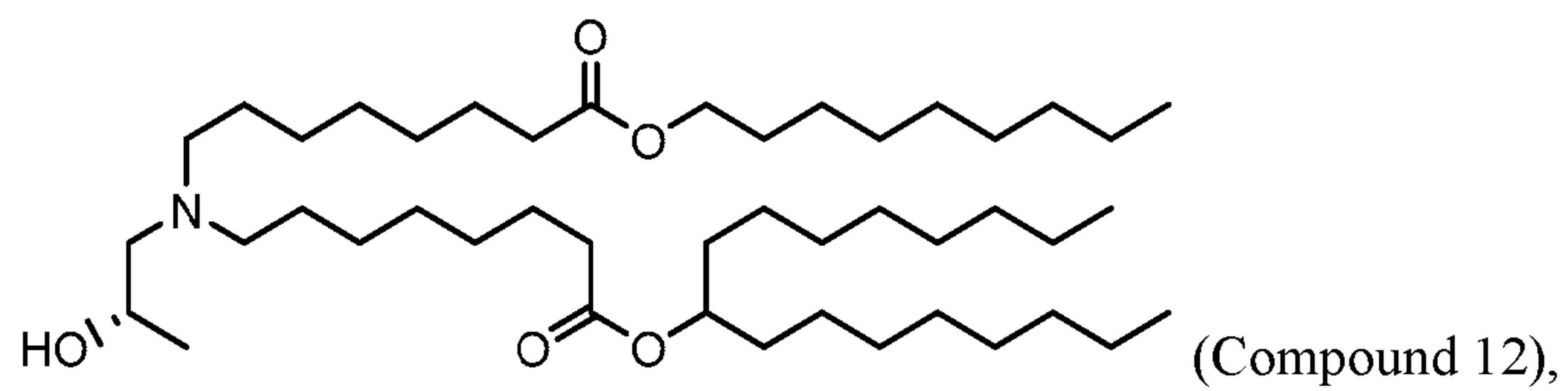
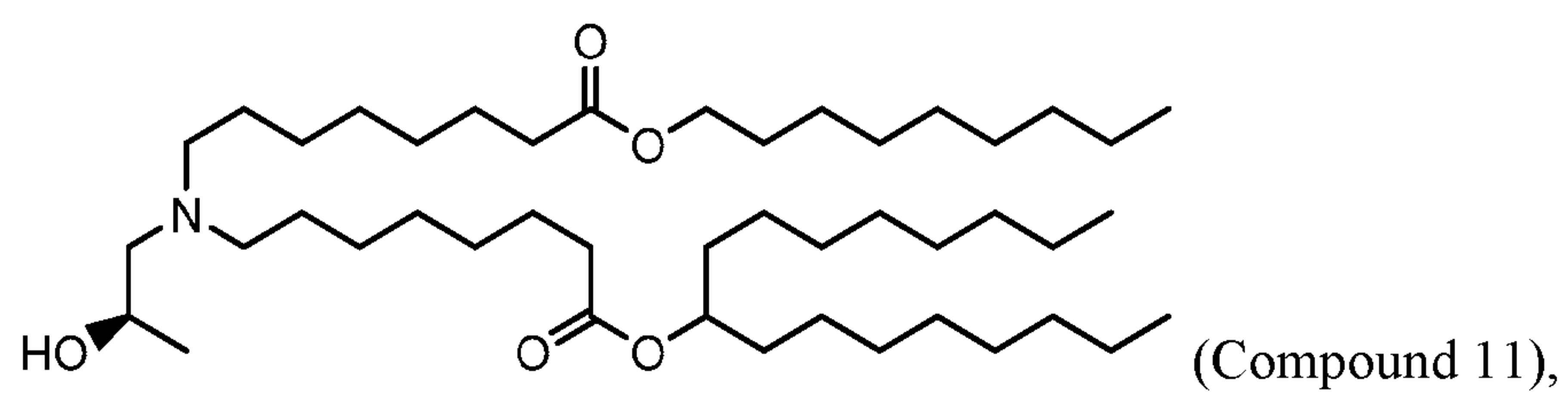
[00194] In some embodiments, at most one occurrence of R₅ and R₆ is C₁₋₃ alkyl, *e.g.*, methyl. In some embodiments, one of the R₅ and R₆ adjacent to M is C₁₋₃ alkyl, *e.g.*, methyl, and the other is H. In some embodiments, one of the R₅ and R₆ adjacent to M is C₁₋₃ alkyl, *e.g.*, methyl and the other is H, and M is -OC(O)- or -C(O)O-.

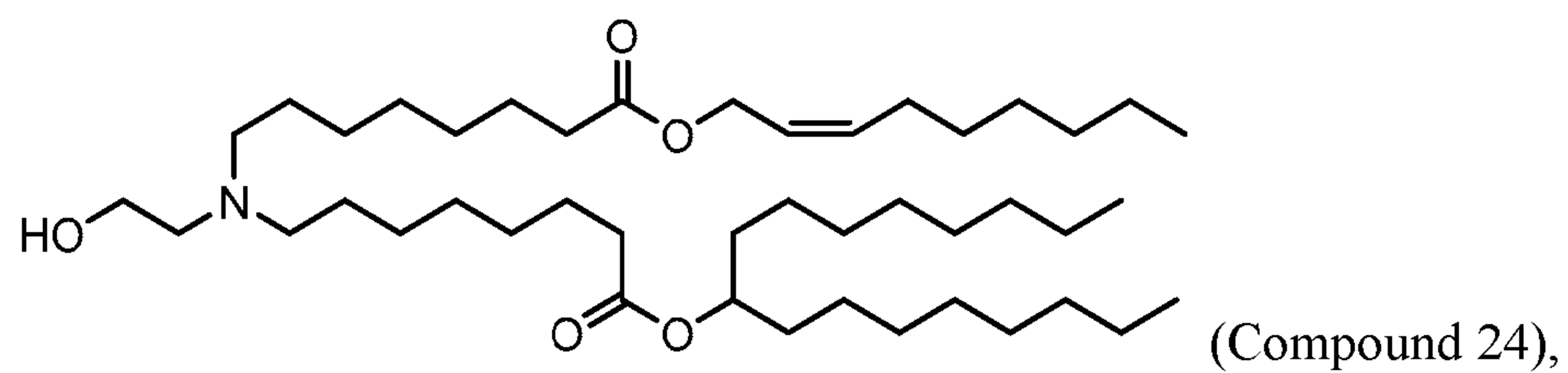
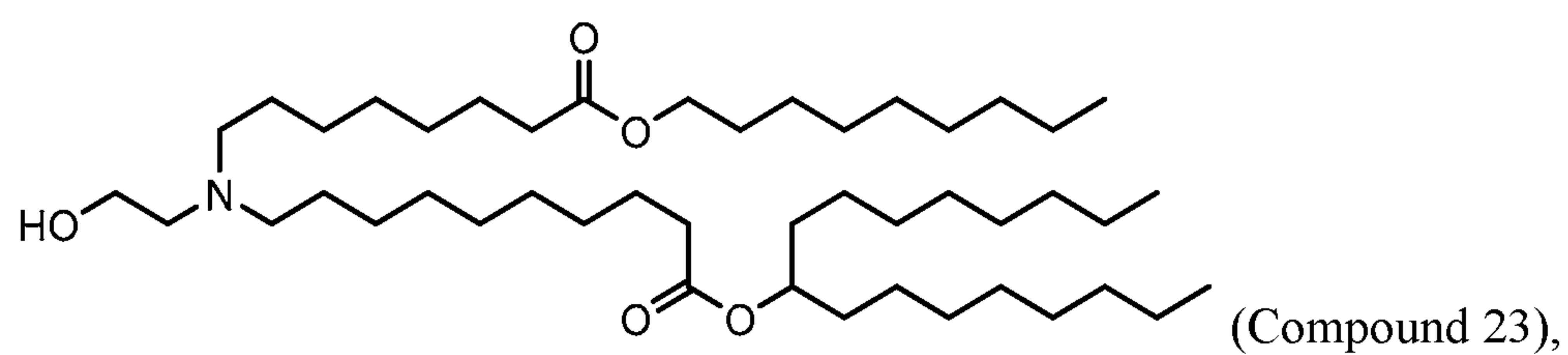
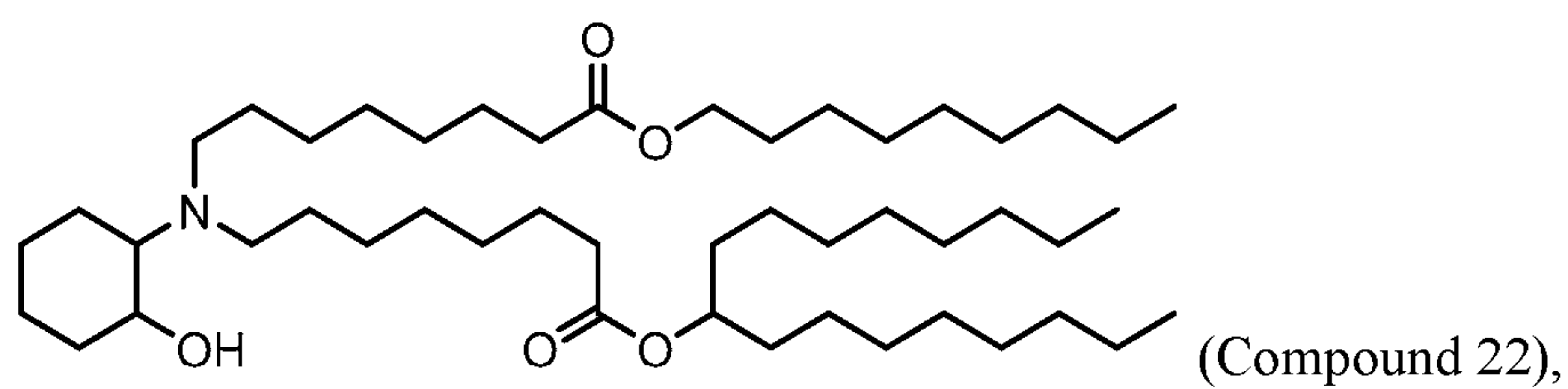
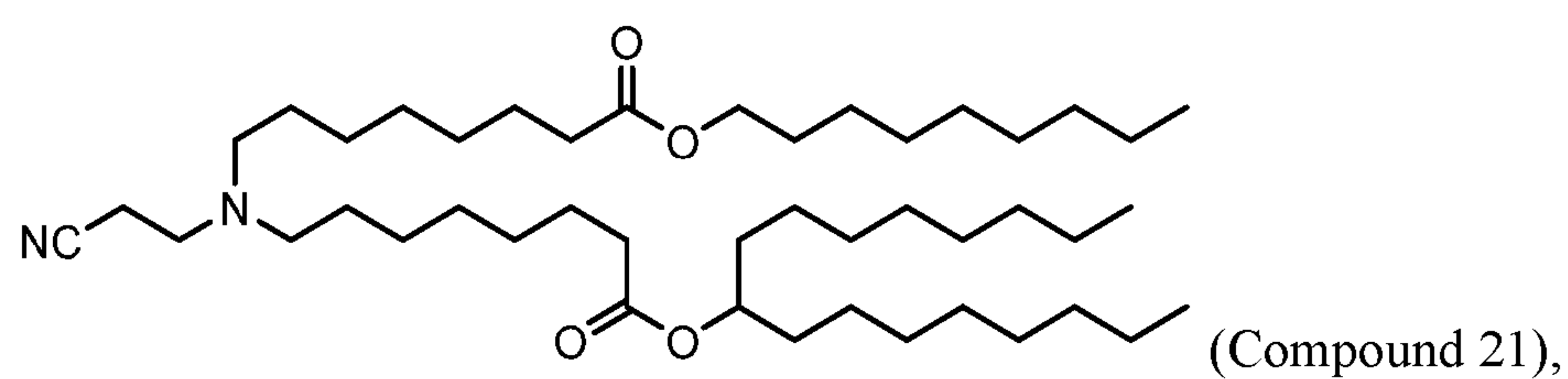
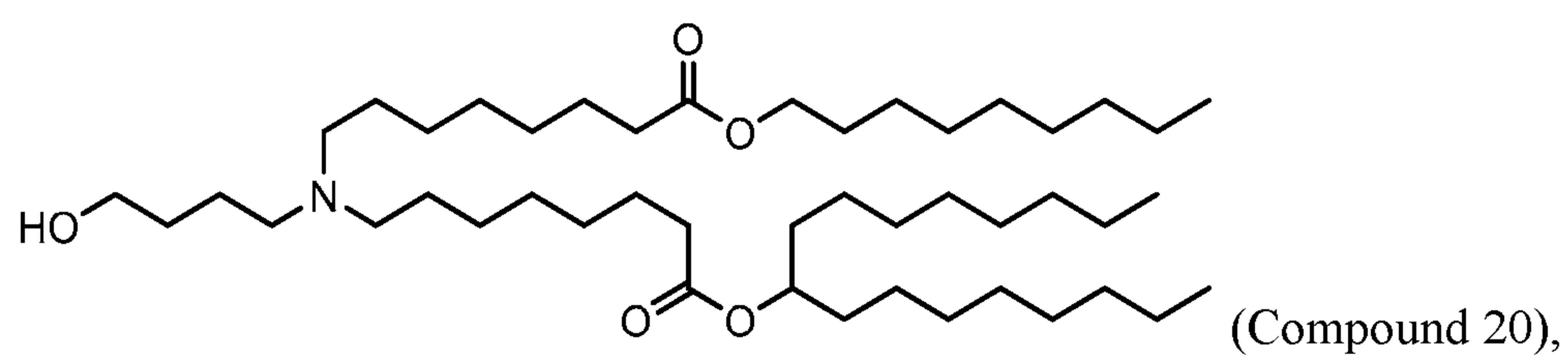
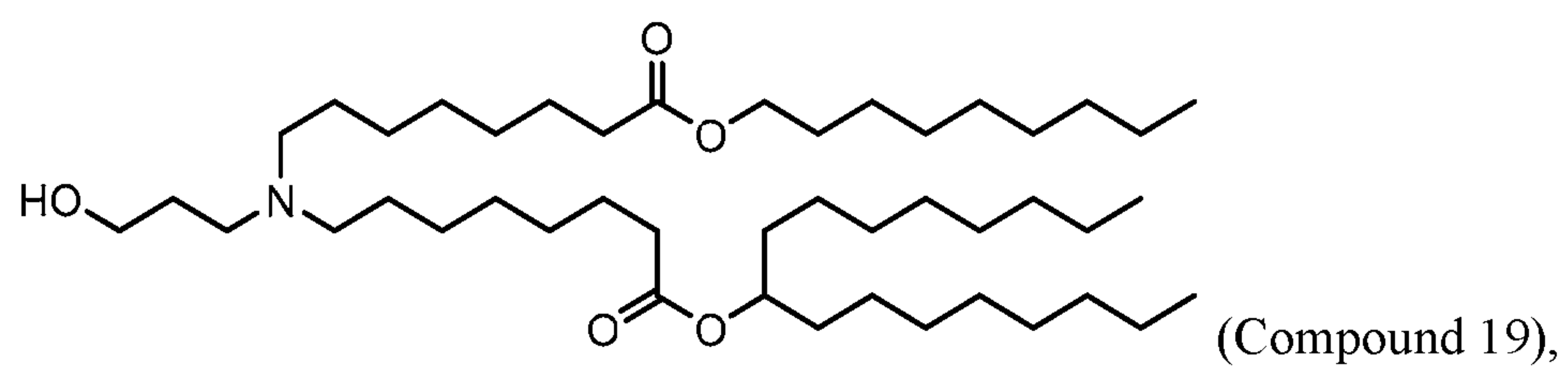
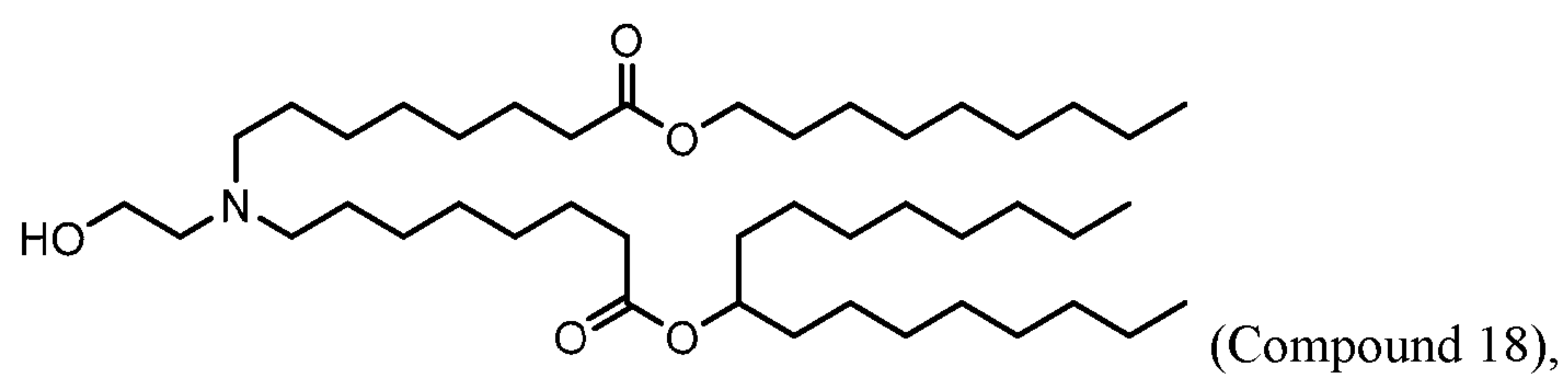
[00195] In some embodiments, each occurrence of R₅ and R₆ is H.

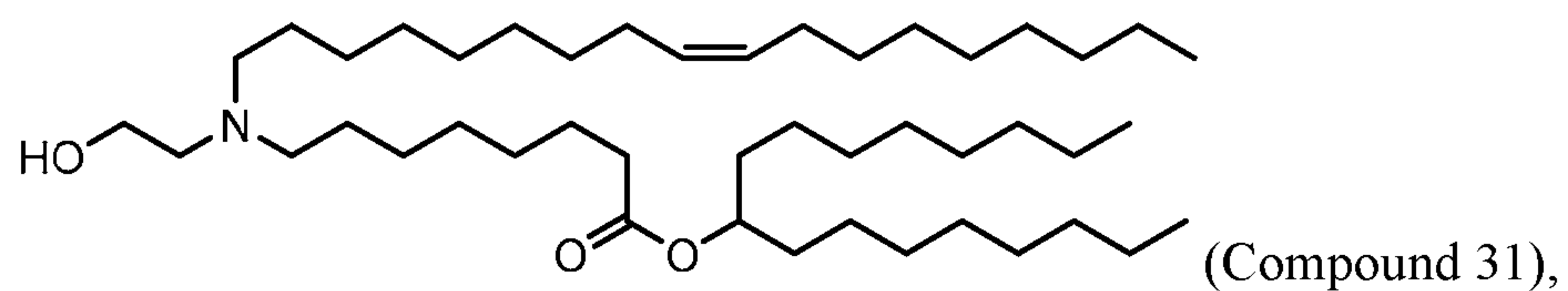
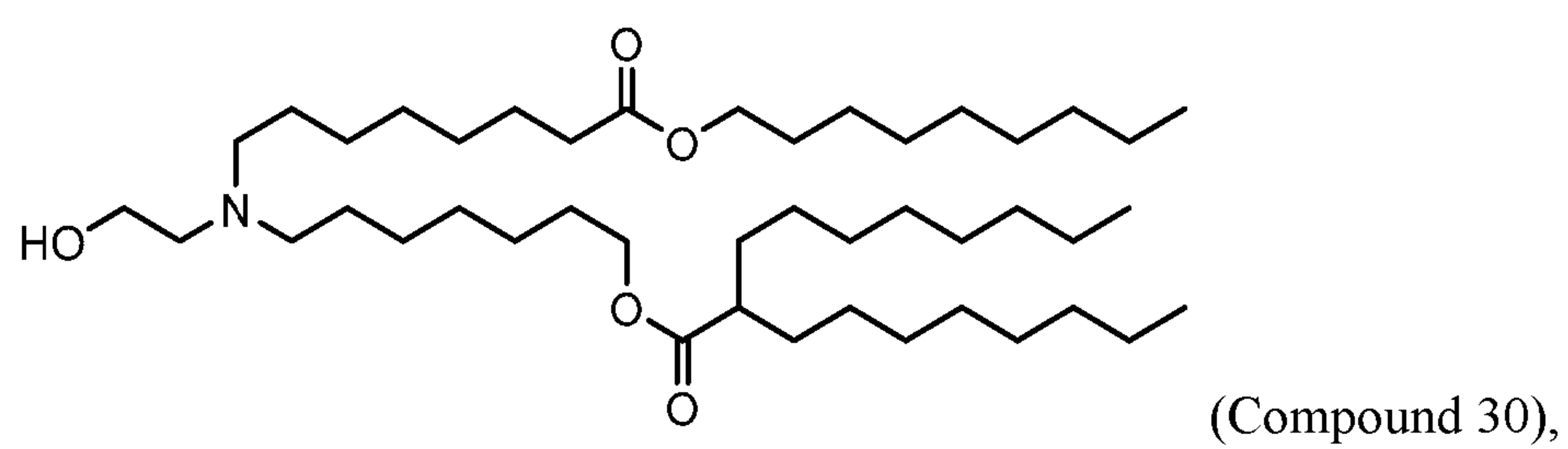
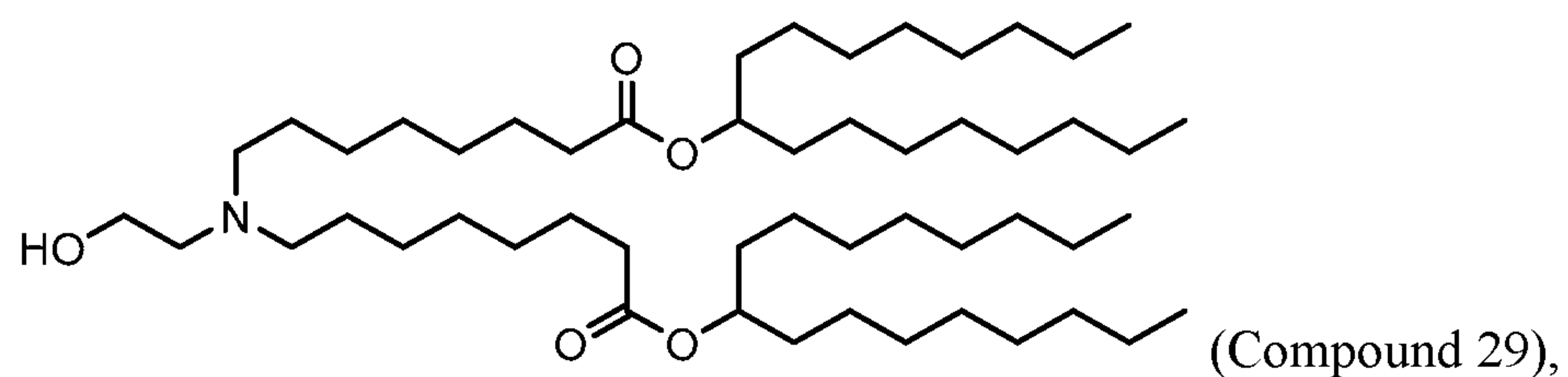
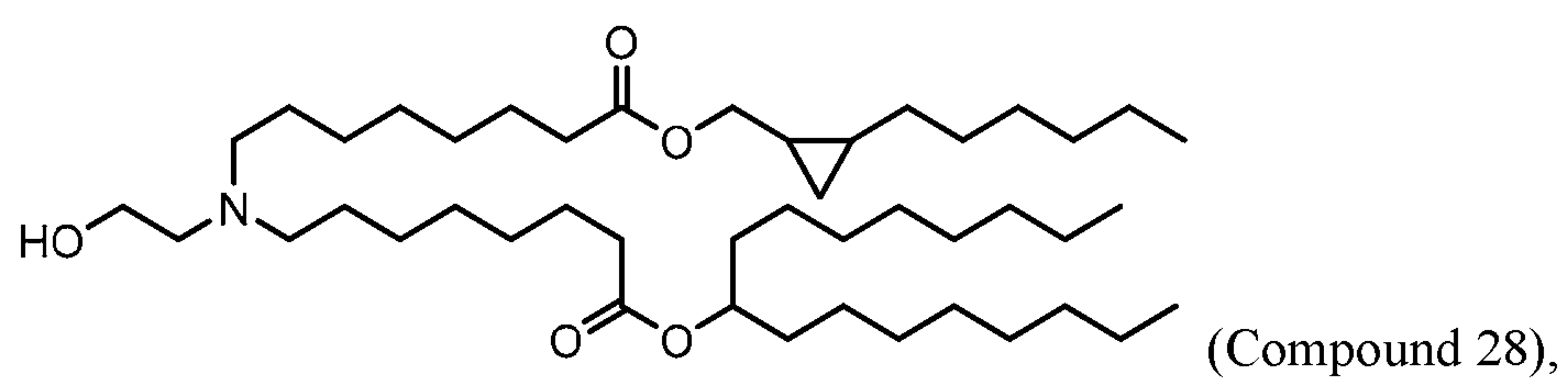
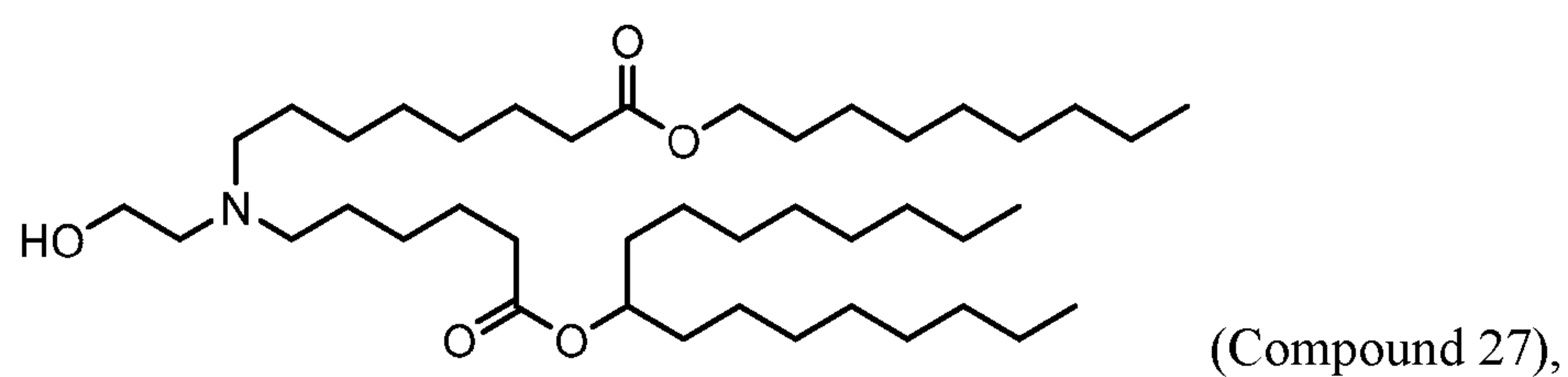
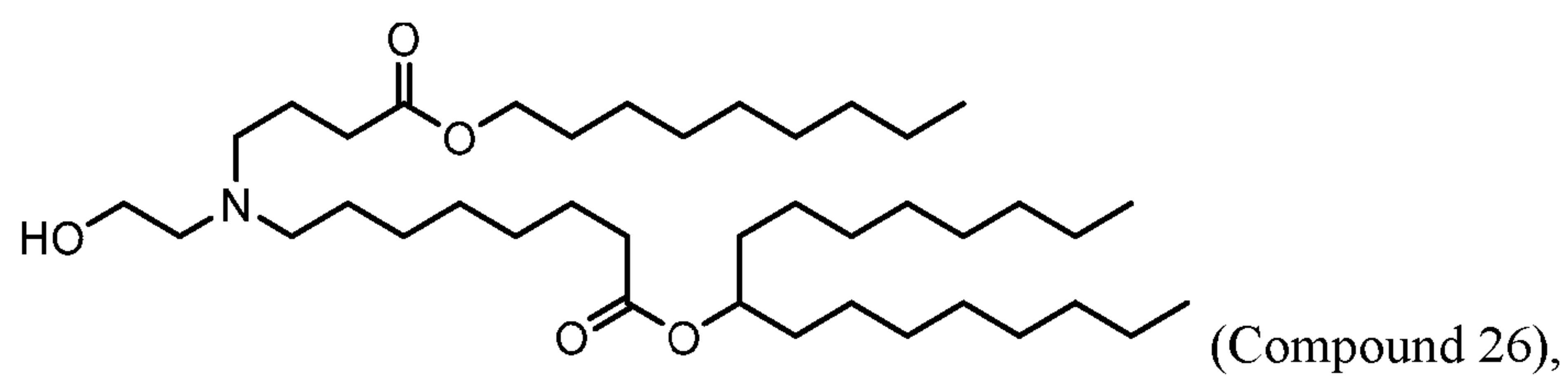
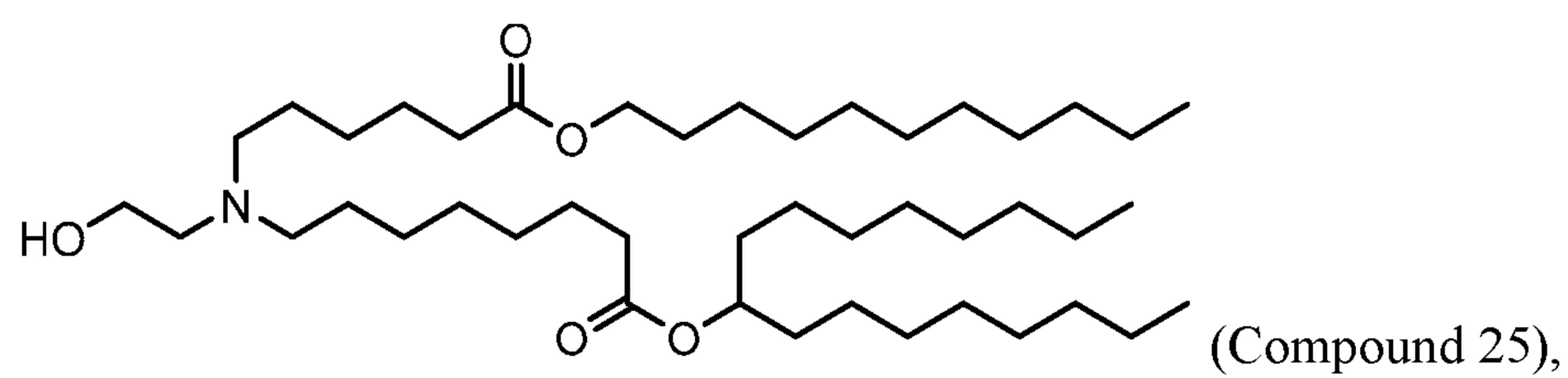
[00196] In some embodiments, the compound of Formula (I) is selected from the group consisting of:

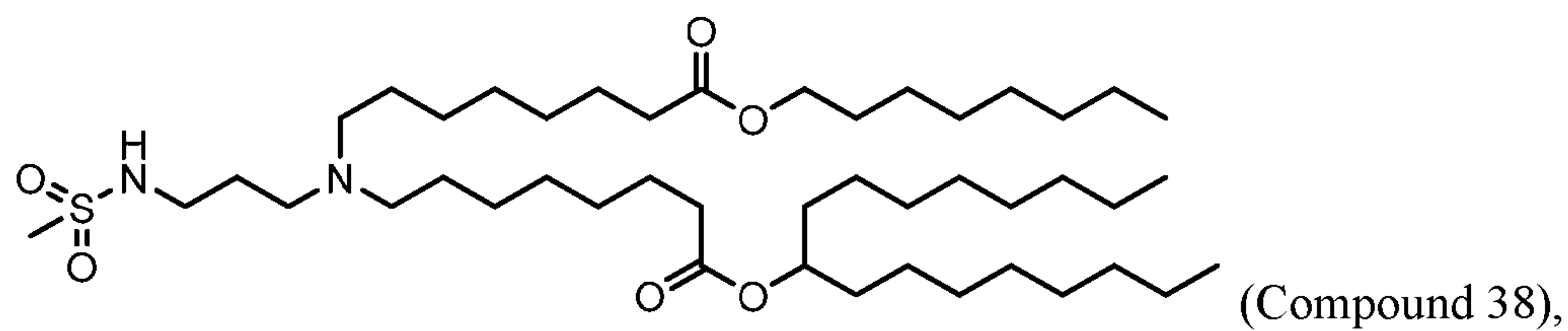
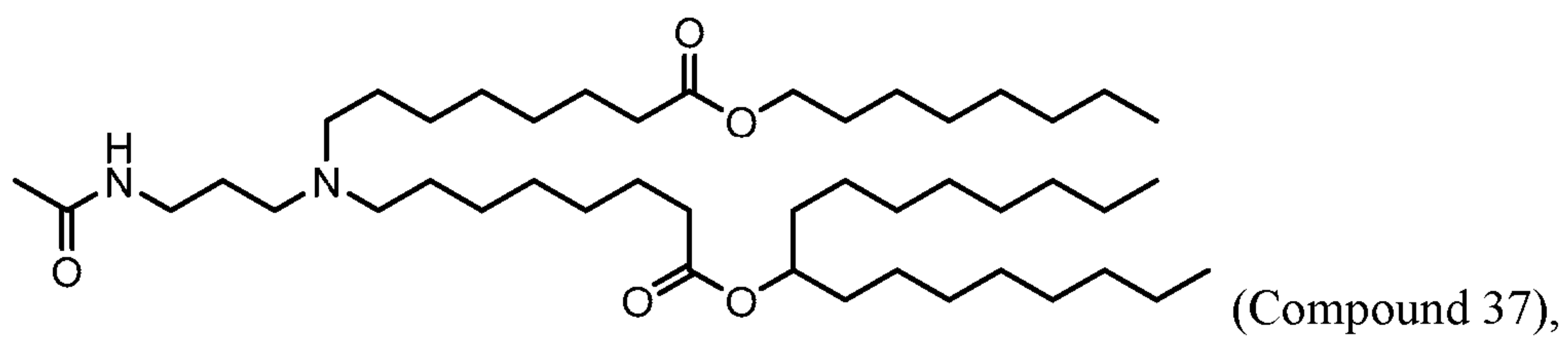
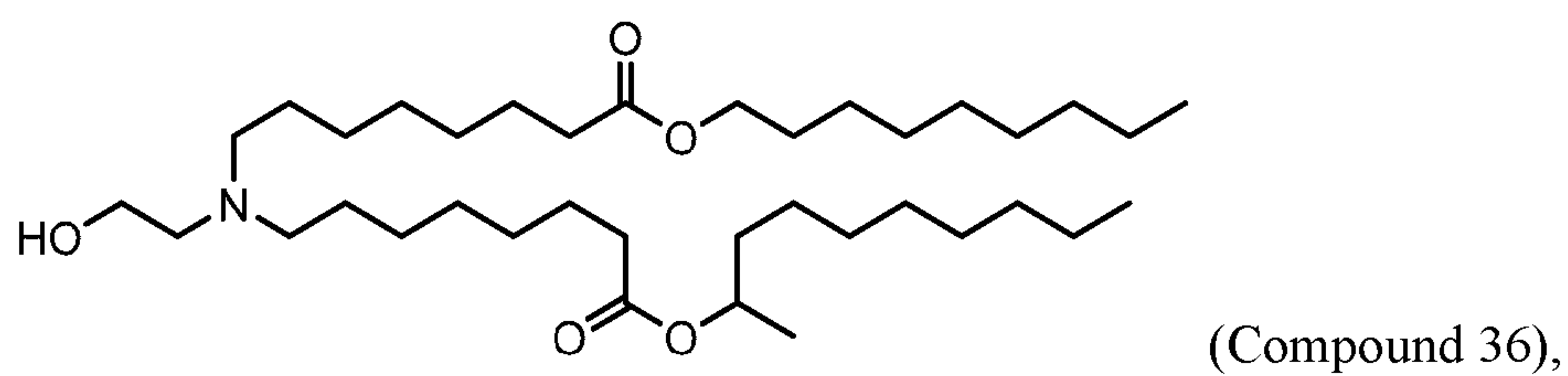
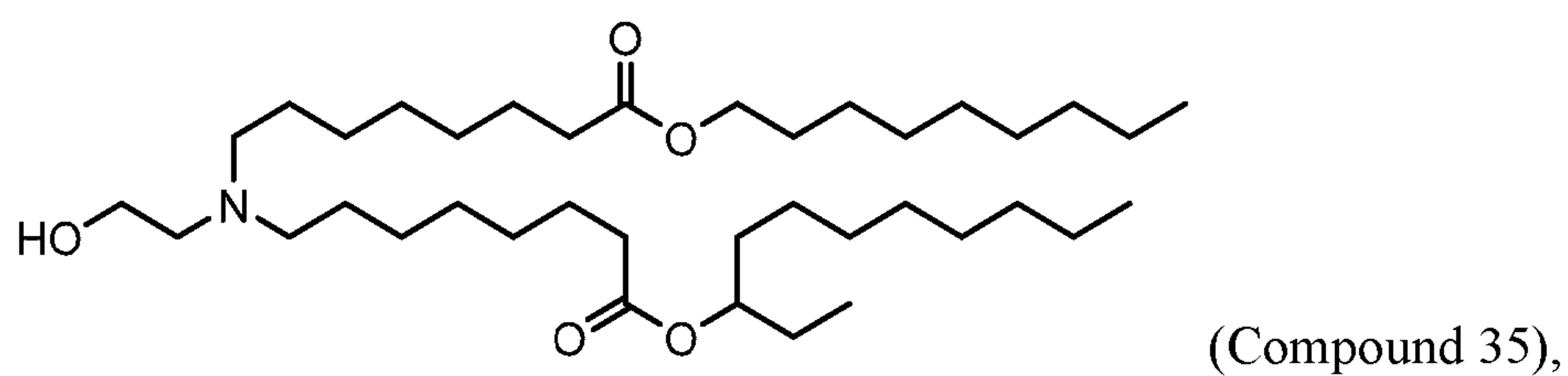
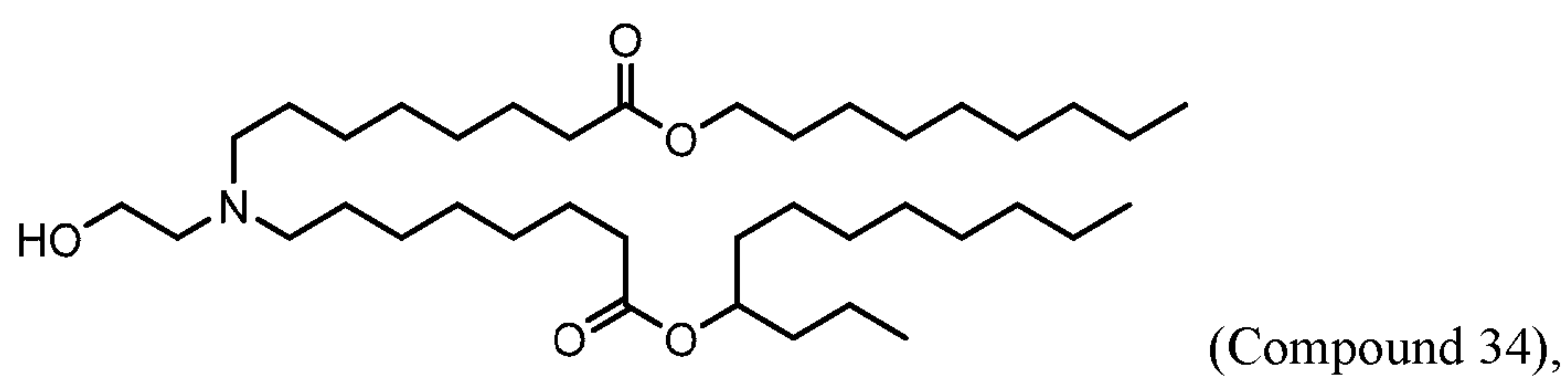
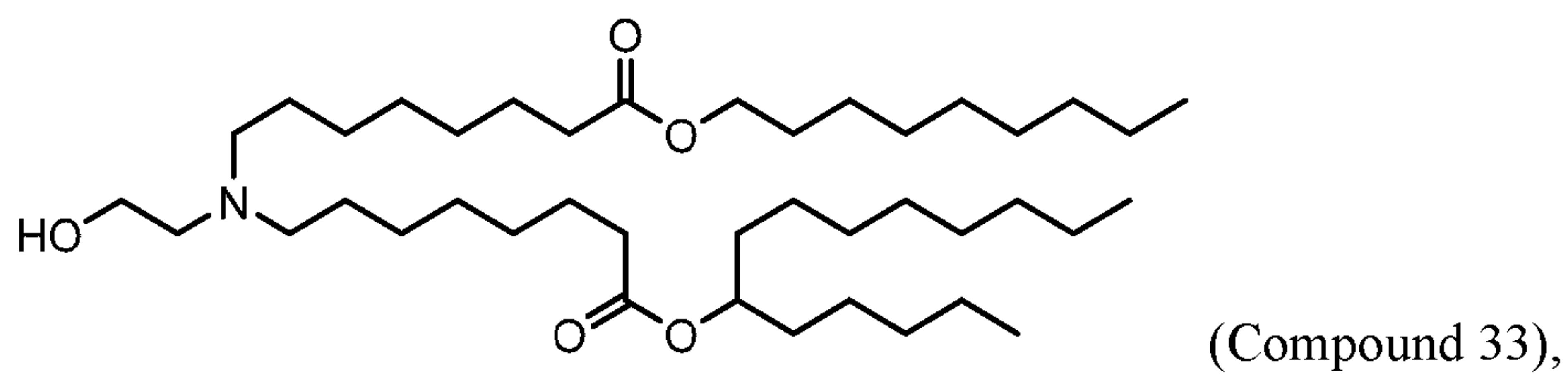
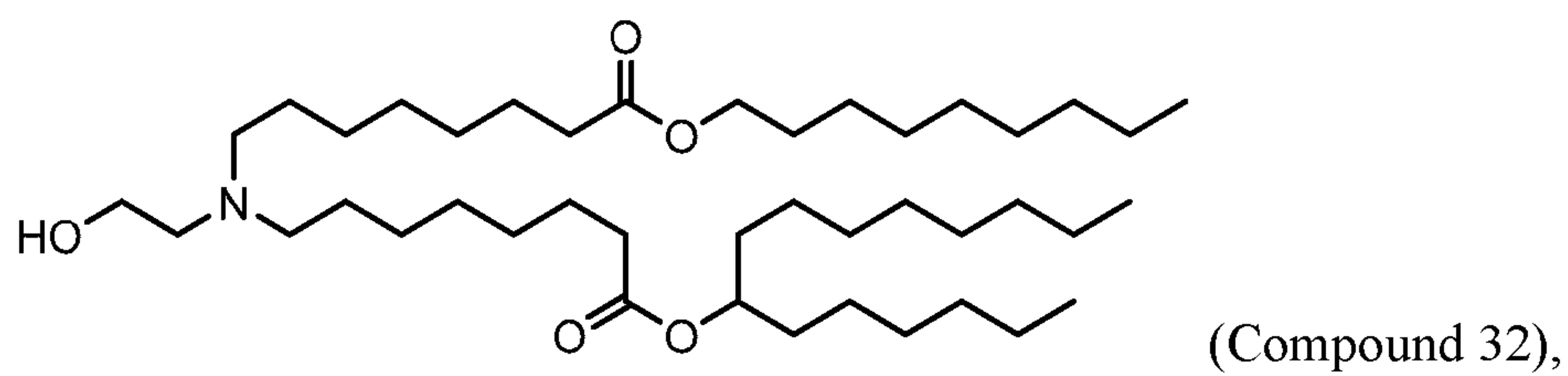


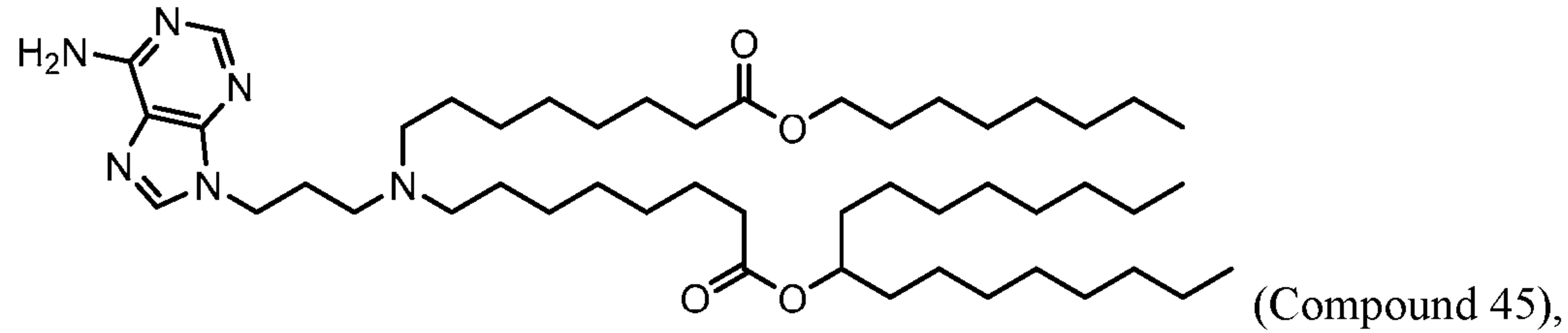
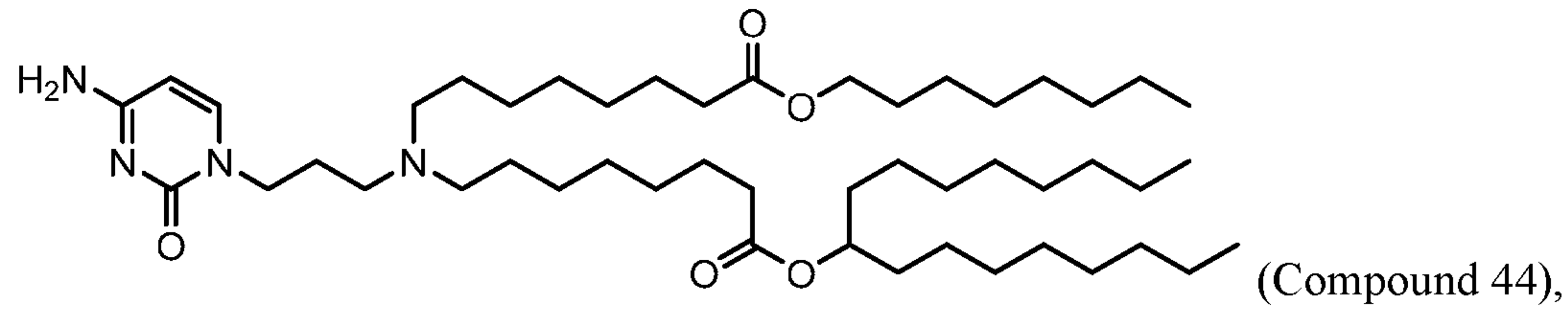
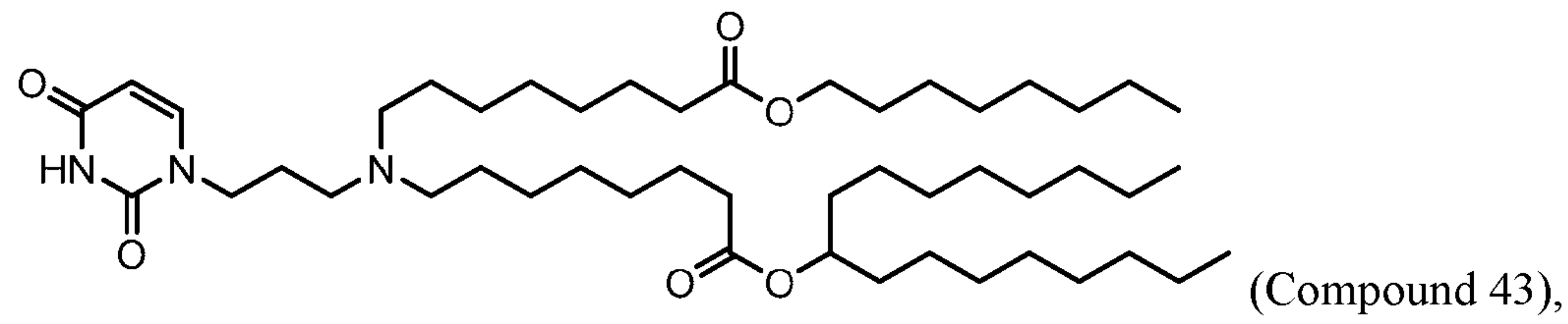
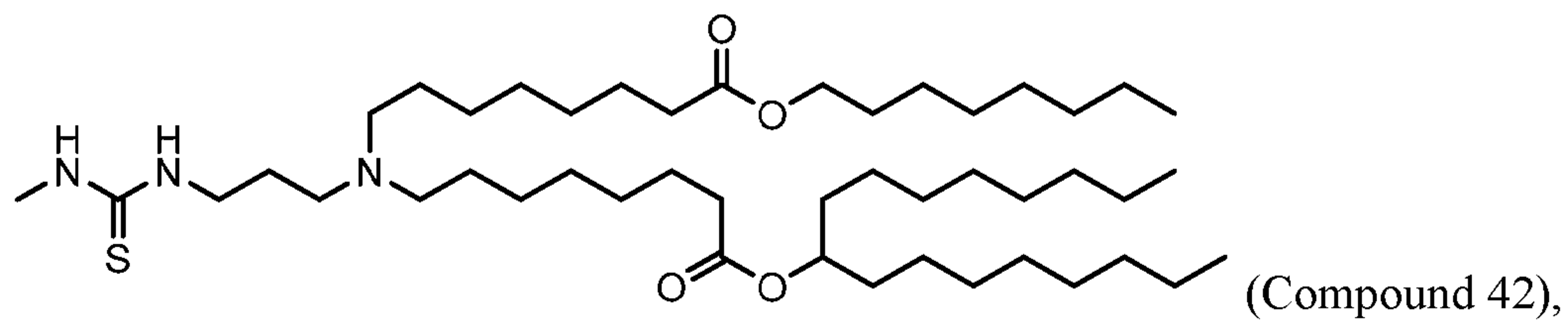
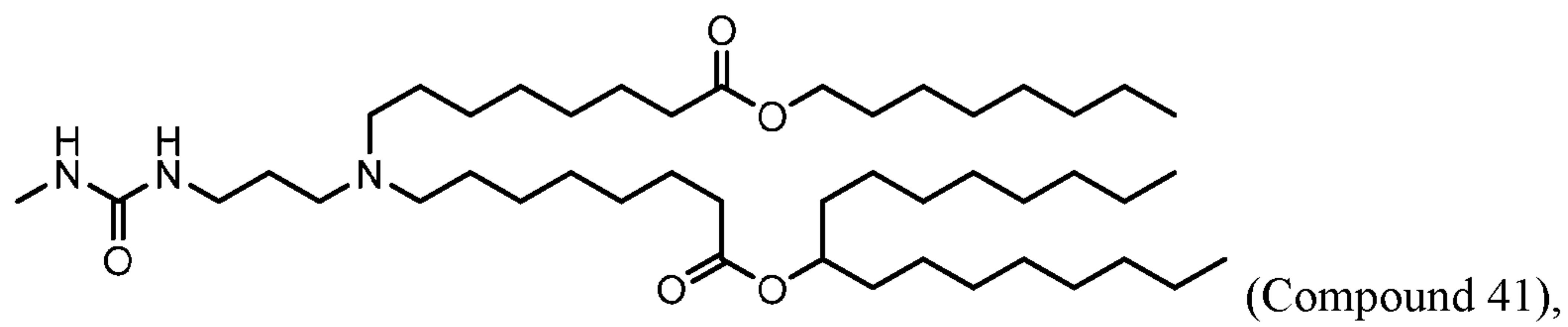
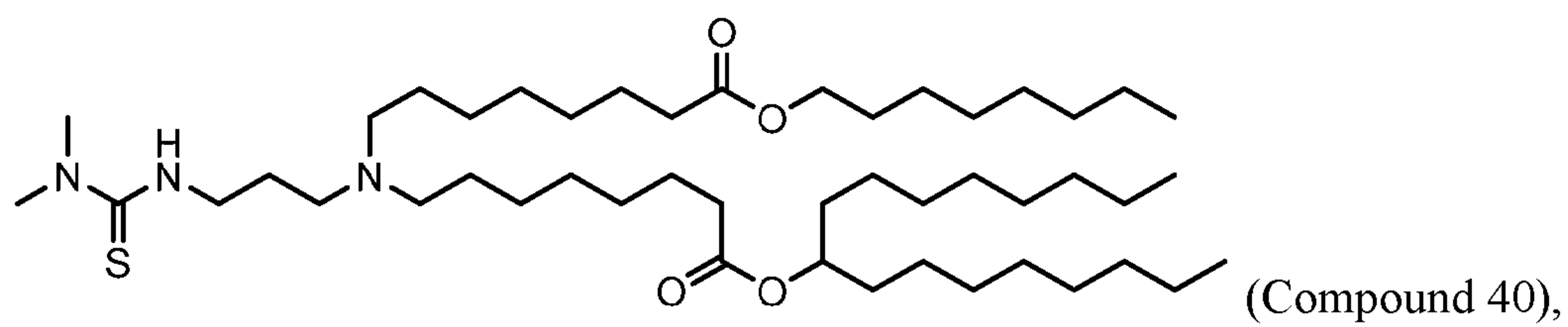
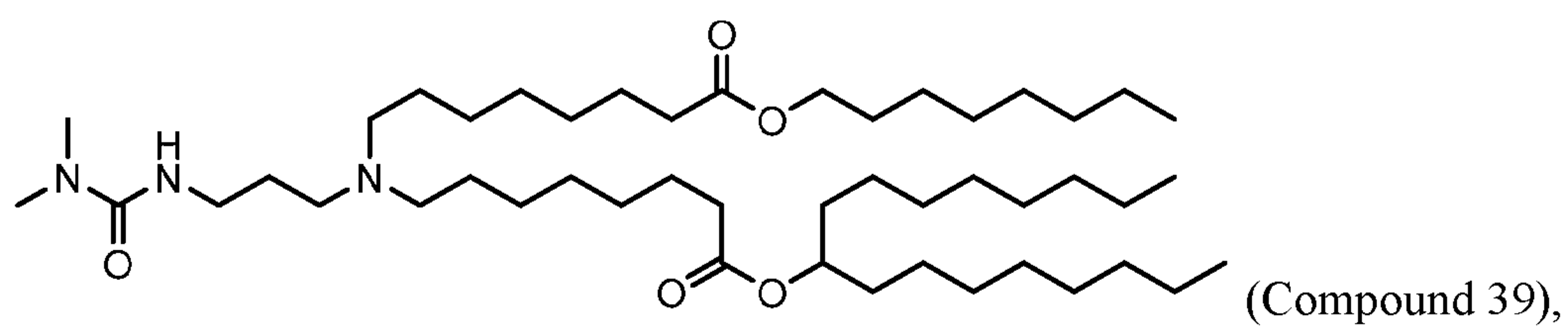


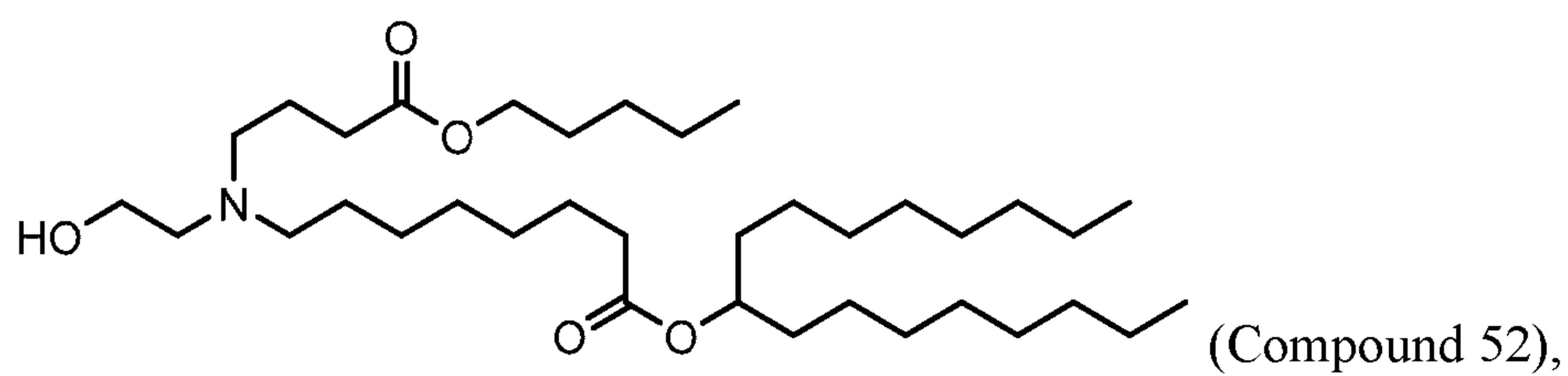


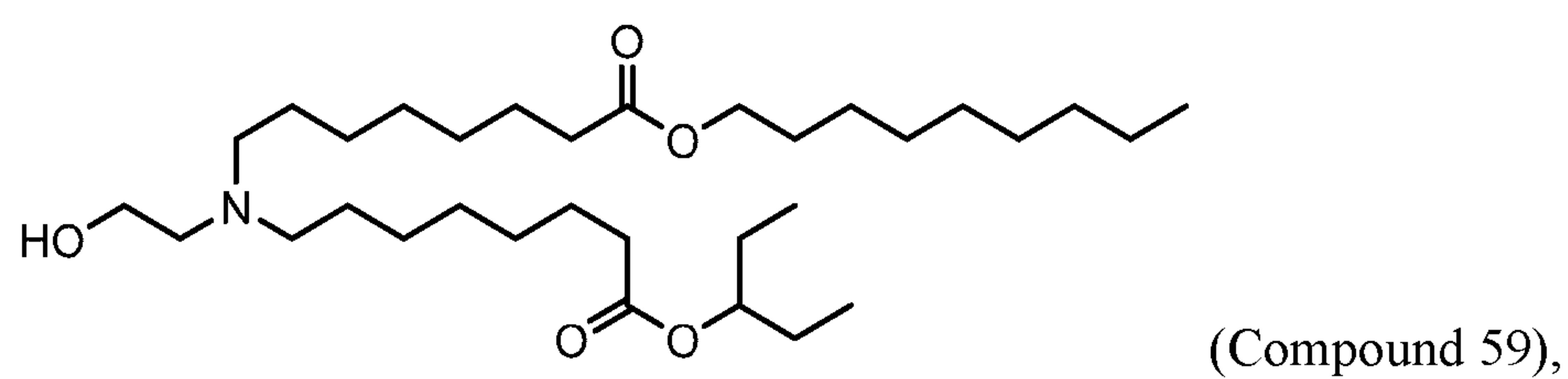
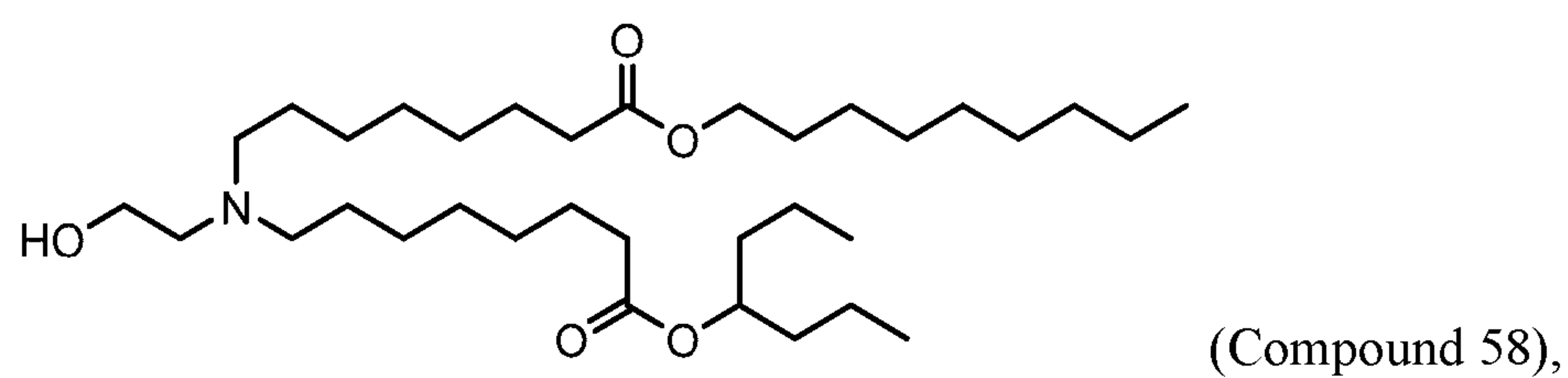
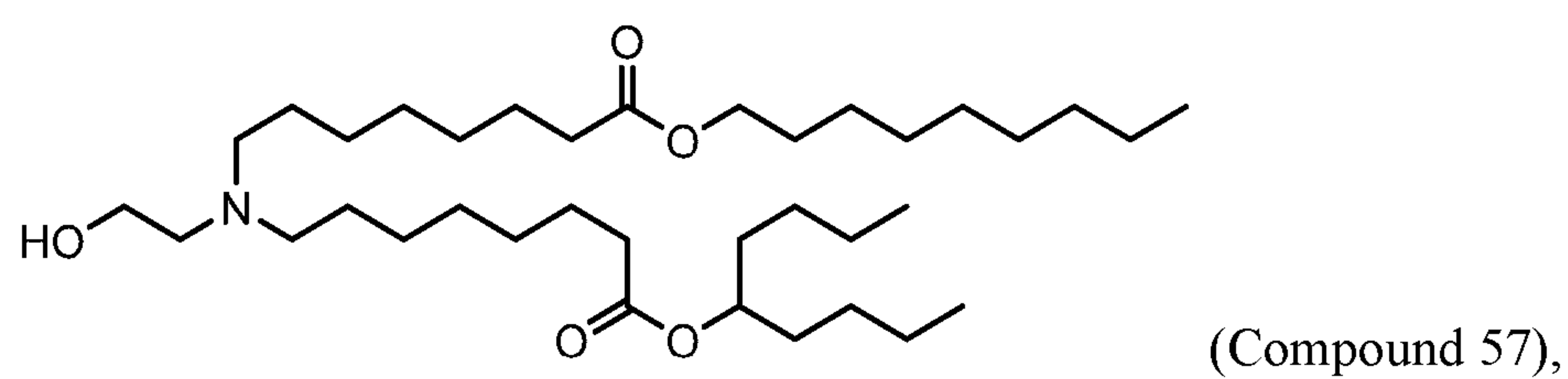
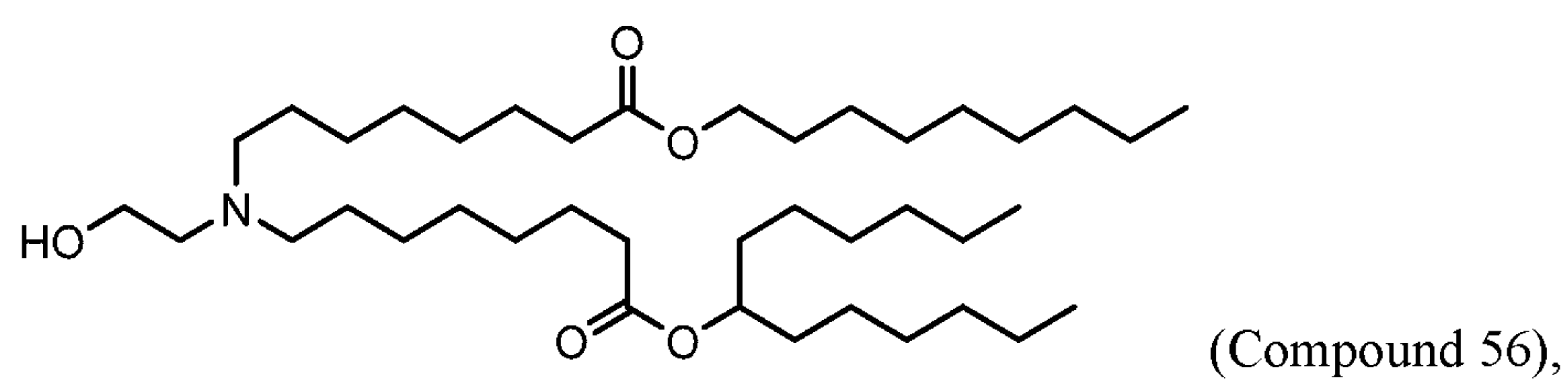
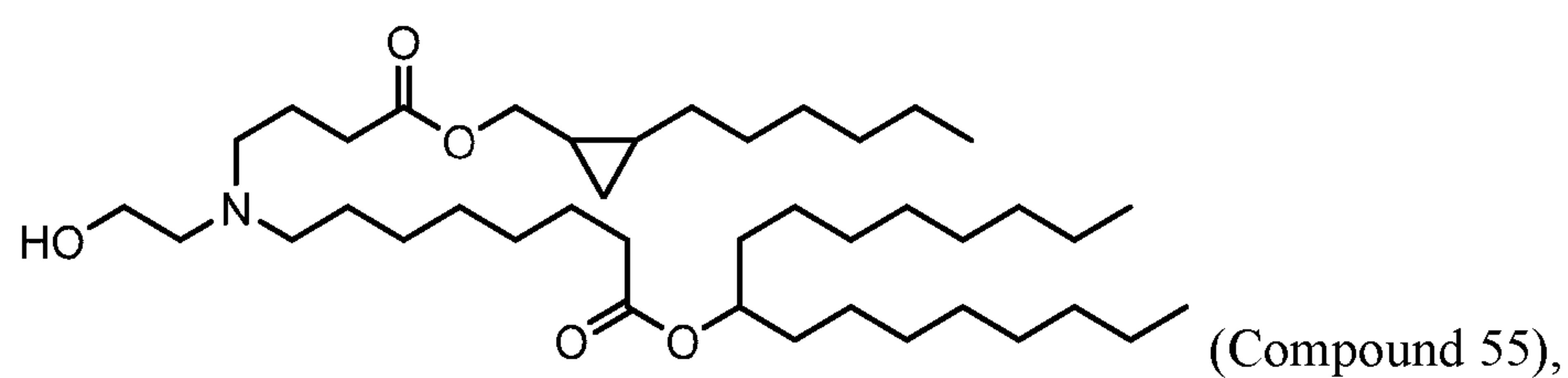
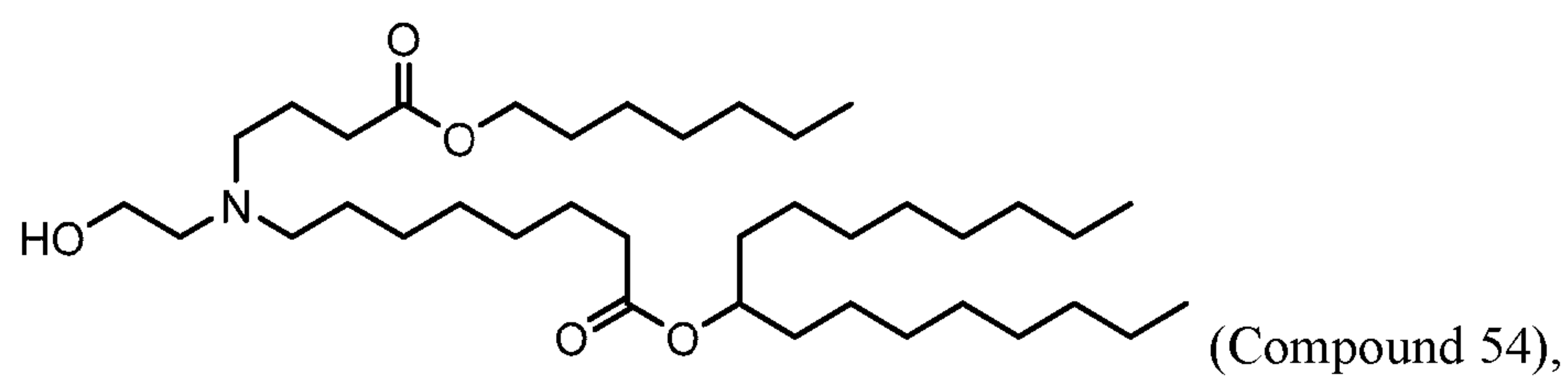
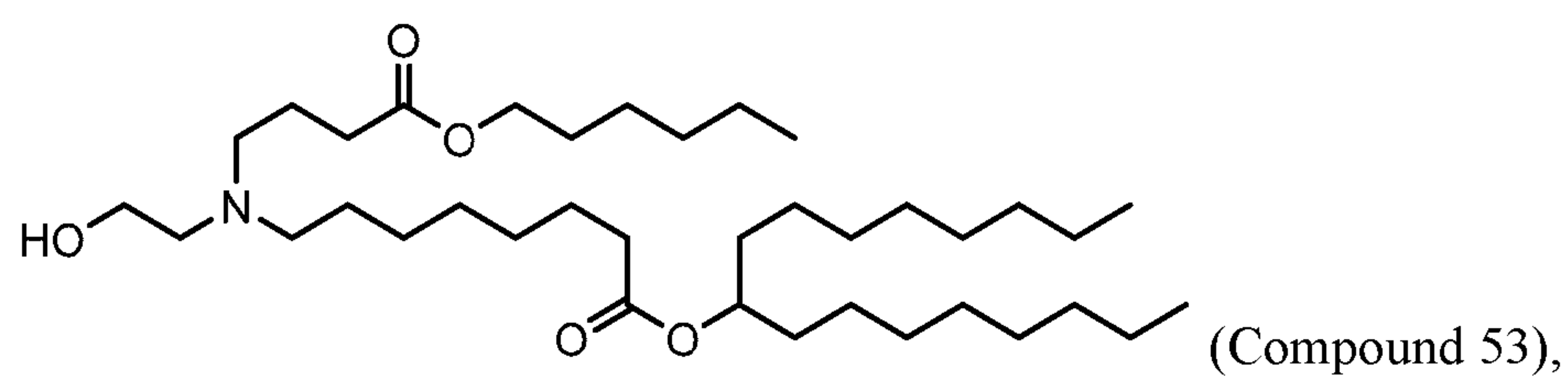


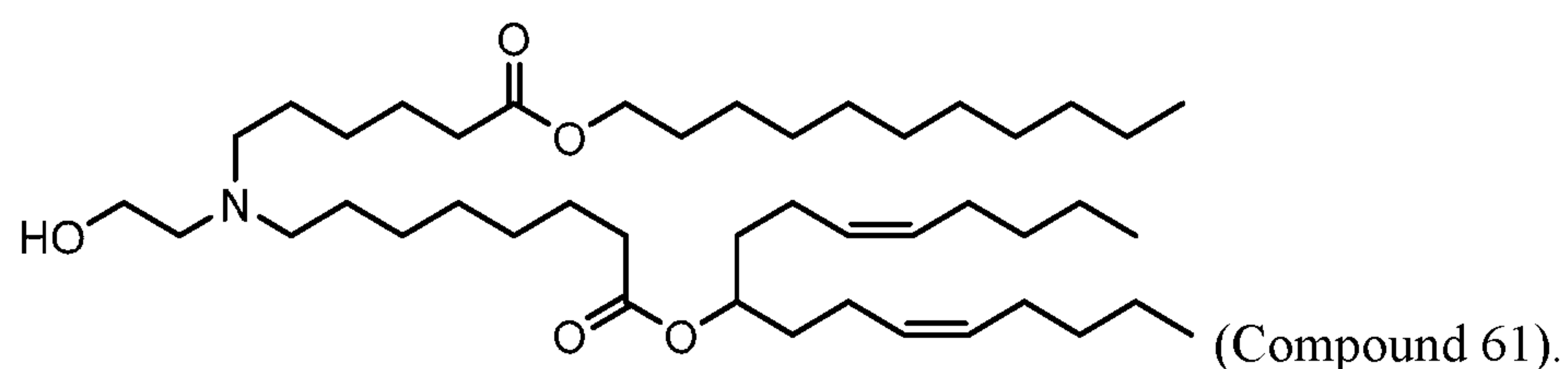
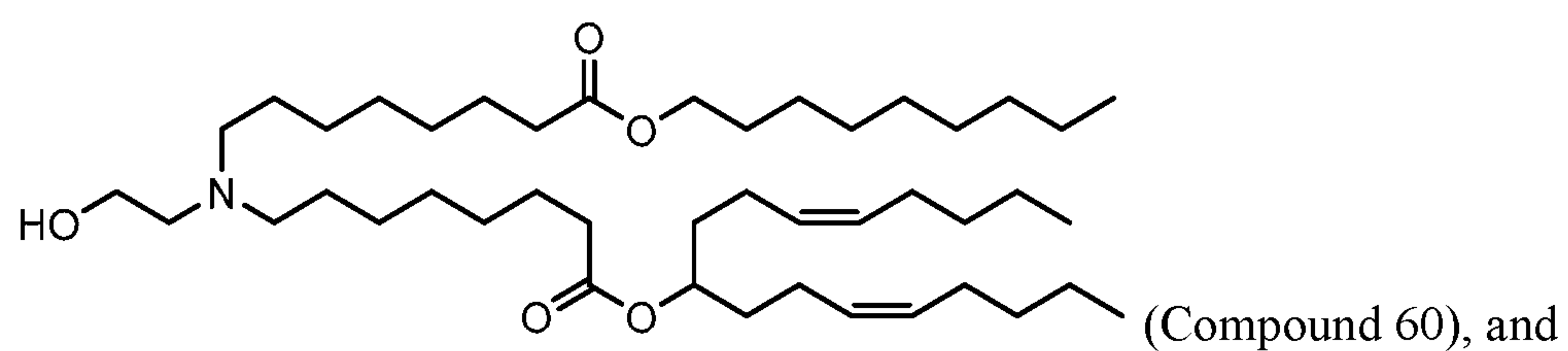




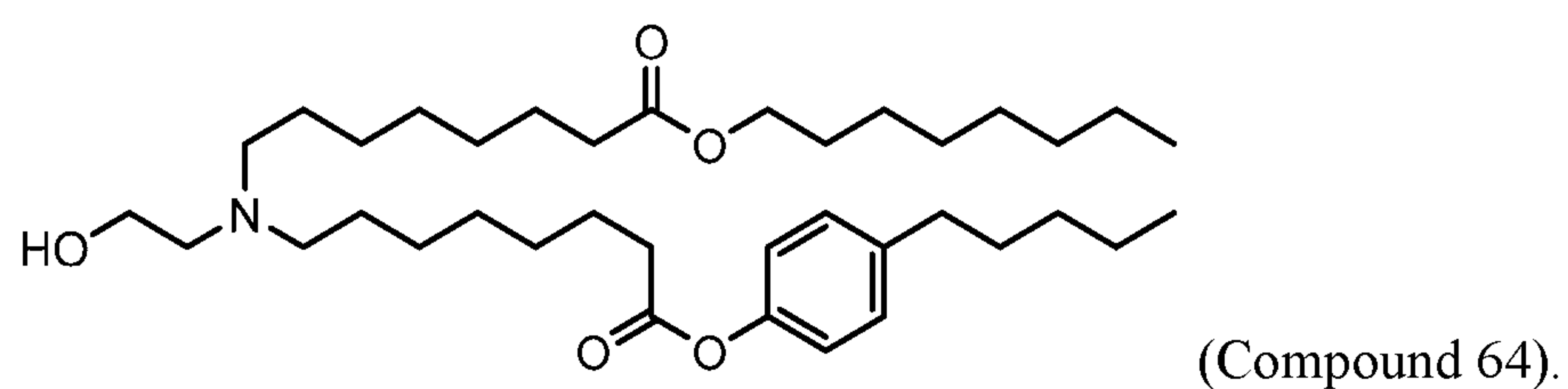
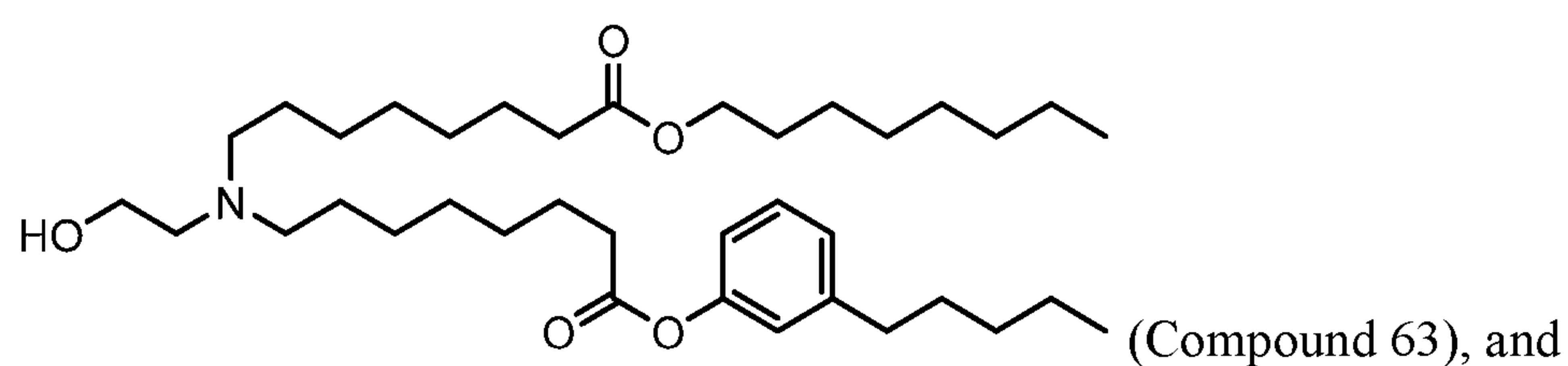
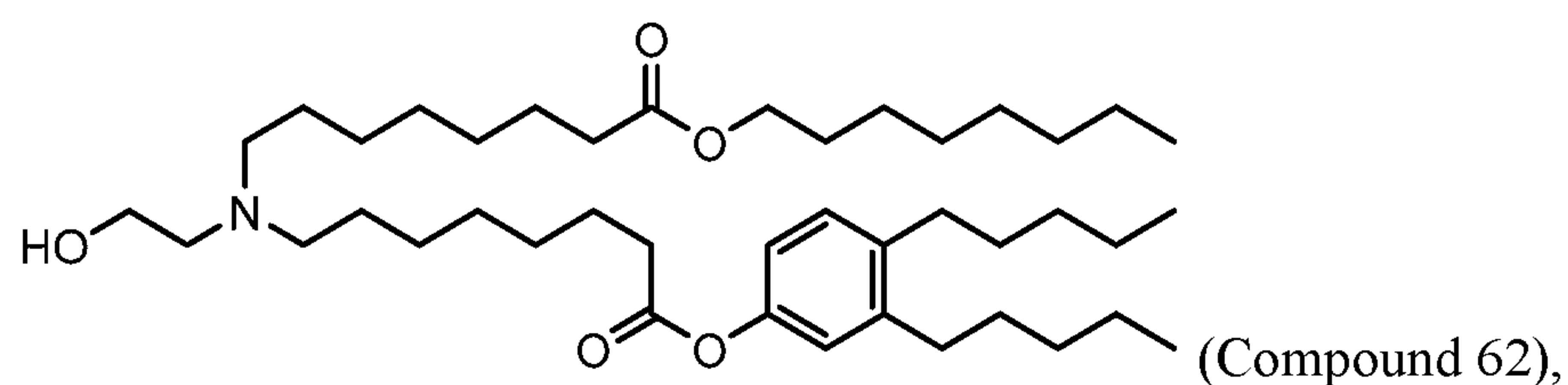




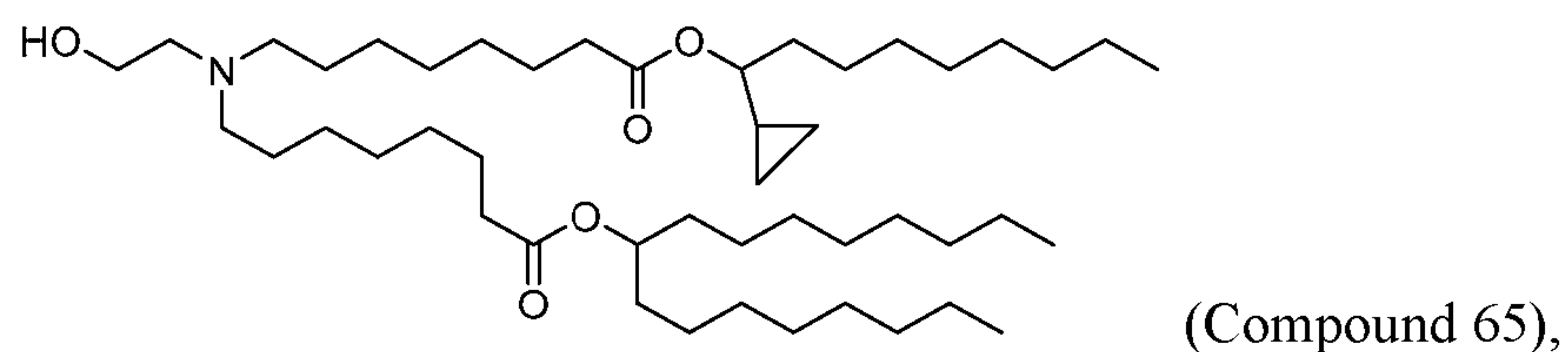


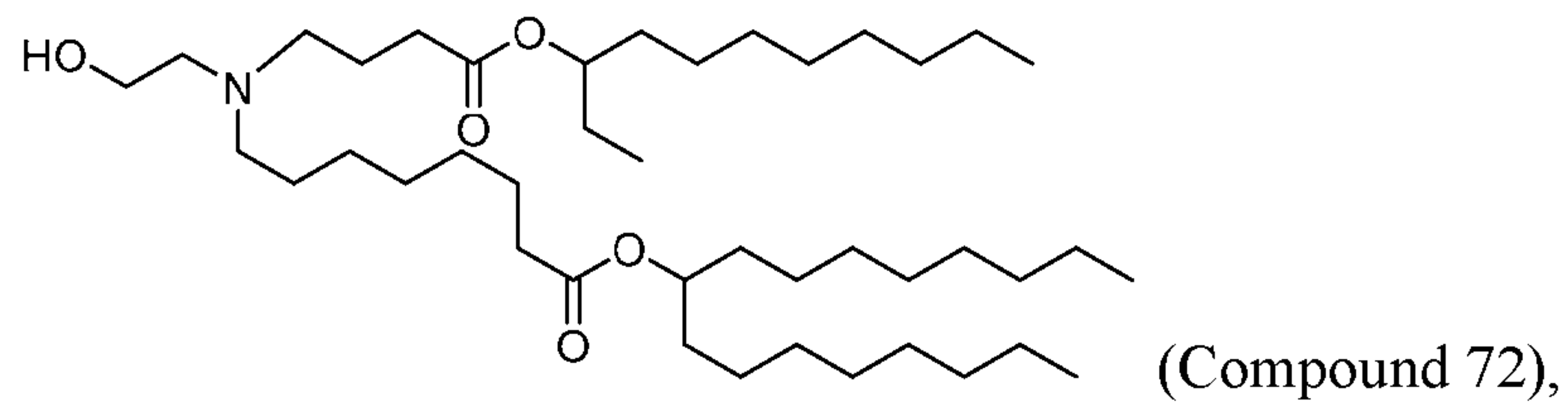


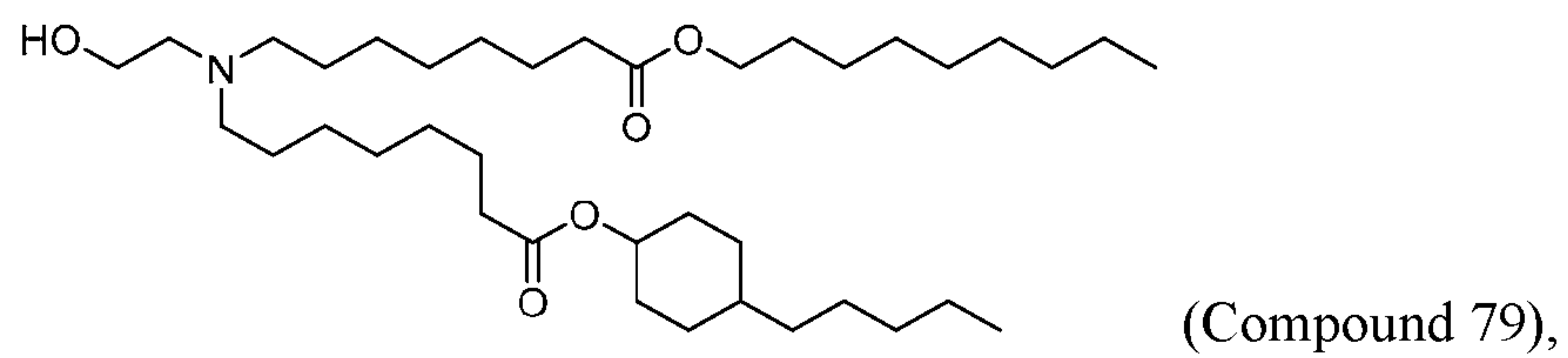
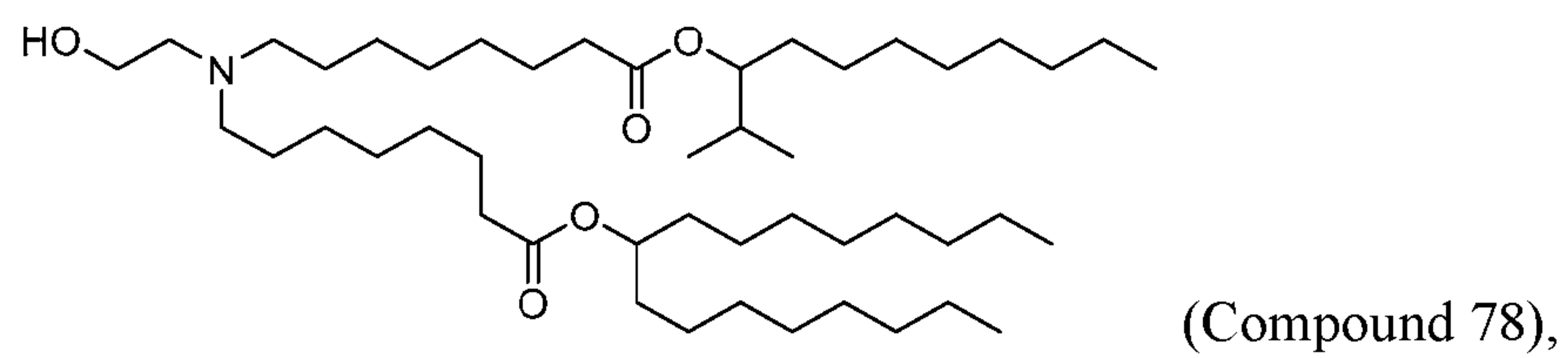
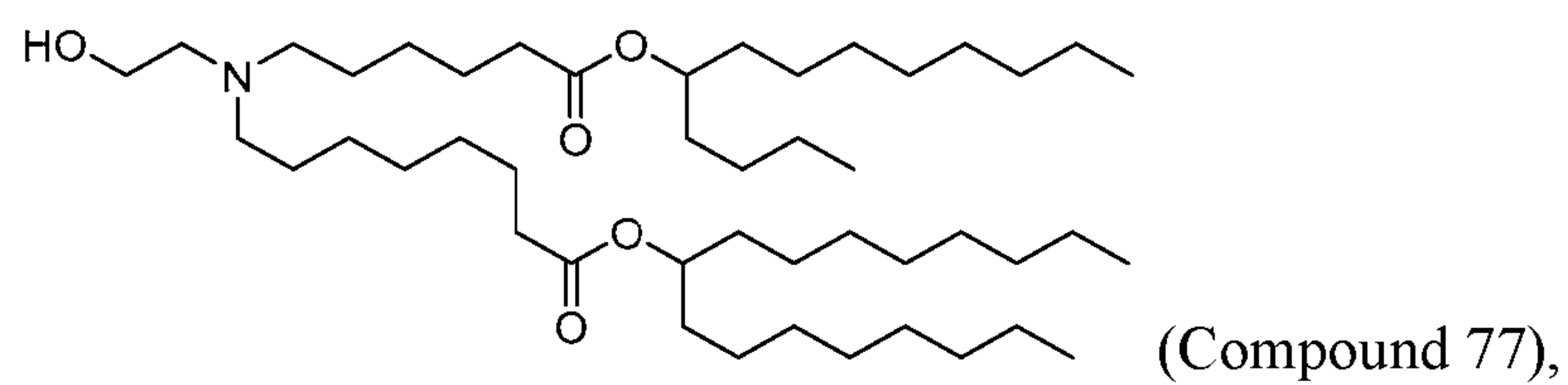
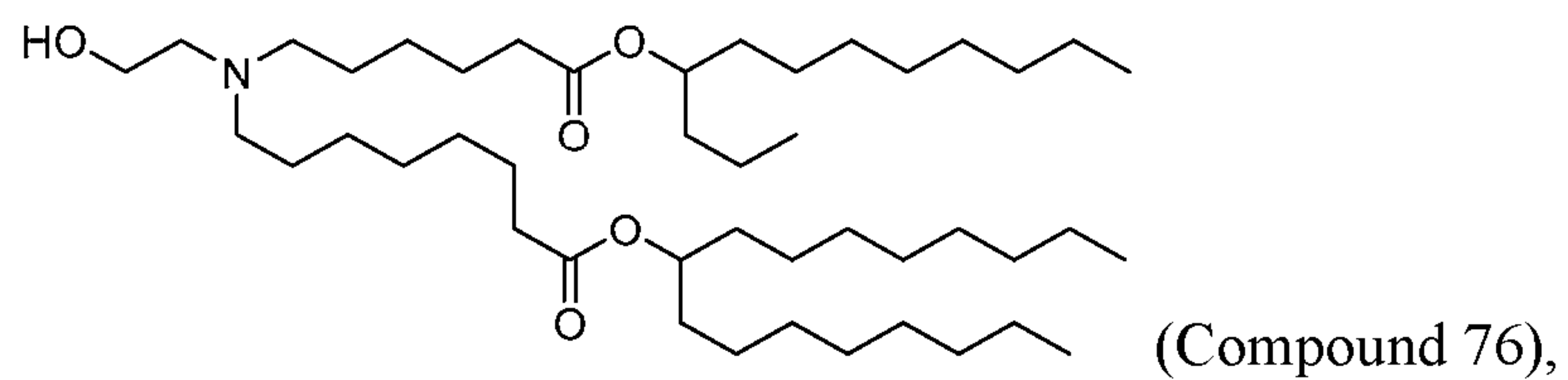
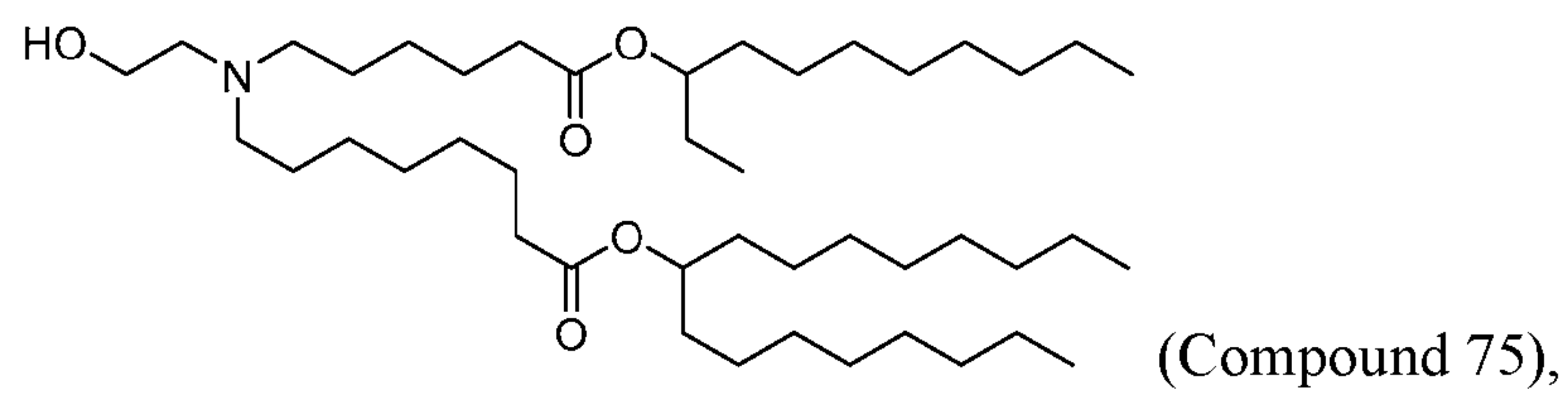
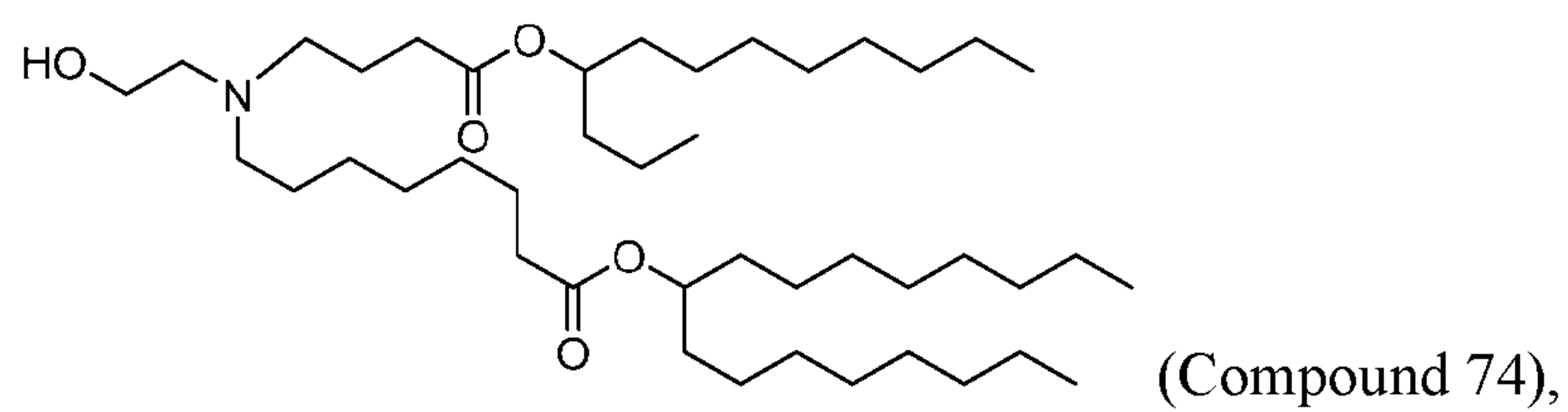
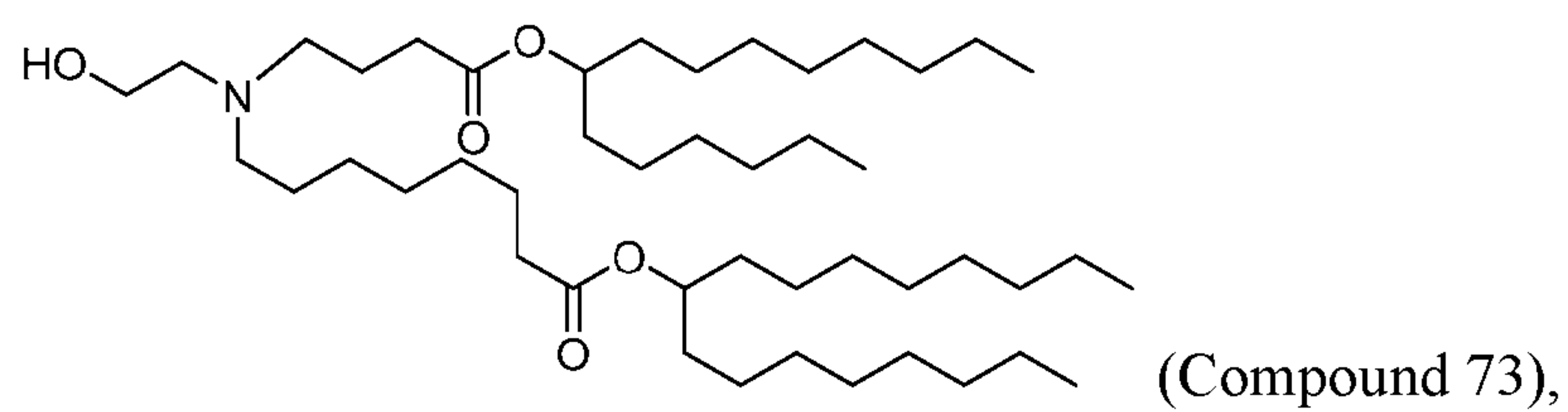
[00197] In further embodiments, the compound of Formula (I) is selected from the group consisting of:

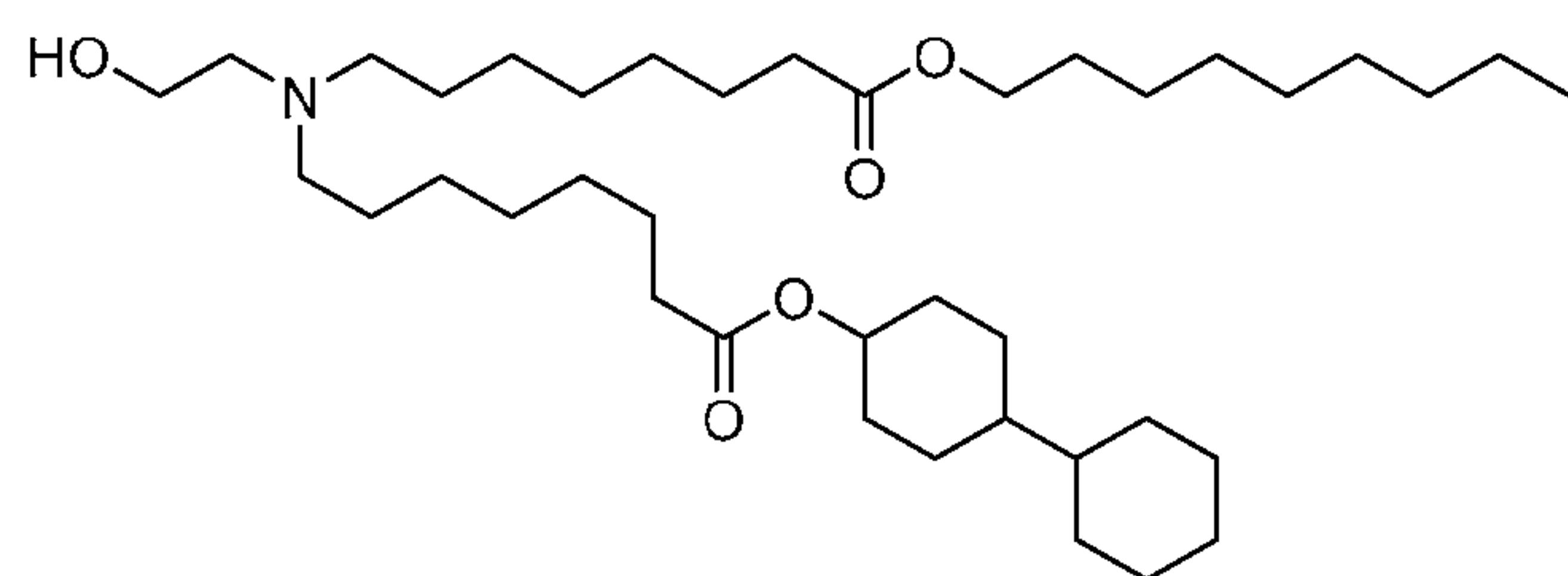


[00198] In some embodiments, the compound of Formula (I) is selected from the group consisting of:

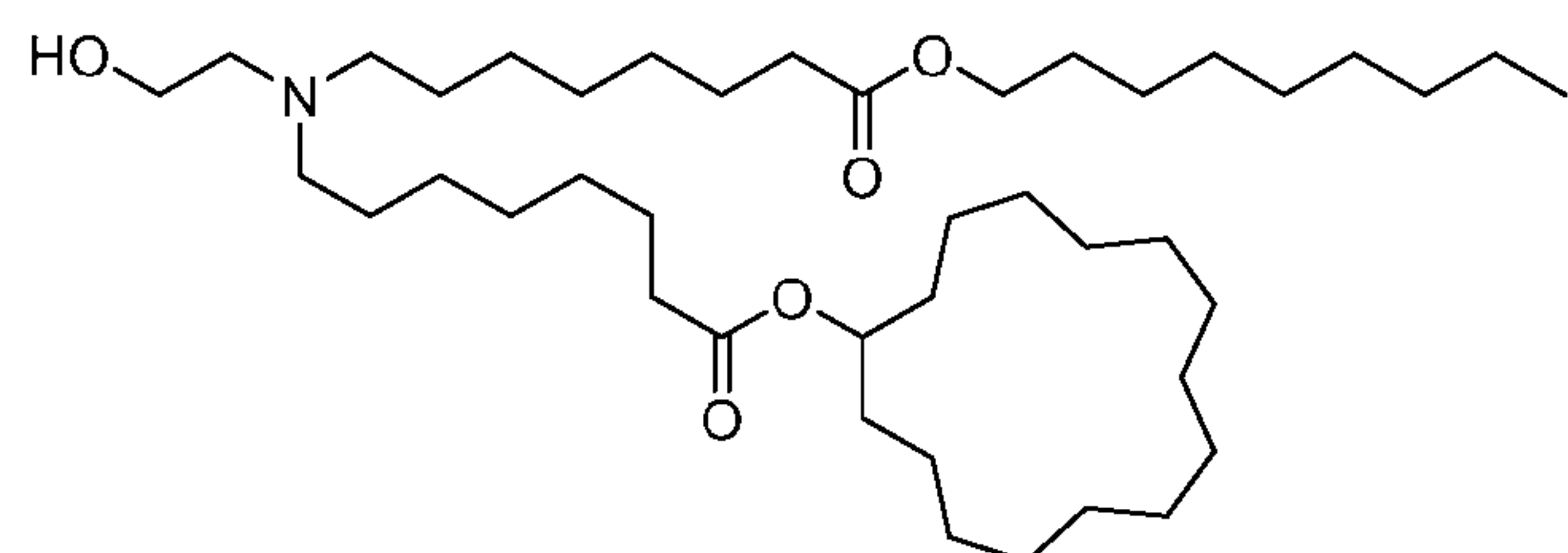




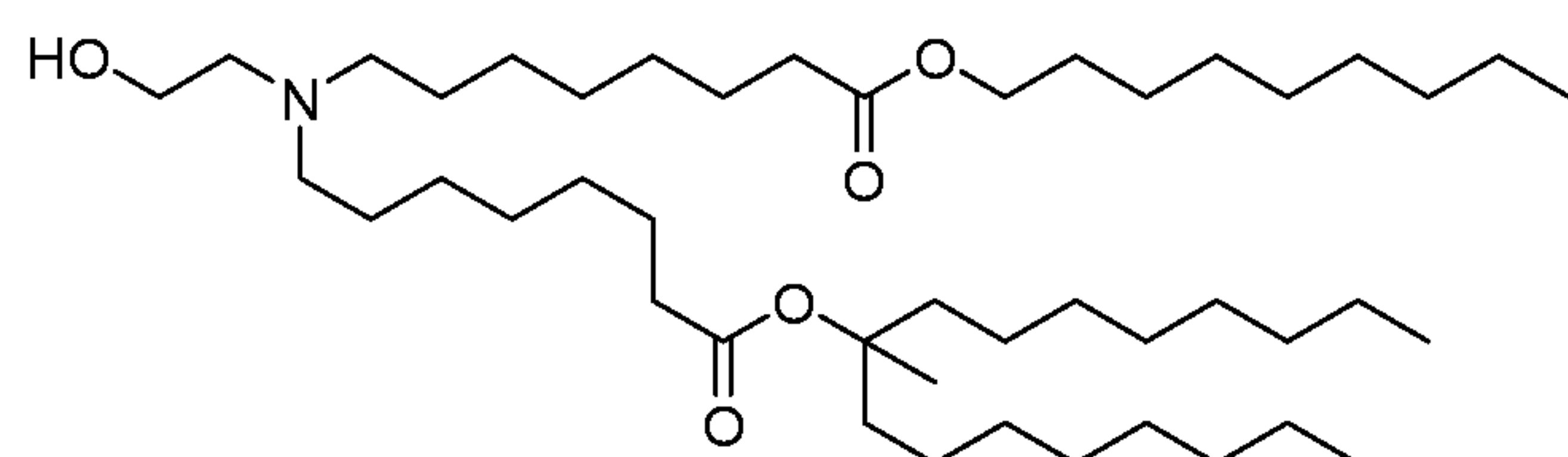




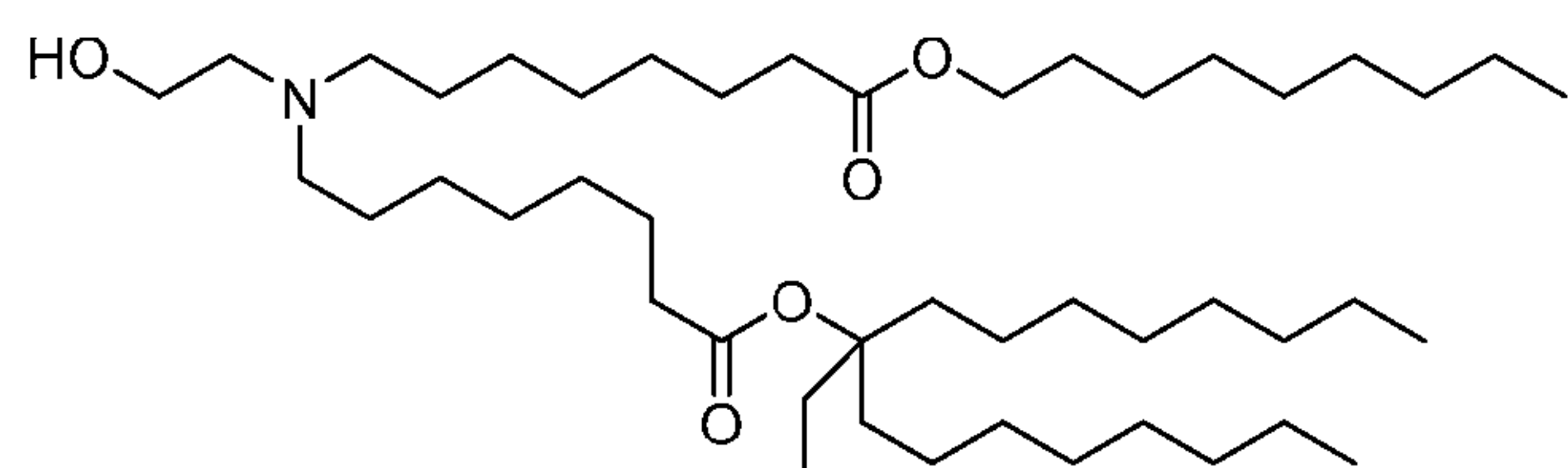
(Compound 80),



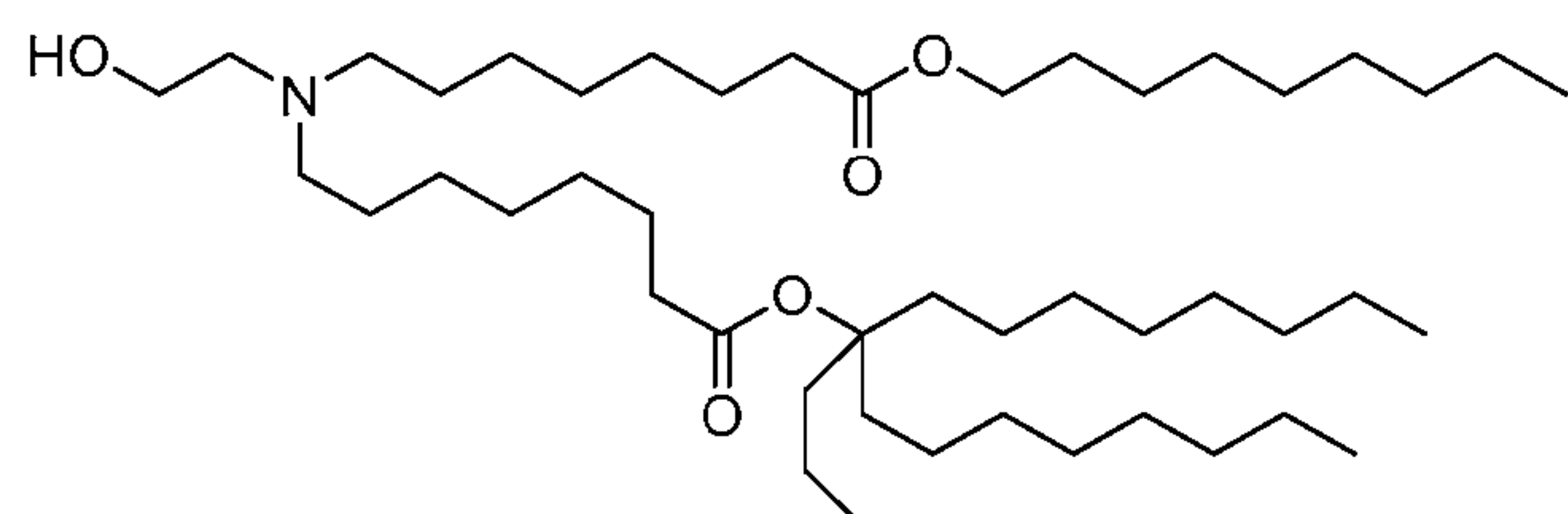
(Compound 81),



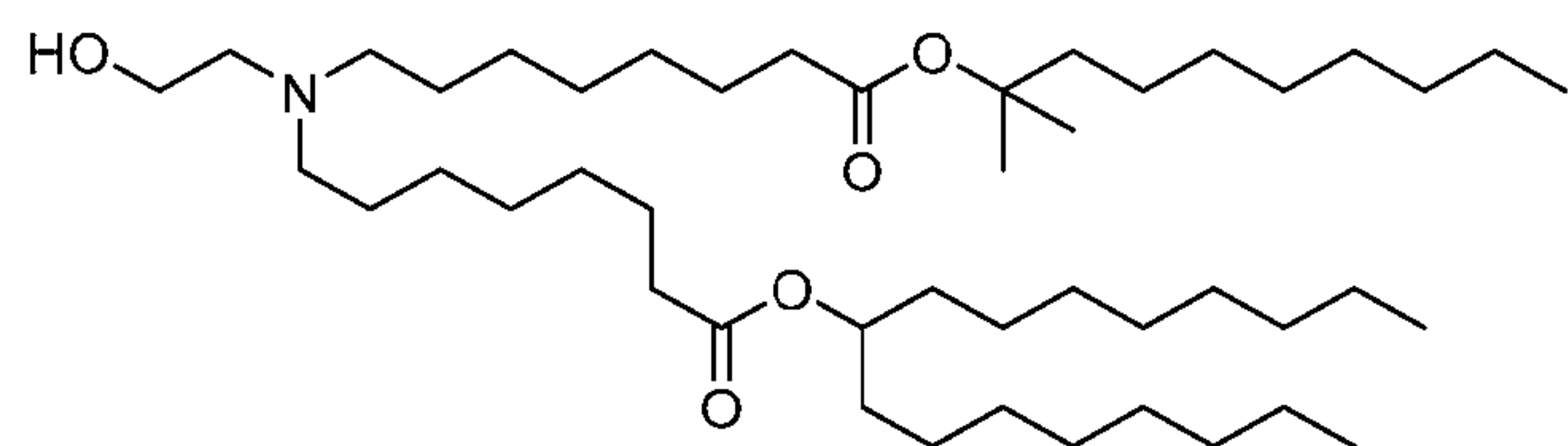
(Compound 82),



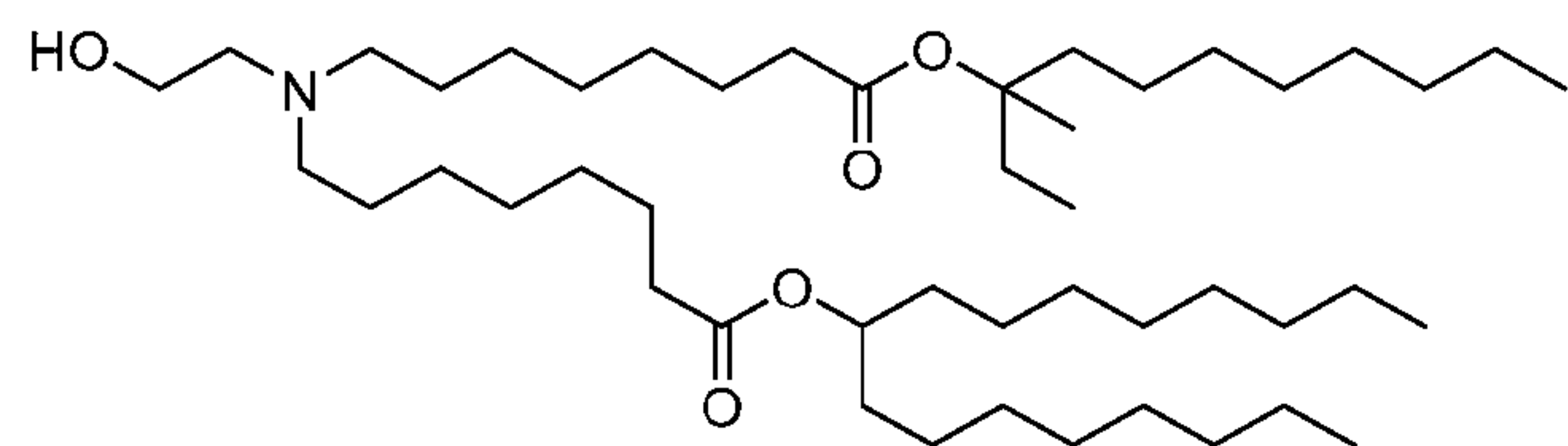
(Compound 83),



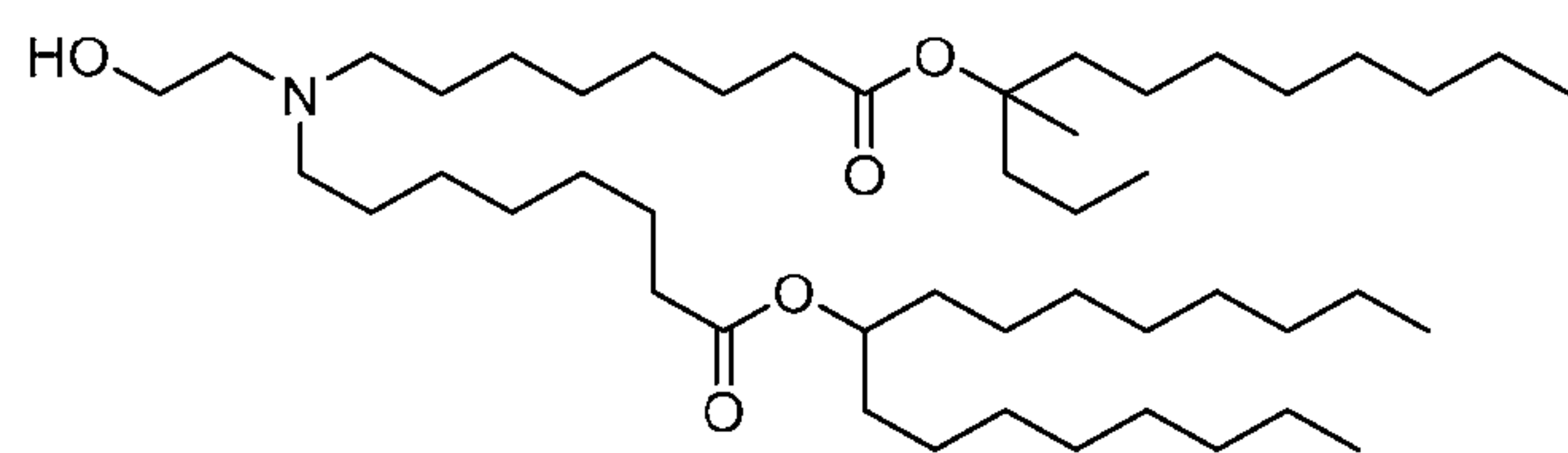
(Compound 84),



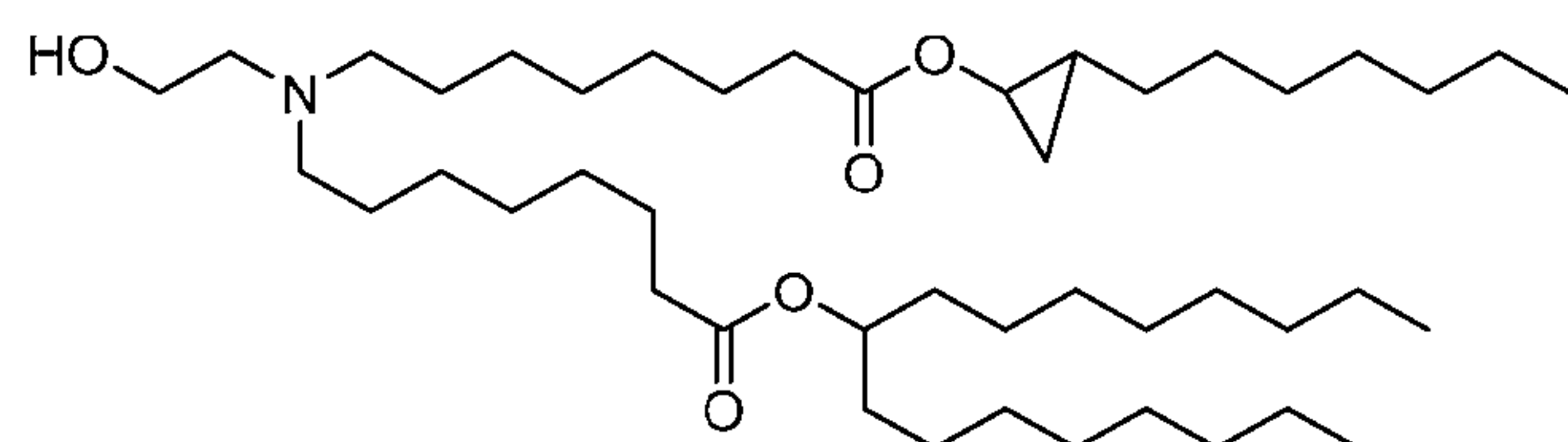
(Compound 85),



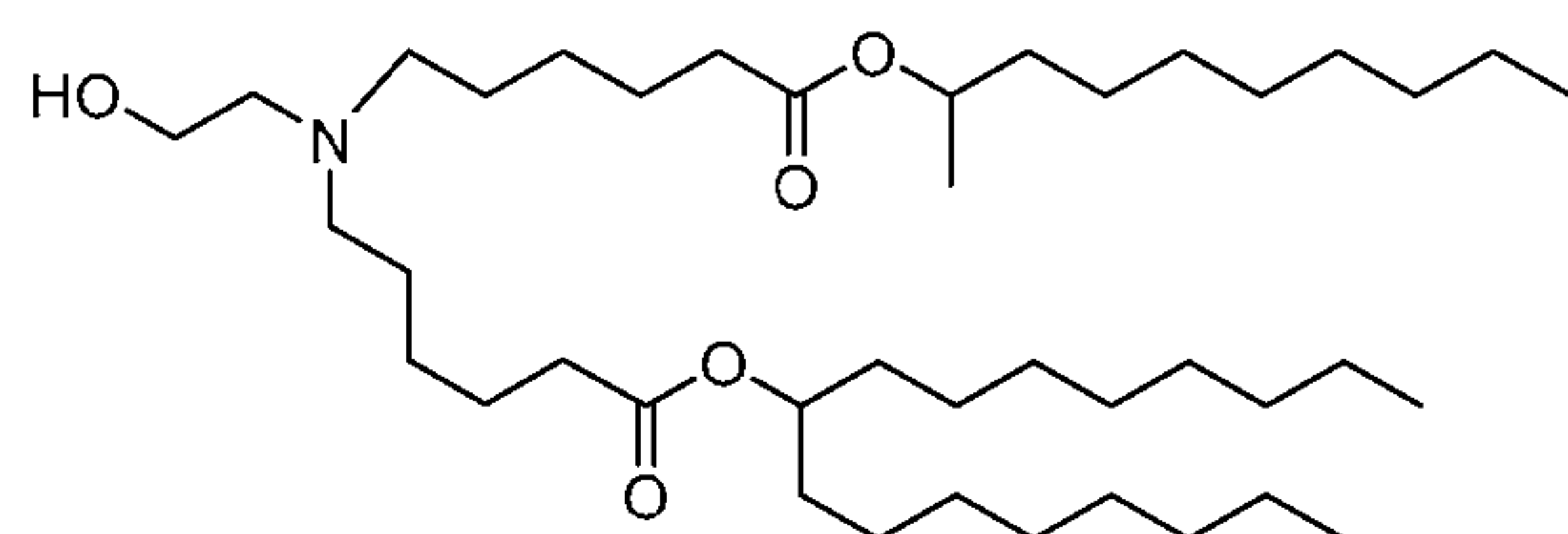
(Compound 86),



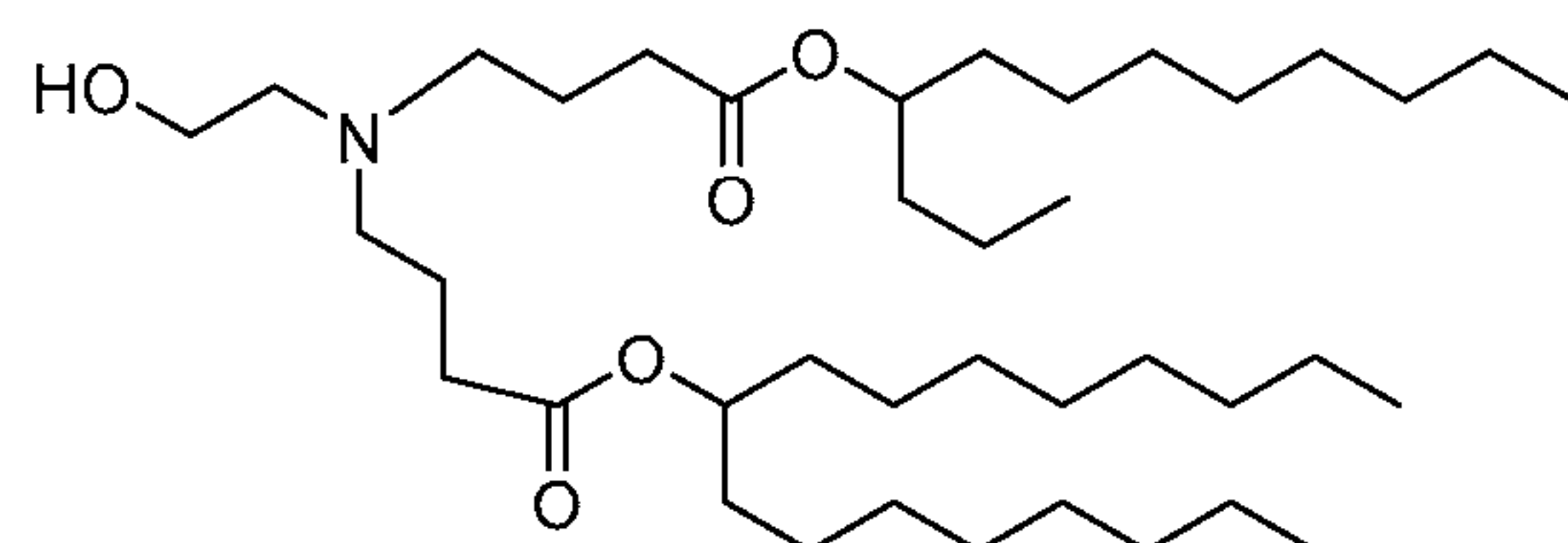
(Compound 87),



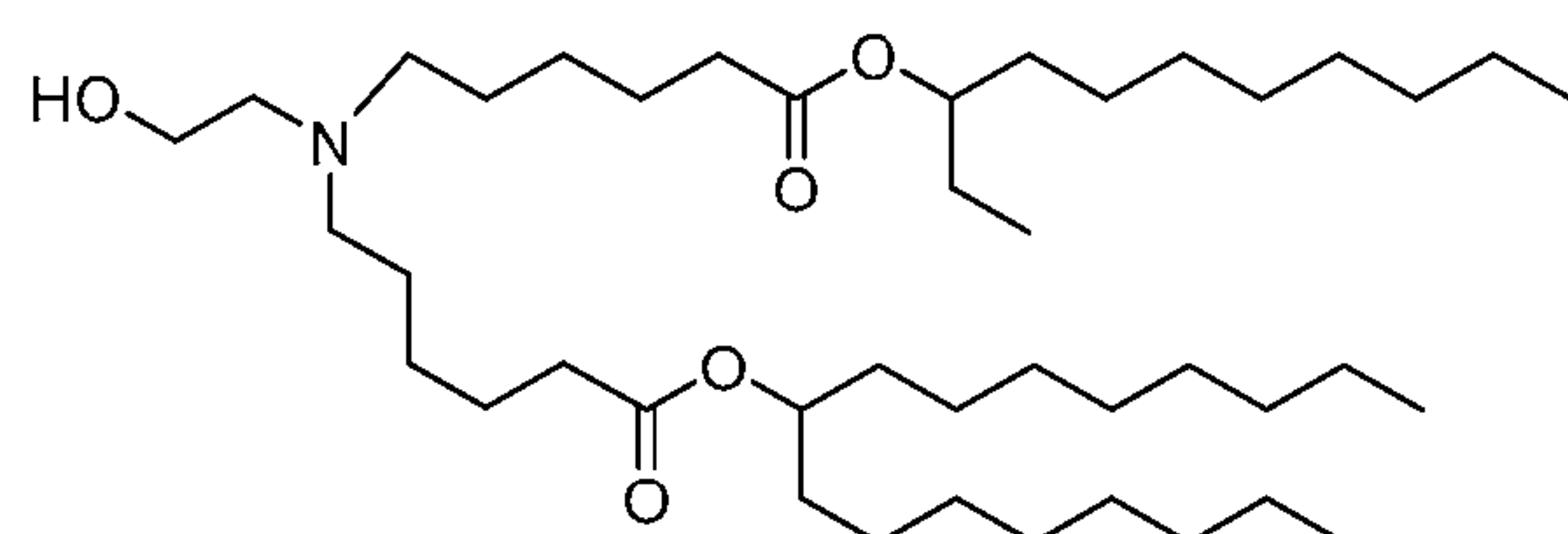
(Compound 88),



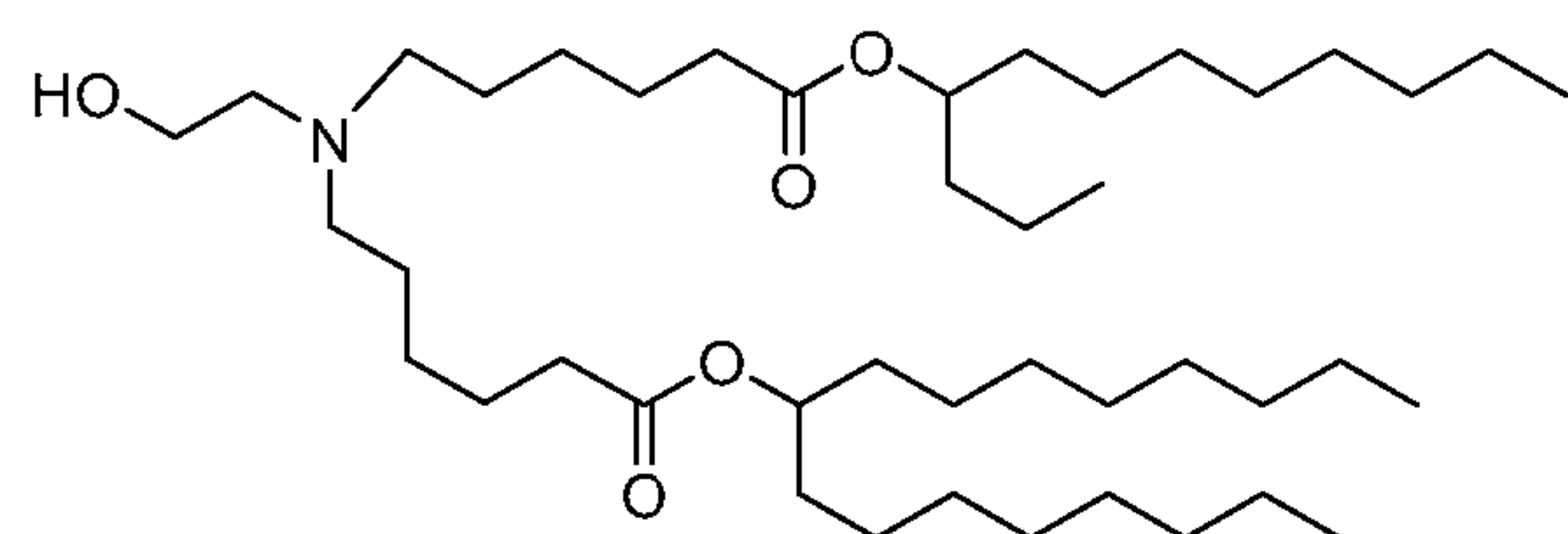
(Compound 89),



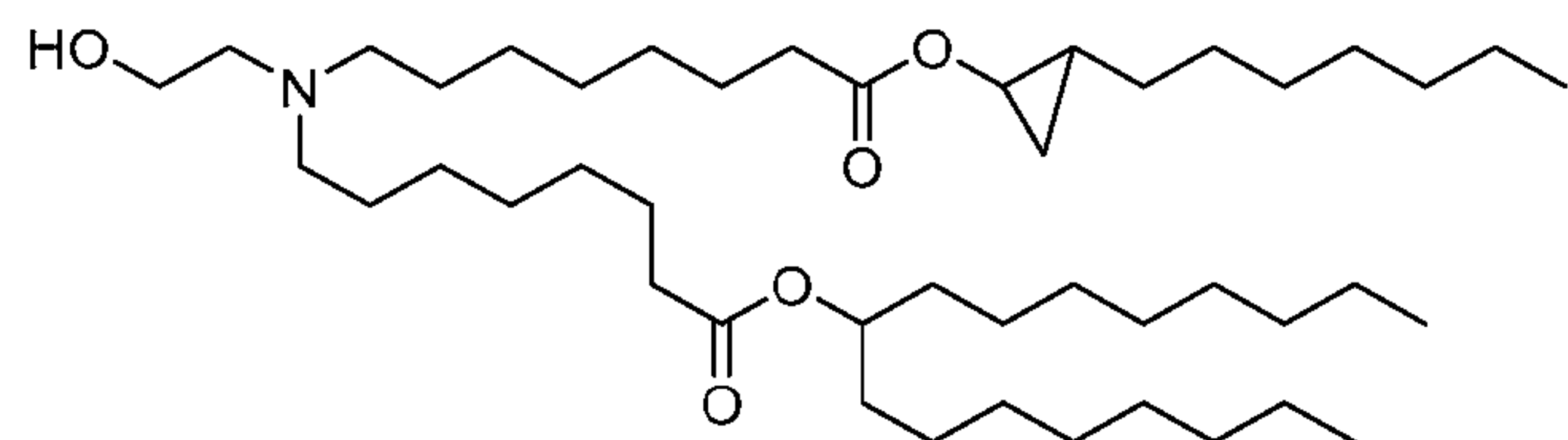
(Compound 90),



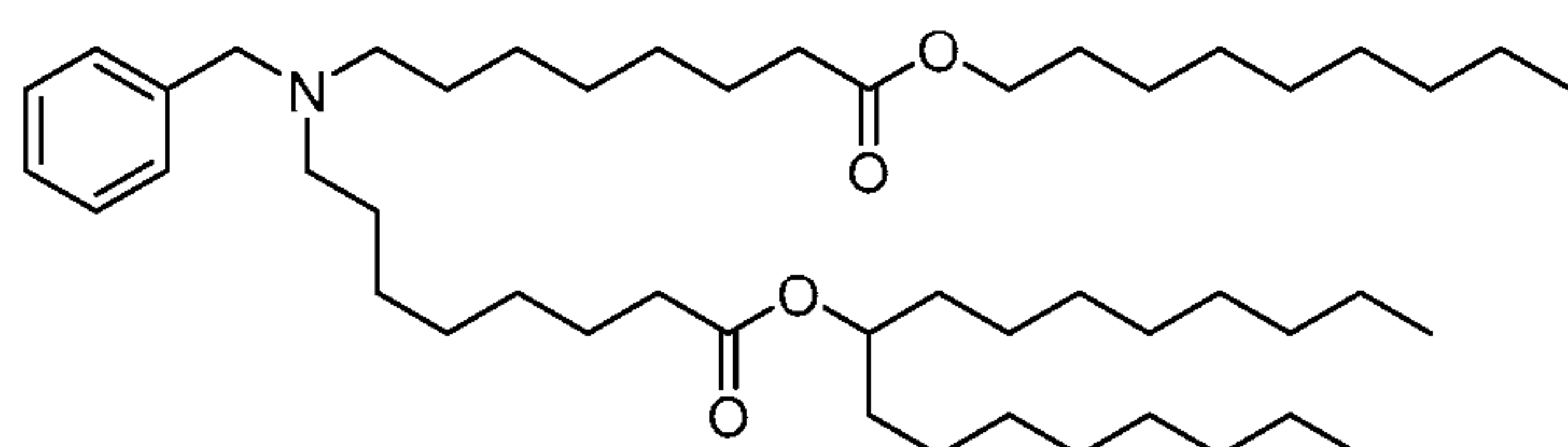
(Compound 91),



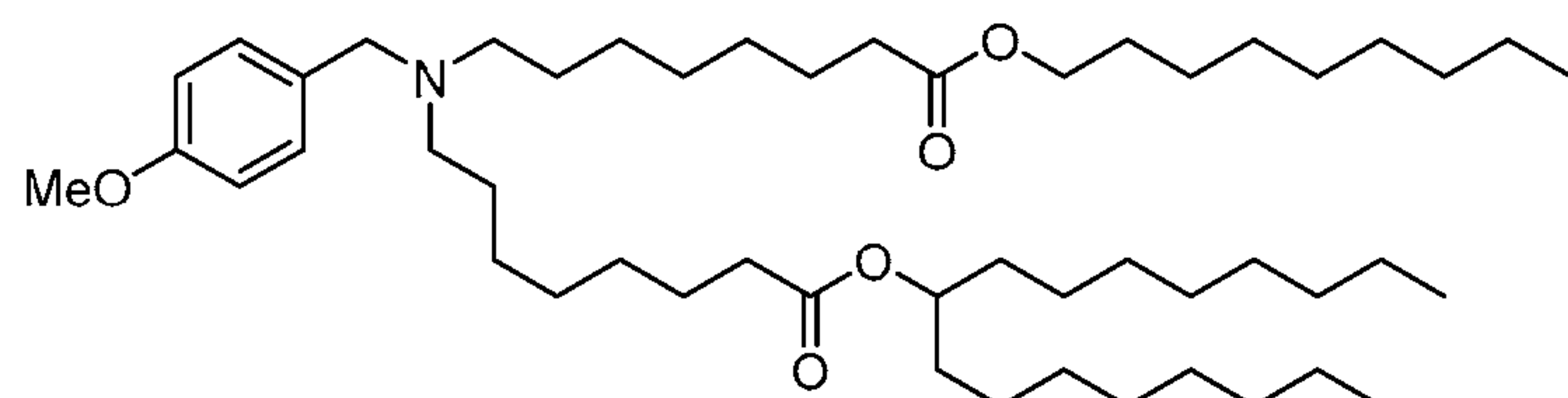
(Compound 92),



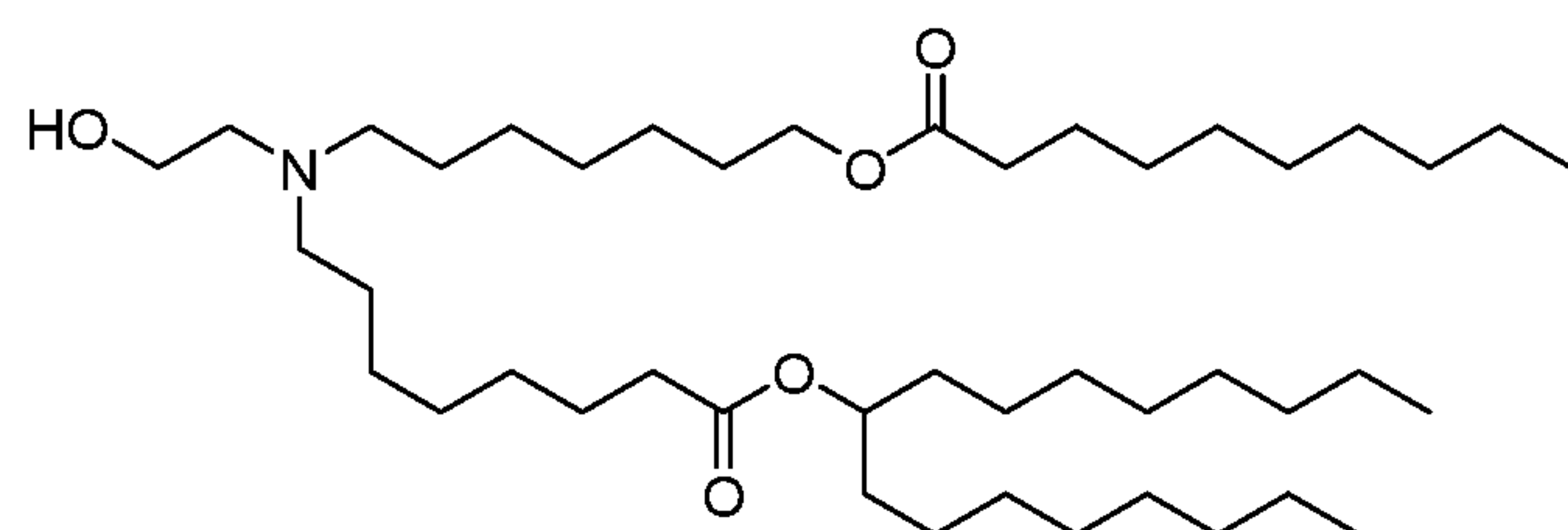
(Compound 93),



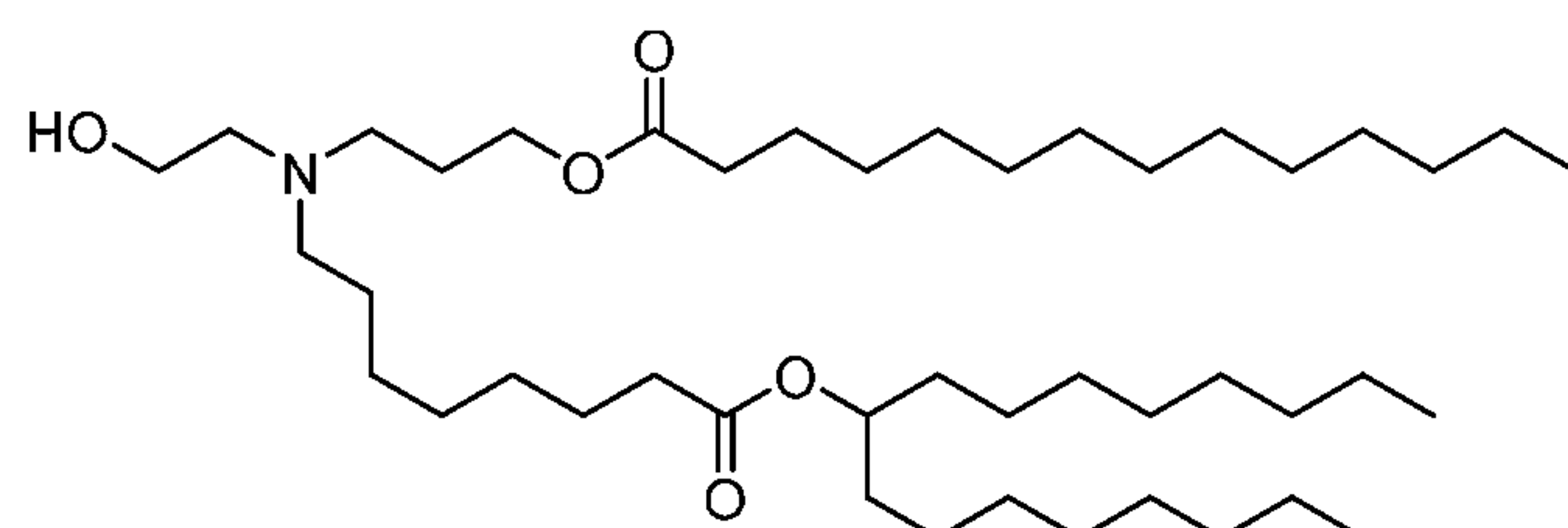
(Compound 94),



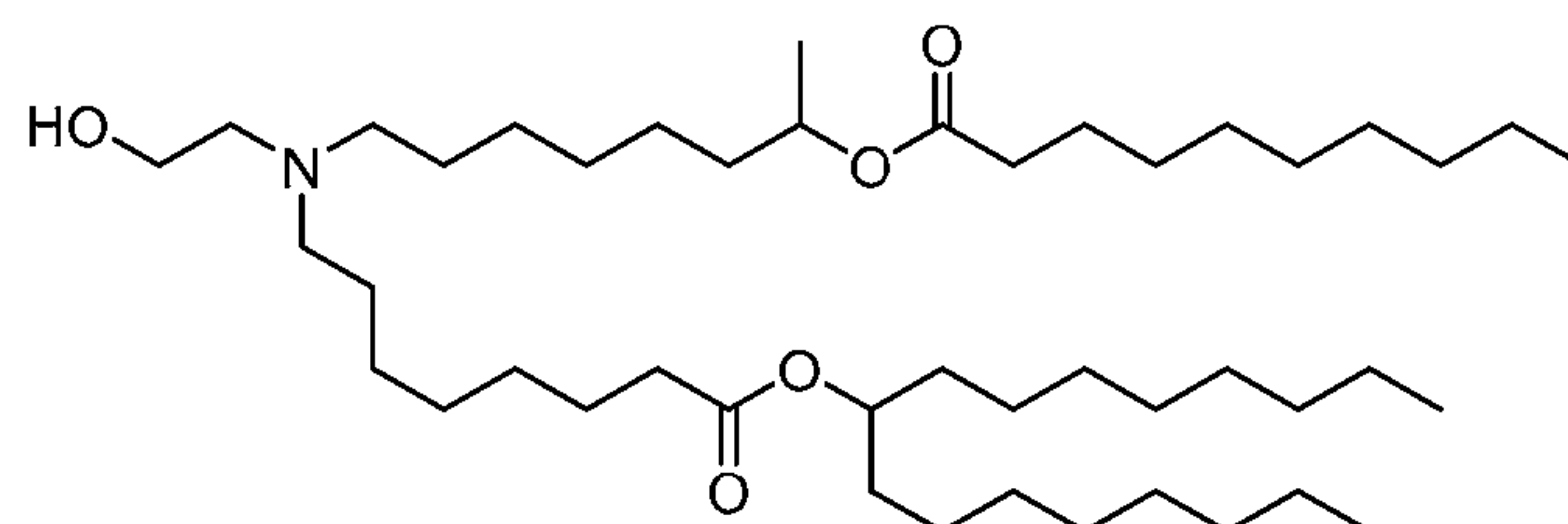
(Compound 95),



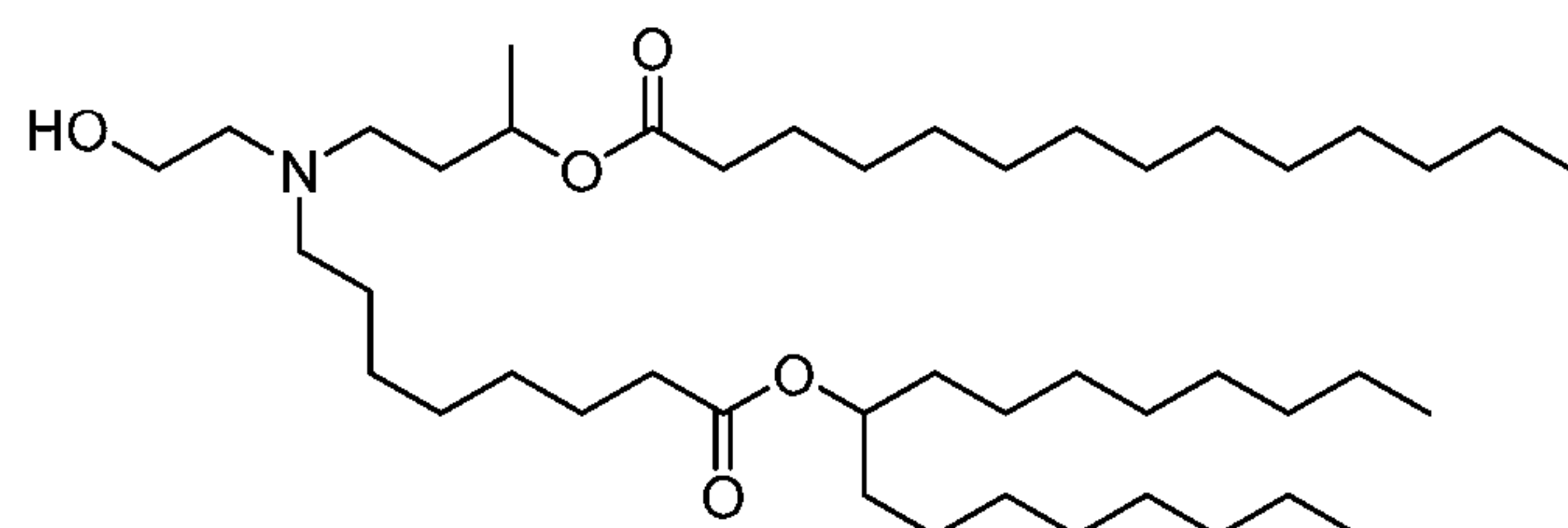
(Compound 96),



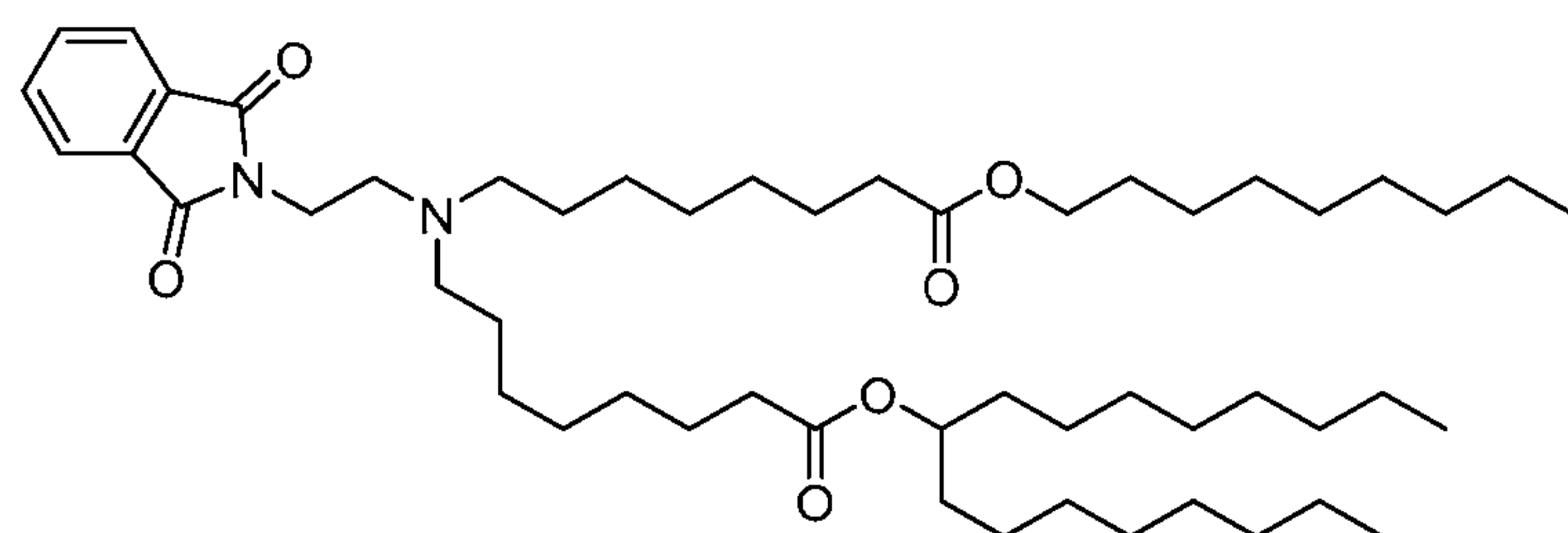
(Compound 97),



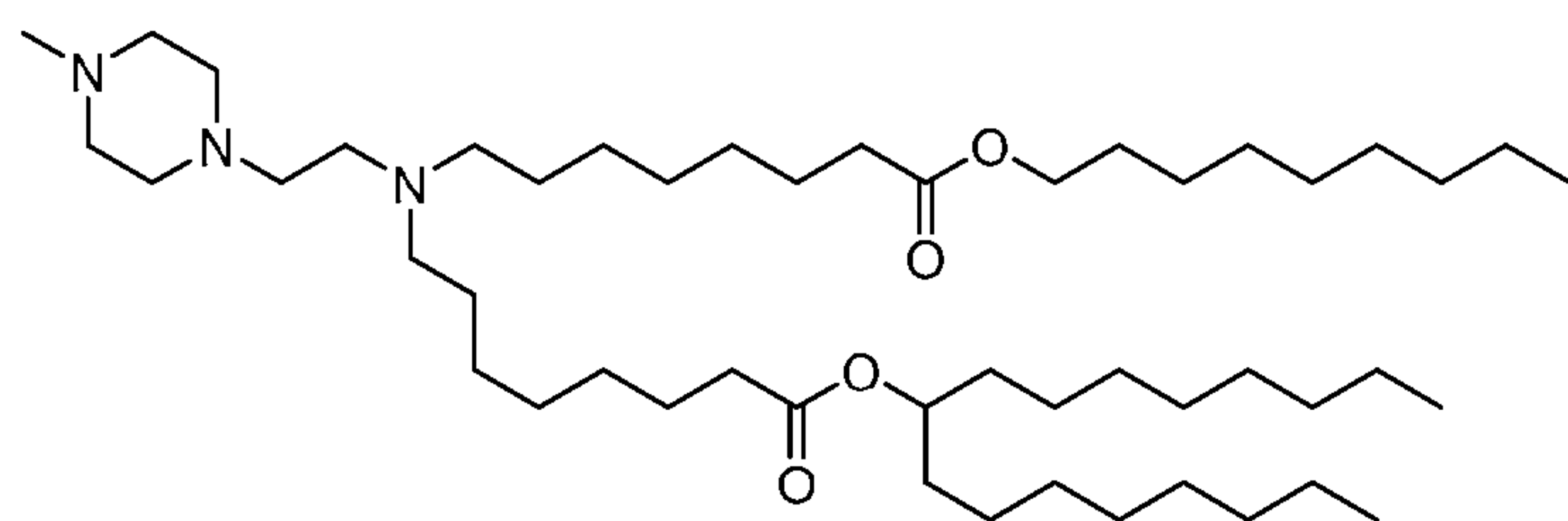
(Compound 98),



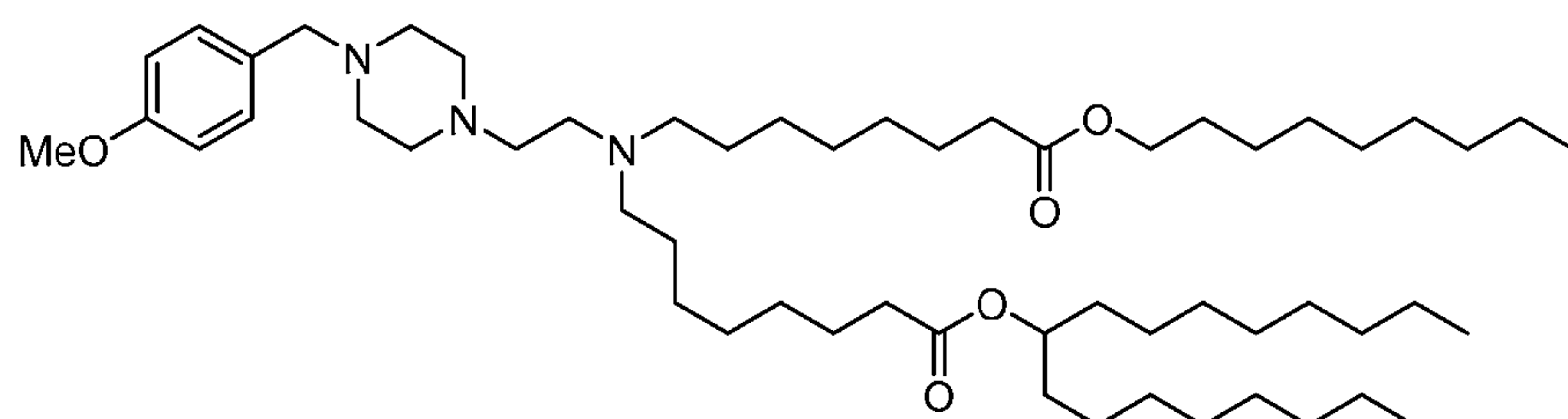
(Compound 99),



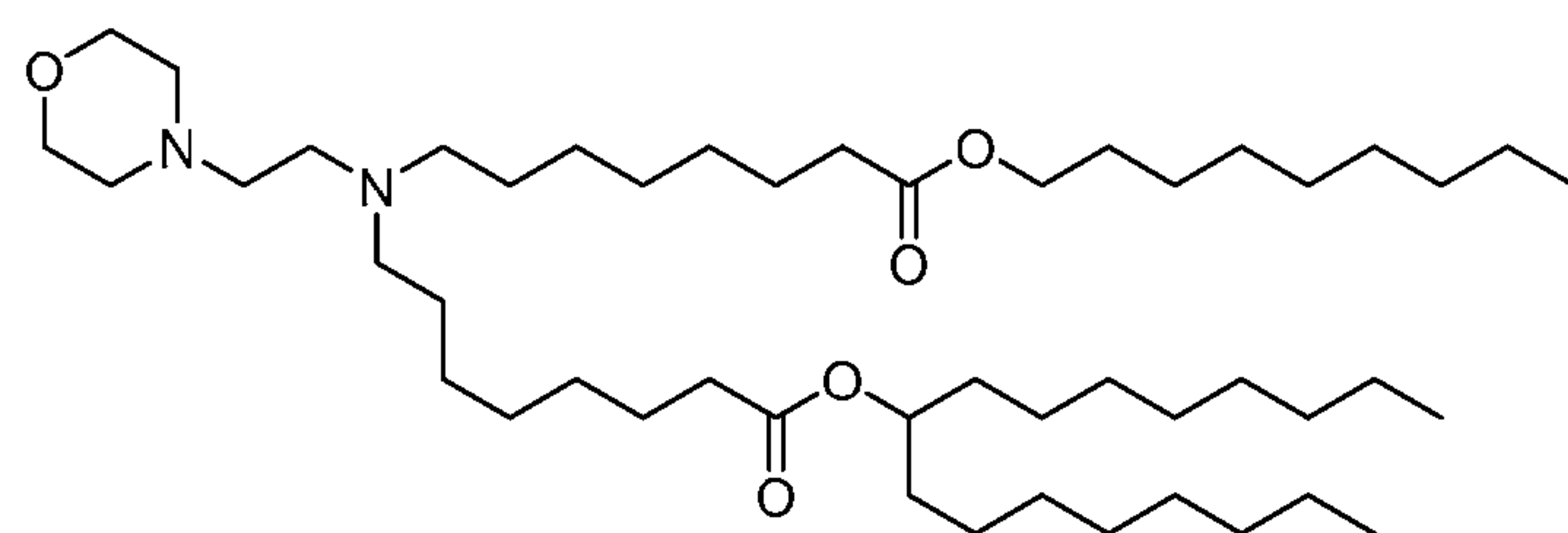
(Compound 100),



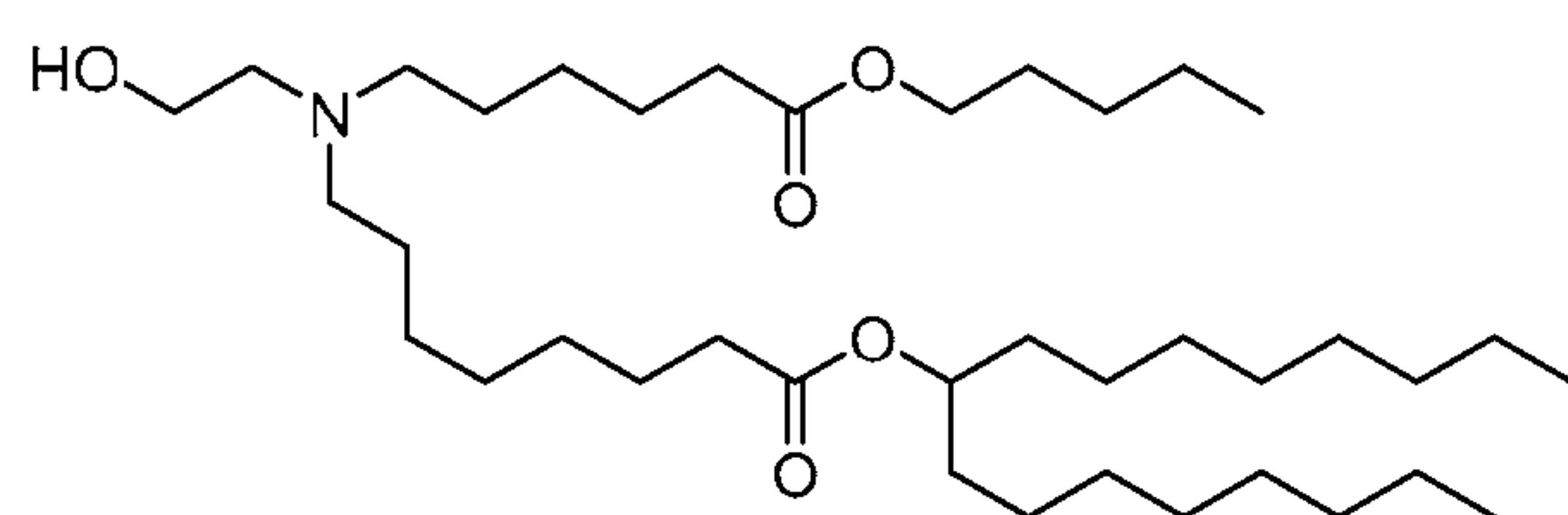
(Compound 101),



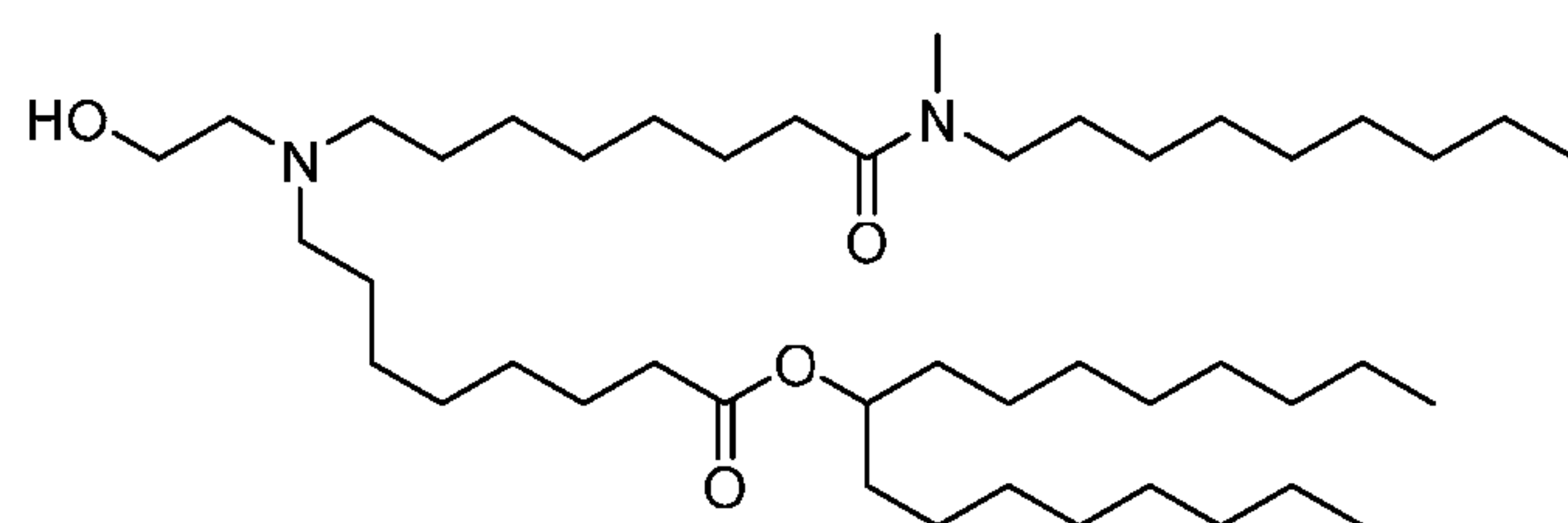
(Compound 102),



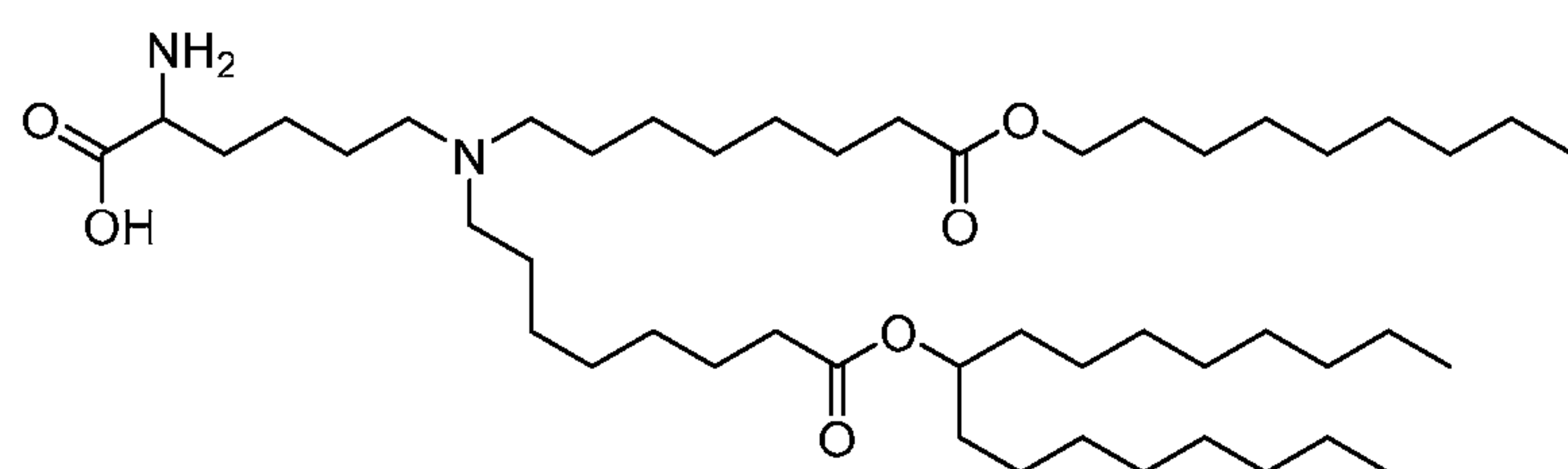
(Compound 103),



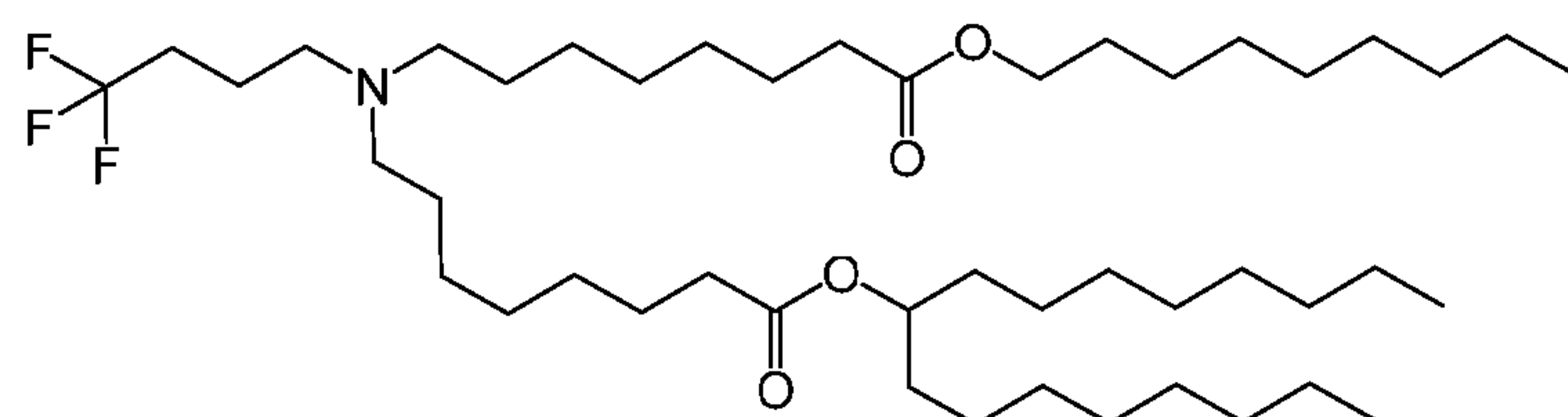
(Compound 104),



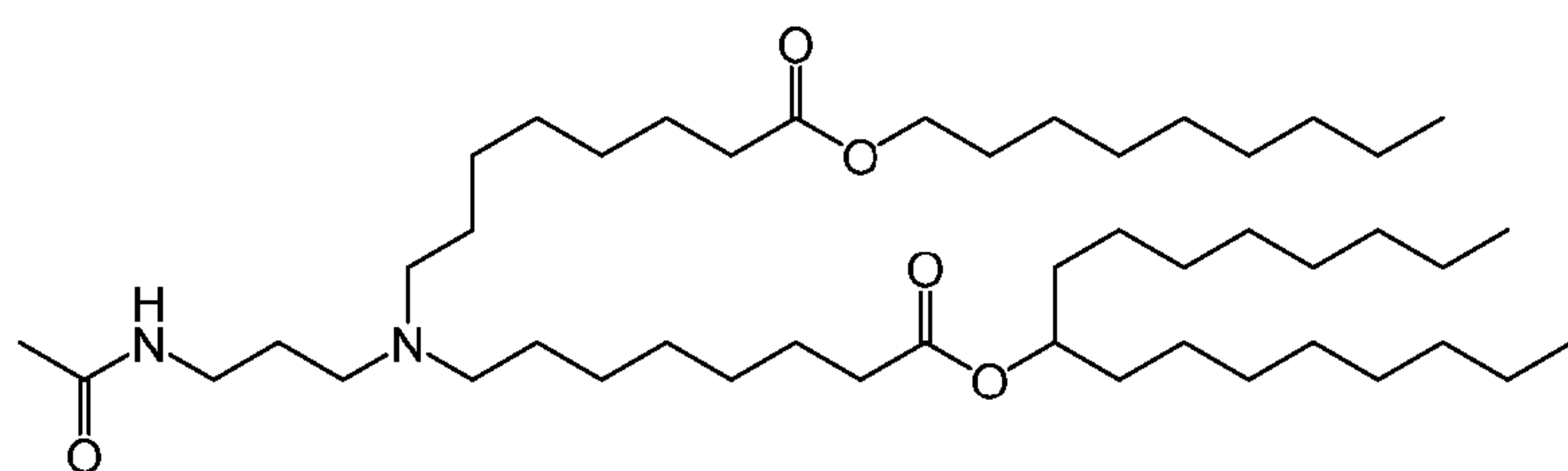
(Compound 105),



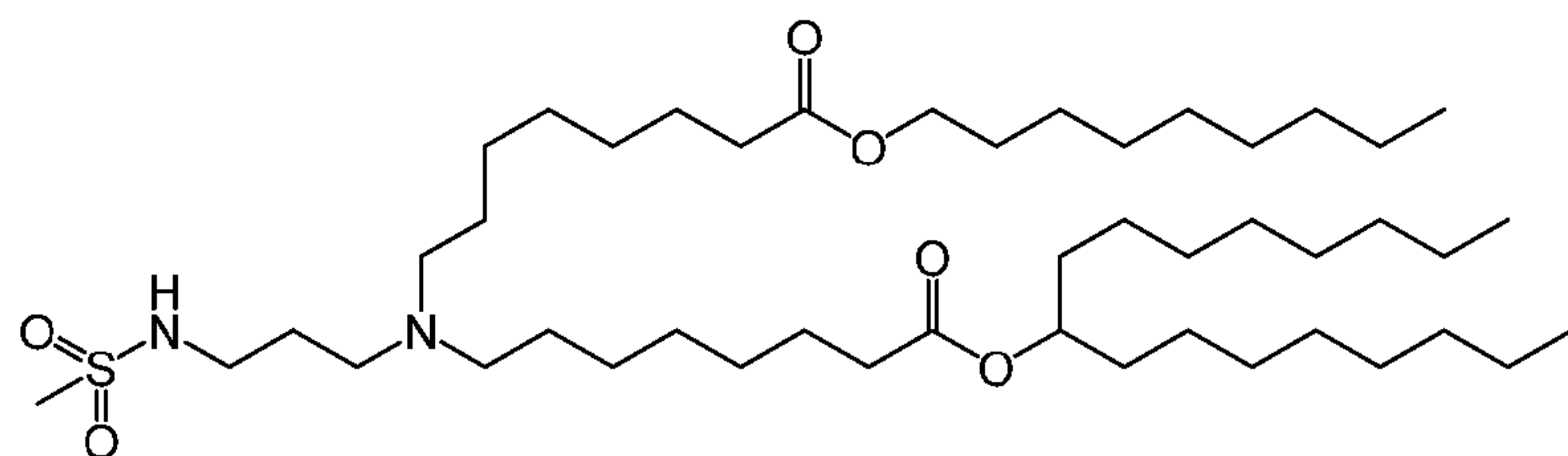
(Compound 106),



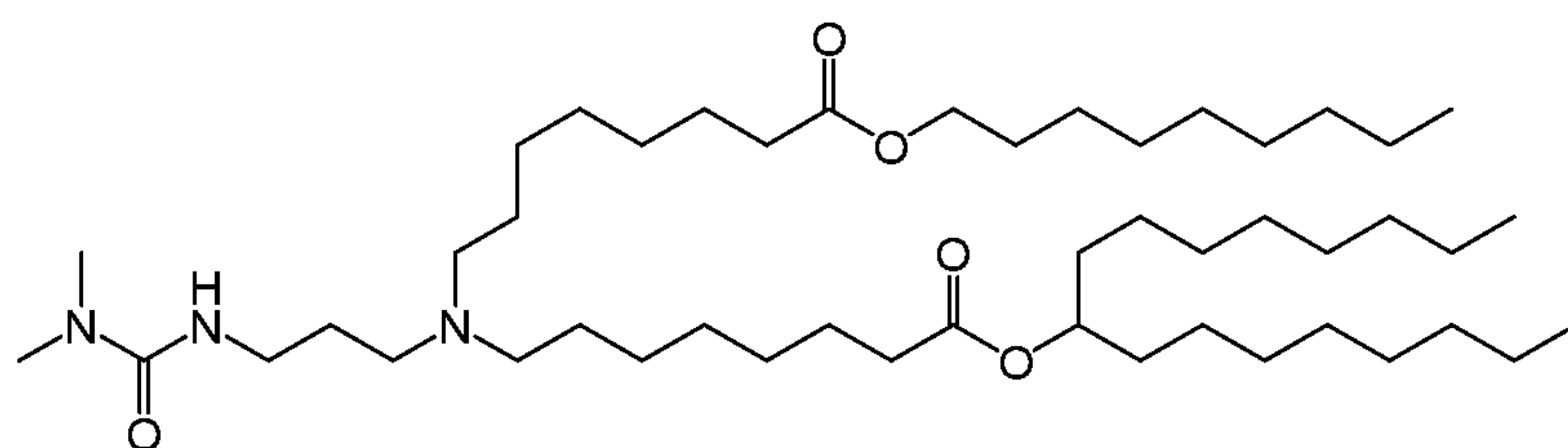
(Compound 107),



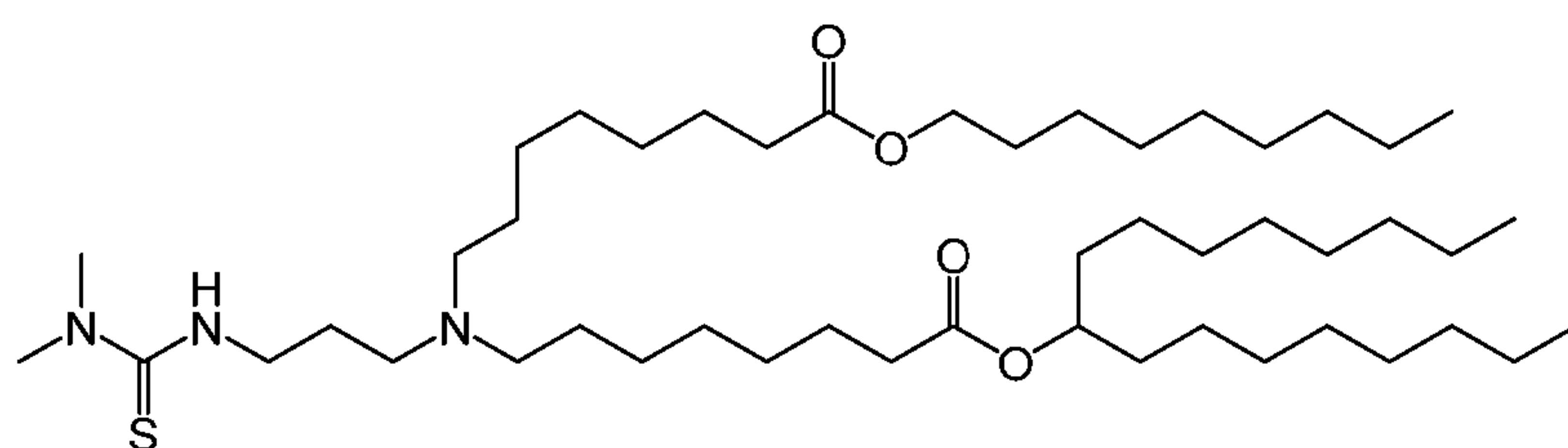
(Compound 108),



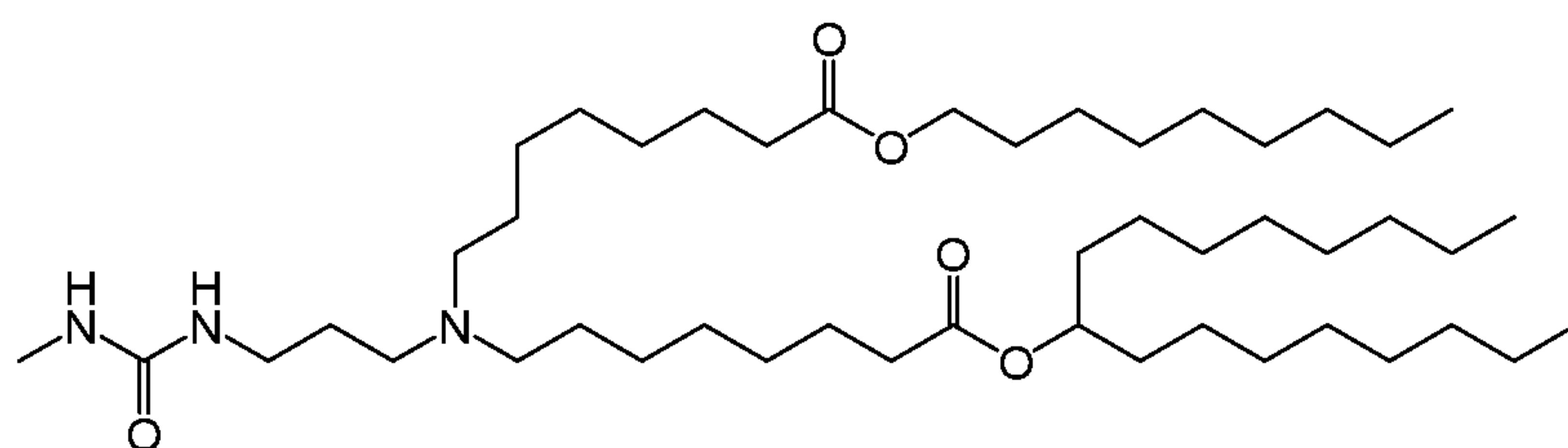
(Compound 109),



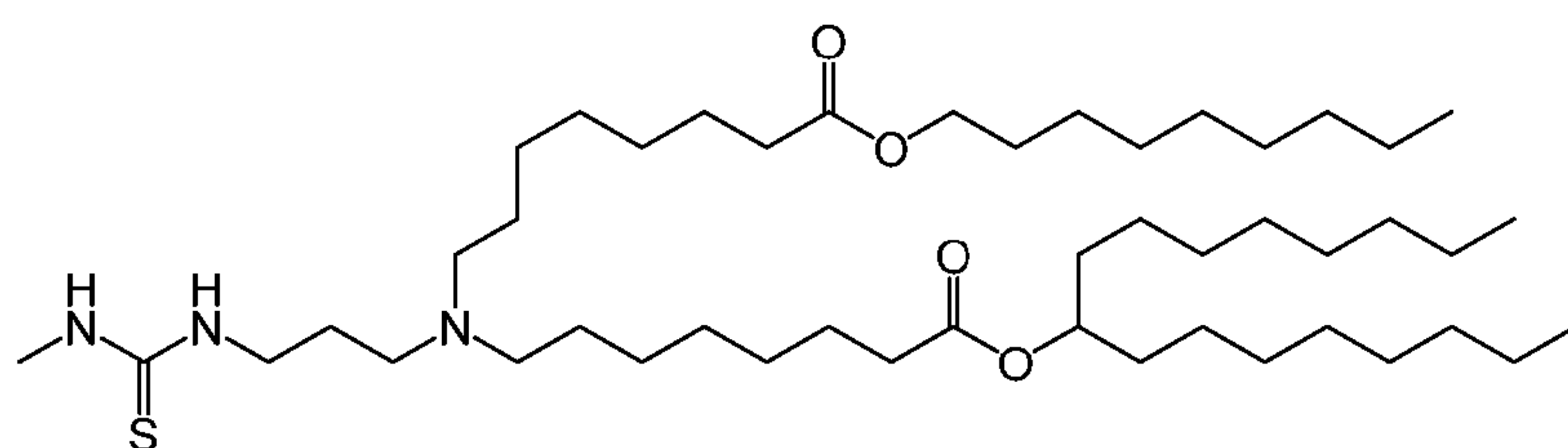
(Compound 110),



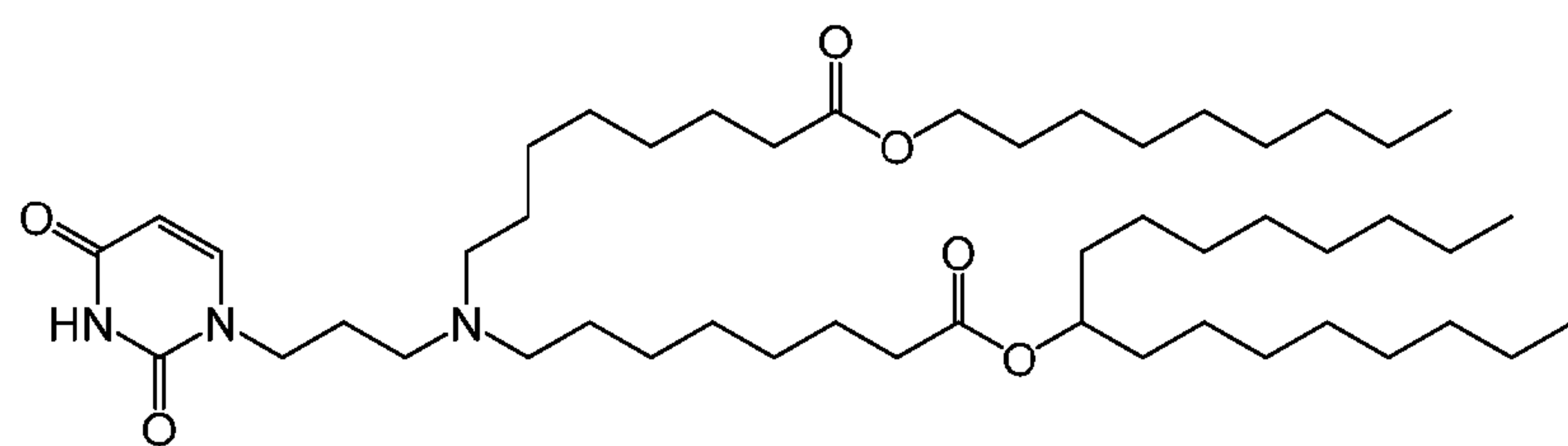
(Compound 111),



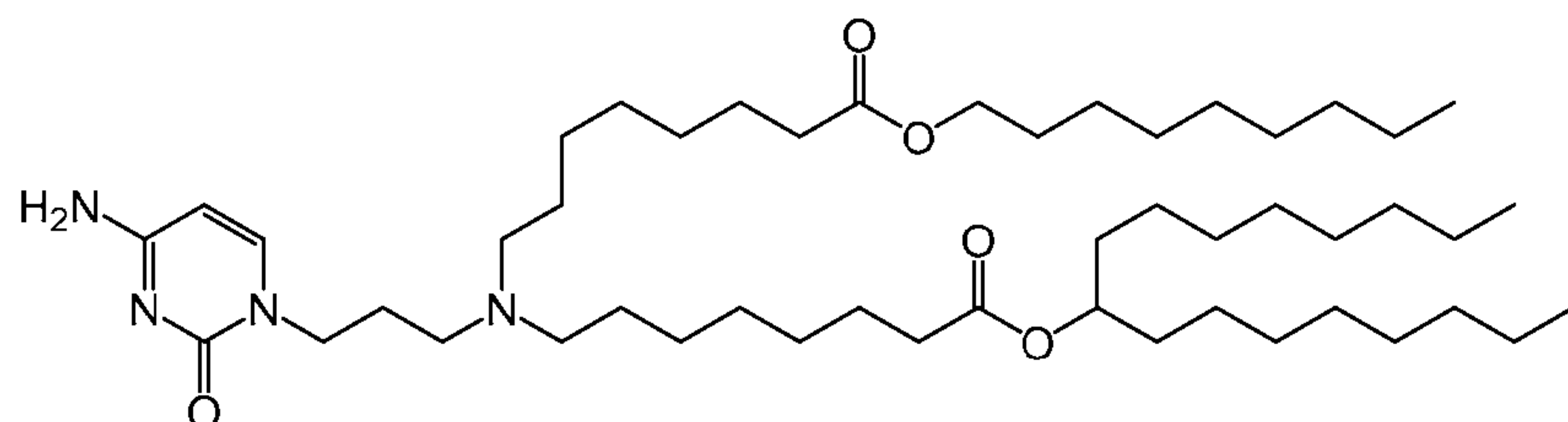
(Compound 112),



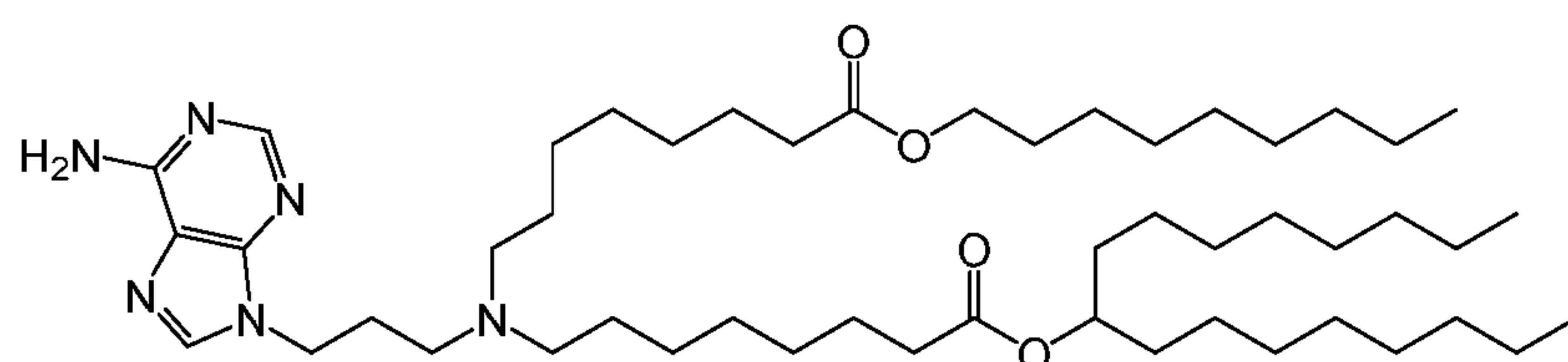
(Compound 113),



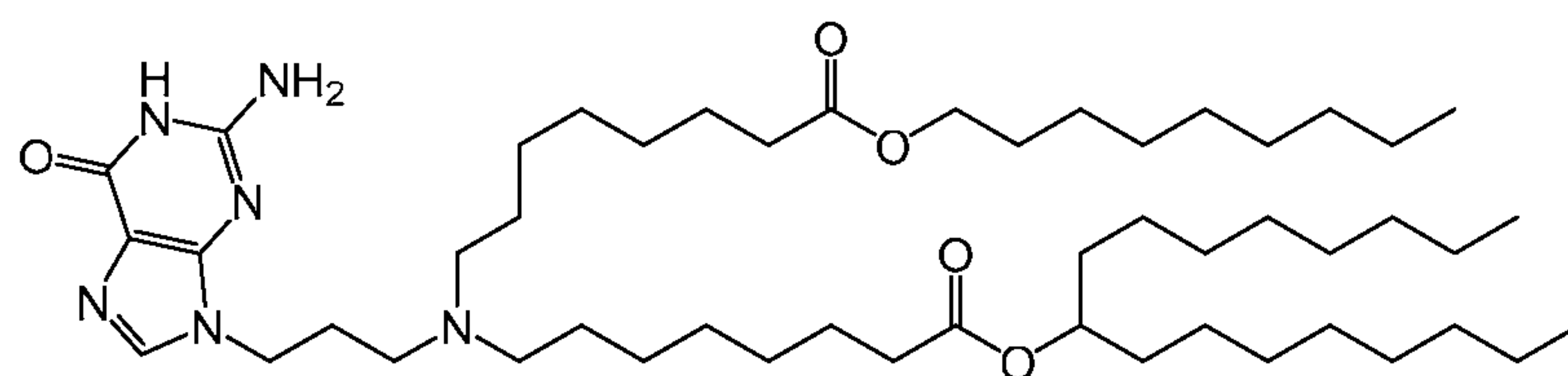
(Compound 114),



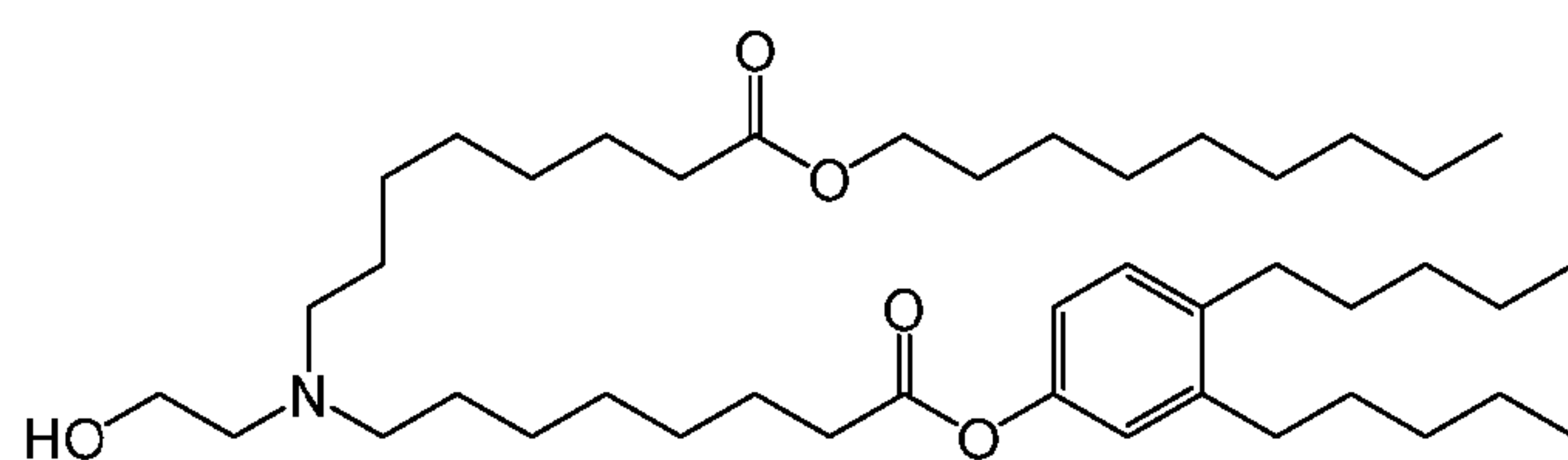
(Compound 115),



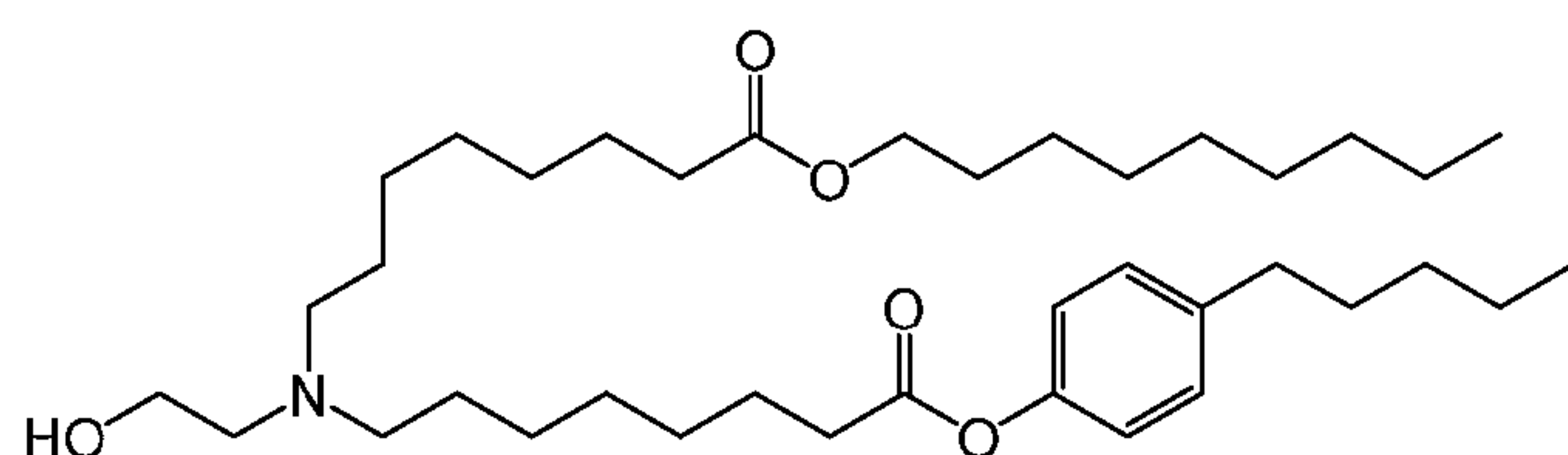
(Compound 116),



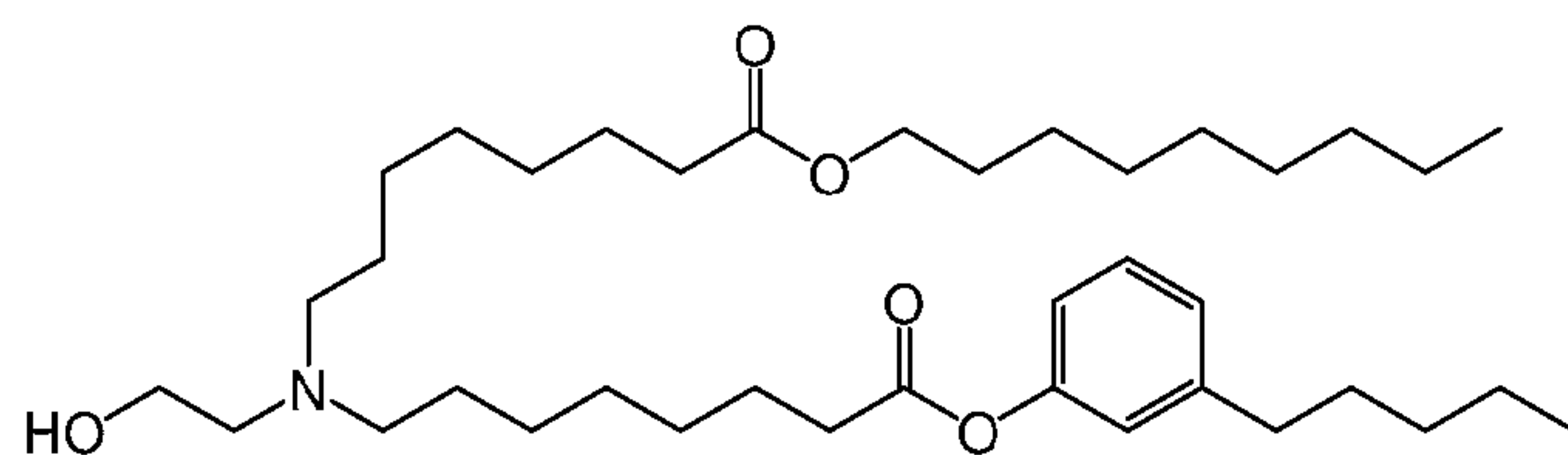
(Compound 117),



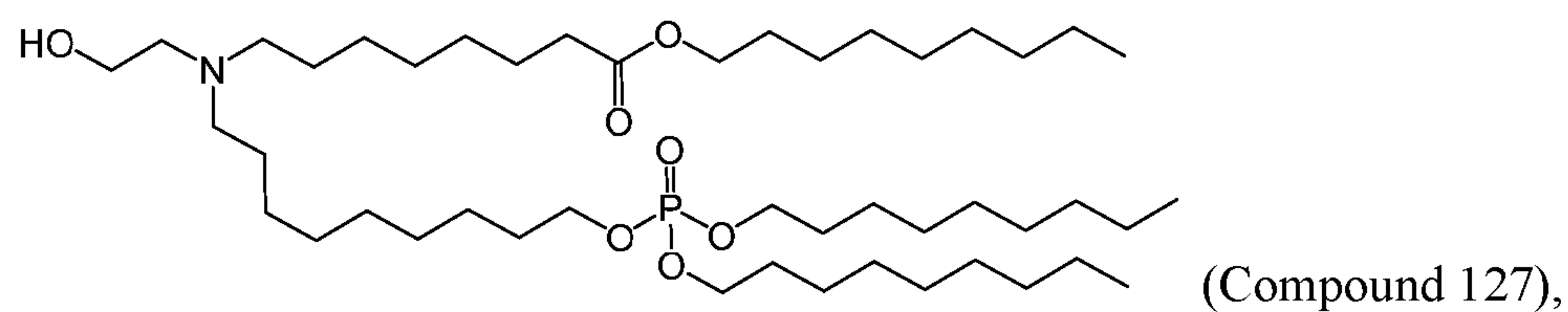
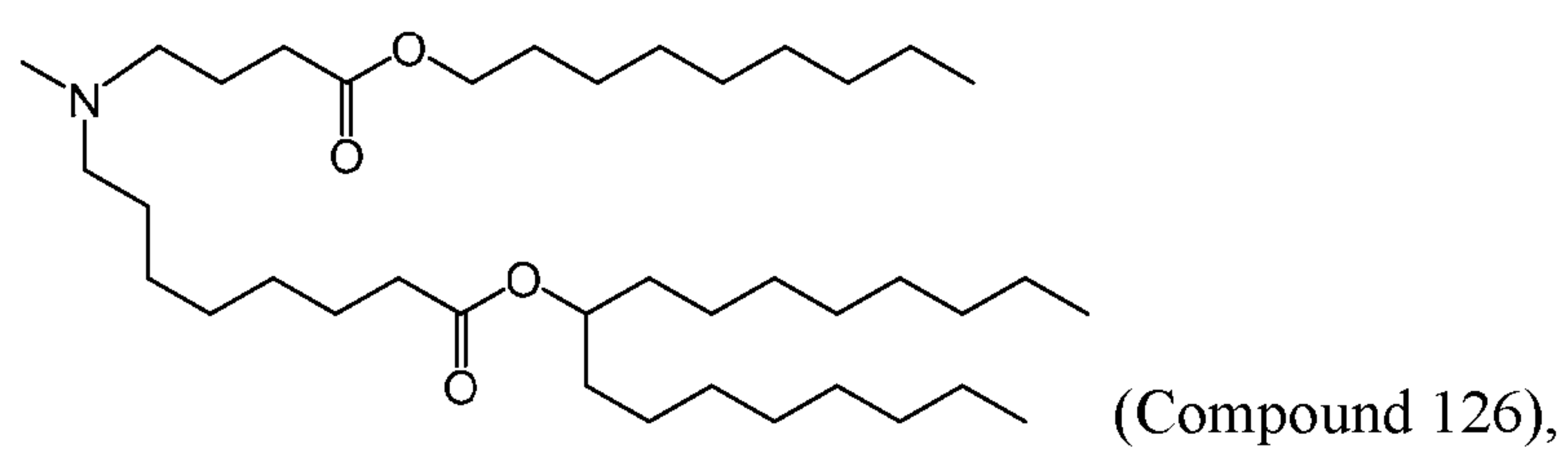
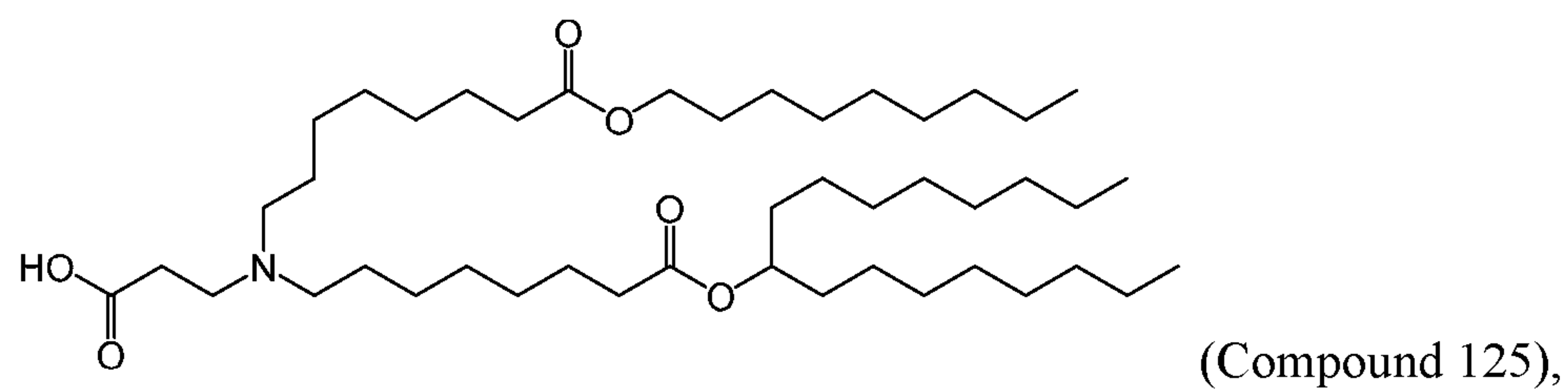
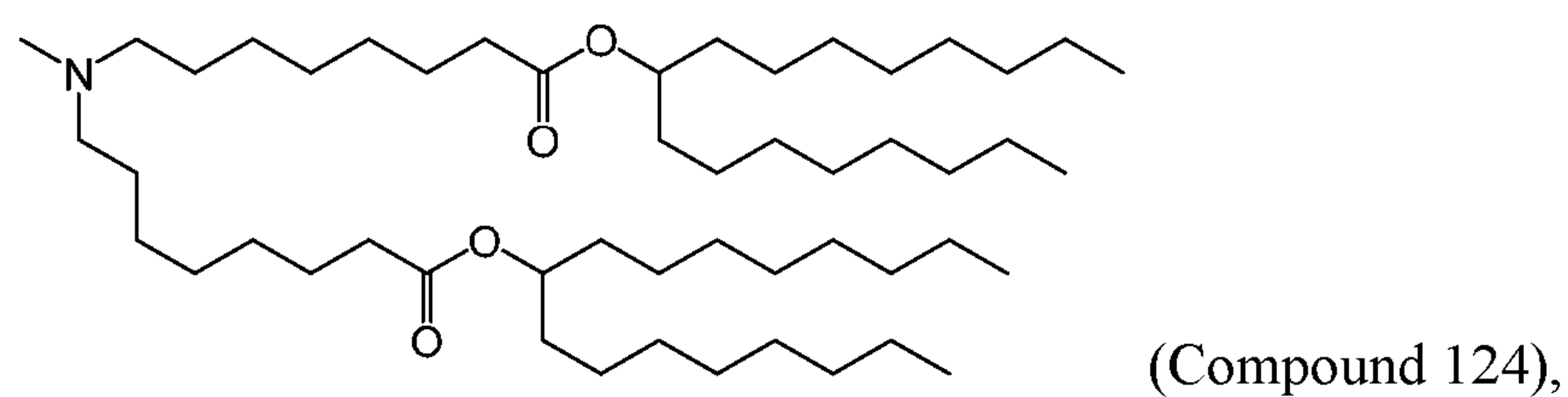
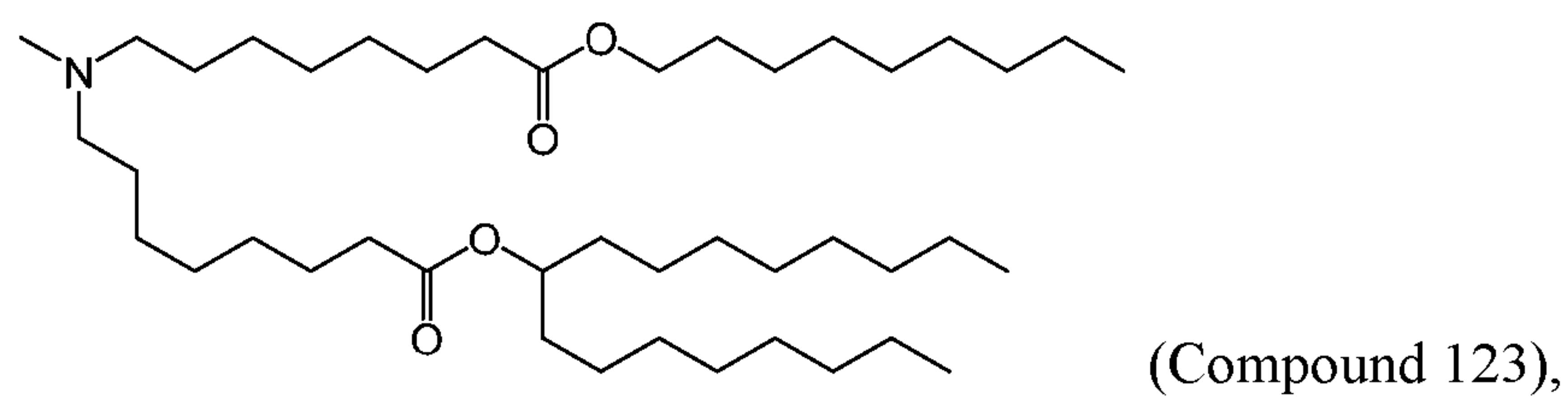
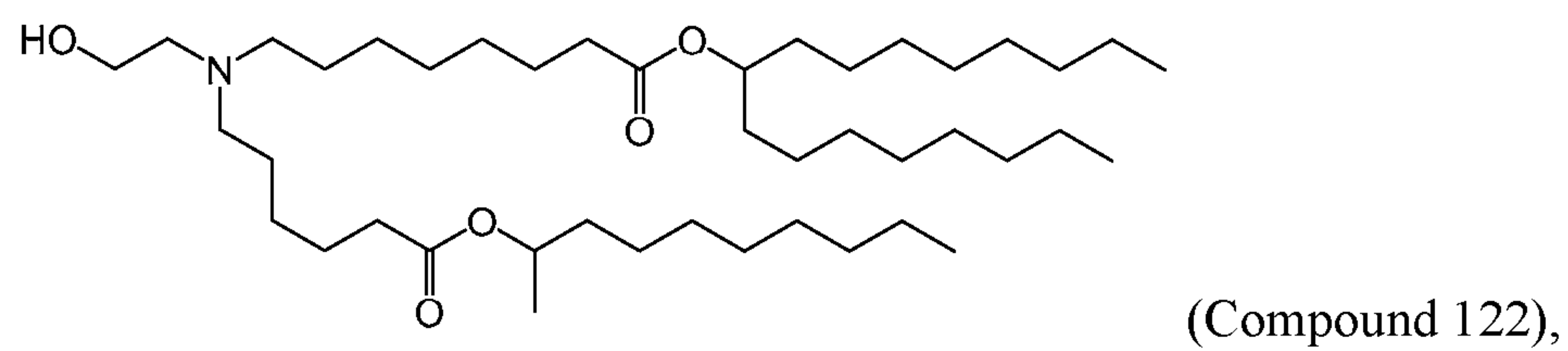
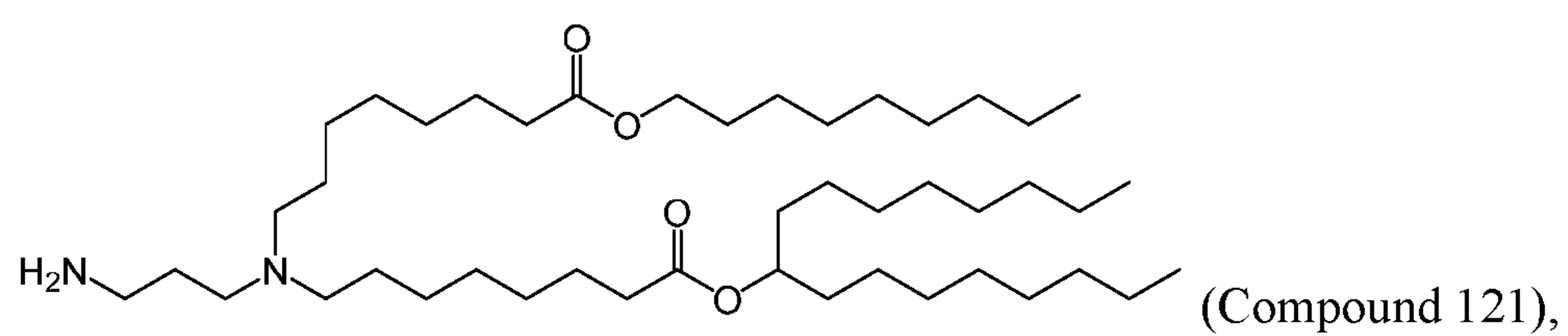
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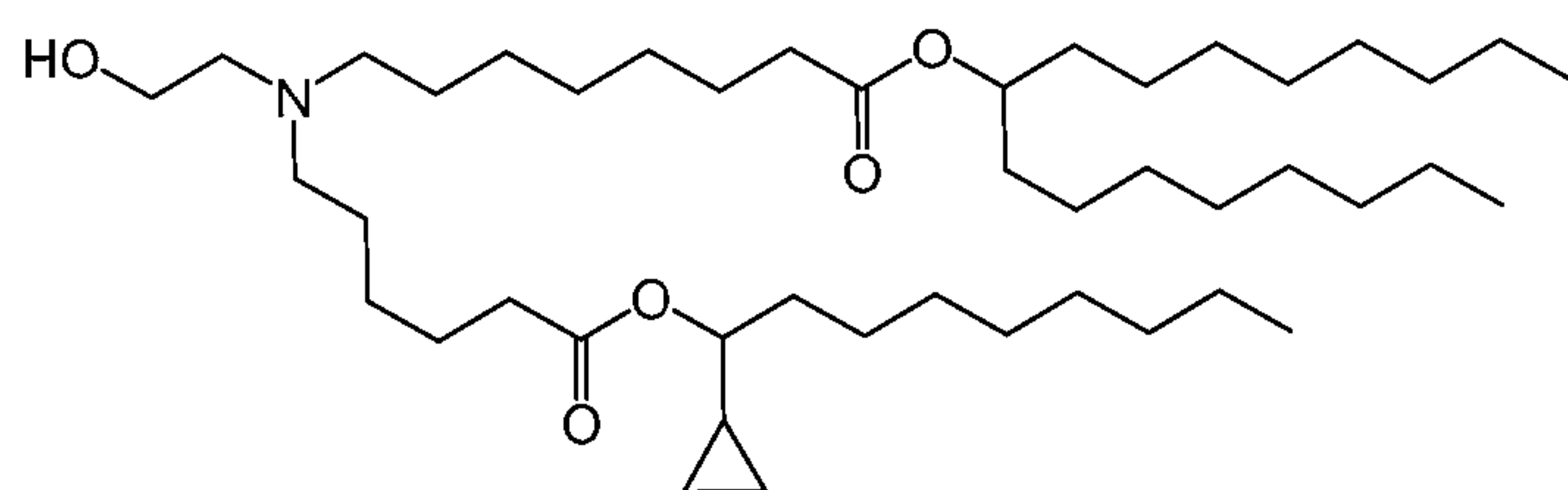


(Compound 119),

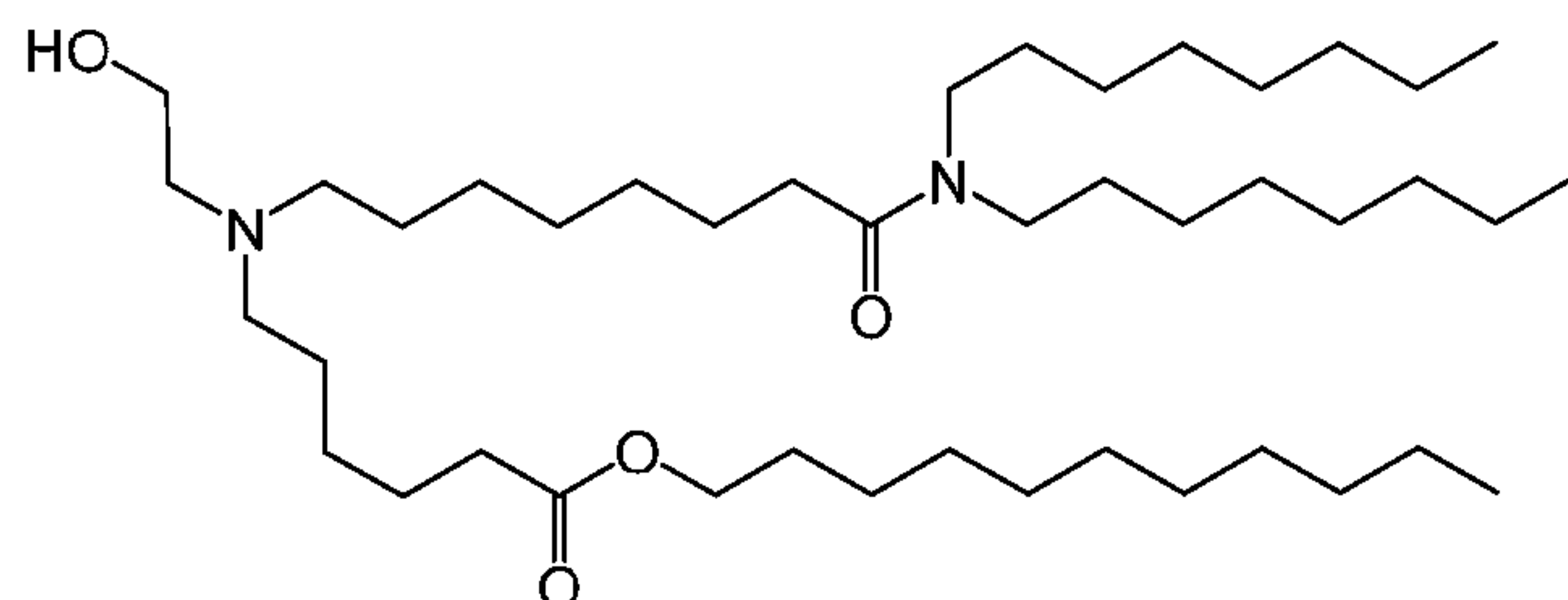


(Compound 120),

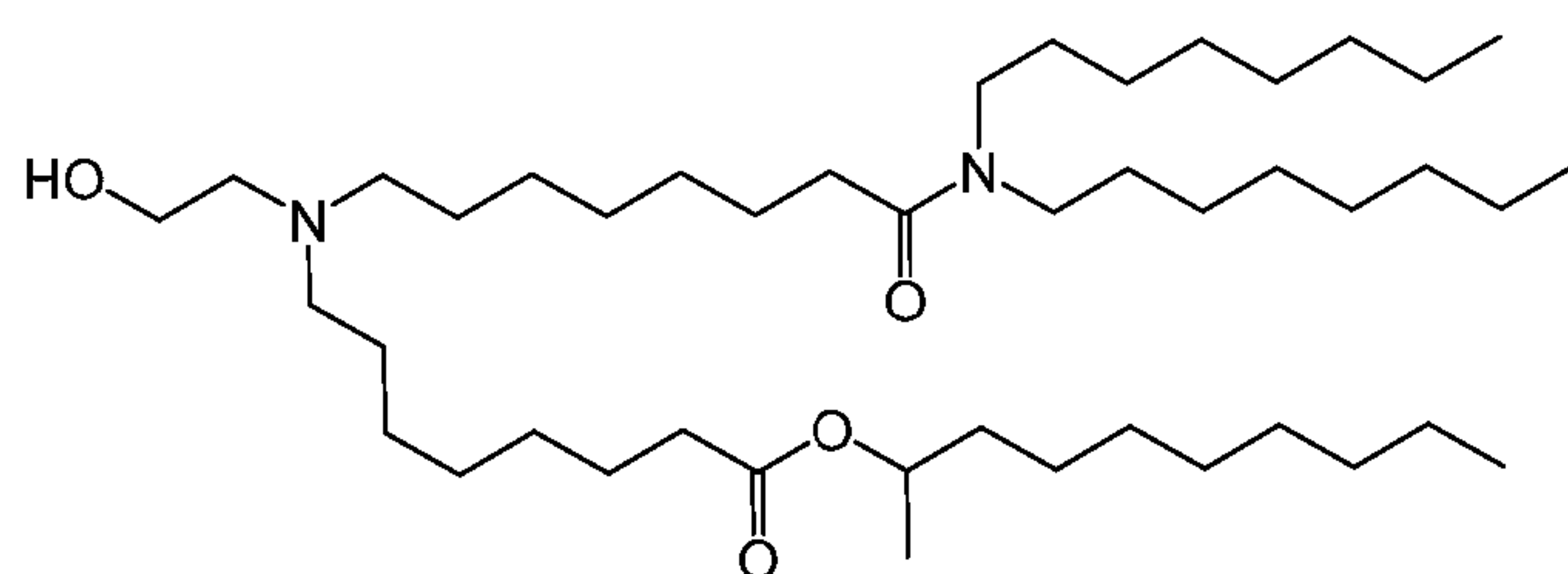




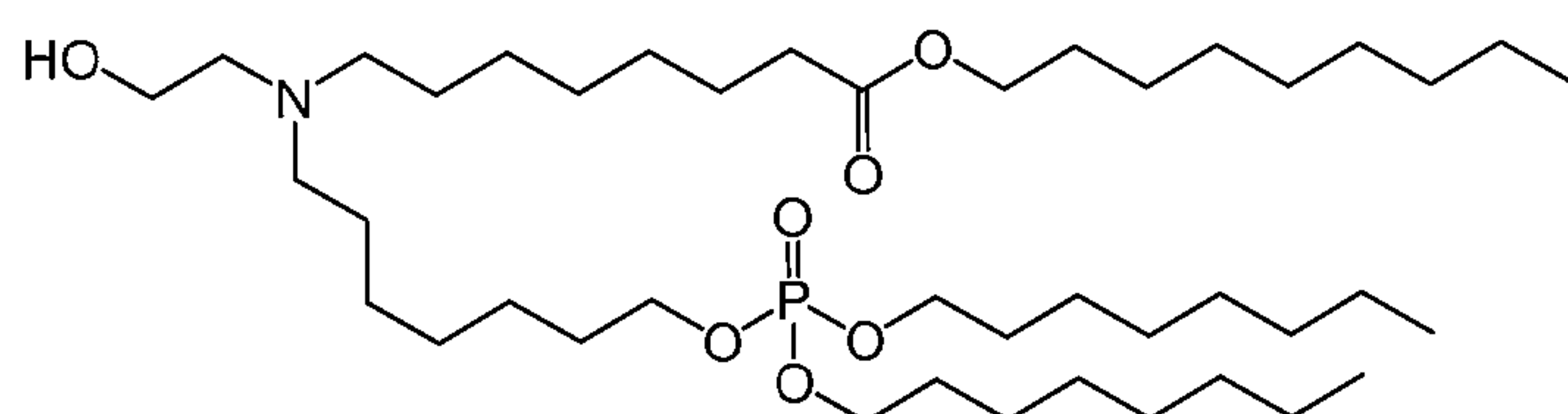
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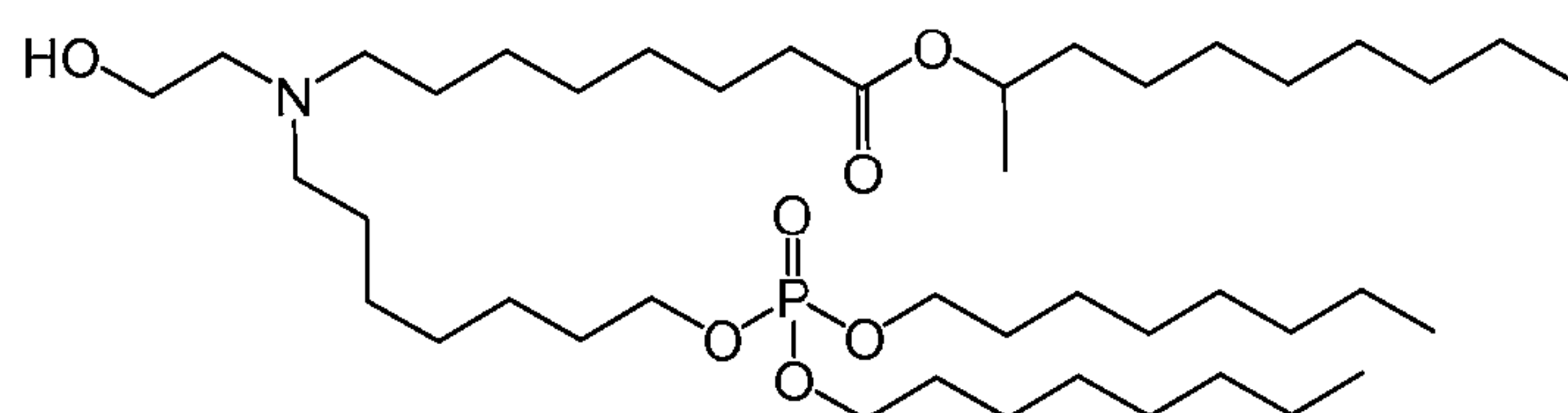
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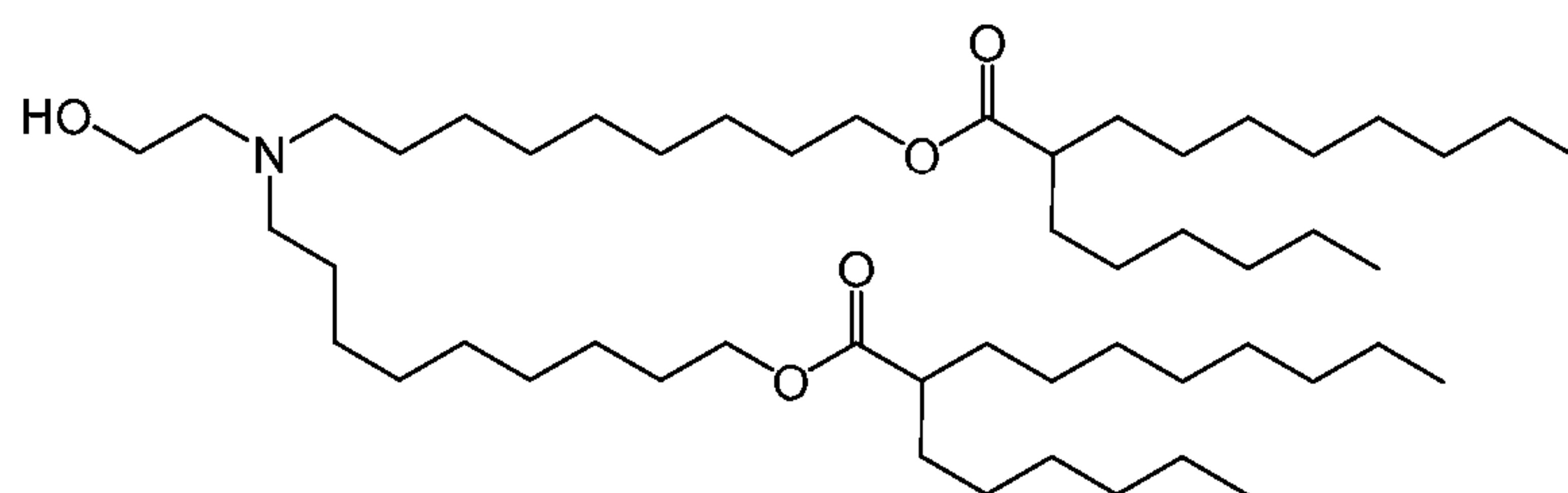
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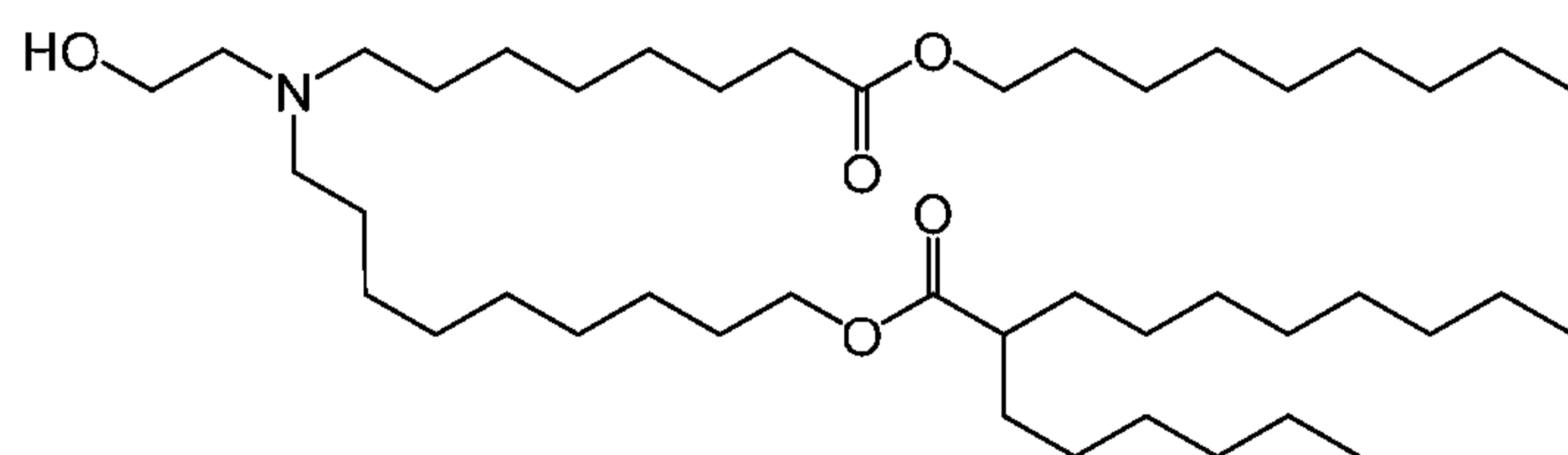
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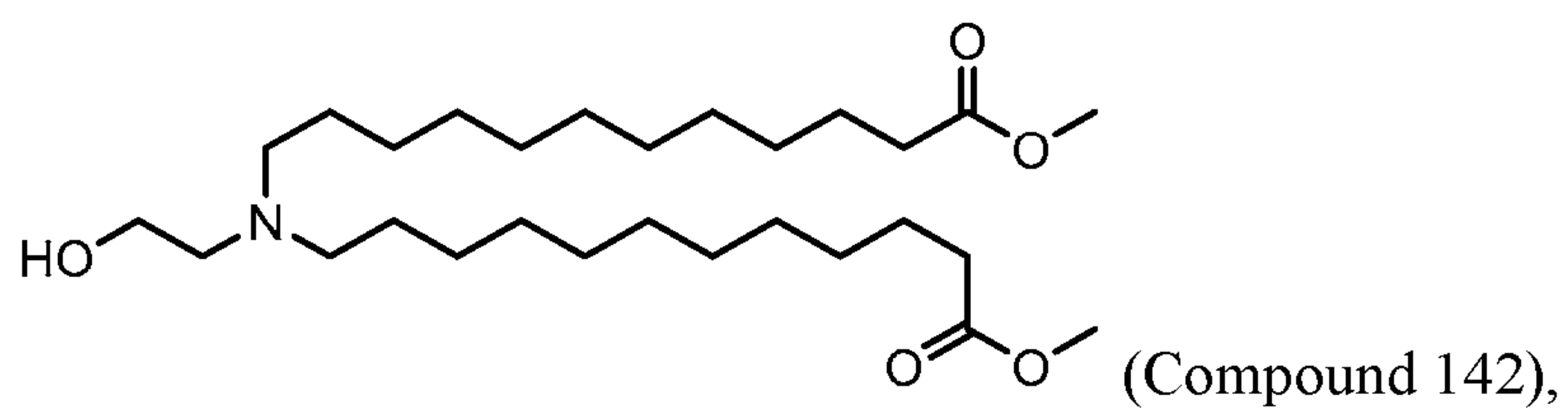
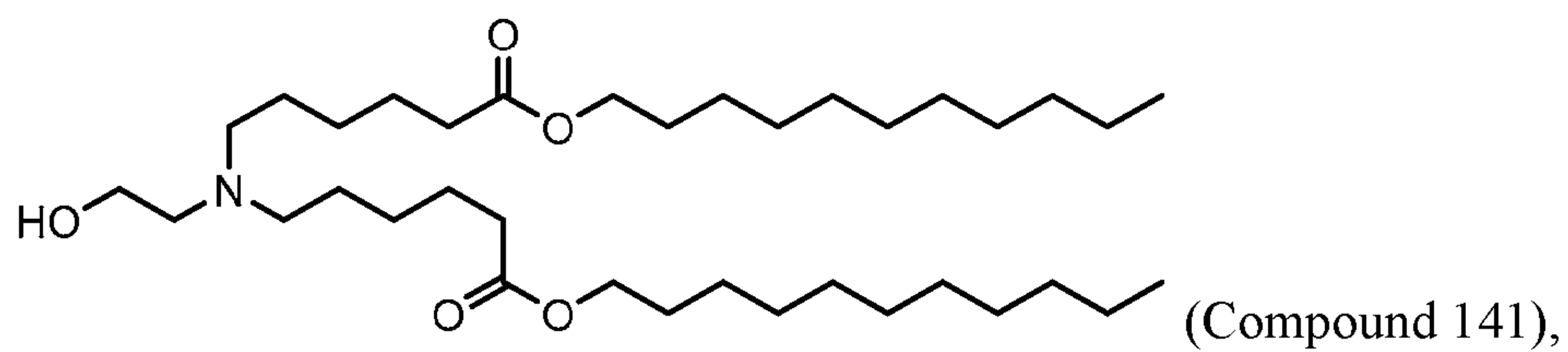
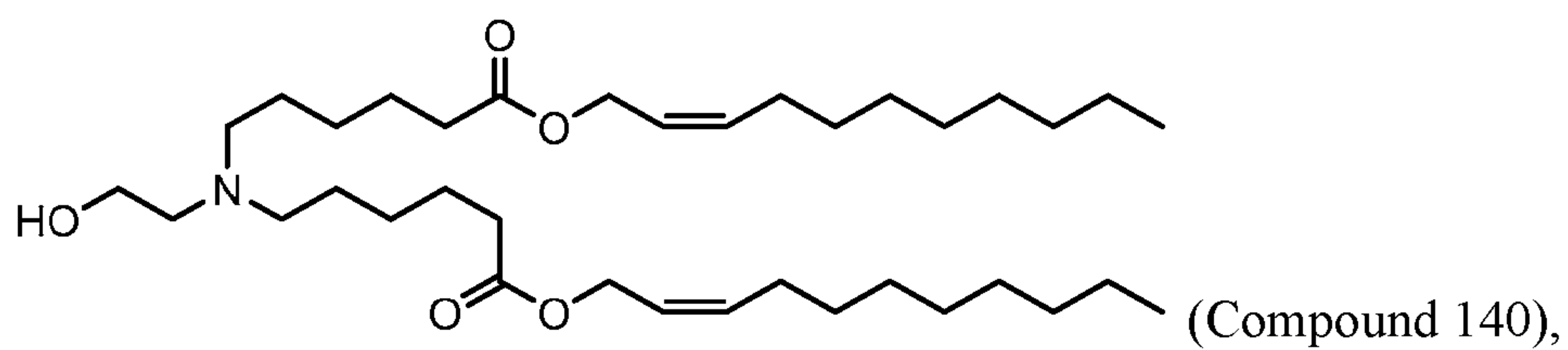
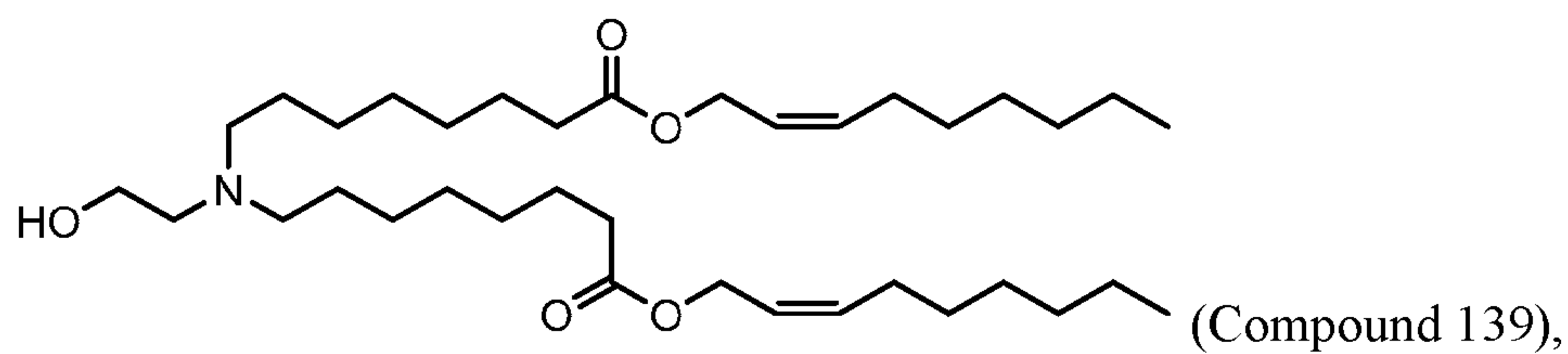
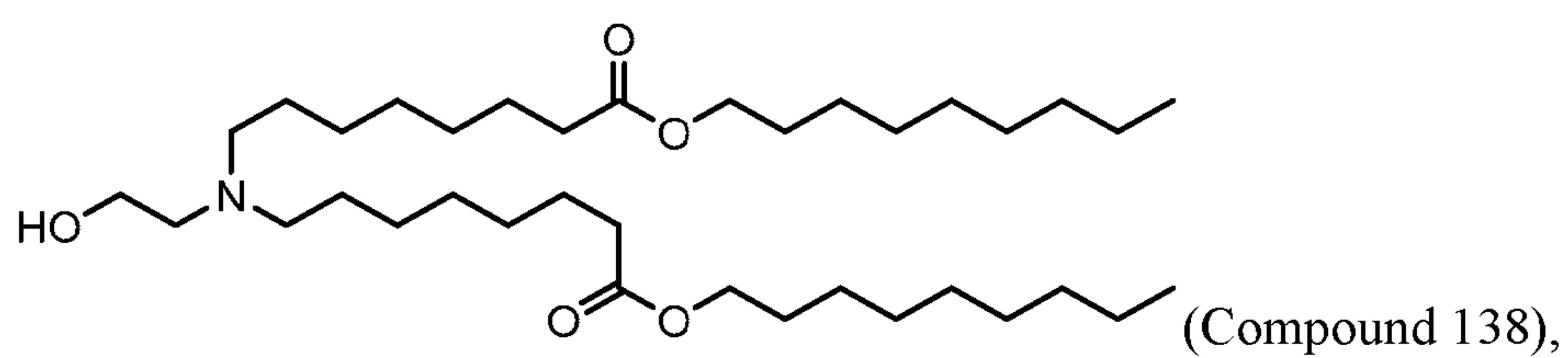
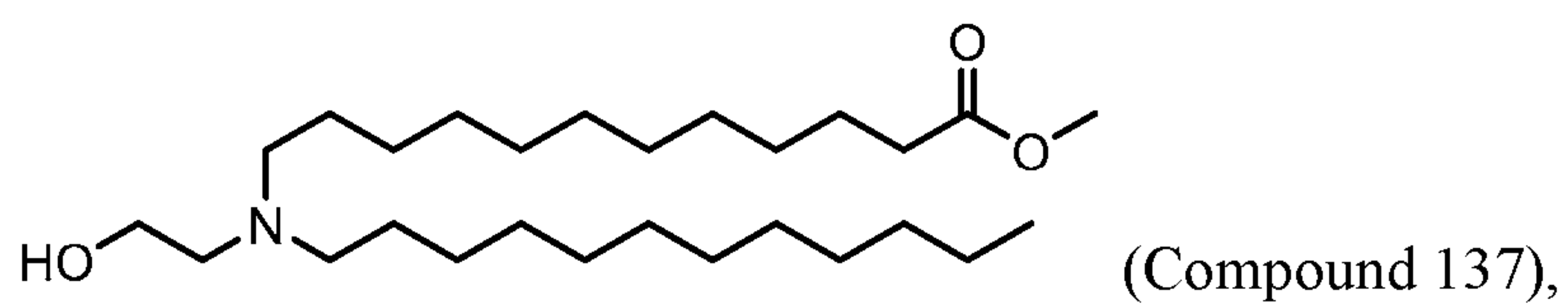
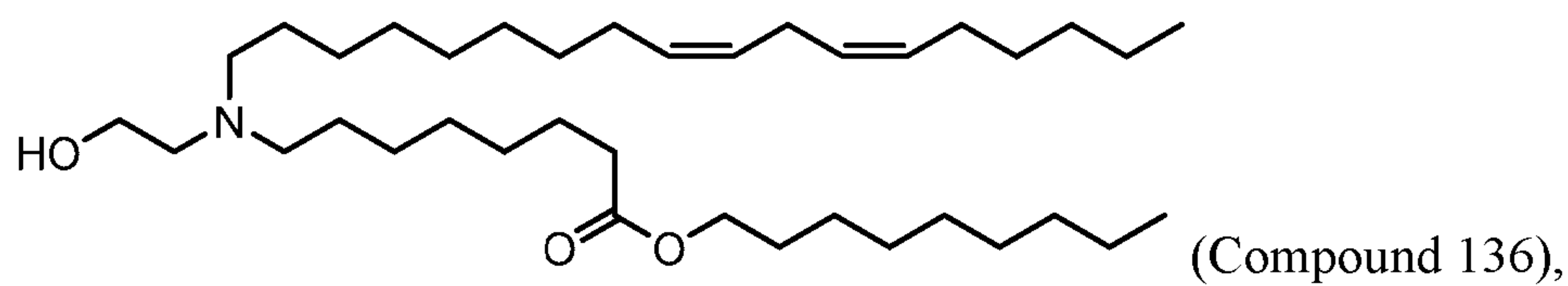
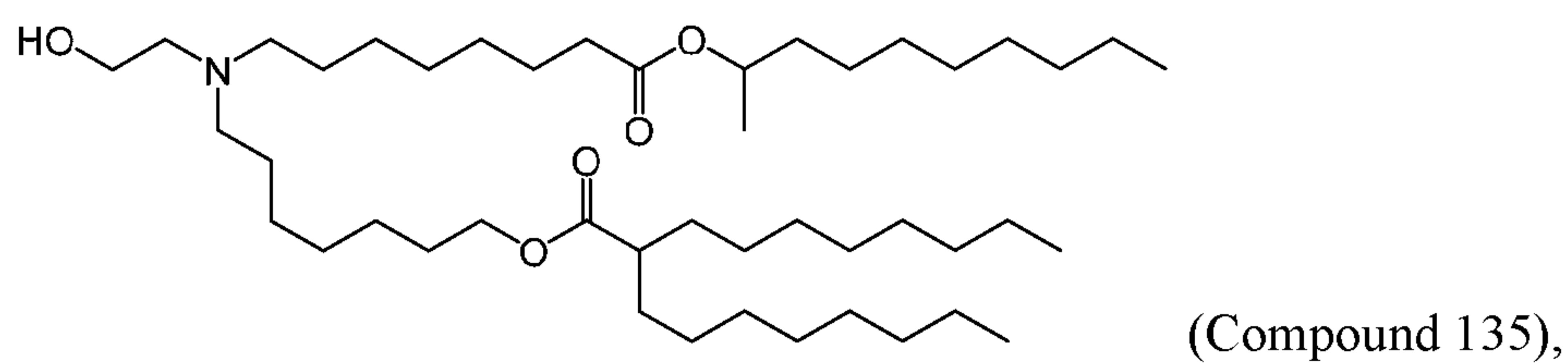
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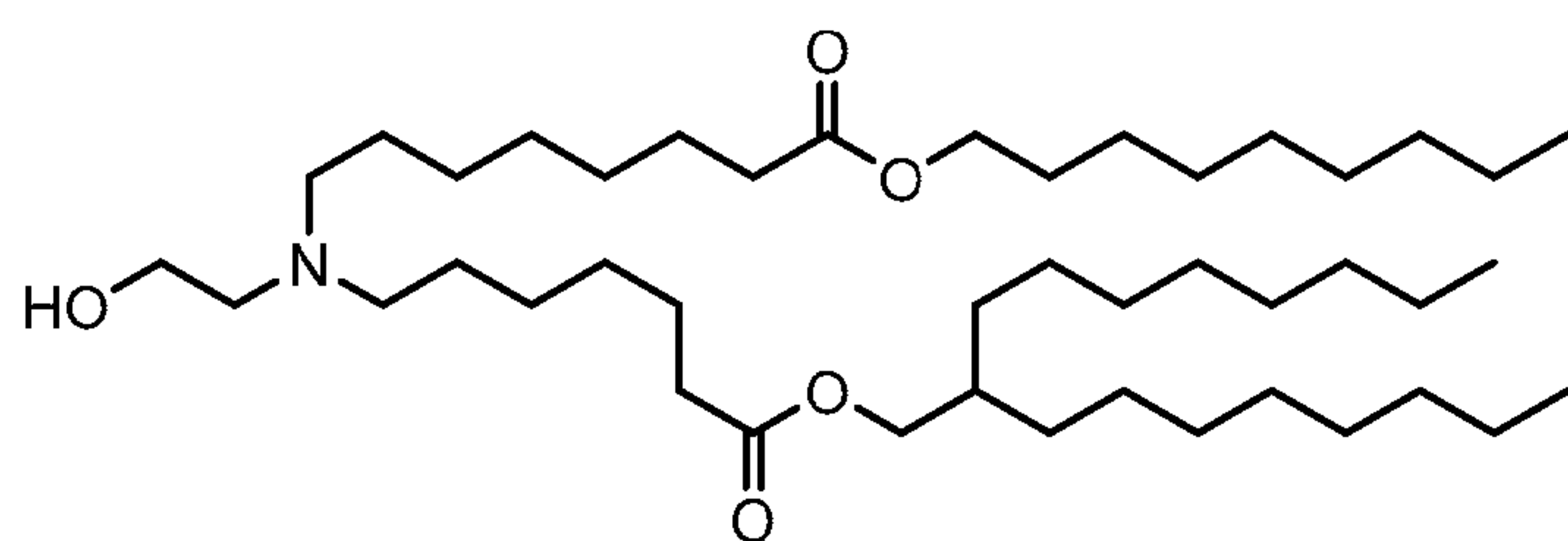


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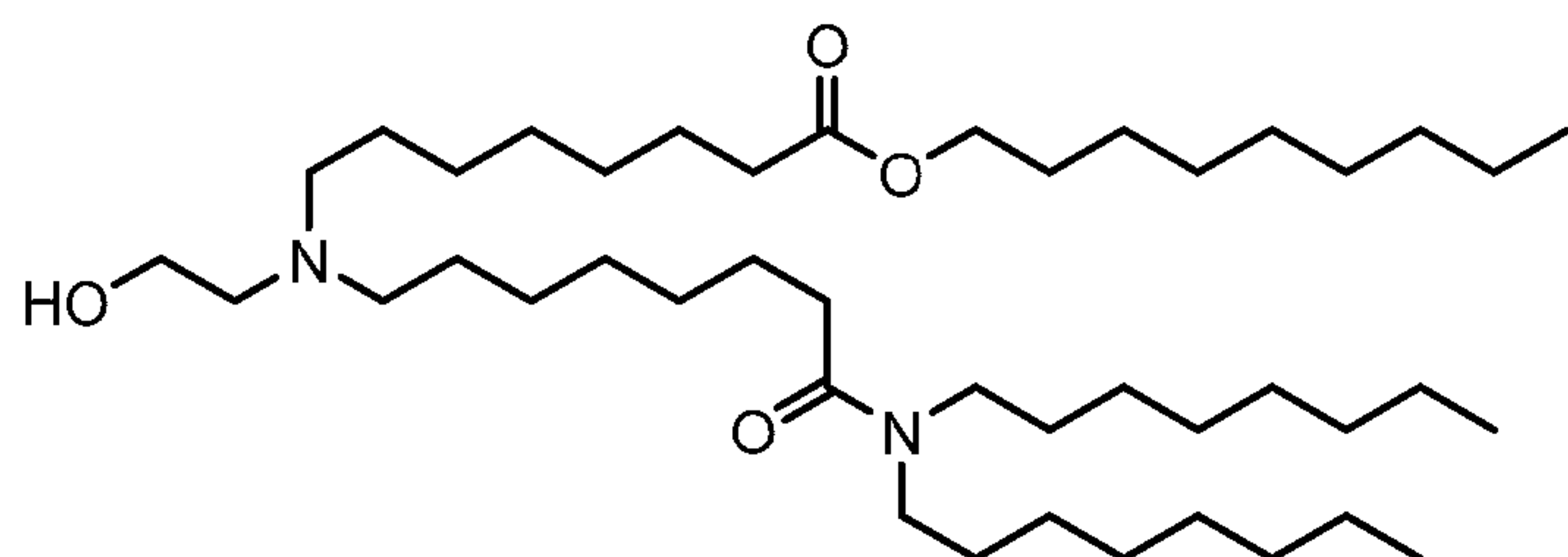


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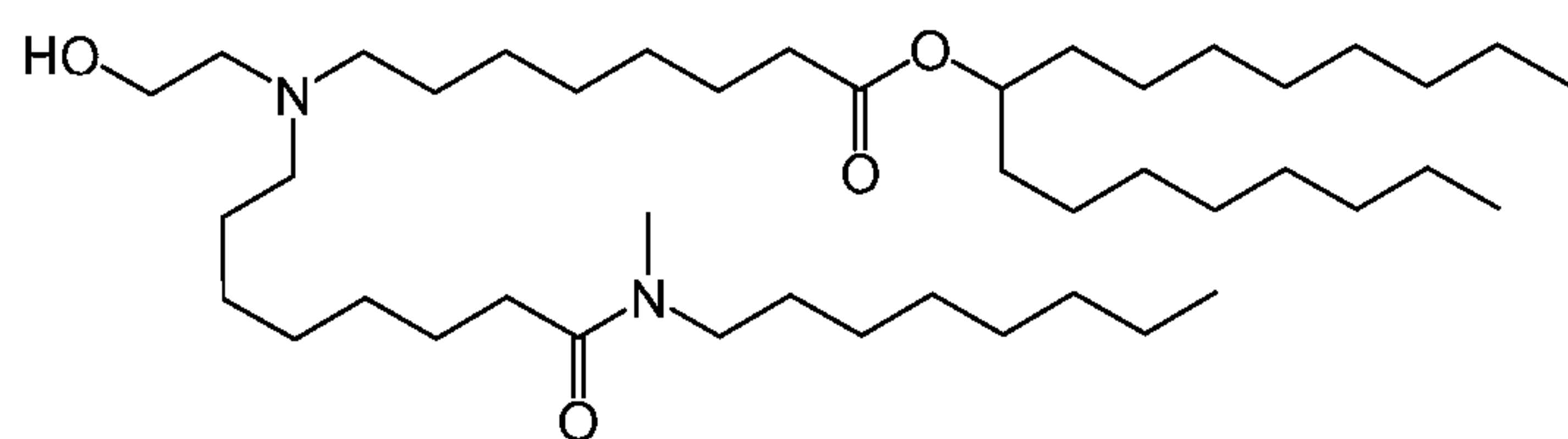




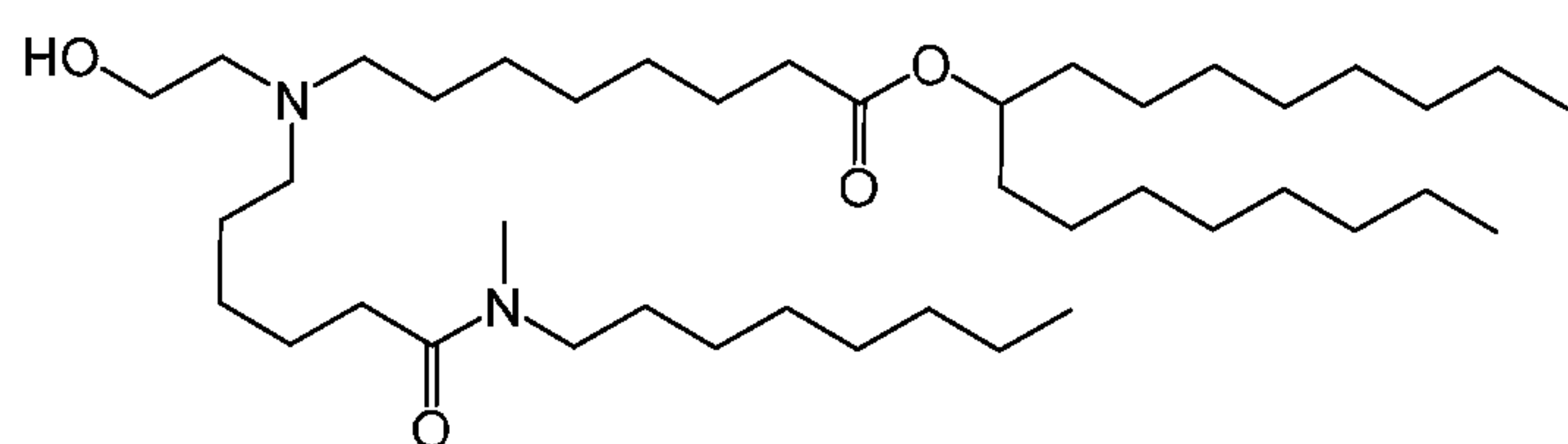
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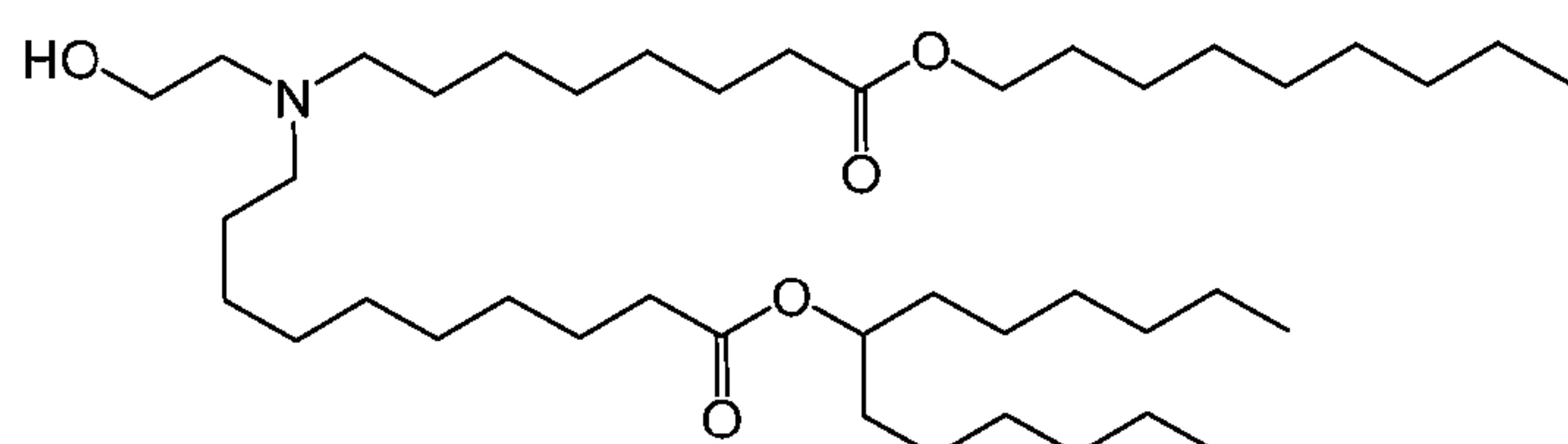
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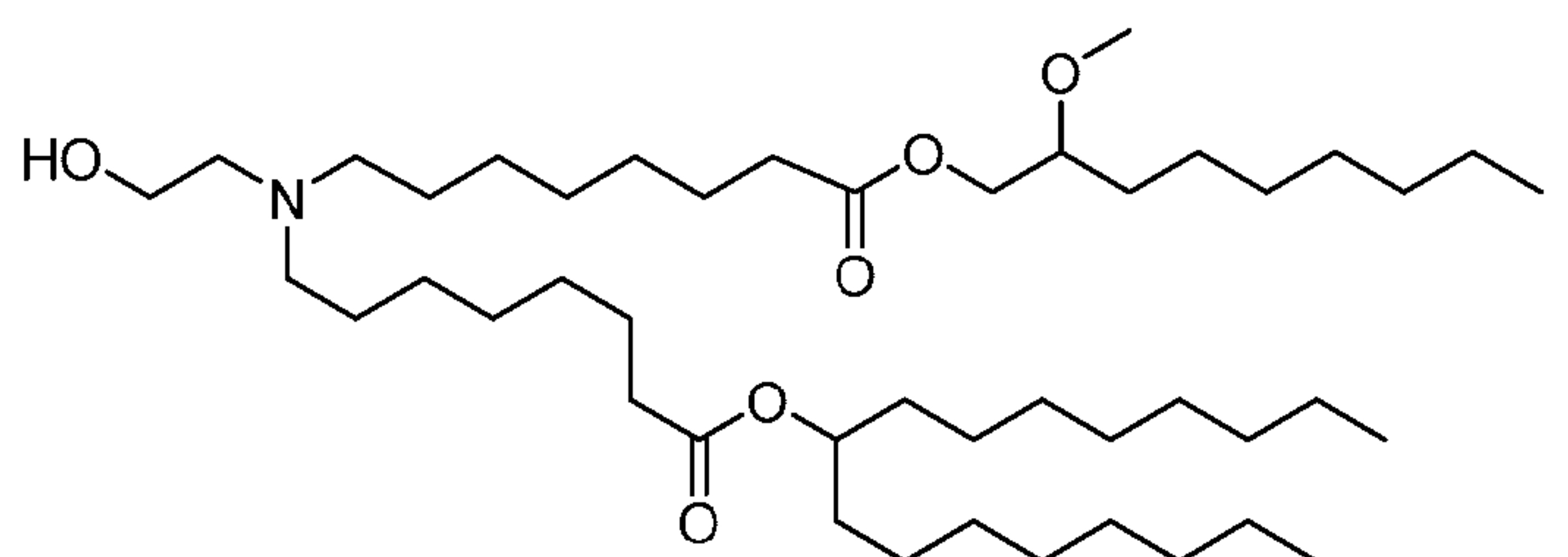
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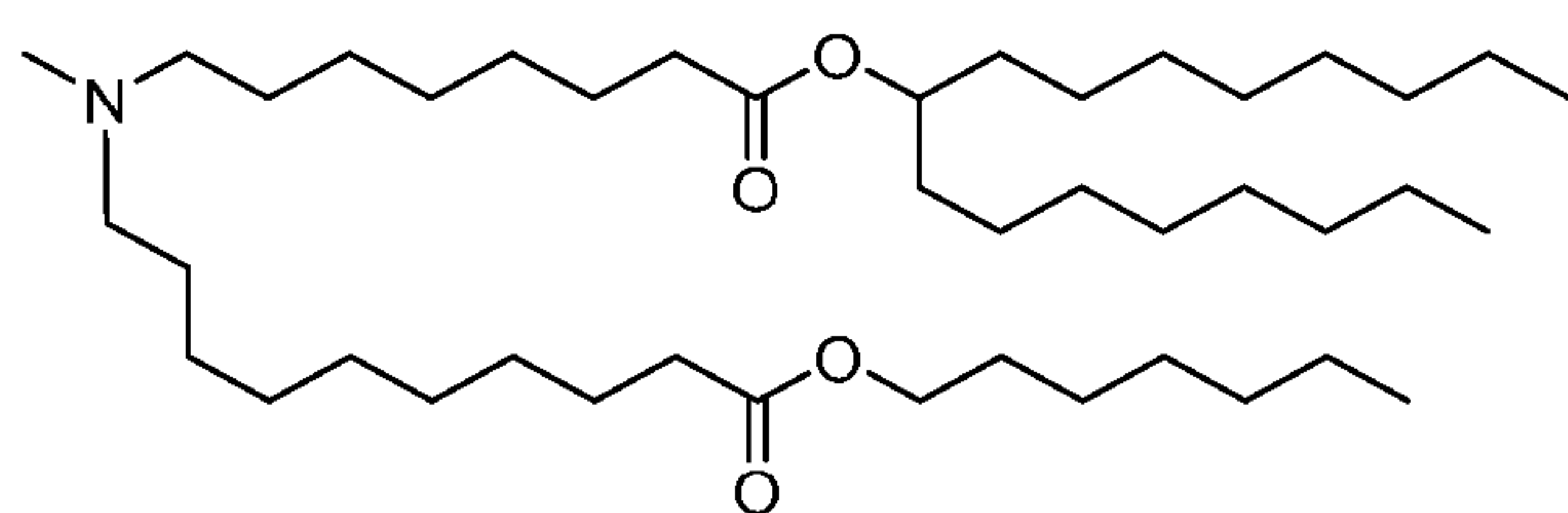
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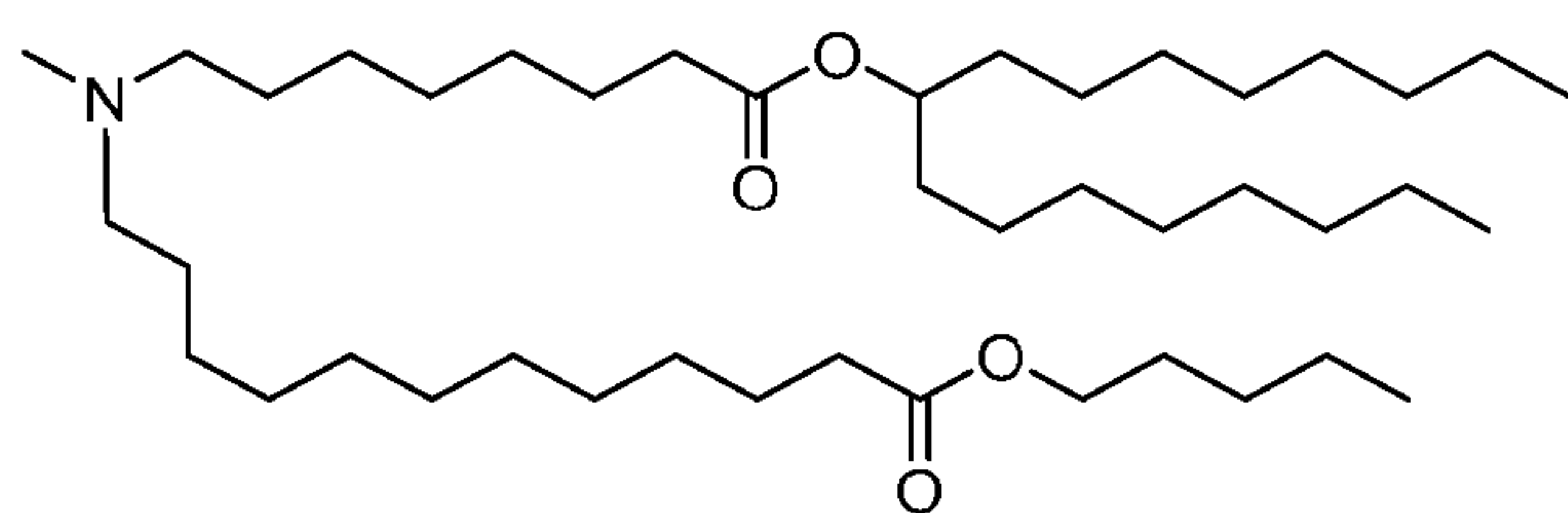
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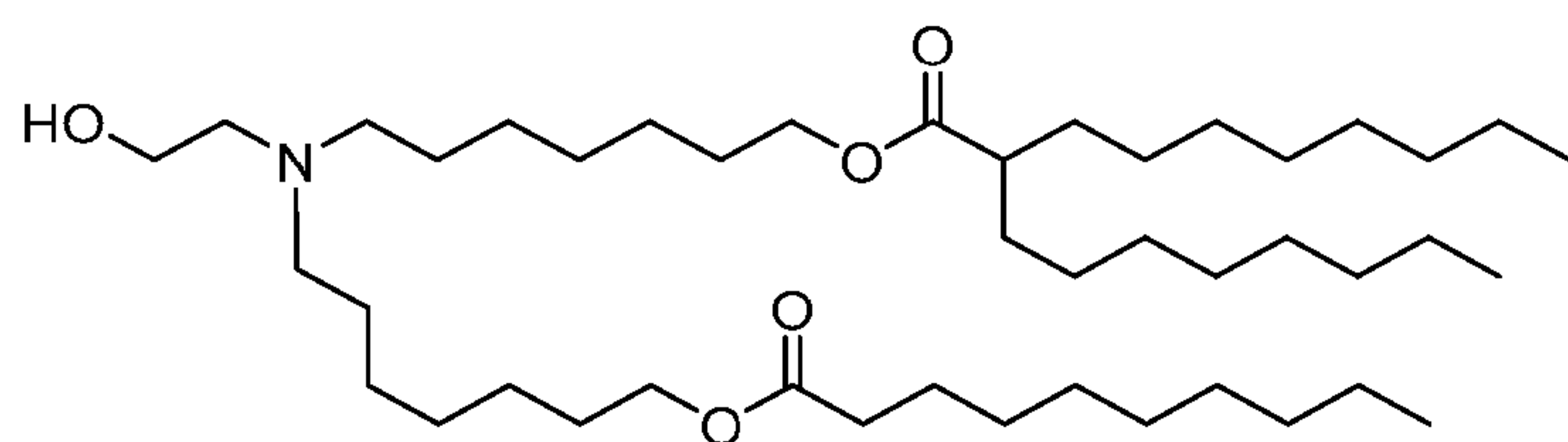
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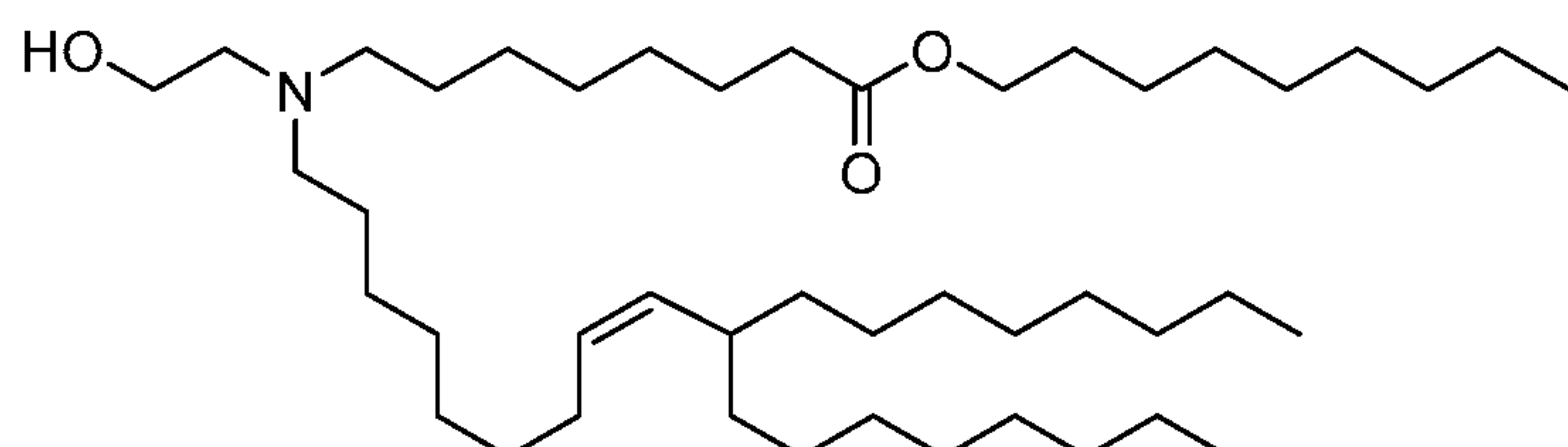
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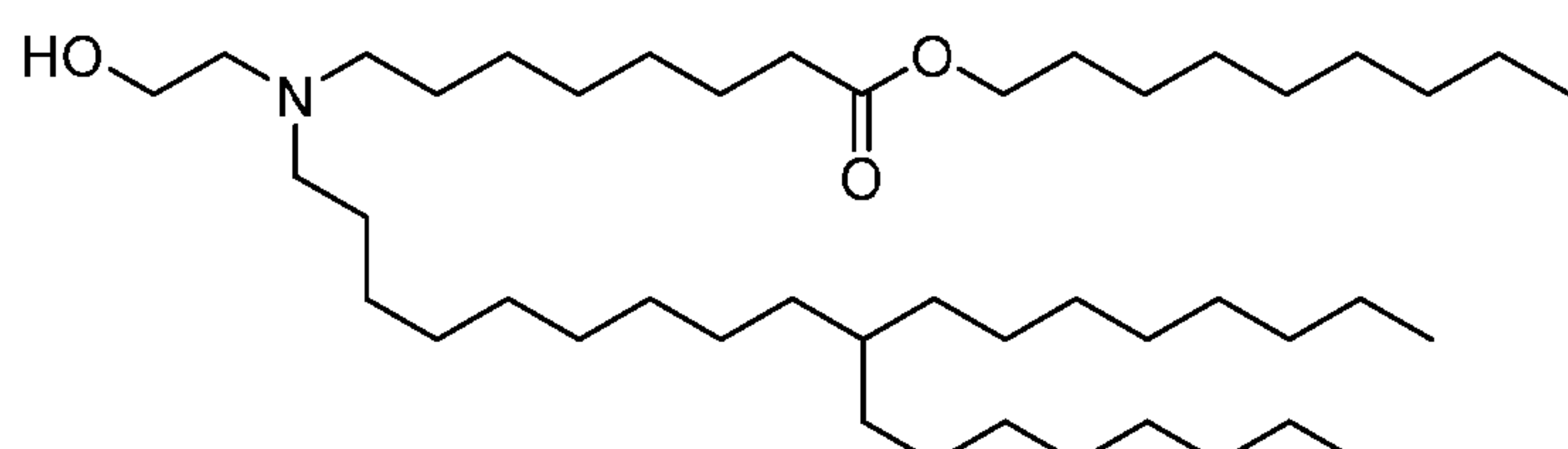
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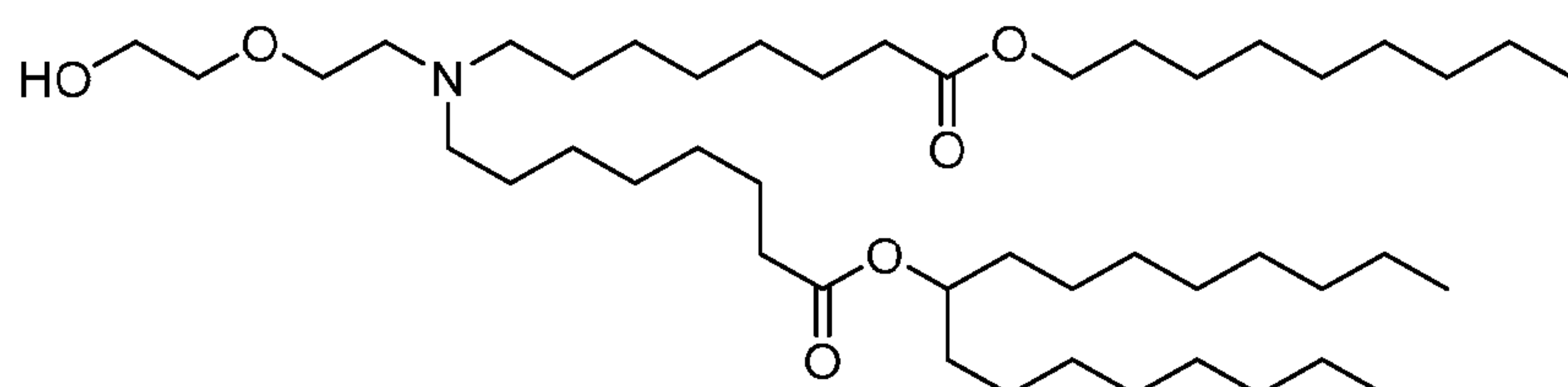
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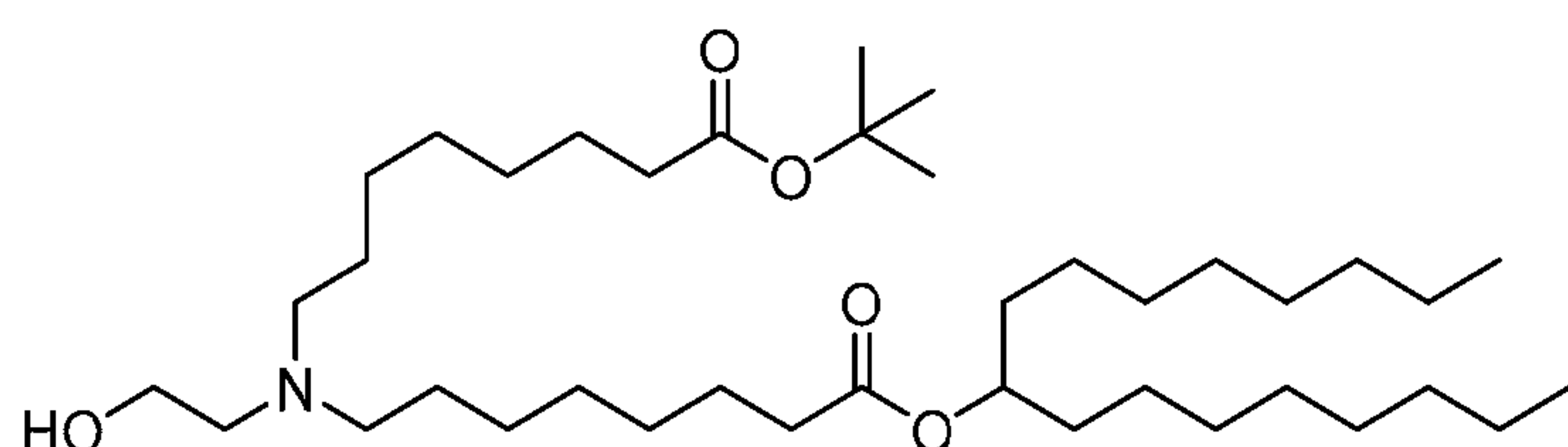
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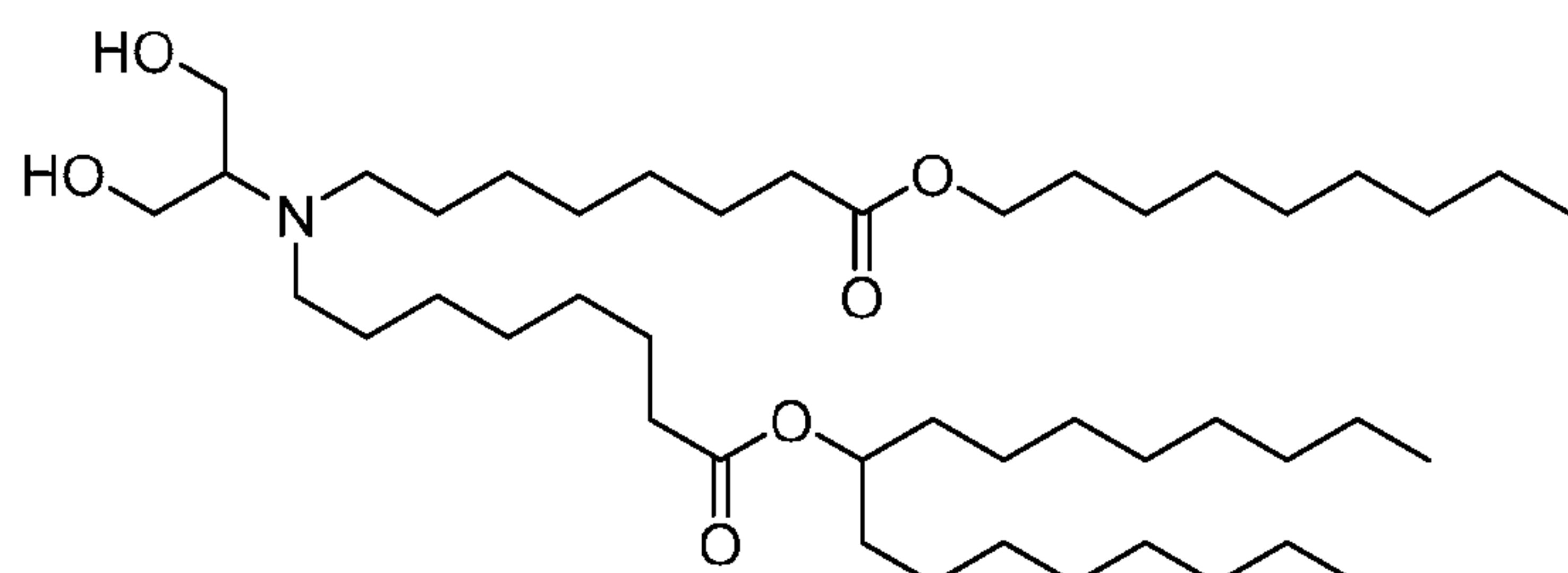
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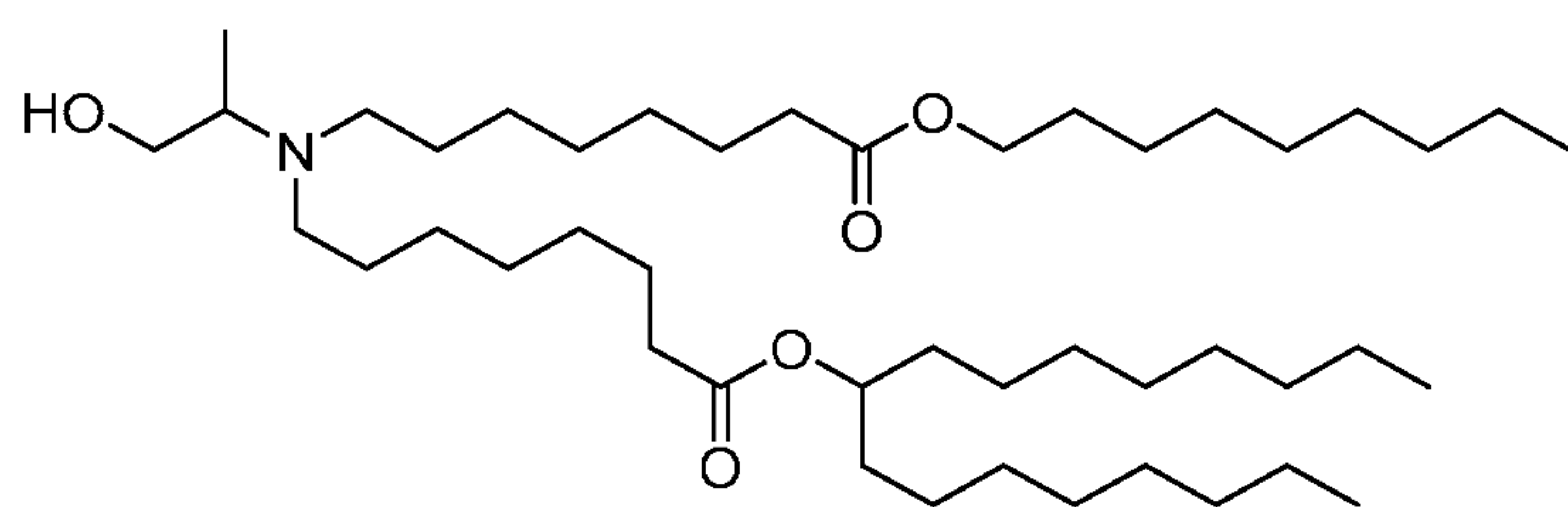
(Compound 154),



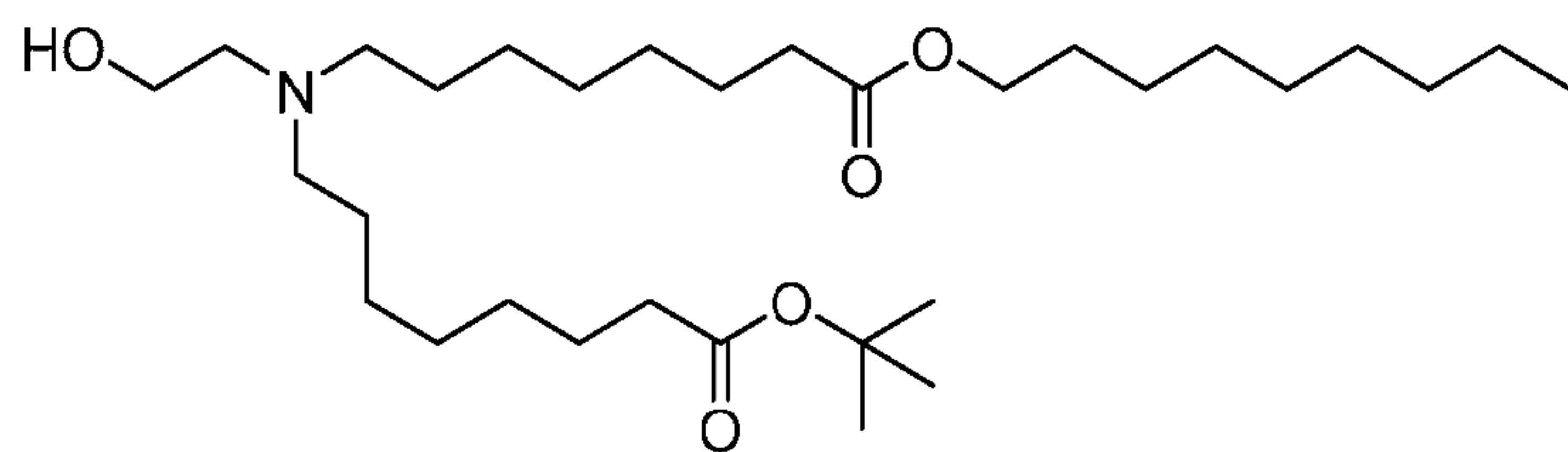
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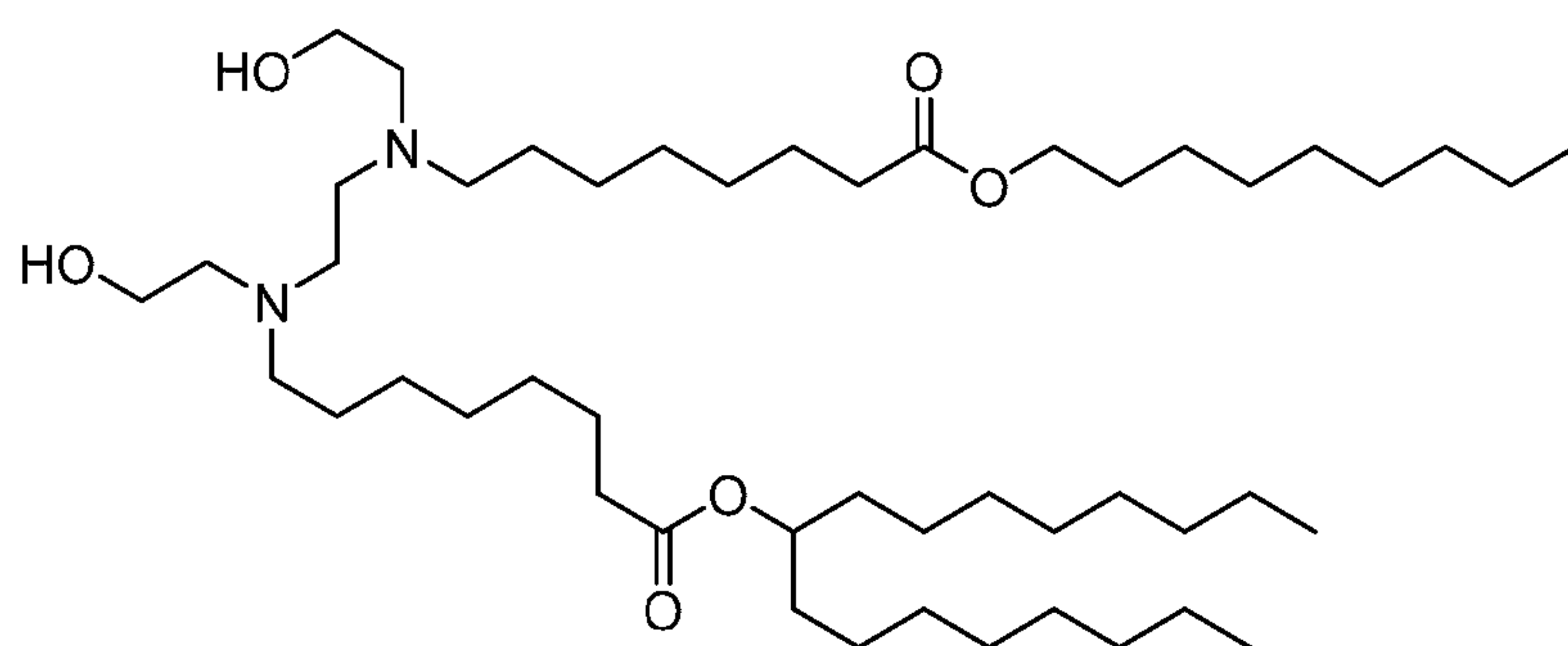
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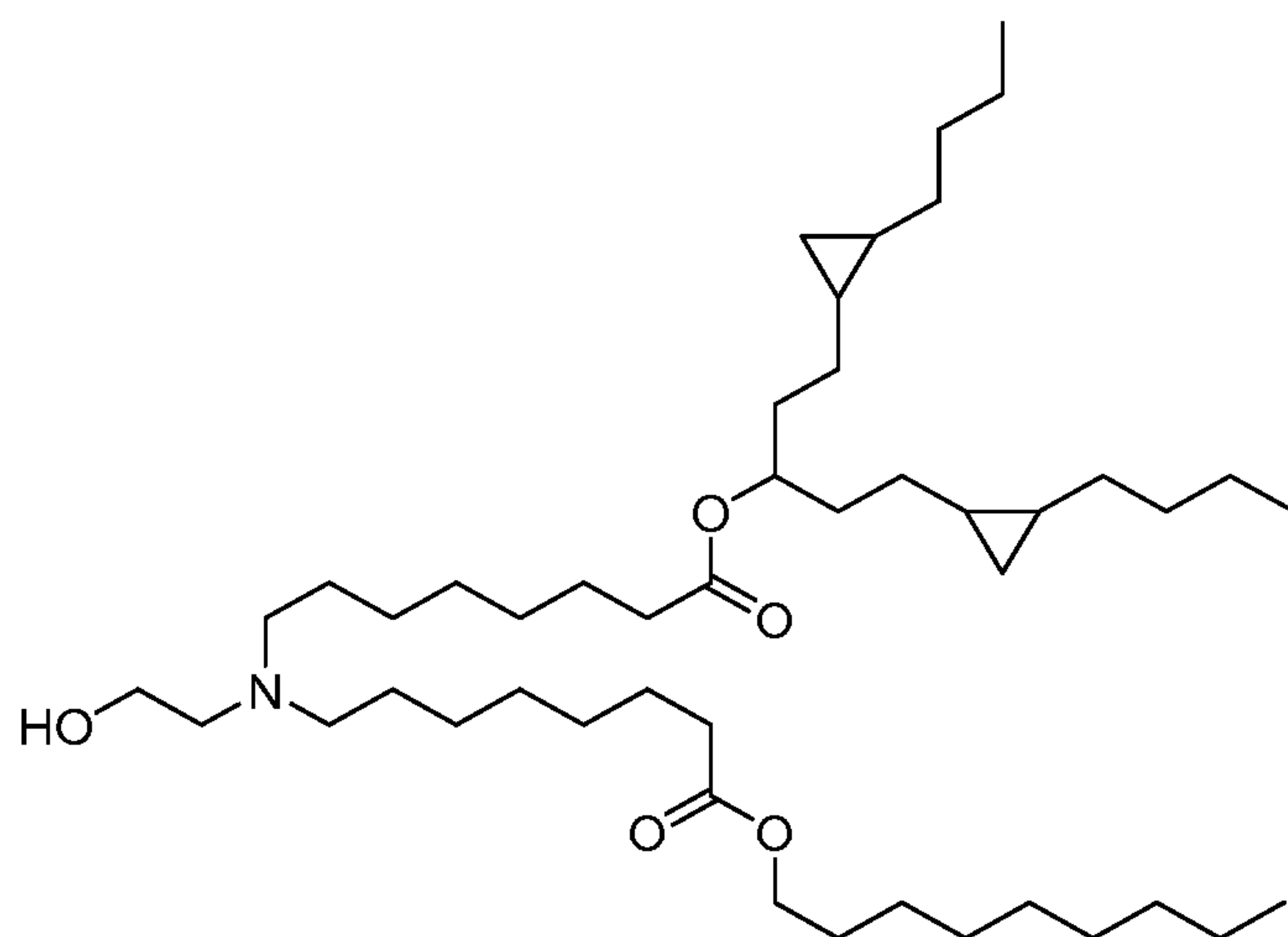
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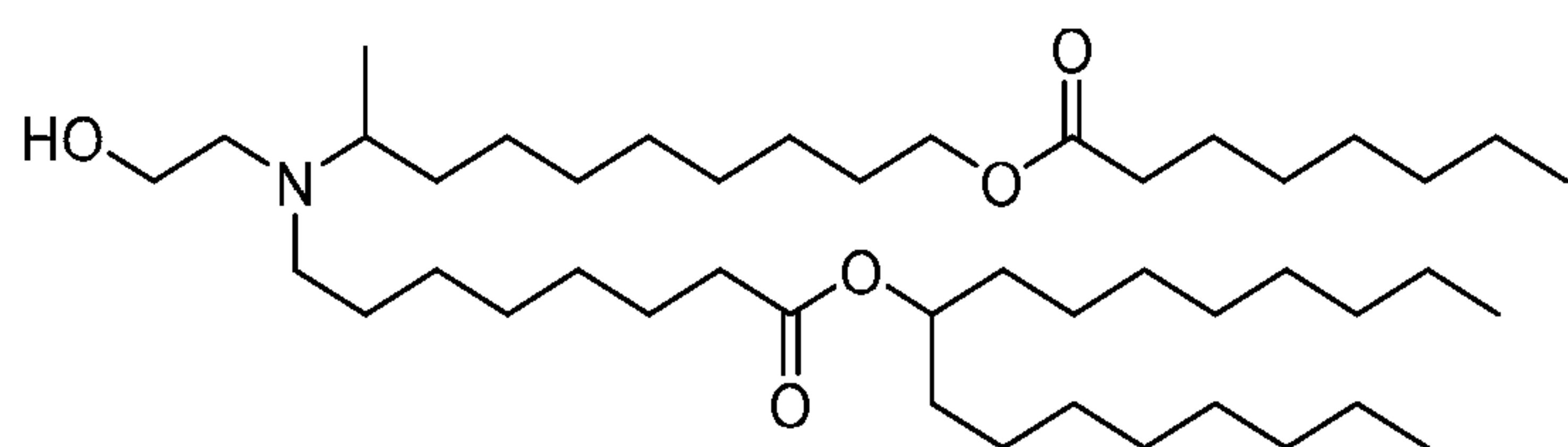
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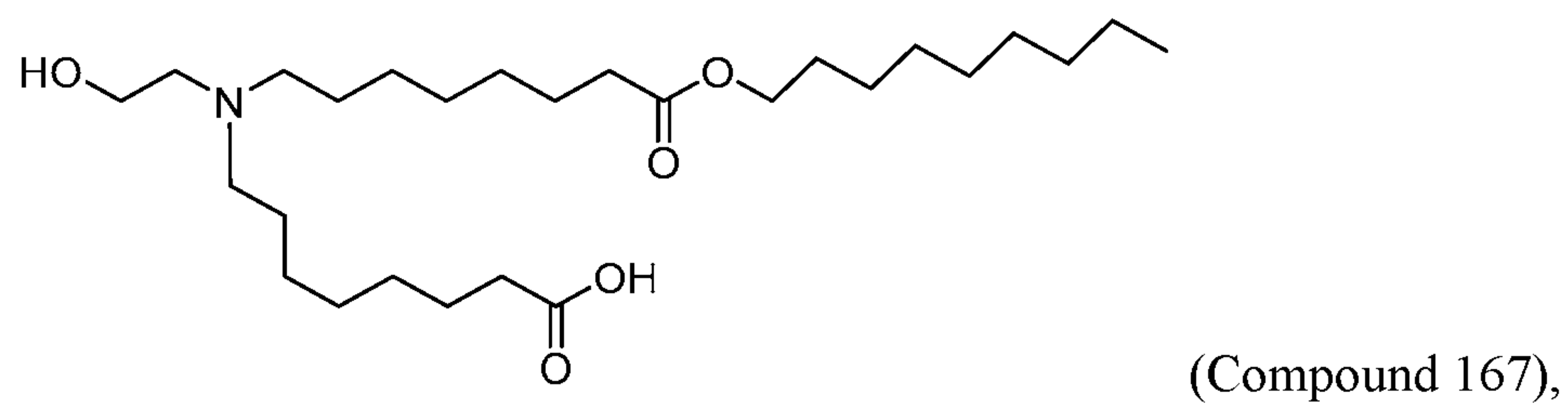
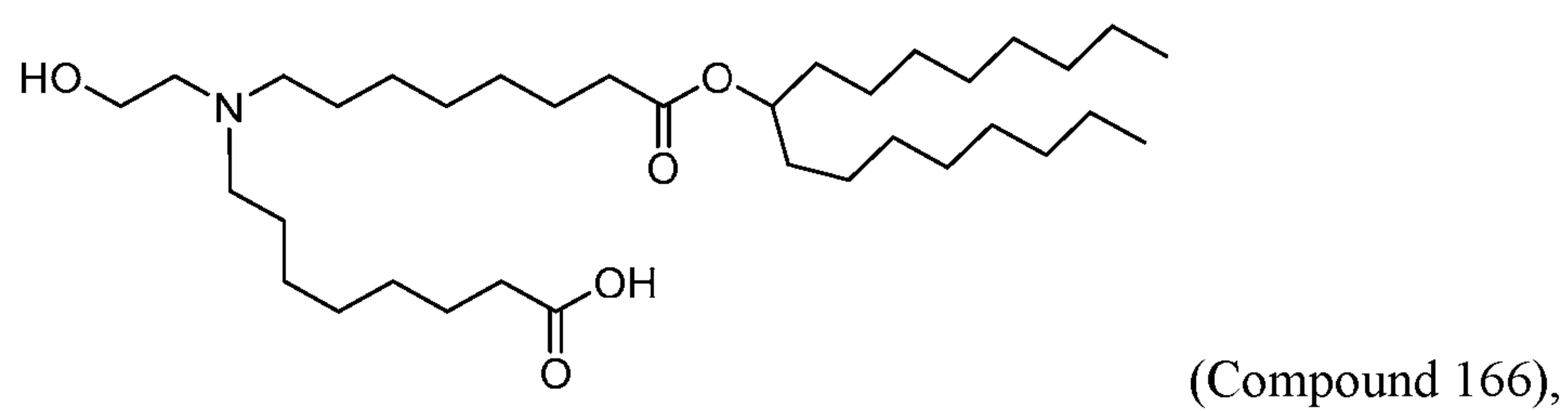
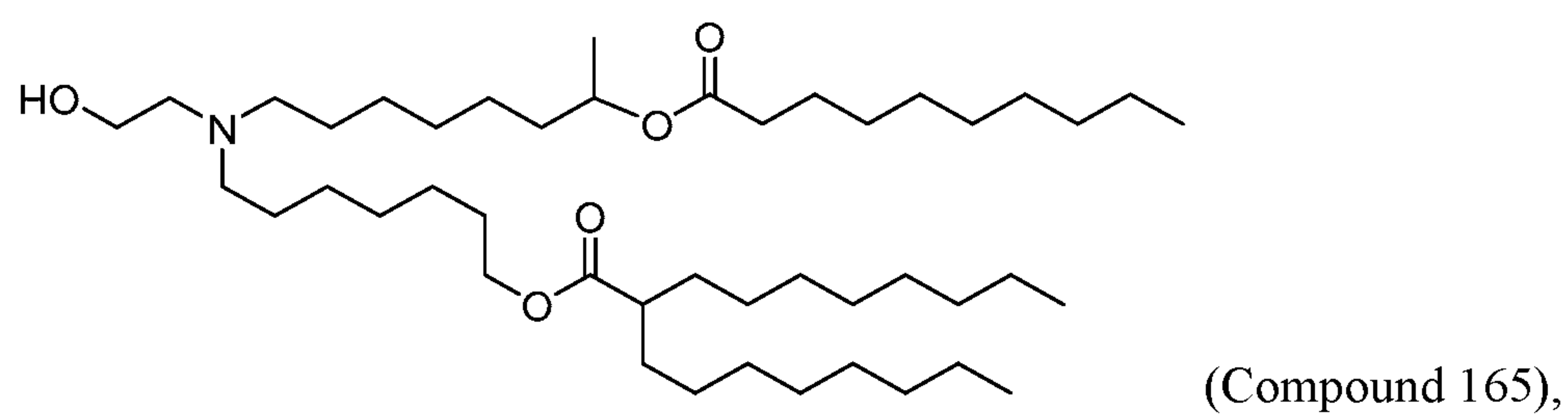
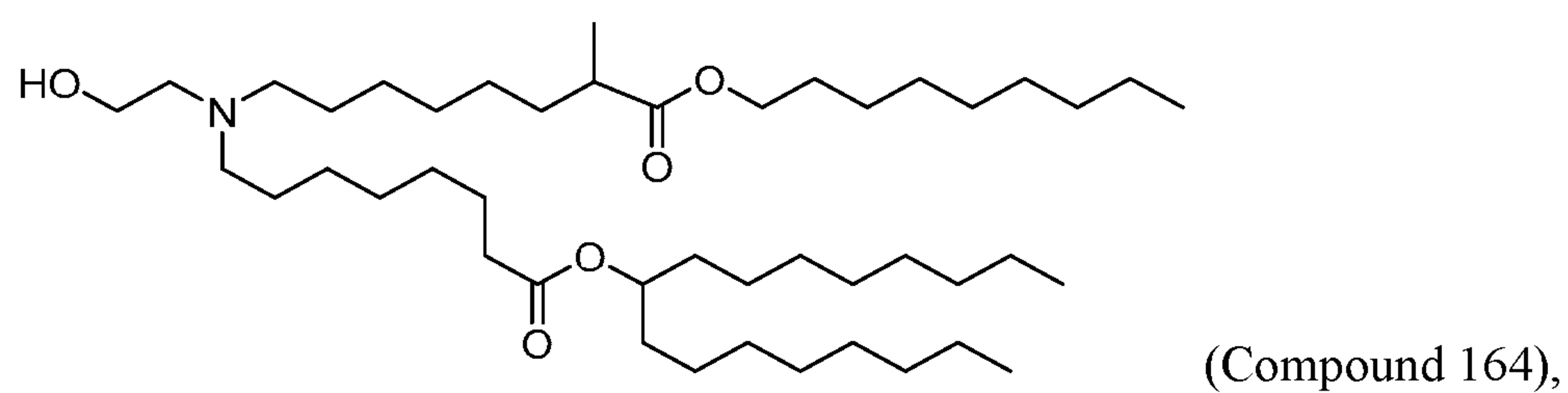
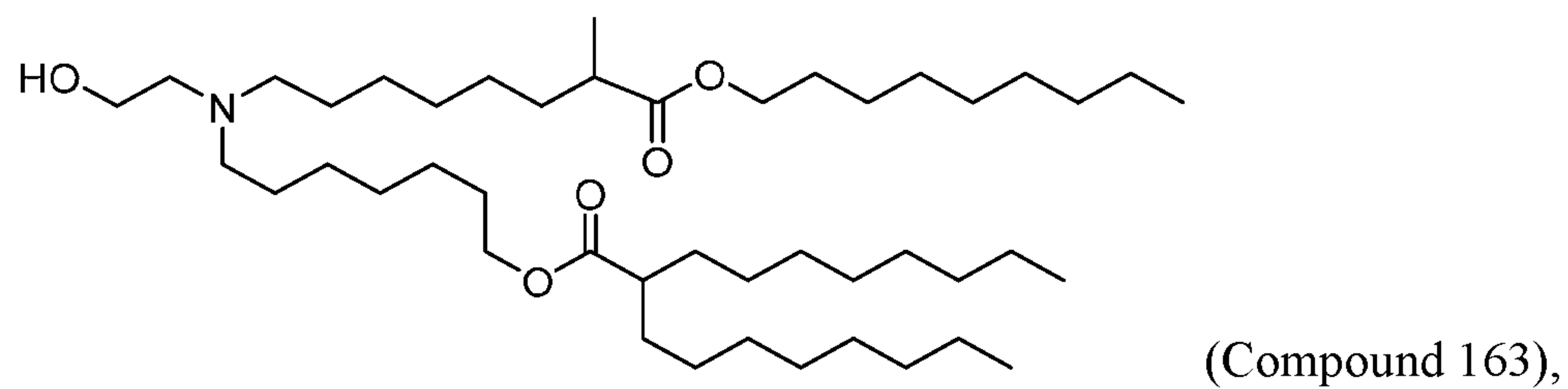
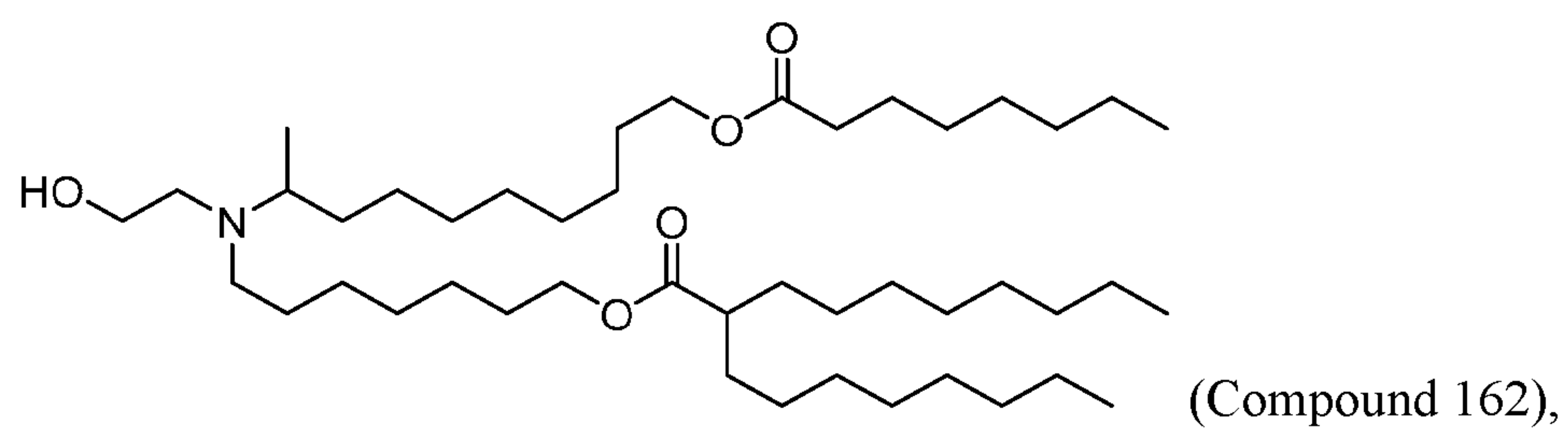
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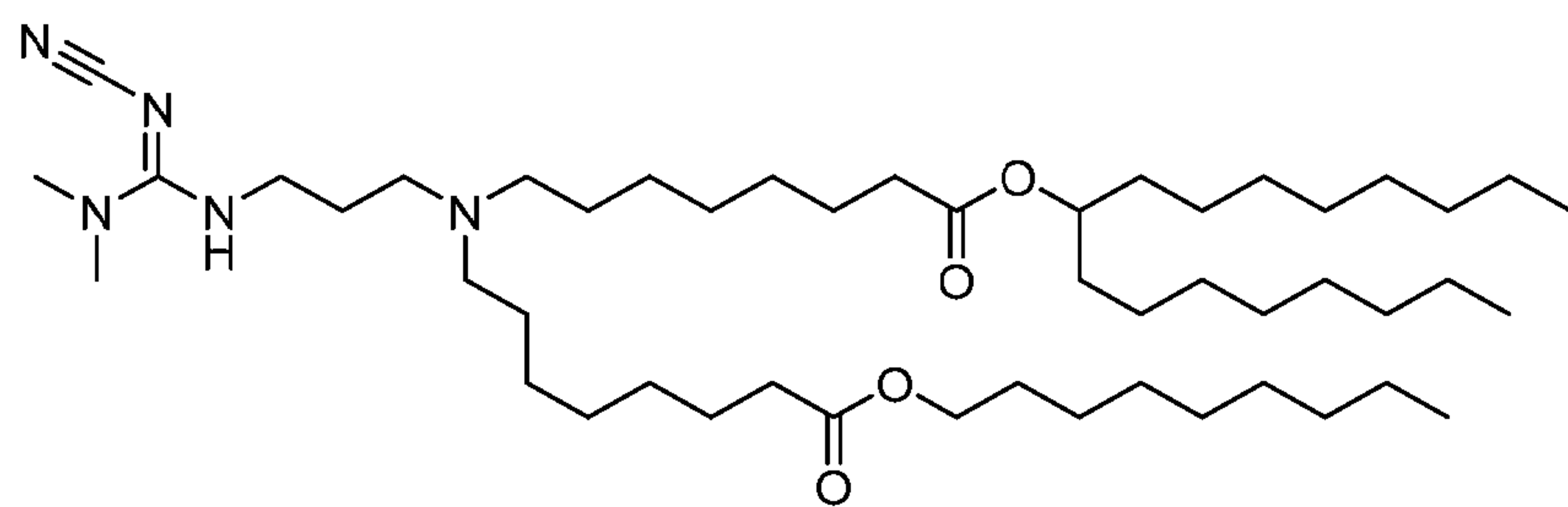


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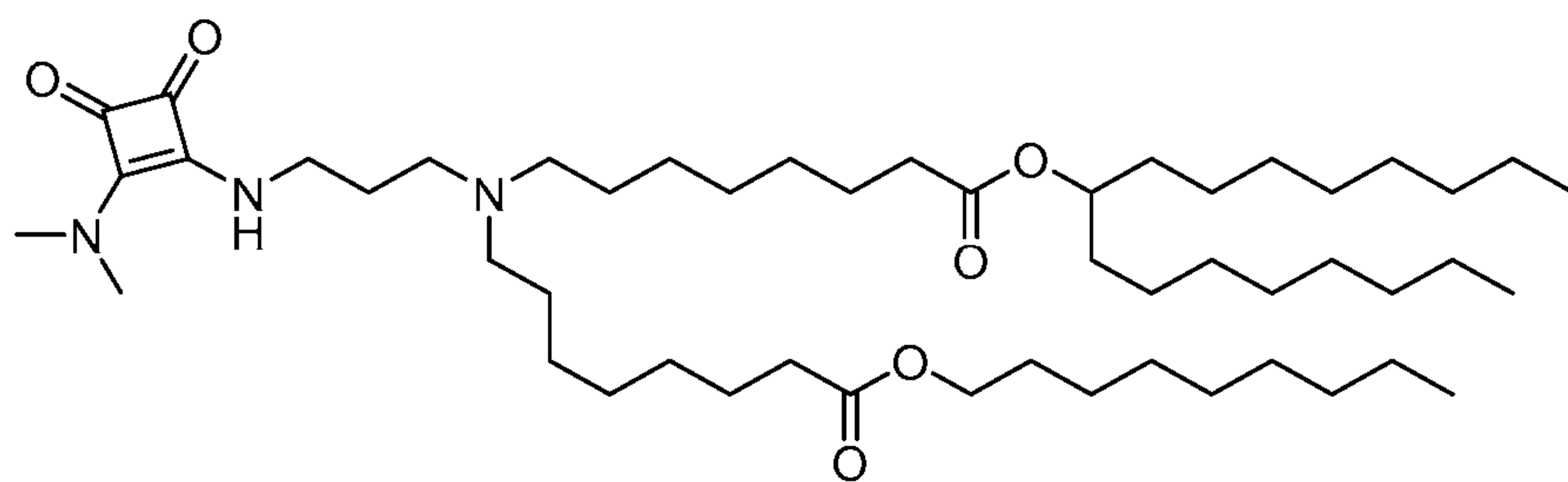


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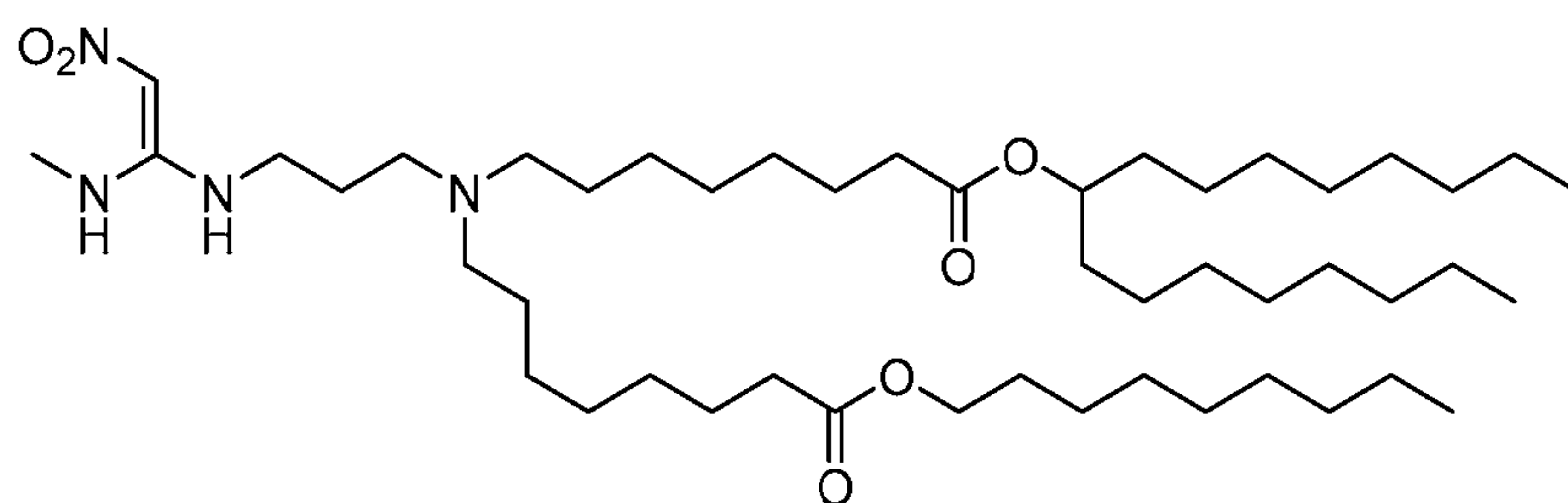




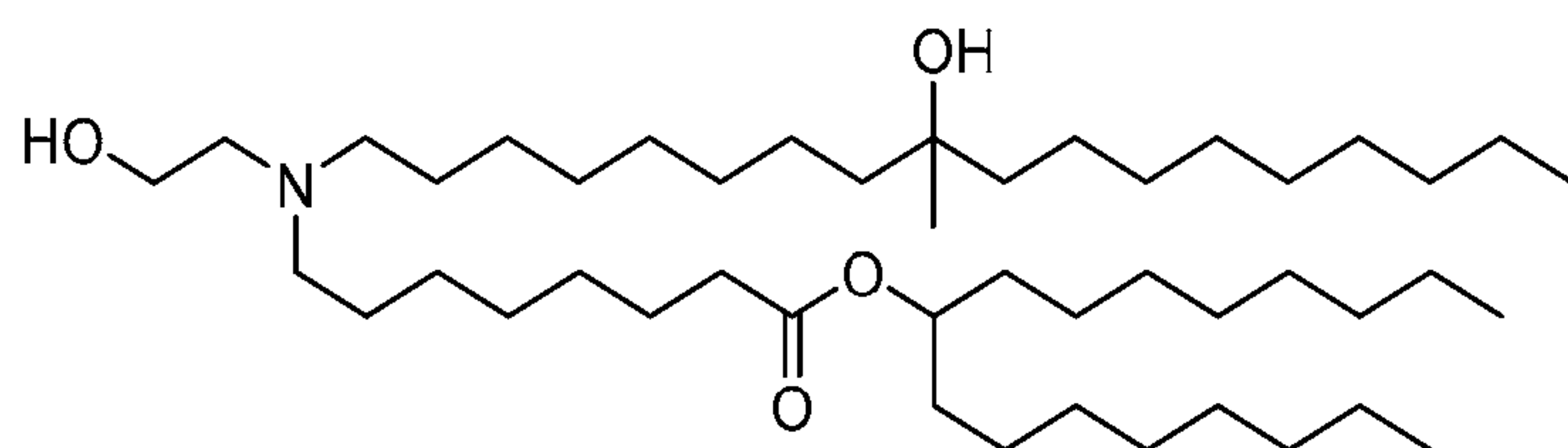
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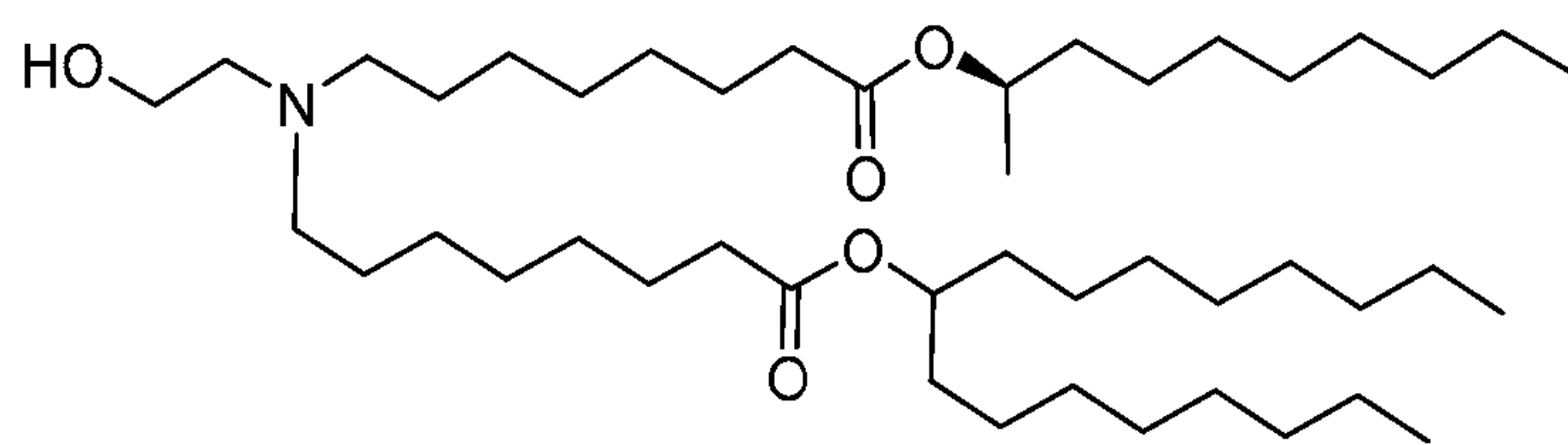
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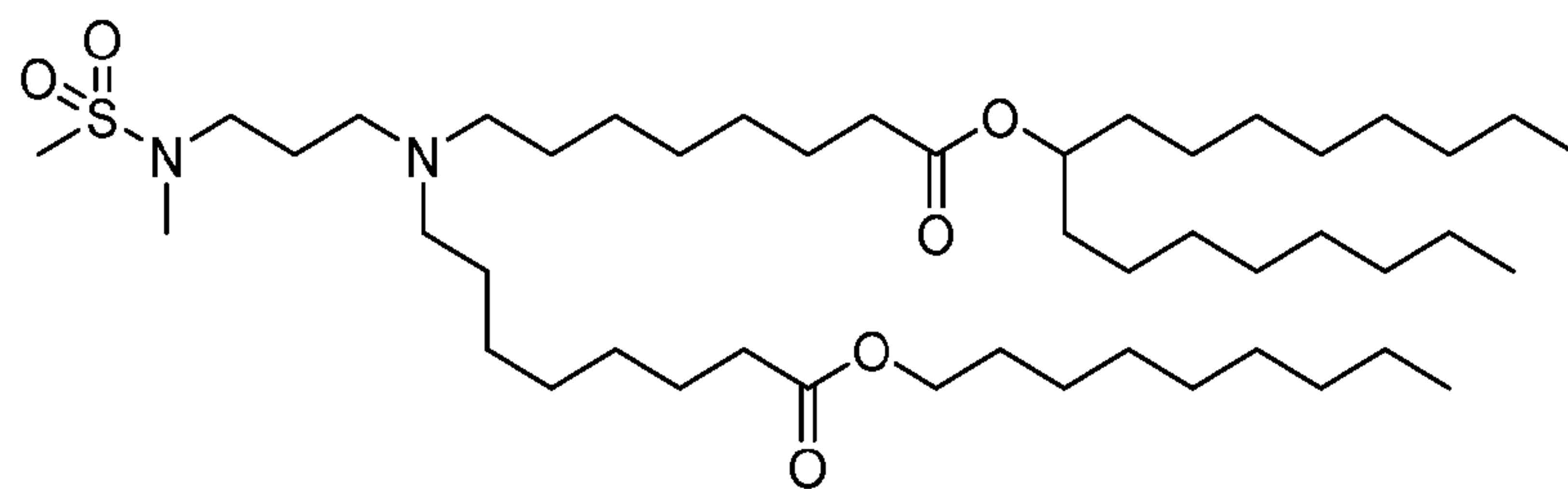
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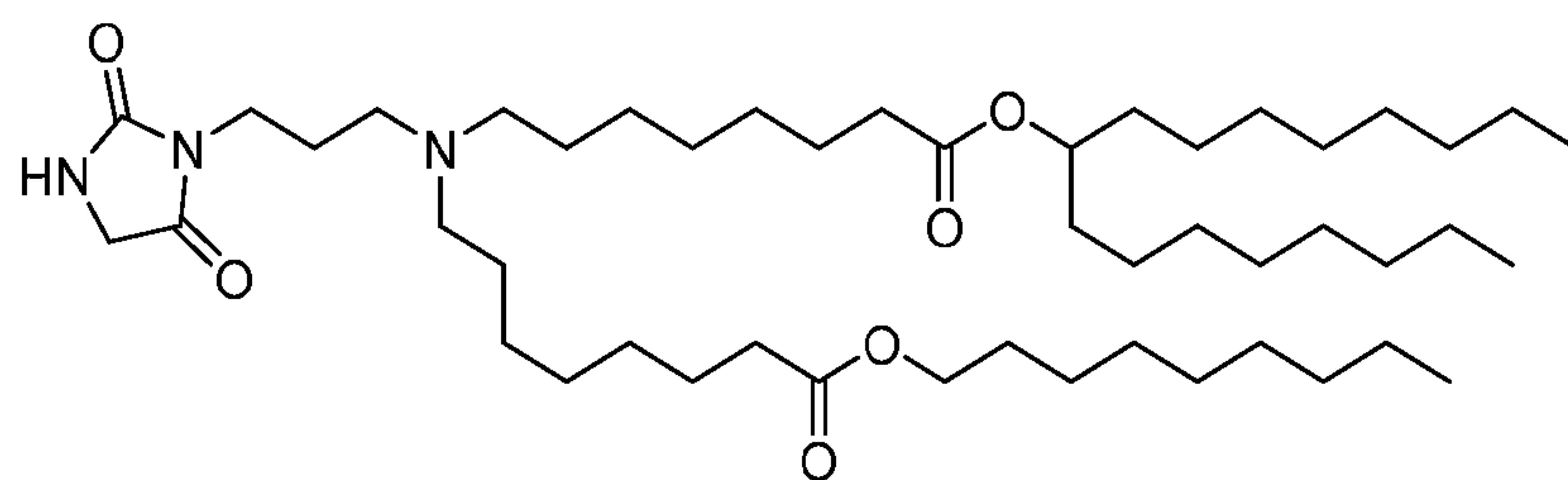
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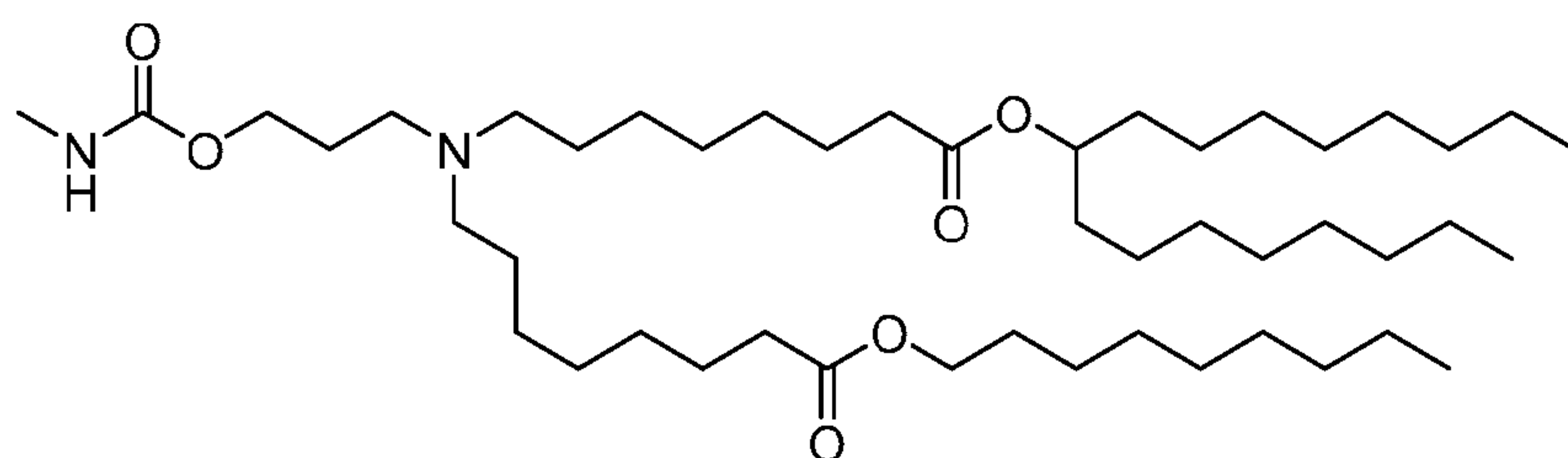
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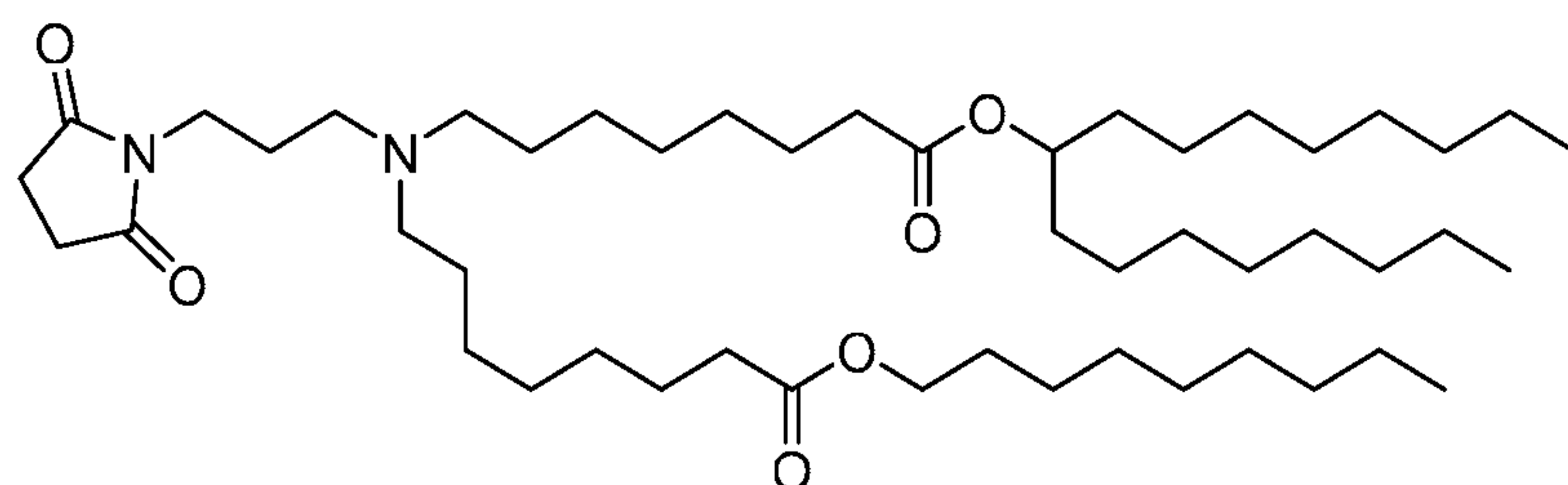
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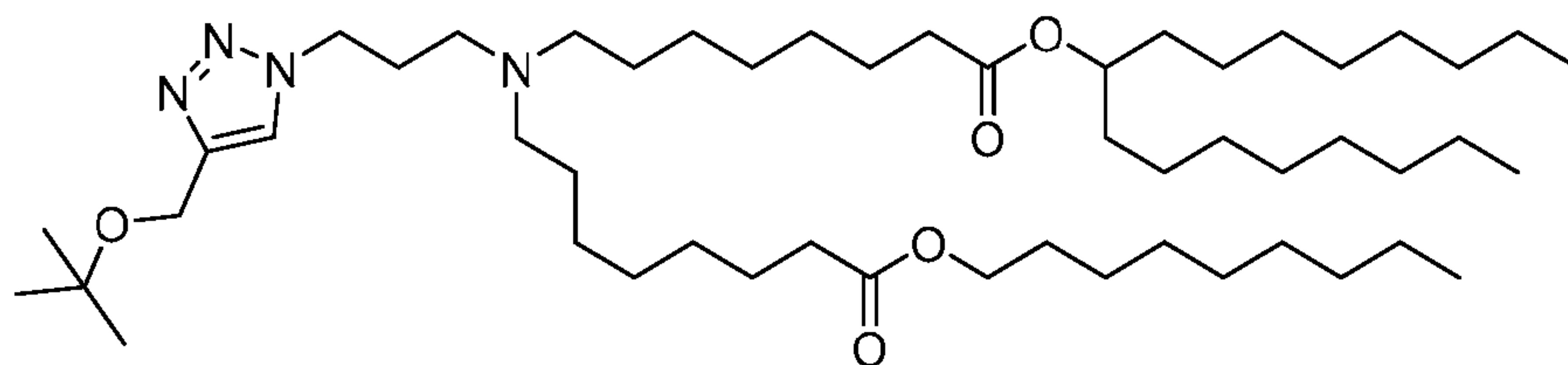
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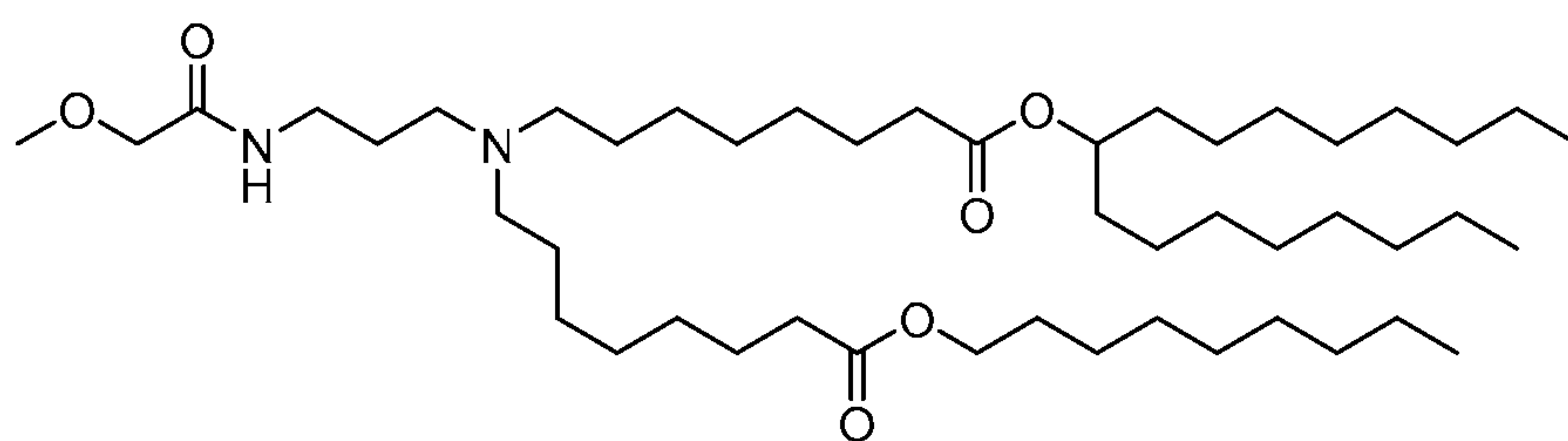
(Compound 175),



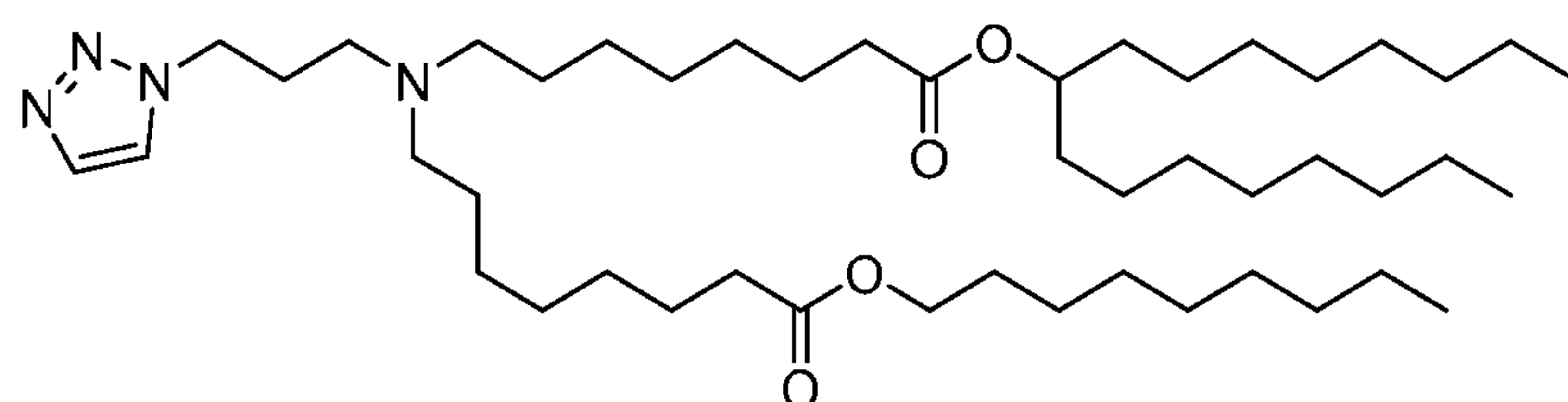
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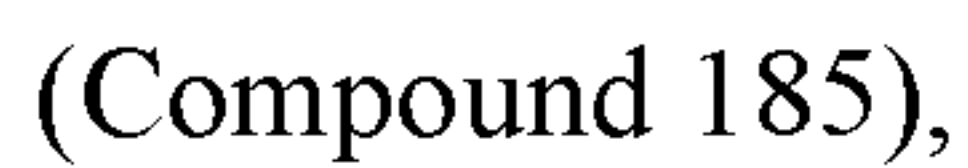
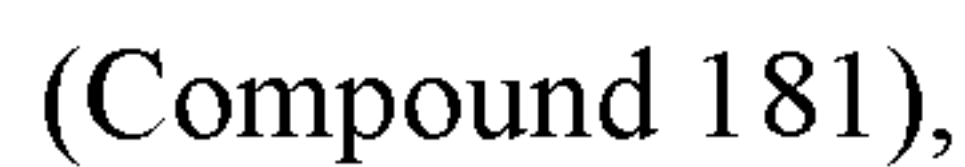
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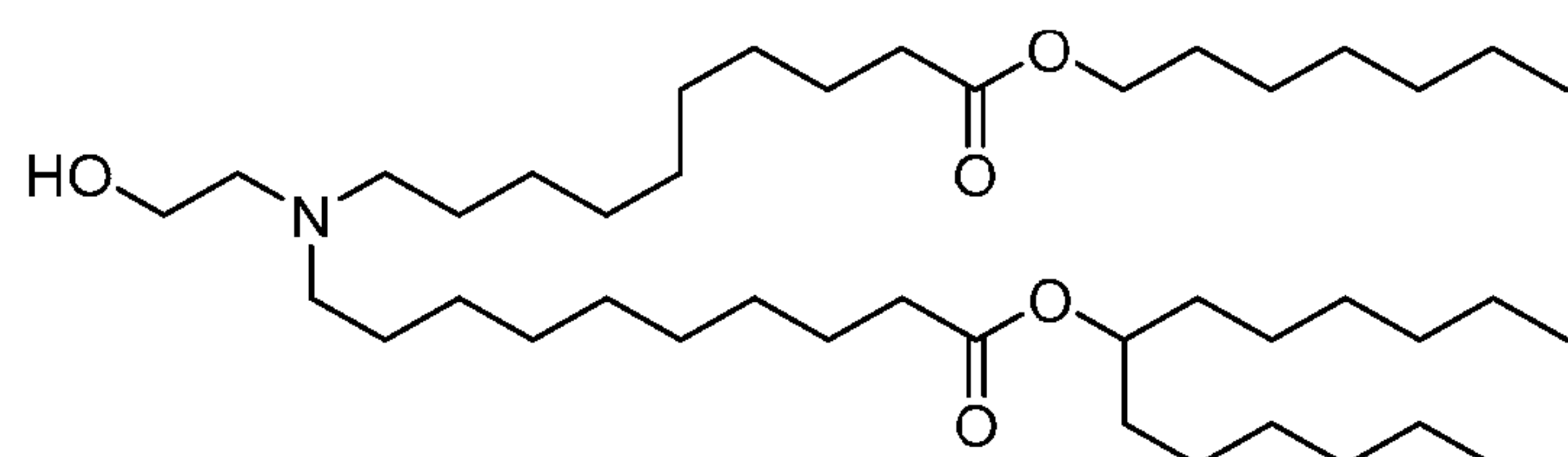


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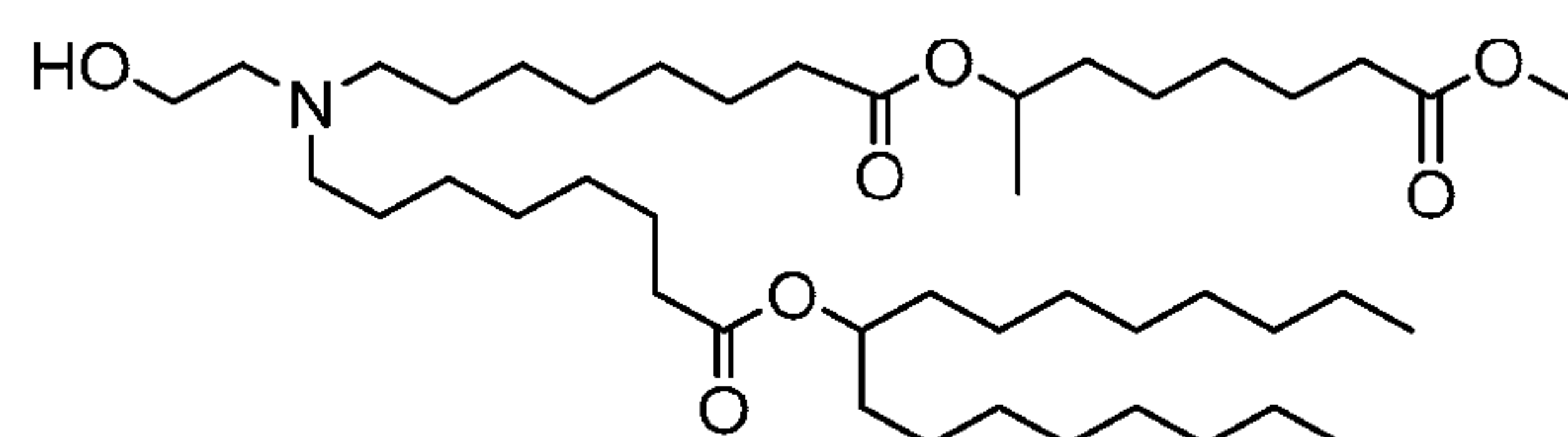


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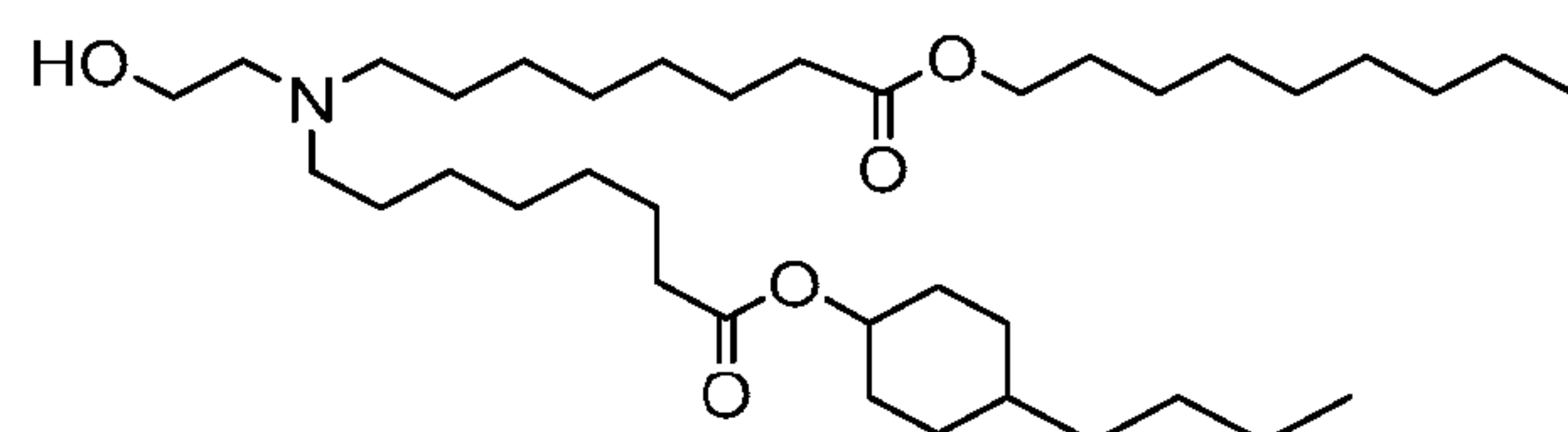




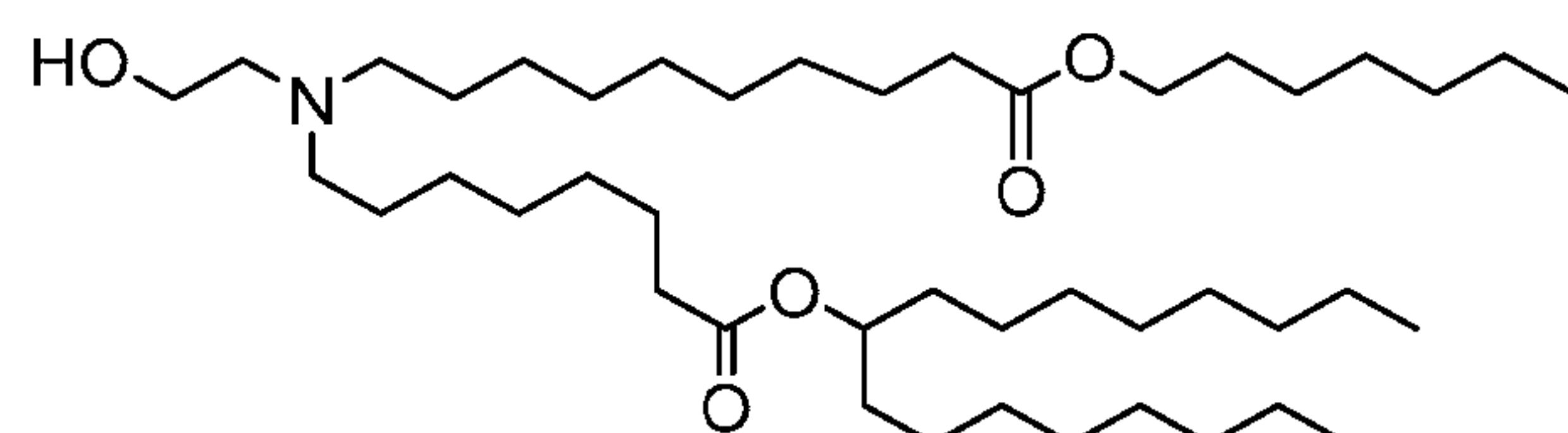
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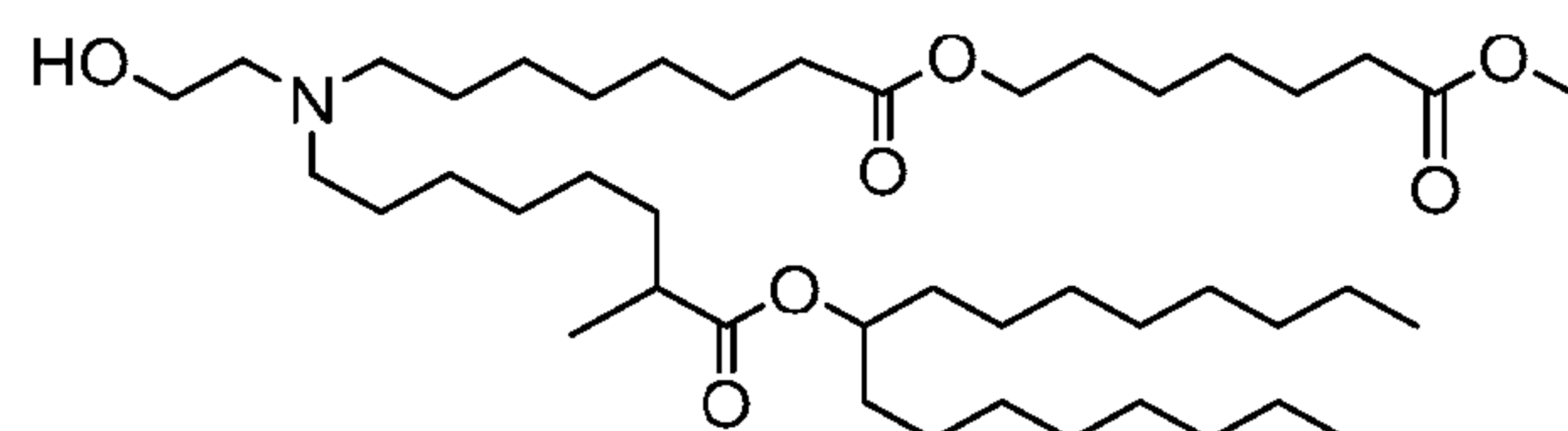
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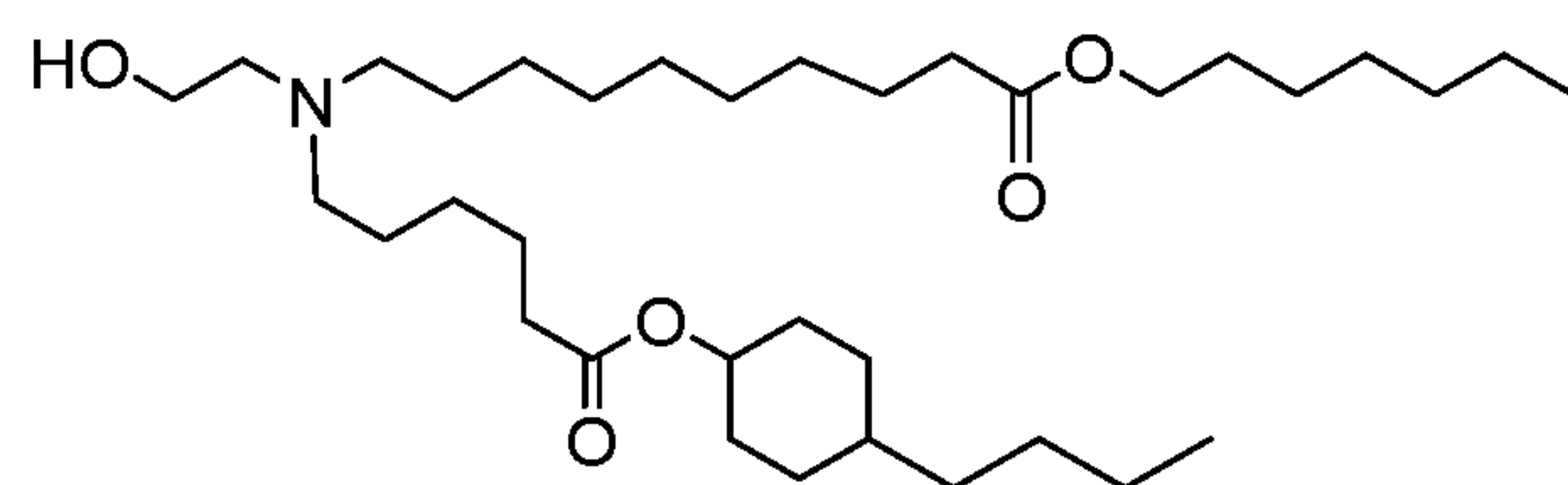
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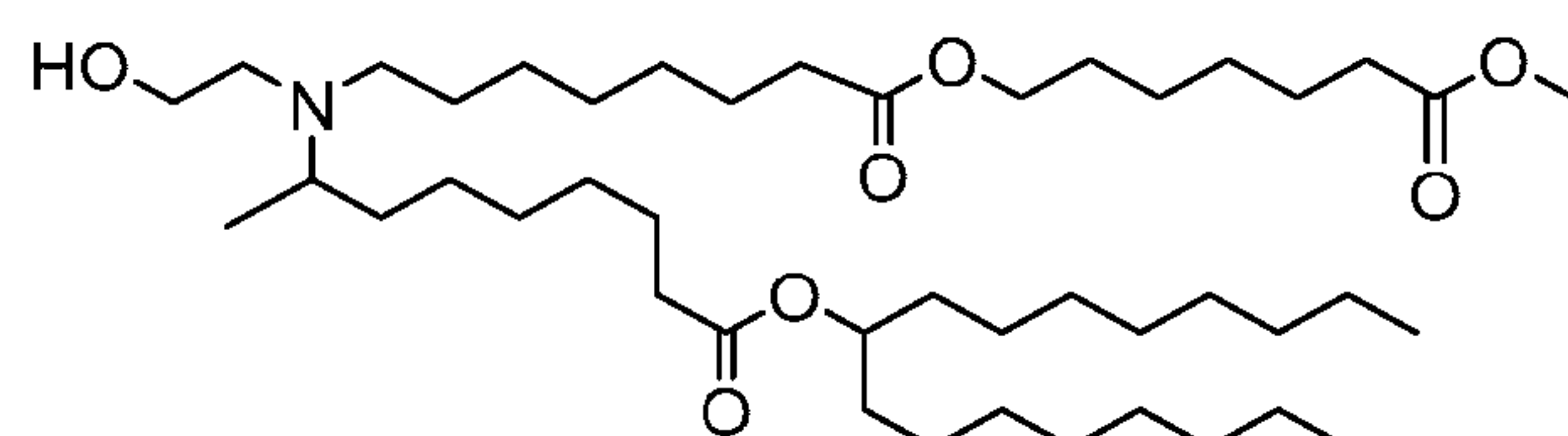
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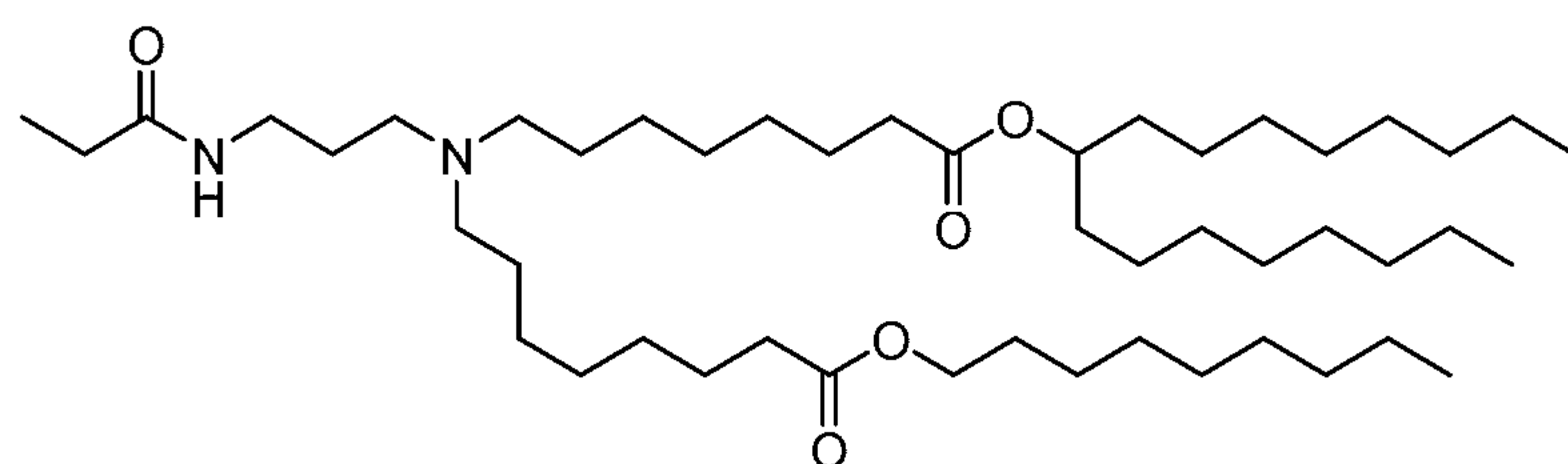
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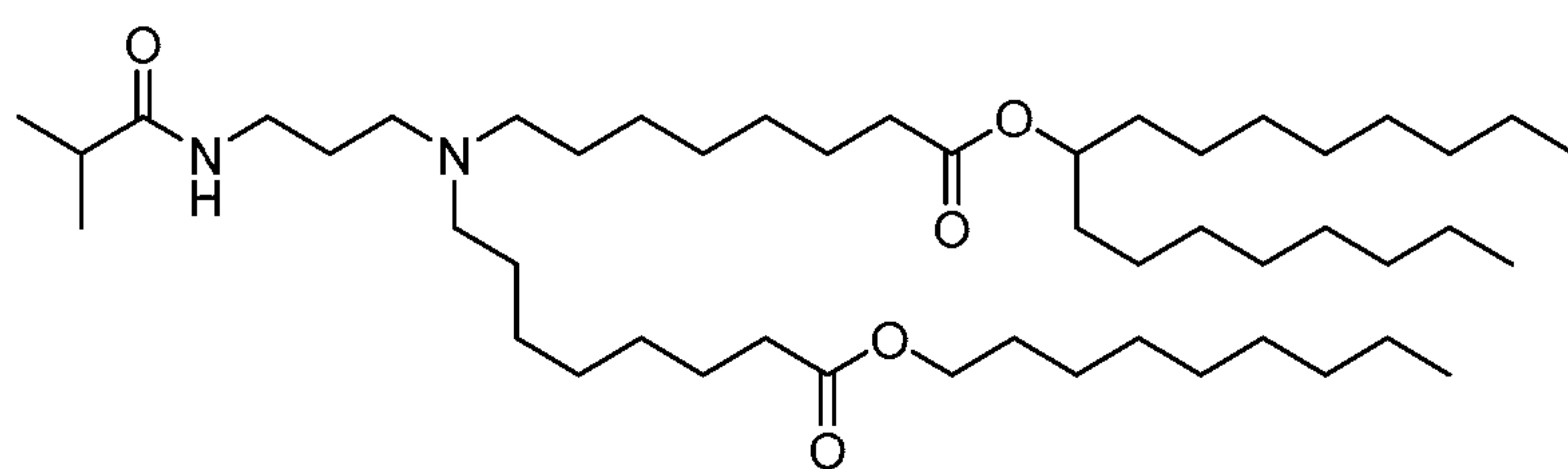
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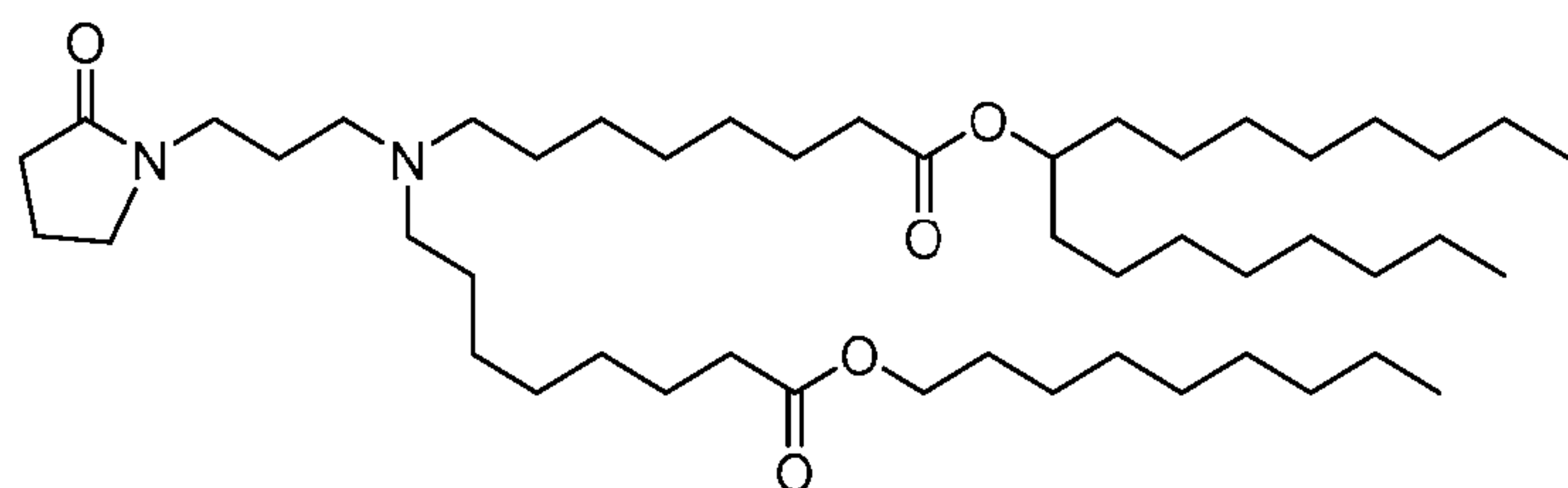
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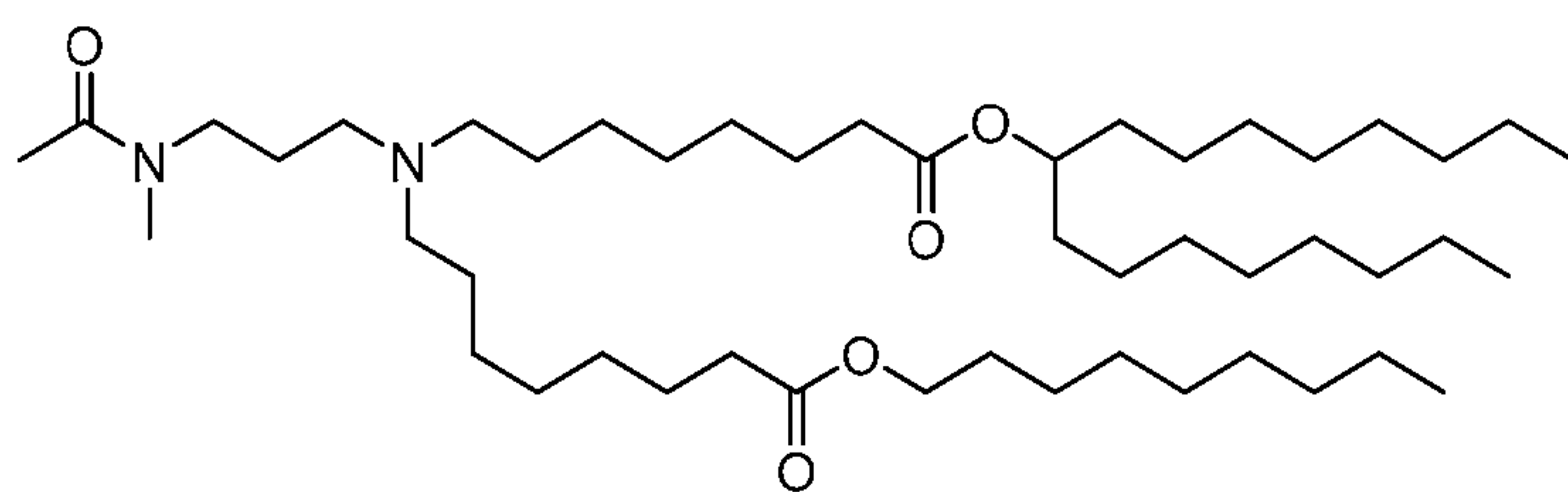
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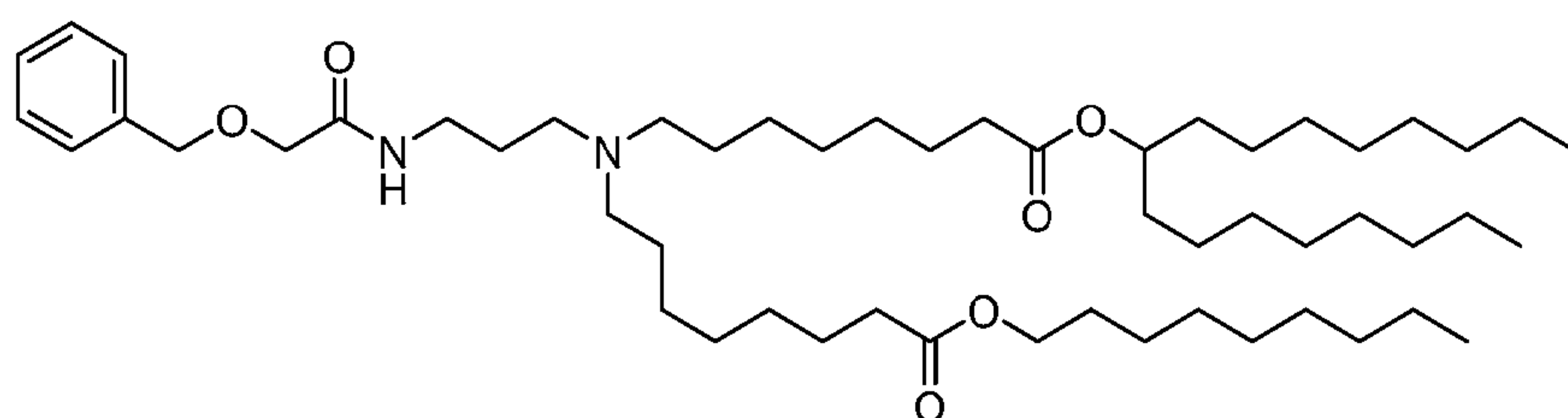
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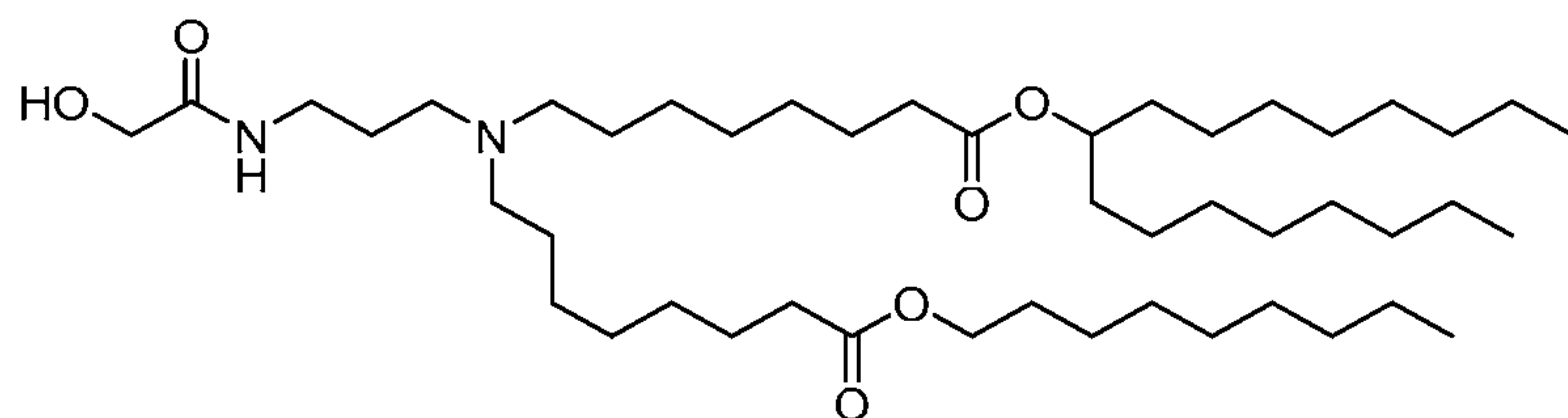
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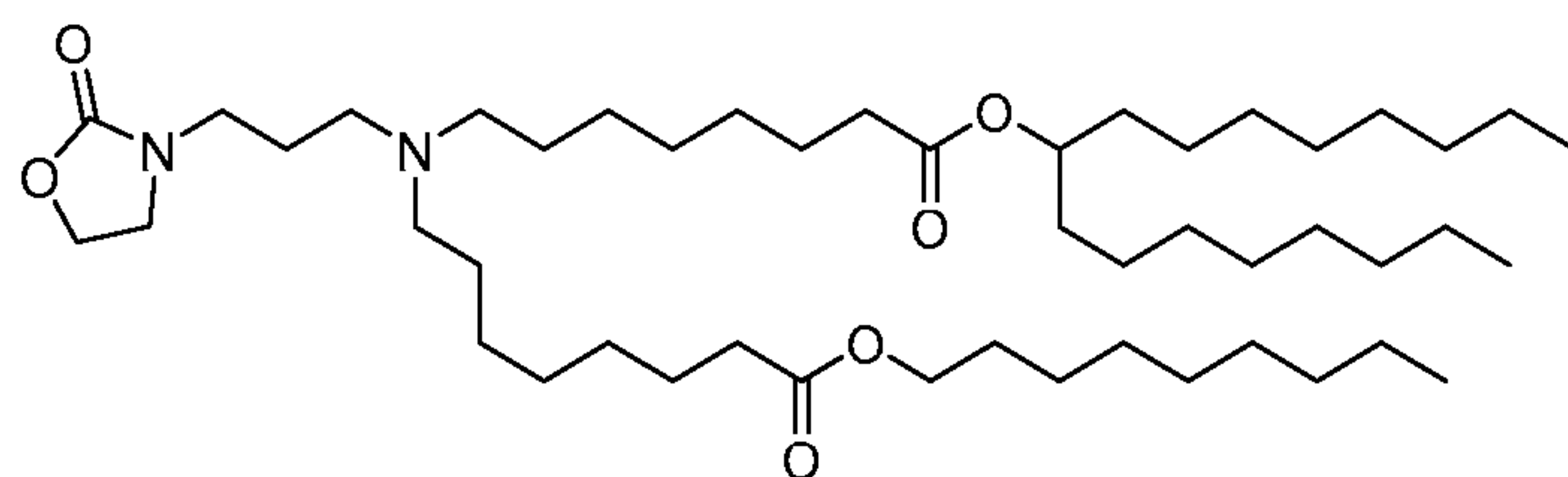
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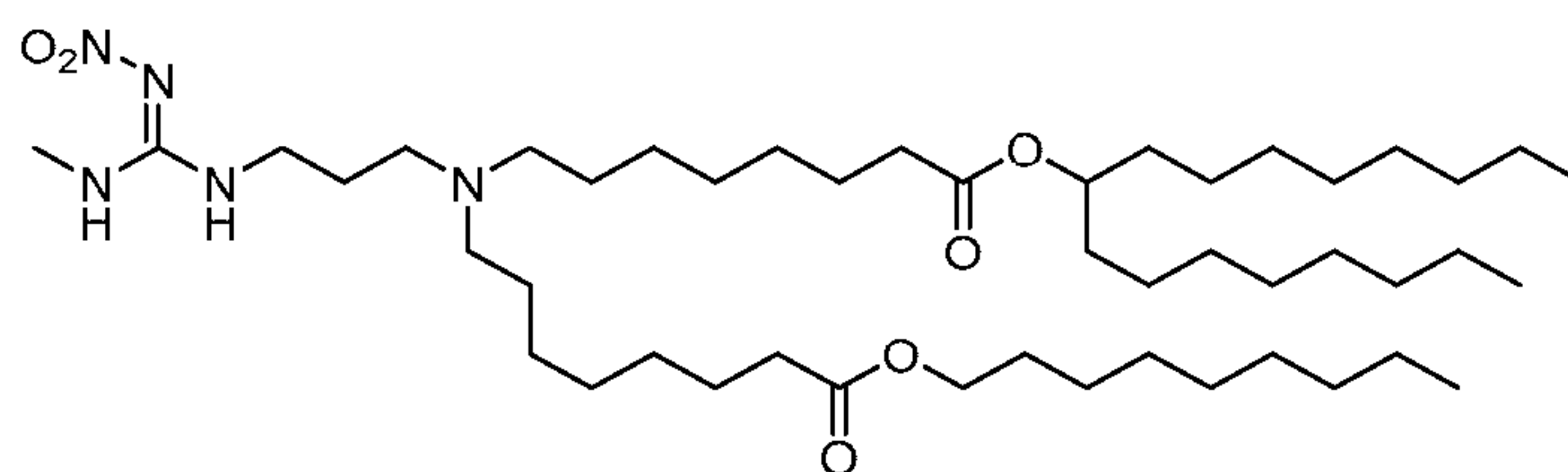
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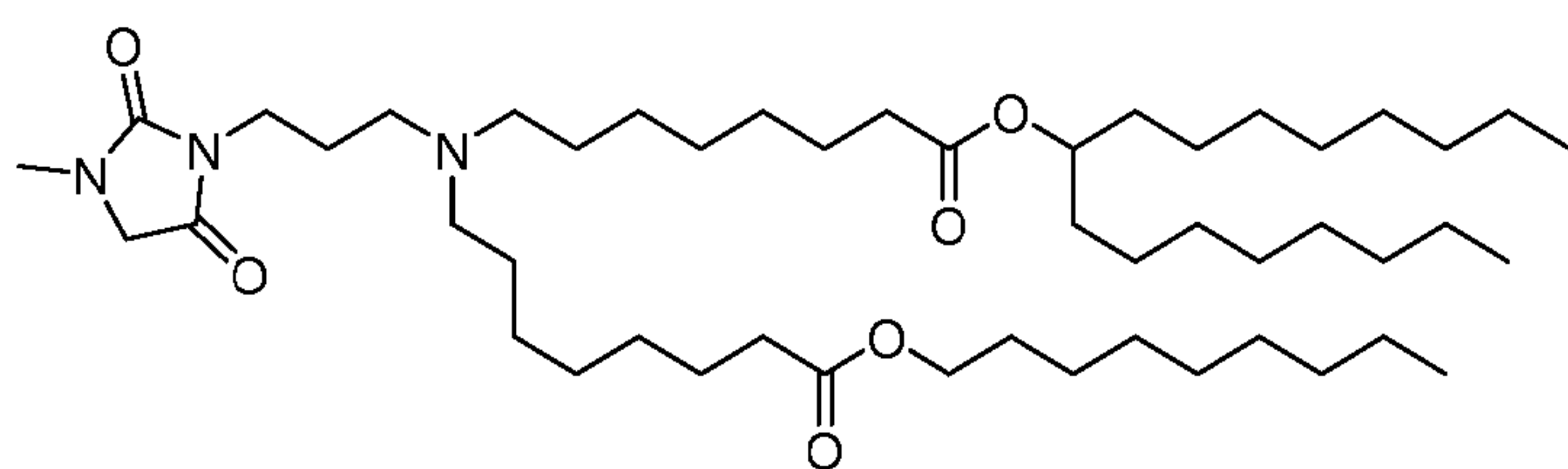
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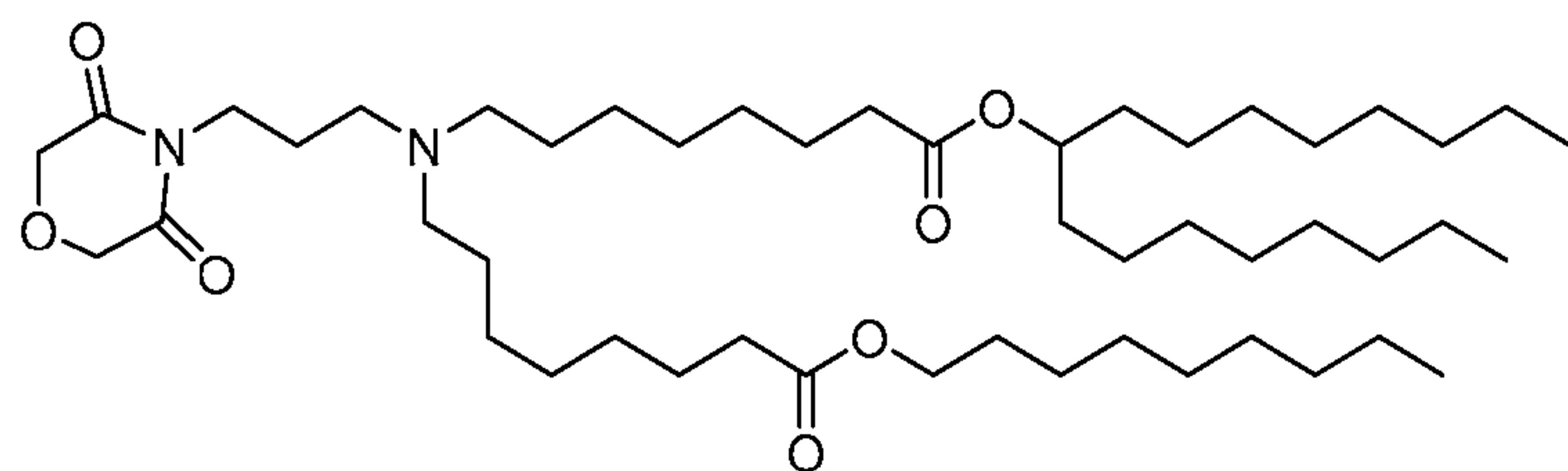
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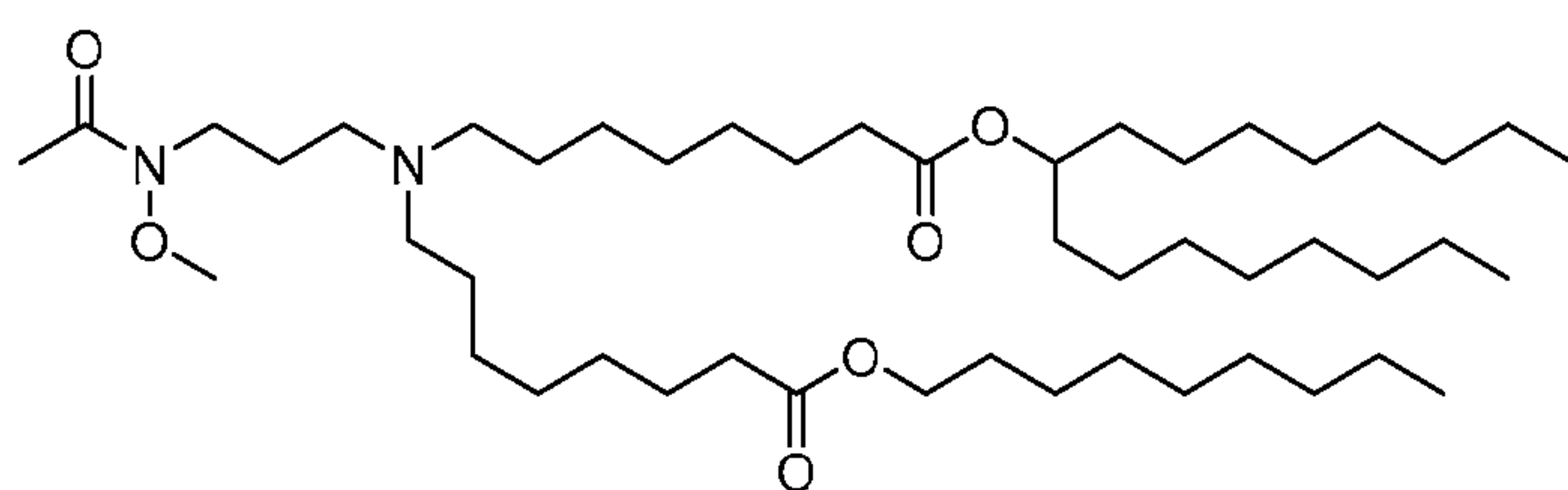
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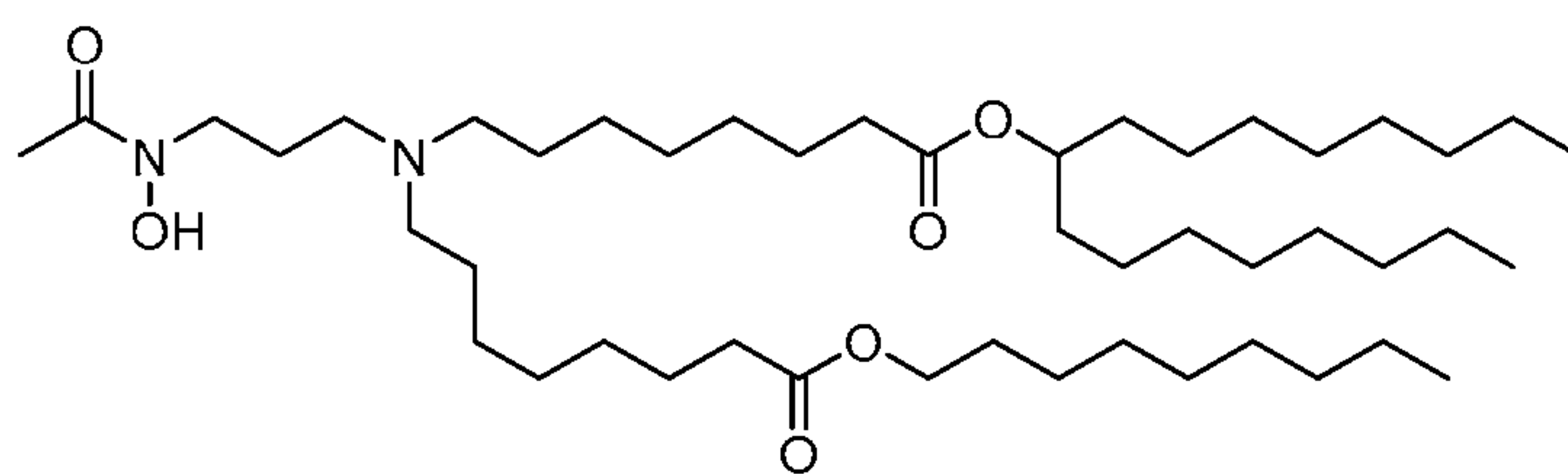
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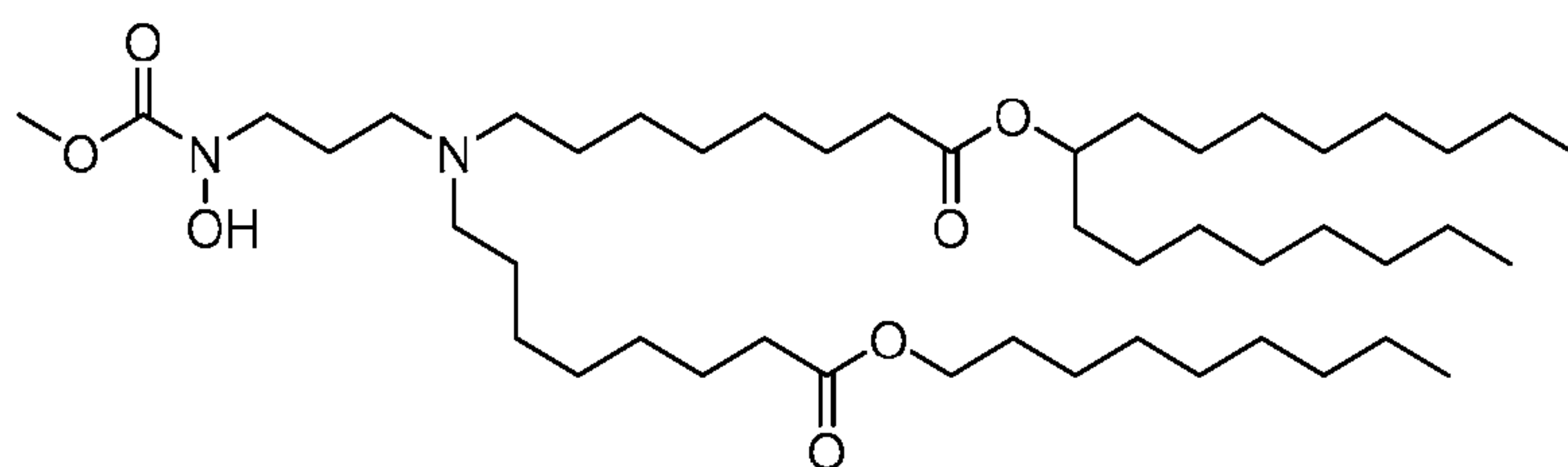
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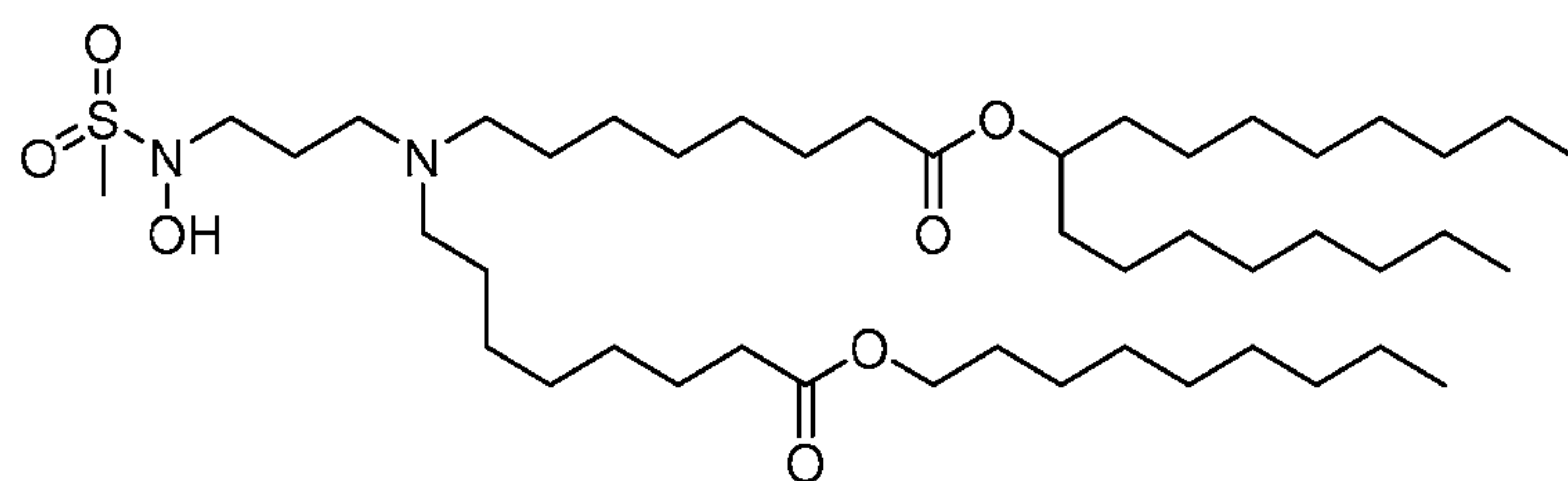
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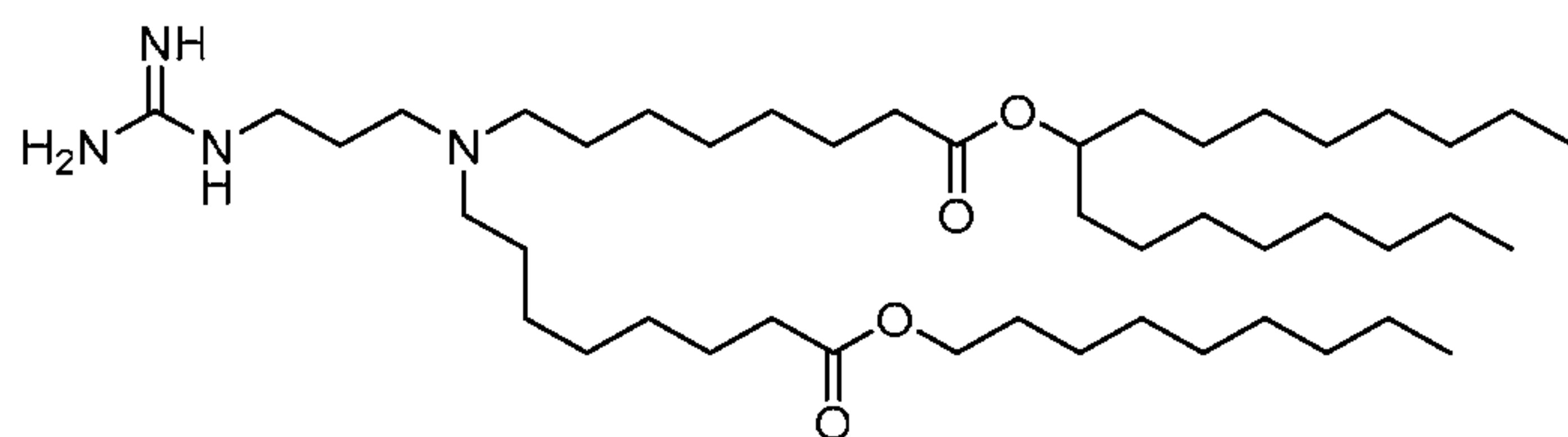
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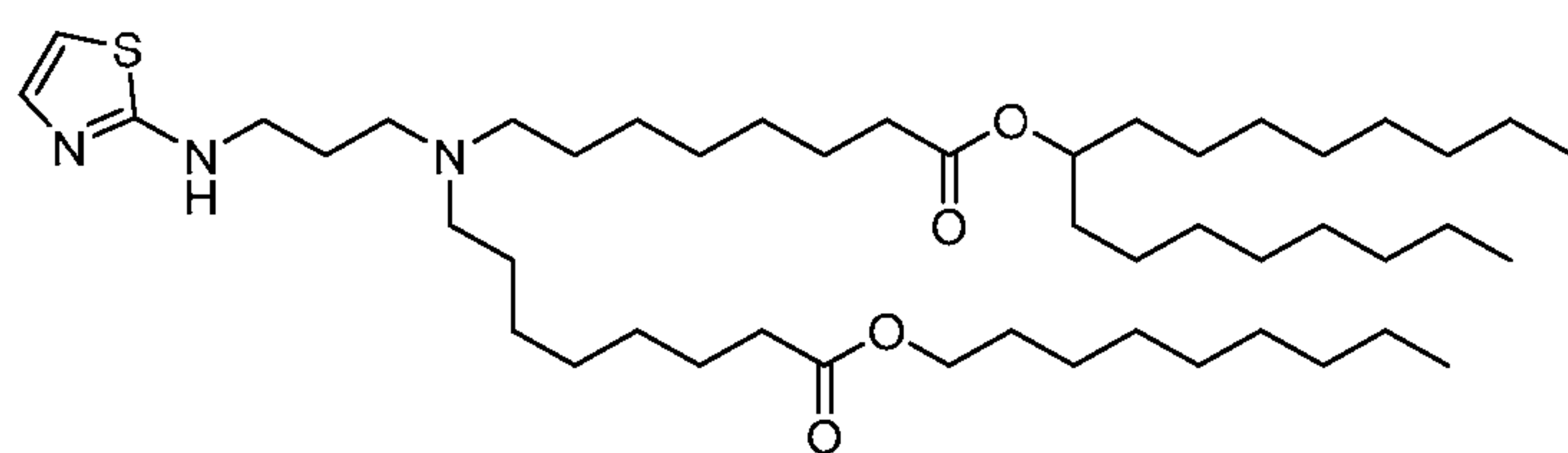
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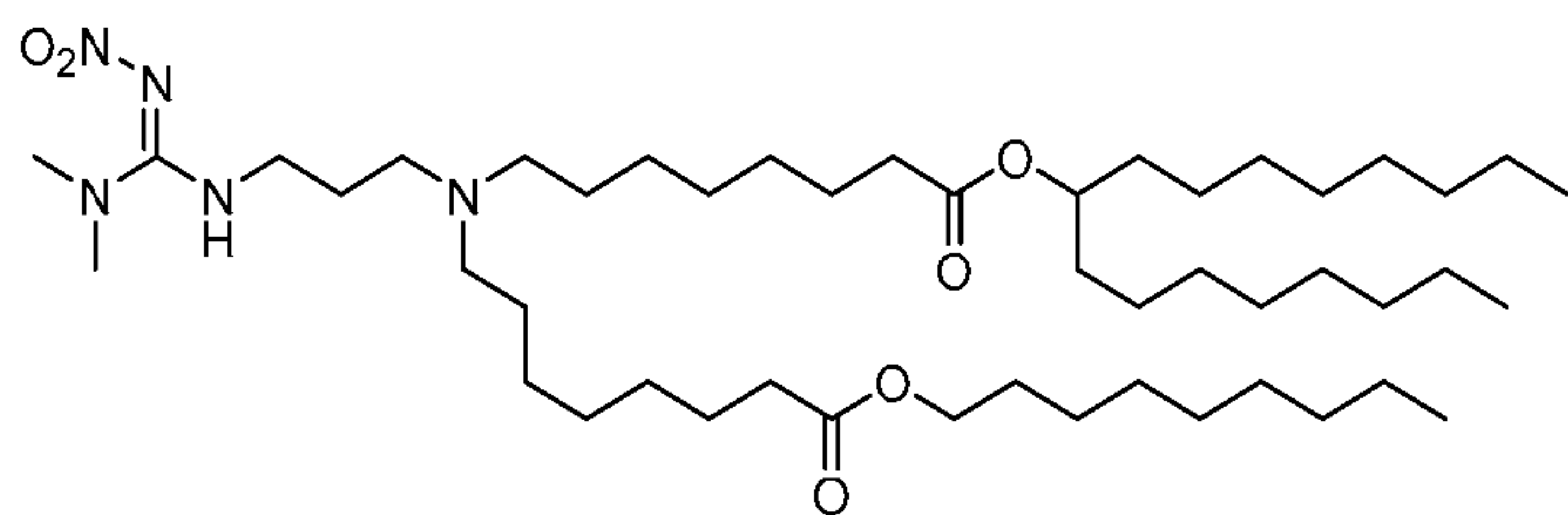
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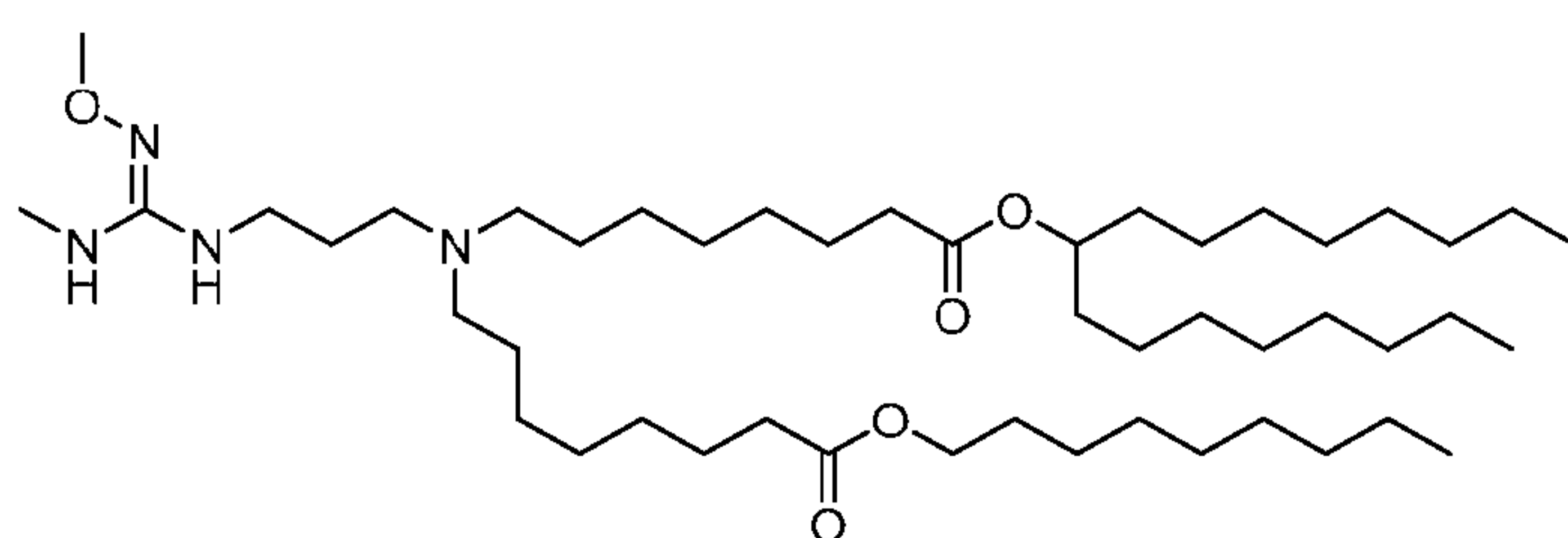
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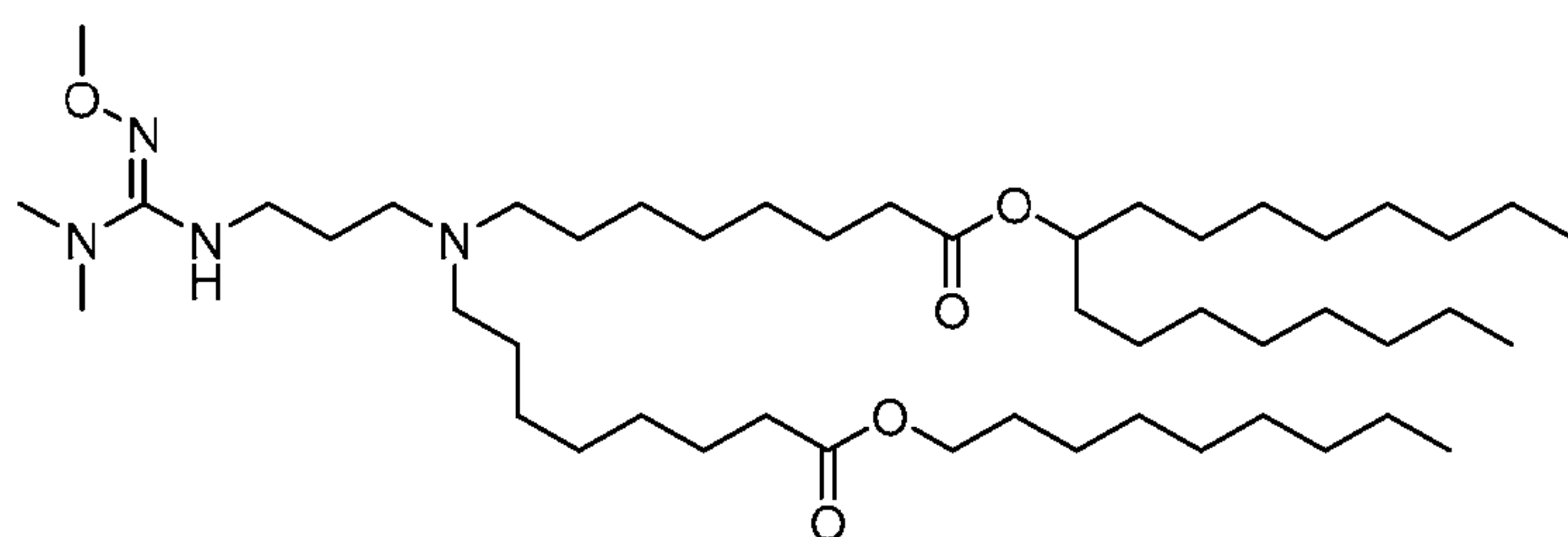
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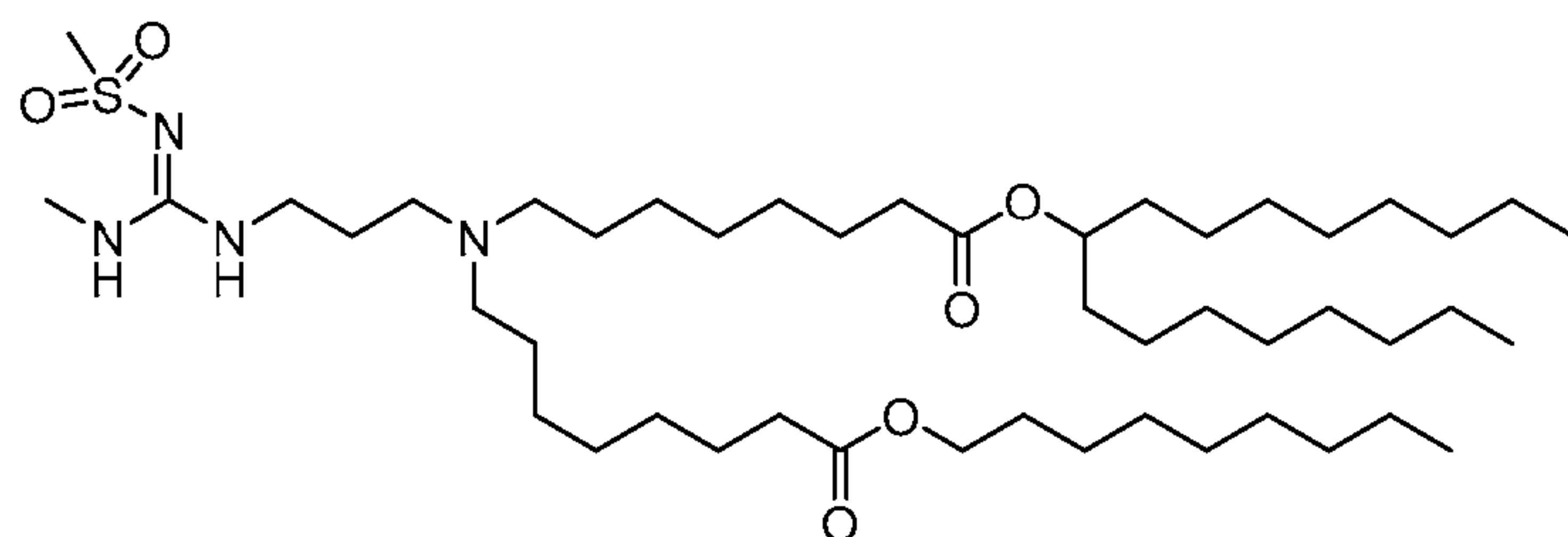
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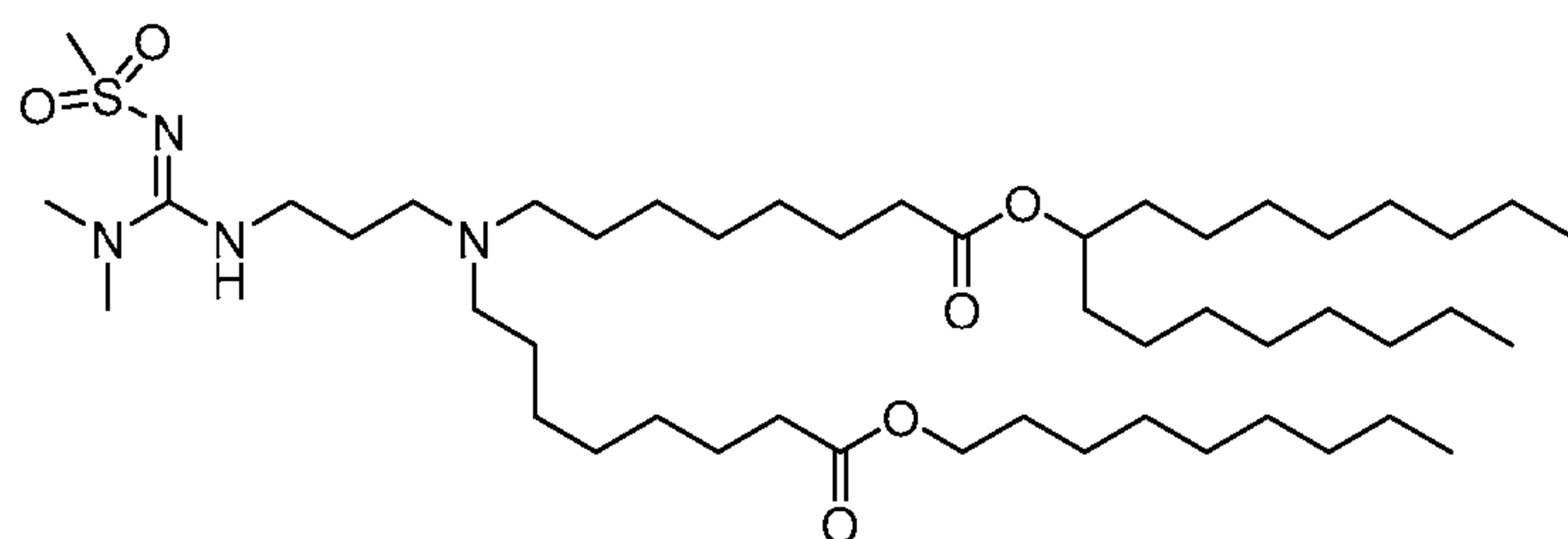
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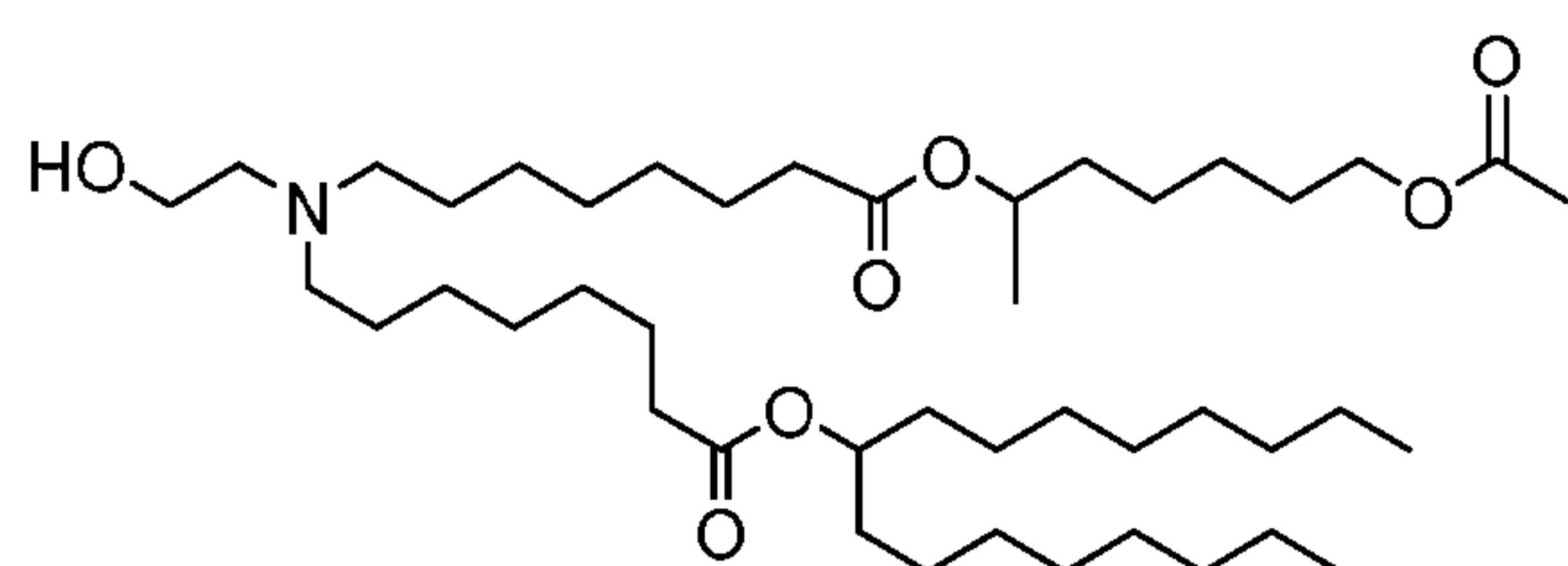
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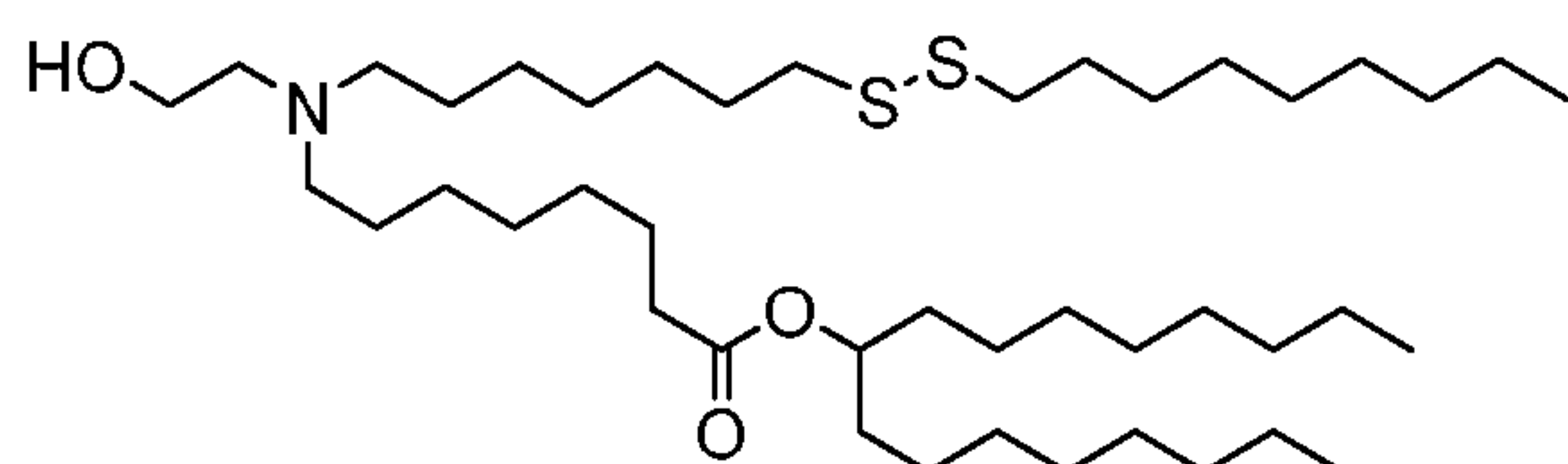
(Compound 212),



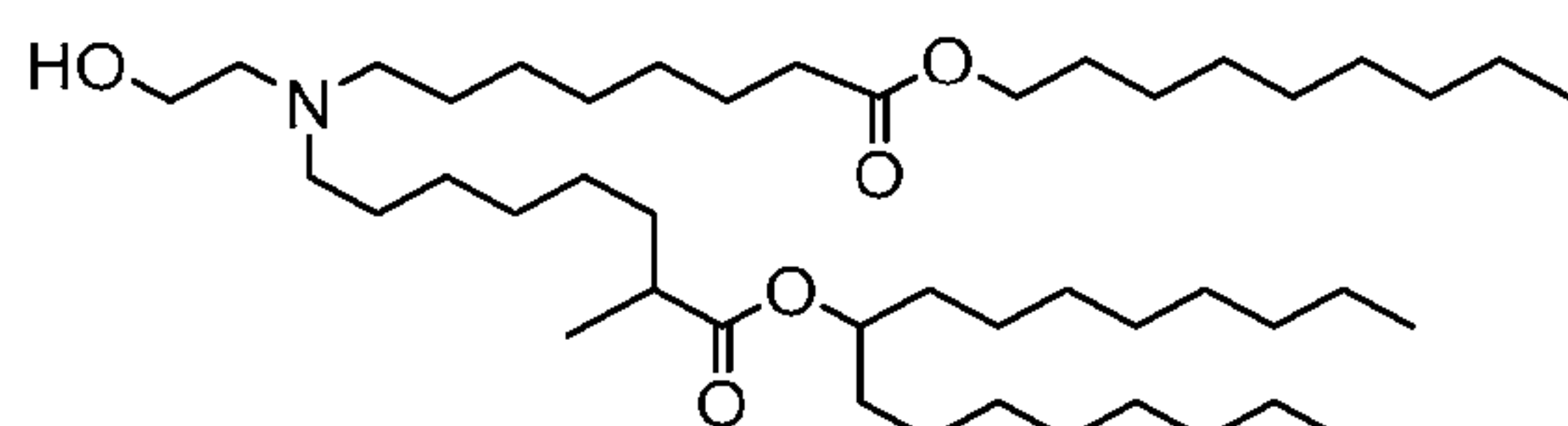
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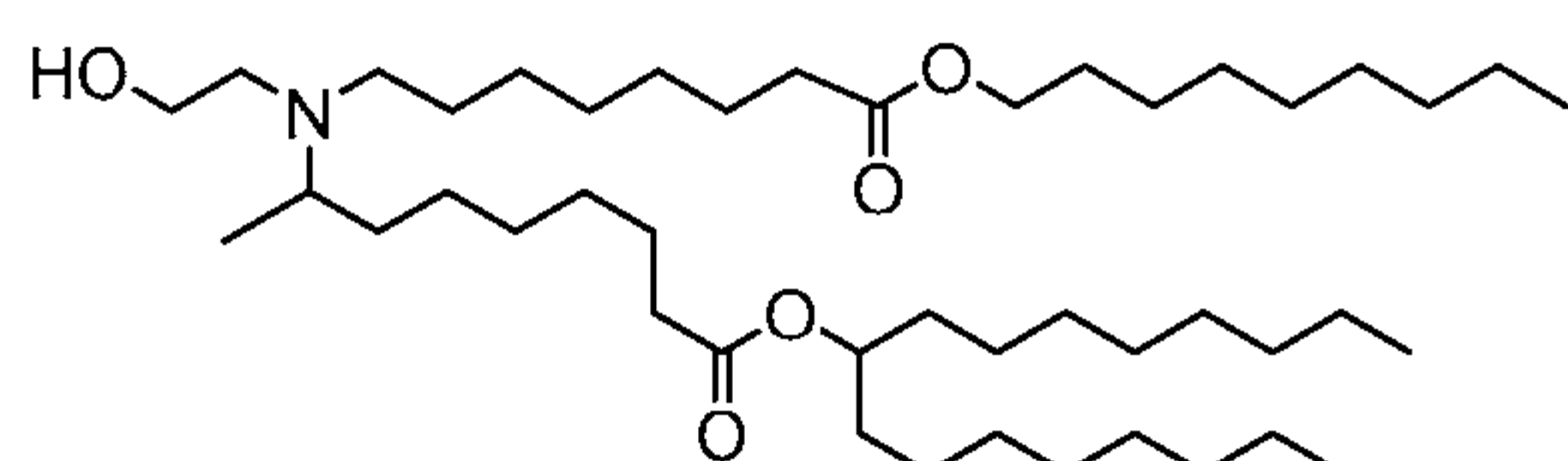
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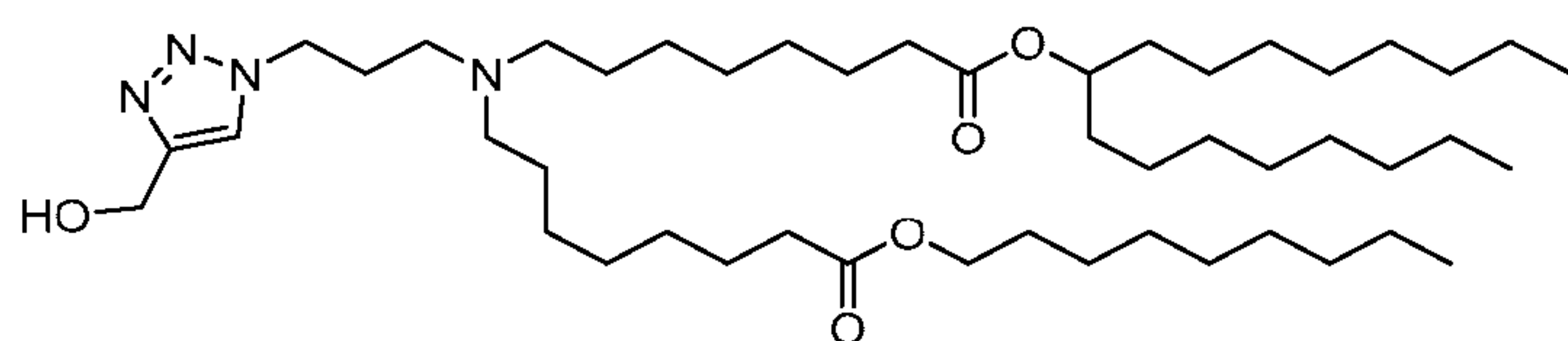
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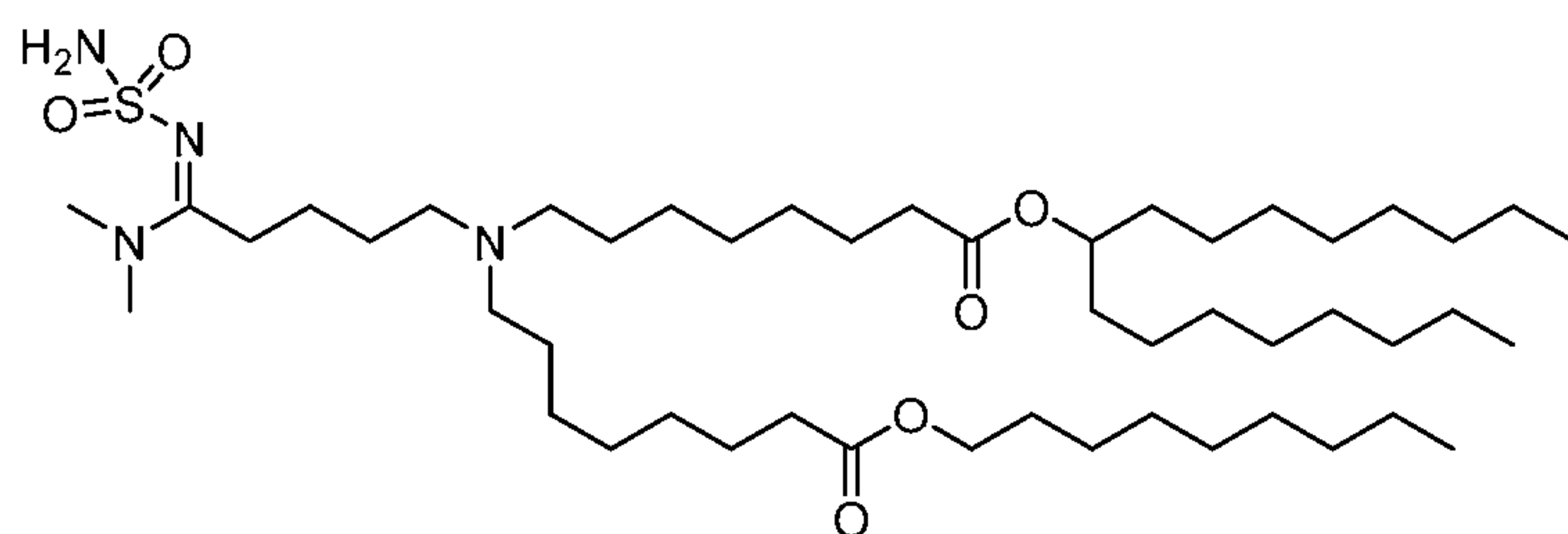
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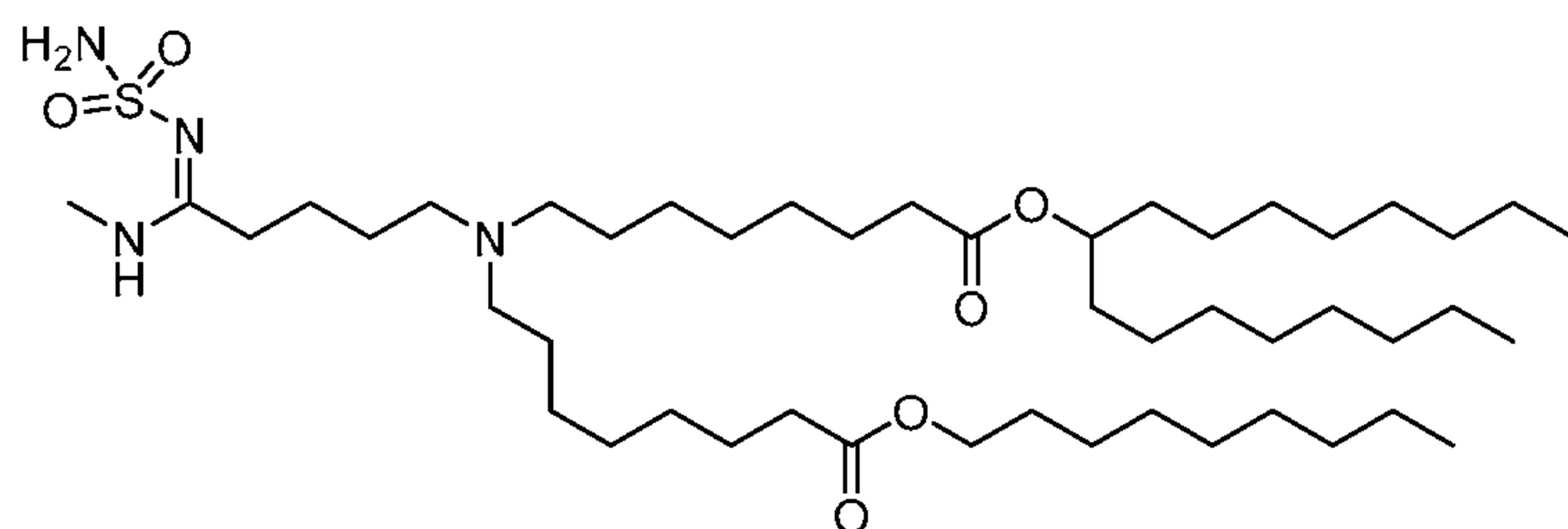
(Compound 217),



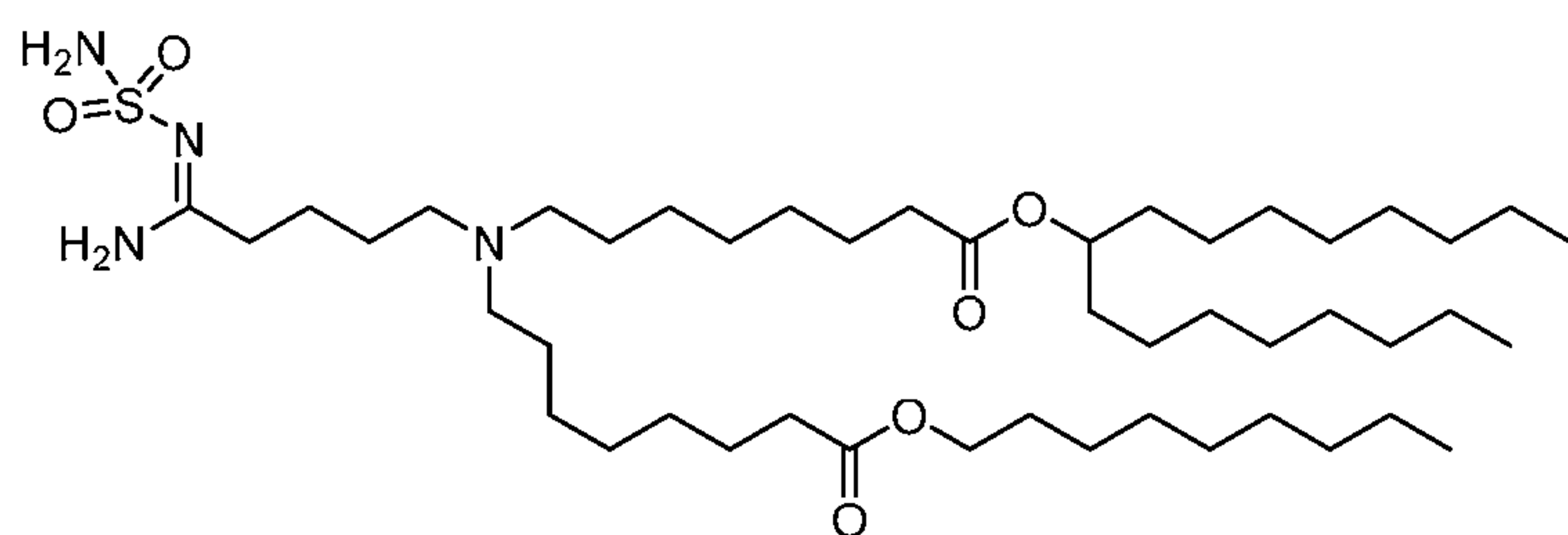
(Compound 218),



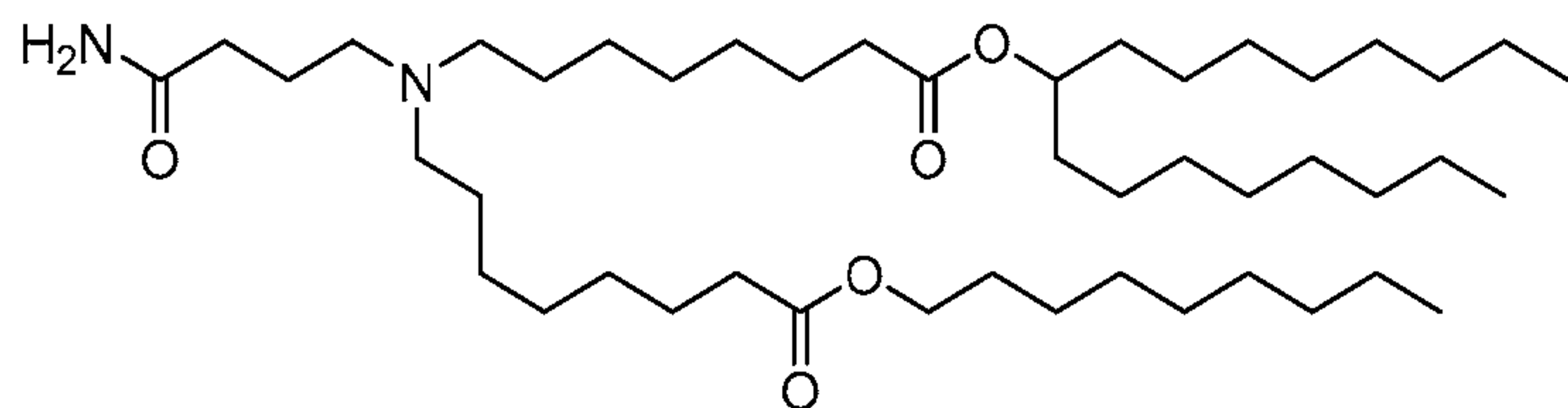
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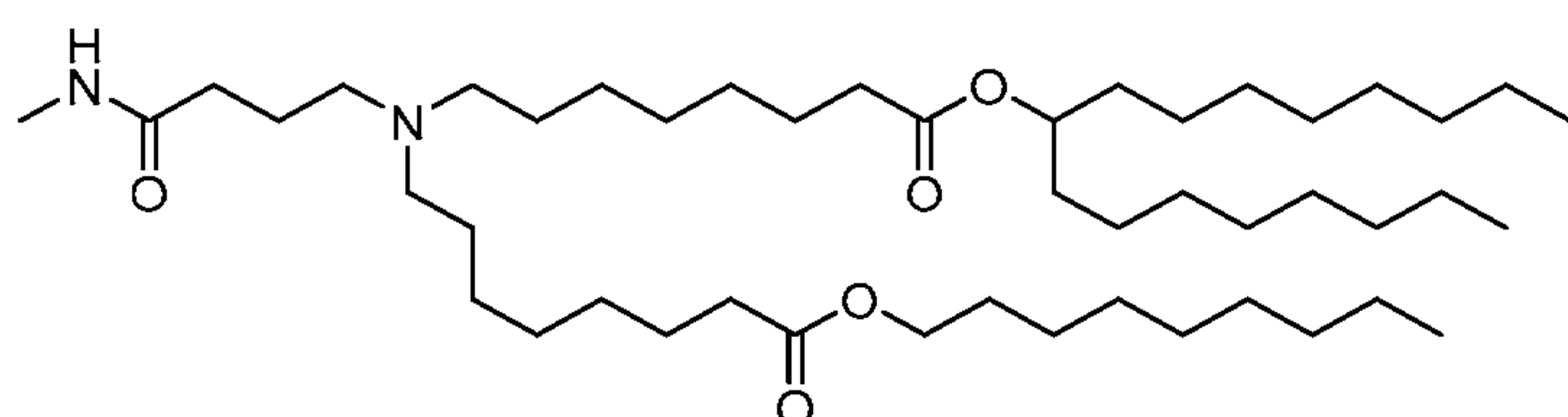
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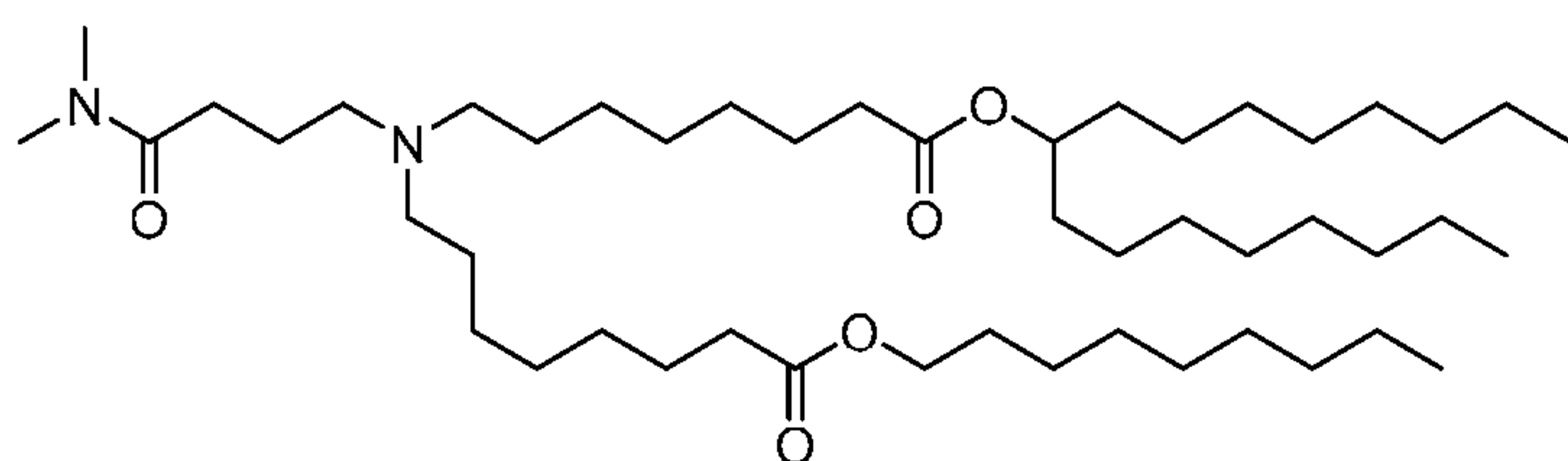
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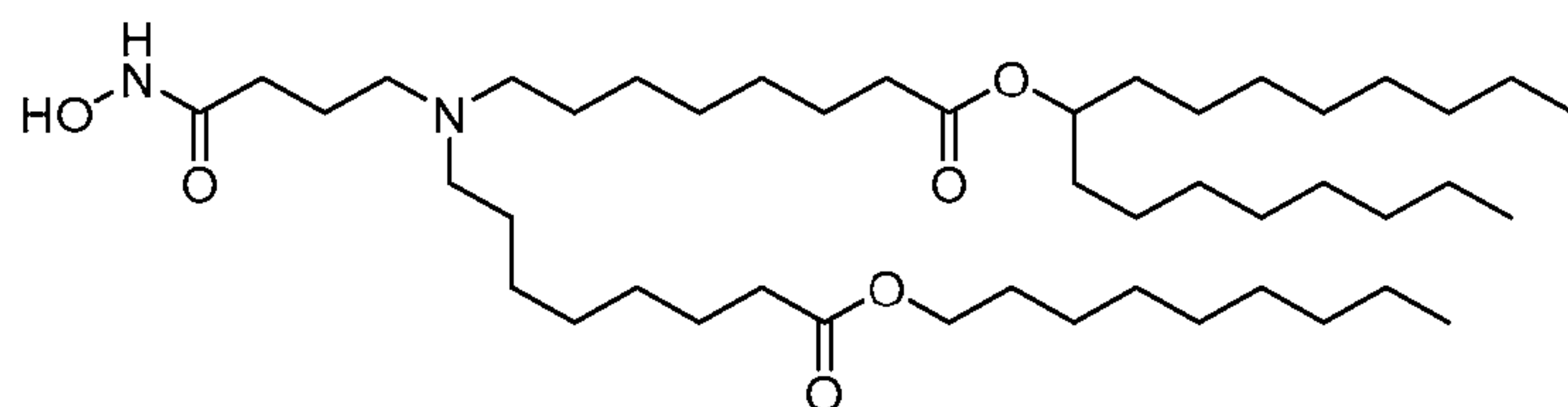
(Compound 222),



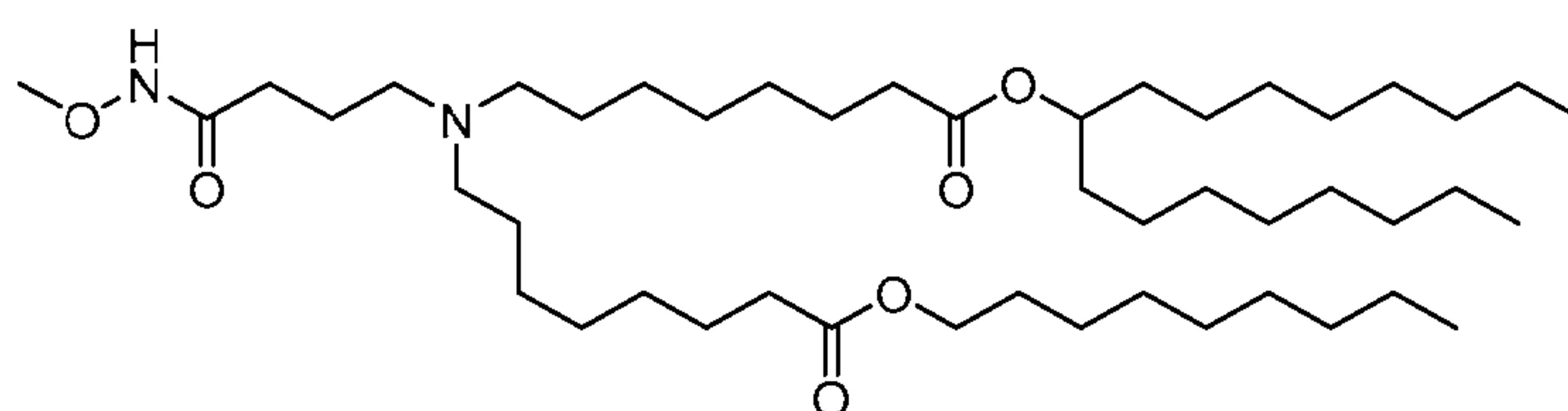
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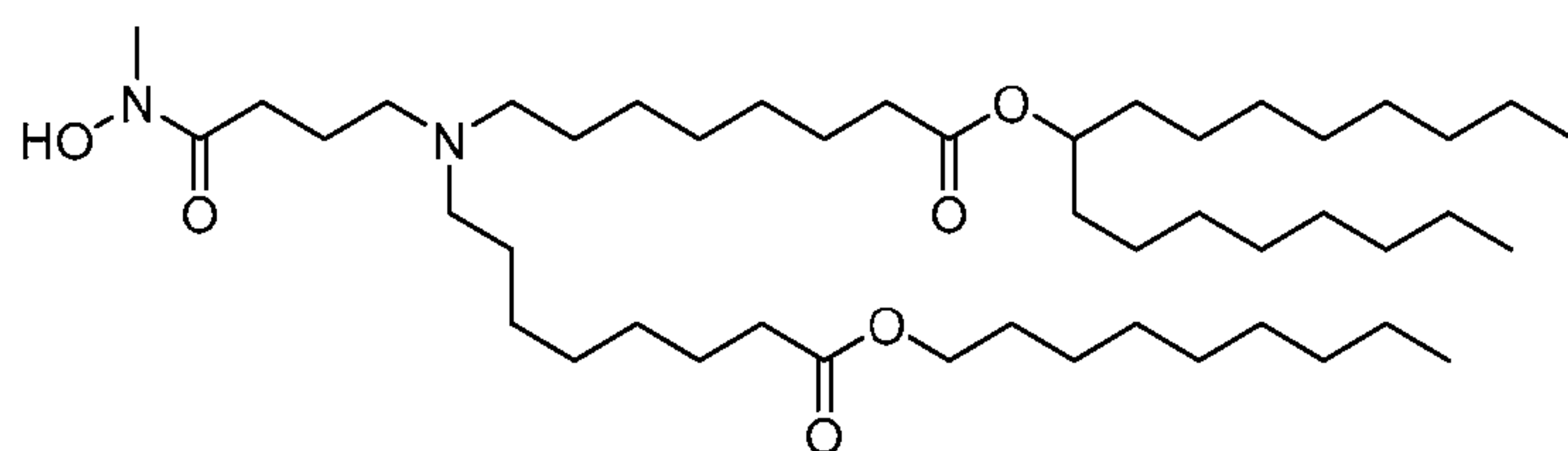
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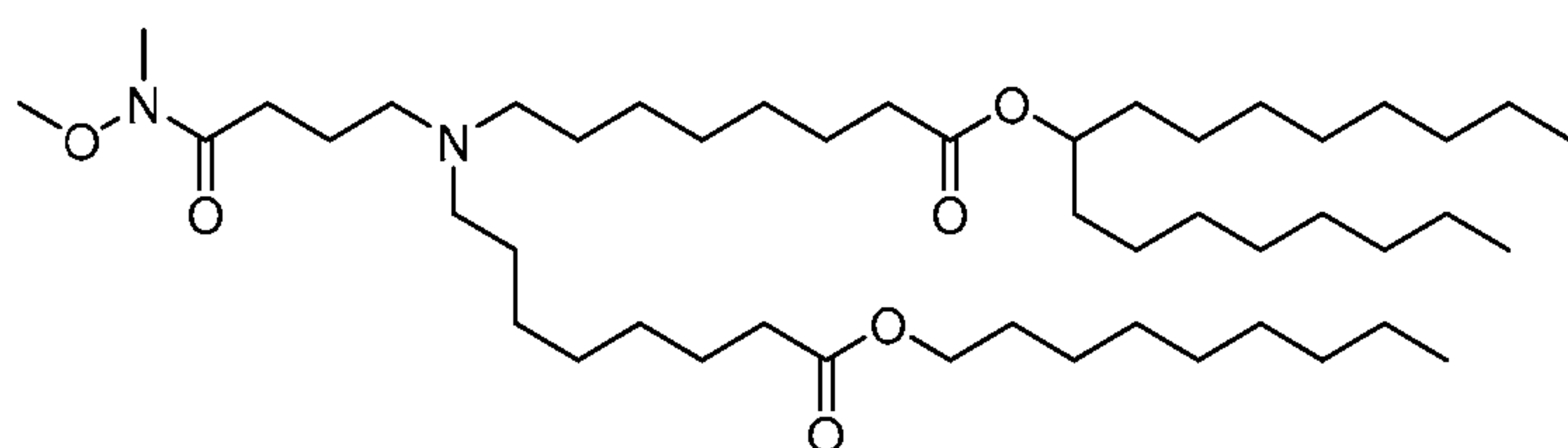
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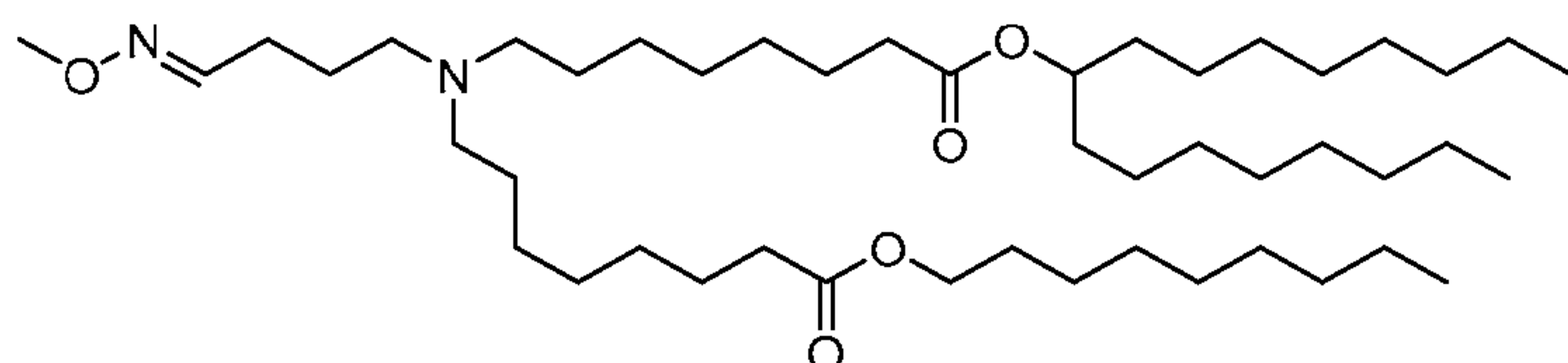
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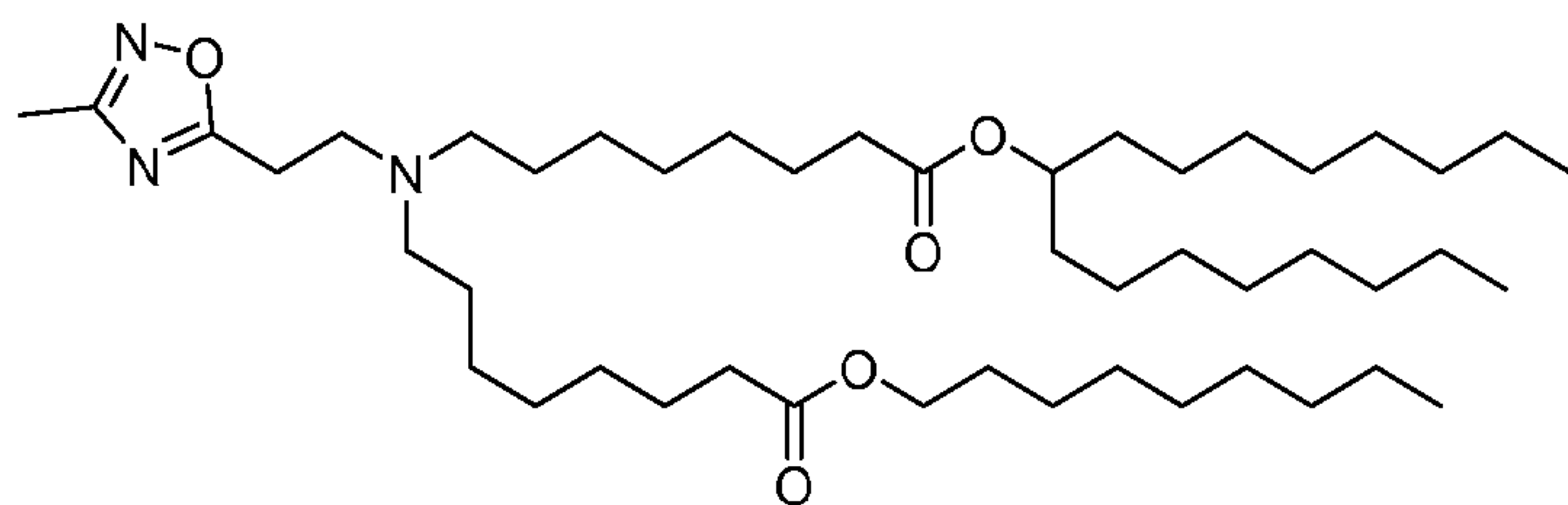
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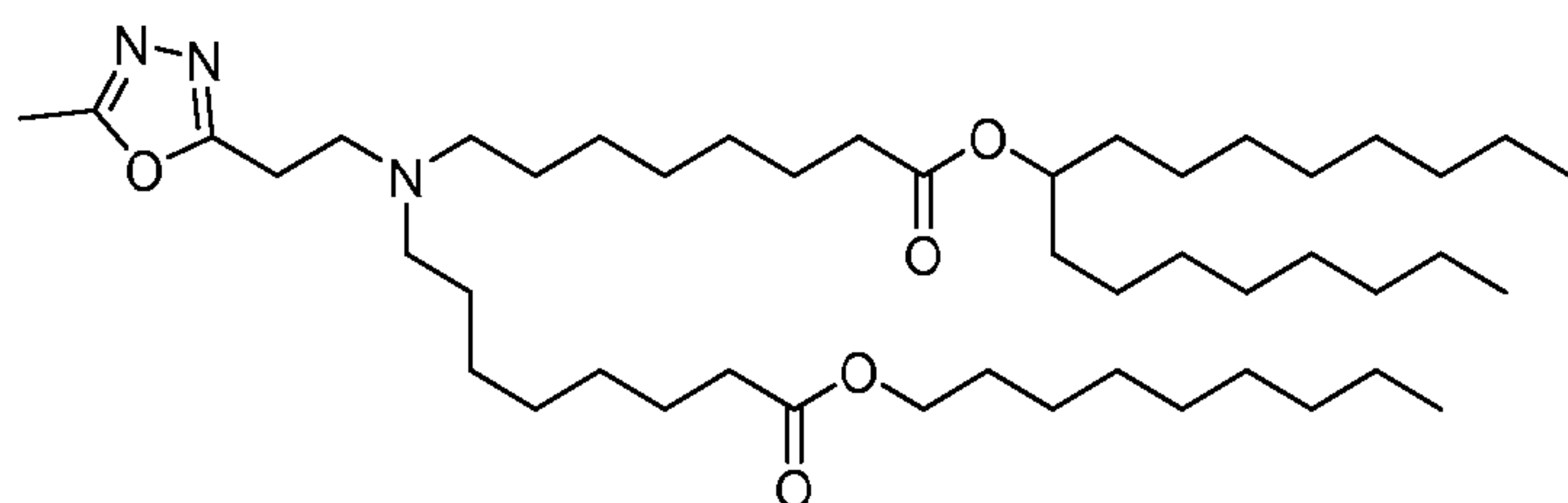
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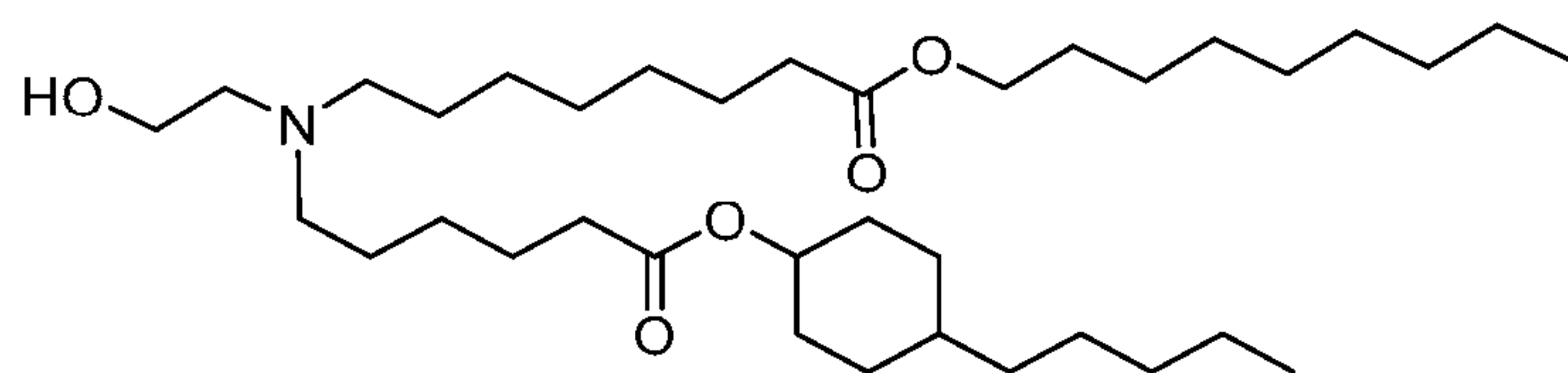
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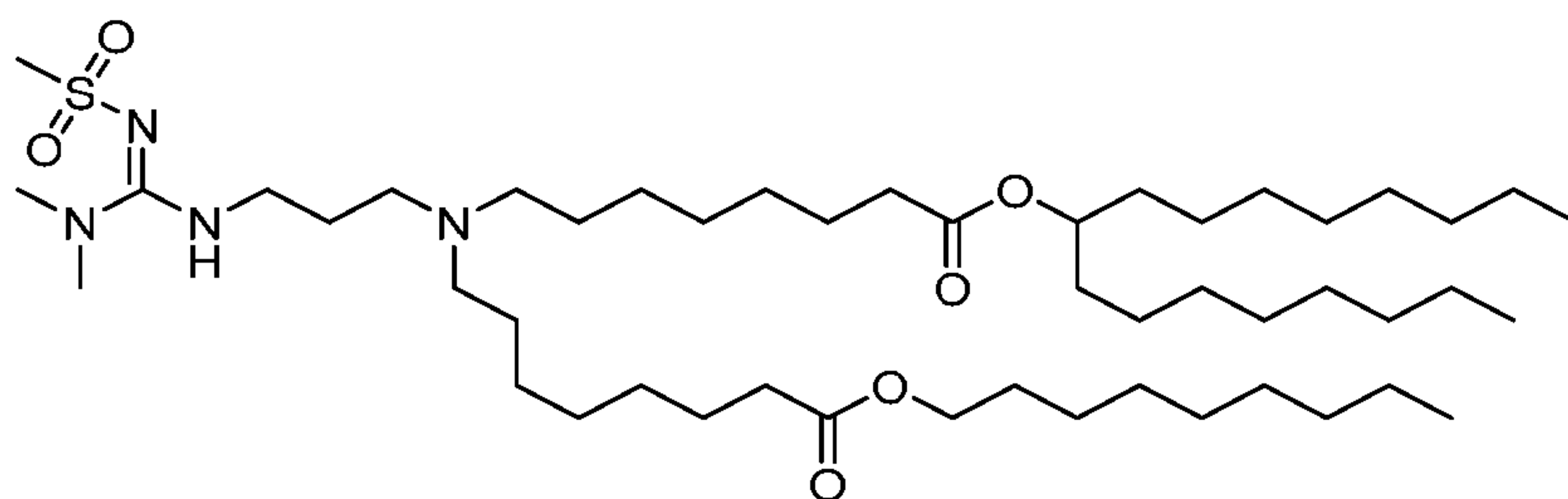
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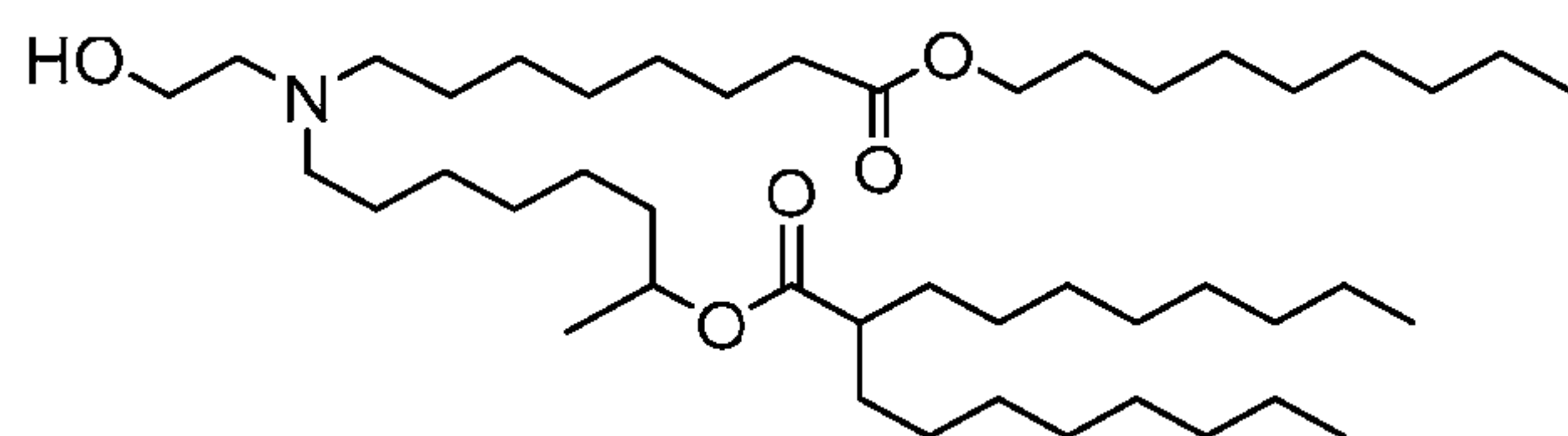
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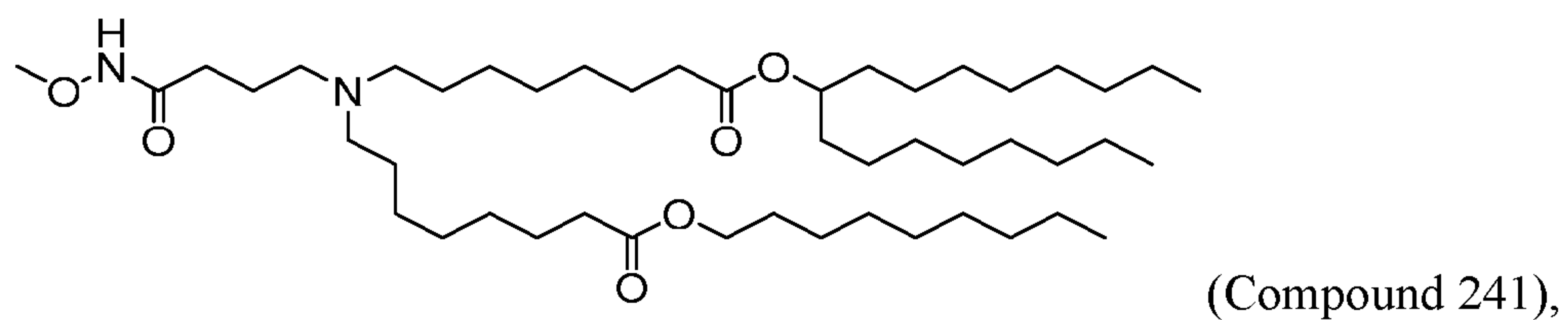
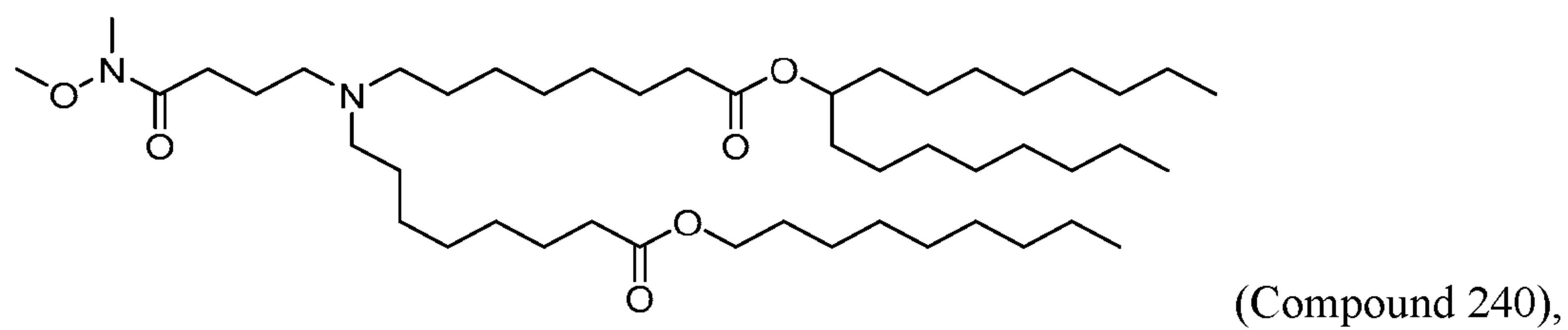
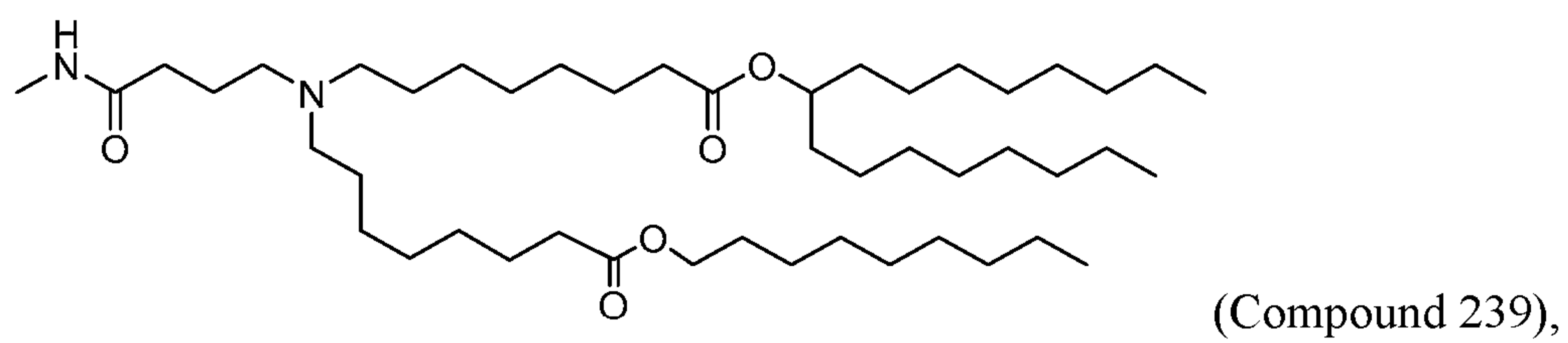
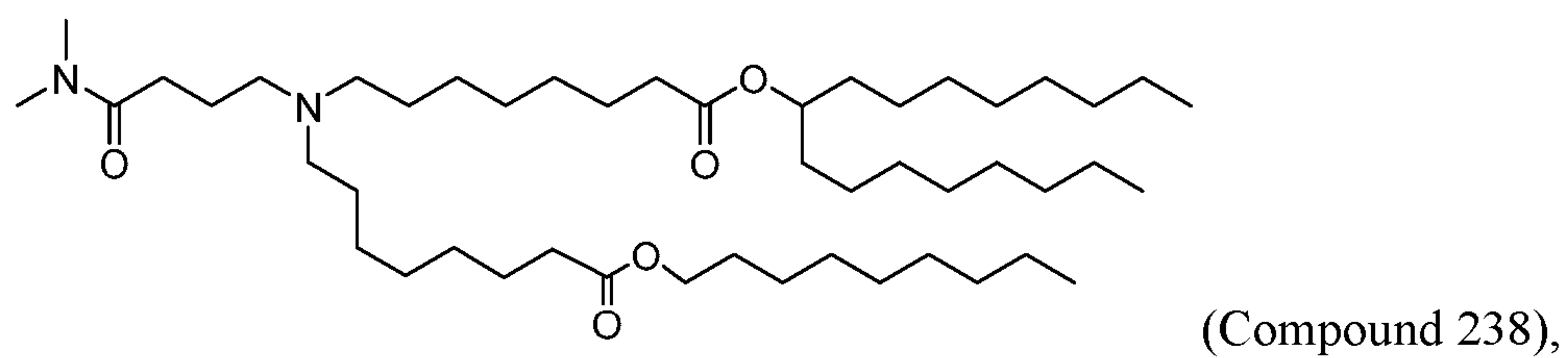
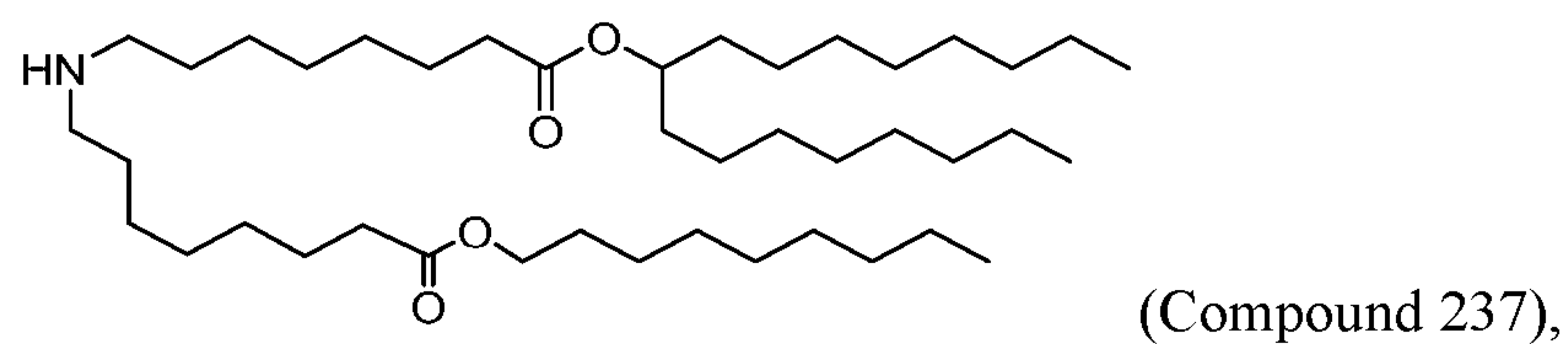
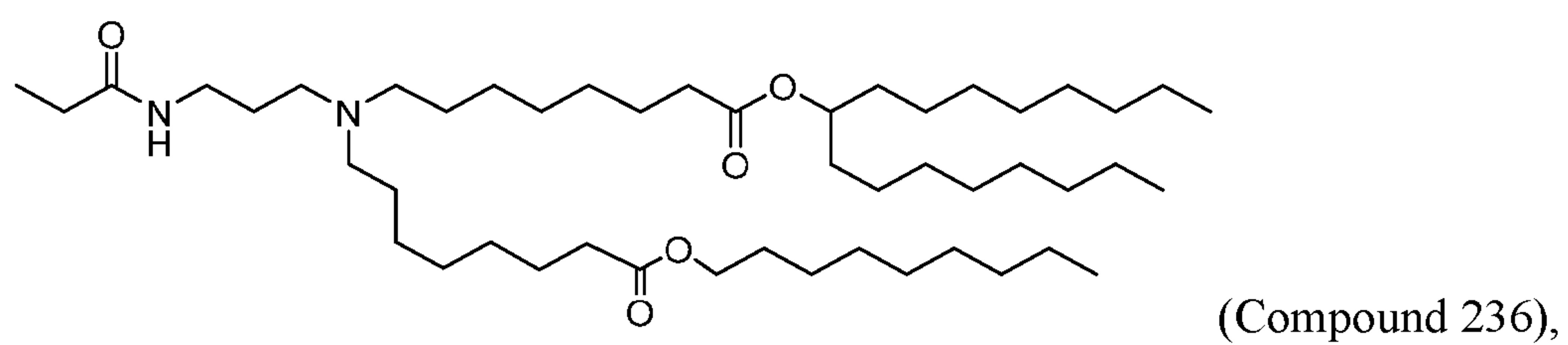
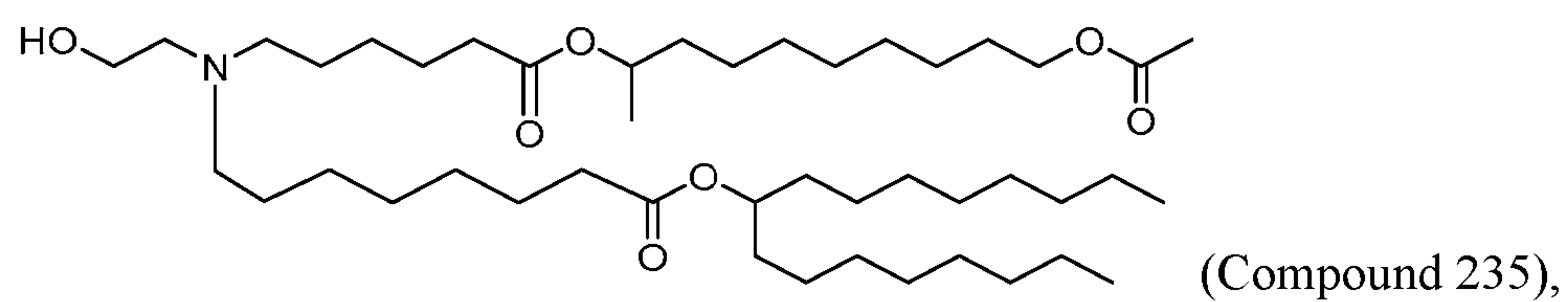
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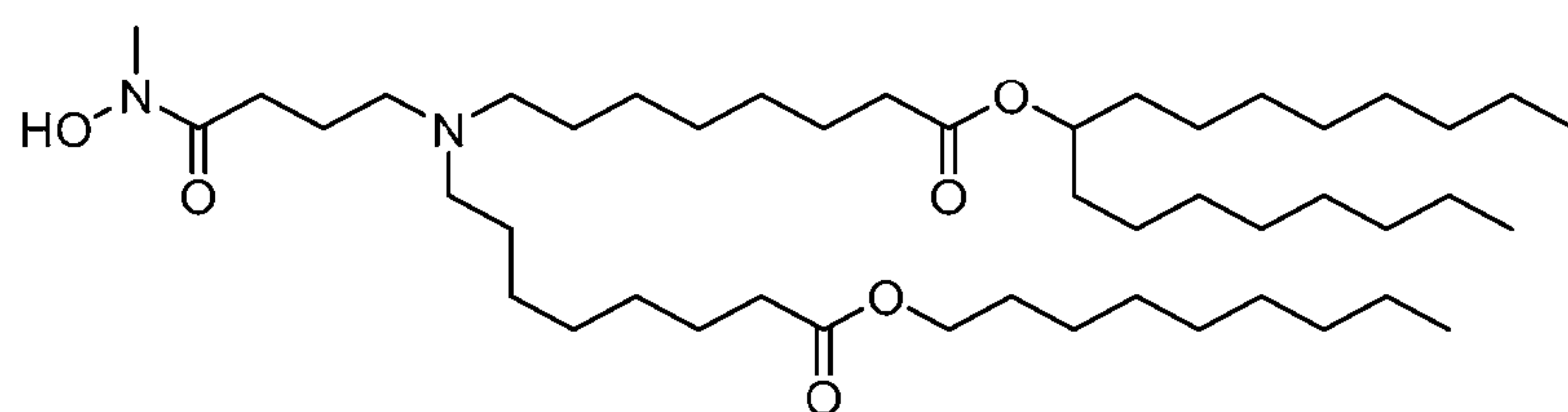


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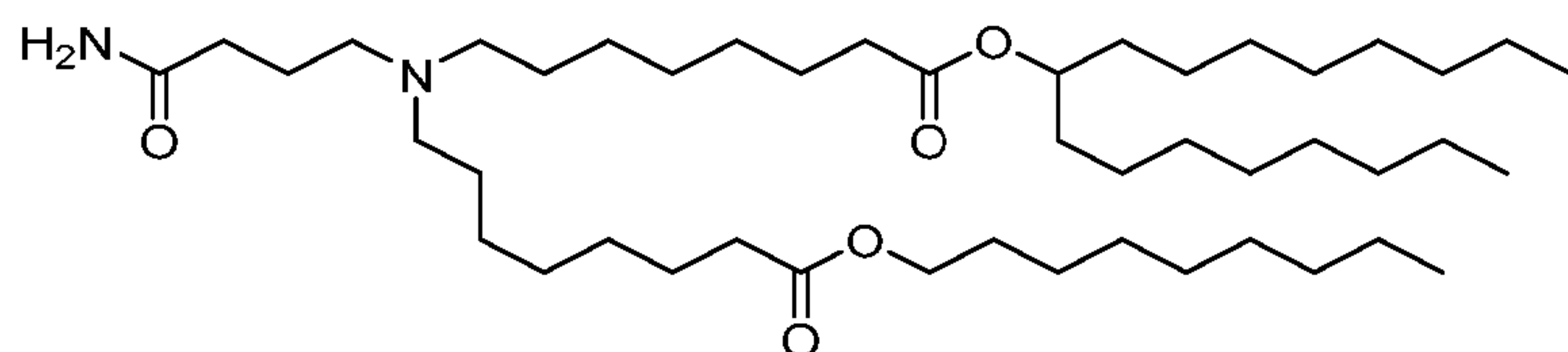


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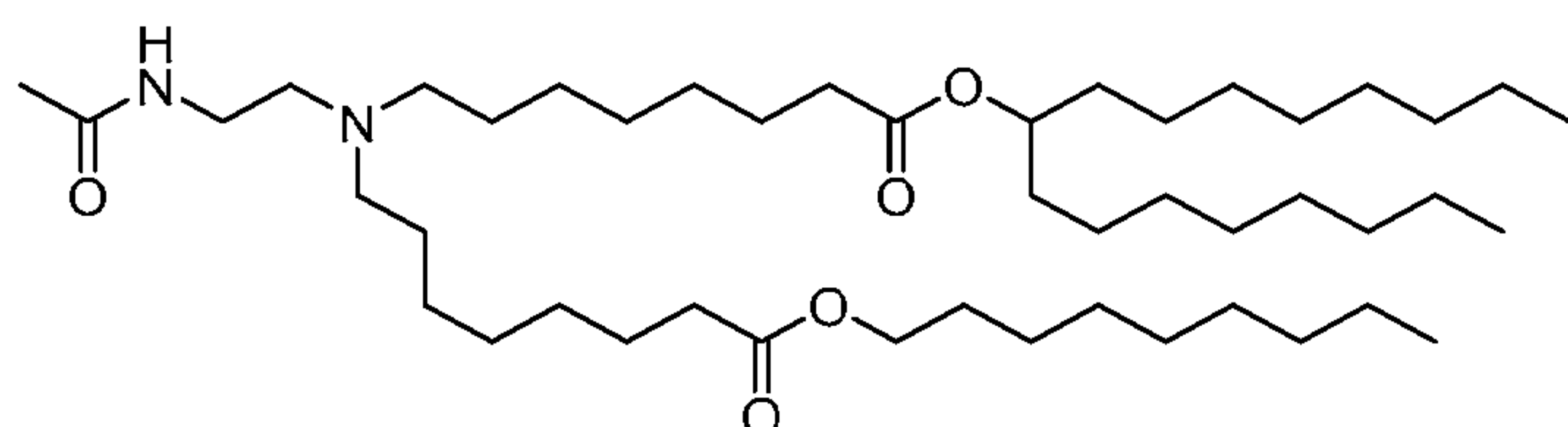




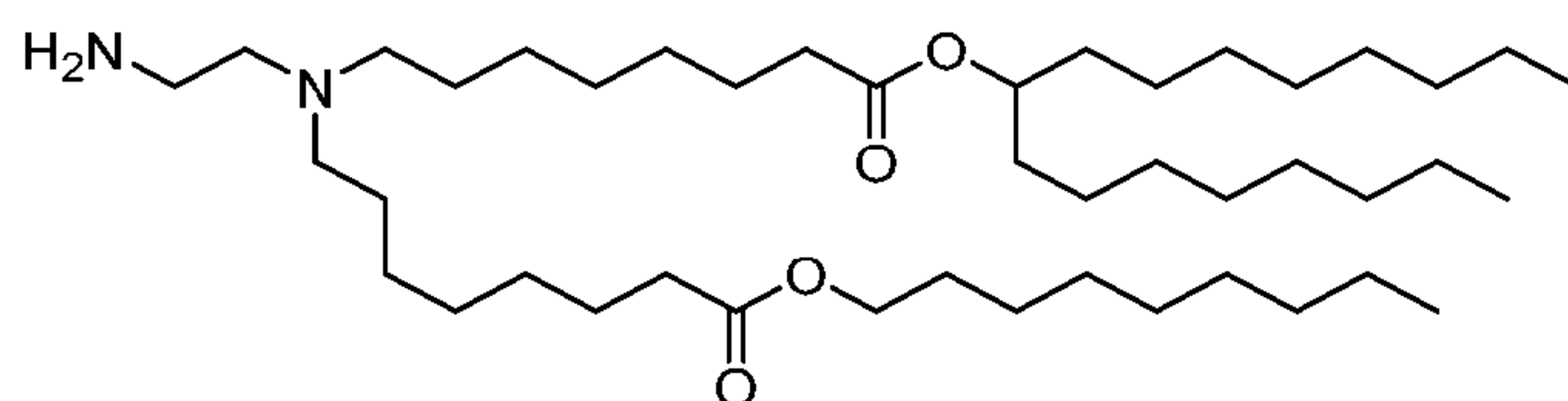
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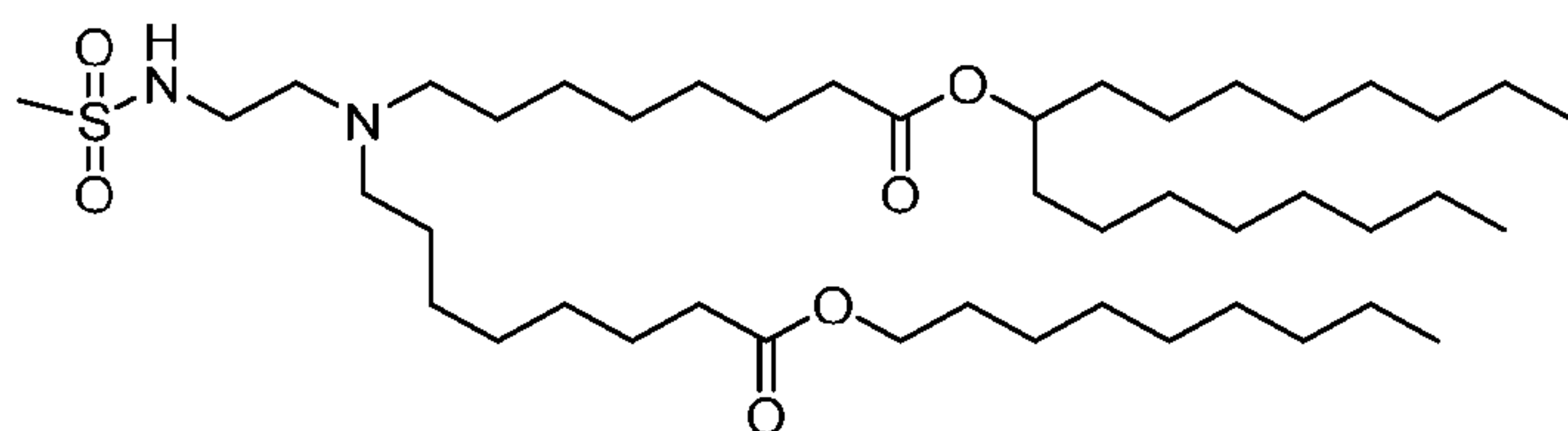
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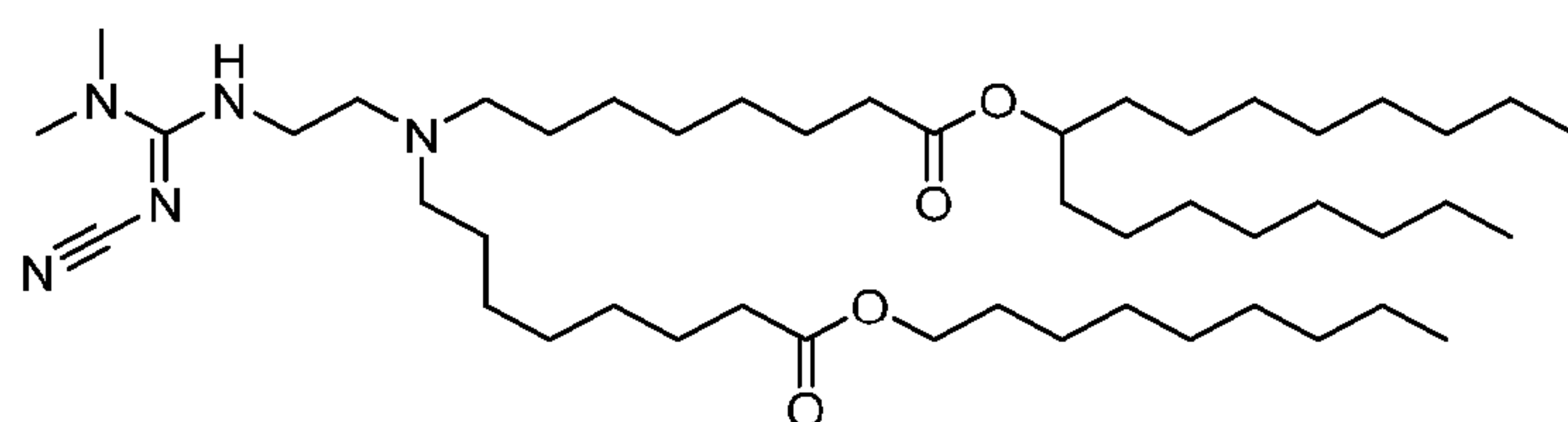
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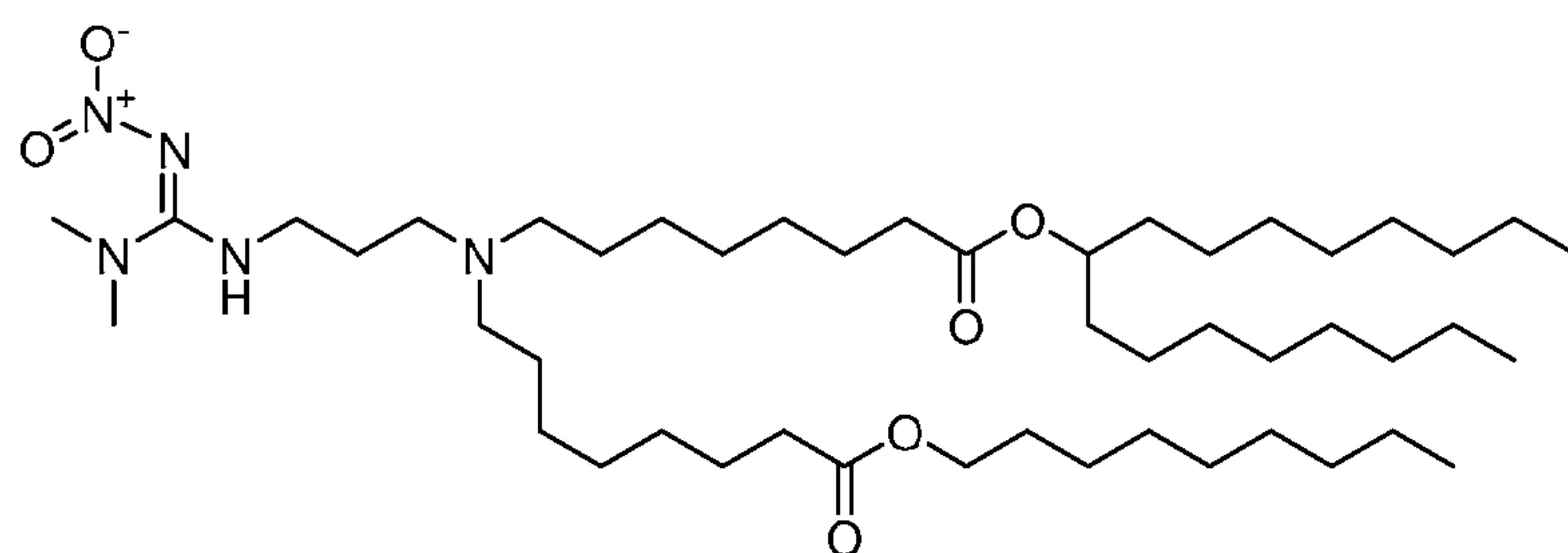
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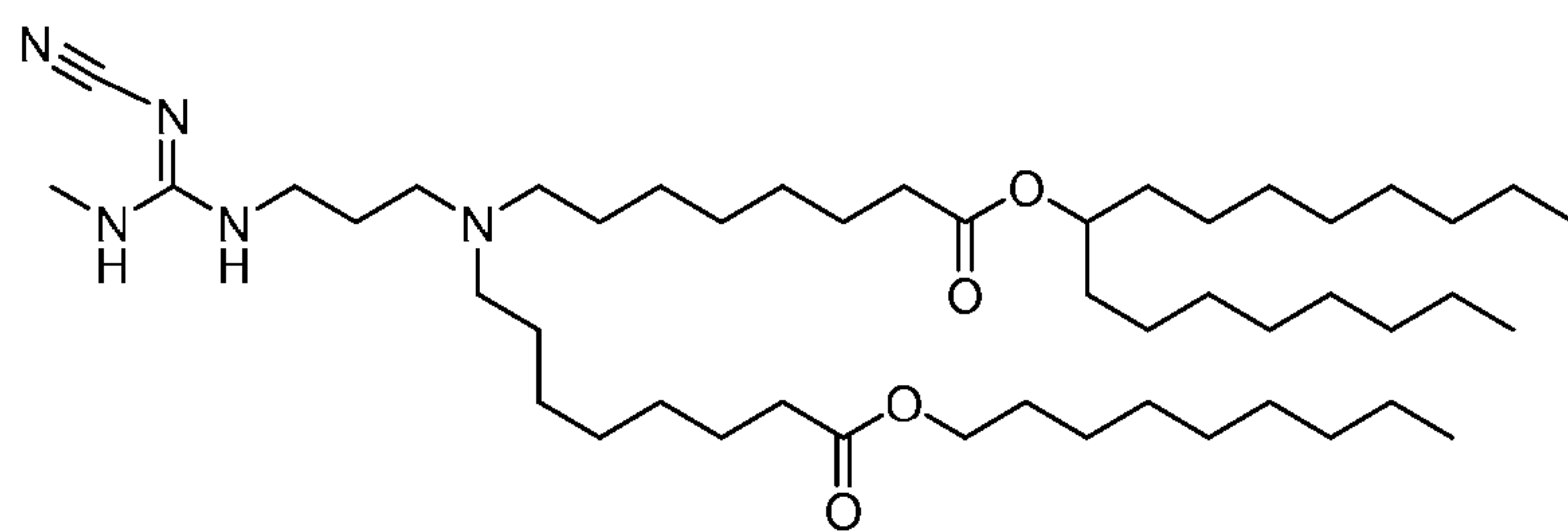
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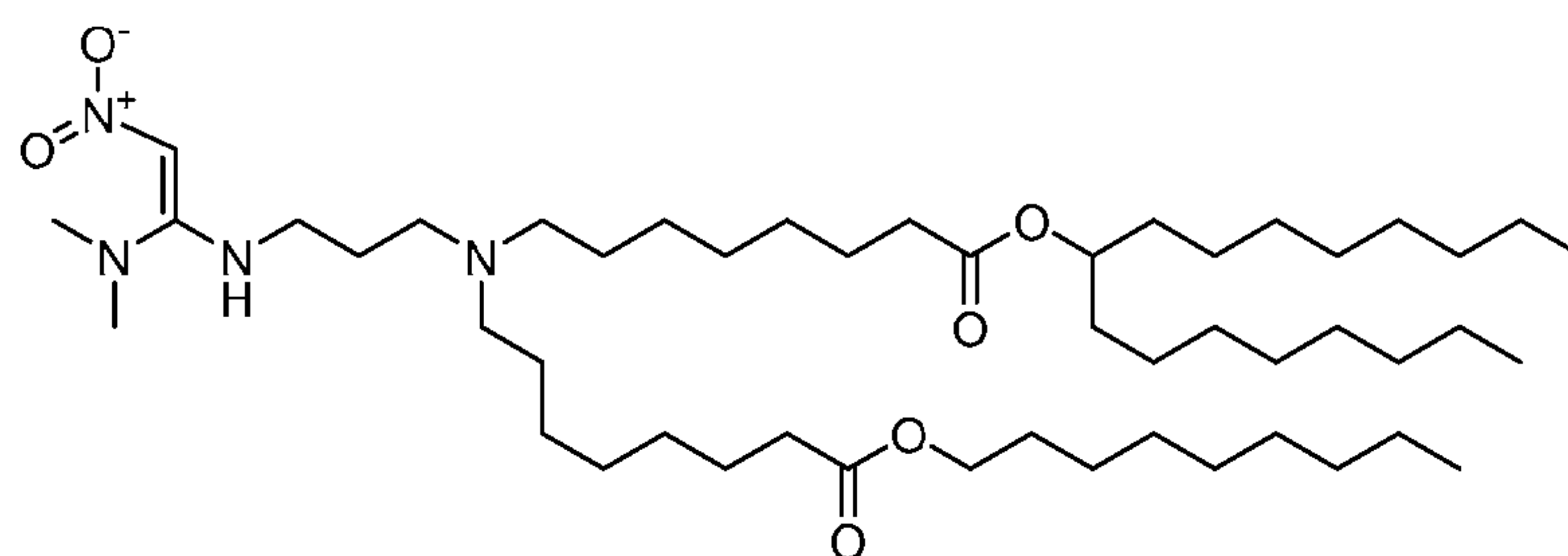
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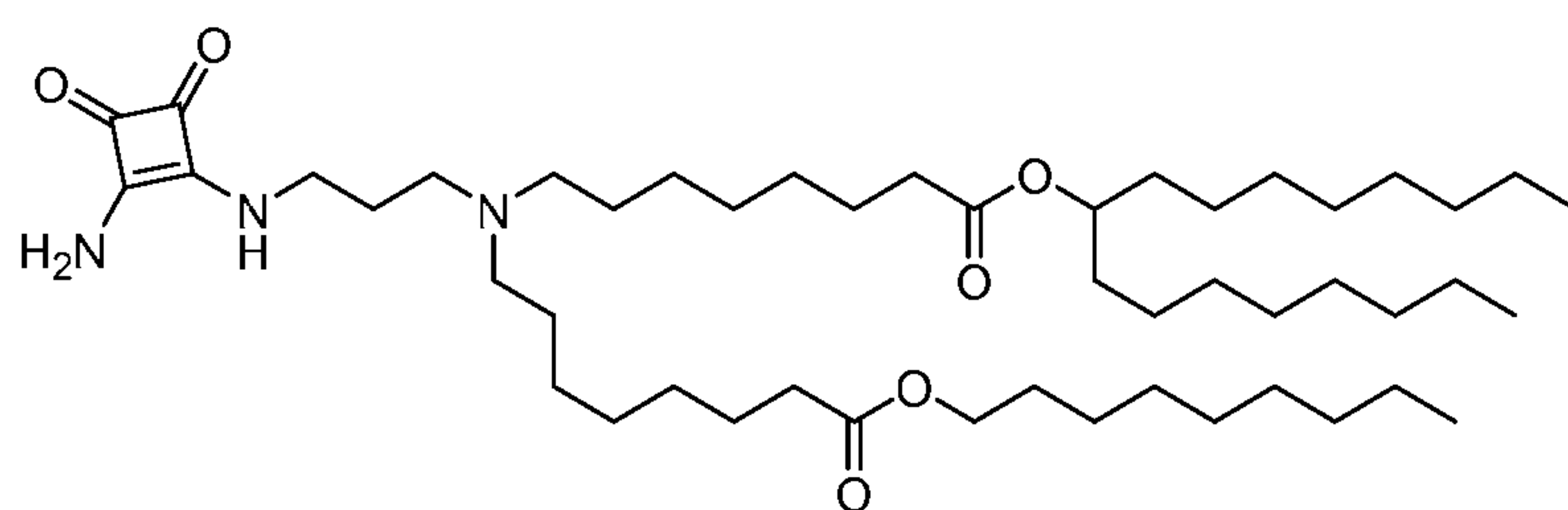
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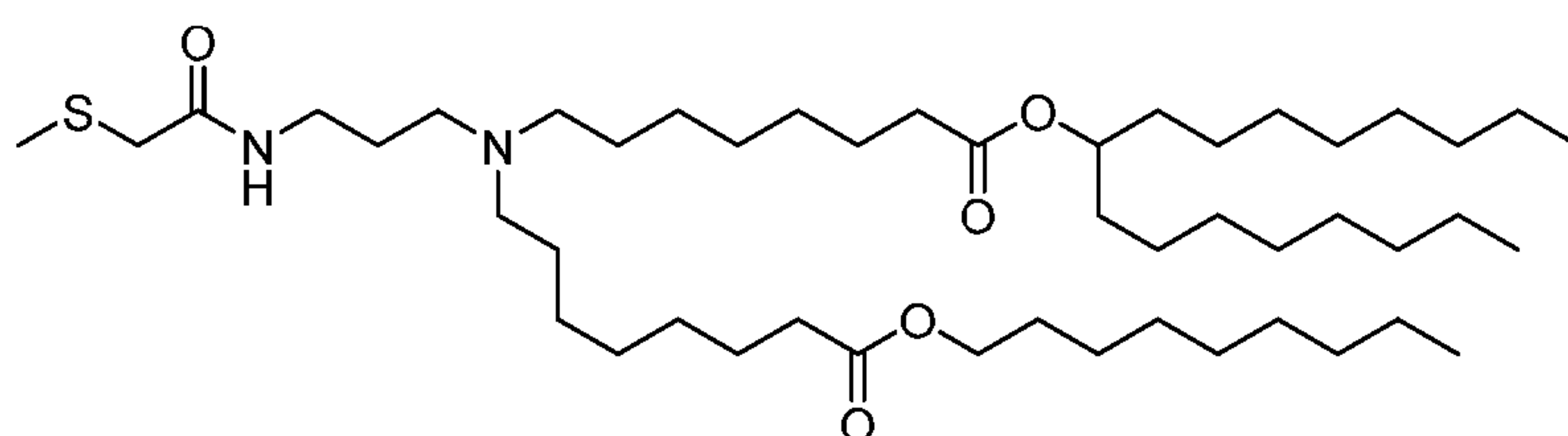
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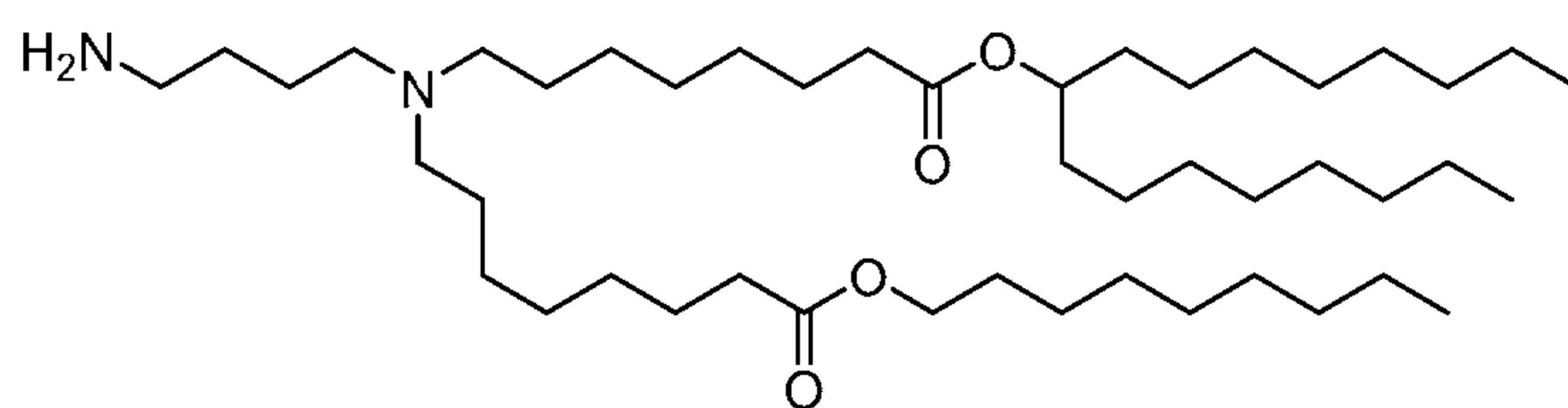
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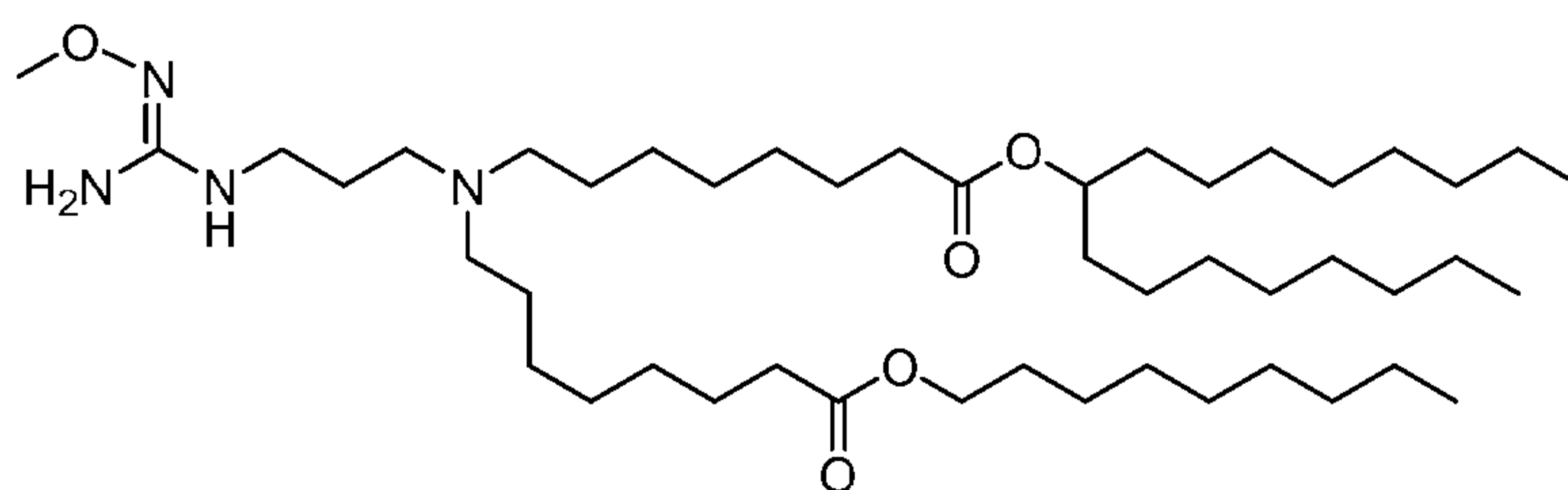
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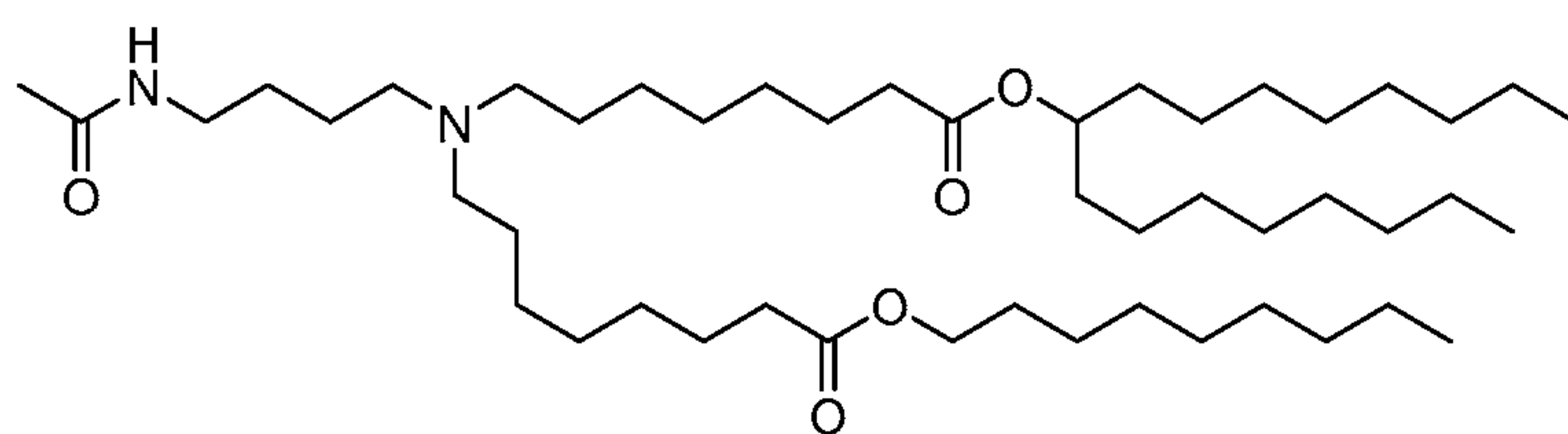
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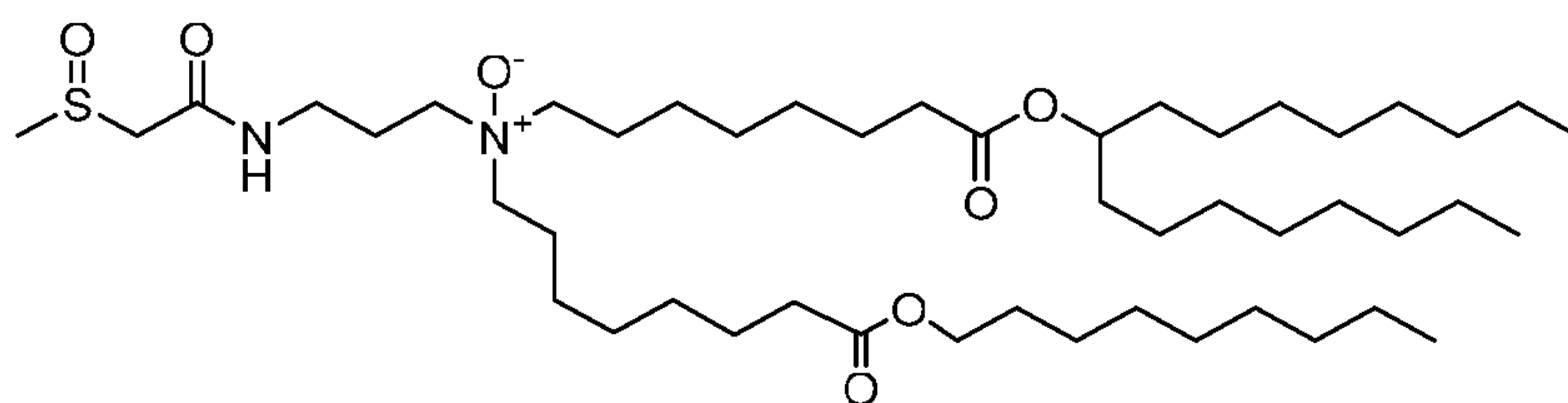
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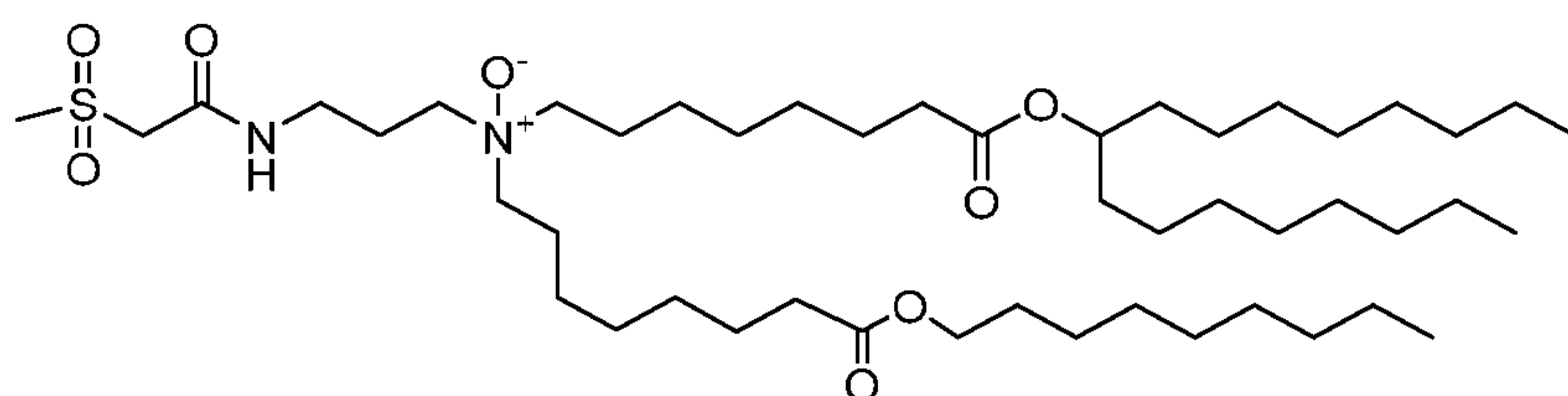
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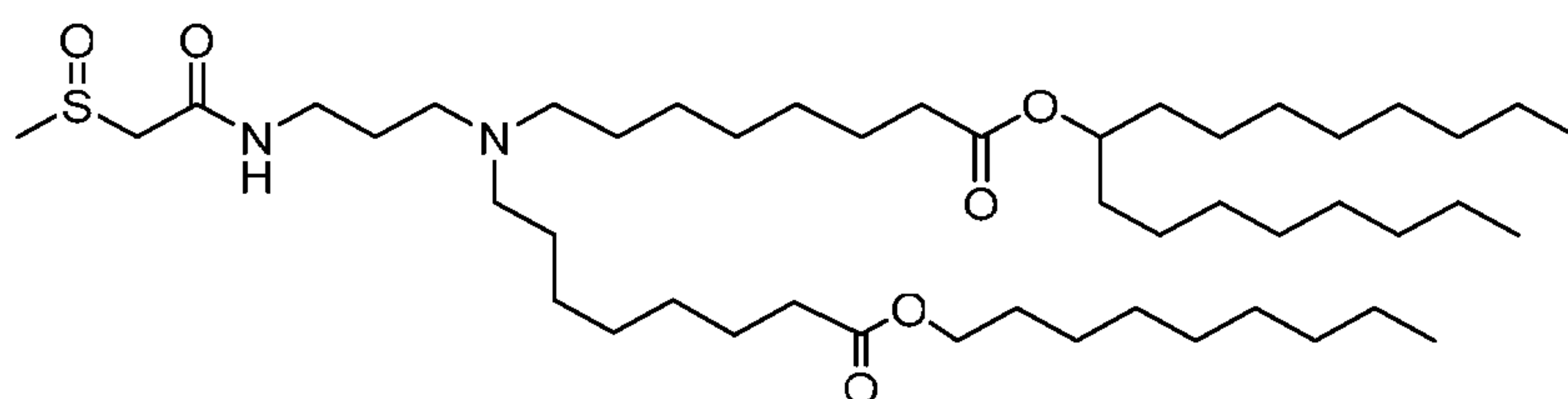
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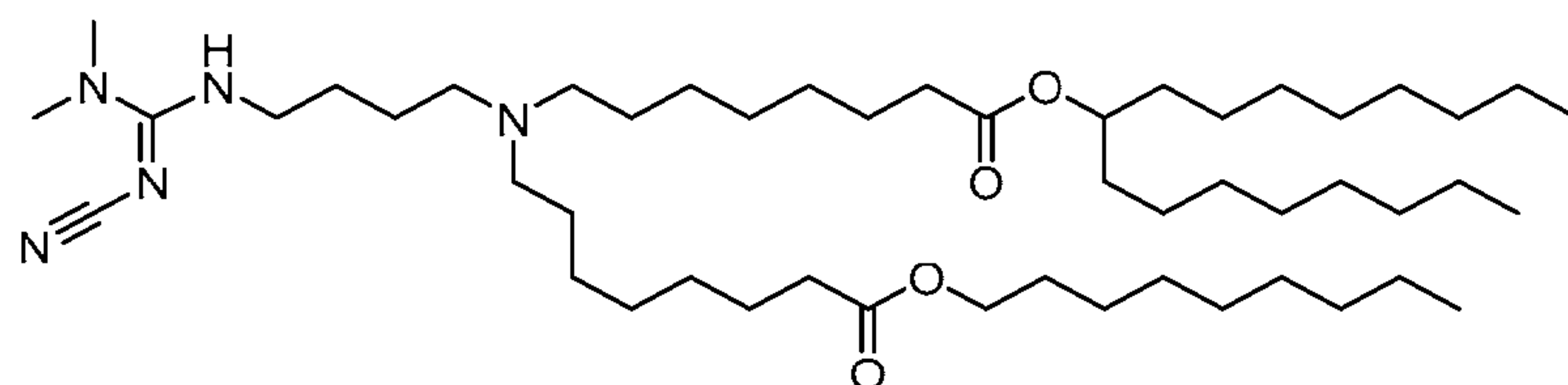
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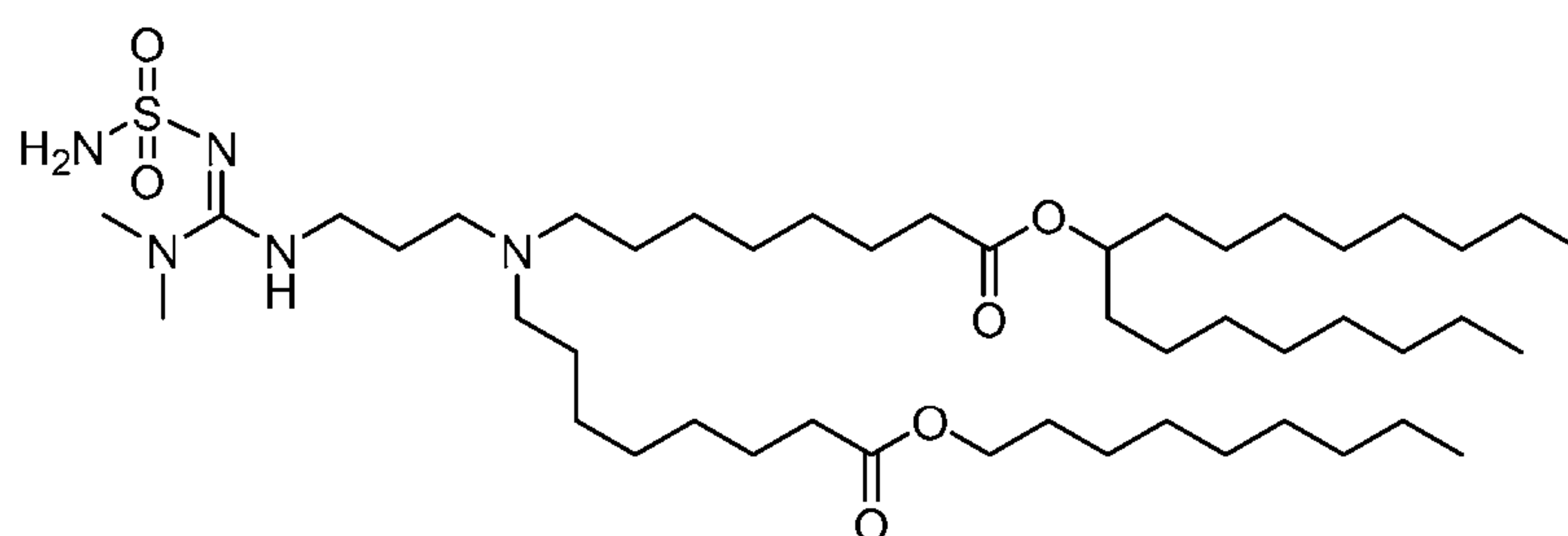
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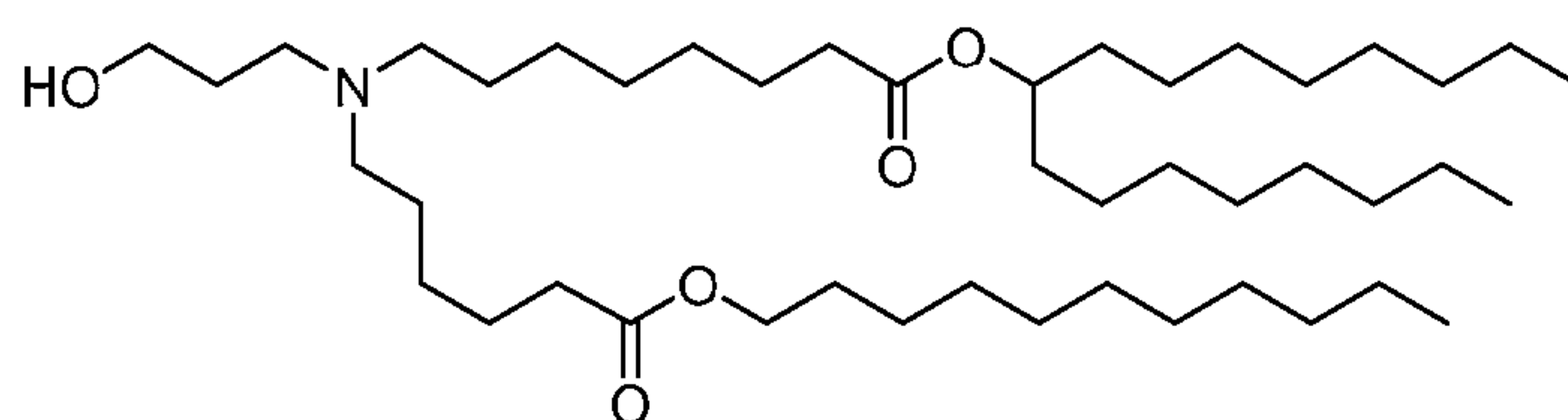
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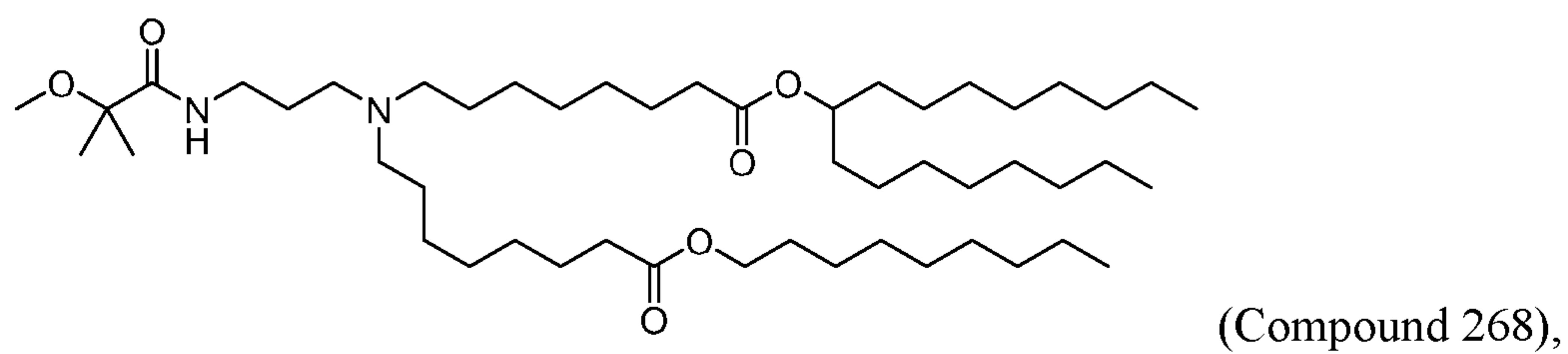
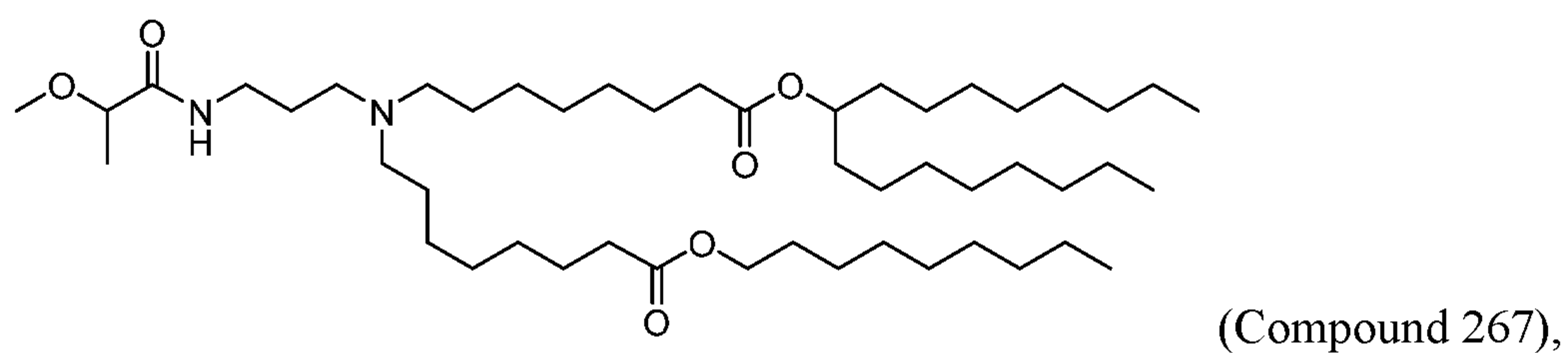
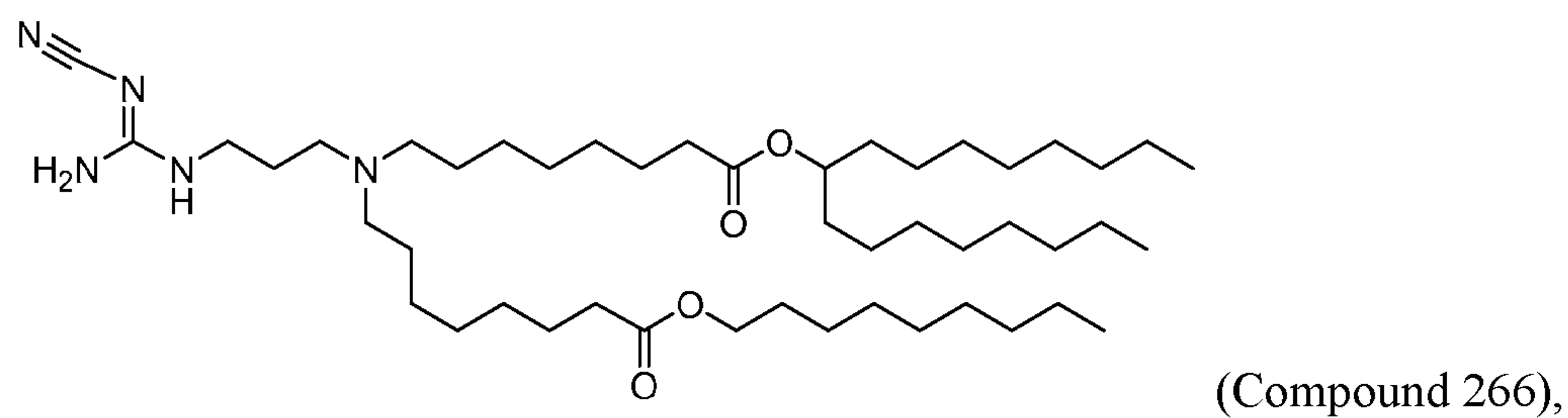
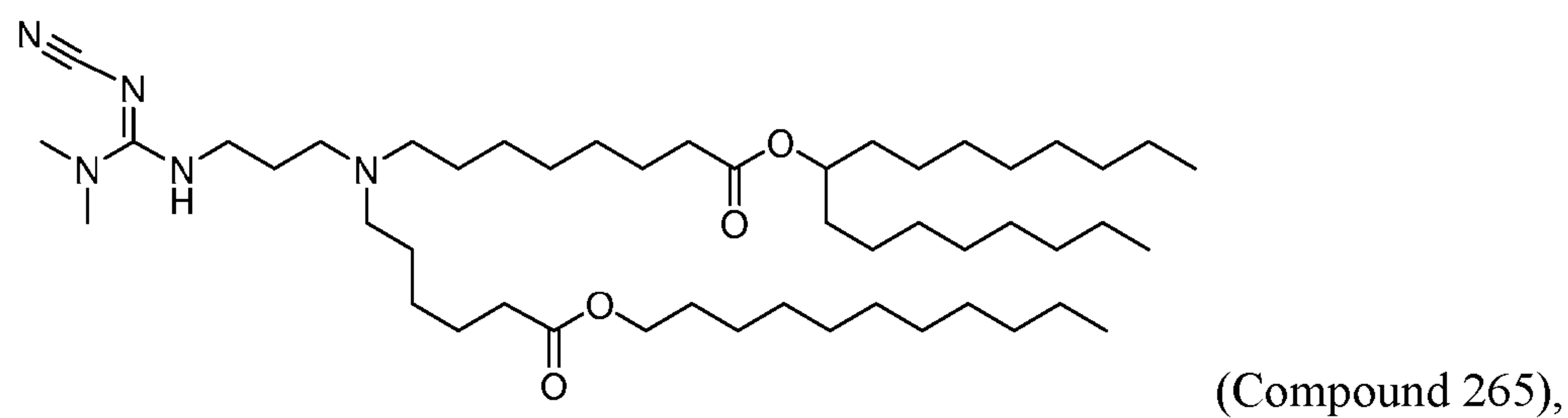
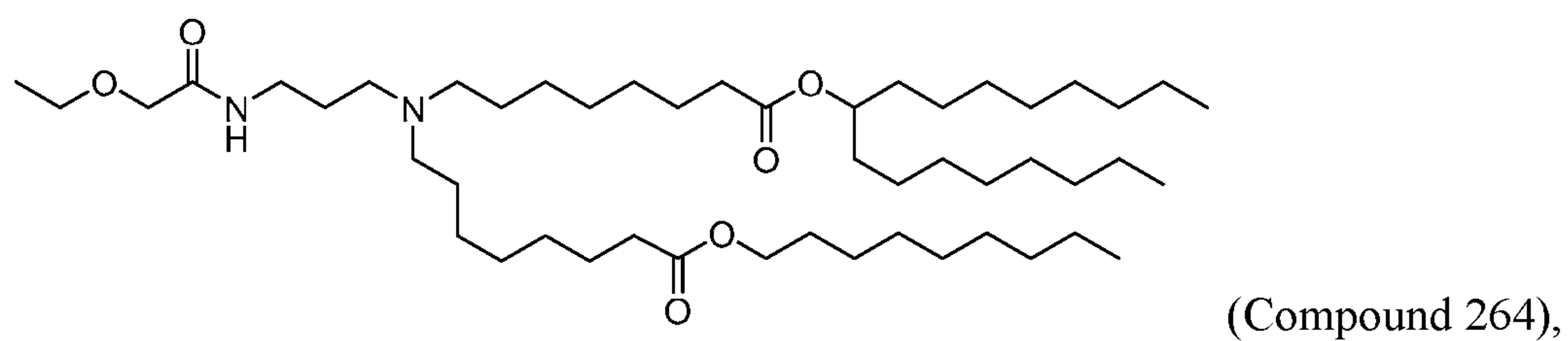
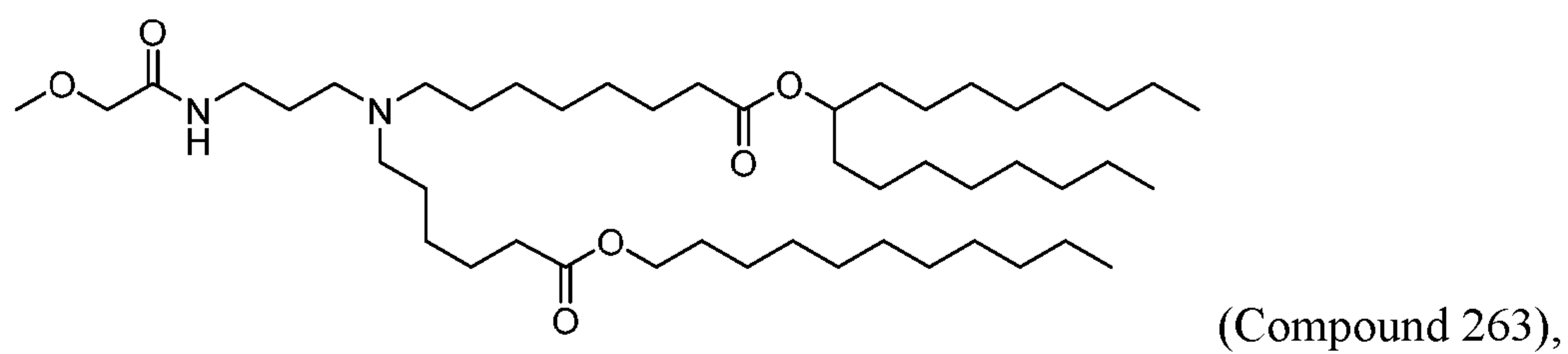
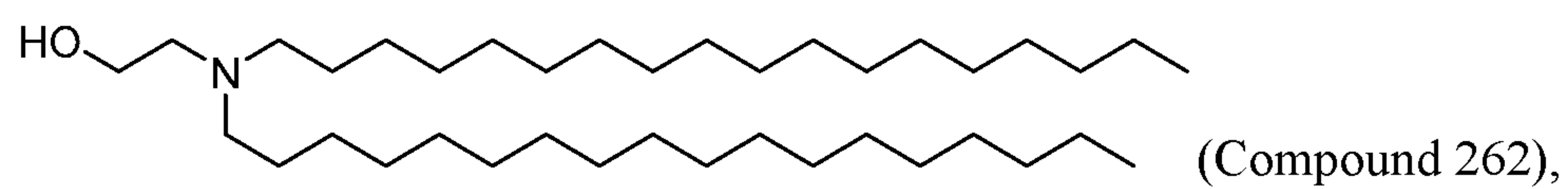
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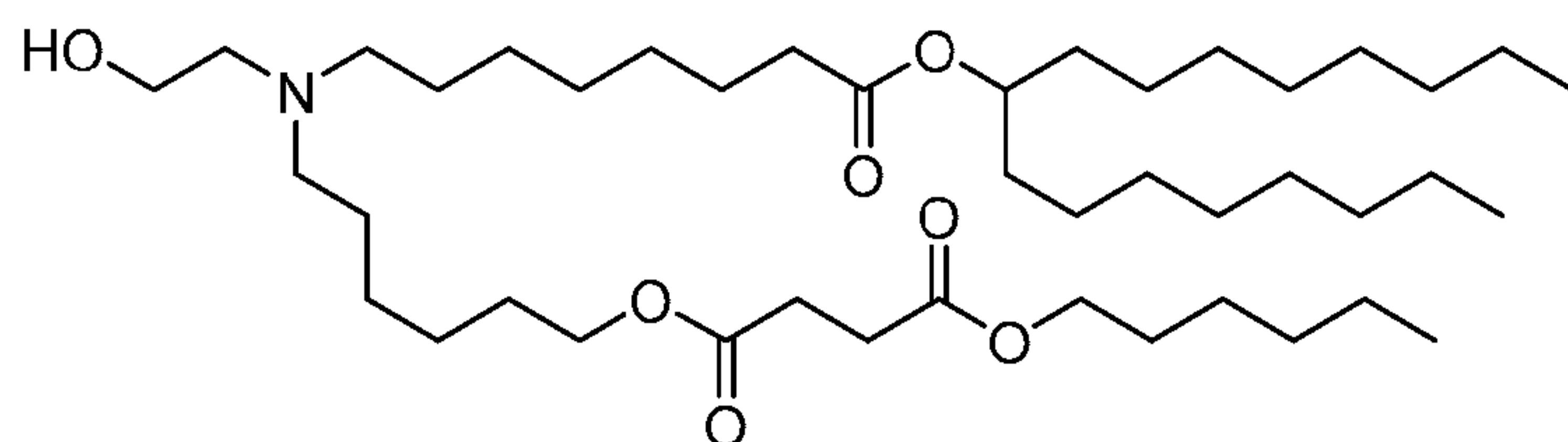


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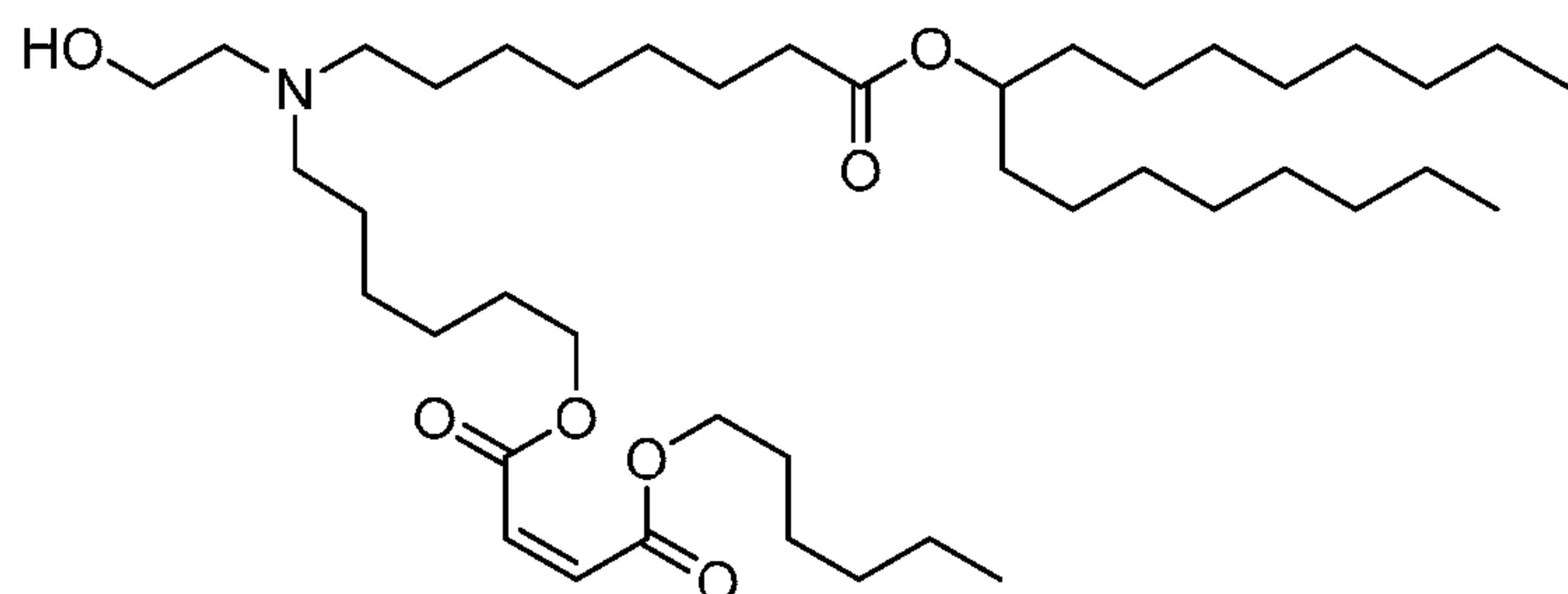


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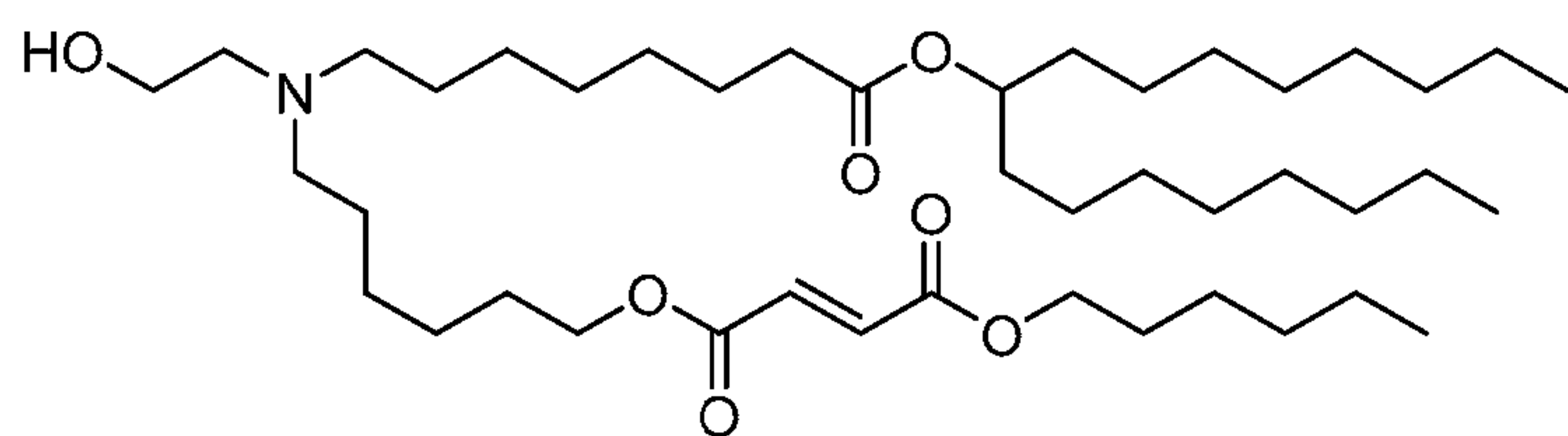




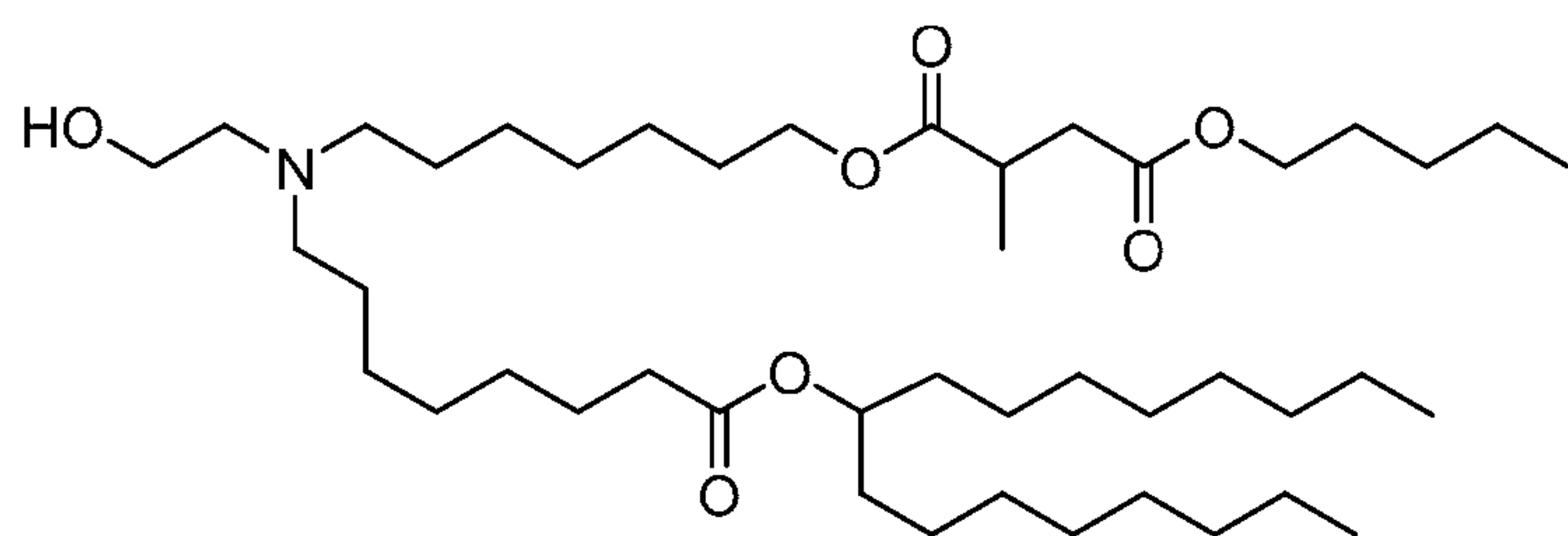
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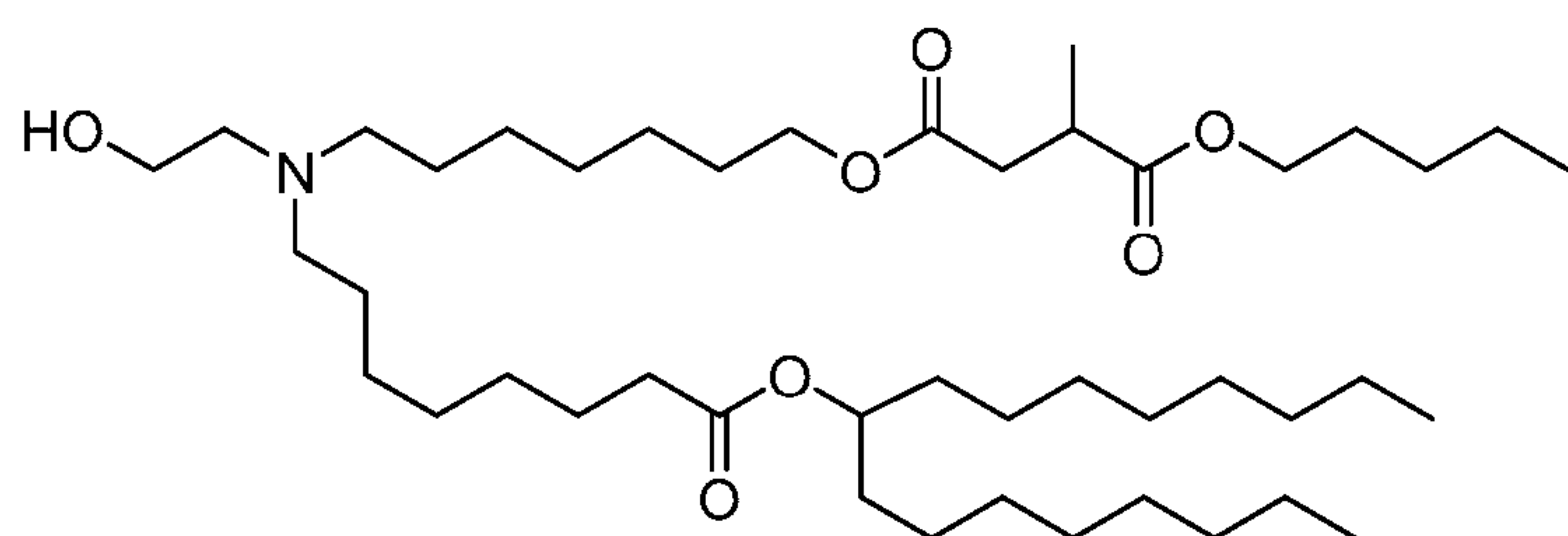
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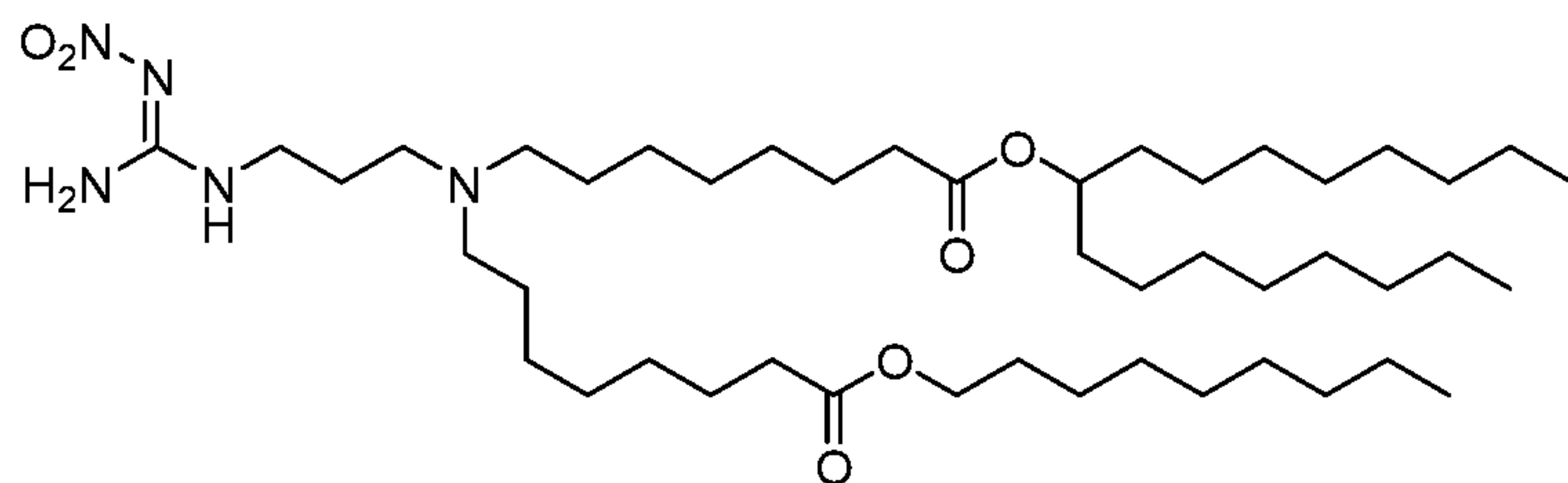
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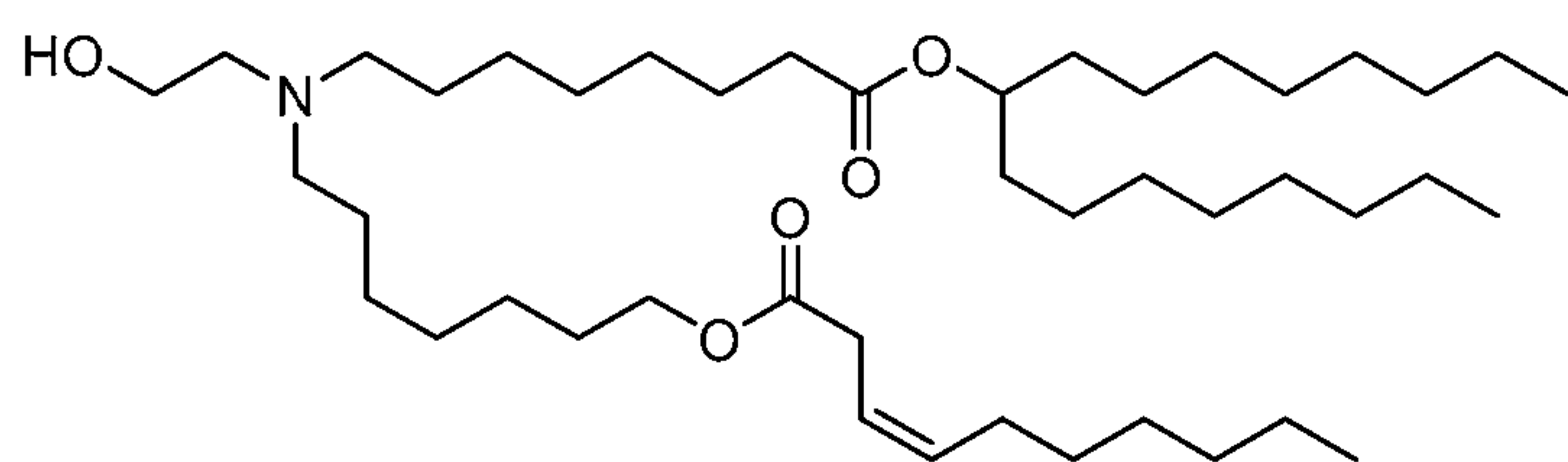
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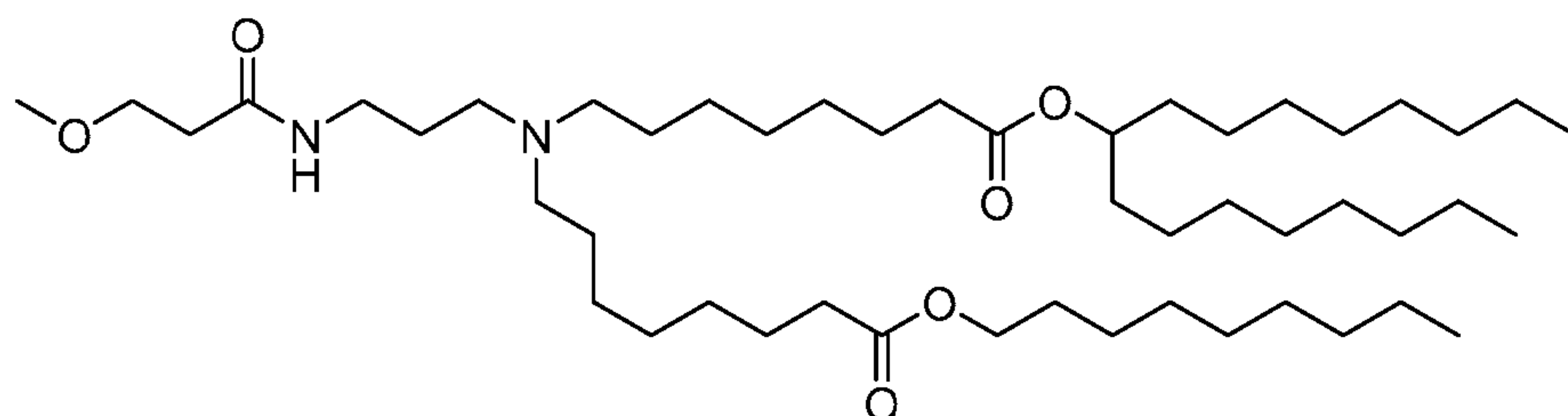
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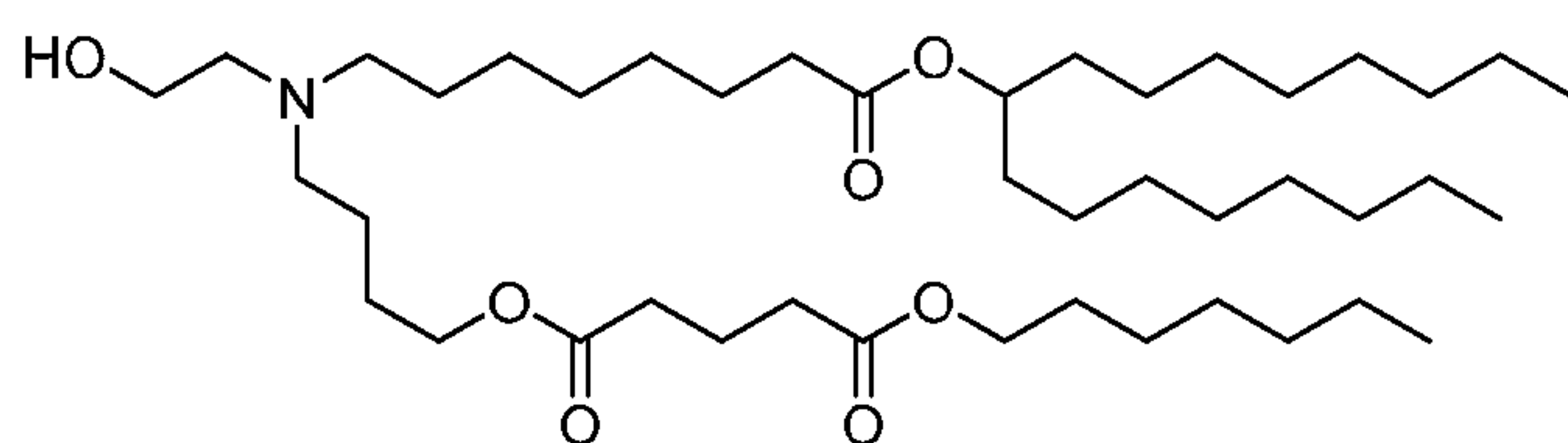
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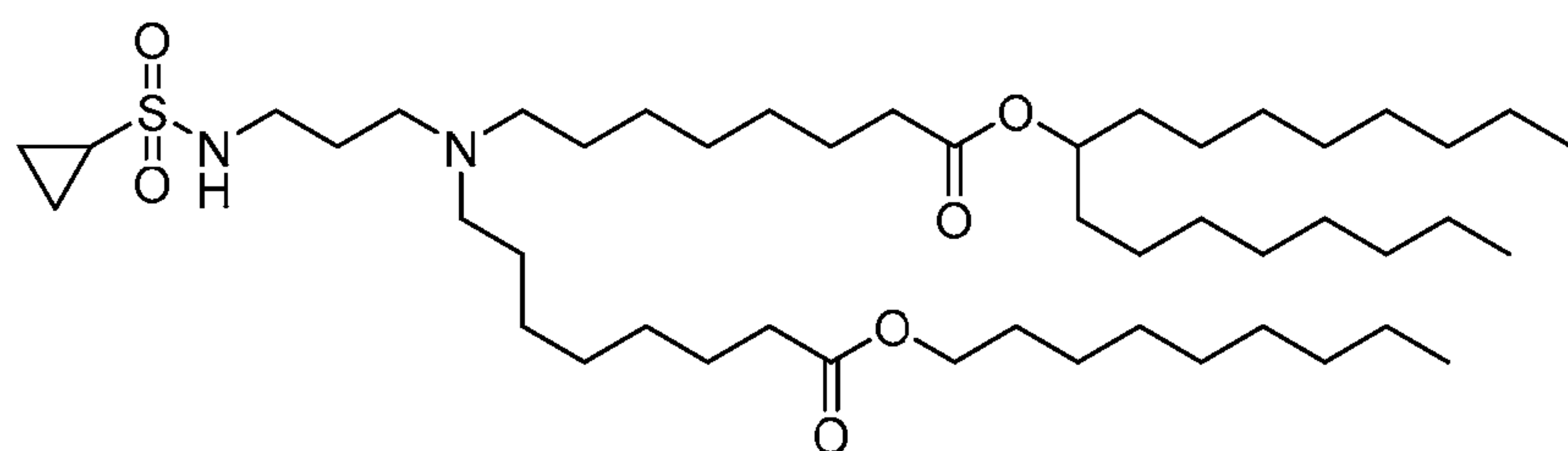
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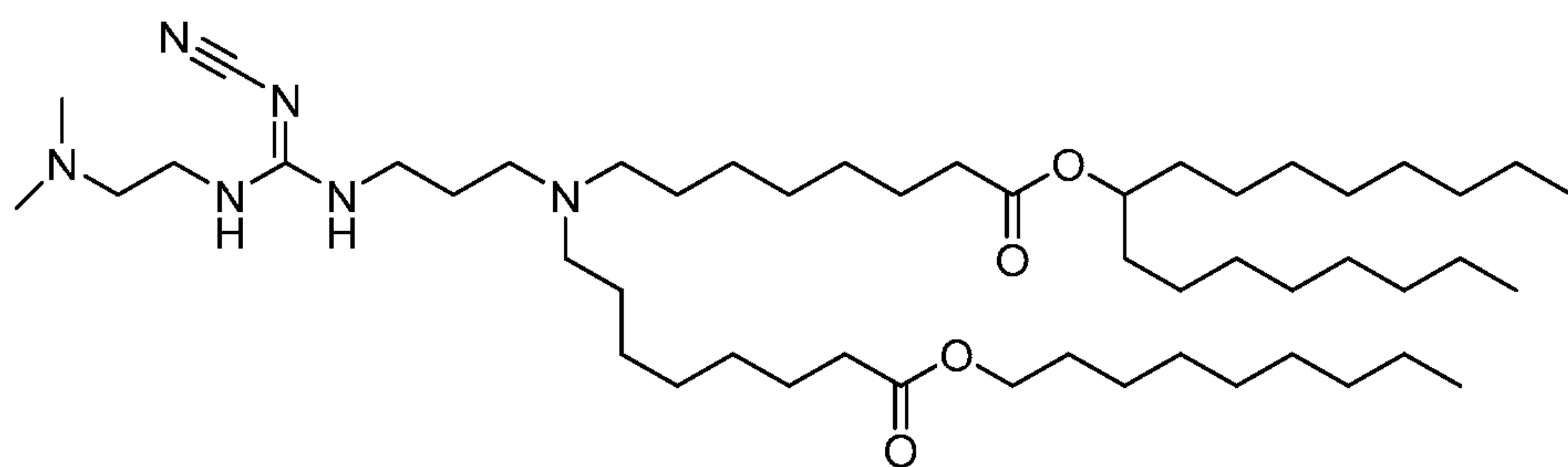
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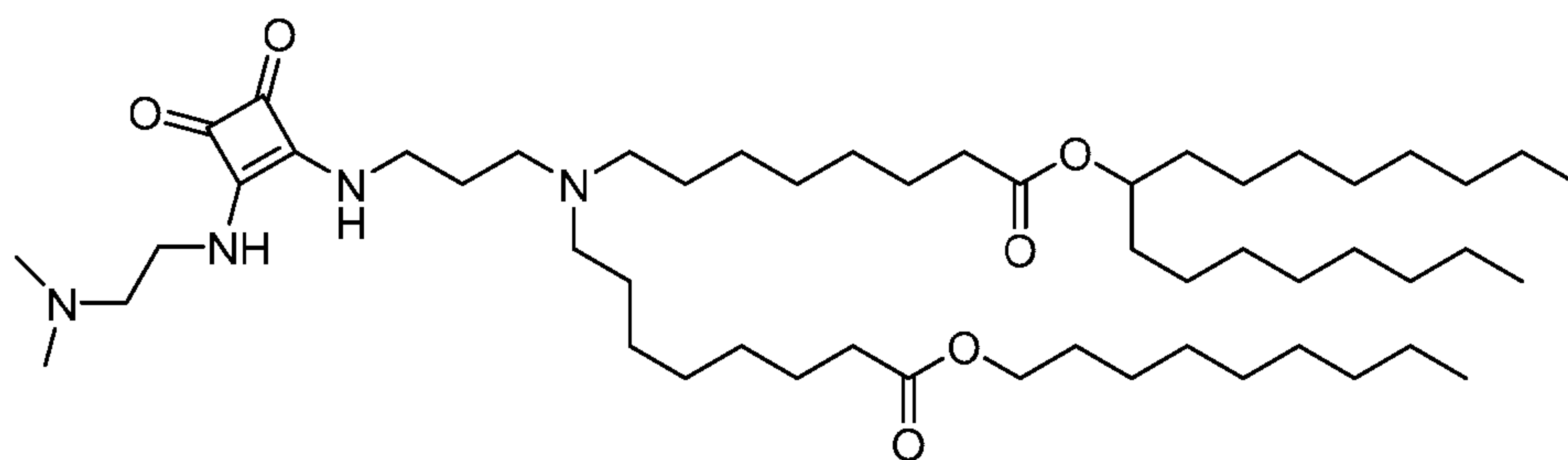
(Compound 277),



(Compound 278),



(Compound 279),



(Compound 280),

and their N-oxides, salts and isomers thereof.

[00199] The central amine moiety of a lipid according to Formula (I), (IA), (IB), (II), (IIa), (IIb), (IIc), (IId), (IIE), (IIf) or (IIg) may be protonated at a physiological pH. Thus, a lipid may have a positive or partial positive charge at physiological pH. Such lipids may be referred to as cationic or ionizable (amino)lipids. Lipids may also be zwitterionic, i.e., neutral molecules having both a positive and a negative charge.

[00200] As used herein, the term “alkyl”, “alkyl group”, or “alkylene” means a linear or branched, saturated hydrocarbon including one or more carbon atoms (*e.g.*, one, two, three, four, five, six, seven, eight, nine, ten, eleven, twelve, thirteen, fourteen, fifteen, sixteen, seventeen, eighteen, nineteen, twenty, or more carbon atoms), which is optionally substituted. The notation “C₁₋₁₄ alkyl” means an optionally substituted linear or branched, saturated hydrocarbon including 1-14 carbon atoms. Unless otherwise specified, an alkyl group described herein refers to both unsubstituted and substituted alkyl groups.

[00201] As used herein, the term “alkenyl”, “alkenyl group”, or “alkenylene” means a linear or branched hydrocarbon including two or more carbon atoms (*e.g.*, two, three, four, five, six, seven, eight, nine, ten, eleven, twelve, thirteen, fourteen, fifteen, sixteen, seventeen, eighteen, nineteen, twenty, or more carbon atoms) and at least one double bond, which is optionally substituted. The notation “C₂₋₁₄ alkenyl” means an optionally substituted linear or branched hydrocarbon including 2-14 carbon atoms and at least one carbon-carbon double bond. An alkenyl group may include one, two, three, four, or more carbon-carbon double bonds. For example, C₁₈ alkenyl may include one or more double bonds. A C₁₈ alkenyl group including two double bonds may be a linoleyl group. Unless otherwise specified, an alkenyl group described herein refers to both unsubstituted and substituted alkenyl groups.

[00202] As used herein, the term “alkynyl”, “alkynyl group”, or “alkynylene” means a linear or branched hydrocarbon including two or more carbon atoms (*e.g.*, two, three, four, five, six, seven, eight, nine, ten, eleven, twelve, thirteen, fourteen, fifteen, sixteen, seventeen, eighteen, nineteen, twenty, or more carbon atoms) and at least one carbon-carbon triple bond, which is optionally substituted. The notation “C₂₋₁₄ alkynyl” means an optionally substituted linear or branched hydrocarbon including 2-14 carbon atoms and at least one carbon-carbon triple bond. An alkynyl group may include one, two, three, four, or more carbon-carbon triple bonds. For example, C₁₈ alkynyl may include one or more carbon-carbon triple bonds. Unless otherwise specified, an alkynyl group described herein refers to both unsubstituted and substituted alkynyl groups.

[00203] As used herein, the term “carbocycle” or “carbocyclic group” means an optionally substituted mono- or multi-cyclic system including one or more rings of carbon atoms. Rings may be three, four, five, six, seven, eight, nine, ten, eleven, twelve, thirteen, fourteen, fifteen, sixteen, seventeen, eighteen, nineteen, or twenty membered rings. The notation “C₃₋₆ carbocycle” means a carbocycle including a single ring having 3-6 carbon atoms. Carbocycles may include one or more carbon-carbon double or triple bonds and may be non-aromatic or aromatic (*e.g.*, cycloalkyl or aryl groups). Examples of carbocycles include cyclopropyl, cyclopentyl, cyclohexyl, phenyl, naphthyl, and 1,2-dihydronaphthyl groups. The term “cycloalkyl” as used herein means a non-aromatic carbocycle and may or may not include any double or triple bond. Unless otherwise specified, carbocycles described herein refers to both unsubstituted and substituted carbocycle groups, *i.e.*, optionally substituted carbocycles.

[00204] As used herein, the term “heterocycle” or “heterocyclic group” means an optionally substituted mono- or multi-cyclic system including one or more rings, where at least one ring includes at least one heteroatom. Heteroatoms may be, for example, nitrogen, oxygen, or sulfur atoms. Rings may be three, four, five, six, seven, eight, nine, ten, eleven, twelve, thirteen, or fourteen membered rings. Heterocycles may include one or more double or triple bonds and may be non-aromatic or aromatic (*e.g.*, heterocycloalkyl or heteroaryl groups). Examples of heterocycles include imidazolyl, imidazolidinyl, oxazolyl, oxazolidinyl, thiazolyl, thiazolidinyl, pyrazolidinyl, pyrazolyl, isoxazolidinyl, isoxazolyl, isothiazolidinyl, isothiazolyl, morpholinyl, pyrrolyl, pyrrolidinyl, furyl, tetrahydrofuryl, thiophenyl, pyridinyl, piperidinyl, quinolyl, and isoquinolyl groups. The term “heterocycloalkyl” as used herein means a non-aromatic heterocycle and may or may not include any double or triple bond. Unless otherwise specified, heterocycles described herein refers to both unsubstituted and substituted heterocycle groups, *i.e.*, optionally substituted heterocycles.

[00205] As used herein, the term “heteroalkyl”, “heteroalkenyl”, or “heteroalkynyl”, refers respectively to an alkyl, alkenyl, alkynyl group, as defined herein, which further comprises one or more (*e.g.*, 1, 2, 3, or 4) heteroatoms (*e.g.*, oxygen, sulfur, nitrogen, boron, silicon, phosphorus) wherein the one or more heteroatoms is inserted between adjacent carbon atoms within the parent carbon chain and/or one or more heteroatoms is inserted between a carbon atom and the parent molecule, *i.e.*, between the point of attachment. Unless otherwise specified, heteroalkyls, heteroalkenyls, or heteroalkynyls described herein refers to both unsubstituted and substituted

heteroalkyls, heteroalkenyls, or heteroalkynyls, i.e., optionally substituted heteroalkyls, heteroalkenyls, or heteroalkynyls.

[00206] As used herein, a “biodegradable group” is a group that may facilitate faster metabolism of a lipid in a mammalian entity. A biodegradable group may be selected from the group consisting of, but is not limited to, $-\text{C}(\text{O})\text{O}-$, $-\text{OC}(\text{O})-$, $-\text{C}(\text{O})\text{N}(\text{R}')$ -, $-\text{N}(\text{R}')\text{C}(\text{O})-$, $-\text{C}(\text{O})-$, $-\text{C}(\text{S})-$, $-\text{C}(\text{S})\text{S}-$, $-\text{SC}(\text{S})-$, $-\text{CH}(\text{OH})-$, $-\text{P}(\text{O})(\text{OR}')\text{O}-$, $-\text{S}(\text{O})_2-$, an aryl group, and a heteroaryl group. As used herein, an “aryl group” is an optionally substituted carbocyclic group including one or more aromatic rings. Examples of aryl groups include phenyl and naphthyl groups. As used herein, a “heteroaryl group” is an optionally substituted heterocyclic group including one or more aromatic rings. Examples of heteroaryl groups include pyrrolyl, furyl, thiophenyl, imidazolyl, oxazolyl, and thiazolyl. Both aryl and heteroaryl groups may be optionally substituted. For example, M and M' can be selected from the non-limiting group consisting of optionally substituted phenyl, oxazole, and thiazole. In the formulas herein, M and M' can be independently selected from the list of biodegradable groups above. Unless otherwise specified, aryl or heteroaryl groups described herein refers to both unsubstituted and substituted groups, i.e., optionally substituted aryl or heteroaryl groups.

[00207] Alkyl, alkenyl, and cyclyl (*e.g.*, carbocyclyl and heterocyclyl) groups may be optionally substituted unless otherwise specified. Optional substituents may be selected from the group consisting of, but are not limited to, a halogen atom (*e.g.*, a chloride, bromide, fluoride, or iodide group), a carboxylic acid (*e.g.*, $-\text{C}(\text{O})\text{OH}$), an alcohol (*e.g.*, a hydroxyl, $-\text{OH}$), an ester (*e.g.*, $-\text{C}(\text{O})\text{OR}$ $-\text{OC}(\text{O})\text{R}$), an aldehyde (*e.g.*, $-\text{C}(\text{O})\text{H}$), a carbonyl (*e.g.*, $-\text{C}(\text{O})\text{R}$, alternatively represented by $\text{C}=\text{O}$), an acyl halide (*e.g.*, $-\text{C}(\text{O})\text{X}$, in which X is a halide selected from bromide, fluoride, chloride, and iodide), a carbonate (*e.g.*, $-\text{OC}(\text{O})\text{OR}$), an alkoxy (*e.g.*, $-\text{OR}$), an acetal (*e.g.*, $-\text{C}(\text{OR})_2\text{R}''''$), in which each OR are alkoxy groups that can be the same or different and R'''' is an alkyl or alkenyl group), a phosphate (*e.g.*, $\text{P}(\text{O})_4^{3-}$), a thiol (*e.g.*, $-\text{SH}$), a sulfoxide (*e.g.*, $-\text{S}(\text{O})\text{R}$), a sulfinic acid (*e.g.*, $-\text{S}(\text{O})\text{OH}$), a sulfonic acid (*e.g.*, $-\text{S}(\text{O})_2\text{OH}$), a thial (*e.g.*, $-\text{C}(\text{S})\text{H}$), a sulfate (*e.g.*, $\text{S}(\text{O})_4^{2-}$), a sulfonyl (*e.g.*, $-\text{S}(\text{O})_2-$), an amide (*e.g.*, $-\text{C}(\text{O})\text{NR}_2$, or $-\text{N}(\text{R})\text{C}(\text{O})\text{R}$), an azido (*e.g.*, $-\text{N}_3$), a nitro (*e.g.*, $-\text{NO}_2$), a cyano (*e.g.*, $-\text{CN}$), an isocyano (*e.g.*, $-\text{NC}$), an acyloxy (*e.g.*, $-\text{OC}(\text{O})\text{R}$), an amino (*e.g.*, $-\text{NR}_2$, $-\text{NRH}$, or $-\text{NH}_2$), a carbamoyl (*e.g.*, $-\text{OC}(\text{O})\text{NR}_2$, $-\text{OC}(\text{O})\text{NRH}$, or $-\text{OC}(\text{O})\text{NH}_2$), a sulfonamide (*e.g.*, $-\text{S}(\text{O})_2\text{NR}_2$, $-\text{S}(\text{O})_2\text{NRH}$, $-\text{S}(\text{O})_2\text{NH}_2$, $-\text{N}(\text{R})\text{S}(\text{O})_2\text{R}$, $-\text{N}(\text{H})\text{S}(\text{O})_2\text{R}$, $-\text{N}(\text{R})\text{S}(\text{O})_2\text{H}$,

or -N(H)S(O)₂H), an alkyl group, an alkenyl group, and a cyclyl (*e.g.*, carbocyclyl or heterocyclyl) group. In any of the preceding, R is an alkyl or alkenyl group, as defined herein. In some embodiments, the substituent groups themselves may be further substituted with, for example, one, two, three, four, five, or six substituents as defined herein. For example, a C₁₋₆ alkyl group may be further substituted with one, two, three, four, five, or six substituents as described herein.

[00208] Compounds of the disclosure that contain nitrogens can be converted to N-oxides by treatment with an oxidizing agent (*e.g.*, 3-chloroperoxybenzoic acid (*m*CPBA) and/or hydrogen peroxides) to afford other compounds of the disclosure. Thus, all shown and claimed nitrogen-containing compounds are considered, when allowed by valency and structure, to include both the compound as shown and its N-oxide derivative (which can be designated as N→O or N⁺-O⁻). Furthermore, in other instances, the nitrogens in the compounds of the disclosure can be converted to N-hydroxy or N-alkoxy compounds. For example, N-hydroxy compounds can be prepared by oxidation of the parent amine by an oxidizing agent such as *m*-CPBA. All shown and claimed nitrogen-containing compounds are also considered, when allowed by valency and structure, to cover both the compound as shown and its N-hydroxy (*i.e.*, N-OH) and N-alkoxy (*i.e.*, N-OR, wherein R is substituted or unsubstituted C₁-C₆ alkyl, C₁-C₆ alkenyl, C₁-C₆ alkynyl, 3-14-membered carbocycle or 3-14-membered heterocycle) derivatives.

[00209] About, Approximately: As used herein, the terms “approximately” and “about,” as applied to one or more values of interest, refer to a value that is similar to a stated reference value. In certain embodiments, the term “approximately” or “about” refers to a range of values that fall within 25%, 20%, 19%, 18%, 17%, 16%, 15%, 14%, 13%, 12%, 11%, 10%, 9%, 8%, 7%, 6%, 5%, 4%, 3%, 2%, 1%, or less in either direction (greater than or less than) of the stated reference value unless otherwise stated or otherwise evident from the context (except where such number would exceed 100% of a possible value). For example, when used in the context of an amount of a given compound in a lipid component of a nanoparticle composition, “about” may mean +/- 10% of the recited value. For instance, a nanoparticle composition including a lipid component having about 40% of a given compound may include 30-50% of the compound.

[00210] As used herein, the term “compound,” is meant to include all isomers and isotopes of the structure depicted. “Isotopes” refers to atoms having the same atomic number but different mass numbers resulting from a different number of neutrons in the nuclei. For example, isotopes of hydrogen include tritium and deuterium. Further, a compound, salt, or complex of the present

disclosure can be prepared in combination with solvent or water molecules to form solvates and hydrates by routine methods.

[00211] As used herein, the term “contacting” means establishing a physical connection between two or more entities. For example, contacting a mammalian cell with a nanoparticle composition means that the mammalian cell and a nanoparticle are made to share a physical connection.

Methods of contacting cells with external entities both in vivo and ex vivo are well known in the biological arts. For example, contacting a nanoparticle composition and a mammalian cell disposed within a mammal may be performed by varied routes of administration (*e.g.*, intravenous, intramuscular, intradermal, and subcutaneous) and may involve varied amounts of nanoparticle compositions. Moreover, more than one mammalian cell may be contacted by a nanoparticle composition.

[00212] As used herein, the term “delivering” means providing an entity to a destination. For example, delivering a therapeutic and/or prophylactic to a subject may involve administering a nanoparticle composition including the therapeutic and/or prophylactic to the subject (*e.g.*, by an intravenous, intramuscular, intradermal, intraperitoneal, intratumoral, or subcutaneous route).

Administration of a nanoparticle composition to a mammal or mammalian cell may involve contacting one or more cells with the nanoparticle composition.

[00213] As used herein, the term “enhanced delivery” means delivery of more (*e.g.*, at least 1.5 fold more, at least 2-fold more, at least 3-fold more, at least 4-fold more, at least 5-fold more, at least 6-fold more, at least 7-fold more, at least 8-fold more, at least 9-fold more, at least 10-fold more) of a therapeutic and/or prophylactic by a nanoparticle to a target tissue of interest (*e.g.*, mammalian liver) compared to the level of delivery of a therapeutic and/or prophylactic by a control nanoparticle to a target tissue of interest (*e.g.*, MC3, KC2, or DLinDMA). The level of delivery of a nanoparticle to a particular tissue may be measured by comparing the amount of protein produced in a tissue to the weight of said tissue, comparing the amount of therapeutic and/or prophylactic in a tissue to the weight of said tissue, comparing the amount of protein produced in a tissue to the amount of total protein in said tissue, or comparing the amount of therapeutic and/or prophylactic in a tissue to the amount of total therapeutic and/or prophylactic in said tissue. It will be understood that the enhanced delivery of a nanoparticle to a target tissue need not be determined in a subject being treated, it may be determined in a surrogate such as an animal model (*e.g.*, a rat model). In certain embodiments, a nanoparticle composition including a compound according to Formula (I),

(IA), (IB), (II), (IIa), (IIb), (IIc), (IId), (IIe), (IIf) or (IIg) has substantively the same level of delivery enhancement regardless of administration routes. For example, certain compounds disclosed herein exhibit similar delivery enhancement when they are used for delivering a therapeutic and/or prophylactic either intravenously or intramuscularly. In other embodiments, certain compounds disclosed herein (*e.g.*, a compound of Formula (IA) or (II), such as Compound 18, 25, 30, 60, 108-112, or 122) exhibit a higher level of delivery enhancement when they are used for delivering a therapeutic and/or prophylactic intramuscularly than intravenously.

[00214] As used herein, the term “specific delivery,” “specifically deliver,” or “specifically delivering” means delivery of more (*e.g.*, at least 1.5 fold more, at least 2-fold more, at least 3-fold more, at least 4-fold more, at least 5-fold more, at least 6-fold more, at least 7-fold more, at least 8-fold more, at least 9-fold more, at least 10-fold more) of a therapeutic and/or prophylactic by a nanoparticle to a target tissue of interest (*e.g.*, mammalian liver) compared to an off-target tissue (*e.g.*, mammalian spleen). The level of delivery of a nanoparticle to a particular tissue may be measured by comparing the amount of protein produced in a tissue to the weight of said tissue, comparing the amount of therapeutic and/or prophylactic in a tissue to the weight of said tissue, comparing the amount of protein produced in a tissue to the amount of total protein in said tissue, or comparing the amount of therapeutic and/or prophylactic in a tissue to the amount of total therapeutic and/or prophylactic in said tissue. For example, for renovascular targeting, a therapeutic and/or prophylactic is specifically provided to a mammalian kidney as compared to the liver and spleen if 1.5, 2-fold, 3-fold, 5-fold, 10-fold, 15 fold, or 20 fold more therapeutic and/or prophylactic per 1 g of tissue is delivered to a kidney compared to that delivered to the liver or spleen following systemic administration of the therapeutic and/or prophylactic. It will be understood that the ability of a nanoparticle to specifically deliver to a target tissue need not be determined in a subject being treated, it may be determined in a surrogate such as an animal model (*e.g.*, a rat model).

[00215] As used herein, “encapsulation efficiency” refers to the amount of a therapeutic and/or prophylactic that becomes part of a nanoparticle composition, relative to the initial total amount of therapeutic and/or prophylactic used in the preparation of a nanoparticle composition. For example, if 97 mg of therapeutic and/or prophylactic are encapsulated in a nanoparticle composition out of a total 100 mg of therapeutic and/or prophylactic initially provided to the composition, the encapsulation efficiency may be given as 97%. As used herein, “encapsulation” may refer to complete, substantial, or partial enclosure, confinement, surrounding, or encasement.

[00216] As used herein, “expression” of a nucleic acid sequence refers to translation of an mRNA into a polypeptide or protein and/or post-translational modification of a polypeptide or protein.

[00217] As used herein, the term “in vitro” refers to events that occur in an artificial environment, *e.g.*, in a test tube or reaction vessel, in cell culture, in a Petri dish, etc., rather than within an organism (*e.g.*, animal, plant, or microbe).

[00218] As used herein, the term “in vivo” refers to events that occur within an organism (*e.g.*, animal, plant, or microbe or cell or tissue thereof).

[00219] As used herein, the term “ex vivo” refers to events that occur outside of an organism (*e.g.*, animal, plant, or microbe or cell or tissue thereof). Ex vivo events may take place in an environment minimally altered from a natural (*e.g.*, in vivo) environment.

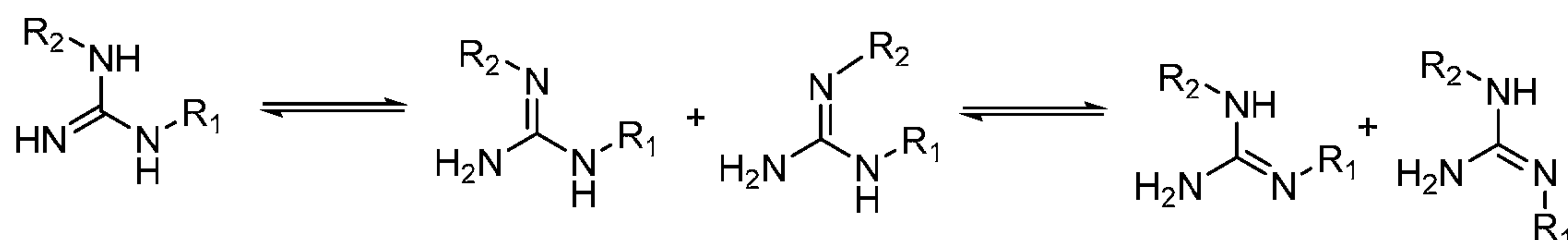
[00220] As used herein, the term “isomer” means any geometric isomer, tautomer, zwitterion, stereoisomer, enantiomer, or diastereomer of a compound. Compounds may include one or more chiral centers and/or double bonds and may thus exist as stereoisomers, such as double-bond isomers (*i.e.*, geometric E/Z isomers) or diastereomers (*e.g.*, enantiomers (*i.e.*, (+) or (-)) or *cis/trans* isomers). The present disclosure encompasses any and all isomers of the compounds described herein, including stereomerically pure forms (*e.g.*, geometrically pure, enantiomerically pure, or diastereomerically pure) and enantiomeric and stereoisomeric mixtures, *e.g.*, racemates. Enantiomeric and stereomeric mixtures of compounds and means of resolving them into their component enantiomers or stereoisomers are well-known.

[00221] “Tautomer” is one of two or more structural isomers that exist in equilibrium and is readily converted from one isomeric form to another. This conversion results in the formal migration of a hydrogen atom accompanied by a switch of adjacent conjugated double bonds. Tautomers exist as a mixture of a tautomeric set in solution. In solutions where tautomerization is possible, a chemical equilibrium of the tautomers will be reached. The exact ratio of the tautomers depends on several factors, including temperature, solvent and pH. The concept of tautomers that are interconvertible by tautomerization is called tautomerism.

[00222] Of the various types of tautomerism that are possible, two are commonly observed. In keto-enol tautomerism a simultaneous shift of electrons and a hydrogen atom occurs. Ring-chain tautomerism arises as a result of the aldehyde group (-CHO) in a sugar chain molecule reacting with

one of the hydroxy groups (-OH) in the same molecule to give it a cyclic (ring-shaped) form as exhibited by glucose.

[00223] Common tautomeric pairs are: ketone-enol, amide-nitrile, lactam-lactim, amide-imidic acid tautomerism in heterocyclic rings (*e.g.*, in nucleobases such as guanine, thymine and cytosine), imine-enamine and enamine-enamine. An example of tautomerism in di-substituted guanidine is shown below.



[00224] It is to be understood that the compounds of the disclosure may be depicted as different tautomers. It should also be understood that when compounds have tautomeric forms, all tautomeric forms are intended to be included in the scope of the disclosure, and the naming of the compounds does not exclude any tautomer form.

[00225] As used herein, a “lipid component” is that component of a nanoparticle composition that includes one or more lipids. For example, the lipid component may include one or more cationic/ionizable, PEGylated, structural, or other lipids, such as phospholipids.

[00226] As used herein, a “linker” is a moiety connecting two moieties, for example, the connection between two nucleosides of a cap species. A linker may include one or more groups including but not limited to phosphate groups (*e.g.*, phosphates, boranophosphates, thiophosphates, selenophosphates, and phosphonates), alkyl groups, amidates, or glycerols. For example, two nucleosides of a cap analog may be linked at their 5' positions by a triphosphate group or by a chain including two phosphate moieties and a boranophosphate moiety.

[00227] As used herein, “methods of administration” may include intravenous, intramuscular, intradermal, subcutaneous, or other methods of delivering a composition to a subject. A method of administration may be selected to target delivery (*e.g.*, to specifically deliver) to a specific region or system of a body.

[00228] As used herein, “modified” means non-natural. For example, an RNA may be a modified RNA. That is, an RNA may include one or more nucleobases, nucleosides, nucleotides, or linkers that are non-naturally occurring. A “modified” species may also be referred to herein as an “altered” species. Species may be modified or altered chemically, structurally, or functionally. For

example, a modified nucleobase species may include one or more substitutions that are not naturally occurring.

[00229] As used herein, the “N:P ratio” is the molar ratio of ionizable (in the physiological pH range) nitrogen atoms in a lipid to phosphate groups in an RNA, *e.g.*, in a nanoparticle composition including a lipid component and an RNA.

[00230] As used herein, a “nanoparticle composition” is a composition comprising one or more lipids. Nanoparticle compositions are typically sized on the order of micrometers or smaller and may include a lipid bilayer. Nanoparticle compositions encompass lipid nanoparticles (LNPs), liposomes (*e.g.*, lipid vesicles), and lipoplexes. For example, a nanoparticle composition may be a liposome having a lipid bilayer with a diameter of 500 nm or less.

[00231] As used herein, “naturally occurring” means existing in nature without artificial aid.

[00232] As used herein, “patient” refers to a subject who may seek or be in need of treatment, requires treatment, is receiving treatment, will receive treatment, or a subject who is under care by a trained professional for a particular disease or condition.

[00233] As used herein, a “PEG lipid” or “PEGylated lipid” refers to a lipid comprising a polyethylene glycol component.

[00234] The phrase “pharmaceutically acceptable” is used herein to refer to those compounds, materials, compositions, and/or dosage forms which are, within the scope of sound medical judgment, suitable for use in contact with the tissues of human beings and animals without excessive toxicity, irritation, allergic response, or other problem or complication, commensurate with a reasonable benefit/risk ratio.

[00235] The phrase “pharmaceutically acceptable excipient,” as used herein, refers to any ingredient other than the compounds described herein (for example, a vehicle capable of suspending, complexing, or dissolving the active compound) and having the properties of being substantially nontoxic and non-inflammatory in a patient. Excipients may include, for example: anti-adherents, antioxidants, binders, coatings, compression aids, disintegrants, dyes (colors), emollients, emulsifiers, fillers (diluent), film formers or coatings, flavors, fragrances, glidants (flow enhancers), lubricants, preservatives, printing inks, sorbents, suspending or dispersing agents, sweeteners, and waters of hydration. Exemplary excipients include, but are not limited to: butylated hydroxytoluene (BHT), calcium carbonate, calcium phosphate (dibasic), calcium stearate, croscarmellose, crosslinked polyvinyl pyrrolidone, citric acid, crospovidone, cysteine,

ethylcellulose, gelatin, hydroxypropyl cellulose, hydroxypropyl methylcellulose, lactose, magnesium stearate, maltitol, mannitol, methionine, methylcellulose, methyl paraben, microcrystalline cellulose, polyethylene glycol, polyvinyl pyrrolidone, povidone, pregelatinized starch, propyl paraben, retinyl palmitate, shellac, silicon dioxide, sodium carboxymethyl cellulose, sodium citrate, sodium starch glycolate, sorbitol, starch (corn), stearic acid, sucrose, talc, titanium dioxide, vitamin A, vitamin E (alpha-tocopherol), vitamin C, xylitol, and other species disclosed herein.

[00236] In the present specification, the structural formula of the compound represents a certain isomer for convenience in some cases, but the present disclosure includes all isomers, such as geometrical isomers, optical isomers based on an asymmetrical carbon, stereoisomers, tautomers, and the like, it being understood that not all isomers may have the same level of activity. In addition, a crystal polymorphism may be present for the compounds represented by the formula. It is noted that any crystal form, crystal form mixture, or anhydride or hydrate thereof is included in the scope of the present disclosure.

[00237] The term “crystal polymorphs”, “polymorphs” or “crystal forms” means crystal structures in which a compound (or a salt or solvate thereof) can crystallize in different crystal packing arrangements, all of which have the same elemental composition. Different crystal forms usually have different X-ray diffraction patterns, infrared spectral, melting points, density hardness, crystal shape, optical and electrical properties, stability and solubility. Recrystallization solvent, rate of crystallization, storage temperature, and other factors may cause one crystal form to dominate. Crystal polymorphs of the compounds can be prepared by crystallization under different conditions.

[00238] Compositions may also include salts of one or more compounds. Salts may be pharmaceutically acceptable salts. As used herein, “pharmaceutically acceptable salts” refers to derivatives of the disclosed compounds wherein the parent compound is altered by converting an existing acid or base moiety to its salt form (*e.g.*, by reacting a free base group with a suitable organic acid). Examples of pharmaceutically acceptable salts include, but are not limited to, mineral or organic acid salts of basic residues such as amines; alkali or organic salts of acidic residues such as carboxylic acids; and the like. Representative acid addition salts include acetate, adipate, alginate, ascorbate, aspartate, benzenesulfonate, benzoate, bisulfate, borate, butyrate, camphorate, camphorsulfonate, citrate, cyclopentanepropionate, digluconate, dodecylsulfate,

ethanesulfonate, fumarate, glucoheptonate, glycerophosphate, hemisulfate, heptonate, hexanoate, hydrobromide, hydrochloride, hydroiodide, 2-hydroxy-ethanesulfonate, lactobionate, lactate, laurate, lauryl sulfate, malate, maleate, malonate, methanesulfonate, 2-naphthalenesulfonate, nicotinate, nitrate, oleate, oxalate, palmitate, pamoate, pectinate, persulfate, 3-phenylpropionate, phosphate, picrate, pivalate, propionate, stearate, succinate, sulfate, tartrate, thiocyanate, toluenesulfonate, undecanoate, valerate salts, and the like. Representative alkali or alkaline earth metal salts include sodium, lithium, potassium, calcium, magnesium, and the like, as well as nontoxic ammonium, quaternary ammonium, and amine cations, including, but not limited to ammonium, tetramethylammonium, tetraethylammonium, methylamine, dimethylamine, trimethylamine, triethylamine, ethylamine, and the like. The pharmaceutically acceptable salts of the present disclosure include the conventional non-toxic salts of the parent compound formed, for example, from non-toxic inorganic or organic acids. The pharmaceutically acceptable salts of the present disclosure can be synthesized from the parent compound which contains a basic or acidic moiety by conventional chemical methods. Generally, such salts can be prepared by reacting the free acid or base forms of these compounds with a stoichiometric amount of the appropriate base or acid in water or in an organic solvent, or in a mixture of the two; generally, nonaqueous media like ether, ethyl acetate, ethanol, isopropanol, or acetonitrile are preferred. Lists of suitable salts are found in Remington's Pharmaceutical Sciences, 17th ed., Mack Publishing Company, Easton, Pa., 1985, p. 1418, Pharmaceutical Salts: Properties, Selection, and Use, P.H. Stahl and C.G. Wermuth (eds.), Wiley-VCH, 2008, and Berge et al., Journal of Pharmaceutical Science, 66, 1-19 (1977), each of which is incorporated herein by reference in its entirety.

[00239] As used herein, a "phospholipid" is a lipid that includes a phosphate moiety and one or more carbon chains, such as unsaturated fatty acid chains. A phospholipid may include one or more multiple (*e.g.*, double or triple) bonds (*e.g.*, one or more unsaturations). Particular phospholipids may facilitate fusion to a membrane. For example, a cationic phospholipid may interact with one or more negatively charged phospholipids of a membrane (*e.g.*, a cellular or intracellular membrane). Fusion of a phospholipid to a membrane may allow one or more elements of a lipid-containing composition to pass through the membrane permitting, *e.g.*, delivery of the one or more elements to a cell.

[00240] As used herein, the “polydispersity index” is a ratio that describes the homogeneity of the particle size distribution of a system. A small value, *e.g.*, less than 0.3, indicates a narrow particle size distribution.

[00241] As used herein, the term “polypeptide” or “polypeptide of interest” refers to a polymer of amino acid residues typically joined by peptide bonds that can be produced naturally (*e.g.*, isolated or purified) or synthetically.

[00242] As used herein, an “RNA” refers to a ribonucleic acid that may be naturally or non-naturally occurring. For example, an RNA may include modified and/or non-naturally occurring components such as one or more nucleobases, nucleosides, nucleotides, or linkers. An RNA may include a cap structure, a chain terminating nucleoside, a stem loop, a polyA sequence, and/or a polyadenylation signal. An RNA may have a nucleotide sequence encoding a polypeptide of interest. For example, an RNA may be a messenger RNA (mRNA). Translation of an mRNA encoding a particular polypeptide, for example, in vivo translation of an mRNA inside a mammalian cell, may produce the encoded polypeptide. RNAs may be selected from the non-limiting group consisting of small interfering RNA (siRNA), asymmetrical interfering RNA (aiRNA), microRNA (miRNA), Dicer-substrate RNA (dsRNA), small hairpin RNA (shRNA), mRNA, single-guide RNA (sgRNA), cas9 mRNA, and mixtures thereof.

[00243] As used herein, a “single unit dose” is a dose of any therapeutic administered in one dose/at one time/single route/single point of contact, *i.e.*, single administration event.

[00244] As used herein, a “split dose” is the division of single unit dose or total daily dose into two or more doses.

[00245] As used herein, a “total daily dose” is an amount given or prescribed in 24 hour period. It may be administered as a single unit dose.

[00246] As used herein, “size” or “mean size” in the context of nanoparticle compositions refers to the mean diameter of a nanoparticle composition.

[00247] As used herein, the term “subject” or “patient” refers to any organism to which a composition in accordance with the disclosure may be administered, *e.g.*, for experimental, diagnostic, prophylactic, and/or therapeutic purposes. Typical subjects include animals (*e.g.*, mammals such as mice, rats, rabbits, non-human primates, and humans) and/or plants.

[00248] As used herein, “targeted cells” refers to any one or more cells of interest. The cells may be found in vitro, in vivo, in situ, or in the tissue or organ of an organism. The organism may be an animal, preferably a mammal, more preferably a human and most preferably a patient.

[00249] As used herein “target tissue” refers to any one or more tissue types of interest in which the delivery of a therapeutic and/or prophylactic would result in a desired biological and/or pharmacological effect. Examples of target tissues of interest include specific tissues, organs, and systems or groups thereof. In particular applications, a target tissue may be a kidney, a lung, a spleen, vascular endothelium in vessels (*e.g.*, intra-coronary or intra-femoral), or tumor tissue (*e.g.*, via intratumoral injection). An “off-target tissue” refers to any one or more tissue types in which the expression of the encoded protein does not result in a desired biological and/or pharmacological effect. In particular applications, off-target tissues may include the liver and the spleen.

[00250] The term “therapeutic agent” or “prophylactic agent” refers to any agent that, when administered to a subject, has a therapeutic, diagnostic, and/or prophylactic effect and/or elicits a desired biological and/or pharmacological effect. Therapeutic agents are also referred to as “actives” or “active agents.” Such agents include, but are not limited to, cytotoxins, radioactive ions, chemotherapeutic agents, small molecule drugs, proteins, and nucleic acids.

[00251] As used herein, the term “therapeutically effective amount” means an amount of an agent to be delivered (*e.g.*, nucleic acid, drug, composition, therapeutic agent, diagnostic agent, prophylactic agent, etc.) that is sufficient, when administered to a subject suffering from or susceptible to an infection, disease, disorder, and/or condition, to treat, improve symptoms of, diagnose, prevent, and/or delay the onset of the infection, disease, disorder, and/or condition.

[00252] As used herein, “transfection” refers to the introduction of a species (*e.g.*, an RNA) into a cell. Transfection may occur, for example, in vitro, ex vivo, or in vivo.

[00253] As used herein, the term “treating” refers to partially or completely alleviating, ameliorating, improving, relieving, delaying onset of, inhibiting progression of, reducing severity of, and/or reducing incidence of one or more symptoms or features of a particular infection, disease, disorder, and/or condition. For example, “treating” cancer may refer to inhibiting survival, growth, and/or spread of a tumor. Treatment may be administered to a subject who does not exhibit signs of a disease, disorder, and/or condition and/or to a subject who exhibits only early signs of a disease, disorder, and/or condition for the purpose of decreasing the risk of developing pathology associated with the disease, disorder, and/or condition.

[00254] As used herein, the “zeta potential” is the electrokinetic potential of a lipid, *e.g.*, in a particle composition.

Nanoparticle compositions

[00255] The disclosure also features nanoparticle compositions comprising a lipid component comprising one or more sterols and a compound according to Formula (I), (IA), (IB), (II), (IIa), (IIb), (IIc), (IId), (IId), (IId), (IId), (IId), (IId) or (IIg) as described herein.

[00256] In some embodiments, the largest dimension of a nanoparticle composition is 1 μm or shorter (*e.g.*, 1 μm , 900 nm, 800 nm, 700 nm, 600 nm, 500 nm, 400 nm, 300 nm, 200 nm, 175 nm, 150 nm, 125 nm, 100 nm, 75 nm, 50 nm, or shorter), *e.g.*, when measured by dynamic light scattering (DLS), transmission electron microscopy, scanning electron microscopy, or another method. Nanoparticle compositions include, for example, lipid nanoparticles (LNPs), liposomes, lipid vesicles, and lipoplexes. In some embodiments, nanoparticle compositions are vesicles including one or more lipid bilayers. In certain embodiments, a nanoparticle composition includes two or more concentric bilayers separated by aqueous compartments. Lipid bilayers may be functionalized and/or crosslinked to one another. Lipid bilayers may include one or more ligands, proteins, or channels.

[00257] Nanoparticle compositions comprise a lipid component including at least one compound according to Formula (I), (IA), (IB), (II), (IIa), (IIb), (IIc), (IId), (IId), (IId), (IId), (IId), (IId) or (IIg). For example, the lipid component of a nanoparticle composition may include one or more of Compounds 1-280. Nanoparticle compositions may also include a variety of other components. For example, the lipid component of a nanoparticle composition may include one or more other lipids in addition to a lipid according to Formula (I), (IA), (IB), (II), (IIa), (IIb), (IIc), (IId), (IId), (IId), (IId), (IId), (IId) or (IIg).

Cationic/ionizable lipids

[00258] A nanoparticle composition may include one or more cationic and/or ionizable lipids (*e.g.*, lipids that may have a positive or partial positive charge at physiological pH) in addition to a lipid according to Formula (I), (IA), (IB), (II), (IIa), (IIb), (IIc), (IId), (IId), (IId), (IId), (IId), (IId) or (IIg). Cationic and/or ionizable lipids may be selected from the non-limiting group consisting of 3-(didodecylamino)-N1,N1,4-tridodecyl-1-piperazineethanamine (KL10), N1-[2-(didodecylamino)ethyl]-N1,N4,N4-tridodecyl-1,4-piperazinediethanamine (KL22), 14,25-ditridecyl-15,18,21,24-tetraaza-octatriacontane (KL25),

1,2-dilinoleyloxy-N,N-dimethylaminopropane (DLin-DMA),
 2,2-dilinoleyl-4-dimethylaminomethyl-[1,3]-dioxolane (DLin-K-DMA),
 heptatriaconta-6,9,28,31-tetraen-19-yl 4-(dimethylamino)butanoate (DLin-MC3-DMA),
 2,2-dilinoleyl-4-(2-dimethylaminoethyl)-[1,3]-dioxolane (DLin-KC2-DMA),
 1,2-dioleyloxy-N,N-dimethylaminopropane (DODMA),
 2-({8-[(3 β)-cholest-5-en-3-yloxy]octyl}oxy)-N,N-dimethyl-3-[(9Z,12Z)-octadeca-9,12-dien-1-yloxy]propan-1-amine (Octyl-CLinDMA),
 (2R)-2-({8-[(3 β)-cholest-5-en-3-yloxy]octyl}oxy)-N,N-dimethyl-3-[(9Z,12Z)-octadeca-9,12-dien-1-yloxy]propan-1-amine (Octyl-CLinDMA (2R)), and
 (2S)-2-({8-[(3 β)-cholest-5-en-3-yloxy]octyl}oxy)-N,N-dimethyl-3-[(9Z,12Z)-octadeca-9,12-dien-1-yloxy]propan-1-amine (Octyl-CLinDMA (2S)). In addition to these, a cationic lipid may also be a lipid including a cyclic amine group.

[00259] Cationic and/or ionizable lipids may also be selected from the non-limiting group consisting of 1-Linoleoyl-2-linoleyloxy-3-dimethylaminopropane (DLin-2-DMAP),
 1,2-Dilinoleylcarbamoyloxy-3-dimethylaminopropane (DLin-C-DAP),
 1,2-Dilinoleoyl-3-dimethylaminopropane (DLin-DAP),
 1,2-Dilinoleyloxy-N,N-dimethylaminopropane (DLin-DMA),
 2,2-Dilinoleyl-4-dimethylaminomethyl-[1,3]-dioxolane (DLin-K-DMA),
 2,2-dilinoleyl-4-(2-dimethylaminoethyl)-[1,3]-dioxolane (DLin-KC2-DMA),
 (6Z,9Z,28Z,31Z)-heptatriaconta-6,9,28,31-tetraen-19-yl 4-(dimethylamino)butanoate (DLin-MC3-DMA),
 1,2-dioleoyl-3-dimethylammonium propane (DODAP),
 N,N-dimethyl-(2,3-dioleyloxy)propylamine (DODMA),
 dioctadecylamidoglycyl carboxyspermine (DOGS),
 Spermine cholesterylcarbamate (GL-67),
 bis-guanidinium- spermidine-cholesterol (BGTC),
 3 β -(N—(N',N'-dimethylaminoethane)-carbamoyl)cholesterol (DC-Chol),
 1,1'-(2-(4-(2-((2-(bis(2-hydroxydodecyl)amino)ethyl)(2-hydroxydodecyl)amino)ethyl)piperazin-1-yl)ethylazanediyldidodecan-2-ol (C12-200),
 N-t-butyl-N'-tetradecylamino-propionamidine (*diC14-amidine*),
 Dimethyldioctadecylammoniumbromide (DDAB),

N-(1,2-dimyristyloxyprop-3-yl)-N,N-dimethyl-N-hydroxyethyl ammonium bromide (DMRIE),
 N,N-dioleoyl-N,N-dimethylammonium chloride (DODAC),
 Dioleyloxypropyl-3-dimethyl hydroxyethyl ammonium bromide (DORIE),
 N-(1-(2,3-dioleyloxy)propyl)-N-2-(sperminecarboxamido)ethyl)-N,N-dimethylammonium
 trifluoroacetate (DOSPA),
 1,2-dioleoyltrimethyl ammonium propane chloride (DOTAP),
 N-(1-(2,3-dioleyloxy)propyl)-N,N,N-trimethylammonium chloride (DOTMA),
 Aminopropyl-dimethyl-bis(dodecyloxy)-propanaminiumbromide (GAP-DLRIE),
 1,2-dioleoyl-sn-3-phosphoethanolamine ("DOPE"), and a combination thereof.

PEG lipids

[00260] The lipid component of a nanoparticle composition may include one or more PEG or PEG-modified lipids. Such species may be alternately referred to as PEGylated lipids. A PEG lipid is a lipid modified with polyethylene glycol. A PEG lipid may be selected from the non-limiting group consisting of PEG-modified phosphatidylethanolamines, PEG-modified phosphatidic acids, PEG-modified ceramides (PEG-CER), PEG-modified dialkylamines, PEG-modified diacylglycerols (PEG-DAG), PEG-modified dialkylglycerols, and mixtures thereof. For example, a PEG lipid may be PEG-c-DOMG, PEG-DMG, PEG-DLPE, PEG-DMPE, PEG-DPPC or a PEG-DSPE lipid.

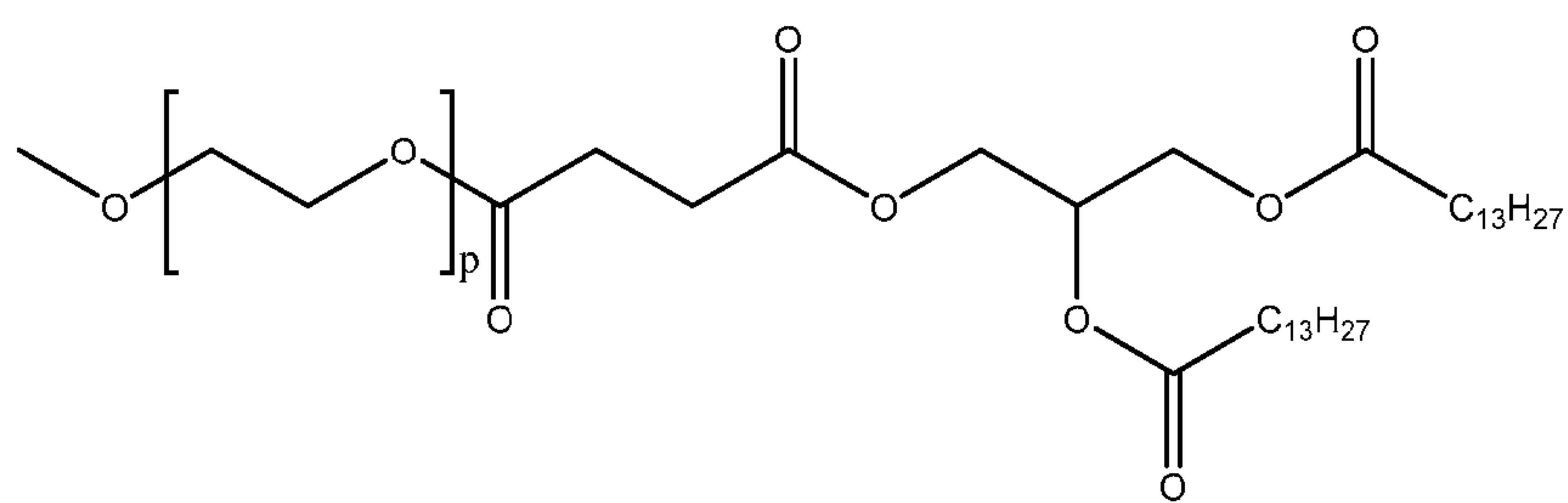
Sterols

[00261] The lipid component of a nanoparticle composition may include one or more sterols, e.g., those disclose herein. In some embodiments, the composition includes cholesterol and a phytosterol. In some embodiments, the composition includes cholesterol and a tocopherol. In some embodiments, the composition includes a phytosterol and a tocopherol. In some embodiments, the composition further includes a corticosteroid (such as prednisolone, dexamethasone, prednisone, and hydrocortisone).

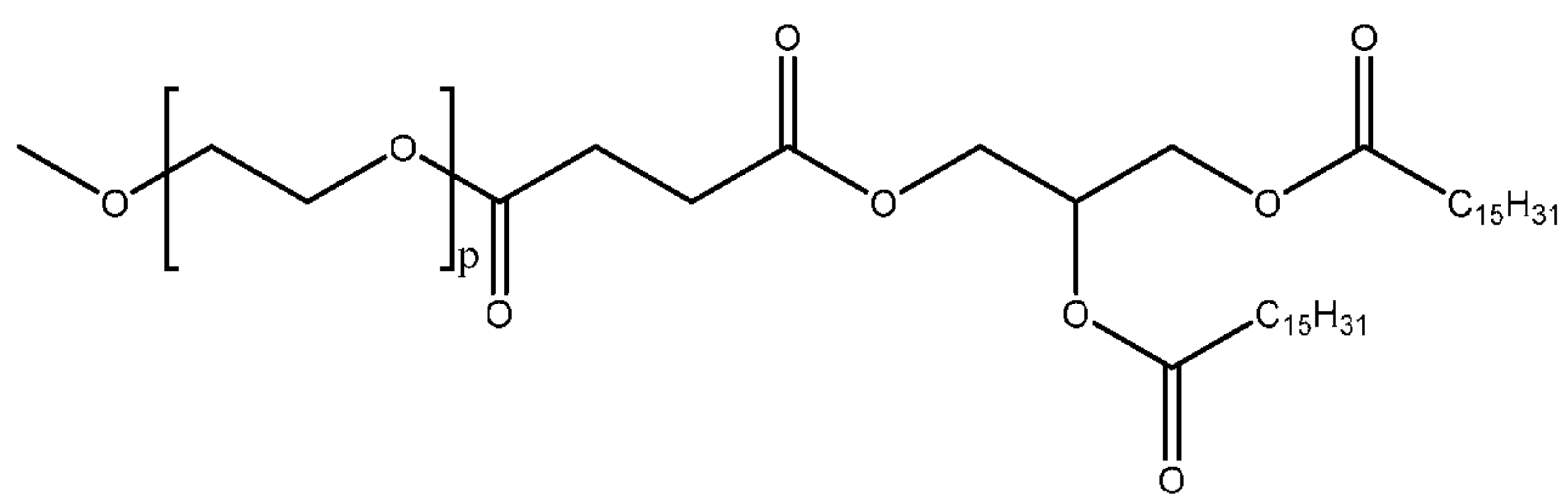
[00262] In some embodiments, the surfactant is a PEG moiety having a size of from about 1000 daltons to about 20,000 daltons.

[00263] In some embodiments, the surfactant is a PEG-diacylglycerol (PEG-DAG), PEG-ceramide (PEG-CER), or PEG-dialkyl glycerol.

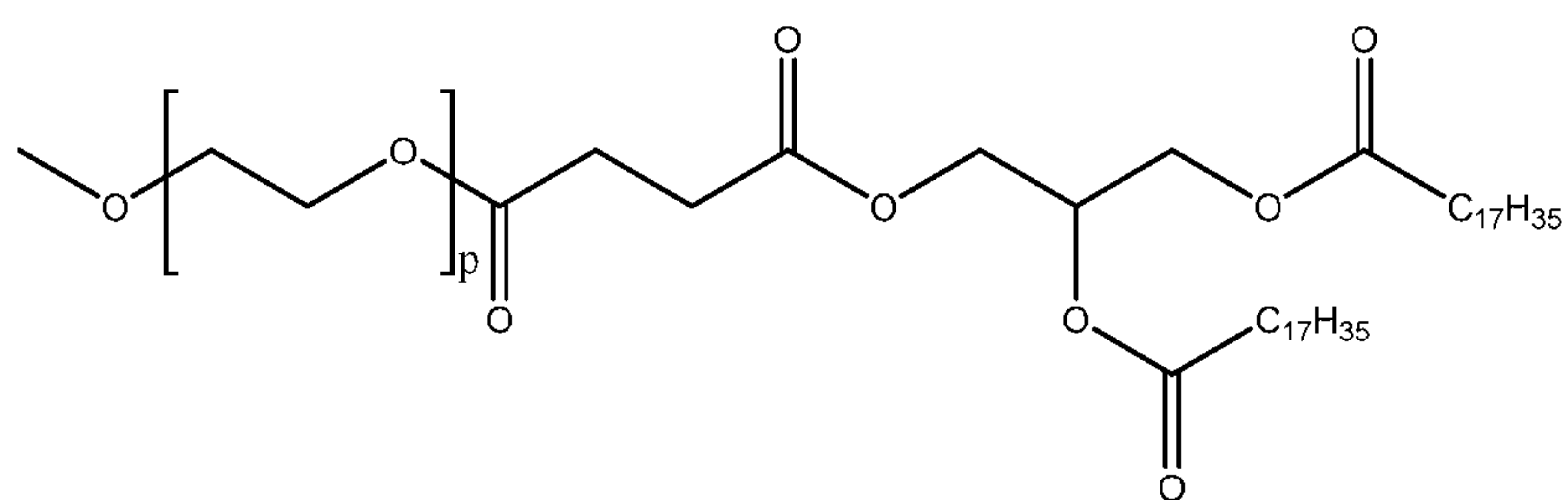
[00264] In some embodiments, the PEG lipid is selected from



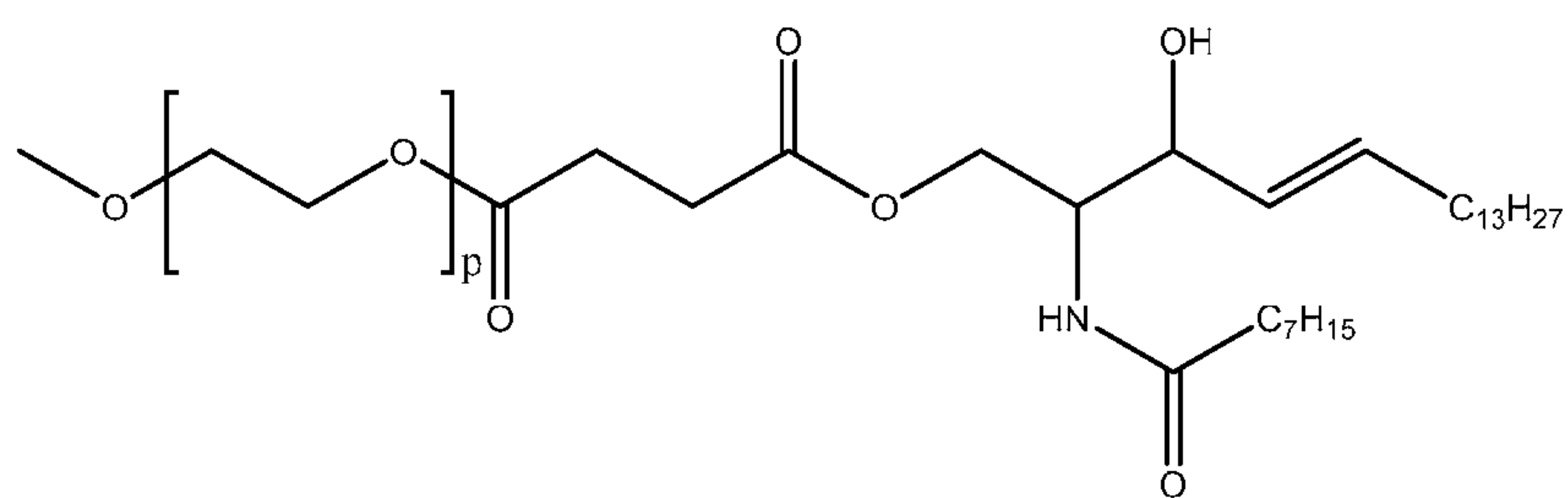
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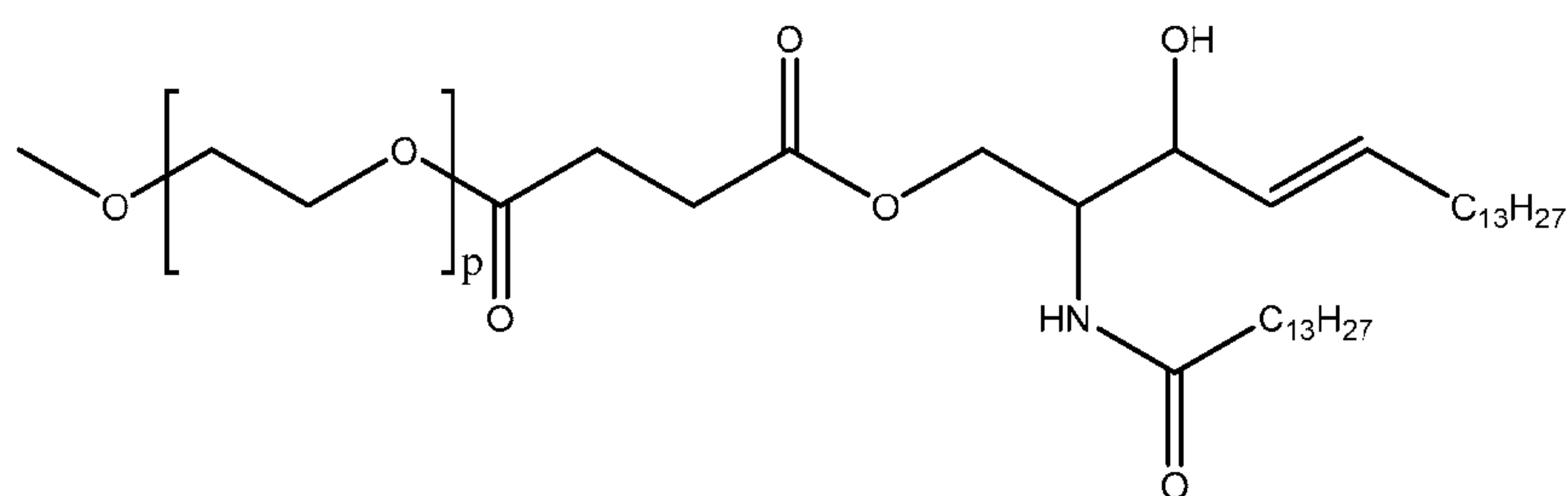
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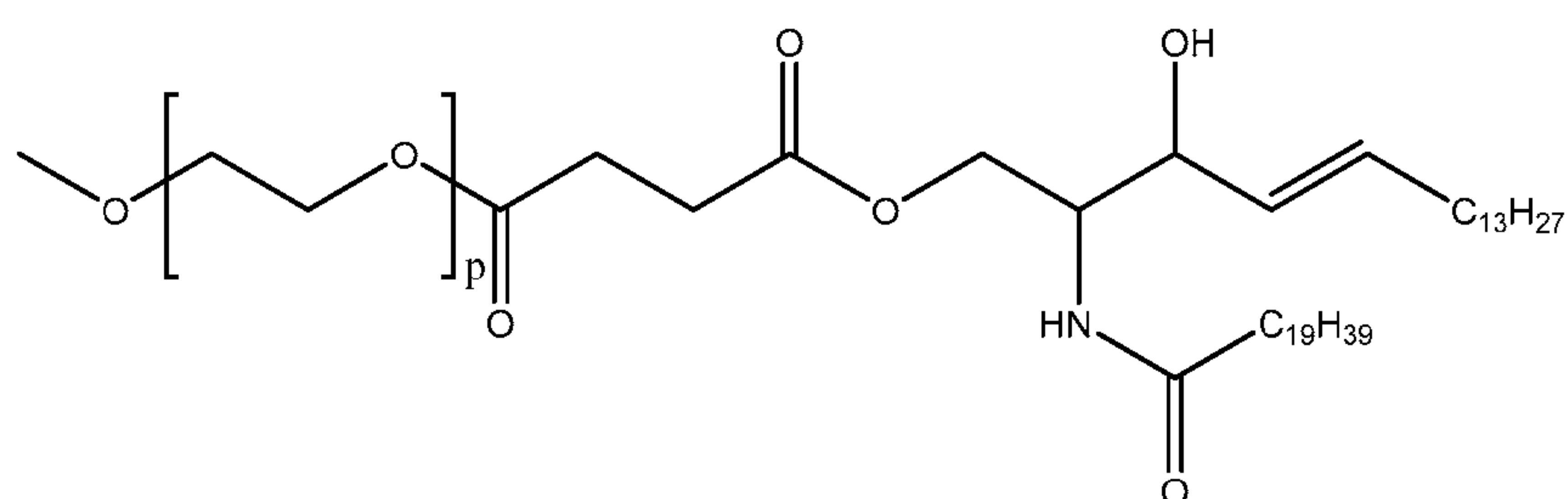
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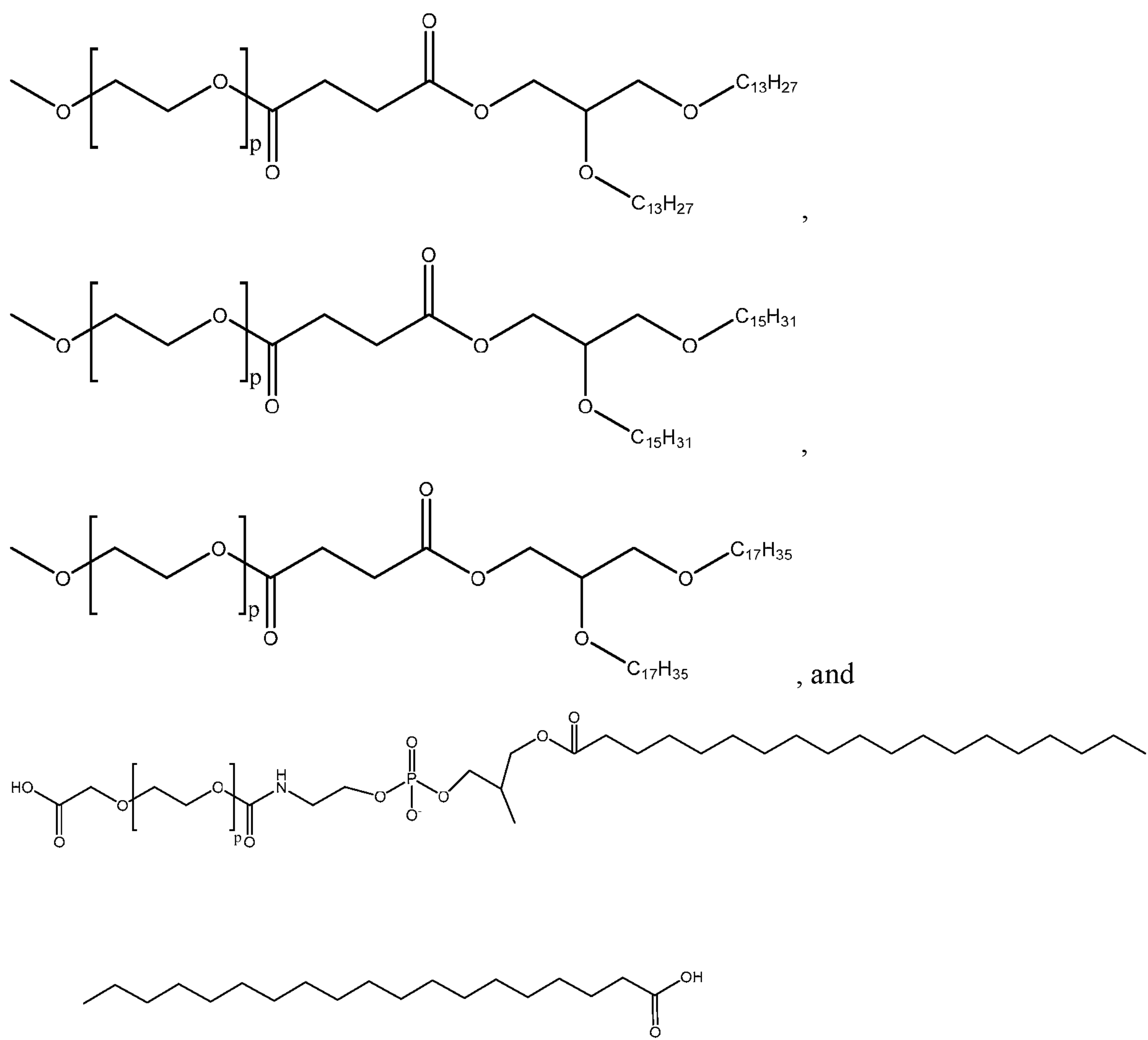
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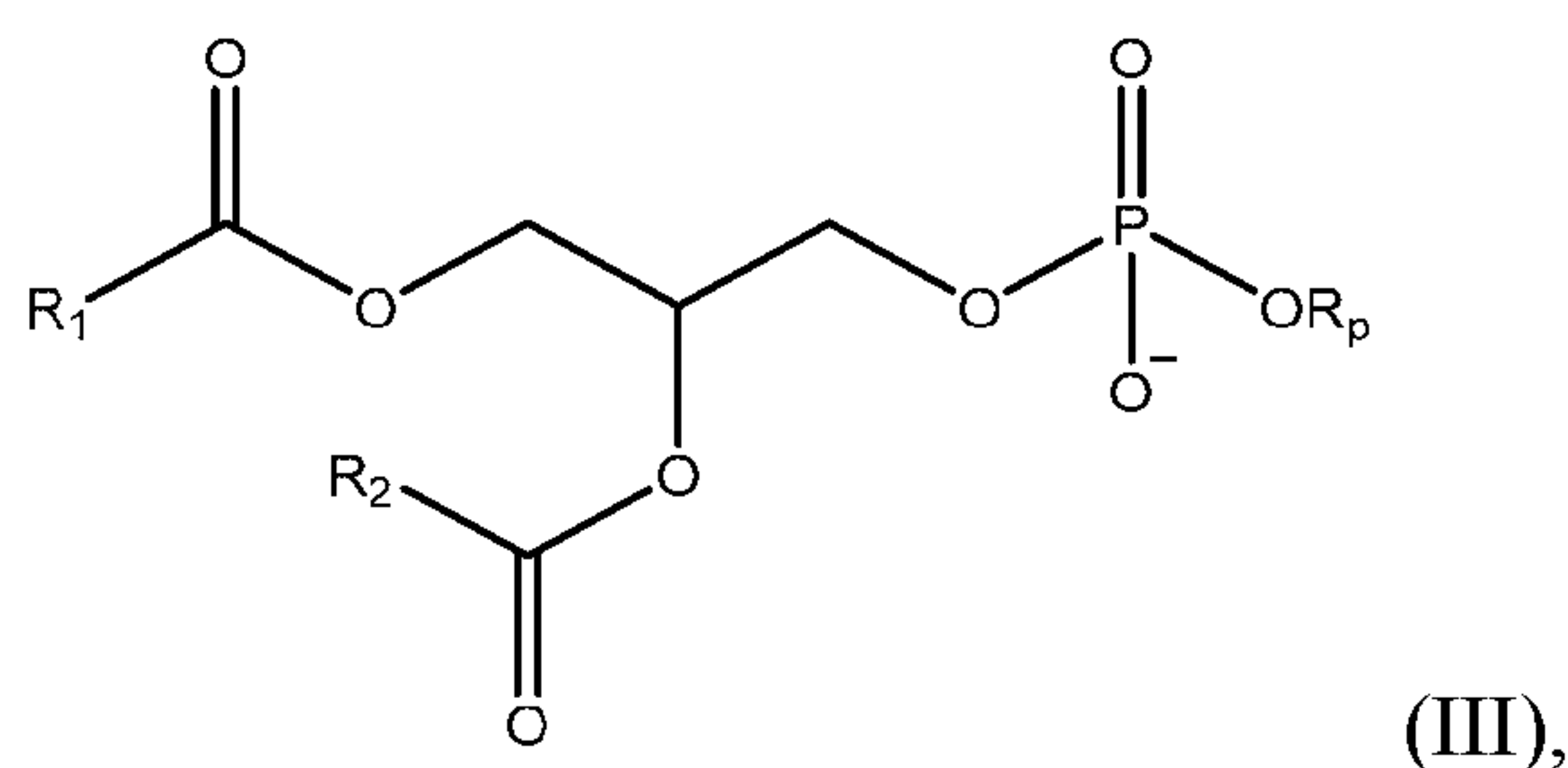
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wherein p is from 1 to 40.

Phospholipids

[00265] The lipid component of a nanoparticle composition may include one or more phospholipids, such as one or more (poly)unsaturated lipids. Phospholipids may assemble into one or more lipid bilayers. In general, phospholipids may include a phospholipid moiety and one or more fatty acid moieties. For example, a phospholipid may be a lipid according to Formula (III):



in which R_p represents a phospholipid moiety and R_1 and R_2 represent fatty acid moieties with or without unsaturation that may be the same or different. A phospholipid moiety may be selected from the non-limiting group consisting of phosphatidyl choline, phosphatidyl ethanolamine, phosphatidyl glycerol, phosphatidyl serine, phosphatidic acid, 2-lysophosphatidyl choline, and a sphingomyelin. A fatty acid moiety may be selected from the non-limiting group consisting of lauric acid, myristic acid, myristoleic acid, palmitic acid, palmitoleic acid, stearic acid, oleic acid, linoleic acid, alpha-linolenic acid, erucic acid, phytanic acid, arachidic acid, arachidonic acid, eicosapentaenoic acid, behenic acid, docosapentaenoic acid, and docosahexaenoic acid. Non-natural species including natural species with modifications and substitutions including branching, oxidation, cyclization, and alkynes are also contemplated. For example, a phospholipid may be functionalized with or cross-linked to one or more alkynes (*e.g.*, an alkenyl group in which one or more double bonds is replaced with a triple bond). Under appropriate reaction conditions, an alkyne group may undergo a copper-catalyzed cycloaddition upon exposure to an azide. Such reactions may be useful in functionalizing a lipid bilayer of a nanoparticle composition to facilitate membrane permeation or cellular recognition or in conjugating a nanoparticle composition to a useful component such as a targeting or imaging moiety (*e.g.*, a dye).

[00266] Phospholipids useful in the compositions and methods may be selected from the non-limiting group consisting of 1,2-distearoyl-*sn*-glycero-3-phosphocholine (DSPC), 1,2-dioleoyl-*sn*-glycero-3-phosphoethanolamine (DOPE), 1,2-dilinoleoyl-*sn*-glycero-3-phosphocholine (DLPC), 1,2-dimyristoyl-*sn*-glycero-phosphocholine (DMPC), 1,2-dioleoyl-*sn*-glycero-3-phosphocholine (DOPC), 1,2-dipalmitoyl-*sn*-glycero-3-phosphocholine (DPPC), 1,2-diundecanoyl-*sn*-glycero-phosphocholine (DUPC), 1-palmitoyl-2-oleoyl-*sn*-glycero-3-phosphocholine (POPC), 1,2-di-O-octadecenyl-*sn*-glycero-3-phosphocholine (18:0 Diether PC), 1-oleoyl-2-cholesterylhemisuccinoyl-*sn*-glycero-3-phosphocholine (OChemsPC),

1-hexadecyl-sn-glycero-3-phosphocholine (C16 Lyso PC),
 1,2-dilinolenoyl-sn-glycero-3-phosphocholine, 1,2-diarachidonoyl-sn-glycero-3-phosphocholine,
 1,2-didocosaheptaenoyl-sn-glycero-3-phosphocholine,
 1,2-diphytanoyl-sn-glycero-3-phosphoethanolamine (ME 16.0 PE),
 1,2-distearoyl-sn-glycero-3-phosphoethanolamine,
 1,2-dilinoleoyl-sn-glycero-3-phosphoethanolamine,
 1,2-dilinolenoyl-sn-glycero-3-phosphoethanolamine,
 1,2-diarachidonoyl-sn-glycero-3-phosphoethanolamine,
 1,2-didocosaheptaenoyl-sn-glycero-3-phosphoethanolamine,
 1,2-dioleoyl-sn-glycero-3-phospho-rac-(1-glycerol) sodium salt (DOPG),
 dipalmitoylphosphatidylglycerol (DPPG), palmitoyl-oleoylphosphatidylethanolamine (POPE),
 distearoyl-phosphatidyl-ethanolamine (DSPE), dipalmitoyl phosphatidyl ethanolamine (DPPE),
 dimyristoylphosphoethanolamine (DMPE), 1-stearoyl-2-oleoyl-phosphatidylethanolamine (SOPE),
 1-stearoyl-2-oleoyl-phosphatidylcholine (SOPC), sphingomyelin, phosphatidylcholine,
 phosphatidylethanolamine, phosphatidylserine, phosphatidylinositol, phosphatidic acid,
 palmitoyl-oleoyl phosphatidylcholine, lysophosphatidylcholine, lysophosphatidylethanolamine
 (LPE). In some embodiments, a nanoparticle composition includes DSPC. In certain embodiments,
 a nanoparticle composition includes DOPE. In some embodiments, a nanoparticle composition
 includes both DSPC and DOPE.

Adjuvants

[00267] In some embodiments, a nanoparticle composition that includes one or more lipids described herein may further include one or more adjuvants, e.g., Glucopyranosyl Lipid Adjuvant (GLA), CpG oligodeoxynucleotides (e.g., Class A or B), poly(I:C), aluminum hydroxide, and Pam3CSK4.

Therapeutic agents

[00268] Nanoparticle compositions may include one or more therapeutic and/or prophylactics. The disclosure features methods of delivering a therapeutic and/or prophylactic to a mammalian cell or organ, producing a polypeptide of interest in a mammalian cell, and treating a disease or disorder in a mammal in need thereof comprising administering to a mammal and/or contacting a mammalian cell with a nanoparticle composition including a therapeutic and/or prophylactic. In some embodiments, a therapeutic agent is encapsulated within the nanoparticle.

[00269] Therapeutic and/or prophylactics include biologically active substances and are alternately referred to as “active agents.” A therapeutic and/or prophylactic may be a substance that, once delivered to a cell or organ, brings about a desirable change in the cell, organ, or other bodily tissue or system. Such species may be useful in the treatment of one or more diseases, disorders, or conditions. In some embodiments, a therapeutic and/or prophylactic is a small molecule drug useful in the treatment of a particular disease, disorder, or condition. Examples of drugs useful in the nanoparticle compositions include, but are not limited to, antineoplastic agents (*e.g.*, vincristine, doxorubicin, mitoxantrone, camptothecin, cisplatin, bleomycin, cyclophosphamide, methotrexate, and streptozotocin), antitumor agents (*e.g.*, actinomycin D, vincristine, vinblastine, cytosine arabinoside, anthracyclines, alkylating agents, platinum compounds, antimetabolites, and nucleoside analogs, such as methotrexate and purine and pyrimidine analogs), anti-infective agents, local anesthetics (*e.g.*, dibucaine and chlorpromazine), beta-adrenergic blockers (*e.g.*, propranolol, timolol, and labetalol), antihypertensive agents (*e.g.*, clonidine and hydralazine), anti-depressants (*e.g.*, imipramine, amitriptyline, and doxepin), anti-convulsants (*e.g.*, phenytoin), antihistamines (*e.g.*, diphenhydramine, chlorpheniramine, and promethazine), antibiotic/antibacterial agents (*e.g.*, gentamycin, ciprofloxacin, and cefoxitin), antifungal agents (*e.g.*, miconazole, terconazole, econazole, isoconazole, butaconazole, clotrimazole, itraconazole, nystatin, naftifine, and amphotericin B), antiparasitic agents, hormones, hormone antagonists, immunomodulators, neurotransmitter antagonists, antiglaucoma agents, vitamins, narcotics, and imaging agents.

[00270] In some embodiments, a therapeutic and/or prophylactic is a cytotoxin, a radioactive ion, a chemotherapeutic, a vaccine, a compound that elicits an immune response, and/or another therapeutic and/or prophylactic. A cytotoxin or cytotoxic agent includes any agent that may be detrimental to cells. Examples include, but are not limited to, taxol, cytochalasin B, gramicidin D, ethidium bromide, emetine, mitomycin, etoposide, teniposide, vincristine, vinblastine, colchicine, doxorubicin, daunorubicin, dihydroxyanthracenedione, mitoxantrone, mithramycin, actinomycin D, 1-dehydrotestosterone, glucocorticoids, procaine, tetracaine, lidocaine, propranolol, puromycin, maytansinoids, *e.g.*, maytansinol, rachelmycin (CC-1065), and analogs or homologs thereof. Radioactive ions include, but are not limited to iodine (*e.g.*, iodine 125 or iodine 131), strontium 89, phosphorous, palladium, cesium, iridium, phosphate, cobalt, yttrium 90, samarium 153, and praseodymium. Vaccines include compounds and preparations that are capable of providing

immunity against one or more conditions related to infectious diseases such as influenza, measles, human papillomavirus (HPV), rabies, meningitis, whooping cough, tetanus, plague, hepatitis, and tuberculosis and can include mRNAs encoding infectious disease derived antigens and/or epitopes. Vaccines also include compounds and preparations that direct an immune response against cancer cells and can include mRNAs encoding tumor cell derived antigens, epitopes, and/or neoepitopes. Compounds eliciting immune responses may include vaccines, corticosteroids (*e.g.*, dexamethasone), and other species. In some embodiments, a vaccine and/or a compound capable of eliciting an immune response is administered intramuscularly via a composition including a compound according to Formula (I), (IA), (IB), (II), (IIa), (IIb), (IIc), (IId), (IIf) or (IIg) (*e.g.*, Compound 3, 18, 20, 25, 26, 29, 30, 60, 108-112, or 122). Other therapeutic and/or prophylactics include, but are not limited to, antimetabolites (*e.g.*, methotrexate, 6-mercaptopurine, 6-thioguanine, cytarabine, 5-fluorouracil, dacarbazine), alkylating agents (*e.g.*, mechlorethamine, thiotepa, chlorambucil, rachelmycin (CC-1065), melphalan, carmustine (BSNU), lomustine (CCNU), cyclophosphamide, busulfan, dibromomannitol, streptozotocin, mitomycin C, and cis-dichlorodiamine platinum (II) (DDP) cisplatin), anthracyclines (*e.g.*, daunorubicin (formerly daunomycin) and doxorubicin), antibiotics (*e.g.*, dactinomycin (formerly actinomycin), bleomycin, mithramycin, and anthramycin (AMC)), and anti-mitotic agents (*e.g.*, vincristine, vinblastine, taxol and maytansinoids).

[00271] In other embodiments, a therapeutic and/or prophylactic is a protein. Therapeutic proteins useful in the nanoparticles in the disclosure include, but are not limited to, gentamycin, amikacin, insulin, erythropoietin (EPO), granulocyte-colony stimulating factor (G-CSF), granulocyte-macrophage colony stimulating factor (GM-CSF), Factor VIR, luteinizing hormone-releasing hormone (LHRH) analogs, interferons, heparin, Hepatitis B surface antigen, typhoid vaccine, and cholera vaccine.

Polynucleotides and nucleic acids

[00272] In some embodiments, a therapeutic agent is a polynucleotide or nucleic acid (*e.g.*, ribonucleic acid or deoxyribonucleic acid). The term “polynucleotide,” in its broadest sense, includes any compound and/or substance that is or can be incorporated into an oligonucleotide chain. Exemplary polynucleotides for use in accordance with the present disclosure include, but are not limited to, one or more of deoxyribonucleic acid (DNA), ribonucleic acid (RNA) including messenger mRNA (mRNA), hybrids thereof, RNAi-inducing agents, RNAi agents, siRNAs,

shRNAs, miRNAs, antisense RNAs, ribozymes, catalytic DNA, RNAs that induce triple helix formation, aptamers, vectors, etc. In some embodiments, a therapeutic and/or prophylactic is an RNA. RNAs useful in the compositions and methods described herein can be selected from the group consisting of, but are not limited to, shortmers, antagomirs, antisense, ribozymes, small interfering RNA (siRNA), asymmetrical interfering RNA (aiRNA), microRNA (miRNA), Dicer-substrate RNA (dsRNA), small hairpin RNA (shRNA), transfer RNA (tRNA), messenger RNA (mRNA), and mixtures thereof. In certain embodiments, the RNA is an mRNA.

[00273] In certain embodiments, a therapeutic and/or prophylactic is an mRNA. An mRNA may encode any polypeptide of interest, including any naturally or non-naturally occurring or otherwise modified polypeptide. A polypeptide encoded by an mRNA may be of any size and may have any secondary structure or activity. In some embodiments, a polypeptide encoded by an mRNA may have a therapeutic effect when expressed in a cell.

[00274] In other embodiments, a therapeutic and/or prophylactic is an siRNA. An siRNA may be capable of selectively knocking down or down regulating expression of a gene of interest. For example, an siRNA could be selected to silence a gene associated with a particular disease, disorder, or condition upon administration to a subject in need thereof of a nanoparticle composition including the siRNA. An siRNA may comprise a sequence that is complementary to an mRNA sequence that encodes a gene or protein of interest. In some embodiments, the siRNA may be an immunomodulatory siRNA.

[00275] In certain embodiments, a therapeutic and/or prophylactic is an sgRNA and/or cas9 mRNA. sgRNA and/or cas9 mRNA can be used as gene editing tools. For example, an sgRNA-cas9 complex can affect mRNA translation of cellular genes.

[00276] In some embodiments, a therapeutic and/or prophylactic is an shRNA or a vector or plasmid encoding the same. An shRNA may be produced inside a target cell upon delivery of an appropriate construct to the nucleus. Constructs and mechanisms relating to shRNA are well known in the relevant arts.

[00277] Nucleic acids and polynucleotides useful in the disclosure typically include a first region of linked nucleosides encoding a polypeptide of interest (*e.g.*, a coding region), a first flanking region located at the 5'-terminus of the first region (*e.g.*, a 5'-UTR), a second flanking region located at the 3'-terminus of the first region (*e.g.*, a 3'-UTR), at least one 5'-cap region, and a 3'-stabilizing region. In some embodiments, a nucleic acid or polynucleotide further includes a poly-A

region or a Kozak sequence (*e.g.*, in the 5'-UTR). In some cases, polynucleotides may contain one or more intronic nucleotide sequences capable of being excised from the polynucleotide. In some embodiments, a polynucleotide or nucleic acid (*e.g.*, an mRNA) may include a 5' cap structure, a chain terminating nucleotide, a stem loop, a polyA sequence, and/or a polyadenylation signal. Any one of the regions of a nucleic acid may include one or more alternative components (*e.g.*, an alternative nucleoside). For example, the 3'-stabilizing region may contain an alternative nucleoside such as an L-nucleoside, an inverted thymidine, or a 2'-O-methyl nucleoside and/or the coding region, 5'-UTR, 3'-UTR, or cap region may include an alternative nucleoside such as a 5-substituted uridine (*e.g.*, 5-methoxyuridine), a 1-substituted pseudouridine (*e.g.*, 1-methyl-pseudouridine or 1-ethyl-pseudouridine), and/or a 5-substituted cytidine (*e.g.*, 5-methyl-cytidine).

[00278] Generally, the shortest length of a polynucleotide can be the length of the polynucleotide sequence that is sufficient to encode for a dipeptide. In another embodiment, the length of the polynucleotide sequence is sufficient to encode for a tripeptide. In another embodiment, the length of the polynucleotide sequence is sufficient to encode for a tetrapeptide. In another embodiment, the length of the polynucleotide sequence is sufficient to encode for a pentapeptide. In another embodiment, the length of the polynucleotide sequence is sufficient to encode for a hexapeptide. In another embodiment, the length of the polynucleotide sequence is sufficient to encode for a heptapeptide. In another embodiment, the length of the polynucleotide sequence is sufficient to encode for an octapeptide. In another embodiment, the length of the polynucleotide sequence is sufficient to encode for a nonapeptide. In another embodiment, the length of the polynucleotide sequence is sufficient to encode for a decapeptide.

[00279] Examples of dipeptides that the alternative polynucleotide sequences can encode for include, but are not limited to, carnosine and anserine.

[00280] In some cases, a polynucleotide is greater than 30 nucleotides in length. In another embodiment, the polynucleotide molecule is greater than 35 nucleotides in length. In another embodiment, the length is at least 40 nucleotides. In another embodiment, the length is at least 45 nucleotides. In another embodiment, the length is at least 55 nucleotides. In another embodiment, the length is at least 50 nucleotides. In another embodiment, the length is at least 60 nucleotides. In another embodiment, the length is at least 80 nucleotides. In another embodiment, the length is at least 90 nucleotides. In another embodiment, the length is at least 100 nucleotides. In another embodiment, the length is at least 120 nucleotides. In another embodiment, the length is at least

140 nucleotides. In another embodiment, the length is at least 160 nucleotides. In another embodiment, the length is at least 180 nucleotides. In another embodiment, the length is at least 200 nucleotides. In another embodiment, the length is at least 250 nucleotides. In another embodiment, the length is at least 300 nucleotides. In another embodiment, the length is at least 350 nucleotides. In another embodiment, the length is at least 400 nucleotides. In another embodiment, the length is at least 450 nucleotides. In another embodiment, the length is at least 500 nucleotides. In another embodiment, the length is at least 600 nucleotides. In another embodiment, the length is at least 700 nucleotides. In another embodiment, the length is at least 800 nucleotides. In another embodiment, the length is at least 900 nucleotides. In another embodiment, the length is at least 1000 nucleotides. In another embodiment, the length is at least 1100 nucleotides. In another embodiment, the length is at least 1200 nucleotides. In another embodiment, the length is at least 1300 nucleotides. In another embodiment, the length is at least 1400 nucleotides. In another embodiment, the length is at least 1500 nucleotides. In another embodiment, the length is at least 1600 nucleotides. In another embodiment, the length is at least 1800 nucleotides. In another embodiment, the length is at least 2000 nucleotides. In another embodiment, the length is at least 2500 nucleotides. In another embodiment, the length is at least 3000 nucleotides. In another embodiment, the length is at least 4000 nucleotides. In another embodiment, the length is at least 5000 nucleotides, or greater than 5000 nucleotides.

[00281] Nucleic acids and polynucleotides may include one or more naturally occurring components, including any of the canonical nucleotides A (adenosine), G (guanosine), C (cytosine), U (uridine), or T (thymidine). In one embodiment, all or substantially all of the nucleotides comprising (a) the 5'-UTR, (b) the open reading frame (ORF), (c) the 3'-UTR, (d) the poly A tail, and any combination of (a, b, c, or d above) comprise naturally occurring canonical nucleotides A (adenosine), G (guanosine), C (cytosine), U (uridine), or T (thymidine).

[00282] Nucleic acids and polynucleotides may include one or more alternative components, as described herein, which impart useful properties including increased stability and/or the lack of a substantial induction of the innate immune response of a cell into which the polynucleotide is introduced. For example, an alternative polynucleotide or nucleic acid exhibits reduced degradation in a cell into which the polynucleotide or nucleic acid is introduced, relative to a corresponding unaltered polynucleotide or nucleic acid. These alternative species may enhance the efficiency of

protein production, intracellular retention of the polynucleotides, and/or viability of contacted cells, as well as possess reduced immunogenicity.

[00283] Polynucleotides and nucleic acids may be naturally or non-naturally occurring. Polynucleotides and nucleic acids may include one or more modified (*e.g.*, altered or alternative) nucleobases, nucleosides, nucleotides, or combinations thereof. The nucleic acids and polynucleotides useful in a nanoparticle composition can include any useful modification or alteration, such as to the nucleobase, the sugar, or the internucleoside linkage (*e.g.*, to a linking phosphate / to a phosphodiester linkage / to the phosphodiester backbone). In certain embodiments, alterations (*e.g.*, one or more alterations) are present in each of the nucleobase, the sugar, and the internucleoside linkage. Alterations according to the present disclosure may be alterations of ribonucleic acids (RNAs) to deoxyribonucleic acids (DNAs), *e.g.*, the substitution of the 2'-OH of the ribofuranosyl ring to 2'-H, threose nucleic acids (TNAs), glycol nucleic acids (GNAs), peptide nucleic acids (PNAs), locked nucleic acids (LNAs), or hybrids thereof. Additional alterations are described herein.

[00284] Polynucleotides and nucleic acids may or may not be uniformly altered along the entire length of the molecule. For example, one or more or all types of nucleotide (*e.g.*, purine or pyrimidine, or any one or more or all of A, G, U, C) may or may not be uniformly altered in a polynucleotide or nucleic acid, or in a given predetermined sequence region thereof. In some instances, all nucleotides X in a polynucleotide (or in a given sequence region thereof) are altered, wherein X may any one of nucleotides A, G, U, C, or any one of the combinations A+G, A+U, A+C, G+U, G+C, U+C, A+G+U, A+G+C, G+U+C or A+G+C.

[00285] Different sugar alterations and/or internucleoside linkages (*e.g.*, backbone structures) may exist at various positions in a polynucleotide. One of ordinary skill in the art will appreciate that the nucleotide analogs or other alteration(s) may be located at any position(s) of a polynucleotide such that the function of the polynucleotide is not substantially decreased. An alteration may also be a 5'- or 3'-terminal alteration. In some embodiments, the polynucleotide includes an alteration at the 3'-terminus. The polynucleotide may contain from about 1% to about 100% alternative nucleotides (either in relation to overall nucleotide content, or in relation to one or more types of nucleotide, *i.e.*, any one or more of A, G, U or C) or any intervening percentage (*e.g.*, from 1% to 20%, from 1% to 25%, from 1% to 50%, from 1% to 60%, from 1% to 70%, from 1% to 80%, from 1% to 90%, from 1% to 95%, from 10% to 20%, from 10% to 25%, from 10% to

50%, from 10% to 60%, from 10% to 70%, from 10% to 80%, from 10% to 90%, from 10% to 95%, from 10% to 100%, from 20% to 25%, from 20% to 50%, from 20% to 60%, from 20% to 70%, from 20% to 80%, from 20% to 90%, from 20% to 95%, from 20% to 100%, from 50% to 60%, from 50% to 70%, from 50% to 80%, from 50% to 90%, from 50% to 95%, from 50% to 100%, from 70% to 80%, from 70% to 90%, from 70% to 95%, from 70% to 100%, from 80% to 90%, from 80% to 95%, from 80% to 100%, from 90% to 95%, from 90% to 100%, and from 95% to 100%). It will be understood that any remaining percentage is accounted for by the presence of a canonical nucleotide (*e.g.*, A, G, U, or C).

[00286] Polynucleotides may contain at a minimum zero and at maximum 100% alternative nucleotides, or any intervening percentage, such as at least 5% alternative nucleotides, at least 10% alternative nucleotides, at least 25% alternative nucleotides, at least 50% alternative nucleotides, at least 80% alternative nucleotides, or at least 90% alternative nucleotides. For example, polynucleotides may contain an alternative pyrimidine such as an alternative uracil or cytosine. In some embodiments, at least 5%, at least 10%, at least 25%, at least 50%, at least 80%, at least 90% or 100% of the uracil in a polynucleotide is replaced with an alternative uracil (*e.g.*, a 5-substituted uracil). The alternative uracil can be replaced by a compound having a single unique structure, or can be replaced by a plurality of compounds having different structures (*e.g.*, 2, 3, 4 or more unique structures). In some instances, at least 5%, at least 10%, at least 25%, at least 50%, at least 80%, at least 90% or 100% of the cytosine in the polynucleotide is replaced with an alternative cytosine (*e.g.*, a 5-substituted cytosine). The alternative cytosine can be replaced by a compound having a single unique structure, or can be replaced by a plurality of compounds having different structures (*e.g.*, 2, 3, 4 or more unique structures).

[00287] In some instances, nucleic acids do not substantially induce an innate immune response of a cell into which the polynucleotide (*e.g.*, mRNA) is introduced. Features of an induced innate immune response include 1) increased expression of pro-inflammatory cytokines, 2) activation of intracellular PRRs (RIG-I, MDA5, etc., and/or 3) termination or reduction in protein translation.

[00288] The nucleic acids can optionally include other agents (*e.g.*, RNAi-inducing agents, RNAi agents, siRNAs, shRNAs, miRNAs, antisense RNAs, ribozymes, catalytic DNA, tRNA, RNAs that induce triple helix formation, aptamers, and vectors). In some embodiments, the nucleic acids may include one or more messenger RNAs (mRNAs) having one or more alternative nucleoside or nucleotides (*i.e.*, alternative mRNA molecules).

[00289] In some embodiments, a nucleic acid (*e.g.* mRNA) molecule, formula, composition or method associated therewith comprises one or more polynucleotides comprising features as described in WO2002/098443, WO2003/051401, WO2008/052770, WO2009127230, WO2006122828, WO2008/083949, WO2010088927, WO2010/037539, WO2004/004743, WO2005/016376, WO2006/024518, WO2007/095976, WO2008/014979, WO2008/077592, WO2009/030481, WO2009/095226, WO2011069586, WO2011026641, WO2011/144358, WO2012019780, WO2012013326, WO2012089338, WO2012113513, WO2012116811, WO2012116810, WO2013113502, WO2013113501, WO2013113736, WO2013143698, WO2013143699, WO2013143700, WO2013/120626, WO2013120627, WO2013120628, WO2013120629, WO2013174409, WO2014127917, WO2015/024669, WO2015/024668, WO2015/024667, WO2015/024665, WO2015/024666, WO2015/024664, WO2015101415, WO2015101414, WO2015024667, WO2015062738, WO2015101416, all of which are incorporated by reference herein.

Nucleobase alternatives

[00290] The alternative nucleosides and nucleotides can include an alternative nucleobase. A nucleobase of a nucleic acid is an organic base such as a purine or pyrimidine or a derivative thereof. A nucleobase may be a canonical base (*e.g.*, adenine, guanine, uracil, thymine, and cytosine). These nucleobases can be altered or wholly replaced to provide polynucleotide molecules having enhanced properties, *e.g.*, increased stability such as resistance to nucleases. Non-canonical or modified bases may include, for example, one or more substitutions or modifications including but not limited to alkyl, aryl, halo, oxo, hydroxyl, alkyloxy, and/or thio substitutions; one or more fused or open rings; oxidation; and/or reduction.

[00291] Alternative nucleotide base pairing encompasses not only the standard adenine-thymine, adenine-uracil, or guanine-cytosine base pairs, but also base pairs formed between nucleotides and/or alternative nucleotides including non-standard or alternative bases, wherein the arrangement of hydrogen bond donors and hydrogen bond acceptors permits hydrogen bonding between a non-standard base and a standard base or between two complementary non-standard base structures. One example of such non-standard base pairing is the base pairing between the alternative nucleotide inosine and adenine, cytosine, or uracil.

[00292] In some embodiments, the nucleobase is an alternative uracil. Exemplary nucleobases and nucleosides having an alternative uracil include pseudouridine (ψ), pyridin-4-one

ribonucleoside, 5-aza-uracil, 6-aza-uracil, 2-thio-5-aza-uracil, 2-thio-uracil (s^2U), 4-thio-uracil (s^4U), 4-thio-pseudouridine, 2-thio-pseudouridine, 5-hydroxy-uracil (ho^5U), 5-aminoallyl-uracil, 5-halo-uracil (*e.g.*, 5-iodo-uracil or 5-bromo-uracil), 3-methyl-uracil (m^3U), 5-methoxy-uracil (mo^5U), uracil 5-oxyacetic acid (cmo^5U), uracil 5-oxyacetic acid methyl ester ($mcmo^5U$), 5-carboxymethyl-uracil (cm^5U), 1-carboxymethyl-pseudouridine, 5-carboxyhydroxymethyl-uracil (chm^5U), 5-carboxyhydroxymethyl-uracil methyl ester ($mchm^5U$), 5-methoxycarbonylmethyl-uracil (mcm^5U), 5-methoxycarbonylmethyl-2-thio-uracil (mcm^5s^2U), 5-aminomethyl-2-thio-uracil (nm^5s^2U), 5-methylaminomethyl-uracil (mnm^5U), 5-methylaminomethyl-2-thio-uracil (mnm^5s^2U), 5-methylaminomethyl-2-seleno-uracil (mnm^5se^2U), 5-carbamoylmethyl-uracil (ncm^5U), 5-carboxymethylaminomethyl-uracil ($cmnm^5U$), 5-carboxymethylaminomethyl-2-thio-uracil ($cmnm^5s^2U$), 5-propynyl-uracil, 1-propynyl-pseudouracil, 5-aurinomethyl-uracil (τm^5U), 1-aurinomethyl-pseudouridine, 5-aurinomethyl-2-thio-uracil (τm^5s^2U), 1-aurinomethyl-4-thio-pseudouridine, 5-methyl-uracil (m^5U , *i.e.*, having the nucleobase deoxythymine), 1-methyl-pseudouridine ($m^1\psi$), 1-ethyl-pseudouridine ($Et^1\psi$), 5-methyl-2-thio-uracil (m^5s^2U), 1-methyl-4-thio-pseudouridine ($m^1s^4\psi$), 4-thio-1-methyl-pseudouridine, 3-methyl-pseudouridine ($m^3\psi$), 2-thio-1-methyl-pseudouridine, 1-methyl-1-deaza-pseudouridine, 2-thio-1-methyl-1-deaza-pseudouridine, dihydrouracil (D), dihydropseudouridine, 5,6-dihydrouracil, 5-methyl-dihydrouracil (m^5D), 2-thio-dihydrouracil, 2-thio-dihydropseudouridine, 2-methoxy-uracil, 2-methoxy-4-thio-uracil, 4-methoxy-pseudouridine, 4-methoxy-2-thio-pseudouridine, N1-methyl-pseudouridine, 3-(3-amino-3-carboxypropyl)uracil (acp^3U), 1-methyl-3-(3-amino-3-carboxypropyl)pseudouridine ($acp^3\psi$), 5-(isopentenylaminomethyl)uracil (inm^5U), 5-(isopentenylaminomethyl)-2-thio-uracil (inm^5s^2U), 5,2'-O-dimethyl-uridine (m^5Um), 2-thio-2'-O-methyl-uridine (s^2Um), 5-methoxycarbonylmethyl-2'-O-methyl-uridine (mcm^5Um), 5-carbamoylmethyl-2'-O-methyl-uridine (ncm^5Um), 5-carboxymethylaminomethyl-2'-O-methyl-uridine ($cmnm^5Um$), 3,2'-O-dimethyl-uridine (m^3Um), and 5-(isopentenylaminomethyl)-2'-O-methyl-uridine (inm^5Um), 1-thio-uracil, deoxythymidine, 5-(2-carbomethoxyvinyl)-uracil, 5-(carbamoylhydroxymethyl)-uracil, 5-carbamoylmethyl-2-thio-uracil, 5-carboxymethyl-2-thio-uracil, 5-cyanomethyl-uracil, 5-methoxy-2-thio-uracil, and 5-[3-(1-E-propenylamino)]uracil.

[00293] In some embodiments, the nucleobase is an alternative cytosine. Exemplary nucleobases and nucleosides having an alternative cytosine include 5-aza-cytosine, 6-aza-cytosine, pseudoisocytidine, 3-methyl-cytosine ($m3C$), N4-acetyl-cytosine ($ac4C$), 5-formyl-cytosine ($f5C$),

N4-methyl-cytosine (m4C), 5-methyl-cytosine (m5C), 5-halo-cytosine (*e.g.*, 5-iodo-cytosine), 5-hydroxymethyl-cytosine (hm5C), 1-methyl-pseudoisocytidine, pyrrolo-cytosine, pyrrolo-pseudoisocytidine, 2-thio-cytosine (s2C), 2-thio-5-methyl-cytosine, 4-thio-pseudoisocytidine, 4-thio-1-methyl-pseudoisocytidine, 4-thio-1-methyl-1-deaza-pseudoisocytidine, 1-methyl-1-deaza-pseudoisocytidine, zebularine, 5-aza-zebularine, 5-methyl-zebularine, 5-aza-2-thio-zebularine, 2-thio-zebularine, 2-methoxy-cytosine, 2-methoxy-5-methyl-cytosine, 4-methoxy-pseudoisocytidine, 4-methoxy-1-methyl-pseudoisocytidine, lysidine (k2C), 5,2'-O-dimethyl-cytidine (m5Cm), N4-acetyl-2'-O-methyl-cytidine (ac4Cm), N4,2'-O-dimethyl-cytidine (m4Cm), 5-formyl-2'-O-methyl-cytidine (f5Cm), N4,N4,2'-O-trimethyl-cytidine (m42Cm), 1-thio-cytosine, 5-hydroxy-cytosine, 5-(3-azidopropyl)-cytosine, and 5-(2-azidoethyl)-cytosine.

[00294] In some embodiments, the nucleobase is an alternative adenine. Exemplary nucleobases and nucleosides having an alternative adenine include 2-amino-purine, 2,6-diaminopurine, 2-amino-6-halo-purine (*e.g.*, 2-amino-6-chloro-purine), 6-halo-purine (*e.g.*, 6-chloro-purine), 2-amino-6-methyl-purine, 8-azido-adenine, 7-deaza-adenine, 7-deaza-8-aza-adenine, 7-deaza-2-amino-purine, 7-deaza-8-aza-2-amino-purine, 7-deaza-2,6-diaminopurine, 7-deaza-8-aza-2,6-diaminopurine, 1-methyl-adenine (m1A), 2-methyl-adenine (m2A), N6-methyl-adenine (m6A), 2-methylthio-N6-methyl-adenine (ms2m6A), N6-isopentenyl-adenine (i6A), 2-methylthio-N6-isopentenyl-adenine (ms2i6A), N6-(cis-hydroxyisopentenyl)adenine (io6A), 2-methylthio-N6-(cis-hydroxyisopentenyl)adenine (ms2io6A), N6-glycinylicarbamoyl-adenine (g6A), N6-threonylicarbamoyl-adenine (t6A), N6-methyl-N6-threonylicarbamoyl-adenine (m6t6A), 2-methylthio-N6-threonylicarbamoyl-adenine (ms2g6A), N6,N6-dimethyl-adenine (m62A), N6-hydroxynorvalylcarbamoyl-adenine (hn6A), 2-methylthio-N6-hydroxynorvalylcarbamoyl-adenine (ms2hn6A), N6-acetyl-adenine (ac6A), 7-methyl-adenine, 2-methylthio-adenine, 2-methoxy-adenine, N6,2'-O-dimethyl-adenosine (m6Am), N6,N6,2'-O-trimethyl-adenosine (m62Am), 1,2'-O-dimethyl-adenosine (m1Am), 2-amino-N6-methyl-purine, 1-thio-adenine, 8-azido-adenine, N6-(19-amino-pentaoxanonadecyl)-adenine, 2,8-dimethyl-adenine, N6-formyl-adenine, and N6-hydroxymethyl-adenine.

[00295] In some embodiments, the nucleobase is an alternative guanine. Exemplary nucleobases and nucleosides having an alternative guanine include inosine (I), 1-methyl-inosine (m1I), wyosine (imG), methylwyosine (mimG), 4-demethyl-wyosine (imG-14), isowyosine (imG2), wybutosine (yW), peroxywybutosine (o2yW), hydroxywybutosine (OHyW), undermodified hydroxywybutosine

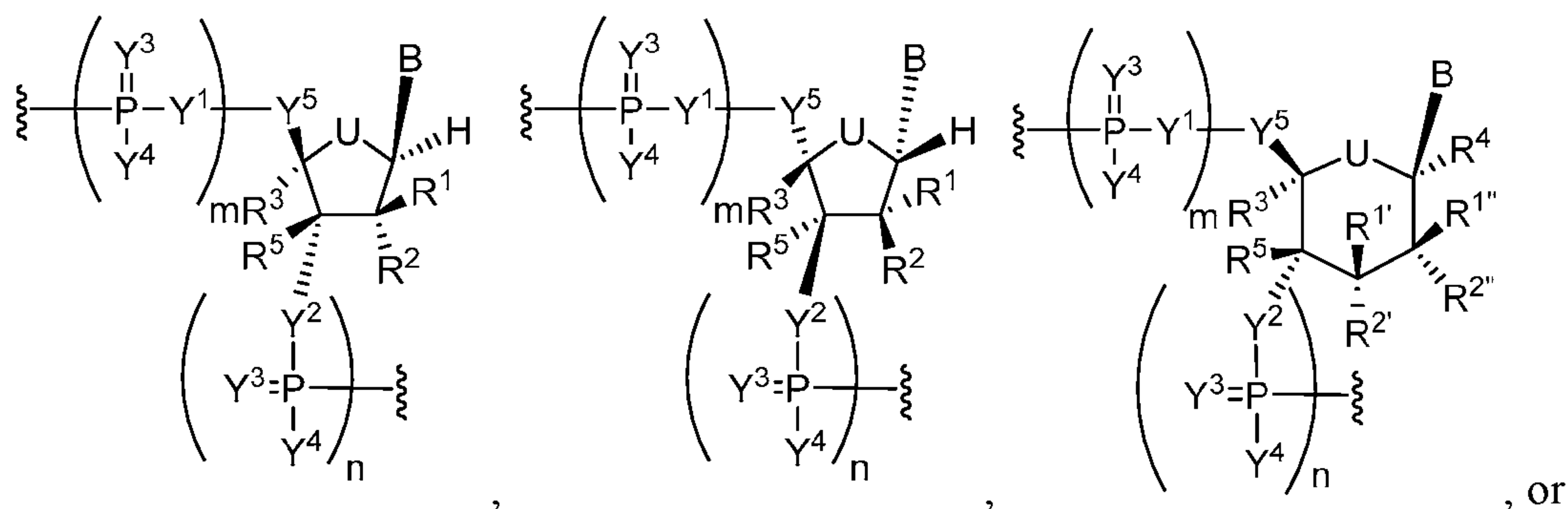
(OHyW*), 7-deaza-guanine, queuosine (Q), epoxyqueuosine (oQ), galactosyl-queuosine (galQ), mannosyl-queuosine (manQ), 7-cyano-7-deaza-guanine (preQ0), 7-aminomethyl-7-deaza-guanine (preQ1), archaeosine (G+), 7-deaza-8-aza-guanine, 6-thio-guanine, 6-thio-7-deaza-guanine, 6-thio-7-deaza-8-aza-guanine, 7-methyl-guanine (m7G), 6-thio-7-methyl-guanine, 7-methyl-inosine, 6-methoxy-guanine, 1-methyl-guanine (m1G), N2-methyl-guanine (m2G), N2,N2-dimethyl-guanine (m22G), N2,7-dimethyl-guanine (m2,7G), N2, N2,7-dimethyl-guanine (m2,2,7G), 8-oxo-guanine, 7-methyl-8-oxo-guanine, 1-methyl-6-thio-guanine, N2-methyl-6-thio-guanine, N2,N2-dimethyl-6-thio-guanine, N2-methyl-2'-O-methyl-guanosine (m2Gm), N2,N2-dimethyl-2'-O-methyl-guanosine (m22Gm), 1-methyl-2'-O-methyl-guanosine (m1Gm), N2,7-dimethyl-2'-O-methyl-guanosine (m2,7Gm), 2'-O-methyl-inosine (Im), 1,2'-O-dimethyl-inosine (m1Im), 1-thio-guanine, and O-6-methyl-guanine.

[00296] The alternative nucleobase of a nucleotide can be independently a purine, a pyrimidine, a purine or pyrimidine analog. For example, the nucleobase can be an alternative to adenine, cytosine, guanine, uracil, or hypoxanthine. In another embodiment, the nucleobase can also include, for example, naturally-occurring and synthetic derivatives of a base, including pyrazolo[3,4-d]pyrimidines, 5-methylcytosine (5-me-C), 5-hydroxymethyl cytosine, xanthine, hypoxanthine, 2-aminoadenine, 6-methyl and other alkyl derivatives of adenine and guanine, 2-propyl and other alkyl derivatives of adenine and guanine, 2-thiouracil, 2-thiothymine and 2-thiocytosine, 5-propynyl uracil and cytosine, 6-azo uracil, cytosine and thymine, 5-uracil (pseudouracil), 4-thiouracil, 8-halo (*e.g.*, 8-bromo), 8-amino, 8-thiol, 8-thioalkyl, 8-hydroxy and other 8-substituted adenines and guanines, 5-halo particularly 5-bromo, 5-trifluoromethyl and other 5-substituted uracils and cytosines, 7-methylguanine and 7-methyladenine, 8-azaguanine and 8-azaadenine, deazaguanine, 7-deazaguanine, 3-deazaguanine, deazaadenine, 7-deazaadenine, 3-deazaadenine, pyrazolo[3,4-d]pyrimidine, imidazo[1,5-a]1,3,5 triazinones, 9-deazapurines, imidazo[4,5-d]pyrazines, thiazolo[4,5-d]pyrimidines, pyrazin-2-ones, 1,2,4-triazine, pyridazine; or 1,3,5 triazine. When the nucleotides are depicted using the shorthand A, G, C, T or U, each letter refers to the representative base and/or derivatives thereof, *e.g.*, A includes adenine or adenine analogs, *e.g.*, 7-deaza adenine).

Alterations on the sugar

[00297] Nucleosides include a sugar molecule (*e.g.*, a 5-carbon or 6-carbon sugar, such as pentose, ribose, arabinose, xylose, glucose, galactose, or a deoxy derivative thereof) in combination

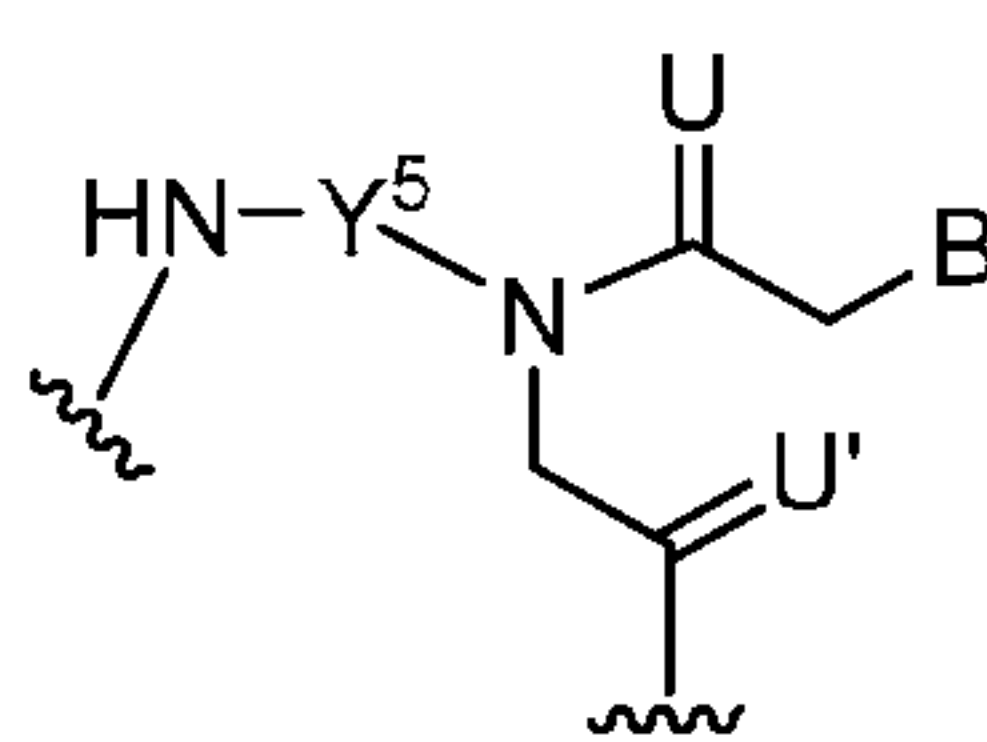
with a nucleobase, while nucleotides are nucleosides containing a nucleoside and a phosphate group or alternative group (*e.g.*, boranophosphate, thiophosphate, selenophosphate, phosphonate, alkyl group, amidate, and glycerol). A nucleoside or nucleotide may be a canonical species, *e.g.*, a nucleoside or nucleotide including a canonical nucleobase, sugar, and, in the case of nucleotides, a phosphate group, or may be an alternative nucleoside or nucleotide including one or more alternative components. For example, alternative nucleosides and nucleotides can be altered on the sugar of the nucleoside or nucleotide. In some embodiments, the alternative nucleosides or nucleotides include the structure:



Formula IV

Formula V

Formula VI



Formula VII.

In each of the Formulae IV, V, VI and VII,

each of m and n is independently, an integer from 0 to 5,

each of U and U' independently, is O , S , $N(R^U)_{nu}$, or $C(R^U)_{nu}$, wherein nu is an integer from 0 to 2 and each R^U is, independently, H , halo, or optionally substituted alkyl;

each of $R^{1'}$, $R^{2'}$, $R^{1''}$, $R^{2''}$, R^1 , R^2 , R^3 , R^4 , and R^5 is, independently, if present, H , halo, hydroxy, thiol, optionally substituted alkyl, optionally substituted alkoxy, optionally substituted alkenyloxy, optionally substituted alkynyloxy, optionally substituted aminoalkoxy, optionally substituted alkoxyalkoxy, optionally substituted hydroxyalkoxy, optionally substituted amino, azido, optionally substituted aryl, optionally substituted aminoalkyl, optionally substituted aminoalkenyl, optionally substituted aminoalkynyl, or absent; wherein the combination of R^3 with one or more of $R^{1'}$, $R^{1''}$, $R^{2'}$, $R^{2''}$, or R^5 (*e.g.*, the combination of $R^{1'}$ and R^3 , the combination of $R^{1''}$

and R^3 , the combination of $R^{2'}$ and R^3 , the combination of $R^{2''}$ and R^3 , or the combination of R^5 and R^3) can join together to form optionally substituted alkylene or optionally substituted heteroalkylene and, taken together with the carbons to which they are attached, provide an optionally substituted heterocyclyl (e.g., a bicyclic, tricyclic, or tetracyclic heterocyclyl); wherein the combination of R^5 with one or more of $R^{1'}$, $R^{1''}$, $R^{2'}$, or $R^{2''}$ (e.g., the combination of $R^{1'}$ and R^5 , the combination of $R^{1''}$ and R^5 , the combination of $R^{2'}$ and R^5 , or the combination of $R^{2''}$ and R^5) can join together to form optionally substituted alkylene or optionally substituted heteroalkylene and, taken together with the carbons to which they are attached, provide an optionally substituted heterocyclyl (e.g., a bicyclic, tricyclic, or tetracyclic heterocyclyl); and wherein the combination of R^4 and one or more of $R^{1'}$, $R^{1''}$, $R^{2'}$, $R^{2''}$, R^3 , or R^5 can join together to form optionally substituted alkylene or optionally substituted heteroalkylene and, taken together with the carbons to which they are attached, provide an optionally substituted heterocyclyl (e.g., a bicyclic, tricyclic, or tetracyclic heterocyclyl); each of m' and m'' is, independently, an integer from 0 to 3 (e.g., from 0 to 2, from 0 to 1, from 1 to 3, or from 1 to 2);

each of Y^1 , Y^2 , and Y^3 , is, independently, O, S, Se, $—NR^{N1}—$, optionally substituted alkylene, or optionally substituted heteroalkylene, wherein R^{N1} is H, optionally substituted alkyl, optionally substituted alkenyl, optionally substituted alkynyl, optionally substituted aryl, or absent; each Y^4 is, independently, H, hydroxy, thiol, boranyl, optionally substituted alkyl, optionally substituted alkenyl, optionally substituted alkynyl, optionally substituted alkoxy, optionally substituted alkenyloxy, optionally substituted alkynyloxy, optionally substituted thioalkoxy, optionally substituted alkoxyalkoxy, or optionally substituted amino;

each Y^5 is, independently, O, S, Se, optionally substituted alkylene (e.g., methylene), or optionally substituted heteroalkylene; and

B is a nucleobase, either modified or unmodified. In some embodiments, the 2'-hydroxy group (OH) can be modified or replaced with a number of different substituents. Exemplary substitutions at the 2'-position include, but are not limited to, H, azido, halo (e.g., fluoro), optionally substituted C_{1-6} alkyl (e.g., methyl); optionally substituted C_{1-6} alkoxy (e.g., methoxy or ethoxy); optionally substituted C_{6-10} aryloxy; optionally substituted C_{3-8} cycloalkyl; optionally substituted C_{6-10} aryl- C_{1-6} alkoxy, optionally substituted C_{1-12} (heterocyclyl)oxy; a sugar (e.g., ribose, pentose, or any described herein); a polyethyleneglycol (PEG), $-O(CH_2CH_2O)_nCH_2CH_2OR$, where R is H or optionally substituted alkyl, and n is an integer from 0 to 20 (e.g., from 0 to 4, from 0 to 8, from 0 to

10, from 0 to 16, from 1 to 4, from 1 to 8, from 1 to 10, from 1 to 16, from 1 to 20, from 2 to 4, from 2 to 8, from 2 to 10, from 2 to 16, from 2 to 20, from 4 to 8, from 4 to 10, from 4 to 16, and from 4 to 20); “locked” nucleic acids (LNA) in which the 2'-hydroxy is connected by a C₁₋₆ alkylene or C₁₋₆ heteroalkylene bridge to the 4'-carbon of the same ribose sugar, where exemplary bridges included methylene, propylene, ether, or amino bridges; aminoalkyl, as defined herein; aminoalkoxy, as defined herein; amino as defined herein; and amino acid, as defined herein.

[00299] Generally, RNA includes the sugar group ribose, which is a 5-membered ring having an oxygen. Exemplary, non-limiting alternative nucleotides include replacement of the oxygen in ribose (*e.g.*, with S, Se, or alkylene, such as methylene or ethylene); addition of a double bond (*e.g.*, to replace ribose with cyclopentenyl or cyclohexenyl); ring contraction of ribose (*e.g.*, to form a 4-membered ring of cyclobutane or oxetane); ring expansion of ribose (*e.g.*, to form a 6- or 7-membered ring having an additional carbon or heteroatom, such as for anhydrohexitol, alritol, mannitol, cyclohexanyl, cyclohexenyl, and morpholino (that also has a phosphoramidate backbone)); multicyclic forms (*e.g.*, tricyclo and “unlocked” forms, such as glycol nucleic acid (GNA) (*e.g.*, R-GNA or S-GNA, where ribose is replaced by glycol units attached to phosphodiester bonds), threose nucleic acid (TNA, where ribose is replaced with α -L-threofuranosyl-(3'→2')), and peptide nucleic acid (PNA, where 2-amino-ethyl-glycine linkages replace the ribose and phosphodiester backbone).

[00300] In some embodiments, the sugar group contains one or more carbons that possess the opposite stereochemical configuration of the corresponding carbon in ribose. Thus, a polynucleotide molecule can include nucleotides containing, *e.g.*, arabinose or L-ribose, as the sugar.

[00301] In some embodiments, the polynucleotide includes at least one nucleoside wherein the sugar is L-ribose, 2'-O-methyl-ribose, 2'-fluoro-ribose, arabinose, hexitol, an LNA, or a PNA.

Alterations on the internucleoside linkage

[00302] Alternative nucleotides can be altered on the internucleoside linkage (*e.g.*, phosphate backbone). Herein, in the context of the polynucleotide backbone, the phrases “phosphate” and “phosphodiester” are used interchangeably. Backbone phosphate groups can be altered by replacing one or more of the oxygen atoms with a different substituent.

[00303] The alternative nucleotides can include the wholesale replacement of an unaltered phosphate moiety with another internucleoside linkage as described herein. Examples of alternative

phosphate groups include, but are not limited to, phosphorothioate, phosphoroselenates, boranophosphates, boranophosphate esters, hydrogen phosphonates, phosphoramidates, phosphorodiamidates, alkyl or aryl phosphonates, and phosphotriesters. Phosphorodithioates have both non-linking oxygens replaced by sulfur. The phosphate linker can also be altered by the replacement of a linking oxygen with nitrogen (bridged phosphoramidates), sulfur (bridged phosphorothioates), and carbon (bridged methylene-phosphonates).

[00304] The alternative nucleosides and nucleotides can include the replacement of one or more of the non-bridging oxygens with a borane moiety (BH₃), sulfur (thio), methyl, ethyl, and/or methoxy. As a non-limiting example, two non-bridging oxygens at the same position (*e.g.*, the alpha (α), beta (β) or gamma (γ) position) can be replaced with a sulfur (thio) and a methoxy.

[00305] The replacement of one or more of the oxygen atoms at the α position of the phosphate moiety (*e.g.*, α-thio phosphate) is provided to confer stability (such as against exonucleases and endonucleases) to RNA and DNA through the unnatural phosphorothioate backbone linkages. Phosphorothioate DNA and RNA have increased nuclease resistance and subsequently a longer half-life in a cellular environment.

[00306] Other internucleoside linkages that may be employed according to the present disclosure, including internucleoside linkages which do not contain a phosphorous atom, are described herein.

Internal ribosome entry sites

[00307] Polynucleotides may contain an internal ribosome entry site (IRES). An IRES may act as the sole ribosome binding site, or may serve as one of multiple ribosome binding sites of an mRNA. A polynucleotide containing more than one functional ribosome binding site may encode several peptides or polypeptides that are translated independently by the ribosomes (*e.g.*, multicistronic mRNA). When polynucleotides are provided with an IRES, further optionally provided is a second translatable region. Examples of IRES sequences that can be used according to the present disclosure include without limitation, those from picornaviruses (*e.g.*, FMDV), pest viruses (CFFV), polio viruses (PV), encephalomyocarditis viruses (ECMV), foot-and-mouth disease viruses (FMDV), hepatitis C viruses (HCV), classical swine fever viruses (CSFV), murine leukemia virus (MLV), simian immune deficiency viruses (SIV) or cricket paralysis viruses (CrPV).

5'-cap structure

[00308] A polynucleotide (*e.g.*, an mRNA) may include a 5'-cap structure. The 5'-cap structure of a polynucleotide is involved in nuclear export and increasing polynucleotide stability and binds the mRNA Cap Binding Protein (CBP), which is responsible for polynucleotide stability in the cell and translation competency through the association of CBP with poly-A binding protein to form the mature cyclic mRNA species. The cap further assists the removal of 5'-proximal introns removal during mRNA splicing.

[00309] Endogenous polynucleotide molecules may be 5'-end capped generating a 5'-ppp-5'-triphosphate linkage between a terminal guanosine cap residue and the 5'-terminal transcribed sense nucleotide of the polynucleotide. This 5'-guanylate cap may then be methylated to generate an N7-methyl-guanylate residue. The ribose sugars of the terminal and/or anteterminal transcribed nucleotides of the 5' end of the polynucleotide may optionally also be 2'-O-methylated. 5'-decapping through hydrolysis and cleavage of the guanylate cap structure may target a polynucleotide molecule, such as an mRNA molecule, for degradation.

[00310] Alterations to polynucleotides may generate a non-hydrolyzable cap structure preventing decapping and thus increasing polynucleotide half-life. Because cap structure hydrolysis requires cleavage of 5'-ppp-5' phosphodiester linkages, alternative nucleotides may be used during the capping reaction. For example, a Vaccinia Capping Enzyme from New England Biolabs (Ipswich, MA) may be used with α -thio-guanosine nucleotides according to the manufacturer's instructions to create a phosphorothioate linkage in the 5'-ppp-5' cap. Additional alternative guanosine nucleotides may be used such as α -methyl-phosphonate and seleno-phosphate nucleotides.

[00311] Additional alterations include, but are not limited to, 2'-O-methylation of the ribose sugars of 5'-terminal and/or 5'-anteterminal nucleotides of the polynucleotide (as mentioned above) on the 2'-hydroxy group of the sugar. Multiple distinct 5'-cap structures can be used to generate the 5'-cap of a polynucleotide, such as an mRNA molecule.

[00312] 5'-Cap structures include those described in International Patent Publication Nos. WO2008127688, WO 2008016473, and WO 2011015347, the cap structures of each of which are incorporated herein by reference.

[00313] Cap analogs, which herein are also referred to as synthetic cap analogs, chemical caps, chemical cap analogs, or structural or functional cap analogs, differ from natural (*i.e.*, endogenous, wild-type, or physiological) 5'-caps in their chemical structure, while retaining cap function. Cap

analog may be chemically (i.e., non-enzymatically) or enzymatically synthesized and/linked to a polynucleotide.

[00314] For example, the Anti-Reverse Cap Analog (ARCA) cap contains two guanosines linked by a 5'-5'-triphosphate group, wherein one guanosine contains an N7-methyl group as well as a 3'-O-methyl group (i.e., N7,3'-O-dimethyl-guanosine-5'-triphosphate-5'-guanosine, m⁷G-3'mppp-G, which may equivalently be designated 3' O-Me-m⁷G(5')ppp(5')G). The 3'-O atom of the other, unaltered, guanosine becomes linked to the 5'-terminal nucleotide of the capped polynucleotide (e.g., an mRNA). The N7- and 3'-O-methylated guanosine provides the terminal moiety of the capped polynucleotide (e.g., mRNA).

[00315] Another exemplary cap is mCAP, which is similar to ARCA but has a 2'-O-methyl group on guanosine (i.e., N7,2'-O-dimethyl-guanosine-5'-triphosphate-5'-guanosine, m⁷Gm-ppp-G).

[00316] A cap may be a dinucleotide cap analog. As a non-limiting example, the dinucleotide cap analog may be modified at different phosphate positions with a boranophosphate group or a phosphoroselenoate group such as the dinucleotide cap analogs described in US Patent No. 8,519,110, the cap structures of which are herein incorporated by reference.

[00317] Alternatively, a cap analog may be a N7-(4-chlorophenoxyethyl) substituted dinucleotide cap analog known in the art and/or described herein. Non-limiting examples of N7-(4-chlorophenoxyethyl) substituted dinucleotide cap analogs include a N7-(4-chlorophenoxyethyl)-G(5')ppp(5')G and a N7-(4-chlorophenoxyethyl)-m³'-OG(5')ppp(5')G cap analog (see, e.g., the various cap analogs and the methods of synthesizing cap analogs described in Kore et al. Bioorganic & Medicinal Chemistry 2013 21:4570-4574; the cap structures of which are herein incorporated by reference). In other instances, a cap analog useful in the polynucleotides of the present disclosure is a 4-chloro/bromophenoxyethyl analog.

[00318] While cap analogs allow for the concomitant capping of a polynucleotide in an *in vitro* transcription reaction, up to 20% of transcripts remain uncapped. This, as well as the structural differences of a cap analog from endogenous 5'-cap structures of polynucleotides produced by the endogenous, cellular transcription machinery, may lead to reduced translational competency and reduced cellular stability.

[00319] Alternative polynucleotides may also be capped post-transcriptionally, using enzymes, in order to generate more authentic 5'-cap structures. As used herein, the phrase “more authentic”

refers to a feature that closely mirrors or mimics, either structurally or functionally, an endogenous or wild type feature. That is, a “more authentic” feature is better representative of an endogenous, wild-type, natural or physiological cellular function, and/or structure as compared to synthetic features or analogs of the prior art, or which outperforms the corresponding endogenous, wild-type, natural, or physiological feature in one or more respects. Non-limiting examples of more authentic 5'-cap structures useful in the polynucleotides of the present disclosure are those which, among other things, have enhanced binding of cap binding proteins, increased half life, reduced susceptibility to 5'-endonucleases, and/or reduced 5'-decapping, as compared to synthetic 5'-cap structures known in the art (or to a wild-type, natural or physiological 5'-cap structure). For example, recombinant Vaccinia Virus Capping Enzyme and recombinant 2'-O-methyltransferase enzyme can create a canonical 5'-5'-triphosphate linkage between the 5'-terminal nucleotide of a polynucleotide and a guanosine cap nucleotide wherein the cap guanosine contains an N7-methylation and the 5'-terminal nucleotide of the polynucleotide contains a 2'-O-methyl. Such a structure is termed the Cap1 structure. This cap results in a higher translational-competency, cellular stability, and a reduced activation of cellular pro-inflammatory cytokines, as compared, *e.g.*, to other 5' cap analog structures known in the art. Other exemplary cap structures include 7mG(5')ppp(5')N,pN2p (Cap 0), 7mG(5')ppp(5')NlmpNp (Cap 1), 7mG(5')-ppp(5')NlmpN2mp (Cap 2), and m(7)Gpppm(3)(6,6,2')Apm(2')Apm(2')Cpm(2)(3,2')Up (Cap 4).

[00320] Because the alternative polynucleotides may be capped post-transcriptionally, and because this process is more efficient, nearly 100% of the alternative polynucleotides may be capped. This is in contrast to ~80% when a cap analog is linked to a polynucleotide in the course of an *in vitro* transcription reaction.

[00321] 5'-terminal caps may include endogenous caps or cap analogs. A 5'-terminal cap may include a guanosine analog. Useful guanosine analogs include inosine, N1-methyl-guanosine, 2'-fluoro-guanosine, 7-deaza-guanosine, 8-oxo-guanosine, 2-amino-guanosine, LNA-guanosine, and 2-azido-guanosine.

[00322] In some cases, a polynucleotide contains a modified 5'-cap. A modification on the 5'-cap may increase the stability of polynucleotide, increase the half-life of the polynucleotide, and could increase the polynucleotide translational efficiency. The modified 5'-cap may include, but is not limited to, one or more of the following modifications: modification at the 2'- and/or 3'-position of a capped guanosine triphosphate (GTP), a replacement of the sugar ring oxygen (that produced

the carbocyclic ring) with a methylene moiety (CH₂), a modification at the triphosphate bridge moiety of the cap structure, or a modification at the nucleobase (G) moiety.

5'-UTRs

[00323] A 5'-UTR may be provided as a flanking region to polynucleotides (*e.g.*, mRNAs). A 5'-UTR may be homologous or heterologous to the coding region found in a polynucleotide. Multiple 5'-UTRs may be included in the flanking region and may be the same or of different sequences. Any portion of the flanking regions, including none, may be codon optimized and any may independently contain one or more different structural or chemical alterations, before and/or after codon optimization.

[00324] Shown in Table 21 in US Provisional Application No 61/775,509, and in Table 21 and in Table 22 in US Provisional Application No. 61/829,372, of which are incorporated herein by reference, is a listing of the start and stop site of alternative polynucleotides (*e.g.*, mRNA). In Table 21 each 5'-UTR (5'-UTR-005 to 5'-UTR 68511) is identified by its start and stop site relative to its native or wild type (homologous) transcript (ENST; the identifier used in the ENSEMBL database).

[00325] To alter one or more properties of a polynucleotide (*e.g.*, mRNA), 5'-UTRs which are heterologous to the coding region of an alternative polynucleotide (*e.g.*, mRNA) may be engineered. The polynucleotides (*e.g.*, mRNA) may then be administered to cells, tissue or organisms and outcomes such as protein level, localization, and/or half-life may be measured to evaluate the beneficial effects the heterologous 5'-UTR may have on the alternative polynucleotides (mRNA). Variants of the 5'-UTRs may be utilized wherein one or more nucleotides are added or removed to the termini, including A, T, C or G. 5'-UTRs may also be codon-optimized, or altered in any manner described herein.

5'-UTRs, 3'-UTRs, and translation enhancer elements (TEEs)

[00326] The 5'-UTR of a polynucleotides (*e.g.*, mRNA) may include at least one translation enhancer element. The term “translational enhancer element” refers to sequences that increase the amount of polypeptide or protein produced from a polynucleotide. As a non-limiting example, the TEE may be located between the transcription promoter and the start codon. The polynucleotides (*e.g.*, mRNA) with at least one TEE in the 5'-UTR may include a cap at the 5'-UTR. Further, at least one TEE may be located in the 5'-UTR of polynucleotides (*e.g.*, mRNA) undergoing cap-dependent or cap-independent translation.

[00327] In one aspect, TEEs are conserved elements in the UTR which can promote translational activity of a polynucleotide such as, but not limited to, cap-dependent or cap-independent translation. The conservation of these sequences has been previously shown by Panek et al. (Nucleic Acids Research, 2013, 1-10) across 14 species including humans.

[00328] In one non-limiting example, the TEEs known may be in the 5'-leader of the Gtx homeodomain protein (Chappell et al., Proc. Natl. Acad. Sci. USA 101:9590-9594, 2004, the TEEs of which are incorporated herein by reference).

[00329] In another non-limiting example, TEEs are disclosed in US Patent Publication Nos. 2009/0226470 and 2013/0177581, International Patent Publication Nos. WO2009/075886, WO2012/009644, and WO1999/024595, and US Patent Nos. 6,310,197 and 6,849,405, the TEE sequences of each of which are incorporated herein by reference.

[00330] In yet another non-limiting example, the TEE may be an internal ribosome entry site (IRES), HCV-IRES or an IRES element such as, but not limited to, those described in US Patent No. 7,468,275, US Patent Publication Nos. 2007/0048776 and 2011/0124100 and International Patent Publication Nos. WO2007/025008 and WO2001/055369, the IRES sequences of each of which are incorporated herein by reference. The IRES elements may include, but are not limited to, the Gtx sequences (*e.g.*, Gtx9-nt, Gtx8-nt, Gtx7-nt) described by Chappell et al. (Proc. Natl. Acad. Sci. USA 101:9590-9594, 2004) and Zhou et al. (PNAS 102:6273-6278, 2005) and in US Patent Publication Nos. 2007/0048776 and 2011/0124100 and International Patent Publication No. WO2007/025008, the IRES sequences of each of which are incorporated herein by reference.

[00331] "Translational enhancer polynucleotides" are polynucleotides which include one or more of the specific TEE exemplified herein and/or disclosed in the art (see *e.g.*, U.S. Patent Nos. 6,310,197, 6,849,405, 7,456,273, 7,183,395, U.S. Patent Publication Nos. 20090/226470, 2007/0048776, 2011/0124100, 2009/0093049, 2013/0177581, International Patent Publication Nos. WO2009/075886, WO2007/025008, WO2012/009644, WO2001/055371 WO1999/024595, and European Patent Nos. 2610341 and 2610340; the TEE sequences of each of which are incorporated herein by reference) or their variants, homologs or functional derivatives. One or multiple copies of a specific TEE can be present in a polynucleotide (*e.g.*, mRNA). The TEEs in the translational enhancer polynucleotides can be organized in one or more sequence segments. A sequence segment can harbor one or more of the specific TEEs exemplified herein, with each TEE being present in one or more copies. When multiple sequence segments are present in a translational enhancer

polynucleotide, they can be homogenous or heterogeneous. Thus, the multiple sequence segments in a translational enhancer polynucleotide can harbor identical or different types of the specific TEEs exemplified herein, identical or different number of copies of each of the specific TEEs, and/or identical or different organization of the TEEs within each sequence segment.

[00332] A polynucleotide (*e.g.*, mRNA) may include at least one TEE that is described in International Patent Publication Nos. WO1999/024595, WO2012/009644, WO2009/075886, WO2007/025008, WO1999/024595, European Patent Publication Nos. 2610341 and 2610340, US Patent Nos. 6,310,197, 6,849,405, 7,456,273, 7,183,395, and US Patent Publication Nos. 2009/0226470, 2011/0124100, 2007/0048776, 2009/0093049, and 2013/0177581 the TEE sequences of each of which are incorporated herein by reference. The TEE may be located in the 5'-UTR of the polynucleotides (*e.g.*, mRNA).

[00333] A polynucleotide (*e.g.*, mRNA) may include at least one TEE that has at least 50%, at least 55%, at least 60%, at least 65%, at least 70%, at least 75%, at least 80%, at least 85%, at least 90%, at least 95% or at least 99% identity with the TEEs described in US Patent Publication Nos. 2009/0226470, 2007/0048776, 2013/0177581 and 2011/0124100, International Patent Publication Nos. WO1999/024595, WO2012/009644, WO2009/075886 and WO2007/025008, European Patent Publication Nos. 2610341 and 2610340, US Patent Nos. 6,310,197, 6,849,405, 7,456,273, 7,183,395, the TEE sequences of each of which are incorporated herein by reference.

[00334] The 5'-UTR of a polynucleotide (*e.g.*, mRNA) may include at least 1, at least 2, at least 3, at least 4, at least 5, at least 6, at least 7, at least 8, at least 9, at least 10, at least 11, at least 12, at least 13, at least 14, at least 15, at least 16, at least 17, at least 18 at least 19, at least 20, at least 21, at least 22, at least 23, at least 24, at least 25, at least 30, at least 35, at least 40, at least 45, at least 50, at least 55 or more than 60 TEE sequences. The TEE sequences in the 5'-UTR of a polynucleotide (*e.g.*, mRNA) may be the same or different TEE sequences. The TEE sequences may be in a pattern such as ABABAB, AABBAABBAABB, or ABCABCABC, or variants thereof, repeated once, twice, or more than three times. In these patterns, each letter, A, B, or C represent a different TEE sequence at the nucleotide level.

[00335] In some cases, the 5'-UTR may include a spacer to separate two TEE sequences. As a non-limiting example, the spacer may be a 15 nucleotide spacer and/or other spacers known in the art. As another non-limiting example, the 5'-UTR may include a TEE sequence-spacer module

repeated at least once, at least twice, at least 3 times, at least 4 times, at least 5 times, at least 6 times, at least 7 times, at least 8 times, at least 9 times, or more than 9 times in the 5'-UTR.

[00336] In other instances, the spacer separating two TEE sequences may include other sequences known in the art which may regulate the translation of the polynucleotides (*e.g.*, mRNA) of the present disclosure such as, but not limited to, miR sequences (*e.g.*, miR binding sites and miR seeds). As a non-limiting example, each spacer used to separate two TEE sequences may include a different miR sequence or component of a miR sequence (*e.g.*, miR seed sequence).

[00337] In some instances, the TEE in the 5'-UTR of a polynucleotide (*e.g.*, mRNA) may include at least 5%, at least 10%, at least 15%, at least 20%, at least 25%, at least 30%, at least 35%, at least 40%, at least 45%, at least 50%, at least 55%, at least 60%, at least 65%, at least 70%, at least 75%, at least 80%, at least 85%, at least 90%, at least 95%, at least 99% or more than 99% of the TEE sequences disclosed in US Patent Publication Nos. 2009/0226470, 2007/0048776, 2013/0177581 and 2011/0124100, International Patent Publication Nos. WO1999/024595, WO2012/009644, WO2009/075886 and WO2007/025008, European Patent Publication Nos. 2610341 and 2610340, and US Patent Nos. 6,310,197, 6,849,405, 7,456,273, and 7,183,395 the TEE sequences of each of which are incorporated herein by reference. In another embodiment, the TEE in the 5'-UTR of the polynucleotides (*e.g.*, mRNA) of the present disclosure may include a 5-30 nucleotide fragment, a 5-25 nucleotide fragment, a 5-20 nucleotide fragment, a 5-15 nucleotide fragment, a 5-10 nucleotide fragment of the TEE sequences disclosed in US Patent Publication Nos. 2009/0226470, 2007/0048776, 2013/0177581 and 2011/0124100, International Patent Publication Nos. WO1999/024595, WO2012/009644, WO2009/075886 and WO2007/025008, European Patent Publication Nos. 2610341 and 2610340, and US Patent Nos. 6,310,197, 6,849,405, 7,456,273, and 7,183,395; the TEE sequences of each of which are incorporated herein by reference.

[00338] In certain cases, the TEE in the 5'-UTR of the polynucleotides (*e.g.*, mRNA) of the present disclosure may include at least 5%, at least 10%, at least 15%, at least 20%, at least 25%, at least 30%, at least 35%, at least 40%, at least 45%, at least 50%, at least 55%, at least 60%, at least 65%, at least 70%, at least 75%, at least 80%, at least 85%, at least 90%, at least 95%, at least 99% or more than 99% of the TEE sequences disclosed in Chappell et al. (Proc. Natl. Acad. Sci. USA 101:9590-9594, 2004) and Zhou et al. (PNAS 102:6273-6278, 2005), in Supplemental Table 1 and in Supplemental Table 2 disclosed by Wellensiek et al (Genome-wide profiling of human cap-independent translation-enhancing elements, Nature Methods, 2013; DOI:10.1038/NMETH.2522);

the TEE sequences of each of which are herein incorporated by reference. In another embodiment, the TEE in the 5'-UTR of the polynucleotides (*e.g.*, mRNA) of the present disclosure may include a 5-30 nucleotide fragment, a 5-25 nucleotide fragment, a 5-20 nucleotide fragment, a 5-15 nucleotide fragment, a 5-10 nucleotide fragment of the TEE sequences disclosed in Chappell et al. (Proc. Natl. Acad. Sci. USA 101:9590-9594, 2004) and Zhou et al. (PNAS 102:6273-6278, 2005), in Supplemental Table 1 and in Supplemental Table 2 disclosed by Wellensiek et al (Genome-wide profiling of human cap-independent translation-enhancing elements, Nature Methods, 2013; DOI:10.1038/NMETH.2522); the TEE sequences of each of which is incorporated herein by reference.

[00339] In some cases, the TEE used in the 5'-UTR of a polynucleotide (*e.g.*, mRNA) is an IRES sequence such as, but not limited to, those described in US Patent No. 7,468,275 and International Patent Publication No. WO2001/055369, the TEE sequences of each of which are incorporated herein by reference.

[00340] In some instances, the TEEs used in the 5'-UTR of a polynucleotide (*e.g.*, mRNA) may be identified by the methods described in US Patent Publication Nos. 2007/0048776 and 2011/0124100 and International Patent Publication Nos. WO2007/025008 and WO2012/009644, the methods of each of which are incorporated herein by reference.

[00341] In some cases, the TEEs used in the 5'-UTR of a polynucleotide (*e.g.*, mRNA) of the present disclosure may be a transcription regulatory element described in US Patent Nos. 7,456,273 and 7,183,395, US Patent Publication No. 2009/0093049, and International Publication No. WO2001/055371, the TEE sequences of each of which is incorporated herein by reference. The transcription regulatory elements may be identified by methods known in the art, such as, but not limited to, the methods described in US Patent Nos. 7,456,273 and 7,183,395, US Patent Publication No. 2009/0093049, and International Publication No. WO2001/055371, the methods of each of which is incorporated herein by reference.

[00342] In yet other instances, the TEE used in the 5'-UTR of a polynucleotide (*e.g.*, mRNA) is a polynucleotide or portion thereof as described in US Patent Nos. 7,456,273 and 7,183,395, US Patent Publication No. 2009/0093049, and International Publication No. WO2001/055371, the TEE sequences of each of which are incorporated herein by reference.

[00343] The 5'-UTR including at least one TEE described herein may be incorporated in a monocistronic sequence such as, but not limited to, a vector system or a polynucleotide vector. As

a non-limiting example, the vector systems and polynucleotide vectors may include those described in US Patent Nos. 7,456,273 and 7,183,395, US Patent Publication Nos. 2007/0048776, 2009/0093049 and 2011/0124100, and International Patent Publication Nos. WO2007/025008 and WO2001/055371, the TEE sequences of each of which are incorporated herein by reference.

[00344] The TEEs described herein may be located in the 5'-UTR and/or the 3'-UTR of the polynucleotides (*e.g.*, mRNA). The TEEs located in the 3'-UTR may be the same and/or different than the TEEs located in and/or described for incorporation in the 5'-UTR.

[00345] In some cases, the 3'-UTR of a polynucleotide (*e.g.*, mRNA) may include at least 1, at least 2, at least 3, at least 4, at least 5, at least 6, at least 7, at least 8, at least 9, at least 10, at least 11, at least 12, at least 13, at least 14, at least 15, at least 16, at least 17, at least 18 at least 19, at least 20, at least 21, at least 22, at least 23, at least 24, at least 25, at least 30, at least 35, at least 40, at least 45, at least 50, at least 55 or more than 60 TEE sequences. The TEE sequences in the 3'-UTR of the polynucleotides (*e.g.*, mRNA) of the present disclosure may be the same or different TEE sequences. The TEE sequences may be in a pattern such as ABABAB, AABBAABBAABB, or ABCABCABC, or variants thereof, repeated once, twice, or more than three times. In these patterns, each letter, A, B, or C represent a different TEE sequence at the nucleotide level.

[00346] In one instance, the 3'-UTR may include a spacer to separate two TEE sequences. As a non-limiting example, the spacer may be a 15 nucleotide spacer and/or other spacers known in the art. As another non-limiting example, the 3'-UTR may include a TEE sequence-spacer module repeated at least once, at least twice, at least 3 times, at least 4 times, at least 5 times, at least 6 times, at least 7 times, at least 8 times, at least 9 times, or more than 9 times in the 3'-UTR.

[00347] In other cases, the spacer separating two TEE sequences may include other sequences known in the art which may regulate the translation of the polynucleotides (*e.g.*, mRNA) of the present disclosure such as, but not limited to, miR sequences described herein (*e.g.*, miR binding sites and miR seeds). As a non-limiting example, each spacer used to separate two TEE sequences may include a different miR sequence or component of a miR sequence (*e.g.*, miR seed sequence).

[00348] In yet other cases, the incorporation of a miR sequence and/or a TEE sequence changes the shape of the stem loop region which may increase and/or decrease translation. (see *e.g.*, Kedde et al. A Pumilio-induced RNA structure switch in p27-3'UTR controls miR-221 and miR-22 accessibility. Nature Cell Biology. 2010).

Stem loops

[00349] Polynucleotides (*e.g.*, mRNAs) may include a stem loop such as, but not limited to, a histone stem loop. The stem loop may be a nucleotide sequence that is about 25 or about 26 nucleotides in length such as, but not limited to, those described in International Patent Publication No. WO2013/103659, which is incorporated herein by reference. The histone stem loop may be located 3'-relative to the coding region (*e.g.*, at the 3'-terminus of the coding region). As a non-limiting example, the stem loop may be located at the 3'-end of a polynucleotide described herein. In some cases, a polynucleotide (*e.g.*, an mRNA) includes more than one stem loop (*e.g.*, two stem loops). Examples of stem loop sequences are described in International Patent Publication Nos. WO2012/019780 and WO201502667, the stem loop sequences of which are herein incorporated by reference. In some instances, a polynucleotide includes the stem loop sequence CAAAGGCTCTTTTCAGAGCCACCA (SEQ ID NO: 1). In others, a polynucleotide includes the stem loop sequence CAAAGGCUCUUUCAGAGCCACCA (SEQ ID NO: 2).

[00350] A stem loop may be located in a second terminal region of a polynucleotide. As a non-limiting example, the stem loop may be located within an untranslated region (*e.g.*, 3'-UTR) in a second terminal region.

[00351] In some cases, a polynucleotide such as, but not limited to mRNA, which includes the histone stem loop may be stabilized by the addition of a 3'-stabilizing region (*e.g.*, a 3'-stabilizing region including at least one chain terminating nucleoside). Not wishing to be bound by theory, the addition of at least one chain terminating nucleoside may slow the degradation of a polynucleotide and thus can increase the half-life of the polynucleotide.

[00352] In other cases, a polynucleotide such as, but not limited to mRNA, which includes the histone stem loop may be stabilized by an alteration to the 3'-region of the polynucleotide that can prevent and/or inhibit the addition of oligio(U) (see *e.g.*, International Patent Publication No. WO2013/103659).

[00353] In yet other cases, a polynucleotide such as, but not limited to mRNA, which includes the histone stem loop may be stabilized by the addition of an oligonucleotide that terminates in a 3'-deoxynucleoside, 2',3'-dideoxynucleoside 3'-O- methyl nucleosides, 3'-O-ethyl nucleosides, 3'-arabinosides, and other alternative nucleosides known in the art and/or described herein.

[00354] In some instances, the polynucleotides of the present disclosure may include a histone stem loop, a poly-A region, and/or a 5'-cap structure. The histone stem loop may be before and/or

after the poly-A region. The polynucleotides including the histone stem loop and a poly-A region sequence may include a chain terminating nucleoside described herein.

[00355] In other instances, the polynucleotides of the present disclosure may include a histone stem loop and a 5'-cap structure. The 5'-cap structure may include, but is not limited to, those described herein and/or known in the art.

[00356] In some cases, the conserved stem loop region may include a miR sequence described herein. As a non-limiting example, the stem loop region may include the seed sequence of a miR sequence described herein. In another non-limiting example, the stem loop region may include a miR-122 seed sequence.

[00357] In certain instances, the conserved stem loop region may include a miR sequence described herein and may also include a TEE sequence.

[00358] In some cases, the incorporation of a miR sequence and/or a TEE sequence changes the shape of the stem loop region which may increase and/or decrease translation. (See, e.g., Kedde et al. A Pumilio-induced RNA structure switch in p27-3'UTR controls miR-221 and miR-22 accessibility. *Nature Cell Biology*. 2010, herein incorporated by reference in its entirety).

[00359] Polynucleotides may include at least one histone stem-loop and a poly-A region or polyadenylation signal. Non-limiting examples of polynucleotide sequences encoding for at least one histone stem-loop and a poly-A region or a polyadenylation signal are described in International Patent Publication No. WO2013/120497, WO2013/120629, WO2013/120500, WO2013/120627, WO2013/120498, WO2013/120626, WO2013/120499 and WO2013/120628, the sequences of each of which are incorporated herein by reference. In certain cases, the polynucleotide encoding for a histone stem loop and a poly-A region or a polyadenylation signal may code for a pathogen antigen or fragment thereof such as the polynucleotide sequences described in International Patent Publication No WO2013/120499 and WO2013/120628, the sequences of both of which are incorporated herein by reference. In other cases, the polynucleotide encoding for a histone stem loop and a poly-A region or a polyadenylation signal may code for a therapeutic protein such as the polynucleotide sequences described in International Patent Publication No WO2013/120497 and WO2013/120629, the sequences of both of which are incorporated herein by reference. In some cases, the polynucleotide encoding for a histone stem loop and a poly-A region or a polyadenylation signal may code for a tumor antigen or fragment thereof such as the polynucleotide sequences described in International Patent Publication No WO2013/120500 and WO2013/120627, the

sequences of both of which are incorporated herein by reference. In other cases, the polynucleotide encoding for a histone stem loop and a poly-A region or a polyadenylation signal may code for an allergenic antigen or an autoimmune self-antigen such as the polynucleotide sequences described in International Patent Publication No WO2013/120498 and WO2013/120626, the sequences of both of which are incorporated herein by reference.

Poly-A regions

[00360] A polynucleotide or nucleic acid (*e.g.*, an mRNA) may include a polyA sequence and/or polyadenylation signal. A polyA sequence may be comprised entirely or mostly of adenine nucleotides or analogs or derivatives thereof. A polyA sequence may be a tail located adjacent to a 3' untranslated region of a nucleic acid.

[00361] During RNA processing, a long chain of adenosine nucleotides (poly-A region) is normally added to messenger RNA (mRNA) molecules to increase the stability of the molecule. Immediately after transcription, the 3'-end of the transcript is cleaved to free a 3'-hydroxy. Then poly-A polymerase adds a chain of adenosine nucleotides to the RNA. The process, called polyadenylation, adds a poly-A region that is between 100 and 250 residues long.

[00362] Unique poly-A region lengths may provide certain advantages to the alternative polynucleotides of the present disclosure.

[00363] Generally, the length of a poly-A region of the present disclosure is at least 30 nucleotides in length. In another embodiment, the poly-A region is at least 35 nucleotides in length. In another embodiment, the length is at least 40 nucleotides. In another embodiment, the length is at least 45 nucleotides. In another embodiment, the length is at least 55 nucleotides. In another embodiment, the length is at least 60 nucleotides. In another embodiment, the length is at least 70 nucleotides. In another embodiment, the length is at least 80 nucleotides. In another embodiment, the length is at least 90 nucleotides. In another embodiment, the length is at least 100 nucleotides. In another embodiment, the length is at least 120 nucleotides. In another embodiment, the length is at least 140 nucleotides. In another embodiment, the length is at least 160 nucleotides. In another embodiment, the length is at least 180 nucleotides. In another embodiment, the length is at least 200 nucleotides. In another embodiment, the length is at least 250 nucleotides. In another embodiment, the length is at least 300 nucleotides. In another embodiment, the length is at least 350 nucleotides. In another embodiment, the length is at least 400 nucleotides. In another embodiment, the length is at least 450 nucleotides. In another embodiment, the length is at least

500 nucleotides. In another embodiment, the length is at least 600 nucleotides. In another embodiment, the length is at least 700 nucleotides. In another embodiment, the length is at least 800 nucleotides. In another embodiment, the length is at least 900 nucleotides. In another embodiment, the length is at least 1000 nucleotides. In another embodiment, the length is at least 1100 nucleotides. In another embodiment, the length is at least 1200 nucleotides. In another embodiment, the length is at least 1300 nucleotides. In another embodiment, the length is at least 1400 nucleotides. In another embodiment, the length is at least 1500 nucleotides. In another embodiment, the length is at least 1600 nucleotides. In another embodiment, the length is at least 1700 nucleotides. In another embodiment, the length is at least 1800 nucleotides. In another embodiment, the length is at least 1900 nucleotides. In another embodiment, the length is at least 2000 nucleotides. In another embodiment, the length is at least 2500 nucleotides. In another embodiment, the length is at least 3000 nucleotides.

[00364] In some instances, the poly-A region may be 80 nucleotides, 120 nucleotides, 160 nucleotides in length on an alternative polynucleotide molecule described herein.

[00365] In other instances, the poly-A region may be 20, 40, 80, 100, 120, 140 or 160 nucleotides in length on an alternative polynucleotide molecule described herein.

[00366] In some cases, the poly-A region is designed relative to the length of the overall alternative polynucleotide. This design may be based on the length of the coding region of the alternative polynucleotide, the length of a particular feature or region of the alternative polynucleotide (such as mRNA), or based on the length of the ultimate product expressed from the alternative polynucleotide. When relative to any feature of the alternative polynucleotide (*e.g.*, other than the mRNA portion which includes the poly-A region) the poly-A region may be 10, 20, 30, 40, 50, 60, 70, 80, 90 or 100% greater in length than the additional feature. The poly-A region may also be designed as a fraction of the alternative polynucleotide to which it belongs. In this context, the poly-A region may be 10, 20, 30, 40, 50, 60, 70, 80, or 90% or more of the total length of the construct or the total length of the construct minus the poly-A region.

[00367] In certain cases, engineered binding sites and/or the conjugation of polynucleotides (*e.g.*, mRNA) for poly-A binding protein may be used to enhance expression. The engineered binding sites may be sensor sequences which can operate as binding sites for ligands of the local microenvironment of the polynucleotides (*e.g.*, mRNA). As a non-limiting example, the polynucleotides (*e.g.*, mRNA) may include at least one engineered binding site to alter the binding

affinity of poly-A binding protein (PABP) and analogs thereof. The incorporation of at least one engineered binding site may increase the binding affinity of the PABP and analogs thereof.

[00368] Additionally, multiple distinct polynucleotides (*e.g.*, mRNA) may be linked together to the PABP (poly-A binding protein) through the 3'-end using alternative nucleotides at the 3'-terminus of the poly-A region. Transfection experiments can be conducted in relevant cell lines at and protein production can be assayed by ELISA at 12 hours, 24 hours, 48 hours, 72 hours, and day 7 post-transfection. As a non-limiting example, the transfection experiments may be used to evaluate the effect on PABP or analogs thereof binding affinity as a result of the addition of at least one engineered binding site.

[00369] In certain cases, a poly-A region may be used to modulate translation initiation. While not wishing to be bound by theory, the poly-A region recruits PABP which in turn can interact with translation initiation complex and thus may be essential for protein synthesis.

[00370] In some cases, a poly-A region may also be used in the present disclosure to protect against 3'-5'-exonuclease digestion.

[00371] In some instances, a polynucleotide (*e.g.*, mRNA) may include a polyA-G Quartet. The G-quartet is a cyclic hydrogen bonded array of four guanosine nucleotides that can be formed by G-rich sequences in both DNA and RNA. In this embodiment, the G-quartet is incorporated at the end of the poly-A region. The resultant polynucleotides (*e.g.*, mRNA) may be assayed for stability, protein production and other parameters including half-life at various time points. It has been discovered that the polyA-G quartet results in protein production equivalent to at least 75% of that seen using a poly-A region of 120 nucleotides alone.

[00372] In some cases, a polynucleotide (*e.g.*, mRNA) may include a poly-A region and may be stabilized by the addition of a 3'-stabilizing region. The polynucleotides (*e.g.*, mRNA) with a poly-A region may further include a 5'-cap structure.

[00373] In other cases, a polynucleotide (*e.g.*, mRNA) may include a poly-A-G Quartet. The polynucleotides (*e.g.*, mRNA) with a poly-A-G Quartet may further include a 5'-cap structure.

[00374] In some cases, the 3'-stabilizing region which may be used to stabilize a polynucleotide (*e.g.*, mRNA) including a poly-A region or poly-A-G Quartet may be, but is not limited to, those described in International Patent Publication No. WO2013/103659, the poly-A regions and poly-A-G Quartets of which are incorporated herein by reference. In other cases, the 3'-stabilizing region which may be used with the present disclosure include a chain termination nucleoside such as 3'-

deoxyadenosine (cordycepin), 3'-deoxyuridine, 3'-deoxycytosine, 3'-deoxyguanosine, 3'-deoxythymine, 2',3'-dideoxynucleosides, such as 2',3'-dideoxyadenosine, 2',3'-dideoxyuridine, 2',3'-dideoxycytosine, 2',3'-dideoxyguanosine, 2',3'-dideoxythymine, a 2'-deoxynucleoside, or an O-methylnucleoside.

[00375] In other cases, a polynucleotide such as, but not limited to mRNA, which includes a polyA region or a poly-A-G Quartet may be stabilized by an alteration to the 3'-region of the polynucleotide that can prevent and/or inhibit the addition of oligio(U) (see *e.g.*, International Patent Publication No. WO2013/103659).

[00376] In yet other instances, a polynucleotide such as, but not limited to mRNA, which includes a poly-A region or a poly-A-G Quartet may be stabilized by the addition of an oligonucleotide that terminates in a 3'-deoxynucleoside, 2',3'-dideoxynucleoside 3'-O-methylnucleosides, 3'-O-ethylnucleosides, 3'-arabinosides, and other alternative nucleosides known in the art and/or described herein.

Chain terminating nucleosides

[00377] A nucleic acid may include a chain terminating nucleoside. For example, a chain terminating nucleoside may include those nucleosides deoxygenated at the 2' and/or 3' positions of their sugar group. Such species may include 3'-deoxyadenosine (cordycepin), 3'-deoxyuridine, 3'-deoxycytosine, 3'-deoxyguanosine, 3'-deoxythymine, and 2',3'-dideoxynucleosides, such as 2',3'-dideoxyadenosine, 2',3'-dideoxyuridine, 2',3'-dideoxycytosine, 2',3'-dideoxyguanosine, and 2',3'-dideoxythymine.

Other components

[00378] A nanoparticle composition may include one or more components in addition to those described in the preceding sections. For example, a nanoparticle composition may include one or more small hydrophobic molecules such as a vitamin (*e.g.*, vitamin A or vitamin E) or a sterol.

[00379] Nanoparticle compositions may also include one or more permeability enhancer molecules, carbohydrates, polymers, surface altering agents, or other components. A permeability enhancer molecule may be a molecule described by U.S. patent application publication No. 2005/0222064, for example. Carbohydrates may include simple sugars (*e.g.*, glucose) and polysaccharides (*e.g.*, glycogen and derivatives and analogs thereof).

[00380] A polymer may be included in and/or used to encapsulate or partially encapsulate a nanoparticle composition. A polymer may be biodegradable and/or biocompatible. A polymer may

be selected from, but is not limited to, polyamines, polyethers, polyamides, polyesters, polycarbamates, polyureas, polycarbonates, polystyrenes, polyimides, polysulfones, polyurethanes, polyacetylenes, polyethylenes, polyethyleneimines, polyisocyanates, polyacrylates, polymethacrylates, polyacrylonitriles, and polyarylates. For example, a polymer may include poly(caprolactone) (PCL), ethylene vinyl acetate polymer (EVA), poly(lactic acid) (PLA), poly(L-lactic acid) (PLLA), poly(glycolic acid) (PGA), poly(lactic acid-co-glycolic acid) (PLGA), poly(L-lactic acid-co-glycolic acid) (PLLGA), poly(D,L-lactide) (PDLA), poly(L-lactide) (PLLA), poly(D,L-lactide-co-caprolactone), poly(D,L-lactide-co-caprolactone-co-glycolide), poly(D,L-lactide-co-PEO-co-D,L-lactide), poly(D,L-lactide-co-PPO-co-D,L-lactide), polyalkyl cyanoacrylate, polyurethane, poly-L-lysine (PLL), hydroxypropyl methacrylate (HPMA), polyethyleneglycol, poly-L-glutamic acid, poly(hydroxy acids), polyanhydrides, polyorthoesters, poly(ester amides), polyamides, poly(ester ethers), polycarbonates, polyalkylenes such as polyethylene and polypropylene, polyalkylene glycols such as poly(ethylene glycol) (PEG), polyalkylene oxides (PEO), polyalkylene terephthalates such as poly(ethylene terephthalate), polyvinyl alcohols (PVA), polyvinyl ethers, polyvinyl esters such as poly(vinyl acetate), polyvinyl halides such as poly(vinyl chloride) (PVC), polyvinylpyrrolidone (PVP), polysiloxanes, polystyrene (PS), polyurethanes, derivatized celluloses such as alkyl celluloses, hydroxyalkyl celluloses, cellulose ethers, cellulose esters, nitro celluloses, hydroxypropylcellulose, carboxymethylcellulose, polymers of acrylic acids, such as poly(methyl(meth)acrylate) (PMMA), poly(ethyl(meth)acrylate), poly(butyl(meth)acrylate), poly(isobutyl(meth)acrylate), poly(hexyl(meth)acrylate), poly(isodecyl(meth)acrylate), poly(lauryl(meth)acrylate), poly(phenyl(meth)acrylate), poly(methyl acrylate), poly(isopropyl acrylate), poly(isobutyl acrylate), poly(octadecyl acrylate) and copolymers and mixtures thereof, polydioxanone and its copolymers, polyhydroxyalkanoates, polypropylene fumarate, polyoxymethylene, poloxamers, polyoxamines, poly(ortho)esters, poly(butyric acid), poly(valeric acid), poly(lactide-co-caprolactone), trimethylene carbonate, poly(*N*-acryloylmorpholine) (PAcM), poly(2-methyl-2-oxazoline) (PMOX), poly(2-ethyl-2-oxazoline) (PEOZ), and polyglycerol.

[00381] Surface altering agents may include, but are not limited to, anionic proteins (*e.g.*, bovine serum albumin), surfactants (*e.g.*, cationic surfactants such as dimethyldioctadecyl-ammonium bromide), sugars or sugar derivatives (*e.g.*, cyclodextrin), nucleic acids, polymers (*e.g.*, heparin, polyethylene glycol, and poloxamer), mucolytic agents (*e.g.*, acetylcysteine, mugwort, bromelain, papain, clerodendrum, bromhexine, carbocysteine, eprazinone, mesna, ambroxol, sobrerol,

domiodol, letosteine, stepronin, tiopronin, gelsolin, thymosin β 4, dornase alfa, nelfenexine, and erdosteine), and DNases (*e.g.*, rhDNase). A surface altering agent may be disposed within a nanoparticle and/or on the surface of a nanoparticle composition (*e.g.*, by coating, adsorption, covalent linkage, or other process).

[00382] A nanoparticle composition may also comprise one or more functionalized lipids. For example, a lipid may be functionalized with an alkyne group that, when exposed to an azide under appropriate reaction conditions, may undergo a cycloaddition reaction. In particular, a lipid bilayer may be functionalized in this fashion with one or more groups useful in facilitating membrane permeation, cellular recognition, or imaging. The surface of a nanoparticle composition may also be conjugated with one or more useful antibodies. Functional groups and conjugates useful in targeted cell delivery, imaging, and membrane permeation are well known in the art.

[00383] In addition to these components, nanoparticle compositions may include any substance useful in pharmaceutical compositions. For example, the nanoparticle composition may include one or more pharmaceutically acceptable excipients or accessory ingredients such as, but not limited to, one or more solvents, dispersion media, diluents, dispersion aids, suspension aids, granulating aids, disintegrants, fillers, glidants, liquid vehicles, binders, surface active agents, isotonic agents, thickening or emulsifying agents, buffering agents, lubricating agents, oils, preservatives, and other species. Excipients such as waxes, butters, coloring agents, coating agents, flavorings, and perfuming agents may also be included. Pharmaceutically acceptable excipients are well known in the art (see for example Remington's *The Science and Practice of Pharmacy*, 21st Edition, A. R. Gennaro; Lippincott, Williams & Wilkins, Baltimore, MD, 2006).

[00384] Examples of diluents may include, but are not limited to, calcium carbonate, sodium carbonate, calcium phosphate, dicalcium phosphate, calcium sulfate, calcium hydrogen phosphate, sodium phosphate lactose, sucrose, cellulose, microcrystalline cellulose, kaolin, mannitol, sorbitol, inositol, sodium chloride, dry starch, cornstarch, powdered sugar, and/or combinations thereof. Granulating and dispersing agents may be selected from the non-limiting list consisting of potato starch, corn starch, tapioca starch, sodium starch glycolate, clays, alginic acid, guar gum, citrus pulp, agar, bentonite, cellulose and wood products, natural sponge, cation-exchange resins, calcium carbonate, silicates, sodium carbonate, cross-linked poly(vinyl-pyrrolidone) (crospovidone), sodium carboxymethyl starch (sodium starch glycolate), carboxymethyl cellulose, cross-linked sodium carboxymethyl cellulose (croscarmellose), methylcellulose, pregelatinized starch (starch 1500),

microcrystalline starch, water insoluble starch, calcium carboxymethyl cellulose, magnesium aluminum silicate (VEEGUM®), sodium lauryl sulfate, quaternary ammonium compounds, and/or combinations thereof.

[00385] Surface active agents and/or emulsifiers may include, but are not limited to, natural emulsifiers (*e.g.* acacia, agar, alginic acid, sodium alginate, tragacanth, chondrux, cholesterol, xanthan, pectin, gelatin, egg yolk, casein, wool fat, cholesterol, wax, and lecithin), colloidal clays (*e.g.* bentonite [aluminum silicate] and VEEGUM® [magnesium aluminum silicate]), long chain amino acid derivatives, high molecular weight alcohols (*e.g.* stearyl alcohol, cetyl alcohol, oleyl alcohol, triacetin monostearate, ethylene glycol distearate, glyceryl monostearate, and propylene glycol monostearate, polyvinyl alcohol), carbomers (*e.g.* carboxy polymethylene, polyacrylic acid, acrylic acid polymer, and carboxyvinyl polymer), carrageenan, cellulosic derivatives (*e.g.* carboxymethylcellulose sodium, powdered cellulose, hydroxymethyl cellulose, hydroxypropyl cellulose, hydroxypropyl methylcellulose, methylcellulose), sorbitan fatty acid esters (*e.g.* polyoxyethylene sorbitan monolaurate [TWEEN®20], polyoxyethylene sorbitan [TWEEN® 60], polyoxyethylene sorbitan monooleate [TWEEN®80], sorbitan monopalmitate [SPAN®40], sorbitan monostearate [SPAN®60], sorbitan tristearate [SPAN®65], glyceryl monooleate, sorbitan monooleate [SPAN®80]), polyoxyethylene esters (*e.g.* polyoxyethylene monostearate [MYRJ® 45], polyoxyethylene hydrogenated castor oil, polyethoxylated castor oil, polyoxymethylene stearate, and SOLUTOL®), sucrose fatty acid esters, polyethylene glycol fatty acid esters (*e.g.* CREMOPHOR®), polyoxyethylene ethers, (*e.g.* polyoxyethylene lauryl ether [BRIJ® 30]), poly(vinyl-pyrrolidone), diethylene glycol monolaurate, triethanolamine oleate, sodium oleate, potassium oleate, ethyl oleate, oleic acid, ethyl laurate, sodium lauryl sulfate, PLURONIC®F 68, POLOXAMER® 188, cetrimonium bromide, cetylpyridinium chloride, benzalkonium chloride, docusate sodium, and/or combinations thereof.

[00386] A binding agent may be starch (*e.g.* cornstarch and starch paste); gelatin; sugars (*e.g.* sucrose, glucose, dextrose, dextrin, molasses, lactose, lactitol, mannitol); natural and synthetic gums (*e.g.*, acacia, sodium alginate, extract of Irish moss, panwar gum, ghatti gum, mucilage of isapol husks, carboxymethylcellulose, methylcellulose, ethylcellulose, hydroxyethylcellulose, hydroxypropyl cellulose, hydroxypropyl methylcellulose, microcrystalline cellulose, cellulose acetate, poly(vinyl-pyrrolidone), magnesium aluminum silicate (VEEGUM®), and larch arabogalactan); alginates; polyethylene oxide; polyethylene glycol; inorganic calcium salts; silicic

acid; polymethacrylates; waxes; water; alcohol; and combinations thereof, or any other suitable binding agent.

[00387] Examples of preservatives may include, but are not limited to, antioxidants, chelating agents, antimicrobial preservatives, antifungal preservatives, alcohol preservatives, acidic preservatives, and/or other preservatives. Examples of antioxidants include, but are not limited to, alpha tocopherol, ascorbic acid, acorbyl palmitate, butylated hydroxyanisole, butylated hydroxytoluene, monothioglycerol, potassium metabisulfite, propionic acid, propyl gallate, sodium ascorbate, sodium bisulfite, sodium metabisulfite, and/or sodium sulfite. Examples of chelating agents include ethylenediaminetetraacetic acid (EDTA), citric acid monohydrate, disodium edetate, dipotassium edetate, edetic acid, fumaric acid, malic acid, phosphoric acid, sodium edetate, tartaric acid, and/or trisodium edetate. Examples of antimicrobial preservatives include, but are not limited to, benzalkonium chloride, benzethonium chloride, benzyl alcohol, bronopol, cetrimide, cetylpyridinium chloride, chlorhexidine, chlorobutanol, chlorocresol, chloroxylenol, cresol, ethyl alcohol, glycerin, hexetidine, imidurea, phenol, phenoxyethanol, phenylethyl alcohol, phenylmercuric nitrate, propylene glycol, and/or thimerosal. Examples of antifungal preservatives include, but are not limited to, butyl paraben, methyl paraben, ethyl paraben, propyl paraben, benzoic acid, hydroxybenzoic acid, potassium benzoate, potassium sorbate, sodium benzoate, sodium propionate, and/or sorbic acid. Examples of alcohol preservatives include, but are not limited to, ethanol, polyethylene glycol, benzyl alcohol, phenol, phenolic compounds, bisphenol, chlorobutanol, hydroxybenzoate, and/or phenylethyl alcohol. Examples of acidic preservatives include, but are not limited to, vitamin A, vitamin C, vitamin E, beta-carotene, citric acid, acetic acid, dehydroascorbic acid, ascorbic acid, sorbic acid, and/or phytic acid. Other preservatives include, but are not limited to, tocopherol, tocopherol acetate, deteroxime mesylate, cetrimide, butylated hydroxyanisole (BHA), butylated hydroxytoluene (BHT), ethylenediamine, sodium lauryl sulfate (SLS), sodium lauryl ether sulfate (SLES), sodium bisulfite, sodium metabisulfite, potassium sulfite, potassium metabisulfite, GLYDANT PLUS®, PHENONIP®, methylparaben, GERMALL® 115, GERMABEN®II, NEOLONE™, KATHON™, and/or EUXYL®.

[00388] Examples of buffering agents include, but are not limited to, citrate buffer solutions, acetate buffer solutions, phosphate buffer solutions, ammonium chloride, calcium carbonate, calcium chloride, calcium citrate, calcium gluconate, calcium gluceptate, calcium gluconate, d-gluconic acid, calcium glycerophosphate, calcium lactate, calcium lactobionate, propanoic acid,

calcium levulinate, pentanoic acid, dibasic calcium phosphate, phosphoric acid, tribasic calcium phosphate, calcium hydroxide phosphate, potassium acetate, potassium chloride, potassium gluconate, potassium mixtures, dibasic potassium phosphate, monobasic potassium phosphate, potassium phosphate mixtures, sodium acetate, sodium bicarbonate, sodium chloride, sodium citrate, sodium lactate, dibasic sodium phosphate, monobasic sodium phosphate, sodium phosphate mixtures, tromethamine, amino-sulfonate buffers (*e.g.*, HEPES), magnesium hydroxide, aluminum hydroxide, alginic acid, pyrogen-free water, isotonic saline, Ringer's solution, ethyl alcohol, and/or combinations thereof. Lubricating agents may selected from the non-limiting group consisting of magnesium stearate, calcium stearate, stearic acid, silica, talc, malt, glyceryl behenate, hydrogenated vegetable oils, polyethylene glycol, sodium benzoate, sodium acetate, sodium chloride, leucine, magnesium lauryl sulfate, sodium lauryl sulfate, and combinations thereof.

[00389] Examples of oils include, but are not limited to, almond, apricot kernel, avocado, babassu, bergamot, black current seed, borage, cade, camomile, canola, caraway, carnauba, castor, cinnamon, cocoa butter, coconut, cod liver, coffee, corn, cotton seed, emu, eucalyptus, evening primrose, fish, flaxseed, geraniol, gourd, grape seed, hazel nut, hyssop, isopropyl myristate, jojoba, kukui nut, lavandin, lavender, lemon, litsea cubeba, macademia nut, mallow, mango seed, meadowfoam seed, mink, nutmeg, olive, orange, orange roughy, palm, palm kernel, peach kernel, peanut, poppy seed, pumpkin seed, rapeseed, rice bran, rosemary, safflower, sandalwood, sasquana, savoury, sea buckthorn, sesame, shea butter, silicone, soybean, sunflower, tea tree, thistle, tsubaki, vetiver, walnut, and wheat germ oils as well as butyl stearate, caprylic triglyceride, capric triglyceride, cyclomethicone, diethyl sebacate, dimethicone 360, simethicone, isopropyl myristate, mineral oil, octyldodecanol, oleyl alcohol, silicone oil, and/or combinations thereof.

Formulations

[00390] Nanoparticle compositions may include a lipid component and one or more additional components, such as a therapeutic and/or prophylactic. A nanoparticle composition may be designed for one or more specific applications or targets. The elements of a nanoparticle composition may be selected based on a particular application or target, and/or based on the efficacy, toxicity, expense, ease of use, availability, or other feature of one or more elements. Similarly, the particular formulation of a nanoparticle composition may be selected for a particular application or target according to, for example, the efficacy and toxicity of particular combinations of elements.

[00391] The lipid component of a nanoparticle composition may include, for example, a lipid according to Formula (I), (IA), (IB), (II), (IIa), (IIb), (IIc), (IId), (IIe), (IIf) or (IIg), a phospholipid (such as an unsaturated lipid, *e.g.*, DOPE or DSPC), a PEG lipid, and a structural lipid. The elements of the lipid component may be provided in specific fractions.

[00392] In some embodiments, the lipid component of a nanoparticle composition includes a lipid according to Formula (I), (IA), (IB), (II), (IIa), (IIb), (IIc), (IId), (IIe), (IIf) or (IIg), a phospholipid, a PEG lipid, and a structural lipid. In certain embodiments, the lipid component of the nanoparticle composition includes about 30 mol % to about 60 mol % compound of Formula (I), (IA), (IB), (II), (IIa), (IIb), (IIc), (IId), (IIe), (IIf) or (IIg), about 0 mol % to about 30 mol % phospholipid, about 18.5 mol % to about 48.5 mol % structural lipid, and about 0 mol % to about 10 mol % of PEG lipid, provided that the total mol % does not exceed 100%. In some embodiments, the lipid component of the nanoparticle composition includes about 35 mol % to about 55 mol % compound of Formula (I), (IA), (IB), (II), (IIa), (IIb), (IIc), (IId), (IIe), (IIf) or (IIg), about 5 mol % to about 25 mol % phospholipid, about 30 mol % to about 40 mol % structural lipid, and about 0 mol % to about 10 mol % of PEG lipid. In a particular embodiment, the lipid component includes about 50 mol % said compound, about 10 mol % phospholipid, about 38.5 mol % structural lipid, and about 1.5 mol % of PEG lipid. In another particular embodiment, the lipid component includes about 40 mol % said compound, about 20 mol % phospholipid, about 38.5 mol % structural lipid, and about 1.5 mol % of PEG lipid. In some embodiments, the lipid component of the nanoparticle composition includes about 45 mol % to about 65 mol % compound of Formula (I), (IA), (IB), (II), (IIa), (IIb), (IIc), (IId), (IIe), (IIf) or (IIg), about 5 mol % to about 10 mol % phospholipid, about 25 mol % to about 35 mol % structural lipid, and about 5 mol % to about 10 mol % of PEG lipid, provided that the total mol % does not exceed 100%. In some embodiments, the phospholipid may be DOPE or DSPC. In other embodiments, the PEG lipid may be PEG-DMG and/or the structural lipid may be cholesterol.

[00393] In some embodiments, the lipid component of a nanoparticle composition includes a cationic lipid, a phospholipid, a surfactant, and a cholesterol derivative. In certain embodiments, the lipid component of the nanoparticle composition includes about 30 mol % to about 60 mol % cationic lipid, about 0 mol % to about 30 mol % phospholipid, about 18.5 mol % to about 48.5 mol % surfactant, and about 0 mol % to about 10 mol % of cholesterol derivative, provided that the total mol % does not exceed 100%. In some embodiments, the lipid component of the nanoparticle

composition includes about 45 mol % to about 65 mol % cationic lipid, about 5 mol % to about 10 mol % phospholipid, about 25 mol % to about 35 mol % cholesterol derivative, and about 5 mol % to about 10 mol % of surfactant, provided that the total mol % does not exceed 100%.

[00394] Nanoparticle compositions may be designed for one or more specific applications or targets. For example, a nanoparticle composition may be designed to deliver a therapeutic and/or prophylactic such as an RNA to a particular cell, tissue, organ, or system or group thereof in a mammal's body. Physiochemical properties of nanoparticle compositions may be altered in order to increase selectivity for particular bodily targets. For instance, particle sizes may be adjusted based on the fenestration sizes of different organs. The therapeutic and/or prophylactic included in a nanoparticle composition may also be selected based on the desired delivery target or targets. For example, a therapeutic and/or prophylactic may be selected for a particular indication, condition, disease, or disorder and/or for delivery to a particular cell, tissue, organ, or system or group thereof (*e.g.*, localized or specific delivery). In certain embodiments, a nanoparticle composition may include an mRNA encoding a polypeptide of interest capable of being translated within a cell to produce the polypeptide of interest. Such a composition may be designed to be specifically delivered to a particular organ. In some embodiments, a composition may be designed to be specifically delivered to a mammalian liver.

[00395] The amount of a therapeutic and/or prophylactic in a nanoparticle composition may depend on the size, composition, desired target and/or application, or other properties of the nanoparticle composition as well as on the properties of the therapeutic and/or prophylactic. For example, the amount of an RNA useful in a nanoparticle composition may depend on the size, sequence, and other characteristics of the RNA. The relative amounts of a therapeutic and/or prophylactic and other elements (*e.g.*, lipids) in a nanoparticle composition may also vary. In some embodiments, the wt/wt ratio of the lipid component to a therapeutic and/or prophylactic in a nanoparticle composition may be from about 5:1 to about 60:1, such as 5:1, 6:1, 7:1, 8:1, 9:1, 10:1, 11:1, 12:1, 13:1, 14:1, 15:1, 16:1, 17:1, 18:1, 19:1, 20:1, 25:1, 30:1, 35:1, 40:1, 45:1, 50:1, and 60:1. For example, the wt/wt ratio of the lipid component to a therapeutic and/or prophylactic may be from about 10:1 to about 40:1. In certain embodiments, the wt/wt ratio is about 20:1. The amount of a therapeutic and/or prophylactic in a nanoparticle composition may, for example, be measured using absorption spectroscopy (*e.g.*, ultraviolet-visible spectroscopy).

[00396] In some embodiments, a nanoparticle composition includes one or more RNAs, and the one or more RNAs, lipids, and amounts thereof may be selected to provide a specific N:P ratio. The N:P ratio of the composition refers to the molar ratio of nitrogen atoms in one or more lipids to the number of phosphate groups in an RNA. In general, a lower N:P ratio is preferred. The one or more RNA, lipids, and amounts thereof may be selected to provide an N:P ratio from about 2:1 to about 30:1, such as 2:1, 3:1, 4:1, 5:1, 6:1, 7:1, 8:1, 9:1, 10:1, 12:1, 14:1, 16:1, 18:1, 20:1, 22:1, 24:1, 26:1, 28:1, or 30:1. In certain embodiments, the N:P ratio may be from about 2:1 to about 8:1. In other embodiments, the N:P ratio is from about 5:1 to about 8:1. For example, the N:P ratio may be about 5.0:1, about 5.5:1, about 5.67:1, about 6.0:1, about 6.5:1, or about 7.0:1. For example, the N:P ratio may be about 5.67:1.

Physical properties

[00397] The characteristics of a nanoparticle composition may depend on the components thereof. For example, a nanoparticle composition including cholesterol as a structural lipid may have different characteristics than a nanoparticle composition that includes a different structural lipid. Similarly, the characteristics of a nanoparticle composition may depend on the absolute or relative amounts of its components. For instance, a nanoparticle composition including a higher molar fraction of a phospholipid may have different characteristics than a nanoparticle composition including a lower molar fraction of a phospholipid. Characteristics may also vary depending on the method and conditions of preparation of the nanoparticle composition.

[00398] Nanoparticle compositions may be characterized by a variety of methods. For example, microscopy (*e.g.*, transmission electron microscopy or scanning electron microscopy) may be used to examine the morphology and size distribution of a nanoparticle composition. Dynamic light scattering or potentiometry (*e.g.*, potentiometric titrations) may be used to measure zeta potentials. Dynamic light scattering may also be utilized to determine particle sizes. Instruments such as the Zetasizer Nano ZS (Malvern Instruments Ltd, Malvern, Worcestershire, UK) may also be used to measure multiple characteristics of a nanoparticle composition, such as particle size, polydispersity index, and zeta potential.

[00399] The mean size of a nanoparticle composition may be between 10s of nm and 100s of nm, *e.g.*, measured by dynamic light scattering (DLS). For example, the mean size may be from about 40 nm to about 150 nm, such as about 40 nm, 45 nm, 50 nm, 55 nm, 60 nm, 65 nm, 70 nm, 75 nm, 80 nm, 85 nm, 90 nm, 95 nm, 100 nm, 105 nm, 110 nm, 115 nm, 120 nm, 125 nm, 130 nm, 135 nm,

140 nm, 145 nm, or 150 nm. In some embodiments, the mean size of a nanoparticle composition may be from about 50 nm to about 100 nm, from about 50 nm to about 90 nm, from about 50 nm to about 80 nm, from about 50 nm to about 70 nm, from about 50 nm to about 60 nm, from about 60 nm to about 100 nm, from about 60 nm to about 90 nm, from about 60 nm to about 80 nm, from about 60 nm to about 70 nm, from about 70 nm to about 150 nm, from about 70 nm to about 130 nm, from about 70 nm to about 100 nm, from about 70 nm to about 90 nm, from about 70 nm to about 80 nm, from about 80 nm to about 150 nm, from about 80 nm to about 130 nm, from about 80 nm to about 100 nm, from about 80 nm to about 90 nm, from about 90 nm to about 150 nm, from about 90 nm to about 130 nm, or from about 90 nm to about 100 nm. In certain embodiments, the mean size of a nanoparticle composition may be from about 70 nm to about 130 nm or from about 70 nm to about 100 nm. In a particular embodiment, the mean size may be about 80 nm. In other embodiments, the mean size may be about 100 nm. In other embodiments, the mean size may be about 120 nm.

[00400] A nanoparticle composition may be relatively homogenous. A polydispersity index may be used to indicate the homogeneity of a nanoparticle composition, *e.g.*, the particle size distribution of the nanoparticle compositions. A small (*e.g.*, less than 0.3) polydispersity index generally indicates a narrow particle size distribution. A nanoparticle composition may have a polydispersity index from about 0 to about 0.25, such as 0.01, 0.02, 0.03, 0.04, 0.05, 0.06, 0.07, 0.08, 0.09, 0.10, 0.11, 0.12, 0.13, 0.14, 0.15, 0.16, 0.17, 0.18, 0.19, 0.20, 0.21, 0.22, 0.23, 0.24, or 0.25. In some embodiments, the polydispersity index of a nanoparticle composition may be from about 0.10 to about 0.20.

[00401] The zeta potential of a nanoparticle composition may be used to indicate the electrokinetic potential of the composition. For example, the zeta potential may describe the surface charge of a nanoparticle composition. Nanoparticle compositions with relatively low charges, positive or negative, are generally desirable, as more highly charged species may interact undesirably with cells, tissues, and other elements in the body. In some embodiments, the zeta potential of a nanoparticle composition may be from about -10 mV to about +20 mV, from about -10 mV to about +15 mV, from about -10 mV to about +10 mV, from about -10 mV to about +5 mV, from about -10 mV to about 0 mV, from about -10 mV to about -5 mV, from about -5 mV to about +20 mV, from about -5 mV to about +15 mV, from about -5 mV to about +10 mV, from about -5 mV to about +5 mV, from about -5 mV to about 0 mV, from about 0 mV to about +20 mV, from

about 0 mV to about +15 mV, from about 0 mV to about +10 mV, from about 0 mV to about +5 mV, from about +5 mV to about +20 mV, from about +5 mV to about +15 mV, or from about +5 mV to about +10 mV.

[00402] The efficiency of encapsulation of a therapeutic and/or prophylactic describes the amount of therapeutic and/or prophylactic that is encapsulated or otherwise associated with a nanoparticle composition after preparation, relative to the initial amount provided. The encapsulation efficiency is desirably high (*e.g.*, close to 100%). The encapsulation efficiency may be measured, for example, by comparing the amount of therapeutic and/or prophylactic in a solution containing the nanoparticle composition before and after breaking up the nanoparticle composition with one or more organic solvents or detergents. Fluorescence may be used to measure the amount of free therapeutic and/or prophylactic (*e.g.*, RNA) in a solution. For the nanoparticle compositions described herein, the encapsulation efficiency of a therapeutic and/or prophylactic may be at least 50%, for example 50%, 55%, 60%, 65%, 70%, 75%, 80%, 85%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99%, or 100%. In some embodiments, the encapsulation efficiency may be at least 80%. In certain embodiments, the encapsulation efficiency may be at least 90%.

[00403] A nanoparticle composition may optionally comprise one or more coatings. For example, a nanoparticle composition may be formulated in a capsule, film, or tablet having a coating. A capsule, film, or tablet including a composition described herein may have any useful size, tensile strength, hardness, or density.

Pharmaceutical compositions

[00404] Nanoparticle compositions may be formulated in whole or in part as pharmaceutical compositions. Pharmaceutical compositions may include one or more nanoparticle compositions. For example, a pharmaceutical composition may include one or more nanoparticle compositions including one or more different therapeutic and/or prophylactics. Pharmaceutical compositions may further include one or more pharmaceutically acceptable excipients or accessory ingredients such as those described herein. General guidelines for the formulation and manufacture of pharmaceutical compositions and agents are available, for example, in Remington's *The Science and Practice of Pharmacy*, 21st Edition, A. R. Gennaro; Lippincott, Williams & Wilkins, Baltimore, MD, 2006. Conventional excipients and accessory ingredients may be used in any pharmaceutical composition, except insofar as any conventional excipient or accessory ingredient may be incompatible with one or more components of a nanoparticle composition. An excipient or accessory ingredient may be

incompatible with a component of a nanoparticle composition if its combination with the component may result in any undesirable biological effect or otherwise deleterious effect.

[00405] In some embodiments, one or more excipients or accessory ingredients may make up greater than 50% of the total mass or volume of a pharmaceutical composition including a nanoparticle composition. For example, the one or more excipients or accessory ingredients may make up 50%, 60%, 70%, 80%, 90%, or more of a pharmaceutical convention. In some embodiments, a pharmaceutically acceptable excipient is at least 95%, at least 96%, at least 97%, at least 98%, at least 99%, or 100% pure. In some embodiments, an excipient is approved for use in humans and for veterinary use. In some embodiments, an excipient is approved by United States Food and Drug Administration. In some embodiments, an excipient is pharmaceutical grade. In some embodiments, an excipient meets the standards of the United States Pharmacopoeia (USP), the European Pharmacopoeia (EP), the British Pharmacopoeia, and/or the International Pharmacopoeia.

[00406] Relative amounts of the one or more nanoparticle compositions, the one or more pharmaceutically acceptable excipients, and/or any additional ingredients in a pharmaceutical composition in accordance with the present disclosure will vary, depending upon the identity, size, and/or condition of the subject treated and further depending upon the route by which the composition is to be administered. By way of example, a pharmaceutical composition may comprise between 0.1% and 100% (wt/wt) of one or more nanoparticle compositions.

[00407] In certain embodiments, the nanoparticle compositions and/or pharmaceutical compositions of the disclosure are refrigerated or frozen for storage and/or shipment (e.g., being stored at a temperature of 4 °C or lower, such as a temperature between about -150 °C and about 0 °C or between about -80 °C and about -20 °C (e.g., about -5 °C, -10 °C, -15 °C, -20 °C, -25 °C, -30 °C, -40 °C, -50 °C, -60 °C, -70 °C, -80 °C, -90 °C, -130 °C or -150 °C). For example, the pharmaceutical composition comprising a compound of any of Formulae (I), (IA), (II), and (IIa)-(IIe) is a solution that is refrigerated for storage and/or shipment at, for example, about -20 °C, -30 °C, -40 °C, -50 °C, -60 °C, -70 °C, or -80 °C. In certain embodiments, the disclosure also relates to a method of increasing stability of the nanoparticle compositions and/or pharmaceutical compositions comprising a compound of any of Formulae (I), (IA), (II), and (IIa)-(IIe) by storing the nanoparticle compositions and/or pharmaceutical compositions at a temperature of 4 °C or lower, such as a temperature between about -150 °C and about 0 °C or between about -80 °C and

about -20 °C, e.g., about -5 °C, -10 °C, -15 °C, -20 °C, -25 °C, -30 °C, -40 °C, -50 °C, -60 °C, -70 °C, -80 °C, -90 °C, -130 °C or -150 °C). For example, the nanoparticle compositions and/or pharmaceutical compositions disclosed herein are stable for about at least 1 week, at least 2 weeks, at least 3 weeks, at least 4 weeks, at least 5 weeks, at least 6 weeks, at least 1 month, at least 2 months, at least 4 months, at least 6 months, at least 8 months, at least 10 months, at least 12 months, at least 14 months, at least 16 months, at least 18 months, at least 20 months, at least 22 months, or at least 24 months, e.g., at a temperature of 4 °C or lower (e.g., between about 4 °C and -20 °C). In one embodiment, the formulation is stabilized for at least 4 weeks at about 4 °C. In certain embodiments, the pharmaceutical composition of the disclosure comprises a nanoparticle composition disclosed herein and a pharmaceutically acceptable carrier selected from one or more of Tris, an acetate (e.g., sodium acetate), an citrate (e.g., sodium citrate), saline, PBS, and sucrose. In certain embodiments, the pharmaceutical composition of the disclosure has a pH value between about 7 and 8 (e.g., 6.8 6.9, 7.0, 7.1, 7.2, 7.3, 7.4, 7.5, 7.6, 7.7, 7.8, 7.9 or 8.0, or between 7.5 and 8 or between 7 and 7.8). For example, a pharmaceutical composition of the disclosure comprises a nanoparticle composition disclosed herein, Tris, saline and sucrose, and has a pH of about 7.5-8, which is suitable for storage and/or shipment at, for example, about -20 °C. For example, a pharmaceutical composition of the disclosure comprises a nanoparticle composition disclosed herein and PBS and has a pH of about 7-7.8, suitable for storage and/or shipment at, for example, about 4 °C or lower. “Stability,” “stabilized,” and “stable” in the context of the present disclosure refers to the resistance of nanoparticle compositions and/or pharmaceutical compositions disclosed herein to chemical or physical changes (e.g., degradation, particle size change, aggregation, change in encapsulation, etc.) under given manufacturing, preparation, transportation, storage and/or in-use conditions, e.g., when stress is applied such as shear force, freeze/thaw stress, etc.

[00408] Nanoparticle compositions and/or pharmaceutical compositions including one or more nanoparticle compositions may be administered to any patient or subject, including those patients or subjects that may benefit from a therapeutic effect provided by the delivery of a therapeutic and/or prophylactic to one or more particular cells, tissues, organs, or systems or groups thereof, such as the renal system. Although the descriptions provided herein of nanoparticle compositions and pharmaceutical compositions including nanoparticle compositions are principally directed to compositions which are suitable for administration to humans, it will be understood by the skilled artisan that such compositions are generally suitable for administration to any other mammal.

Modification of compositions suitable for administration to humans in order to render the compositions suitable for administration to various animals is well understood, and the ordinarily skilled veterinary pharmacologist can design and/or perform such modification with merely ordinary, if any, experimentation. Subjects to which administration of the compositions is contemplated include, but are not limited to, humans, other primates, and other mammals, including commercially relevant mammals such as cattle, pigs, horses, sheep, cats, dogs, mice, and/or rats.

[00409] A pharmaceutical composition including one or more nanoparticle compositions may be prepared by any method known or hereafter developed in the art of pharmacology. In general, such preparatory methods include bringing the active ingredient into association with an excipient and/or one or more other accessory ingredients, and then, if desirable or necessary, dividing, shaping, and/or packaging the product into a desired single- or multi-dose unit.

[00410] A pharmaceutical composition in accordance with the present disclosure may be prepared, packaged, and/or sold in bulk, as a single unit dose, and/or as a plurality of single unit doses. As used herein, a “unit dose” is discrete amount of the pharmaceutical composition comprising a predetermined amount of the active ingredient (*e.g.*, nanoparticle composition). The amount of the active ingredient is generally equal to the dosage of the active ingredient which would be administered to a subject and/or a convenient fraction of such a dosage such as, for example, one-half or one-third of such a dosage.

[00411] Pharmaceutical compositions may be prepared in a variety of forms suitable for a variety of routes and methods of administration. For example, pharmaceutical compositions may be prepared in liquid dosage forms (*e.g.*, emulsions, microemulsions, nanoemulsions, solutions, suspensions, syrups, and elixirs), injectable forms, solid dosage forms (*e.g.*, capsules, tablets, pills, powders, and granules), dosage forms for topical and/or transdermal administration (*e.g.*, ointments, pastes, creams, lotions, gels, powders, solutions, sprays, inhalants, and patches), suspensions, powders, and other forms.

[00412] Liquid dosage forms for oral and parenteral administration include, but are not limited to, pharmaceutically acceptable emulsions, microemulsions, nanoemulsions, solutions, suspensions, syrups, and/or elixirs. In addition to active ingredients, liquid dosage forms may comprise inert diluents commonly used in the art such as, for example, water or other solvents, solubilizing agents and emulsifiers such as ethyl alcohol, isopropyl alcohol, ethyl carbonate, ethyl acetate, benzyl alcohol, benzyl benzoate, propylene glycol, 1,3-butylene glycol, dimethylformamide, oils (in

particular, cottonseed, groundnut, corn, germ, olive, castor, and sesame oils), glycerol, tetrahydrofurfuryl alcohol, polyethylene glycols and fatty acid esters of sorbitan, and mixtures thereof. Besides inert diluents, oral compositions can include additional therapeutic and/or prophylactics, additional agents such as wetting agents, emulsifying and suspending agents, sweetening, flavoring, and/or perfuming agents. In certain embodiments for parenteral administration, compositions are mixed with solubilizing agents such as Cremophor[®], alcohols, oils, modified oils, glycols, polysorbates, cyclodextrins, polymers, and/or combinations thereof.

[00413] Injectable preparations, for example, sterile injectable aqueous or oleaginous suspensions may be formulated according to the known art using suitable dispersing agents, wetting agents, and/or suspending agents. Sterile injectable preparations may be sterile injectable solutions, suspensions, and/or emulsions in nontoxic parenterally acceptable diluents and/or solvents, for example, as a solution in 1,3-butanediol. Among the acceptable vehicles and solvents that may be employed are water, Ringer's solution, U.S.P., and isotonic sodium chloride solution. Sterile, fixed oils are conventionally employed as a solvent or suspending medium. For this purpose any bland fixed oil can be employed including synthetic mono- or diglycerides. Fatty acids such as oleic acid can be used in the preparation of injectables.

[00414] Injectable formulations can be sterilized, for example, by filtration through a bacterial-retaining filter, and/or by incorporating sterilizing agents in the form of sterile solid compositions which can be dissolved or dispersed in sterile water or other sterile injectable medium prior to use.

[00415] In order to prolong the effect of an active ingredient, it is often desirable to slow the absorption of the active ingredient from subcutaneous or intramuscular injection. This may be accomplished by the use of a liquid suspension of crystalline or amorphous material with poor water solubility. The rate of absorption of the drug then depends upon its rate of dissolution which, in turn, may depend upon crystal size and crystalline form. Alternatively, delayed absorption of a parenterally administered drug form is accomplished by dissolving or suspending the drug in an oil vehicle. Injectable depot forms are made by forming microencapsulated matrices of the drug in biodegradable polymers such as polylactide-polyglycolide. Depending upon the ratio of drug to polymer and the nature of the particular polymer employed, the rate of drug release can be controlled. Examples of other biodegradable polymers include poly(orthoesters) and poly(anhydrides). Depot injectable formulations are prepared by entrapping the drug in liposomes or microemulsions which are compatible with body tissues.

[00416] Compositions for rectal or vaginal administration are typically suppositories which can be prepared by mixing compositions with suitable non-irritating excipients such as cocoa butter, polyethylene glycol or a suppository wax which are solid at ambient temperature but liquid at body temperature and therefore melt in the rectum or vaginal cavity and release the active ingredient.

[00417] Solid dosage forms for oral administration include capsules, tablets, pills, films, powders, and granules. In such solid dosage forms, an active ingredient is mixed with at least one inert, pharmaceutically acceptable excipient such as sodium citrate or dicalcium phosphate and/or fillers or extenders (*e.g.* starches, lactose, sucrose, glucose, mannitol, and silicic acid), binders (*e.g.*, carboxymethylcellulose, alginates, gelatin, polyvinylpyrrolidone, sucrose, and acacia), humectants (*e.g.*, glycerol), disintegrating agents (*e.g.*, agar, calcium carbonate, potato or tapioca starch, alginic acid, certain silicates, and sodium carbonate), solution retarding agents (*e.g.*, paraffin), absorption accelerators (*e.g.*, quaternary ammonium compounds), wetting agents (*e.g.*, cetyl alcohol and glycerol monostearate), absorbents (*e.g.*, kaolin and bentonite clay, silicates), and lubricants (*e.g.*, talc, calcium stearate, magnesium stearate, solid polyethylene glycols, sodium lauryl sulfate), and mixtures thereof. In the case of capsules, tablets and pills, the dosage form may comprise buffering agents.

[00418] Solid compositions of a similar type may be employed as fillers in soft and hard-filled gelatin capsules using such excipients as lactose or milk sugar as well as high molecular weight polyethylene glycols and the like. Solid dosage forms of tablets, dragees, capsules, pills, and granules can be prepared with coatings and shells such as enteric coatings and other coatings well known in the pharmaceutical formulating art. They may optionally comprise opacifying agents and can be of a composition that they release the active ingredient(s) only, or preferentially, in a certain part of the intestinal tract, optionally, in a delayed manner. Examples of embedding compositions which can be used include polymeric substances and waxes. Solid compositions of a similar type may be employed as fillers in soft and hard-filled gelatin capsules using such excipients as lactose or milk sugar as well as high molecular weight polyethylene glycols and the like.

[00419] Dosage forms for topical and/or transdermal administration of a composition may include ointments, pastes, creams, lotions, gels, powders, solutions, sprays, inhalants, and/or patches. Generally, an active ingredient is admixed under sterile conditions with a pharmaceutically acceptable excipient and/or any needed preservatives and/or buffers as may be required.

Additionally, the present disclosure contemplates the use of transdermal patches, which often have

the added advantage of providing controlled delivery of a compound to the body. Such dosage forms may be prepared, for example, by dissolving and/or dispensing the compound in the proper medium. Alternatively or additionally, rate may be controlled by either providing a rate controlling membrane and/or by dispersing the compound in a polymer matrix and/or gel.

[00420] Suitable devices for use in delivering intradermal pharmaceutical compositions described herein include short needle devices such as those described in U.S. Patents 4,886,499; 5,190,521; 5,328,483; 5,527,288; 4,270,537; 5,015,235; 5,141,496; and 5,417,662. Intradermal compositions may be administered by devices which limit the effective penetration length of a needle into the skin, such as those described in PCT publication WO 99/34850 and functional equivalents thereof. Jet injection devices which deliver liquid compositions to the dermis via a liquid jet injector and/or via a needle which pierces the stratum corneum and produces a jet which reaches the dermis are suitable. Jet injection devices are described, for example, in U.S. Patents 5,480,381; 5,599,302; 5,334,144; 5,993,412; 5,649,912; 5,569,189; 5,704,911; 5,383,851; 5,893,397; 5,466,220; 5,339,163; 5,312,335; 5,503,627; 5,064,413; 5,520,639; 4,596,556; 4,790,824; 4,941,880; 4,940,460; and PCT publications WO 97/37705 and WO 97/13537. Ballistic powder/particle delivery devices which use compressed gas to accelerate vaccine in powder form through the outer layers of the skin to the dermis are suitable. Alternatively or additionally, conventional syringes may be used in the classical mantoux method of intradermal administration.

[00421] Formulations suitable for topical administration include, but are not limited to, liquid and/or semi liquid preparations such as liniments, lotions, oil in water and/or water in oil emulsions such as creams, ointments and/or pastes, and/or solutions and/or suspensions. Topically-administrable formulations may, for example, comprise from about 1% to about 10% (wt/wt) active ingredient, although the concentration of active ingredient may be as high as the solubility limit of the active ingredient in the solvent. Formulations for topical administration may further comprise one or more of the additional ingredients described herein.

[00422] A pharmaceutical composition may be prepared, packaged, and/or sold in a formulation suitable for pulmonary administration via the buccal cavity. Such a formulation may comprise dry particles which comprise the active ingredient. Such compositions are conveniently in the form of dry powders for administration using a device comprising a dry powder reservoir to which a stream of propellant may be directed to disperse the powder and/or using a self-propelling solvent/powder dispensing container such as a device comprising the active ingredient dissolved and/or suspended

in a low-boiling propellant in a sealed container. Dry powder compositions may include a solid fine powder diluent such as sugar and are conveniently provided in a unit dose form.

[00423] Low boiling propellants generally include liquid propellants having a boiling point of below 65 °F at atmospheric pressure. Generally the propellant may constitute 50% to 99.9% (wt/wt) of the composition, and active ingredient may constitute 0.1% to 20% (wt/wt) of the composition. A propellant may further comprise additional ingredients such as a liquid non-ionic and/or solid anionic surfactant and/or a solid diluent (which may have a particle size of the same order as particles comprising the active ingredient).

[00424] Pharmaceutical compositions formulated for pulmonary delivery may provide an active ingredient in the form of droplets of a solution and/or suspension. Such formulations may be prepared, packaged, and/or sold as aqueous and/or dilute alcoholic solutions and/or suspensions, optionally sterile, comprising active ingredient, and may conveniently be administered using any nebulization and/or atomization device. Such formulations may further comprise one or more additional ingredients including, but not limited to, a flavoring agent such as saccharin sodium, a volatile oil, a buffering agent, a surface active agent, and/or a preservative such as methylhydroxybenzoate. Droplets provided by this route of administration may have an average diameter in the range from about 1 nm to about 200 nm.

[00425] Formulations described herein as being useful for pulmonary delivery are useful for intranasal delivery of a pharmaceutical composition. Another formulation suitable for intranasal administration is a coarse powder comprising the active ingredient and having an average particle from about 0.2 μm to 500 μm. Such a formulation is administered in the manner in which snuff is taken, i.e. by rapid inhalation through the nasal passage from a container of the powder held close to the nose.

[00426] Formulations suitable for nasal administration may, for example, comprise from about as little as 0.1% (wt/wt) and as much as 100% (wt/wt) of active ingredient, and may comprise one or more of the additional ingredients described herein. A pharmaceutical composition may be prepared, packaged, and/or sold in a formulation suitable for buccal administration. Such formulations may, for example, be in the form of tablets and/or lozenges made using conventional methods, and may, for example, 0.1% to 20% (wt/wt) active ingredient, the balance comprising an orally dissolvable and/or degradable composition and, optionally, one or more of the additional ingredients described herein. Alternately, formulations suitable for buccal administration may

comprise a powder and/or an aerosolized and/or atomized solution and/or suspension comprising active ingredient. Such powdered, aerosolized, and/or aerosolized formulations, when dispersed, may have an average particle and/or droplet size in the range from about 0.1 nm to about 200 nm, and may further comprise one or more of any additional ingredients described herein.

[00427] A pharmaceutical composition may be prepared, packaged, and/or sold in a formulation suitable for ophthalmic administration. Such formulations may, for example, be in the form of eye drops including, for example, a 0.1/1.0% (wt/wt) solution and/or suspension of the active ingredient in an aqueous or oily liquid excipient. Such drops may further comprise buffering agents, salts, and/or one or more other of any additional ingredients described herein. Other ophthalmically-administrable formulations which are useful include those which comprise the active ingredient in microcrystalline form and/or in a liposomal preparation. Ear drops and/or eye drops are contemplated as being within the scope of this present disclosure.

Methods of producing polypeptides in cells

[00428] The present disclosure provides methods of producing a polypeptide of interest in a mammalian cell. Methods of producing polypeptides involve contacting a cell with a nanoparticle composition including an mRNA encoding the polypeptide of interest. Upon contacting the cell with the nanoparticle composition, the mRNA may be taken up and translated in the cell to produce the polypeptide of interest.

[00429] In general, the step of contacting a mammalian cell with a nanoparticle composition including an mRNA encoding a polypeptide of interest may be performed *in vivo*, *ex vivo*, in culture, or *in vitro*. The amount of nanoparticle composition contacted with a cell, and/or the amount of mRNA therein, may depend on the type of cell or tissue being contacted, the means of administration, the physiochemical characteristics of the nanoparticle composition and the mRNA (*e.g.*, size, charge, and chemical composition) therein, and other factors. In general, an effective amount of the nanoparticle composition will allow for efficient polypeptide production in the cell. Metrics for efficiency may include polypeptide translation (indicated by polypeptide expression), level of mRNA degradation, and immune response indicators.

[00430] The step of contacting a nanoparticle composition including an mRNA with a cell may involve or cause transfection. A phospholipid including in the lipid component of a nanoparticle composition may facilitate transfection and/or increase transfection efficiency, for example, by

interacting and/or fusing with a cellular or intracellular membrane. Transfection may allow for the translation of the mRNA within the cell.

[00431] In some embodiments, the nanoparticle compositions described herein may be used therapeutically. For example, an mRNA included in a nanoparticle composition may encode a therapeutic polypeptide (*e.g.*, in a translatable region) and produce the therapeutic polypeptide upon contacting and/or entry (*e.g.*, transfection) into a cell. In other embodiments, an mRNA included in a nanoparticle composition may encode a polypeptide that may improve or increase the immunity of a subject. For example, an mRNA may encode a granulocyte-colony stimulating factor or trastuzumab.

[00432] In certain embodiments, an mRNA included in a nanoparticle composition may encode a recombinant polypeptide that may replace one or more polypeptides that may be substantially absent in a cell contacted with the nanoparticle composition. The one or more substantially absent polypeptides may be lacking due to a genetic mutation of the encoding gene or a regulatory pathway thereof. Alternatively, a recombinant polypeptide produced by translation of the mRNA may antagonize the activity of an endogenous protein present in, on the surface of, or secreted from the cell. An antagonistic recombinant polypeptide may be desirable to combat deleterious effects caused by activities of the endogenous protein, such as altered activities or localization caused by mutation. In another alternative, a recombinant polypeptide produced by translation of the mRNA may indirectly or directly antagonize the activity of a biological moiety present in, on the surface of, or secreted from the cell. Antagonized biological moieties may include, but are not limited to, lipids (*e.g.*, cholesterol), lipoproteins (*e.g.*, low density lipoprotein), nucleic acids, carbohydrates, and small molecule toxins. Recombinant polypeptides produced by translation of the mRNA may be engineered for localization within the cell, such as within a specific compartment such as the nucleus, or may be engineered for secretion from the cell or for translocation to the plasma membrane of the cell.

[00433] In some embodiments, contacting a cell with a nanoparticle composition including an mRNA may reduce the innate immune response of a cell to an exogenous nucleic acid. A cell may be contacted with a first nanoparticle composition including a first amount of a first exogenous mRNA including a translatable region and the level of the innate immune response of the cell to the first exogenous mRNA may be determined. Subsequently, the cell may be contacted with a second composition including a second amount of the first exogenous mRNA, the second amount being a

lesser amount of the first exogenous mRNA compared to the first amount. Alternatively, the second composition may include a first amount of a second exogenous mRNA that is different from the first exogenous mRNA. The steps of contacting the cell with the first and second compositions may be repeated one or more times. Additionally, efficiency of polypeptide production (*e.g.*, translation) in the cell may be optionally determined, and the cell may be re-contacted with the first and/or second composition repeatedly until a target protein production efficiency is achieved.

Methods of delivering therapeutic agents to cells and organs

[00434] The present disclosure provides methods of delivering a therapeutic and/or prophylactic to a mammalian cell or organ. Delivery of a therapeutic and/or prophylactic to a cell involves administering a nanoparticle composition including the therapeutic and/or prophylactic to a subject, where administration of the composition involves contacting the cell with the composition. For example, a protein, cytotoxic agent, radioactive ion, chemotherapeutic agent, or nucleic acid (such as an RNA, *e.g.*, mRNA) may be delivered to a cell or organ. In the instance that a therapeutic and/or prophylactic is an mRNA, upon contacting a cell with the nanoparticle composition, a translatable mRNA may be translated in the cell to produce a polypeptide of interest. However, mRNAs that are substantially not translatable may also be delivered to cells. Substantially non-translatable mRNAs may be useful as vaccines and/or may sequester translational components of a cell to reduce expression of other species in the cell.

[00435] In some embodiments, a nanoparticle composition may target a particular type or class of cells (*e.g.*, cells of a particular organ or system thereof). For example, a nanoparticle composition including a therapeutic and/or prophylactic of interest may be specifically delivered to a mammalian liver, kidney, spleen, femur, or lung. Specific delivery to a particular class of cells, an organ, or a system or group thereof implies that a higher proportion of nanoparticle compositions including a therapeutic and/or prophylactic are delivered to the destination (*e.g.*, tissue) of interest relative to other destinations, *e.g.*, upon administration of a nanoparticle composition to a mammal. In some embodiments, specific delivery may result in a greater than 2 fold, 5 fold, 10 fold, 15 fold, or 20 fold increase in the amount of therapeutic and/or prophylactic per 1 g of tissue of the targeted destination (*e.g.*, tissue of interest, such as a liver) as compared to another destination (*e.g.*, the spleen). In some embodiments, the tissue of interest is selected from the group consisting of a liver, kidney, a lung, a spleen, a femur, an ocular tissue (*e.g.*, via intraocular, subretinal, or intravitreal

injection), vascular endothelium in vessels (*e.g.*, intra-coronary or intra-femoral) or kidney, and tumor tissue (*e.g.*, via intratumoral injection).

[00436] As another example of targeted or specific delivery, an mRNA that encodes a protein-binding partner (*e.g.*, an antibody or functional fragment thereof, a scaffold protein, or a peptide) or a receptor on a cell surface may be included in a nanoparticle composition. An mRNA may additionally or instead be used to direct the synthesis and extracellular localization of lipids, carbohydrates, or other biological moieties. Alternatively, other therapeutic and/or prophylactics or elements (*e.g.*, lipids or ligands) of a nanoparticle composition may be selected based on their affinity for particular receptors (*e.g.*, low density lipoprotein receptors) such that a nanoparticle composition may more readily interact with a target cell population including the receptors. For example, ligands may include, but are not limited to, members of a specific binding pair, antibodies, monoclonal antibodies, Fv fragments, single chain Fv (scFv) fragments, Fab' fragments, F(ab')₂ fragments, single domain antibodies, camelized antibodies and fragments thereof, humanized antibodies and fragments thereof, and multivalent versions thereof; multivalent binding reagents including mono- or bi-specific antibodies such as disulfide stabilized Fv fragments, scFv tandems, diabodies, tribodies, or tetrabodies; and aptamers, receptors, and fusion proteins.

[00437] In some embodiments, a ligand may be a surface-bound antibody, which can permit tuning of cell targeting specificity. This is especially useful since highly specific antibodies can be raised against an epitope of interest for the desired targeting site. In one embodiment, multiple antibodies are expressed on the surface of a cell, and each antibody can have a different specificity for a desired target. Such approaches can increase the avidity and specificity of targeting interactions.

[00438] A ligand can be selected, *e.g.*, by a person skilled in the biological arts, based on the desired localization or function of the cell. For example an estrogen receptor ligand, such as tamoxifen, can target cells to estrogen-dependent breast cancer cells that have an increased number of estrogen receptors on the cell surface. Other non-limiting examples of ligand/receptor interactions include CCR1 (*e.g.*, for treatment of inflamed joint tissues or brain in rheumatoid arthritis, and/or multiple sclerosis), CCR7, CCR8 (*e.g.*, targeting to lymph node tissue), CCR6, CCR9, CCR10 (*e.g.*, to target to intestinal tissue), CCR4, CCR10 (*e.g.*, for targeting to skin), CXCR4 (*e.g.*, for general enhanced transmigration), HCELL (*e.g.*, for treatment of inflammation and inflammatory disorders, bone marrow), Alpha4beta7 (*e.g.*, for intestinal mucosa targeting), and

VLA-4NCAM-1 (*e.g.*, targeting to endothelium). In general, any receptor involved in targeting (*e.g.*, cancer metastasis) can be harnessed for use in the methods and compositions described herein.

[00439] Targeted cells may include, but are not limited to, hepatocytes, epithelial cells, hematopoietic cells, epithelial cells, endothelial cells, lung cells, bone cells, stem cells, mesenchymal cells, neural cells, cardiac cells, adipocytes, vascular smooth muscle cells, cardiomyocytes, skeletal muscle cells, beta cells, pituitary cells, synovial lining cells, ovarian cells, testicular cells, fibroblasts, B cells, T cells, reticulocytes, leukocytes, granulocytes, and tumor cells.

[00440] In some embodiments, a nanoparticle composition may target hepatocytes. Apolipoproteins such as apolipoprotein E (apoE) have been shown to associate with neutral or near neutral lipid-containing nanoparticle compositions in the body, and are known to associate with receptors such as low-density lipoprotein receptors (LDLRs) found on the surface of hepatocytes. Thus, a nanoparticle composition including a lipid component with a neutral or near neutral charge that is administered to a subject may acquire apoE in a subject's body and may subsequently deliver a therapeutic and/or prophylactic (*e.g.*, an RNA) to hepatocytes including LDLRs in a targeted manner.

Methods of treating diseases and disorders

[00441] Nanoparticle compositions may be useful for treating a disease, disorder, or condition. In particular, such compositions may be useful in treating a disease, disorder, or condition characterized by missing or aberrant protein or polypeptide activity. For example, a nanoparticle composition comprising an mRNA encoding a missing or aberrant polypeptide may be administered or delivered to a cell. Subsequent translation of the mRNA may produce the polypeptide, thereby reducing or eliminating an issue caused by the absence of or aberrant activity caused by the polypeptide. Because translation may occur rapidly, the methods and compositions may be useful in the treatment of acute diseases, disorders, or conditions such as sepsis, stroke, and myocardial infarction. A therapeutic and/or prophylactic included in a nanoparticle composition may also be capable of altering the rate of transcription of a given species, thereby affecting gene expression.

[00442] Diseases, disorders, and/or conditions characterized by dysfunctional or aberrant protein or polypeptide activity for which a composition may be administered include, but are not limited to, rare diseases, infectious diseases (as both vaccines and therapeutics), cancer and proliferative diseases, genetic diseases (*e.g.*, cystic fibrosis), autoimmune diseases, diabetes, neurodegenerative diseases, cardio- and reno-vascular diseases, lysosomal storage disorders and metabolic diseases.

Multiple diseases, disorders, and/or conditions may be characterized by missing (or substantially diminished such that proper protein function does not occur) protein activity. Such proteins may not be present, or they may be essentially non-functional. A specific example of a dysfunctional protein is the missense mutation variants of the cystic fibrosis transmembrane conductance regulator (CFTR) gene, which produce a dysfunctional protein variant of CFTR protein, which causes cystic fibrosis. The present disclosure provides a method for treating such diseases, disorders, and/or conditions in a subject by administering a nanoparticle composition including an RNA and a lipid component including a lipid according to Formula (I), a phospholipid (optionally unsaturated), a PEG lipid, and a structural lipid, wherein the RNA may be an mRNA encoding a polypeptide that antagonizes or otherwise overcomes an aberrant protein activity present in the cell of the subject.

[00443] The disclosure provides methods involving administering nanoparticle compositions including one or more therapeutic and/or prophylactic agents and pharmaceutical compositions including the same. The terms therapeutic and prophylactic can be used interchangeably herein with respect to features and embodiments of the present disclosure. Therapeutic compositions, or imaging, diagnostic, or prophylactic compositions thereof, may be administered to a subject using any reasonable amount and any route of administration effective for preventing, treating, diagnosing, or imaging a disease, disorder, and/or condition and/or any other purpose. The specific amount administered to a given subject may vary depending on the species, age, and general condition of the subject; the purpose of the administration; the particular composition; the mode of administration; and the like. Compositions in accordance with the present disclosure may be formulated in dosage unit form for ease of administration and uniformity of dosage. It will be understood, however, that the total daily usage of a composition of the present disclosure will be decided by an attending physician within the scope of sound medical judgment. The specific therapeutically effective, prophylactically effective, or otherwise appropriate dose level (*e.g.*, for imaging) for any particular patient will depend upon a variety of factors including the severity and identify of a disorder being treated, if any; the one or more therapeutic and/or prophylactics employed; the specific composition employed; the age, body weight, general health, sex, and diet of the patient; the time of administration, route of administration, and rate of excretion of the specific pharmaceutical composition employed; the duration of the treatment; drugs used in combination or

coincidental with the specific pharmaceutical composition employed; and like factors well known in the medical arts.

[00444] A nanoparticle composition including one or more therapeutic and/or prophylactics may be administered by any route. In some embodiments, compositions, including prophylactic, diagnostic, or imaging compositions including one or more nanoparticle compositions described herein, are administered by one or more of a variety of routes, including oral, intravenous, intramuscular, intra-arterial, intramedullary, intrathecal, intraparenchymal, subcutaneous, intraventricular, trans- or intra-dermal, interdermal, rectal, intravaginal, intraperitoneal, intraocular, subretinal, intravitreal, topical (*e.g.* by powders, ointments, creams, gels, lotions, and/or drops), mucosal, nasal, buccal, enteral, vitreal, intratumoral, sublingual, intranasal; by intratracheal instillation, bronchial instillation, and/or inhalation; as an oral spray and/or powder, nasal spray, and/or aerosol, and/or through a portal vein catheter. In some embodiments, a composition may be administered intravenously, intramuscularly, intradermally, intra-arterially, intratumorally, subcutaneously, intraocularly, subretinally, intravitreally, intraparenchymally or by any other parenteral route of administration or by inhalation. However, the present disclosure encompasses the delivery or administration of compositions described herein by any appropriate route taking into consideration likely advances in the sciences of drug delivery. In general, the most appropriate route of administration will depend upon a variety of factors including the nature of the nanoparticle composition including one or more therapeutic and/or prophylactics (*e.g.*, its stability in various bodily environments such as the bloodstream and gastrointestinal tract), the condition of the patient (*e.g.*, whether the patient is able to tolerate particular routes of administration), etc.

[00445] In certain embodiments, compositions in accordance with the present disclosure may be administered at dosage levels sufficient to deliver from about 0.0001 mg/kg to about 10 mg/kg, from about 0.001 mg/kg to about 10 mg/kg, from about 0.005 mg/kg to about 10 mg/kg, from about 0.01 mg/kg to about 10 mg/kg, from about 0.05 mg/kg to about 10 mg/kg, from about 0.1 mg/kg to about 10 mg/kg, from about 1 mg/kg to about 10 mg/kg, from about 2 mg/kg to about 10 mg/kg, from about 5 mg/kg to about 10 mg/kg, from about 0.0001 mg/kg to about 5 mg/kg, from about 0.001 mg/kg to about 5 mg/kg, from about 0.005 mg/kg to about 5 mg/kg, from about 0.01 mg/kg to about 5 mg/kg, from about 0.05 mg/kg to about 5 mg/kg, from about 0.1 mg/kg to about 5 mg/kg, from about 1 mg/kg to about 5 mg/kg, from about 2 mg/kg to about 5 mg/kg, from about 0.0001 mg/kg to about 2.5 mg/kg, from about 0.001 mg/kg to about 2.5 mg/kg, from about 0.005 mg/kg to

about 2.5 mg/kg, from about 0.01 mg/kg to about 2.5 mg/kg, from about 0.05 mg/kg to about 2.5 mg/kg, from about 0.1 mg/kg to about 2.5 mg/kg, from about 1 mg/kg to about 2.5 mg/kg, from about 2 mg/kg to about 2.5 mg/kg, from about 0.0001 mg/kg to about 1 mg/kg, from about 0.001 mg/kg to about 1 mg/kg, from about 0.005 mg/kg to about 1 mg/kg, from about 0.01 mg/kg to about 1 mg/kg, from about 0.05 mg/kg to about 1 mg/kg, from about 0.1 mg/kg to about 1 mg/kg, from about 0.0001 mg/kg to about 0.25 mg/kg, from about 0.001 mg/kg to about 0.25 mg/kg, from about 0.005 mg/kg to about 0.25 mg/kg, from about 0.01 mg/kg to about 0.25 mg/kg, from about 0.05 mg/kg to about 0.25 mg/kg, or from about 0.1 mg/kg to about 0.25 mg/kg of a therapeutic and/or prophylactic (*e.g.*, an mRNA) in a given dose, where a dose of 1 mg/kg (mpk) provides 1 mg of a therapeutic and/or prophylactic per 1 kg of subject body weight. In some embodiments, a dose of about 0.001 mg/kg to about 10 mg/kg of a therapeutic and/or prophylactic (*e.g.*, mRNA) of a nanoparticle composition may be administered. In other embodiments, a dose of about 0.005 mg/kg to about 2.5 mg/kg of a therapeutic and/or prophylactic may be administered. In certain embodiments, a dose of about 0.1 mg/kg to about 1 mg/kg may be administered. In other embodiments, a dose of about 0.05 mg/kg to about 0.25 mg/kg may be administered. A dose may be administered one or more times per day, in the same or a different amount, to obtain a desired level of mRNA expression and/or therapeutic, diagnostic, prophylactic, or imaging effect. The desired dosage may be delivered, for example, three times a day, two times a day, once a day, every other day, every third day, every week, every two weeks, every three weeks, or every four weeks. In certain embodiments, the desired dosage may be delivered using multiple administrations (*e.g.*, two, three, four, five, six, seven, eight, nine, ten, eleven, twelve, thirteen, fourteen, or more administrations). In some embodiments, a single dose may be administered, for example, prior to or after a surgical procedure or in the instance of an acute disease, disorder, or condition.

[00446] Nanoparticle compositions including one or more therapeutic and/or prophylactics may be used in combination with one or more other therapeutic, prophylactic, diagnostic, or imaging agents. By “in combination with,” it is not intended to imply that the agents must be administered at the same time and/or formulated for delivery together, although these methods of delivery are within the scope of the present disclosure. For example, one or more nanoparticle compositions including one or more different therapeutic and/or prophylactics may be administered in combination. Compositions can be administered concurrently with, prior to, or subsequent to, one or more other desired therapeutics or medical procedures. In general, each agent will be

administered at a dose and/or on a time schedule determined for that agent. In some embodiments, the present disclosure encompasses the delivery of compositions, or imaging, diagnostic, or prophylactic compositions thereof in combination with agents that improve their bioavailability, reduce and/or modify their metabolism, inhibit their excretion, and/or modify their distribution within the body.

[00447] It will further be appreciated that therapeutically, prophylactically, diagnostically, or imaging active agents utilized in combination may be administered together in a single composition or administered separately in different compositions. In general, it is expected that agents utilized in combination will be utilized at levels that do not exceed the levels at which they are utilized individually. In some embodiments, the levels utilized in combination may be lower than those utilized individually.

[00448] The particular combination of therapies (therapeutics or procedures) to employ in a combination regimen will take into account compatibility of the desired therapeutics and/or procedures and the desired therapeutic effect to be achieved. It will also be appreciated that the therapies employed may achieve a desired effect for the same disorder (for example, a composition useful for treating cancer may be administered concurrently with a chemotherapeutic agent), or they may achieve different effects (*e.g.*, control of any adverse effects, such as infusion related reactions).

[00449] A nanoparticle composition may be used in combination with an agent to increase the effectiveness and/or therapeutic window of the composition. Such an agent may be, for example, an anti-inflammatory compound, a steroid (*e.g.*, a corticosteroid), a statin, an estradiol, a BTK inhibitor, an S1P1 agonist, a glucocorticoid receptor modulator (GRM), or an anti-histamine. In some embodiments, a nanoparticle composition may be used in combination with dexamethasone, methotrexate, acetaminophen, an H1 receptor blocker, or an H2 receptor blocker. In some embodiments, a method of treating a subject in need thereof or of delivering a therapeutic and/or prophylactic to a subject (*e.g.*, a mammal) may involve pre-treating the subject with one or more agents prior to administering a nanoparticle composition. For example, a subject may be pre-treated with a useful amount (*e.g.*, 10 mg, 20 mg, 30 mg, 40 mg, 50 mg, 60 mg, 70 mg, 80 mg, 90 mg, 100 mg, or any other useful amount) of dexamethasone, methotrexate, acetaminophen, an H1 receptor blocker, or an H2 receptor blocker. Pre-treatment may occur 24 or fewer hours (*e.g.*, 24 hours, 20 hours, 16 hours, 12 hours, 8 hours, 4 hours, 2 hours, 1 hour, 50 minutes, 40 minutes, 30 minutes, 20

minutes, or 10 minutes) before administration of the nanoparticle composition and may occur one, two, or more times in, for example, increasing dosage amounts.

[00450] Those skilled in the art will recognize, or be able to ascertain using no more than routine experimentation, many equivalents to the specific embodiments in accordance with the disclosure described herein. The scope of the present disclosure is not intended to be limited to the above Description, but rather is as set forth in the appended claims.

[00451] In the claims, articles such as “a,” “an,” and “the” may mean one or more than one unless indicated to the contrary or otherwise evident from the context. Claims or descriptions that include “or” between one or more members of a group are considered satisfied if one, more than one, or all of the group members are present in, employed in, or otherwise relevant to a given product or process unless indicated to the contrary or otherwise evident from the context. The disclosure includes embodiments in which exactly one member of the group is present in, employed in, or otherwise relevant to a given product or process. The disclosure includes embodiments in which more than one, or all, of the group members are present in, employed in, or otherwise relevant to a given product or process. As used herein, the expressions “one or more of A, B, or C,” “one or more A, B, or C,” “one or more of A, B, and C,” “one or more A, B, and C,” “selected from A, B, and C,” “selected from the group consisting of A, B, and C,” and the like are used interchangeably and all refer to a selection from a group consisting of A, B, and /or C, i.e., one or more As, one or more Bs, one or more Cs, or any combination thereof, unless otherwise specified.

[00452] It is also noted that the term “comprising” is intended to be open and permits but does not require the inclusion of additional elements or steps. When the term “comprising” is used herein, the terms “consisting essentially of” and “consisting of” are thus also encompassed and disclosed. Throughout the description, where compositions are described as having, including, or comprising specific components, it is contemplated that compositions also consist essentially of, or consist of, the recited components. Similarly, where methods or processes are described as having, including, or comprising specific process steps, the processes also consist essentially of, or consist of, the recited processing steps. Further, it should be understood that the order of steps or order for performing certain actions is immaterial so long as the invention remains operable. Moreover, two or more steps or actions can be conducted simultaneously.

[00453] Where ranges are given, endpoints are included. Furthermore, it is to be understood that unless otherwise indicated or otherwise evident from the context and understanding of one of

ordinary skill in the art, values that are expressed as ranges can assume any specific value or sub-range within the stated ranges in different embodiments of the disclosure, to the tenth of the unit of the lower limit of the range, unless the context clearly dictates otherwise.

[00454] The synthetic processes of the disclosure can tolerate a wide variety of functional groups, therefore various substituted starting materials can be used. The processes generally provide the desired final compound at or near the end of the overall process, although it may be desirable in certain instances to further convert the compound to a pharmaceutically acceptable salt thereof.

[00455] Compounds of the present disclosure can be prepared in a variety of ways using commercially available starting materials, compounds known in the literature, or from readily prepared intermediates, by employing standard synthetic methods and procedures either known to those skilled in the art, or which will be apparent to the skilled artisan in light of the teachings herein. Standard synthetic methods and procedures for the preparation of organic molecules and functional group transformations and manipulations can be obtained from the relevant scientific literature or from standard textbooks in the field. Although not limited to any one or several sources, classic texts such as Smith, M. B., March, J., *March's Advanced Organic Chemistry: Reactions, Mechanisms, and Structure*, 5th edition, John Wiley & Sons: New York, 2001; Greene, T.W., Wuts, P.G. M., *Protective Groups in Organic Synthesis*, 3rd edition, John Wiley & Sons: New York, 1999; R. Larock, *Comprehensive Organic Transformations*, VCH Publishers (1989); L. Fieser and M. Fieser, *Fieser and Fieser's Reagents for Organic Synthesis*, John Wiley and Sons (1994); and L. Paquette, ed., *Encyclopedia of Reagents for Organic Synthesis*, John Wiley and Sons (1995), incorporated by reference herein, are useful and recognized reference textbooks of organic synthesis known to those in the art. The following descriptions of synthetic methods are designed to illustrate, but not to limit, general procedures for the preparation of compounds of the present disclosure.

[00456] In addition, it is to be understood that any particular embodiment of the present disclosure that falls within the prior art may be explicitly excluded from any one or more of the claims. Since such embodiments are deemed to be known to one of ordinary skill in the art, they may be excluded even if the exclusion is not set forth explicitly herein.

[00457] All cited sources, for example, references, publications, databases, database entries, and art cited herein, are incorporated into this application by reference, even if not expressly stated in

the citation. In case of conflicting statements of a cited source and the instant application, the statement in the instant application shall control.

Examples

Example 1: Syntheses of Compounds 1-280

[00458] Syntheses of Compounds 1-280 are described in International Patent Application Publication No. WO 2017/049245, and co-pending application No. PCT/US2018/22717, the contents of each of which are incorporated herein by reference in their entireties.

Example 2: Production of nanoparticle compositions

A. Production of nanoparticle compositions

[00459] In order to investigate safe and efficacious nanoparticle compositions for use in the delivery of therapeutic and/or prophylactics to cells, a range of formulations are prepared and tested. Specifically, the particular elements and ratios thereof in the lipid component of nanoparticle compositions are optimized.

[00460] Nanoparticles can be made with mixing processes such as microfluidics and T-junction mixing of two fluid streams, one of which contains the therapeutic and/or prophylactic and the other has the lipid components.

[00461] Lipid compositions are prepared by combining a lipid according to Formula (I), (IA), (II), (IIa), (IIb), (IIc), (IId), (IIe), (IIf) or a phospholipid (such as DOPE or DSPC, obtainable from Avanti Polar Lipids, Alabaster, AL), a PEG lipid (such as 1,2-dimyristoyl-*sn*-glycerol methoxypolyethylene glycol, also known as PEG-DMG, obtainable from Avanti Polar Lipids, Alabaster, AL), and a structural lipid (such as cholesterol, obtainable from Sigma-Aldrich, Taufkirchen, Germany, cholesterol derivative, or a mixture of cholesterol and cholesterol derivative) at concentrations of about, e.g., 50 mM in a solvent, e.g., ethanol. Solutions should be refrigeration for storage at, for example, -20° C. Lipids are combined to yield desired molar ratios (see, for example, Table 1 below) and diluted with water and ethanol to a final lipid concentration of e.g., between about 5.5 mM and about 25 mM. Chol* in Table 1 refers to cholesterol, cholesterol derivative, or a combination thereof.

Table 1. Exemplary formulations including compounds according to Formula (I), (IA), (IB), (II), (IIa), (IIb), (IIc), (IId), (IId), (IId), (IId), (IId) or (IId).

Composition (mol %)	Components
40:20:38.5:1.5	Compound:Phospholipid:Chol*:PEG-DMG
45:15:38.5:1.5	Compound:Phospholipid:Chol*:PEG-DMG
50:10:38.5:1.5	Compound:Phospholipid:Chol*:PEG-DMG
55:5:38.5:1.5	Compound:Phospholipid:Chol*:PEG-DMG
60:5:33.5:1.5	Compound:Phospholipid:Chol*:PEG-DMG
45:20:33.5:1.5	Compound:Phospholipid:Chol*:PEG-DMG
50:20:28.5:1.5	Compound:Phospholipid:Chol*:PEG-DMG
55:20:23.5:1.5	Compound:Phospholipid:Chol*:PEG-DMG
60:20:18.5:1.5	Compound:Phospholipid:Chol*:PEG-DMG
40:15:43.5:1.5	Compound:Phospholipid:Chol*:PEG-DMG
50:15:33.5:1.5	Compound:Phospholipid:Chol*:PEG-DMG
55:15:28.5:1.5	Compound:Phospholipid:Chol*:PEG-DMG
60:15:23.5:1.5	Compound:Phospholipid:Chol*:PEG-DMG
40:10:48.5:1.5	Compound:Phospholipid:Chol*:PEG-DMG
45:10:43.5:1.5	Compound:Phospholipid:Chol*:PEG-DMG
55:10:33.5:1.5	Compound:Phospholipid:Chol*:PEG-DMG
60:10:28.5:1.5	Compound:Phospholipid:Chol*:PEG-DMG
40:5:53.5:1.5	Compound:Phospholipid:Chol*:PEG-DMG
45:5:48.5:1.5	Compound:Phospholipid:Chol*:PEG-DMG
50:5:43.5:1.5	Compound:Phospholipid:Chol*:PEG-DMG
40:20:40:0	Compound:Phospholipid:Chol*:PEG-DMG
45:20:35:0	Compound:Phospholipid:Chol*:PEG-DMG
50:20:30:0	Compound:Phospholipid:Chol*:PEG-DMG
55:20:25:0	Compound:Phospholipid:Chol*:PEG-DMG
60:20:20:0	Compound:Phospholipid:Chol*:PEG-DMG
40:15:45:0	Compound:Phospholipid:Chol*:PEG-DMG
45:15:40:0	Compound:Phospholipid:Chol*:PEG-DMG

Composition (mol %)	Components
50:15:35:0	Compound:Phospholipid:Chol*:PEG-DMG
55:15:30:0	Compound:Phospholipid:Chol*:PEG-DMG
60:15:25:0	Compound:Phospholipid:Chol*:PEG-DMG
40:10:50:0	Compound:Phospholipid:Chol*:PEG-DMG
45:10:45:0	Compound:Phospholipid:Chol*:PEG-DMG
50:0:48.5:1.5	Compound:Phospholipid:Chol*:PEG-DMG
50:10:40:0	Compound:Phospholipid:Chol*:PEG-DMG
55:10:35:0	Compound:Phospholipid:Chol*:PEG-DMG
60:10:30:0	Compound:Phospholipid:Chol*:PEG-DMG

[00462] Nanoparticle compositions including a therapeutic and/or prophylactic and a lipid component are prepared by combining the lipid solution with a solution including the therapeutic and/or prophylactic at lipid component to therapeutic and/or prophylactic wt:wt ratios between about 5:1 and about 50:1. The lipid solution is rapidly injected using a NanoAssembler microfluidic based system at flow rates between about 10 ml/min and about 18 ml/min into the therapeutic and/or prophylactic solution to produce a suspension with a water to ethanol ratio between about 1:1 and about 4:1.

[00463] For nanoparticle compositions including an RNA, solutions of the RNA at concentrations of 0.1 mg/ml in deionized water are diluted in a buffer, e.g., 50 mM sodium citrate buffer at a pH between 3 and 4 to form a stock solution.

[00464] Nanoparticle compositions can be processed by dialysis to remove ethanol and achieve buffer exchange. Formulations are dialyzed twice against phosphate buffered saline (PBS), pH 7.4, at volumes 200 times that of the primary product using Slide-A-Lyzer cassettes (Thermo Fisher Scientific Inc., Rockford, IL) with a molecular weight cutoff of 10 kDa. The first dialysis is carried out at room temperature for 3 hours. The formulations are then dialyzed overnight at 4° C. The resulting nanoparticle suspension is filtered through 0.2 µm sterile filters (Sarstedt, Nümbrecht, Germany) into glass vials and sealed with crimp closures. Nanoparticle composition solutions of 0.01 mg/ml to 0.10 mg/ml are generally obtained.

[00465] The method described above induces nano-precipitation and particle formation. Alternative processes including, but not limited to, T-junction and direct injection, may be used to achieve the same nano-precipitation.

B. Characterization of nanoparticle compositions

[00466] A Zetasizer Nano ZS (Malvern Instruments Ltd, Malvern, Worcestershire, UK) can be used to determine the particle size, the polydispersity index (PDI) and the zeta potential of the nanoparticle compositions in 1×PBS in determining particle size and 15 mM PBS in determining zeta potential.

[00467] Ultraviolet-visible spectroscopy can be used to determine the concentration of a therapeutic and/or prophylactic (*e.g.*, RNA) in nanoparticle compositions. 100 µL of the diluted formulation in 1×PBS is added to 900 µL of a 4:1 (v/v) mixture of methanol and chloroform. After mixing, the absorbance spectrum of the solution is recorded, for example, between 230 nm and 330 nm on a DU 800 spectrophotometer (Beckman Coulter, Beckman Coulter, Inc., Brea, CA). The concentration of therapeutic and/or prophylactic in the nanoparticle composition can be calculated based on the extinction coefficient of the therapeutic and/or prophylactic used in the composition and on the difference between the absorbance at a wavelength of, for example, 260 nm and the baseline value at a wavelength of, for example, 330 nm.

[00468] For nanoparticle compositions including an RNA, a QUANT-IT™ RIBOGREEN® RNA assay (Invitrogen Corporation Carlsbad, CA) can be used to evaluate the encapsulation of an RNA by the nanoparticle composition. The samples are diluted to a concentration of approximately 5 µg/mL in a TE buffer solution (10 mM Tris-HCl, 1 mM EDTA, pH 7.5). 50 µL of the diluted samples are transferred to a polystyrene 96 well plate and either 50 µL of TE buffer or 50 µL of a 2% Triton X-100 solution is added to the wells. The plate is incubated at a temperature of 37° C for 15 minutes. The RIBOGREEN® reagent is diluted 1:100 in TE buffer, and 100 µL of this solution is added to each well. The fluorescence intensity can be measured using a fluorescence plate reader (Wallac Victor 1420 Multilabel Counter; Perkin Elmer, Waltham, MA) at an excitation wavelength of, for example, about 480 nm and an emission wavelength of, for example, about 520 nm. The fluorescence values of the reagent blank are subtracted from that of each of the samples and the percentage of free RNA is determined by dividing the fluorescence intensity of the intact sample (without addition of Triton X-100) by the fluorescence value of the disrupted sample (caused by the addition of Triton X-100).

C. *In vivo* formulation studies

[00469] In order to monitor how effectively various nanoparticle compositions deliver therapeutic and/or prophylactics to targeted cells, different nanoparticle compositions including a particular therapeutic and/or prophylactic (for example, a modified or naturally occurring RNA such as an mRNA) are prepared and administered to rodent populations. Mice are intravenously, intramuscularly, intraarterially, or intratumorally administered a single dose including a nanoparticle composition with a lipid nanoparticle formulation. In some instances, mice may be made to inhale doses. Dose sizes may range from 0.001 mg/kg to 10 mg/kg, where 10 mg/kg describes a dose including 10 mg of a therapeutic and/or prophylactic in a nanoparticle composition for each 1 kg of body mass of the mouse. A control composition including PBS may also be employed.

[00470] Upon administration of nanoparticle compositions to mice, dose delivery profiles, dose responses, and toxicity of particular formulations and doses thereof can be measured by enzyme-linked immunosorbent assays (ELISA), bioluminescent imaging, or other methods. For nanoparticle compositions including mRNA, time courses of protein expression can also be evaluated. Samples collected from the rodents for evaluation may include blood, sera, and tissue (for example, muscle tissue from the site of an intramuscular injection and internal tissue); sample collection may involve sacrifice of the animals.

[00471] Nanoparticle compositions including mRNA are useful in the evaluation of the efficacy and usefulness of various formulations for the delivery of therapeutic and/or prophylactics. Higher levels of protein expression induced by administration of a composition including an mRNA will be indicative of higher mRNA translation and/or nanoparticle composition mRNA delivery efficiencies. As the non-RNA components are not thought to affect translational machineries themselves, a higher level of protein expression is likely indicative of a higher efficiency of delivery of the therapeutic and/or prophylactic by a given nanoparticle composition relative to other nanoparticle compositions or the absence thereof.

Example 3: Evaluation of lipid formulations with replacements for cholesterol

[00472] The effect of partially or fully replacing cholesterol in common lipid formulations on protein expression and lipid uptake was tested *in vitro*. Exemplary formulations wherein

cholesterol was fully or partially replaced with novel lipids with anti-inflammatory properties (“test material”) are presented in Table 2.

Table 2. Exemplary formulations including partially or fully replaced cholesterol

Formulation	Test material	Molar ratio	%EE	[mRNA], ug/mL	Size (nm)	PDI
Compound 18: DSPC: Chol:PEG(2k)-DMG	-	50:10:38.5:1.5	95	59.4	84.6	0.19
Compound 18: DSPC: Chol: test material : PEG(2k)-DMG	Lupeol	50:10:20: 18.5 :1.5	91	62.3	90.5	0.16
Compound 18: DSPC: Chol: test material : PEG(2k)-DMG	Stigmasterol	50:10:20: 18.5 :1.5	94	61.7	90.9	0.20

[00473] Among the formulations in Table 2, the one comprising both cholesterol and stigmasterol (i.e., cholesterol partially replaced with stigmasterol) showed the highest expression of eGFP and was hence selected for further optimization. The combination of cholesterol and Lupeol (i.e., cholesterol partially replaced with Lupeol) showed higher expression of than the cholesterol control. Stigmasterol ranges were evaluated from 1-37.5 mol% in liquid nanoparticles. Table 3 summarizes particle characteristics for formulations containing different ratios of cholesterol and stigmasterol.

Table 3. Characteristics of nanoparticle compositions including Compound 18, cholesterol and stigmasterol.

% cholesterol	% stigmasterol	Size (nm)	PDI	%EE
1.0%	37.5%	164.9	0.23	12.0
10.0%	28.5%	126.4	0.16	48.5
20.0%	18.5%	90.9	0.20	89.3
30.0%	8.5%	76.8	0.15	94.7
37.5%	1.0%	78.4	0.23	95.4
38.5% ^{##}	0.0%	86.2	0.22	98.1
20.0% ^{##}	18.5%	99.3	0.22	92.8

^{##}Formulated with rhodamine-DOPE

[00474] Formulations comprising different phytosterols (e.g., β -sitosterol and stigmasterol) were prepared and tested *in vitro*. The relative amount of the phytosterol in each nanoparticle composition was varied to optimize the formulation. Compound 18 was selected for use in the

nanoparticle composition. Nanoparticle compositions were prepared with the relative cholesterol and cholesterol derivative contents independently varying between 0 mol % and 38.5 mol %. Formulations were prepared in fluorescent and non-fluorescent batches. Compositions were then evaluated for their size, and encapsulation efficiency. Exemplary formulations useful in the optimization of nanoparticle composition formulations are presented in Table 4. Characteristics of nanoparticle compositions comprising cholesterol and phytosterol, and compositions comprising cholesterol, phytosterol, or a combination thereof, are summarized in Tables 5-7.

Table 4. Formulations including Compound 18, cholesterol, and phytosterol

Formulation	Chol. Derivative (mole %)	Cholesterol (mole %)
Cholesterol	0	38.5
β -Sitosterol 38.5 ^{**}	38.5	0
β -Sitosterol 28.5 ^{**}	28.5	10
β -Sitosterol 18.5 ^{**}	18.5	20
Stigmasterol 38.5 ^{**}	38.5	0
Stigmasterol 28.5 ^{**}	28.5	10
Stigmasterol 18.5 ^{**}	18.5	20

^{**}: Formulated with Compound 18:DSPC:Cholesterol derivative:Cholesterol:PEG-DMG

Table 5. Characteristics of nanoparticle compositions comprising cholesterol and phytosterol

Sample	Diameter (nm)	PDI	Encapsulation Efficiency (%)
Cholesterol	114.4 $\pm$ 34.04	0.077	90.6
Stigmasterol	150.5 $\pm$ 46.89	0.199	13.3
β -Sitosterol	110.4 $\pm$ 25.68	0.042	91.3

Table 6. Characteristics of nanoparticle compositions including Compound 18 (acetate buffer)

Sample	Diameter (nm)	PDI	Encapsulation Efficiency (%)
Cholesterol	77.3	0.15	97
Cholesterol, fluorescent	76.1	0.16	98
β -Sitosterol 38.5	159.1	0.22	49
β -Sitosterol 38.5, fluorescent	146	0.22	59
β -Sitosterol 28.5	107.5	0.23	94
β -Sitosterol 28.5, fluorescent	106.3	0.20	93
β -Sitosterol 18.5	77.5	0.09	98
β -Sitosterol 18.5, fluorescent	76.8	0.09	98
Stigmasterol 38.5	145.3	0.18	-5
Stigmasterol 38.5, fluorescent	128.1	0.16	2

Stigmasterol 28.5	137.6	0.16	38
Stigmasterol 28.5, fluorescent	135.4	0.14	43
Stigmasterol 18.5	89.4	0.18	96
Stigmasterol 18.5, fluorescent	95.1	0.21	95

Table 7. Characteristics of nanoparticle compositions including Compound 18 (citrate buffer)

Sample	Diameter (nm)	PDI	Encapsulation Efficiency (%)
Cholesterol, fluorescent	68.3	0.15	99
β -Sitosterol 38.5, fluorescent	97.8	0.14	94
β -Sitosterol 28.5, fluorescent	83.5	0.11	98
β -Sitosterol 18.5, fluorescent	72.2	0.11	98
Stigmasterol 38.5, fluorescent	149.2	0.21	3
Stigmasterol 28.5, fluorescent	117.3	0.18	59
Stigmasterol 18.5, fluorescent	79.1	0.12	98

Example 4: *In vitro* study of sample formulations

[00475] The connection between cell uptake of lipid nanoparticles and protein expression, as well as B-cell activation, induced by compositions of the disclosure was evaluated. Human cell lines were contacted *in vitro* with nanoparticle compositions according to Table 6 and were evaluated for protein expression levels and cell uptake. The results of the study are shown in Figures 2-6. There is no major difference between fluorescent vs. nonfluorescent in terms of protein expression. In Figures 2-6, “Chol (Ctrl)” denotes no cholesterol replacement, “Beta” refers to β -sitosterol, “stigma” refers to stigmasterol, and “Fluor” refers to the corresponding fluorescent batch.

[00476] The tested compositions showed similar uptake and expression trends in HeLa, Hep3b (human hepatocellular carcinoma), and AML12 (mouse hepatocyte) cells. Protein expression with compositions of the disclosure, i.e., compositions comprising cholesterol and a cholesterol derivative (such as a phytosterol), was found to be 30-50x greater than that of the standard composition (i.e., without cholesterol replacement). In addition, protein expression with the compositions comprising 99.5% -100% replacement of cholesterol with β -sitosterol was found to be 100-200x greater than that of the standard composition (i.e., without cholesterol replacement). See, e.g., Figure 8d. B-cell activation was found to be at media control levels.

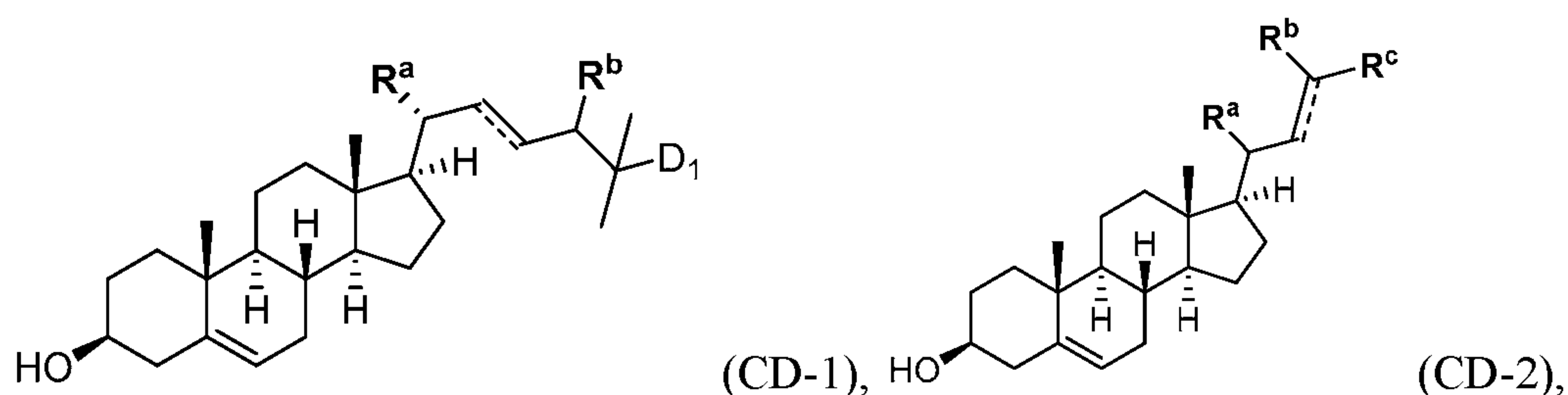
Equivalents

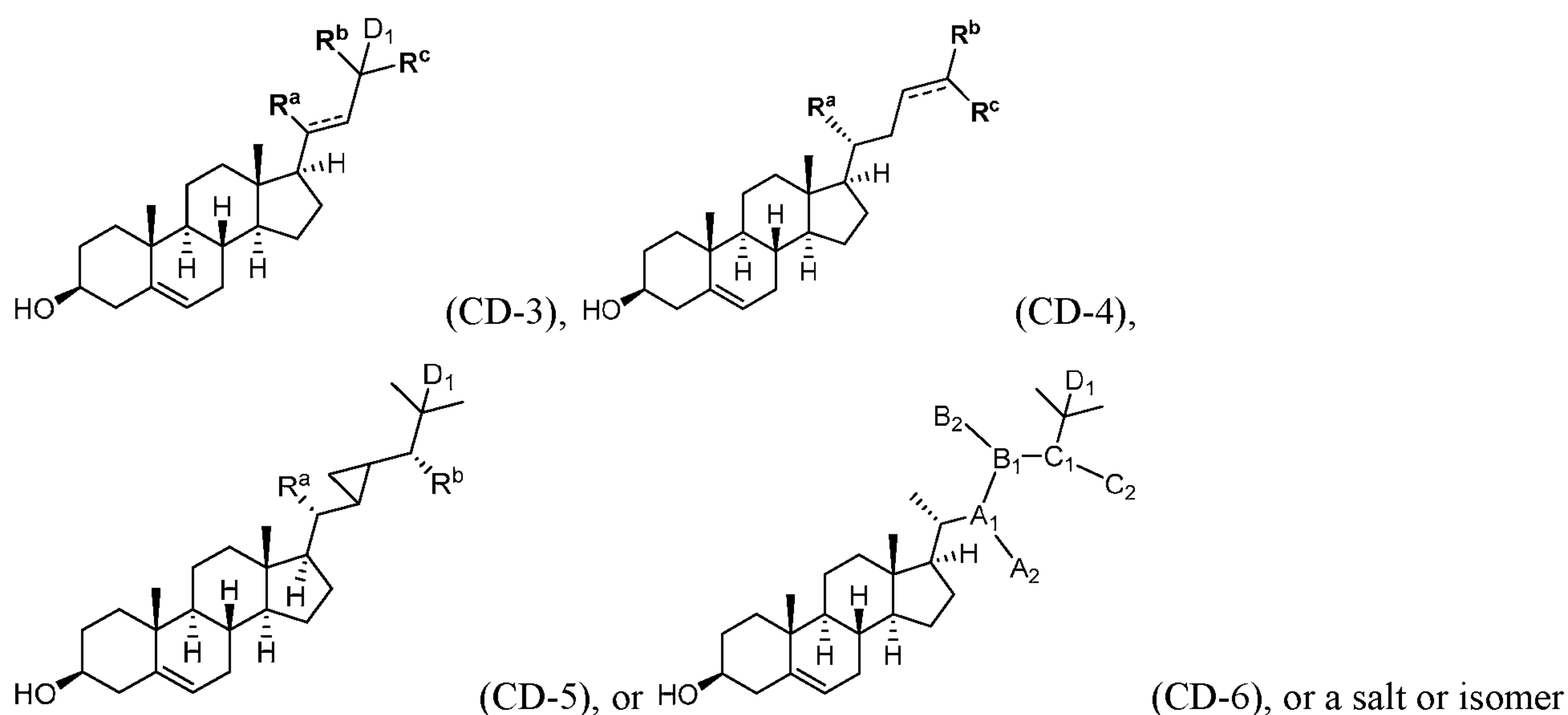
[00477] It is to be understood that while the present disclosure has been described in conjunction with the detailed description thereof, the foregoing description is intended to illustrate and not limit the scope of the present disclosure, which is defined by the scope of the appended claims. Other aspects, advantages, and alterations are within the scope of the following claims.

CLAIMS

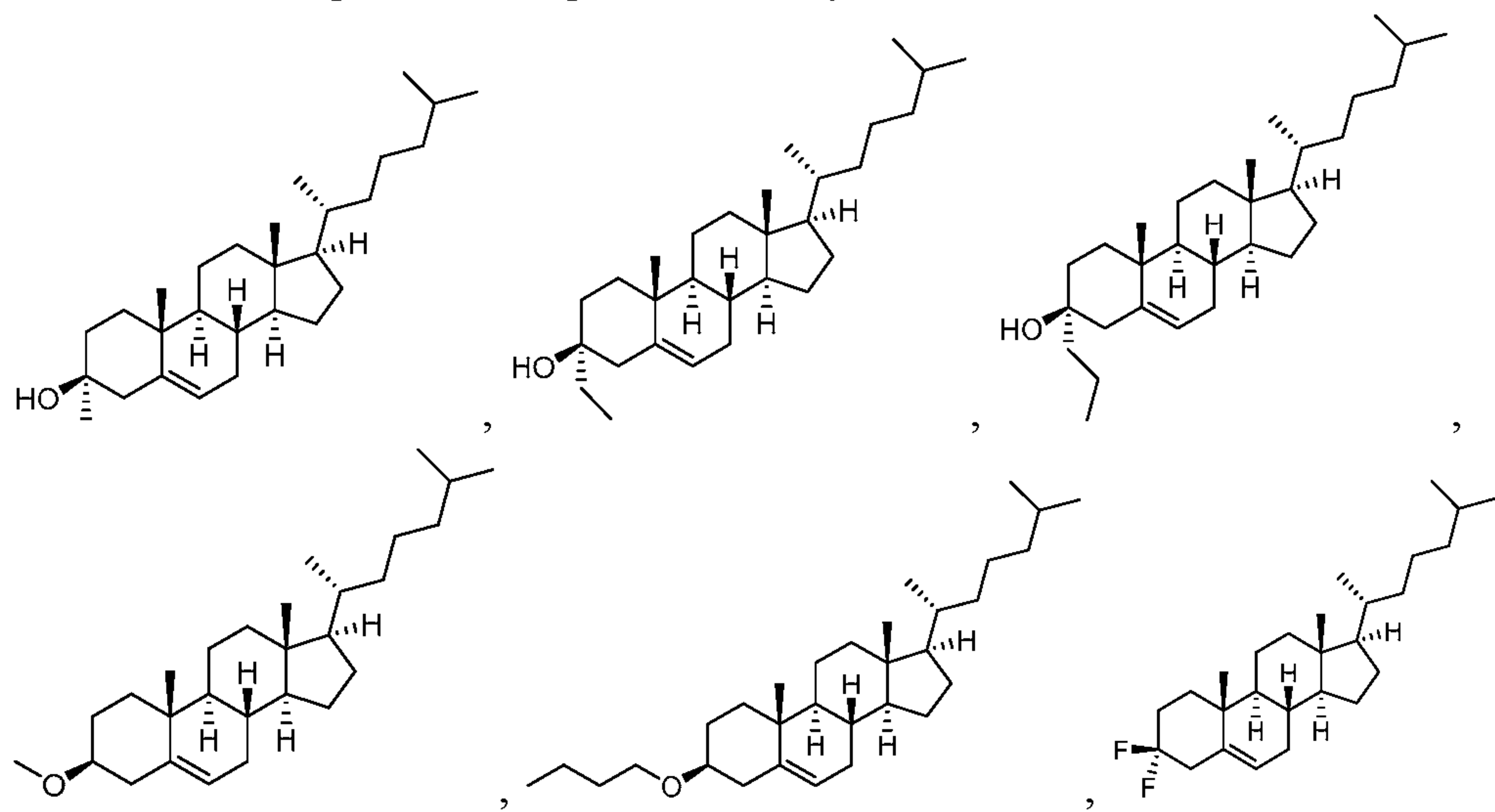
1. A nanoparticle composition comprising a lipid component comprising
an ionizable lipid,
a phospholipid,
a first sterol or a tocopherol, and
optionally a second sterol different from the first sterol wherein the molar ratio between the first and second sterols is between about 1:100 and 100:1, or the molar ratio between the tocopherol and second sterol is between about 1:100 and 100:1.
2. The nanoparticle composition of claim 1, comprising a second sterol.
3. The nanoparticle composition of claim 2, wherein the molar ratio between the first and second sterols is between about 1:10 and 10:1, or between about 1:5 and 5:1, or between about 1:3 and 3:1, or between about 1:2 and 2:1, or about 1:1.
4. The nanoparticle composition of claim 2, wherein the molar ratio between the tocopherol and second sterol is between about 1:10 and 10:1, or between about 1:5 and 5:1, or between about 1:3 and 3:1, or between about 1:2 and 2:1, or about 1:1.
5. The nanoparticle composition of claim 2 or 3, wherein the first sterol is cholesterol and the second sterol is a cholesterol derivative.
6. The nanoparticle composition of claim 1, wherein the first sterol is a cholesterol derivative and the second sterol is absent.
7. The nanoparticle composition of claim 1 or 3, comprising a tocopherol and optionally a second sterol which is cholesterol a cholesterol derivative.
8. The nanoparticle composition of any one of claims 5-7, wherein the cholesterol derivative is a phytosterol.

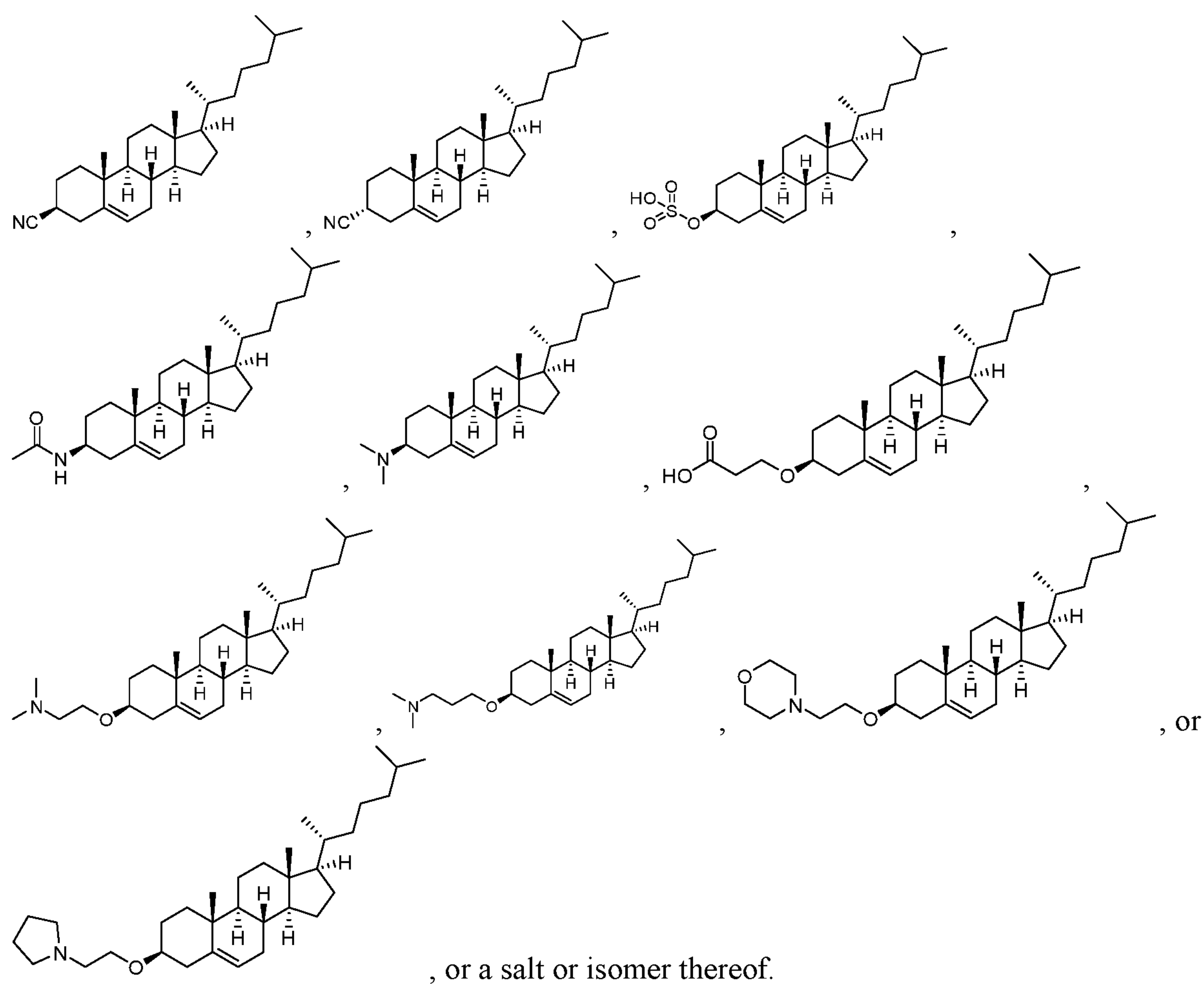
9. The nanoparticle composition of claim 8, wherein the phytosterol is β -sitosterol, campesterol, stigmasterol, fucosterol, or stigmasterol.
10. The nanoparticle composition of any one of claims 5-7, wherein the cholesterol derivative is dihydrocholesterol, ent-cholesterol, epi-cholesterol, desmosterol, cholestanol, cholestanone, cholestenone, cholesteryl-2'-hydroxyethyl ether, cholesteryl-4'-hydroxybutyl ether, 3β -[N-(N'N'-dimethylaminoethyl)carbamoyl cholesterol (DC-Chol), 24(S)-hydroxycholesterol, 25-hydroxycholesterol, 25(R)-27-hydroxycholesterol, 22-oxacholesterol, 23-oxacholesterol, 24-oxacholesterol, cycloartenol, , 22-ketosterol, 20-hydroxysterol, 7-hydroxycholesterol, 19-hydroxycholesterol, 22-hydroxycholesterol, 25-hydroxycholesterol, 7-dehydrocholesterol, 5α -cholest-7-en- 3β -ol, 3,6,9-trioxaoctan-1-ol-cholesteryl-3e-ol, dehydroergosterol, dehydroepiandrosterone, lanosterol, dihydrolanosterol, lanostenol, lumisterol, sitocalciferol, calcipotriol, coprostanol, cholecalciferol, lupeol, ergocalciferol, 22-dihydroergocalciferol, ergosterol, brassicasterol, tomatidine, tomatine, ursolic acid, cholic acid, chenodeoxycholic acid, zymosterol, diosgenin, fucosterol, fecosterol, or fecosterol, or a salt or ester thereof.
11. The nanoparticle composition of any one of claims 5-7, wherein the cholesterol or cholesterol derivative is cholesterol, cholesterol succinic acid, cholesterol sulfate, cholesterol hemisuccinate, cholesterol phthalate, cholesterol phosphate, cholesterol valerate, cholesterol acetate, cholesteryl oleate, cholesteryl linoleate, cholesteryl myristate, cholesteryl palmitate, cholesteryl arachidate, cholesteryl phosphorylcholine, and sodium cholate.
12. The nanoparticle composition of any one of claims 5-7, wherein the cholesterol derivative is a compound of any of Formula (CD-1) through (CD6):



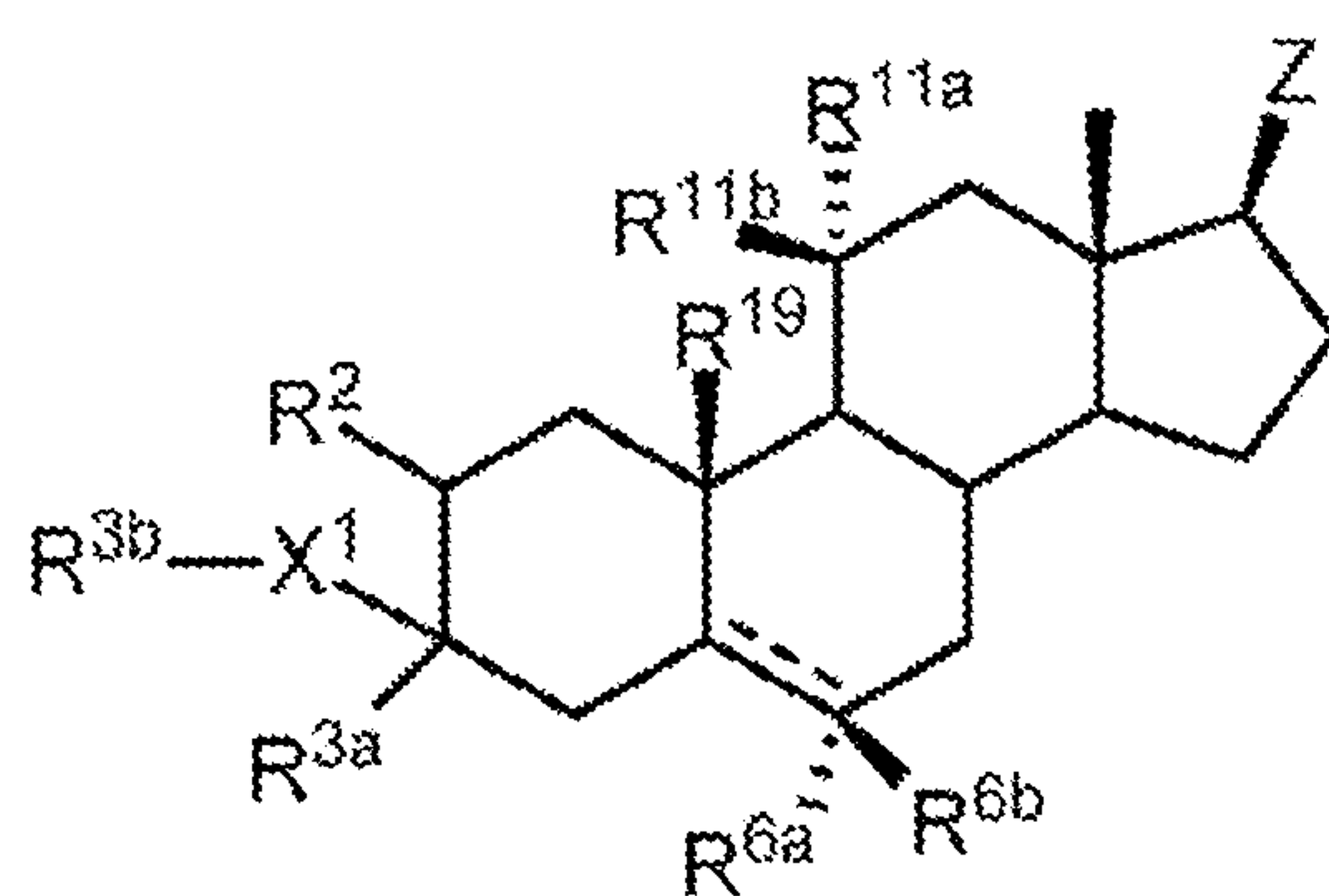


13. The nanoparticle composition of any one of claims 5-7, wherein the cholesterol derivative is



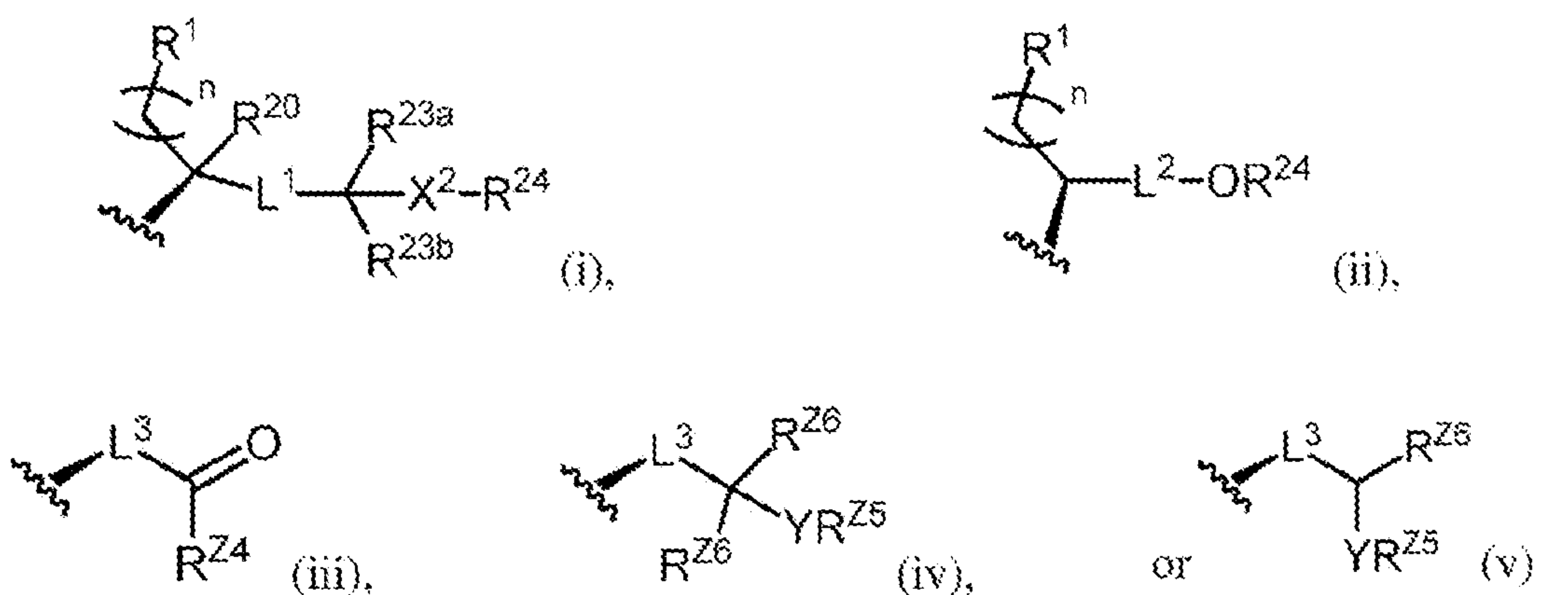


14. The nanoparticle composition of any one of claims 5-7, wherein the cholesterol derivative is a compound of Formula (CD-7):



(CD-7), or a salt or isomer thereof, wherein

Z is a group of the formula (i), (ii), (iii), (iv), or (v)



L^1 and L^2 are selected from a group consisting of a bond, a substituted or unsubstituted C_1 - C_6 alkylene, a substituted or unsubstituted C_2 - C_6 alkenylene, substituted or unsubstituted C_2 - C_6 alkynylene, a substituted or unsubstituted hetero C_1 - C_6 alkylene, a substituted or unsubstituted hetero C_2 - C_6 alkenylene, and a substituted or unsubstituted hetero C_2 - C_6 alkynylene;

L^3 is a substituted or unsubstituted C_1 - C_6 alkylene, a substituted or unsubstituted C_2 - C_6 alkenylene, substituted or unsubstituted C_2 - C_6 alkynylene, a substituted or unsubstituted hetero C_1 - C_6 alkylene, a substituted or unsubstituted hetero C_2 - C_6 alkenylene, or a substituted or unsubstituted hetero C_2 - C_6 alkynylene;

each instance of X^1 and X^2 is independently -O-, -S-, or -NH-;

R^1 is hydrogen or substituted or unsubstituted alkyl;

R^{3b} is hydrogen;

R^{3a} is hydrogen, substituted or unsubstituted alkyl, substituted or unsubstituted alkenyl, or substituted or unsubstituted alkynyl;

each instance of R^2 , R^{11a} and R^{11b} is independently hydrogen or -OR^{B1}, wherein R^{B1} is hydrogen or substituted or unsubstituted alkyl, or R^{11a} and R^{11b} are joined to form an oxo (=O) group;

each of R^{6a} and R^{6b} is independently hydrogen, halo, or substituted or unsubstituted alkyl, and ----- represents a single or double bond, provided if a double bond is present, then one of R^{6a} and R^{6b} is absent, and provided if a single bond is present, then the hydrogen at C5 is in the alpha or beta position;

each instance of R^{19} and R^{20} is independently hydrogen or -CH₃;

each instance of R^{23a} and R^{23b} is independently hydrogen, halogen, or substituted or unsubstituted alkyl, or R^{23a} and R^{23b} are joined together to form substituted or unsubstituted C_3 - C_6 cycloalkyl;

R^{24} is hydrogen or substituted or unsubstituted alkyl;

Y is -O-, -S- or $-NR^{Z5}$;

R^{Z4} is independently substituted or unsubstituted alkyl, substituted or unsubstituted alkenyl, substituted or unsubstituted alkynyl, substituted or unsubstituted carbocyclyl, substituted or unsubstituted heterocyclyl, substituted or unsubstituted aryl, substituted or unsubstituted heteroaryl, $-OR^{Z5}$, $-SR^{Z5}$, or $-N(R^{Z5})_2$;

each instance of R^{Z5} is independently hydrogen or substituted or unsubstituted alkyl;

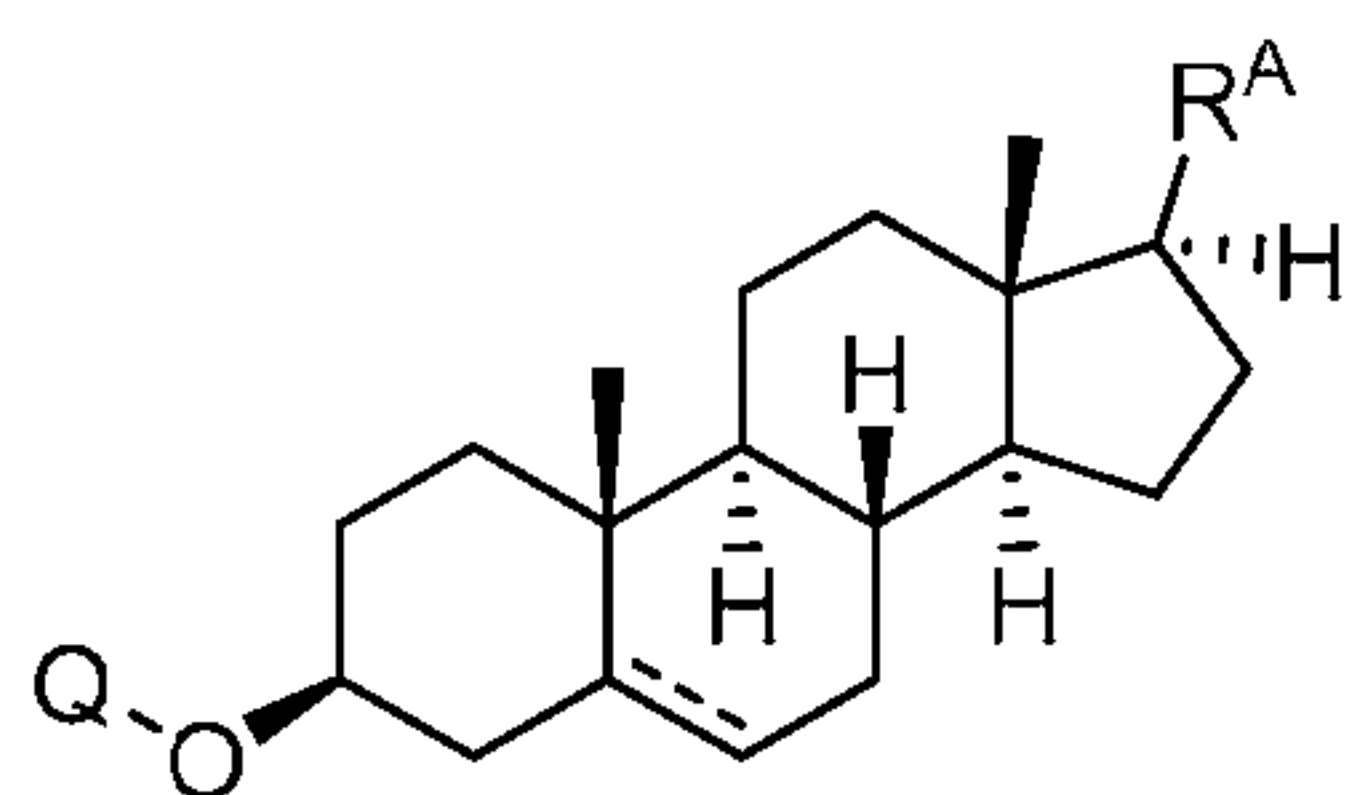
each instance of R^{Z6} is independently hydrogen or substituted or unsubstituted alkyl, or two R^{Z6} groups are joined to form a C_3 - C_6 carbocyclic ring; and

the subscript n is 0 or 1.

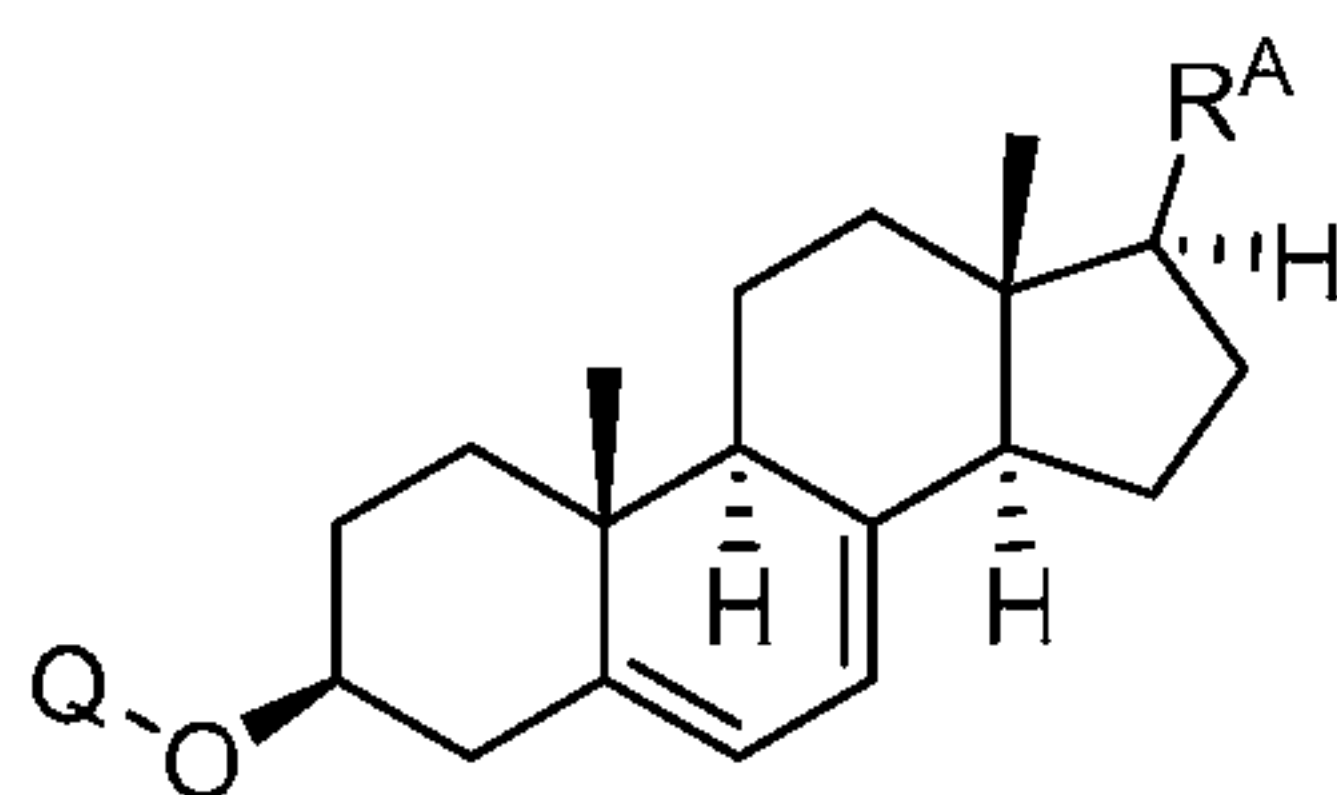
15. The nanoparticle composition of claim 7, wherein the tocopherol is α -tocopherol, β -tocopherol, γ -tocopherol, δ -tocopherol, or a salt or ester thereof.

16. The nanoparticle composition of claim 7 or 15, wherein the tocopherol is tocopherol hemisuccinate.

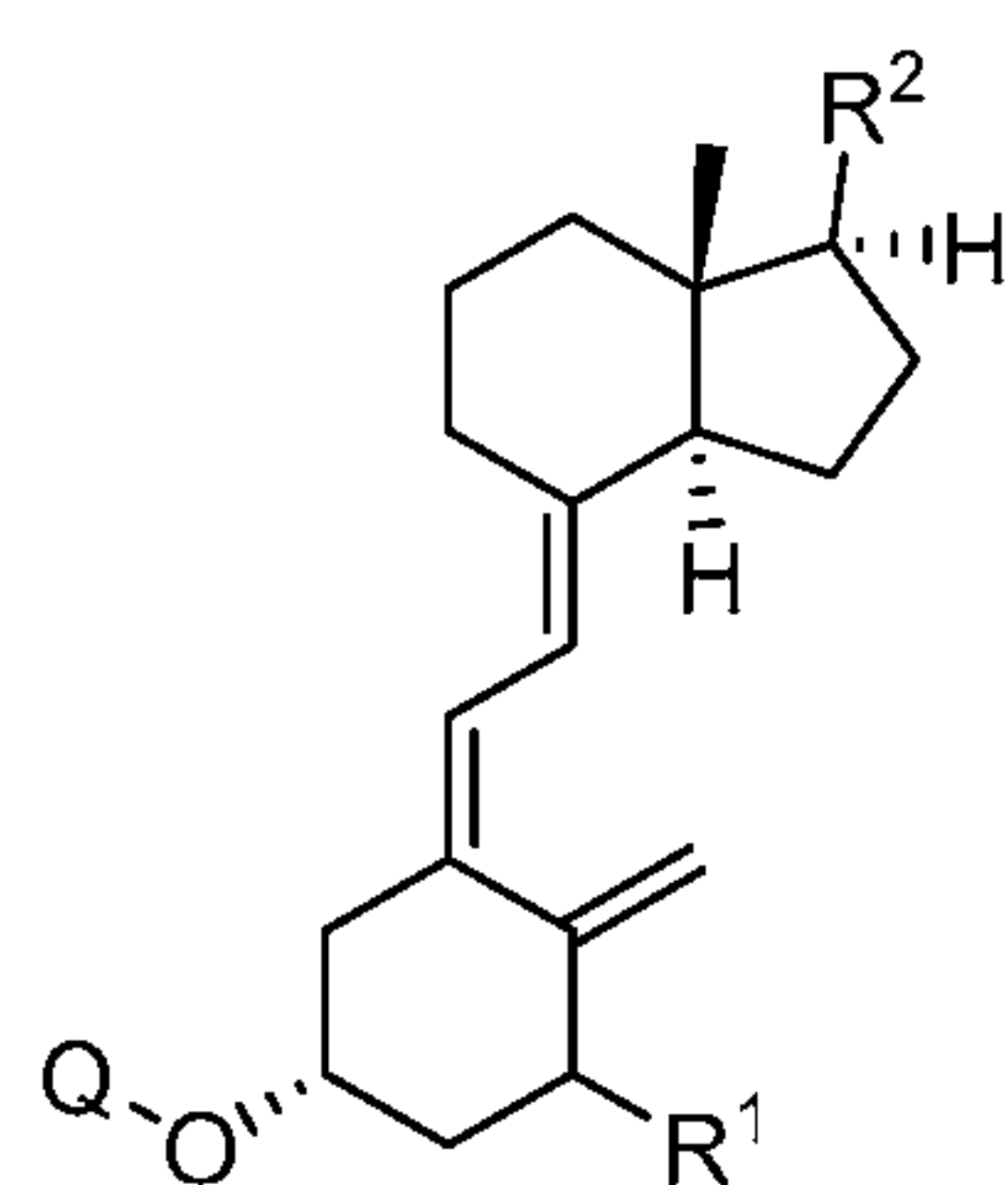
17. The nanoparticle composition of any one of claims 5-7, wherein the cholesterol derivative is of any of Formulae (A1)-(A4):



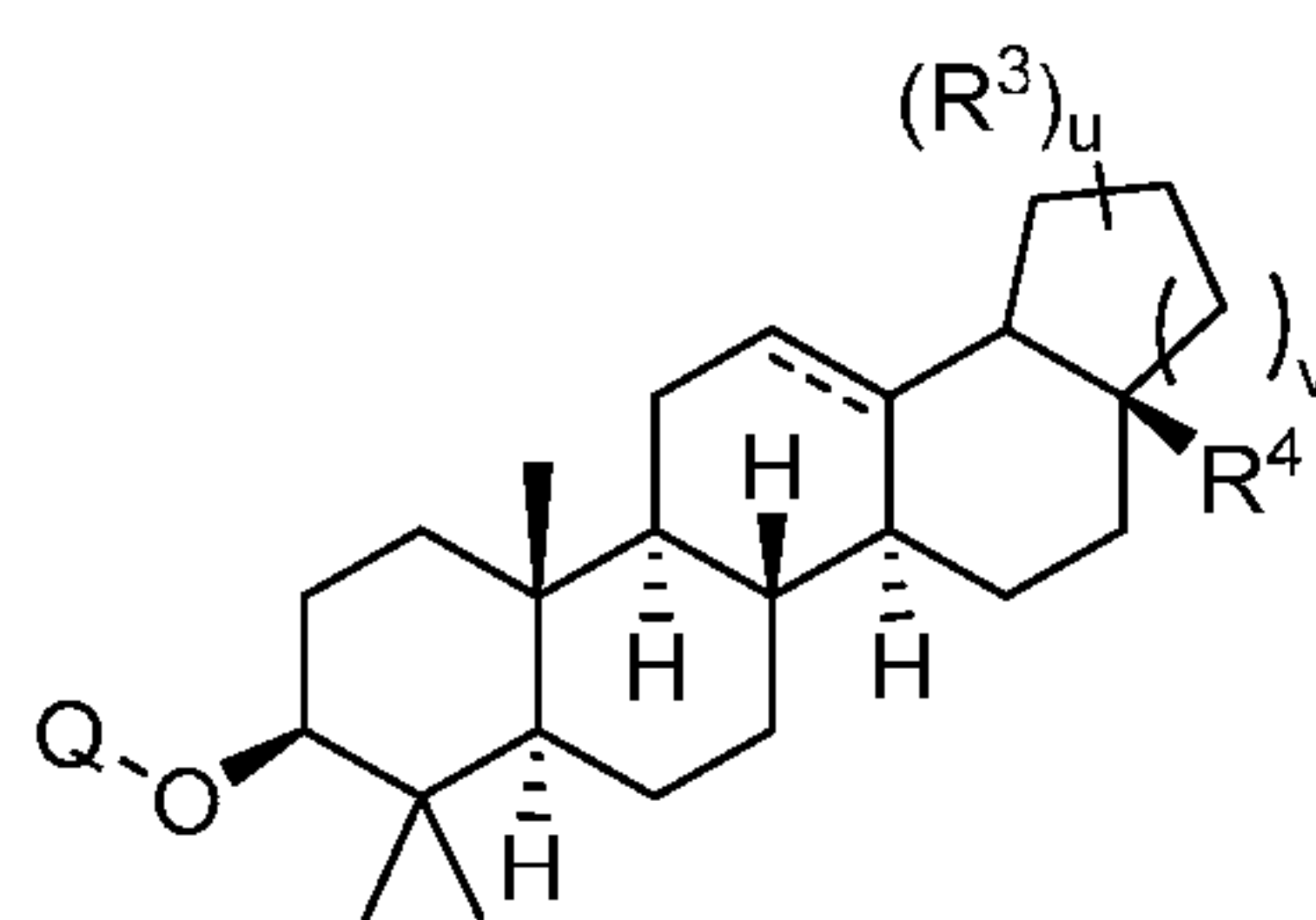
(A1),



(A2),

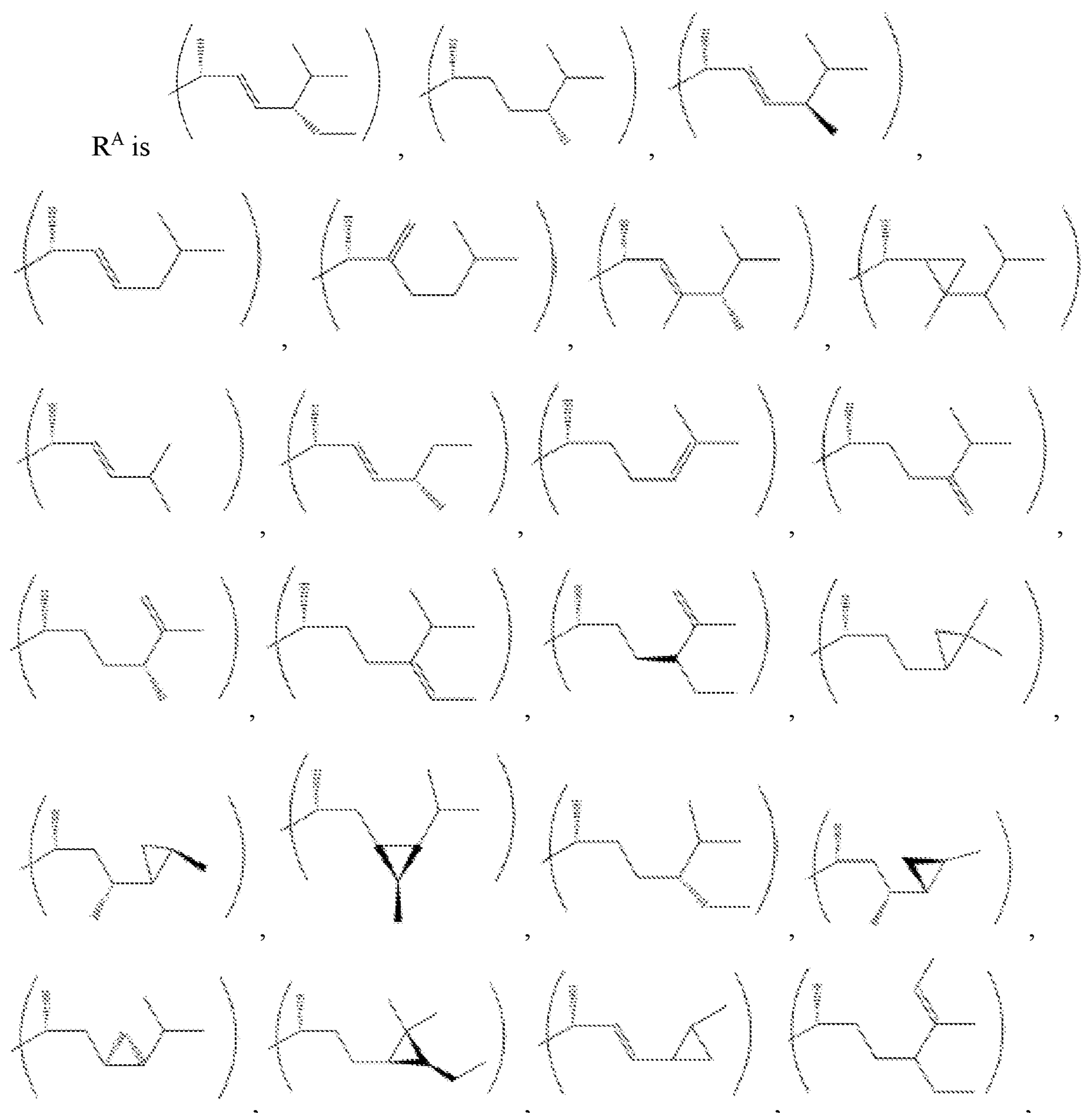


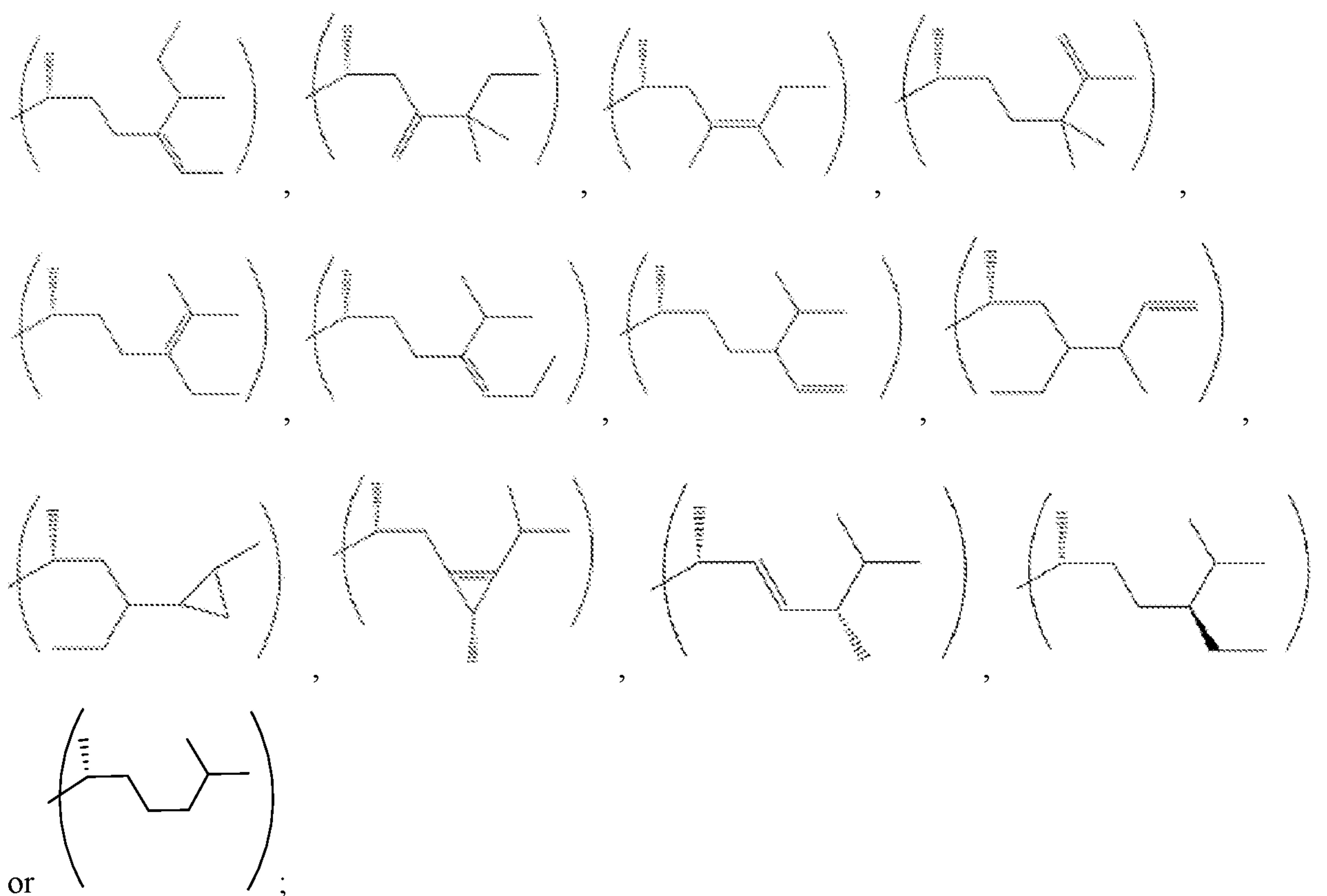
(A3), or



(A4); or a salt or isomer thereof,

wherein ----- denotes a carbon-carbon single or double bond;

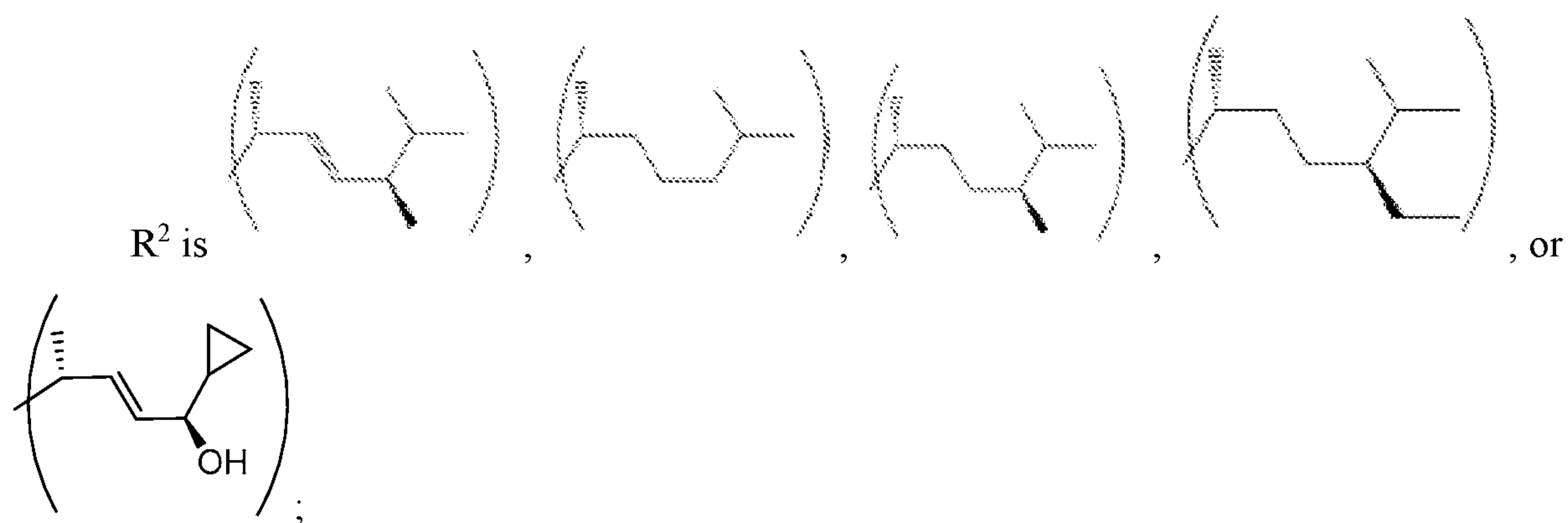




u is 1 or 2;

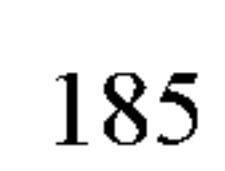
v is 1 or 2;

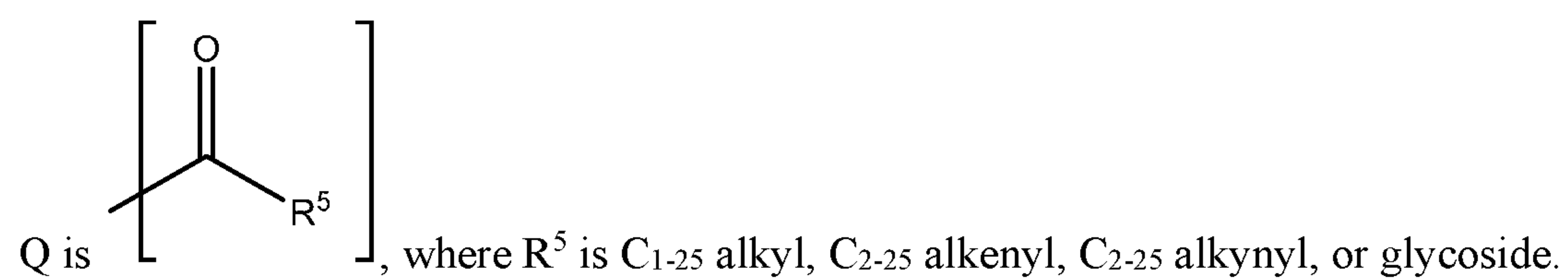
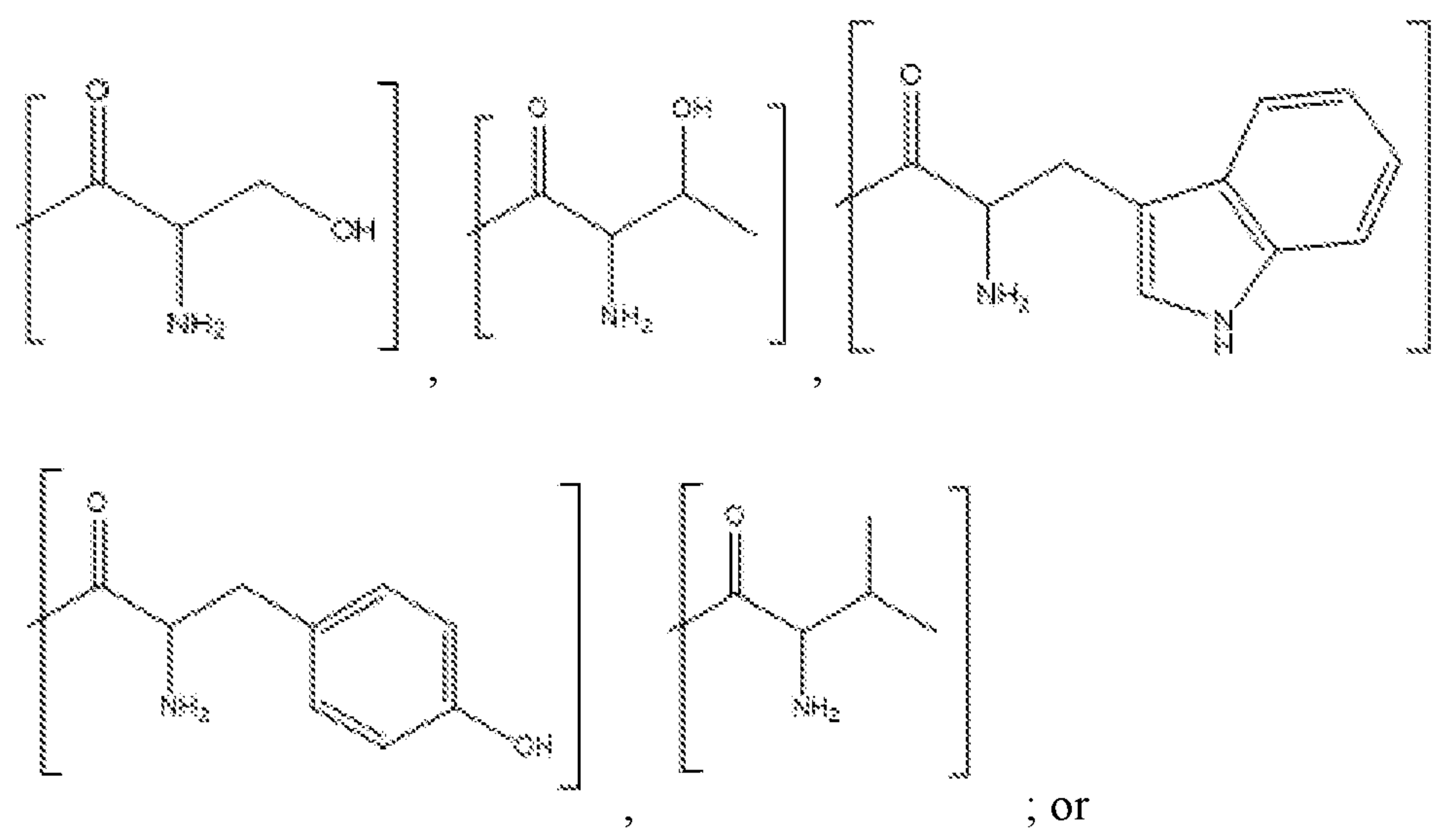
R¹ is H or OH;



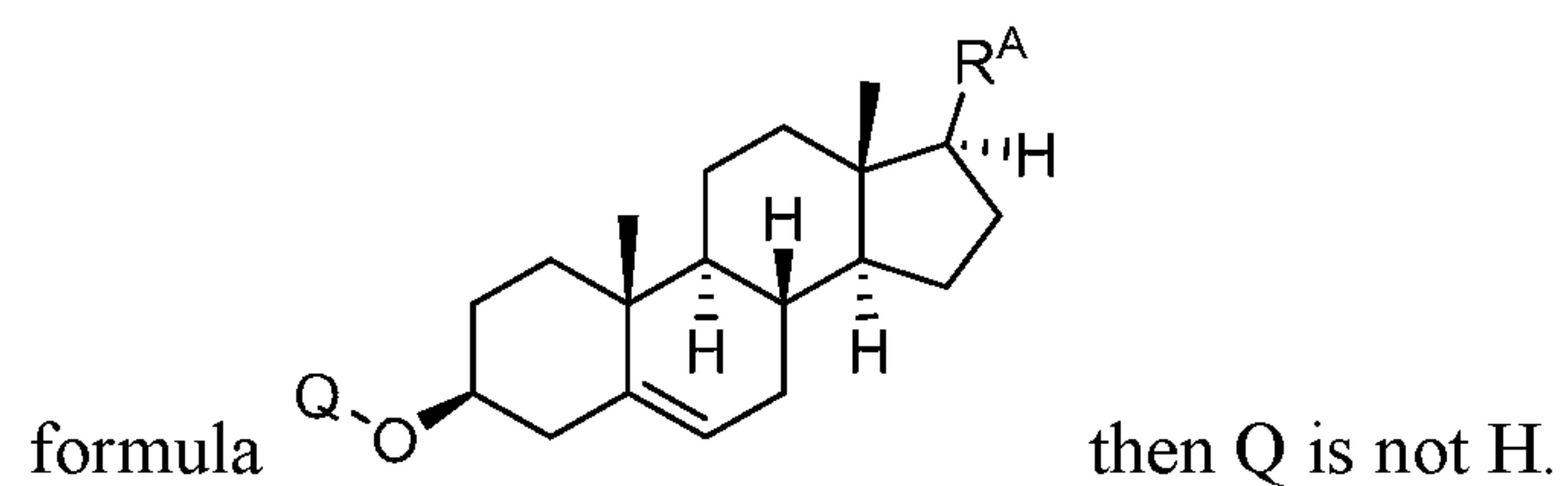
each R³ independently is CH₃, or ;

R⁴ is CH₃, CH₂OH, or CO₂H; and

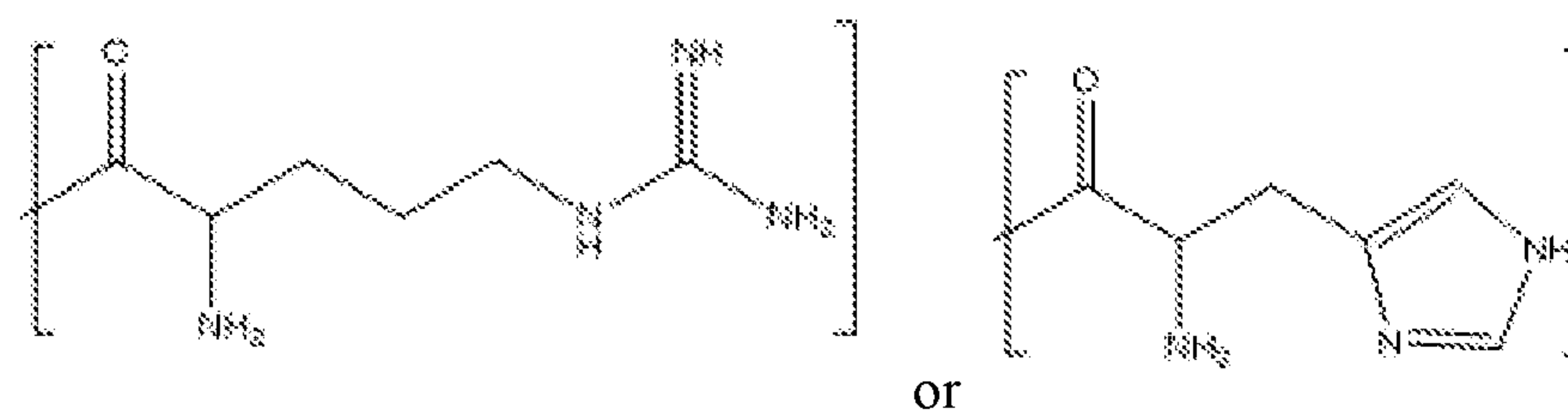




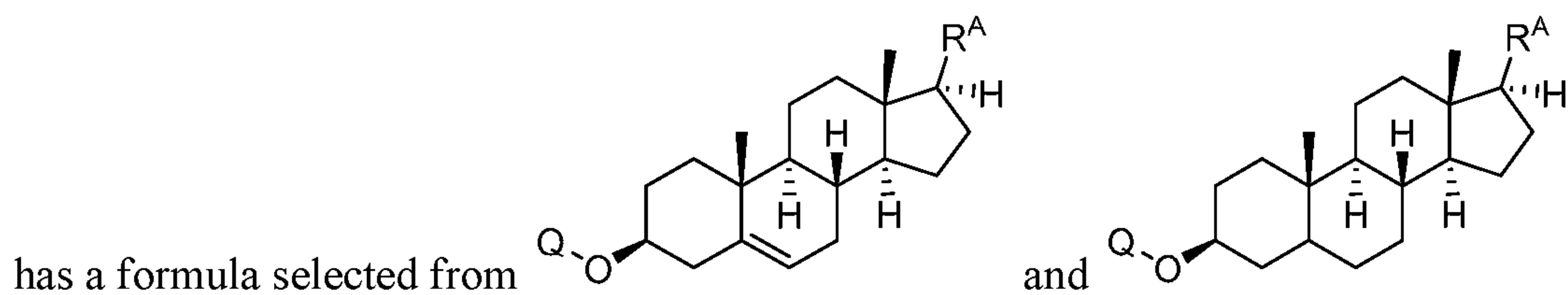
18. The nanoparticle composition of claim 17, wherein when the cholesterol derivative has a



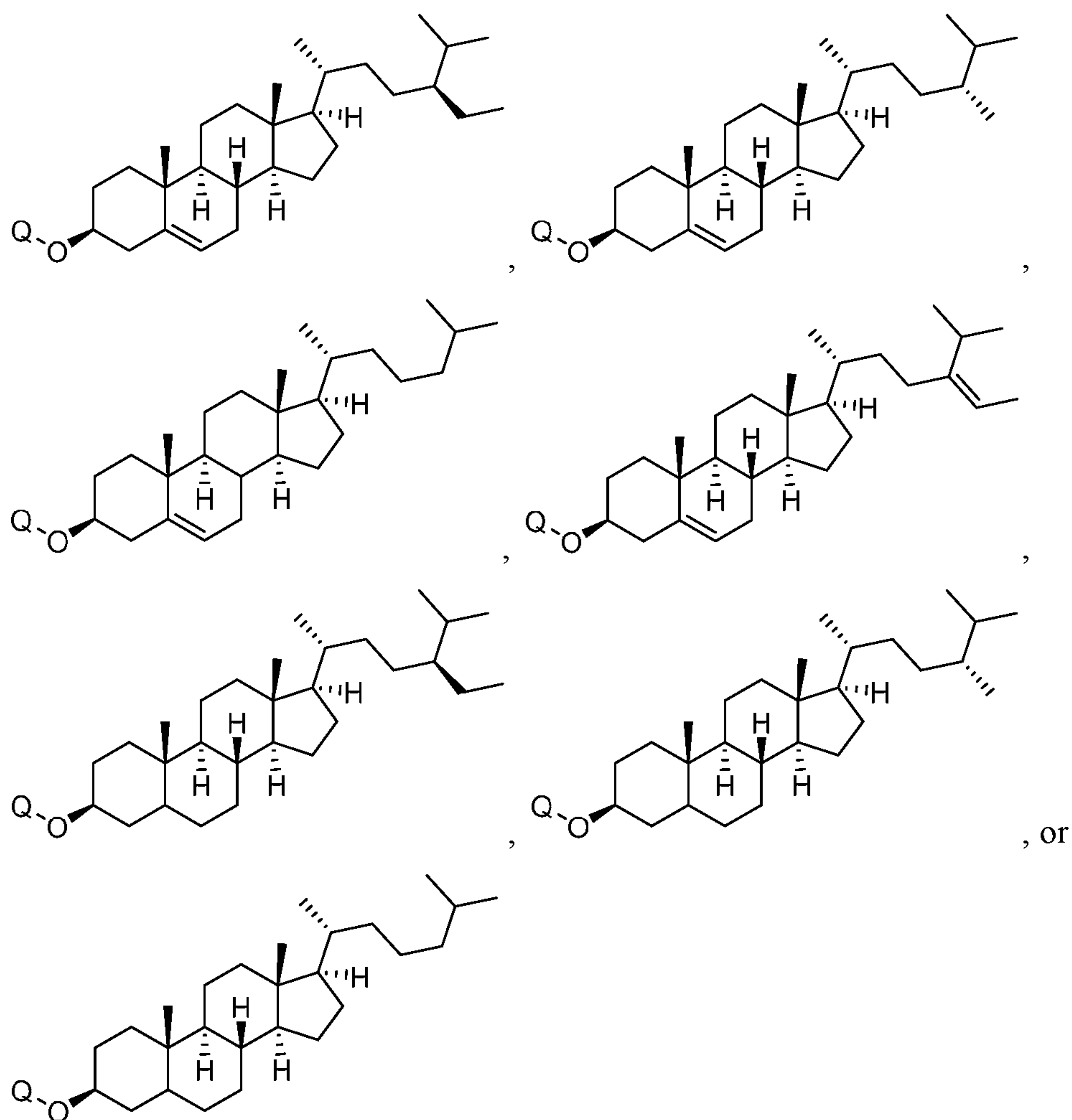
19. The nanoparticle composition of claim 17 or 18, wherein Q is



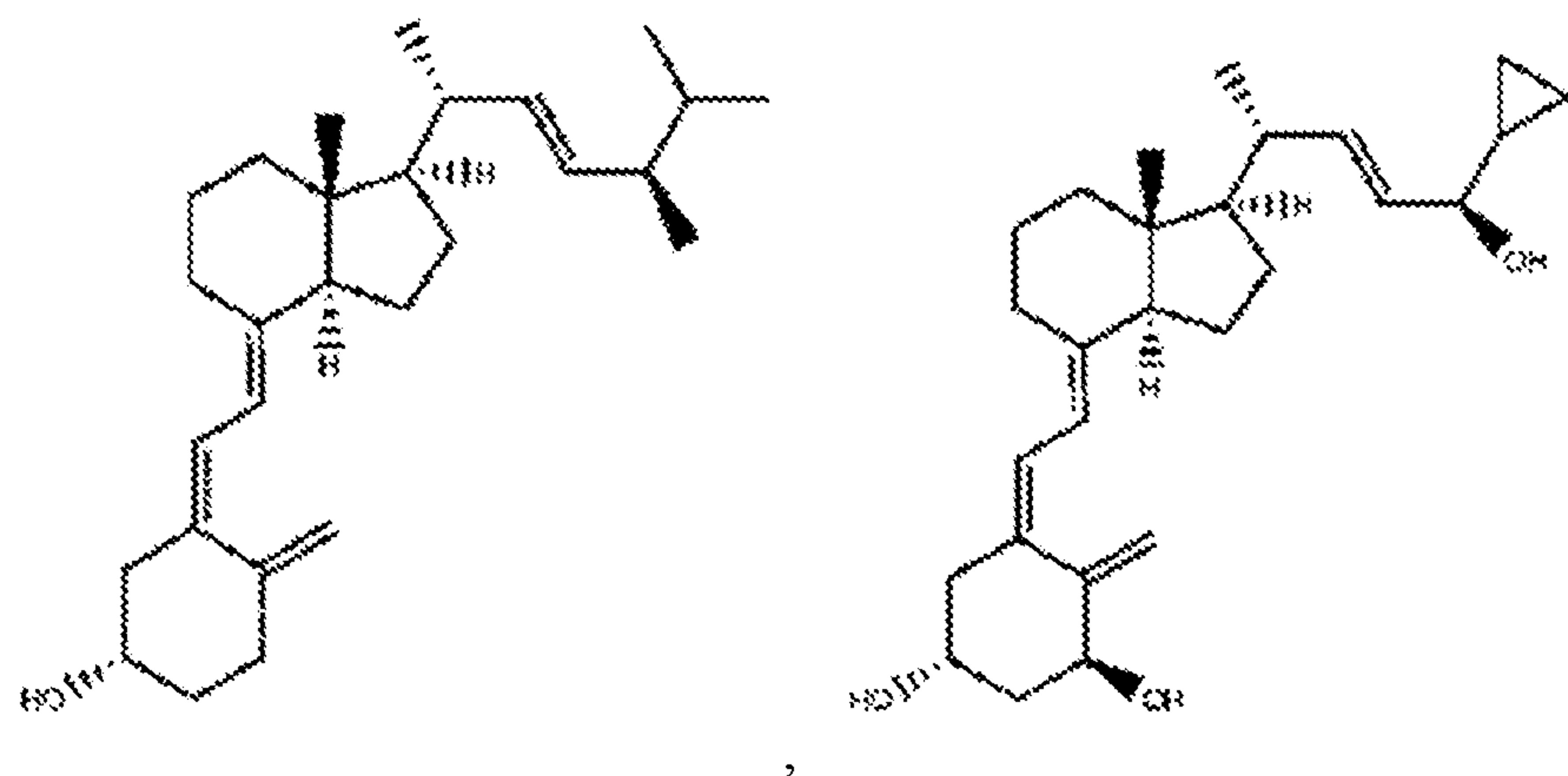
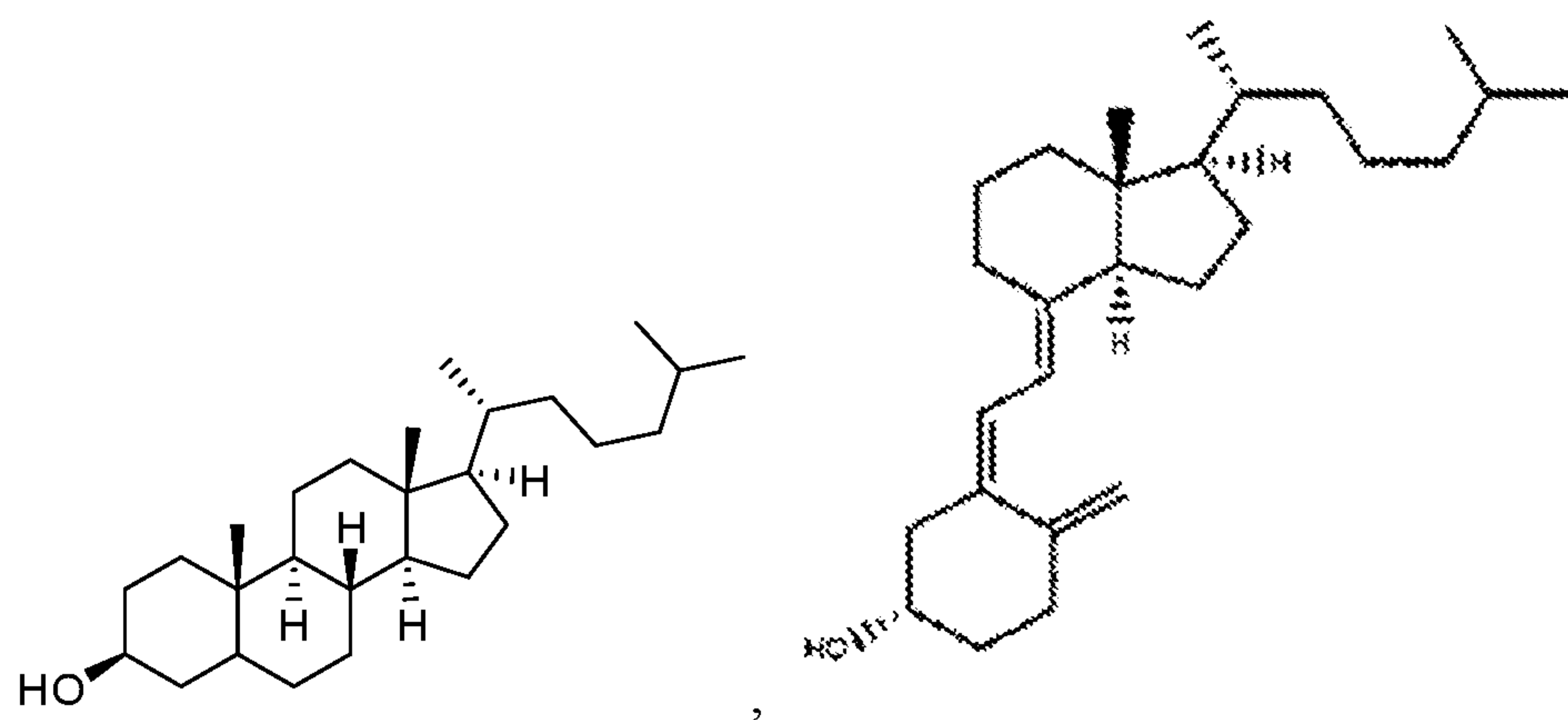
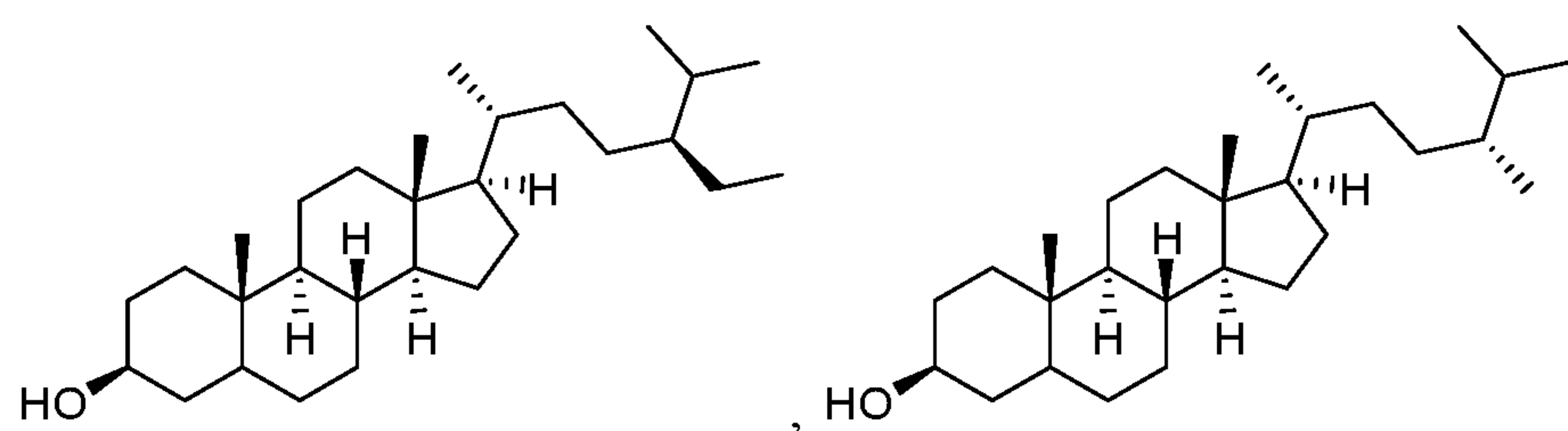
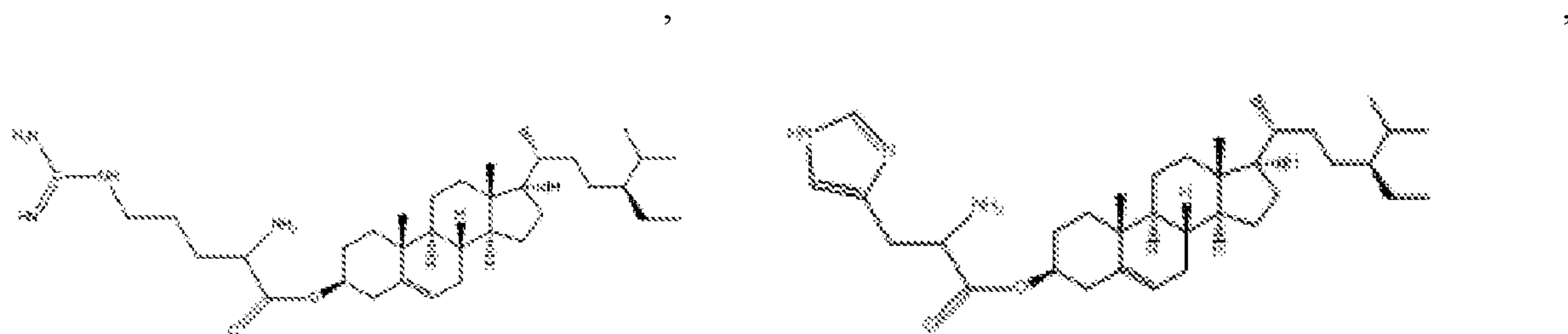
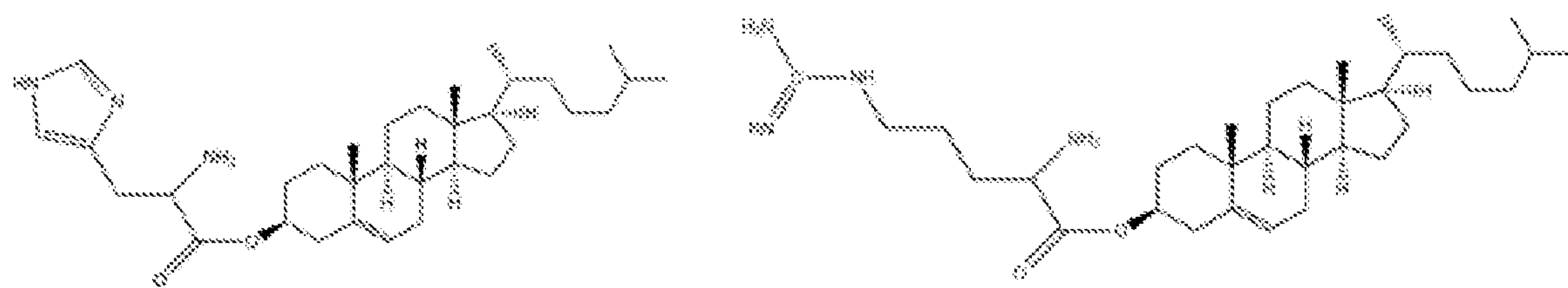
20. The nanoparticle composition of any one of claims 17-19, wherein the cholesterol derivative

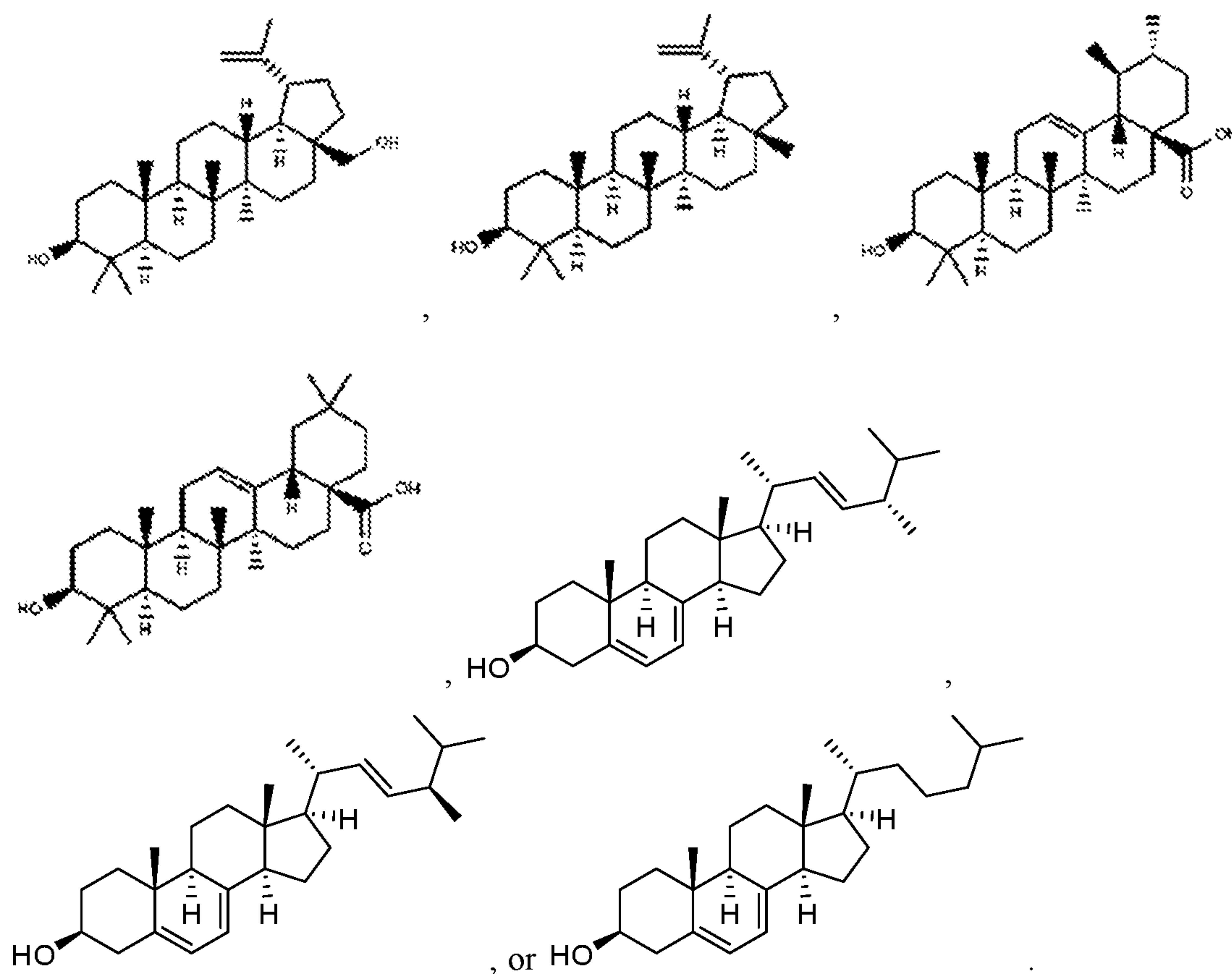


21. The nanoparticle composition of any one of claims 17-20, wherein the cholesterol derivative has a formula:

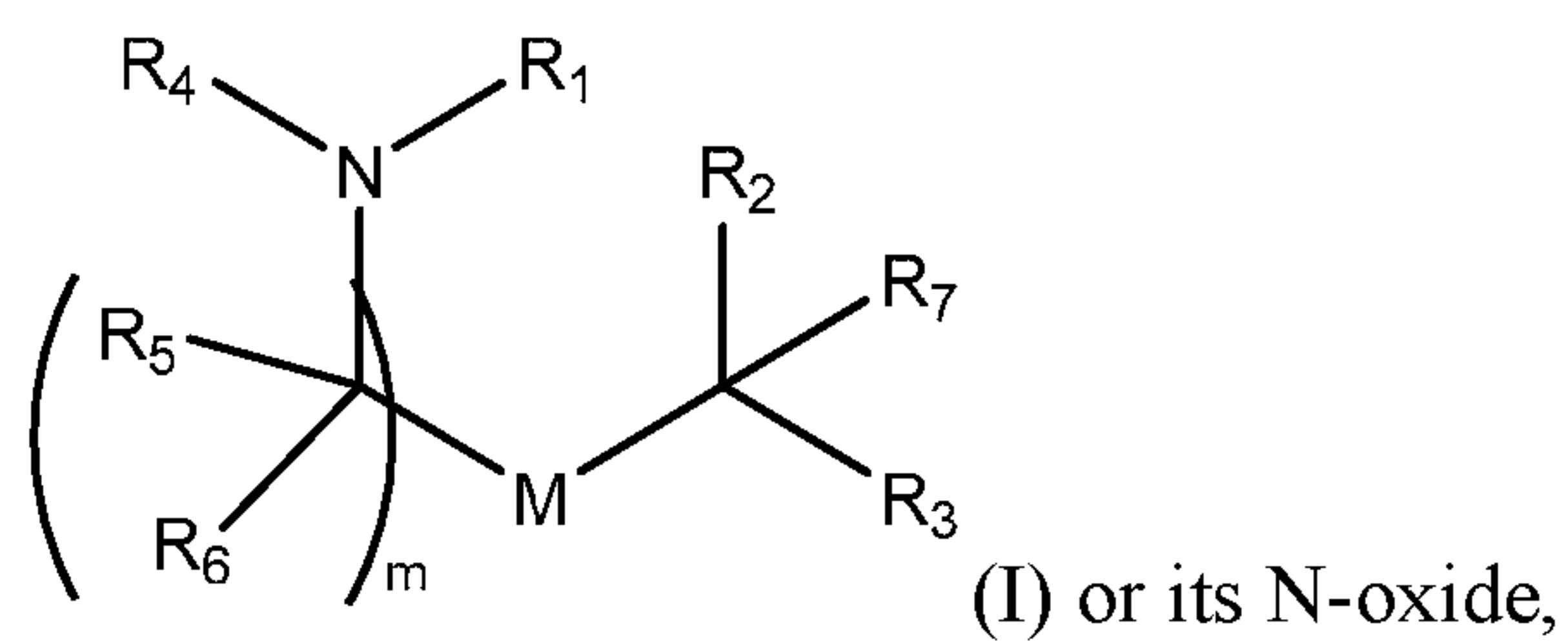


22. The nanoparticle composition of any one of claims 17-21, wherein the cholesterol derivative has a formula of any of the following:





23. The nanoparticle composition of any one of the preceding claims, wherein the ionizable lipid is a compound of Formula (I):



or a salt or isomer thereof, wherein

R_1 is selected from the group consisting of C_{5-30} alkyl, C_{5-20} alkenyl, $-R^*YR''$, $-YR''$, and $-R''M'R'$;

R_2 and R_3 are independently selected from the group consisting of H, C_{1-14} alkyl, C_{2-14} alkenyl, $-R^*YR''$, $-YR''$, and $-R^*OR''$, or R_2 and R_3 , together with the atom to which they are attached, form a heterocycle or carbocycle;

R₄ is selected from the group consisting of hydrogen, a C₃₋₆ carbocycle, $-(CH_2)_nQ$, $-(CH_2)_nCHQR$, $-CHQR$, $-CQ(R)_2$, and unsubstituted C₁₋₆ alkyl, where Q is selected from a carbocycle, heterocycle, $-OR$, $-O(CH_2)_nN(R)_2$, $-C(O)OR$, $-OC(O)R$, $-CX_3$, $-CX_2H$, $-CXH_2$, $-CN$, $-N(R)_2$, $-C(O)N(R)_2$, $-N(R)C(O)R$, $-N(R)S(O)_2R$, $-N(R)C(O)N(R)_2$, $-N(R)C(S)N(R)_2$, $-N(R)R_8$, $-N(R)S(O)_2R_8$, $-O(CH_2)_nOR$, $-N(R)C(=NR_9)N(R)_2$, $-N(R)C(=CHR_9)N(R)_2$, $-OC(O)N(R)_2$, $-N(R)C(O)OR$, $-N(OR)C(O)R$, $-N(OR)S(O)_2R$, $-N(OR)C(O)OR$, $-N(OR)C(O)N(R)_2$, $-N(OR)C(S)N(R)_2$, $-N(OR)C(=NR_9)N(R)_2$, $-N(OR)C(=CHR_9)N(R)_2$, $-C(=NR_9)N(R)_2$, $-C(=NR_9)R$, $-C(O)N(R)OR$, and $-C(R)N(R)_2C(O)OR$, and each n is independently selected from 1, 2, 3, 4, and 5;

each R₅ is independently selected from the group consisting of C₁₋₃ alkyl, C₂₋₃ alkenyl, and H;

each R₆ is independently selected from the group consisting of C₁₋₃ alkyl, C₂₋₃ alkenyl, and H;

M and M' are independently selected from $-C(O)O-$, $-OC(O)-$, $-OC(O)-M''-C(O)O-$, $-C(O)N(R')-$, $-N(R')C(O)-$, $-C(O)-$, $-C(S)-$, $-C(S)S-$, $-SC(S)-$, $-CH(OH)-$, $-P(O)(OR')O-$, $-S(O)_2-$, $-S-$, an aryl group, and a heteroaryl group, in which M'' is a bond, C₁₋₁₃ alkyl or C₂₋₁₃ alkenyl;

R₇ is selected from the group consisting of C₁₋₃ alkyl, C₂₋₃ alkenyl, and H;

R₈ is selected from the group consisting of C₃₋₆ carbocycle and heterocycle;

R₉ is selected from the group consisting of H, CN, NO₂, C₁₋₆ alkyl, $-OR$, $-S(O)_2R$, $-S(O)_2N(R)_2$, C₂₋₆ alkenyl, C₃₋₆ carbocycle and heterocycle;

each R is independently selected from the group consisting of C₁₋₃ alkyl, C₂₋₃ alkenyl, and H;

each R' is independently selected from the group consisting of C₁₋₁₈ alkyl, C₂₋₁₈ alkenyl, $-R^*YR''$, $-YR''$, and H;

each R'' is independently selected from the group consisting of C₃₋₁₅ alkyl and C₃₋₁₅ alkenyl;

each R* is independently selected from the group consisting of C₁₋₁₂ alkyl and C₂₋₁₂ alkenyl;

each Y is independently a C₃₋₆ carbocycle;

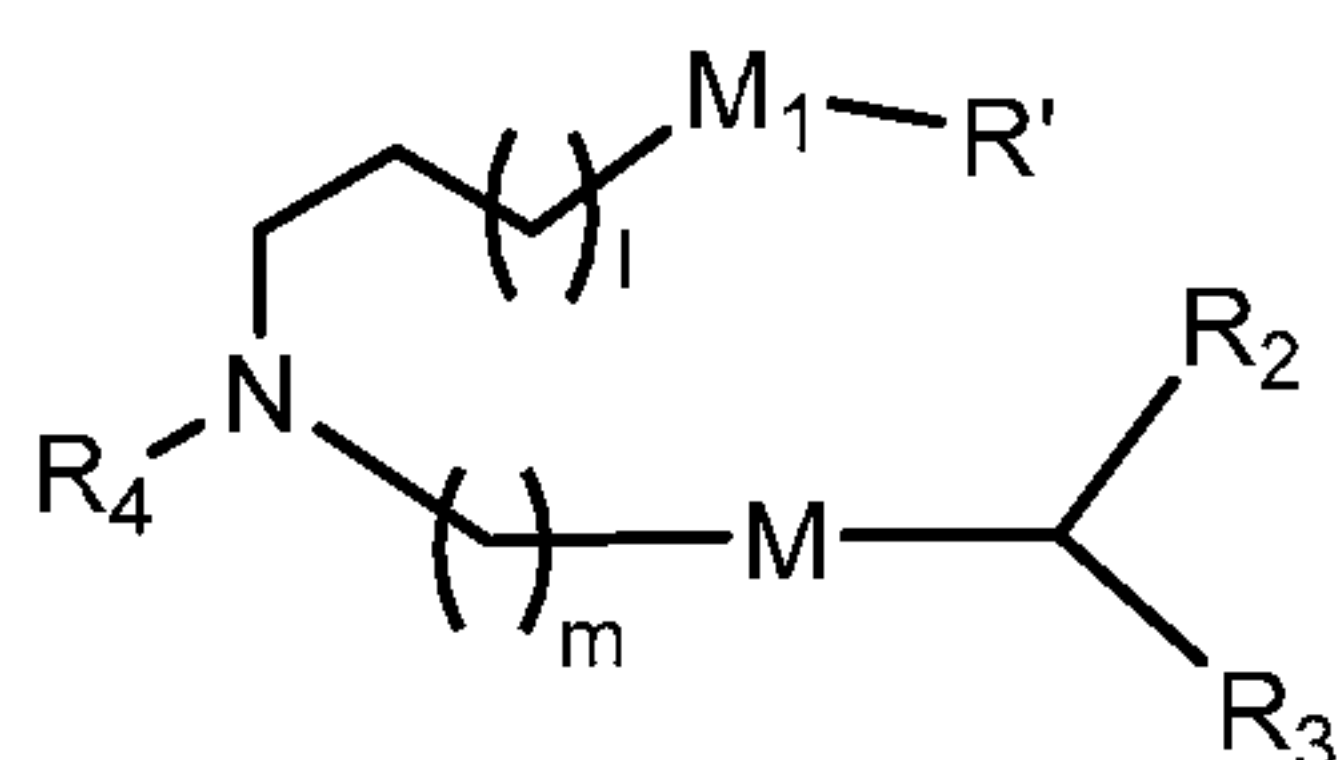
each X is independently selected from the group consisting of F, Cl, Br, and I; and

m is selected from 5, 6, 7, 8, 9, 10, 11, 12, and 13.

24. The nanoparticle composition of claim 23, wherein when R_4 is $-(CH_2)_nQ$, $-(CH_2)_nCHQR$, $-CHQR$, or $-CQ(R)_2$, then (i) Q is not $-N(R)_2$ when n is 1, 2, 3, 4 or 5, or (ii) Q is not 5, 6, or 7-membered heterocycloalkyl when n is 1 or 2.

25. The nanoparticle composition of claim 23 or 24, wherein R_1 is different from $-(CHR_5R_6)_m-M-CR_2R_3R_7$.

26. The nanoparticle composition of any one of claims 23-25, wherein the ionizable lipid is a compound of Formula (IA):



(IA) or its N-oxide,

or a salt or isomer thereof, wherein

l is selected from 1, 2, 3, 4, and 5;

m is selected from 5, 6, 7, 8, and 9;

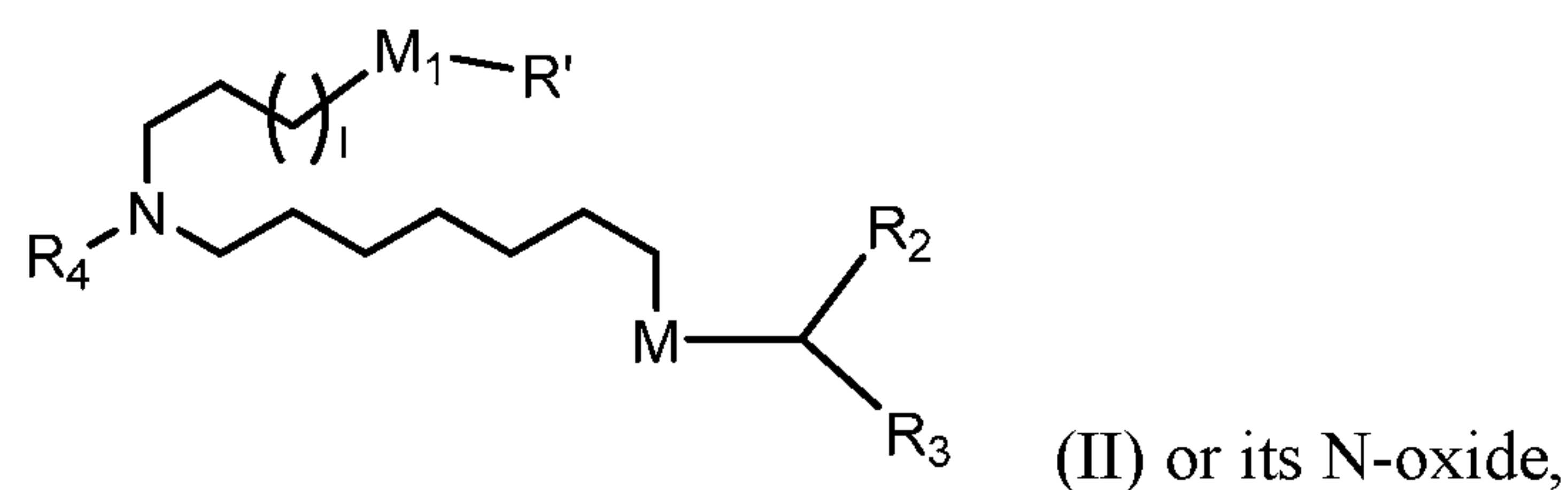
M_1 is a bond or M' ;

R_4 is hydrogen, unsubstituted C_{1-3} alkyl, or $-(CH_2)_nQ$, in which Q is OH, $-NHC(S)N(R)_2$, $-NHC(O)N(R)_2$, $-N(R)C(O)R$, $-N(R)S(O)_2R$, $-N(R)R_8$, $-N(R)S(O)_2R_8$, $-NHC(=NR_9)N(R)_2$, $-NHC(=CHR_9)N(R)_2$, $-OC(O)N(R)_2$, $-N(R)C(O)OR$, $-N(OR)C(O)R$, $-N(OR)S(O)_2R$, $-N(OR)C(O)OR$, $-N(OR)C(O)N(R)_2$, $-N(OR)C(S)N(R)_2$, $-N(OR)C(=NR_9)N(R)_2$, $-N(OR)C(=CHR_9)N(R)_2$, heteroaryl or heterocycloalkyl;

M and M' are independently selected from $-C(O)O-$, $-OC(O)-$, $-OC(O)-M''-C(O)O-$, $-C(O)N(R')-$, $-P(O)(OR')O-$, $-S-S-$, an aryl group, and a heteroaryl group; and

R_2 and R_3 are independently selected from the group consisting of H, C_{1-14} alkyl, and C_{2-14} alkenyl.

27. The nanoparticle composition of claim 23 or 24, wherein the ionizable lipid is a compound of Formula (II):



or a salt or isomer thereof, wherein

1 is selected from 1, 2, 3, 4, and 5;

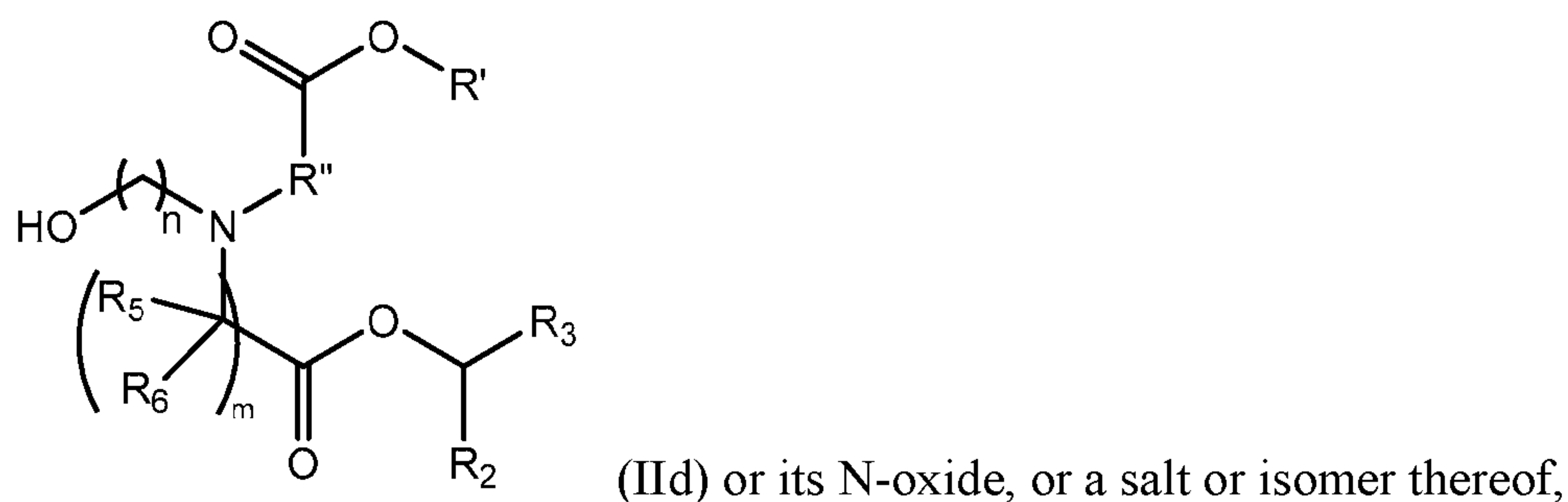
M_1 is a bond or M' ;

R₄ is hydrogen, unsubstituted C₁₋₃ alkyl, or -(CH₂)_nQ, in which n is 2, 3, or 4 and Q is OH, -NHC(S)N(R)₂, -NHC(O)N(R)₂, -N(R)C(O)R, -N(R)S(O)₂R, -N(R)R₈, -N(R)S(O)₂R₈, -NHC(=NR₉)N(R)₂, -NHC(=CHR₉)N(R)₂, -OC(O)N(R)₂, -N(R)C(O)OR, -N(OR)C(O)R, -N(OR)S(O)₂R, -N(OR)C(O)OR, -N(OR)C(O)N(R)₂, -N(OR)C(S)N(R)₂, -N(OR)C(=NR₉)N(R)₂, -N(OR)C(=CHR₉)N(R)₂, heteroaryl or heterocycloalkyl;

M and M' are independently selected from -C(O)O-, -OC(O)-, -C(O)N(R')-, -OC(O)-M''-C(O)O-, -P(O)(OR')O-, -S-S-, an aryl group, and a heteroaryl group; and

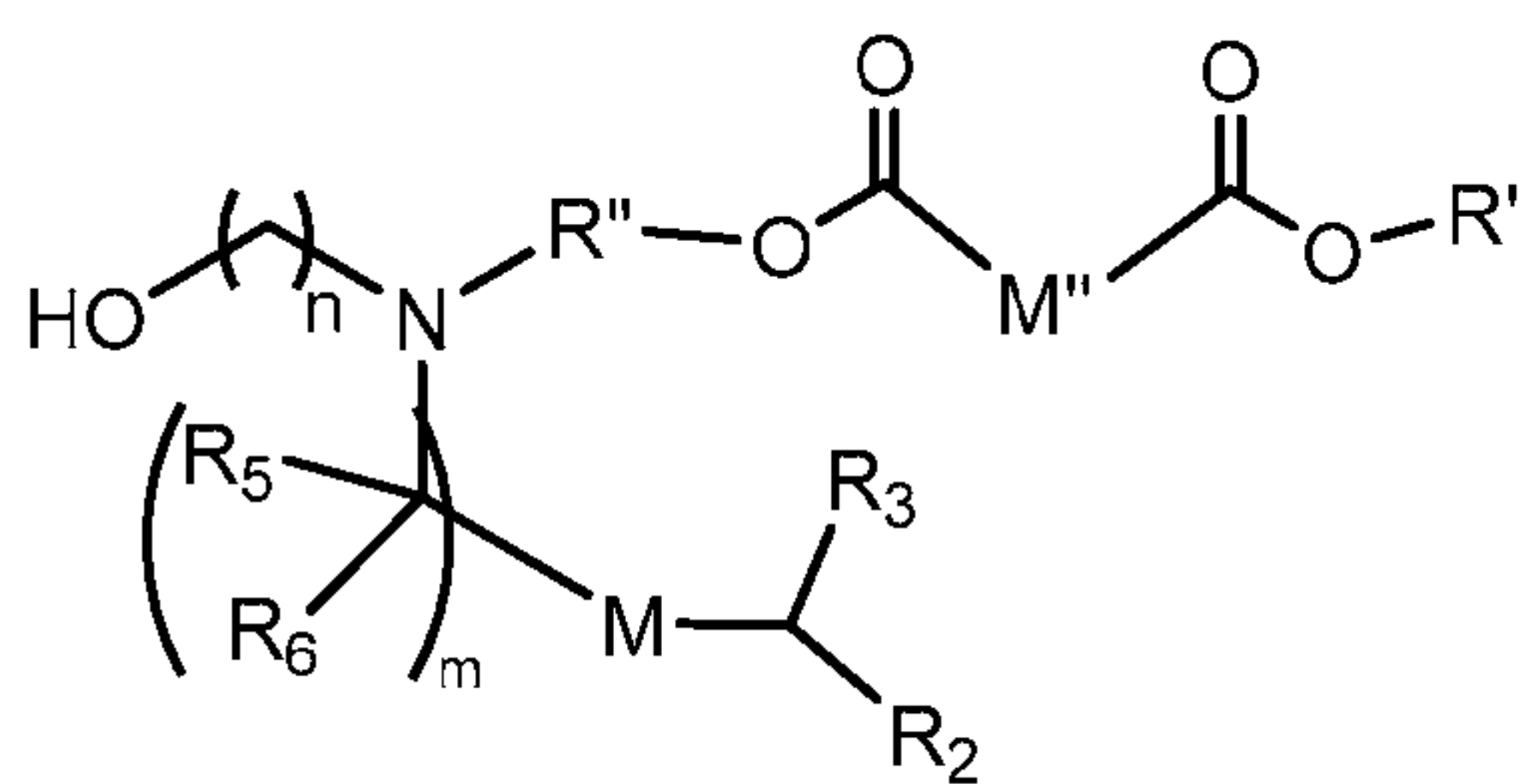
R₂ and R₃ are independently selected from the group consisting of H, C₁₋₁₄ alkyl, and C₂₋₁₄ alkenyl.

28. The nanoparticle composition of any one of claims 23-27, wherein the ionizable lipid is a compound of Formula (IIId):



wherein R₂ and R₃ are independently selected from the group consisting of C₅₋₁₄ alkyl and C₅₋₁₄ alkenyl, and n is selected from 2, 3, and 4.

29. The nanoparticle composition of any one of claims 23-27, wherein the ionizable lipid is a compound of Formula (II_f):



(IIIf) or its N-oxide, or a salt or isomer thereof,

wherein M is -C(O)O- or -OC(O)-, M' is C₁₋₆ alkyl or C₂₋₆ alkenyl, R₂ and R₃ are independently selected from the group consisting of C₅₋₁₄ alkyl and C₅₋₁₄ alkenyl, and n is selected from 2, 3, and 4.

30. The nanoparticle composition of any one of claims 23-29, wherein the ionizable lipid is selected from the group consisting of Compounds 1-280.

31. The nanoparticle composition of any one of claims 17-22, wherein the ionizable lipid is selected from the group consisting of 1-Linoleoyl-2-linoleyloxy-3-dimethylaminopropane (DLin-2-DMAP); 1,2-Dilinoleylcarbamoyloxy-3-dimethylaminopropane (DLin-C-DAP); 1,2-Dilinoleoyl-3-dimethylaminopropane (DLin-DAP); 1,2-Dilinoleyloxy-N,N-dimethylaminopropane (DLin-DMA); 2,2-Dilinoleyl-4-dimethylaminomethyl-[1,3]-dioxolane (DLin-K-DMA); 2,2-dilinoleyl-4-(2-dimethylaminoethyl)-[1,3]-dioxolane (DLin-KC2-DMA); (6Z,9Z,28Z,31Z)-heptatriaconta-6,9,28,31-tetraen-19-yl 4-(dimethylamino)butanoate (DLin-MC3-DMA); 1,2-dioleoyl-3-dimethylammonium propane (DODAP); N,N-dimethyl-(2,3-dioleyloxy)propylamine (DODMA); dioctadecylamidoglycyl carboxyspermine (DOGS); Spermine cholesterylcarbamate(GL-67); bis-guanidinium- spermidine-cholesterol (BGTC); 3 β -(N—(N',N'-dimethylaminoethane)-carbamoyl)cholesterol (DC-Chol); 1,1'-(2-(4-(2-((2-(bis(2-hydroxydodecyl)amino)ethyl)(2-hydroxydodecyl)amino)ethyl)piperazin-1-yl)ethylazanediyl)didodecan-2-ol (C12-200); N-t-butyl-N'-tetradecylamino-propionamidine (*diC14-amidine*); Dimethyldioctadecylammoniumbromide (DDAB); N-(1,2-dimyristyloxyprop-3-yl)-N,N-dimethyl-N-hydroxyethyl ammonium bromide (DMRIE); N,N-dioleoyl-N,N-dimethylammonium chloride (DODAC); Dioleyloxypropyl-3-dimethyl hydroxyethyl ammonium bromide (DORIE); N-(1-(2,3-dioleyloxy)propyl)-N-2-(sperminecarboxamido)ethyl)-N,N-dimethylammonium trifluoroacetate (DOSPA); 1,2-dioleoyltrimethyl ammonium propane chloride (DOTAP); N-(1-(2,3-dioleyloxy)propyl)-N,N,N-

trimethylammonium chloride (DOTMA); Aminopropyl-dimethyl-bis(dodecyloxy)-propanaminiumbromide (GAP-DLRIE); or a combination thereof.

32. The nanoparticle composition of any one of claims 2-5 and 7-16, wherein the ionizable lipid is selected from the group consisting of 1-Linoleoyl-2-linoleyloxy-3-dimethylaminopropane (DLin-2-DMAP); 1,2-Dilinoleylcarbamoxyloxy-3-dimethylaminopropane (DLin-C-DAP); 1,2-Dilinoleoyl-3-dimethylaminopropane (DLin-DAP); 1,2-Dilinoleyloxy-N,N-dimethylaminopropane (DLin-DMA); 2,2-Dilinoleyl-4-dimethylaminomethyl-[1,3]-dioxolane (DLin-K-DMA); 2,2-dilinoleyl-4-(2-dimethylaminoethyl)-[1,3]-dioxolane (DLin-KC2-DMA); (6Z,9Z,28Z,31Z)-heptatriaconta-6,9,28,31-tetraen-19-yl 4-(dimethylamino)butanoate (DLin-MC3-DMA); 1,2-dioleoyl-3-dimethylammonium propane (DODAP); N,N-dimethyl-(2,3-dioleyloxy)propylamine (DODMA); dioctadecylamidoglycyl carboxyspermine (DOGS); Spermine cholesterylcarbamate (GL-67); bis-guanidinium-spermidine-cholesterol (BGTC); 3 β -(N—(N',N'-dimethylaminoethane)-carbamoxy)cholesterol (DC-Chol); 1,1'-(2-(4-(2-((2-(bis(2-hydroxydodecyl)amino)ethyl)(2-hydroxydodecyl)amino)ethyl)piperazin-1-yl)ethylazanediyldidodecan-2-ol (C12-200); N-t-butyl-N'-tetradecylamino-propionamidine (*diC14-amidine*); Dimethyldioctadecylammoniumbromide (DDAB); N-(1,2-dimyristyloxyprop-3-yl)-N,N-dimethyl-N-hydroxyethyl ammonium bromide (DMRIE); N,N-dioleoyl-N,N-dimethylammonium chloride (DODAC); Dioleyloxypropyl-3-dimethyl hydroxyethyl ammonium bromide (DORIE); N-(1-(2,3-dioleyloxy)propyl)-N-2-(sperminecarboxamido)ethyl)-N,N-dimethylammonium trifluoroacetate (DOSPA); 1,2-dioleoyltrimethyl ammonium propane chloride (DOTAP); N-(1-(2,3-dioleyloxy)propyl)-N,N,N-trimethylammonium chloride (DOTMA); Aminopropyl-dimethyl-bis(dodecyloxy)-propanaminiumbromide (GAP-DLRIE); or a combination thereof.

33. The nanoparticle composition of any one of the preceding claims, wherein the phospholipid is selected from the group consisting of 1,2-dilinoleoyl-sn-glycero-3-phosphocholine (DLPC), 1,2-dimyristoyl-sn-glycero-phosphocholine (DMPC), 1,2-dioleoyl-sn-glycero-3-phosphocholine (DOPC), 1,2-dipalmitoyl-sn-glycero-3-phosphocholine (DPPC), 1,2-distearoyl-sn-glycero-3-phosphocholine (DSPC), 1,2-diundecanoyl-sn-glycero-phosphocholine (DUPC), 1-palmitoyl-2-oleoyl-sn-glycero-3-phosphocholine (POPC), 1,2-di-O-octadecenyl-sn-glycero-3-phosphocholine (18:0 Diether PC),

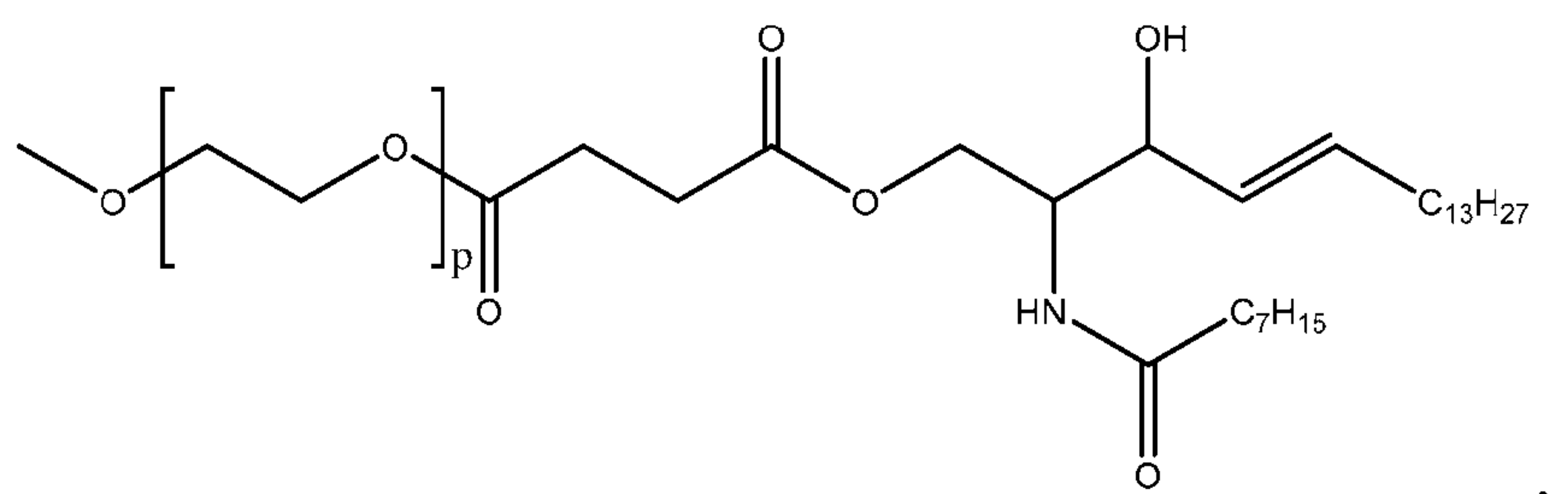
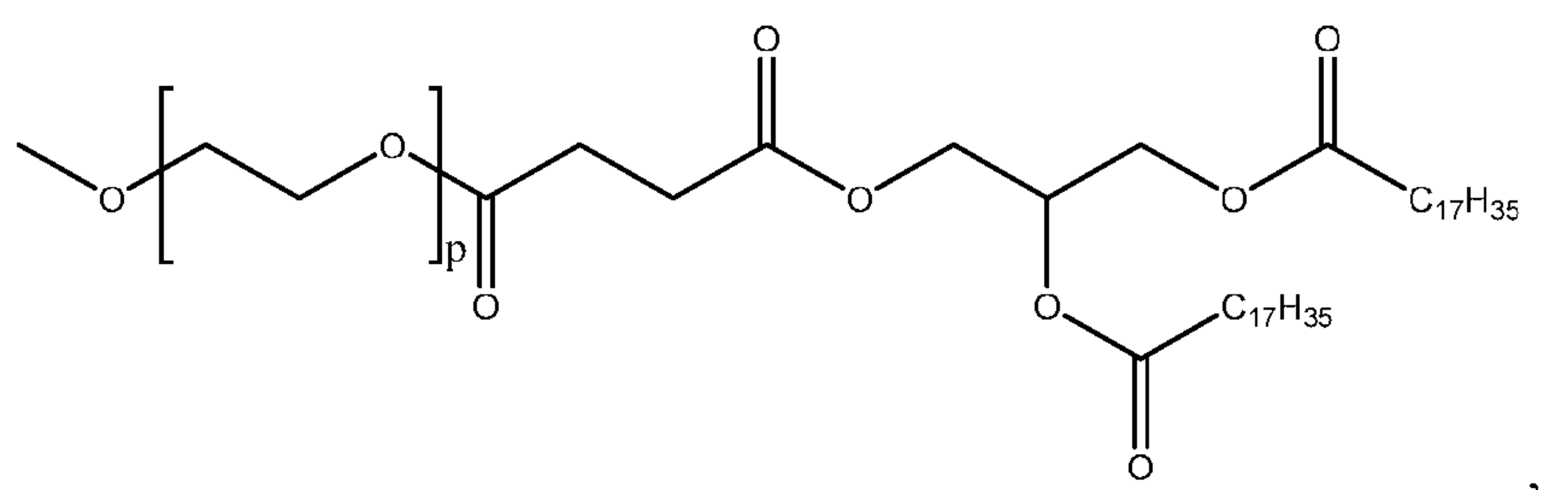
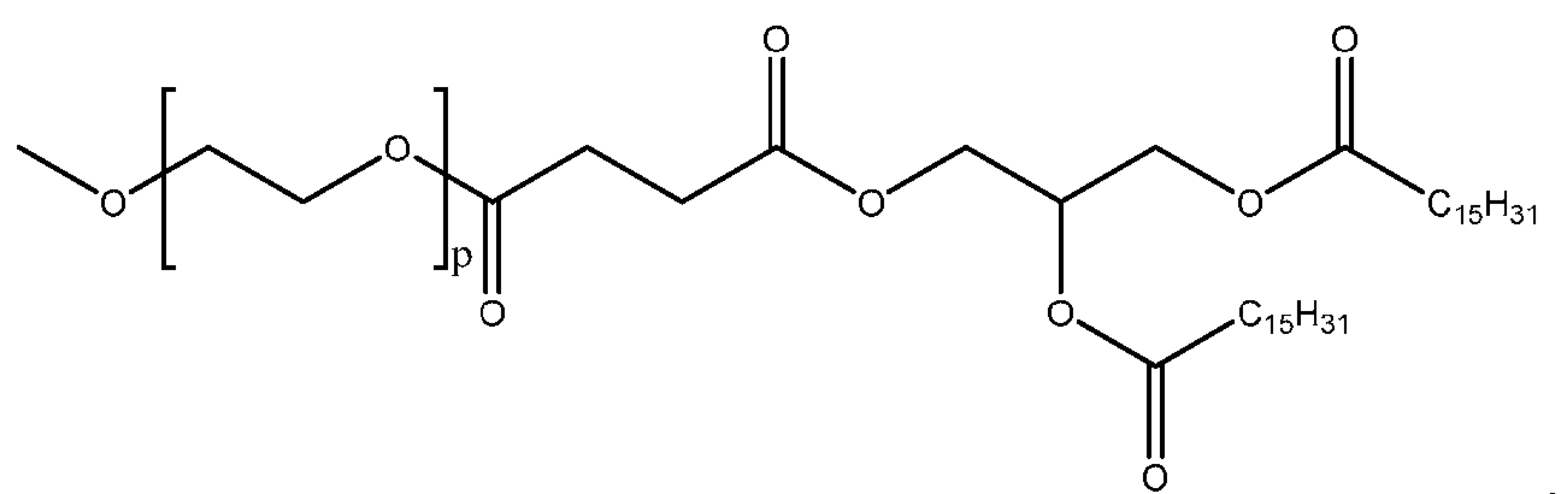
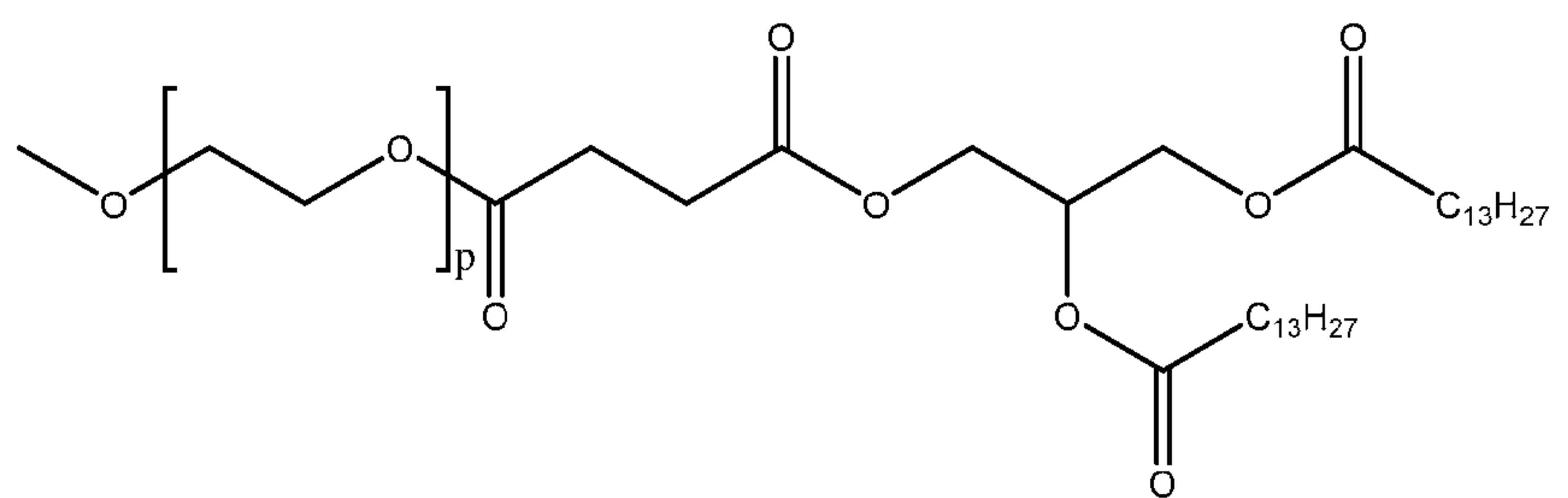
1-oleoyl-2-cholesterylhemisuccinoyl-*sn*-glycero-3-phosphocholine (OChemPC),
 1-hexadecyl-*sn*-glycero-3-phosphocholine (C16 Lyso PC),
 1,2-dilinolenoyl-*sn*-glycero-3-phosphocholine, 1,2-diarachidonoyl-*sn*-glycero-3-phosphocholine,
 1,2-didocosaheptaenoyl-*sn*-glycero-3-phosphocholine,
 1,2-dioleoyl-*sn*-glycero-3-phosphoethanolamine (DOPE),
 1,2-diphytanoyl-*sn*-glycero-3-phosphoethanolamine (ME 16.0 PE),
 1,2-distearoyl-*sn*-glycero-3-phosphoethanolamine,
 1,2-dilinoleoyl-*sn*-glycero-3-phosphoethanolamine,
 1,2-dilinolenoyl-*sn*-glycero-3-phosphoethanolamine,
 1,2-diarachidonoyl-*sn*-glycero-3-phosphoethanolamine,
 1,2-didocosaheptaenoyl-*sn*-glycero-3-phosphoethanolamine,
 1,2-dioleoyl-*sn*-glycero-3-phospho-rac-(1-glycerol) sodium salt (DOPG),
 dipalmitoylphosphatidylglycerol (DPPG), palmitoyl-oleoylphosphatidylethanolamine (POPE),
 distearoyl-phosphatidyl-ethanolamine (DSPE), dipalmitoyl phosphatidyl ethanolamine (DPPE),
 dimyristoylphosphoethanolamine (DMPE), 1-stearoyl-2-oleoyl-phosphatidylethanolamine (SOPE),
 1-stearoyl-2-oleoyl-phosphatidylcholine (SOPC), sphingomyelin, phosphatidylcholine,
 phosphatidylethanolamine, phosphatidylserine, phosphatidylinositol, phosphatidic acid,
 palmitoyl-oleoyl phosphatidylcholine, lysophosphatidylcholine, lysophosphatidylethanolamine
 (LPE), and mixtures thereof.

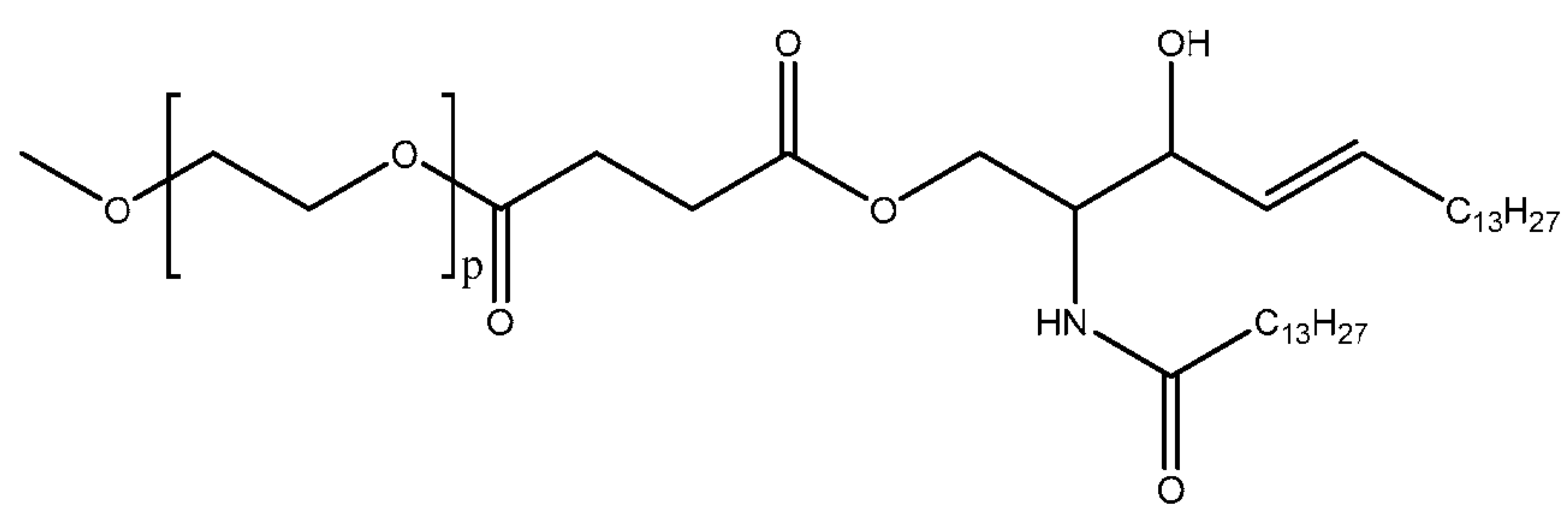
34. The nanoparticle composition of any one of the preceding claims, wherein the lipid component further comprises a PEG lipid.

35. The nanoparticle composition of claim 34, wherein the PEG lipid is selected from the group consisting of a PEG-modified phosphatidylethanolamine, a PEG-modified phosphatidic acid, a PEG-modified ceramide, a PEG-modified dialkylamine, a PEG-modified diacylglycerol, a PEG-modified dialkylglycerol, and mixtures thereof.

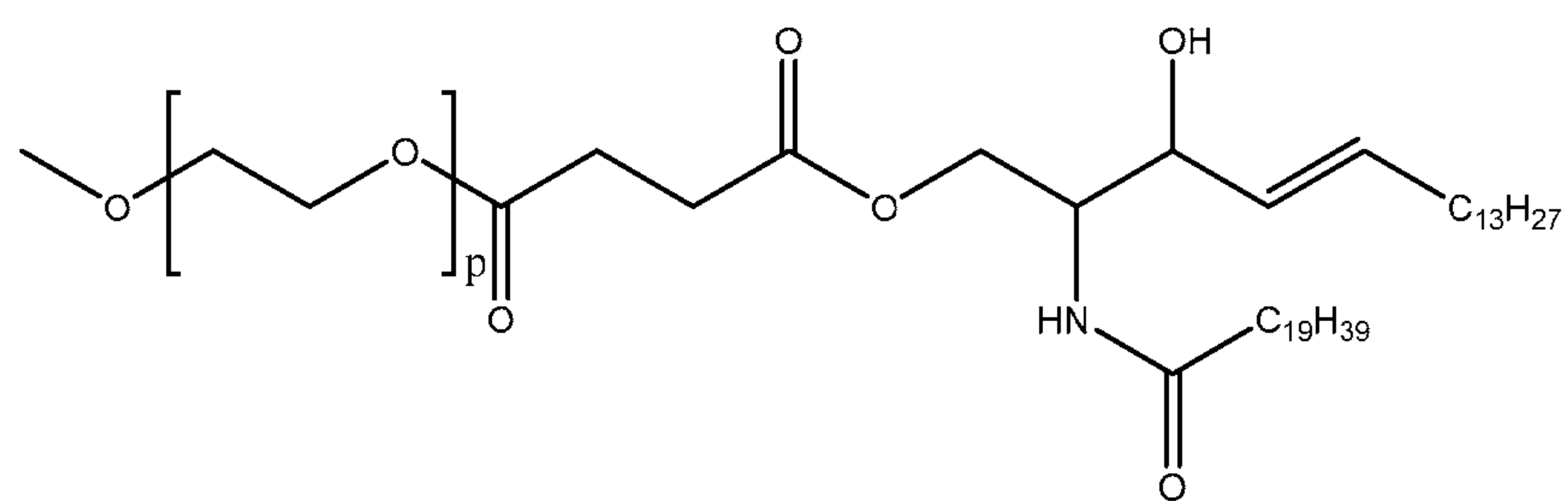
36. The nanoparticle composition of claim 34 or 35, wherein the PEG lipid includes a PEG moiety having a size of from about 1000 Da to about 20 kDa.

37. The nanoparticle composition of any one of claims 34-36, wherein the PEG lipid is selected from

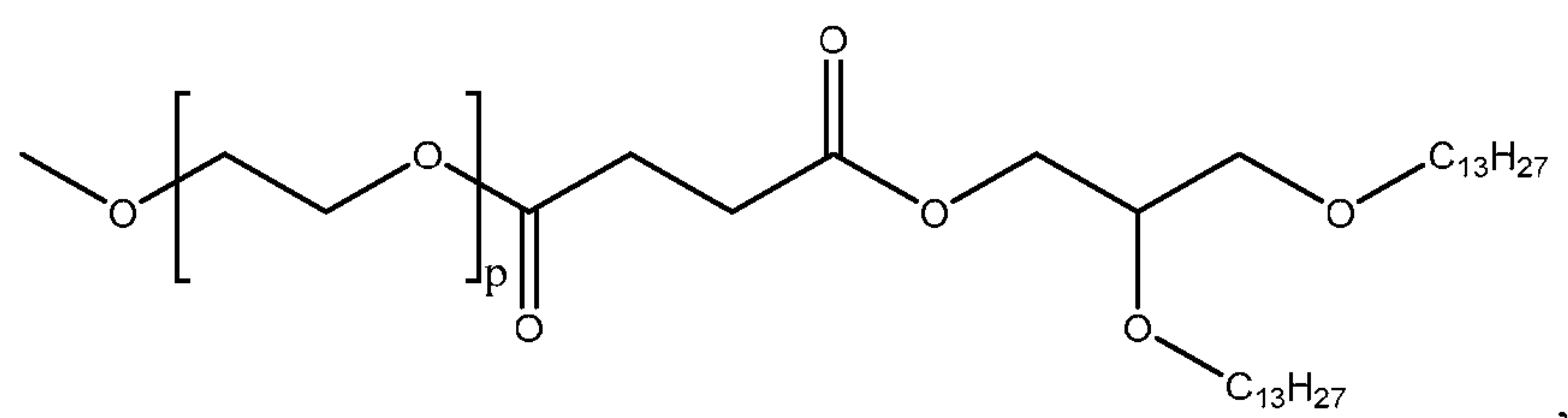




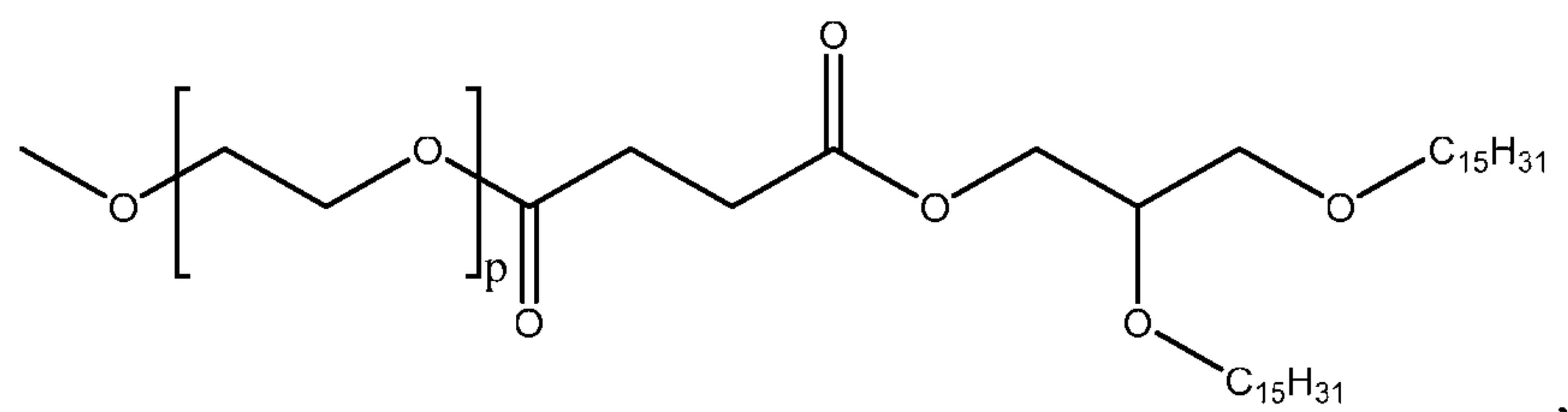
,



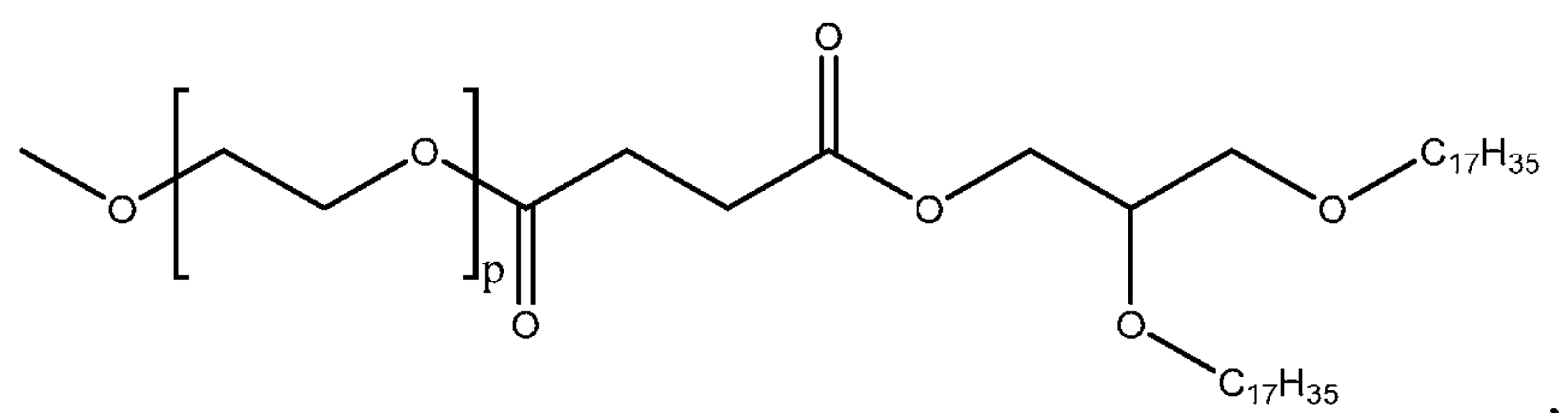
,



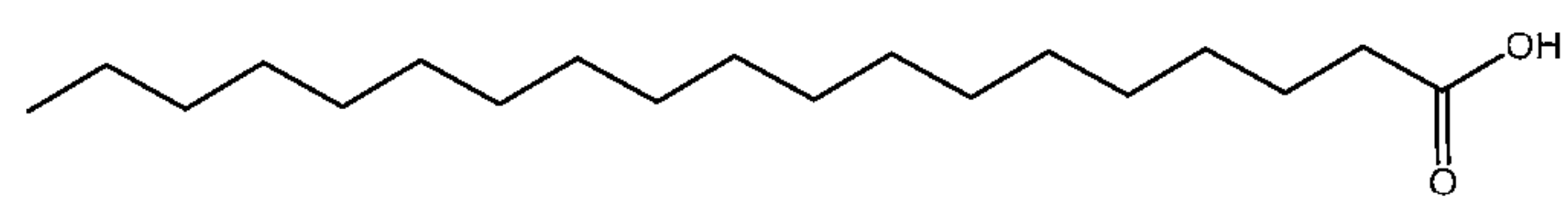
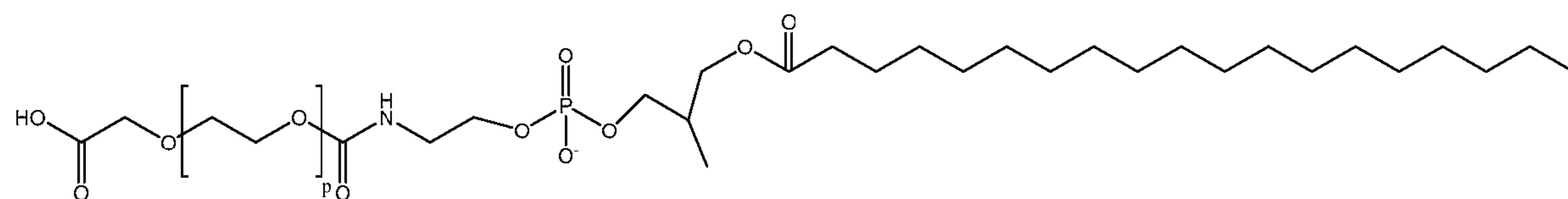
,



,



, or



;

wherein p is from 1 to 40.

38. The nanoparticle composition of any one of the preceding claims, wherein the composition comprises about 30 mol % to about 60 mol % ionizable lipid, about 0.01 mol % to about 30 mol % phospholipid, about 18.5 mol % to about 48.5 mol % first and second sterols combined, and about 0 mol % to about 10 mol % PEG lipid.

39. The nanoparticle composition of any one of the preceding claims, wherein the composition comprises about 45 mol % to about 65 mol % ionizable lipid, about 5 mol % to about 10 mol % phospholipid, about 25 mol % to about 40 mol % first and second sterols combined, and about 0.5 mol % to about 10 mol % PEG lipid.

40. The nanoparticle composition of any one of the preceding claims, wherein the composition comprises about 50 mol % ionizable lipid, about 10 mol % phospholipid, about 38.5 mol % first and second sterols combined, and about 1.5 mol % PEG lipid.

41. The nanoparticle composition of any one of the preceding claims, wherein the composition further comprises a cationic and/or ionizable lipid selected from the group consisting of 3-(didodecylamino)-N1,N1,4-tridodecyl-1-piperazineethanamine (KL10), N1-[2-(didodecylamino)ethyl]-N1,N4,N4-tridodecyl-1,4-piperazinediethanamine (KL22), 14,25-ditridecyl-15,18,21,24-tetraaza-octatriacontane (KL25), 1,2-dilinoleyloxy-N,N-dimethylaminopropane (DLin-DMA), 2,2-dilinoleyl-4-dimethylaminomethyl-[1,3]-dioxolane (DLin-K-DMA), heptatriaconta-6,9,28,31-tetraen-19-yl 4-(dimethylamino)butanoate (DLin-MC3-DMA), 2,2-dilinoleyl-4-(2-dimethylaminoethyl)-[1,3]-dioxolane (DLin-KC2-DMA), 1,2-dioleyloxy-N,N-dimethylaminopropane (DODMA), 2-({8-[(3 β)-cholest-5-en-3-yloxy]octyl}oxy)-N,N-dimethyl-3-[(9Z,12Z)-octadeca-9,12-dien-1-yloxy]propan-1-amine (Octyl-CLinDMA), (2R)-2-({8-[(3 β)-cholest-5-en-3-yloxy]octyl}oxy)-N,N-dimethyl-3-[(9Z,12Z)-octadeca-9,12-dien-1-yloxy]propan-1-amine (Octyl-CLinDMA (2R)),

(2S)-2-({8-[(3 β)-cholest-5-en-3-yloxy]octyl}oxy)-N,N-dimethyl-3-[(9Z,12Z)-octadeca-9,12-dien-1-yloxy]propan-1-amine (Octyl-CLinDMA (2S)),
 (12Z, 15Z)-N,N-dimethyl-2-nonylhenicosa-12,15-dien-1-amine, and
 N,N-dimethyl-1-{(1S,2R)-2-octylcyclopropyl}heptadecan-8-amine.

42. The nanoparticle composition of any one of the preceding claims, further comprising a therapeutic and/or prophylactic agent.

43. The nanoparticle composition of claim 42, wherein the therapeutic and/or prophylactic agent is a ribonucleic acid (RNA).

44. The nanoparticle composition of claim 43, wherein the composition has about 0.025 mg/mL to about 4 mg/mL of the RNA, preferably about 0.025 mg/mL to about 0.4, 0.05 mg/mL to about 0.2 mg/mL, or 0.05 mg/mL to about 0.1 mg/mL of the RNA.

45. The nanoparticle composition of any one of claims 42-44, wherein the RNA is selected from the group consisting of a small interfering RNA (siRNA), an asymmetrical interfering RNA (aiRNA), a microRNA (miRNA), a Dicer-substrate RNA (dsRNA), a small hairpin RNA (shRNA), a messenger RNA (mRNA), a long non-coding RNA (lncRNA) and mixtures thereof.

46. The nanoparticle composition of any one of claims 42-44, wherein the RNA is an mRNA.

47. The nanoparticle composition of claim 46, wherein the mRNA includes one or more of a stem loop, a chain terminating nucleoside, a polyA sequence, a polyadenylation signal, and/or a 5' cap structure.

48. The nanoparticle composition of claim 46 or 47, wherein the mRNA is at least 30 nucleotides in length.

49. The nanoparticle composition of claim 46 or 47, wherein the mRNA is at least 300 nucleotides in length.

50. The nanoparticle composition of any one of the preceding claims, wherein the encapsulation efficiency of the therapeutic and/or prophylactic agent is at least 50%, at least 80%, at least 90%, or at least 95%.
51. The nanoparticle composition of any one of the preceding claims, wherein the nanoparticle composition has both the first and second sterols and the composition has substantively the same or an increased cell uptake efficiency as compared to a corresponding composition which comprises either the first sterol or the second sterol but not both.
52. The nanoparticle composition of claim 51, wherein the cell uptake efficiency is increased by at least 5%, 10%, 15%, 20%, or 25%.
53. The nanoparticle composition of any one of the preceding claims, wherein the wt/wt ratio of the lipid component to the therapeutic and/or prophylactic agents is from about 10:1 to about 60:1.
54. The nanoparticle composition of any one of the preceding claims, wherein the N:P ratio is from about 2:1 to about 30:1.
55. The nanoparticle composition of any one of the preceding claims, wherein the mean size of the composition is from about 70 nm to about 130 nm.
56. A pharmaceutical composition comprising the nanoparticle composition of any one of the preceding claims and a pharmaceutically acceptable carrier.
57. A method of delivering a therapeutic and/or prophylactic agent to a mammalian cell, the method comprising administering to a subject the nanoparticle composition of any one of the preceding claims, said administering comprising contacting the cell with the nanoparticle composition, whereby the therapeutic and/or prophylactic agent is delivered to the cell.

58. A method of specifically delivering a therapeutic and/or prophylactic agent to a mammalian organ, the method comprising administering to a mammal the nanoparticle composition of any one of the preceding claims, said administering comprising contacting the mammalian organ with the nanoparticle composition, whereby the therapeutic and/or prophylactic agent is delivered to the organ.
59. The method of claim 57 or 58, wherein the nanoparticle composition has both the first and second sterols and the delivery efficiency of the therapeutic and/or prophylactic agent is enhanced as compared to administering a corresponding composition which comprises either the first sterol or the second sterol but not both.
60. A method of producing a polypeptide of interest in a mammalian cell, the method comprising contacting the cell with the nanoparticle composition of any one of the preceding claims, wherein the therapeutic and/or prophylactic agent is an mRNA, and wherein the mRNA encodes the polypeptide of interest, whereby the mRNA is capable of being translated in the cell to produce the polypeptide of interest.
61. The method of claim 60, wherein the nanoparticle composition has both the first and second sterols and production of the polypeptide of interest is increased as compared to administering a corresponding composition which comprises either the first sterol or the second sterol but not both.
62. The method of claim 61, wherein the polypeptide production is increased by at least 10%, 20%, 30%, 40%, 50%, or 100%.
63. The method of any one of claims 60-62 or wherein the nanoparticle composition has both the first and second sterols and the cell uptake efficiency of the nanoparticle composition is substantively the same as or is increased as compared to administering a corresponding composition which comprises either the first sterol or the second sterol but not both.
64. The method of claim 63, wherein the cell uptake efficiency is increased by at least 5%, 10%, 15%, 20%, or 25%.

65. The method of claim 63, wherein the degree of increase in the production of the polypeptide is not less than that of the cell uptake efficiency.

66. The method of any one of the preceding claims, wherein the mammalian cell or organ is in a mammal.

67. A method of treating a disease or disorder in a subject in need thereof, the method comprising administering to the subject a therapeutically effective amount of the nanoparticle composition of any one of the preceding claims.

68. A lipid nanoparticle, comprising:

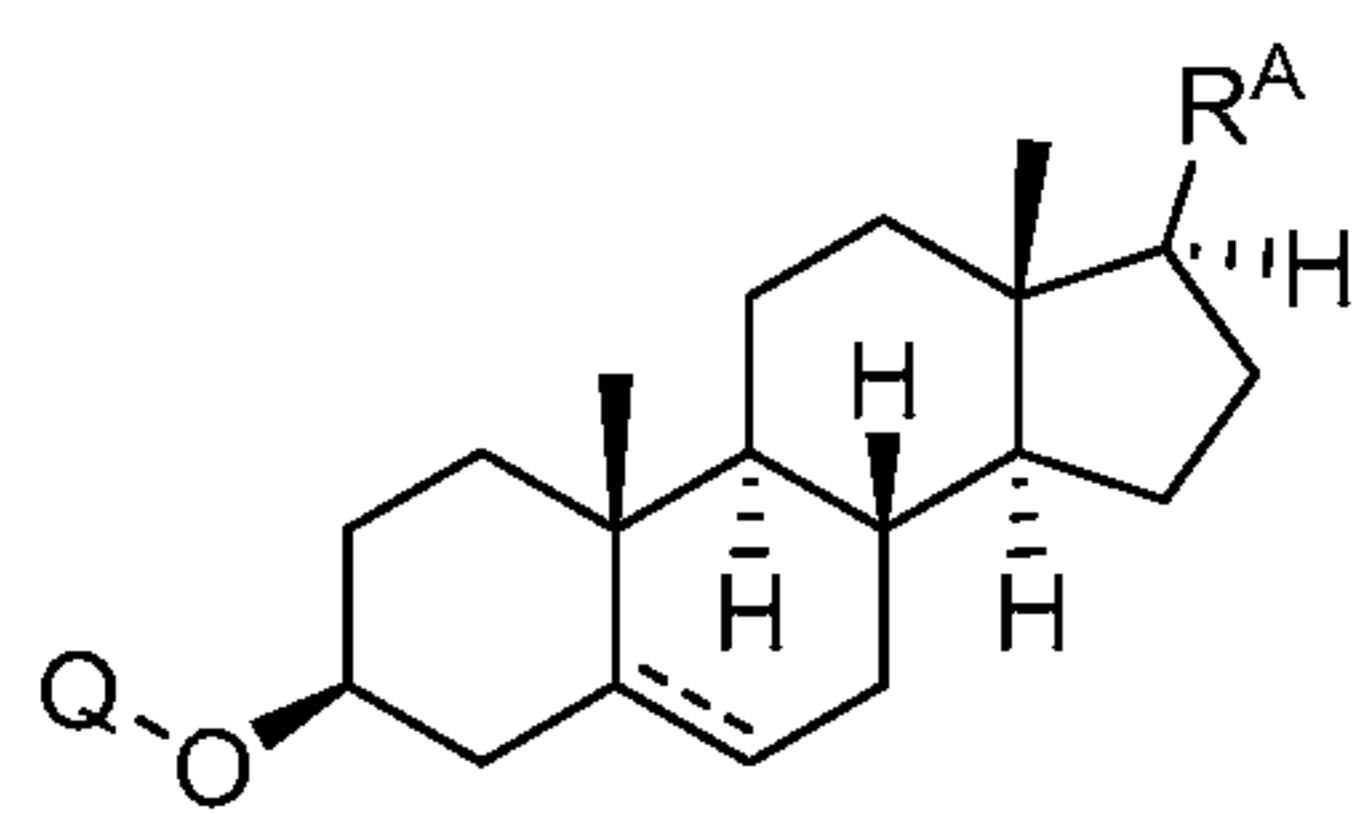
an ionizable lipid;

a phospholipid;

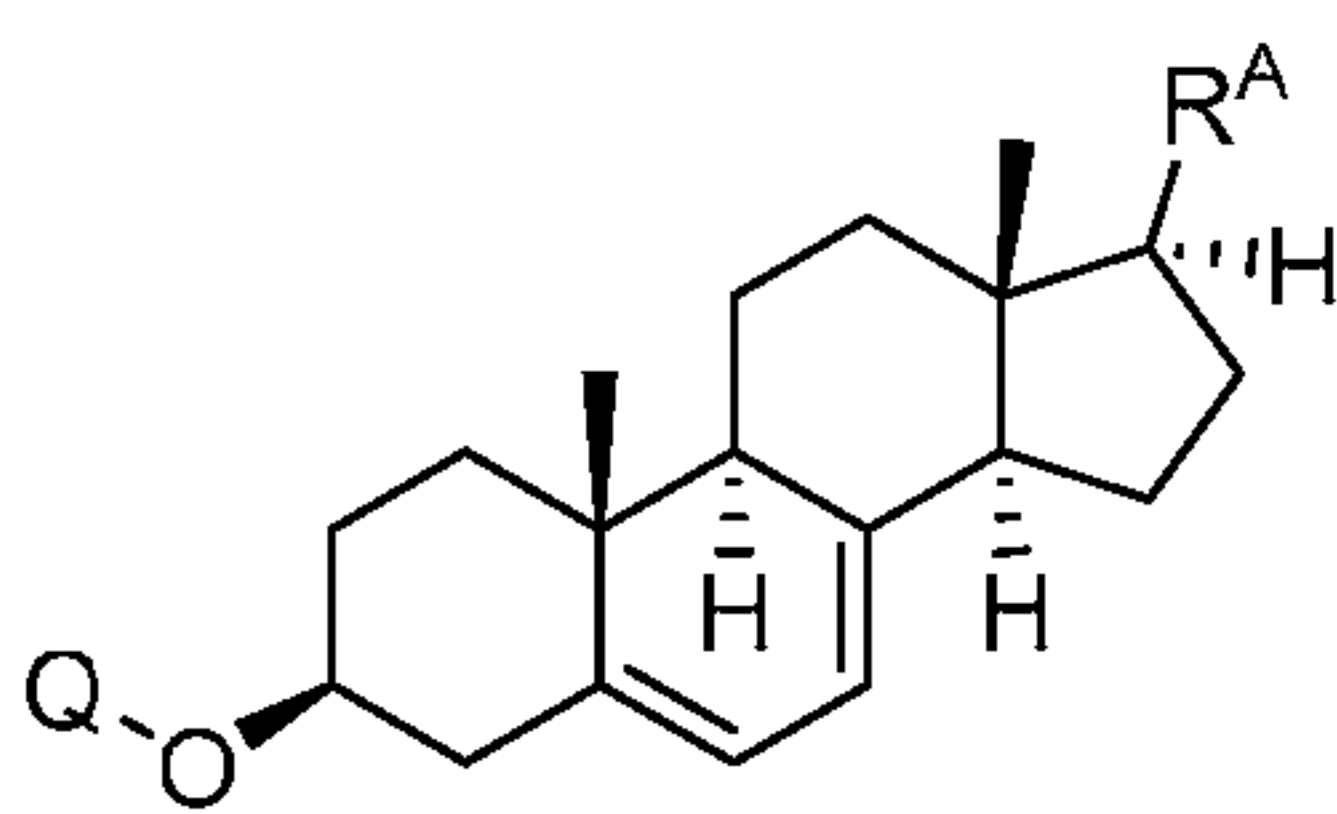
a surfactant;

a nucleic acid moiety; and

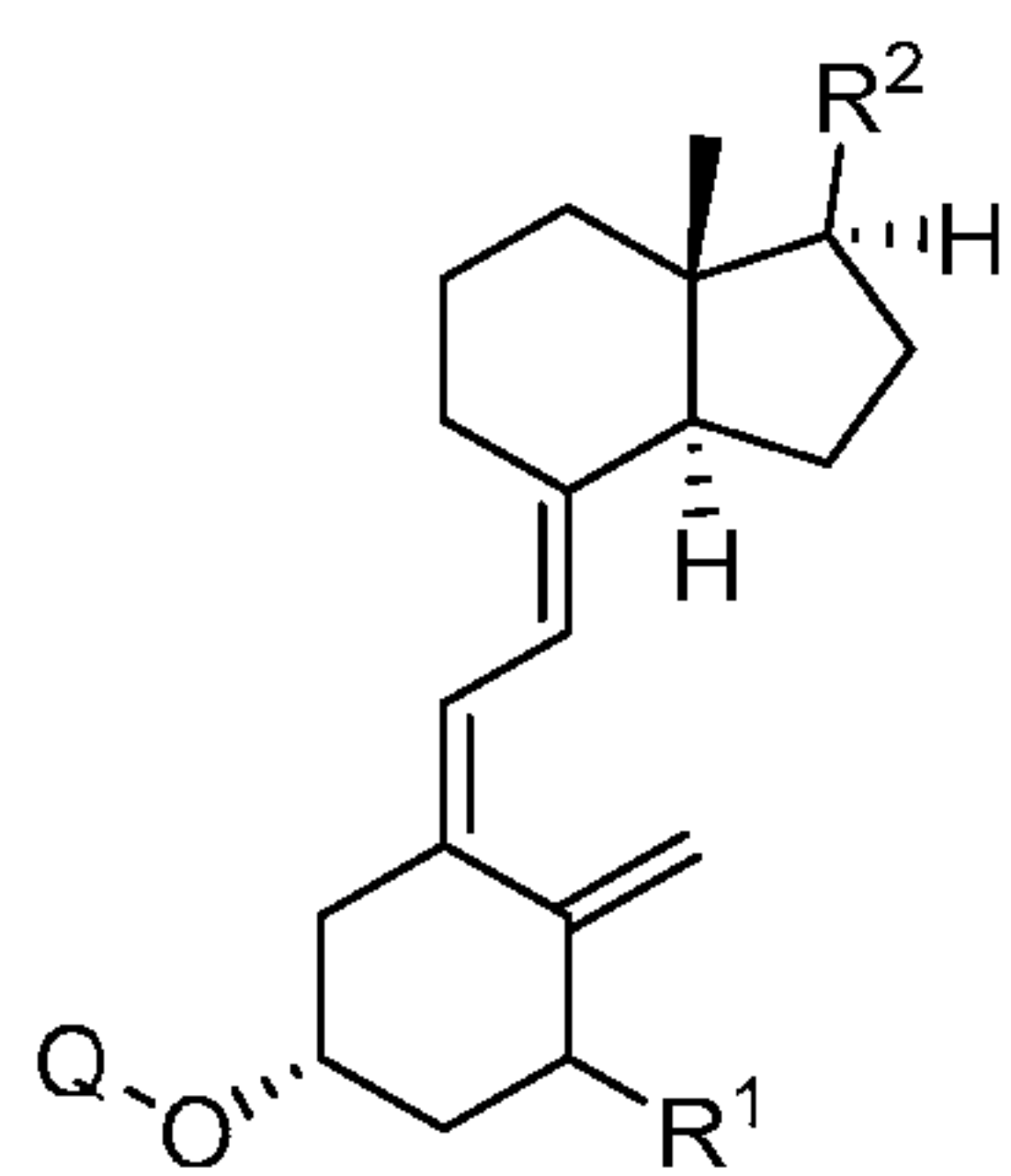
a cholesterol derivative having a formula selected from



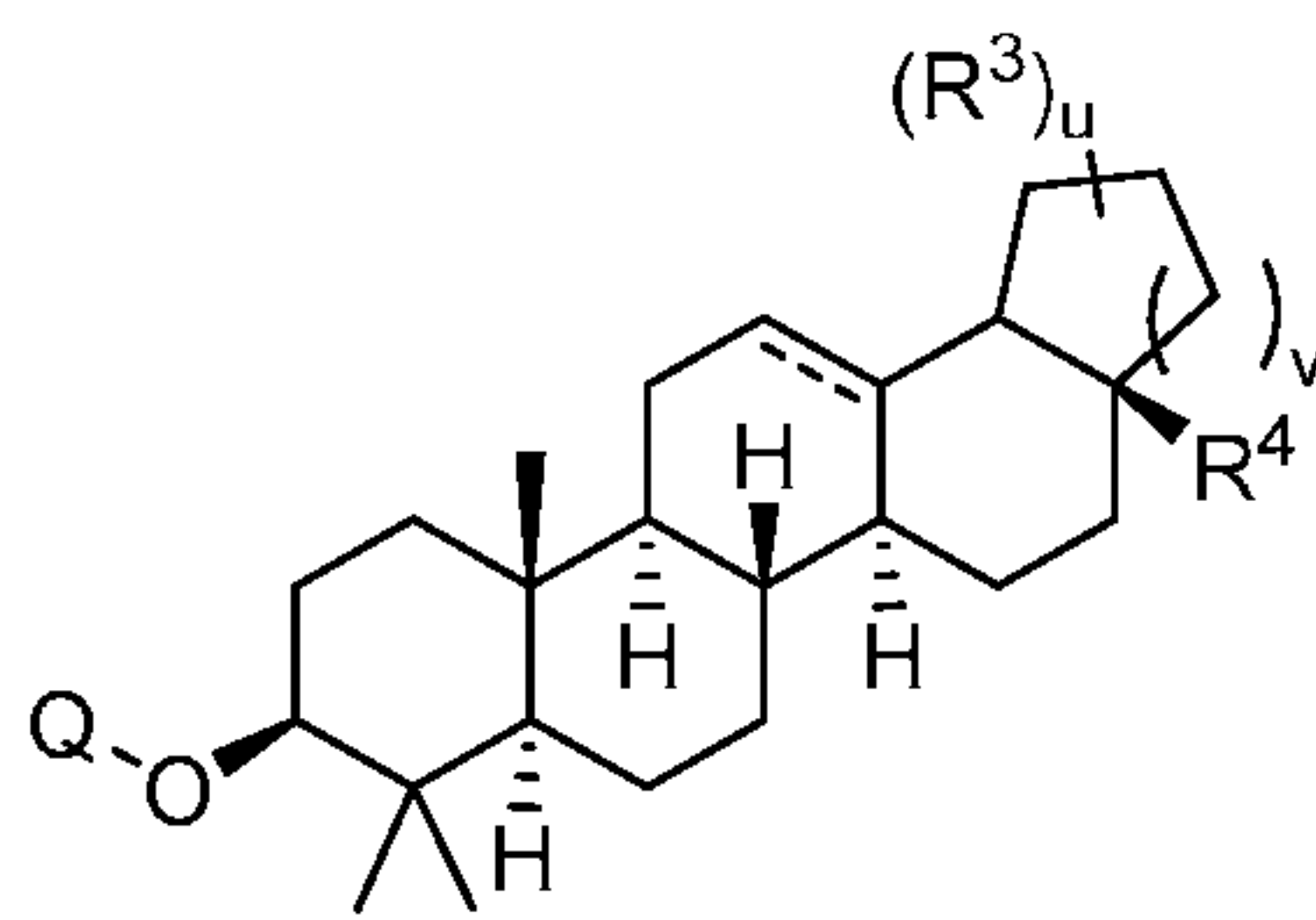
(A1),



(A2),



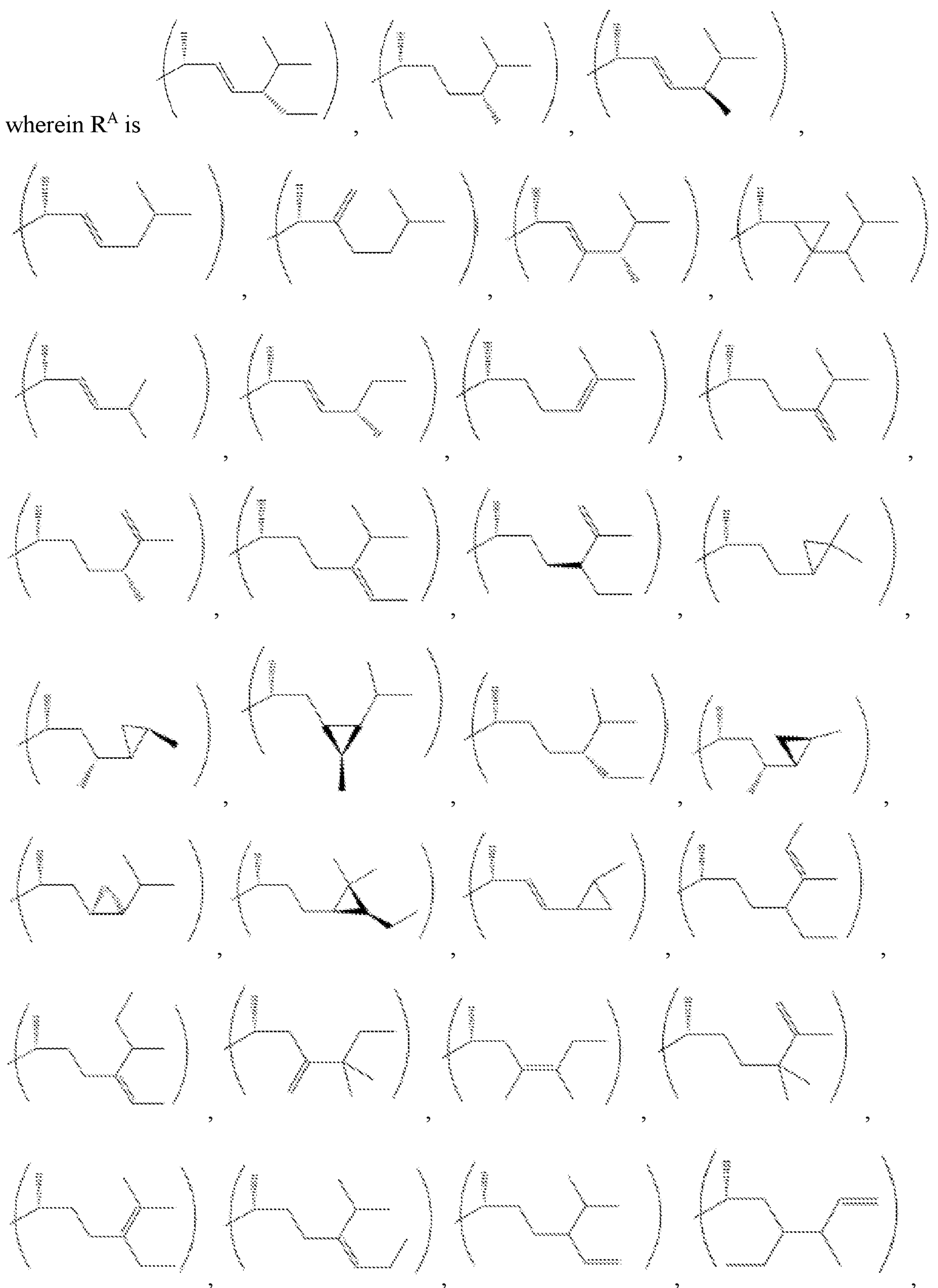
(A3), or

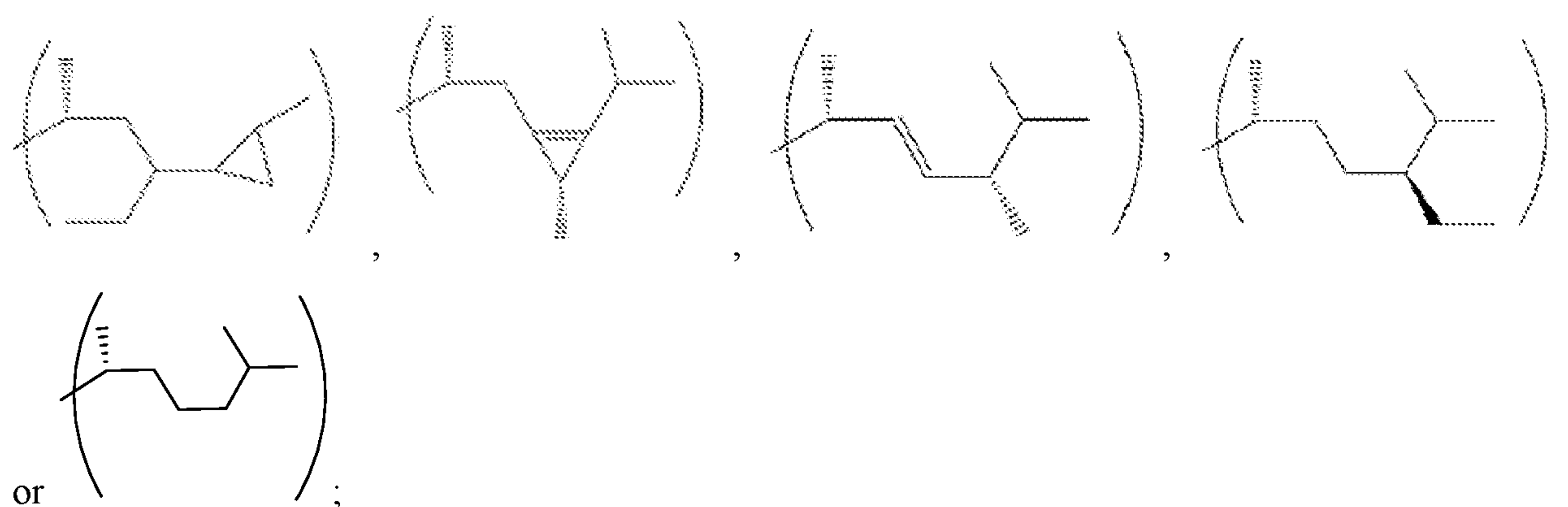


(A4); wherein ----- denotes a carbon-

carbon single or double bond;

wherein R^A is



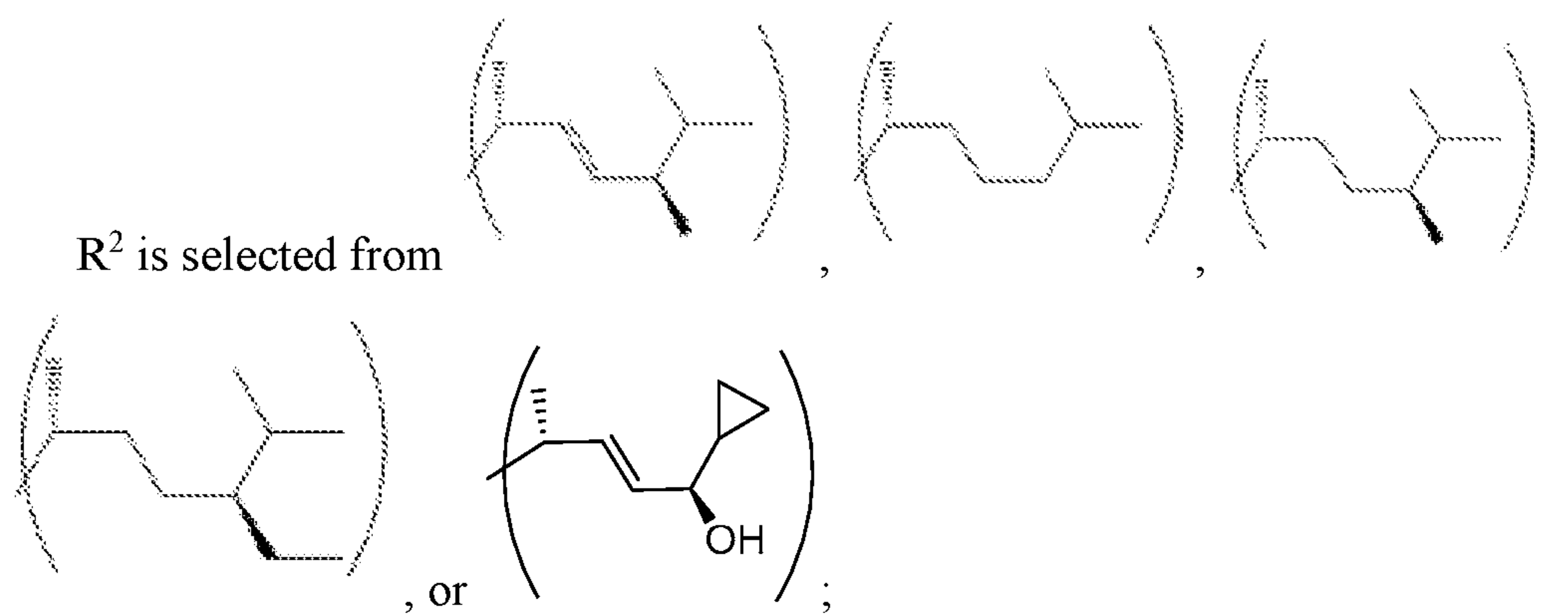


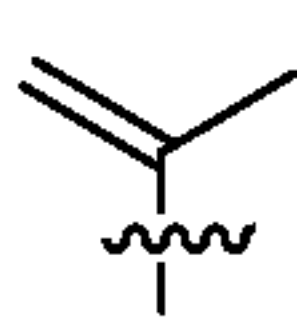
u is 1 or 2;

v is 1 or 2;

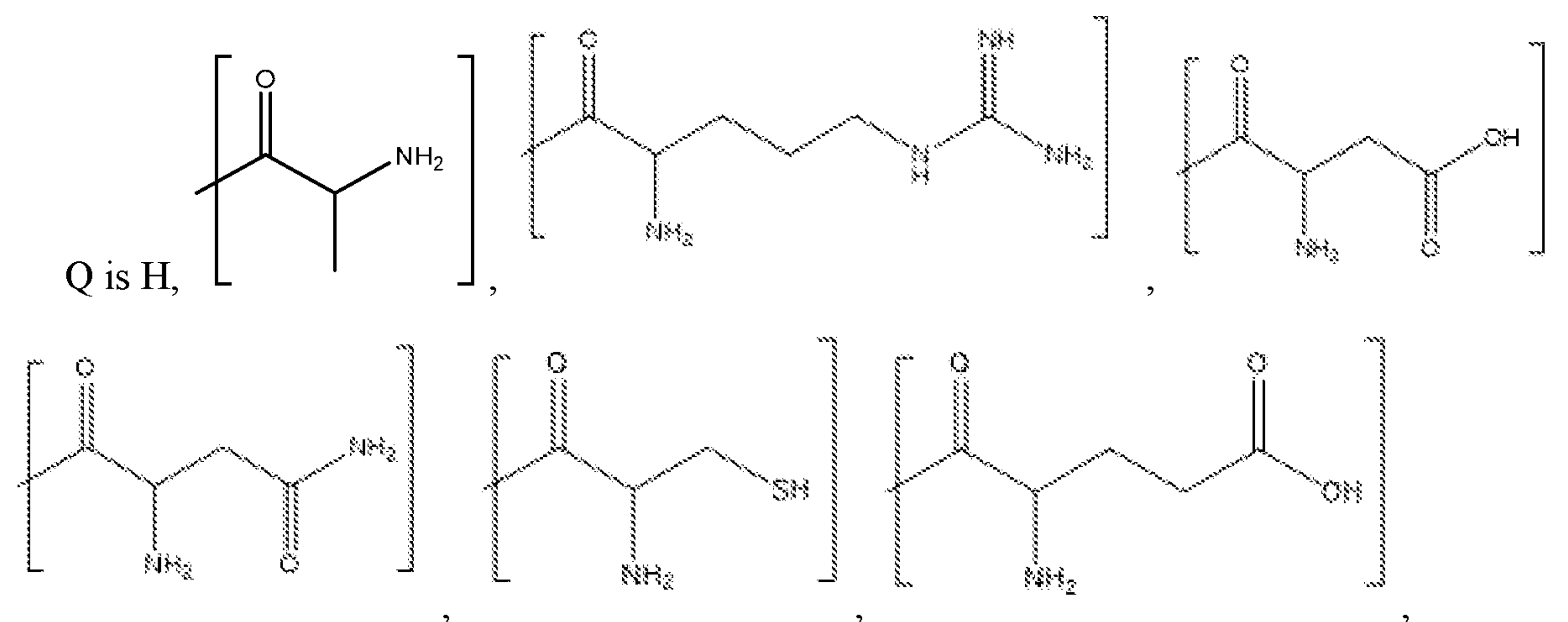
R¹ is H or OH;

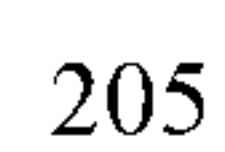
R² is selected from

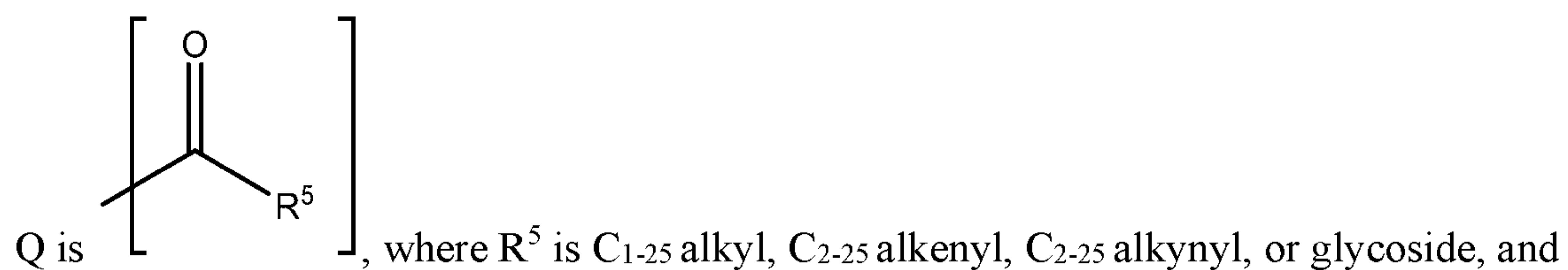


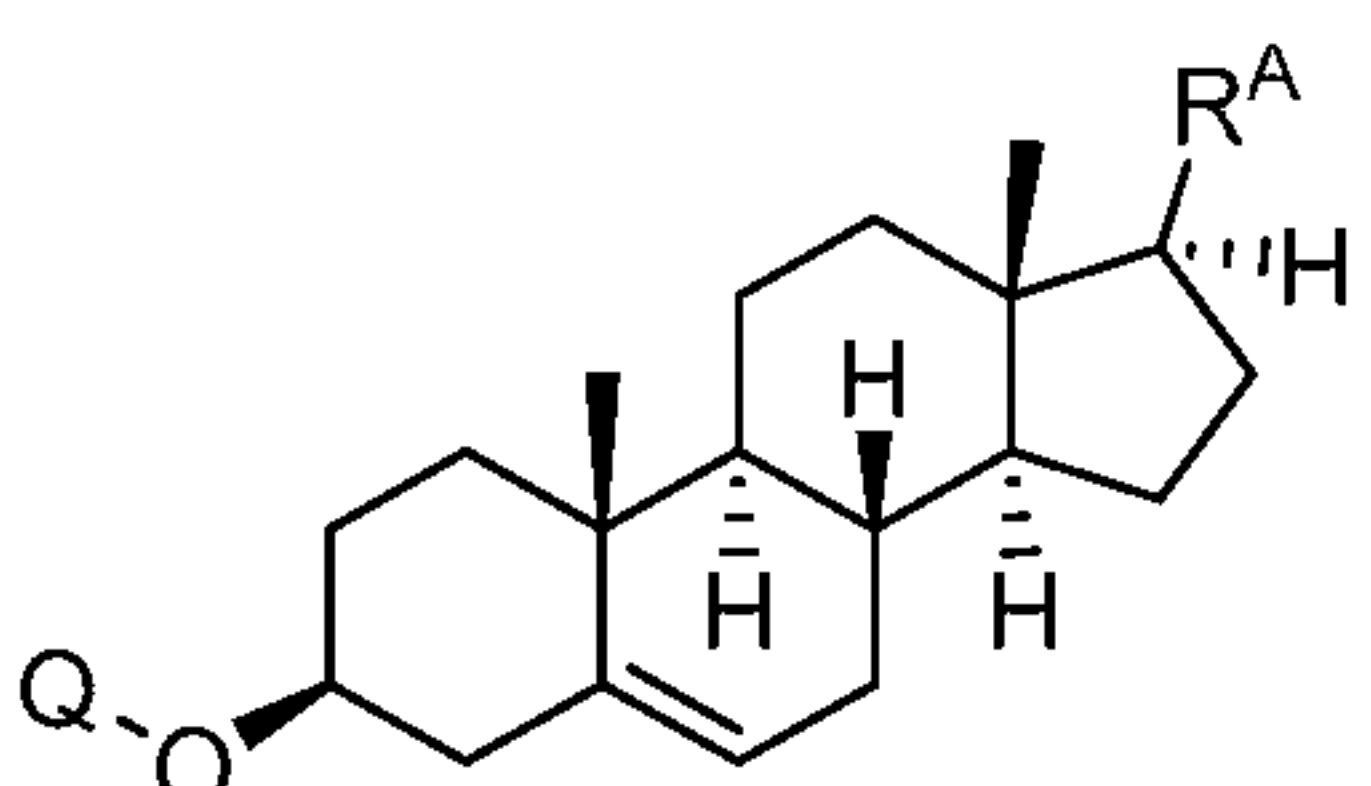
each R³ independently is CH₃, or ;

R⁴ is CH₃, CH₂OH, or CO₂H; and





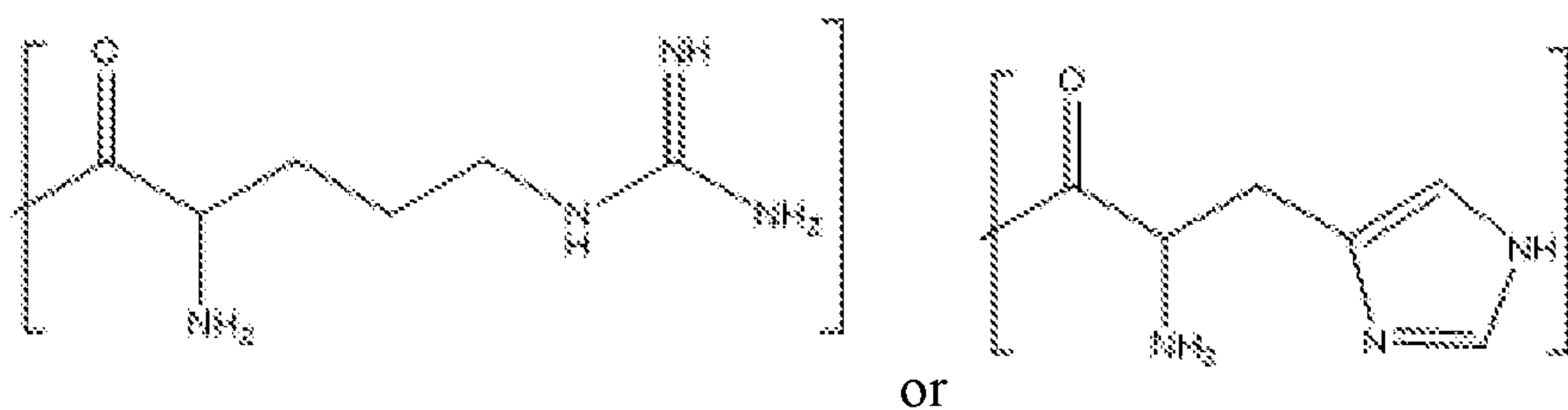


wherein when the cholesterol derivative has a formula , then Q is not H.

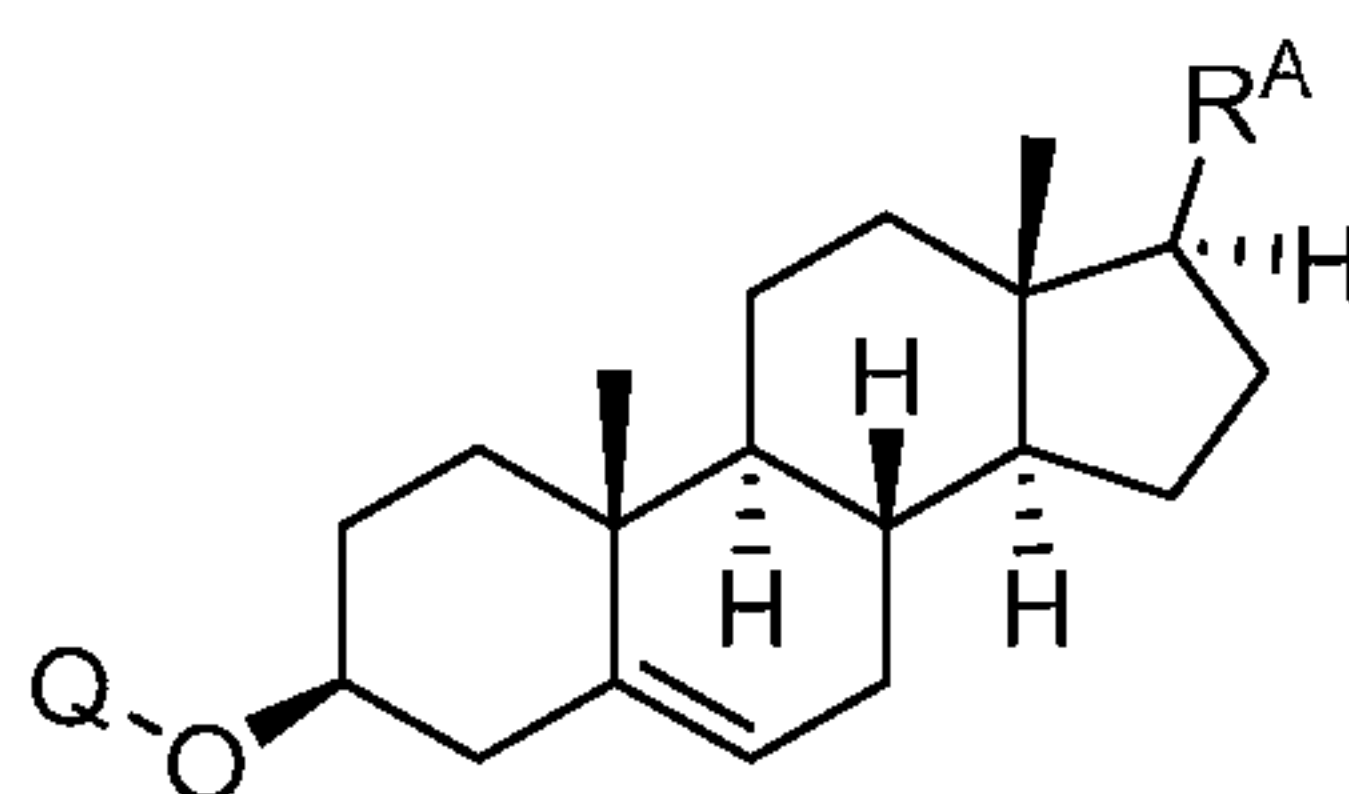
69. The lipid nanoparticle of claim 68, wherein the nucleic acid moiety is an mRNA.

70. The lipid nanoparticle of claim 69, wherein the nucleic acid moiety is encapsulated within the lipid nanoparticle.

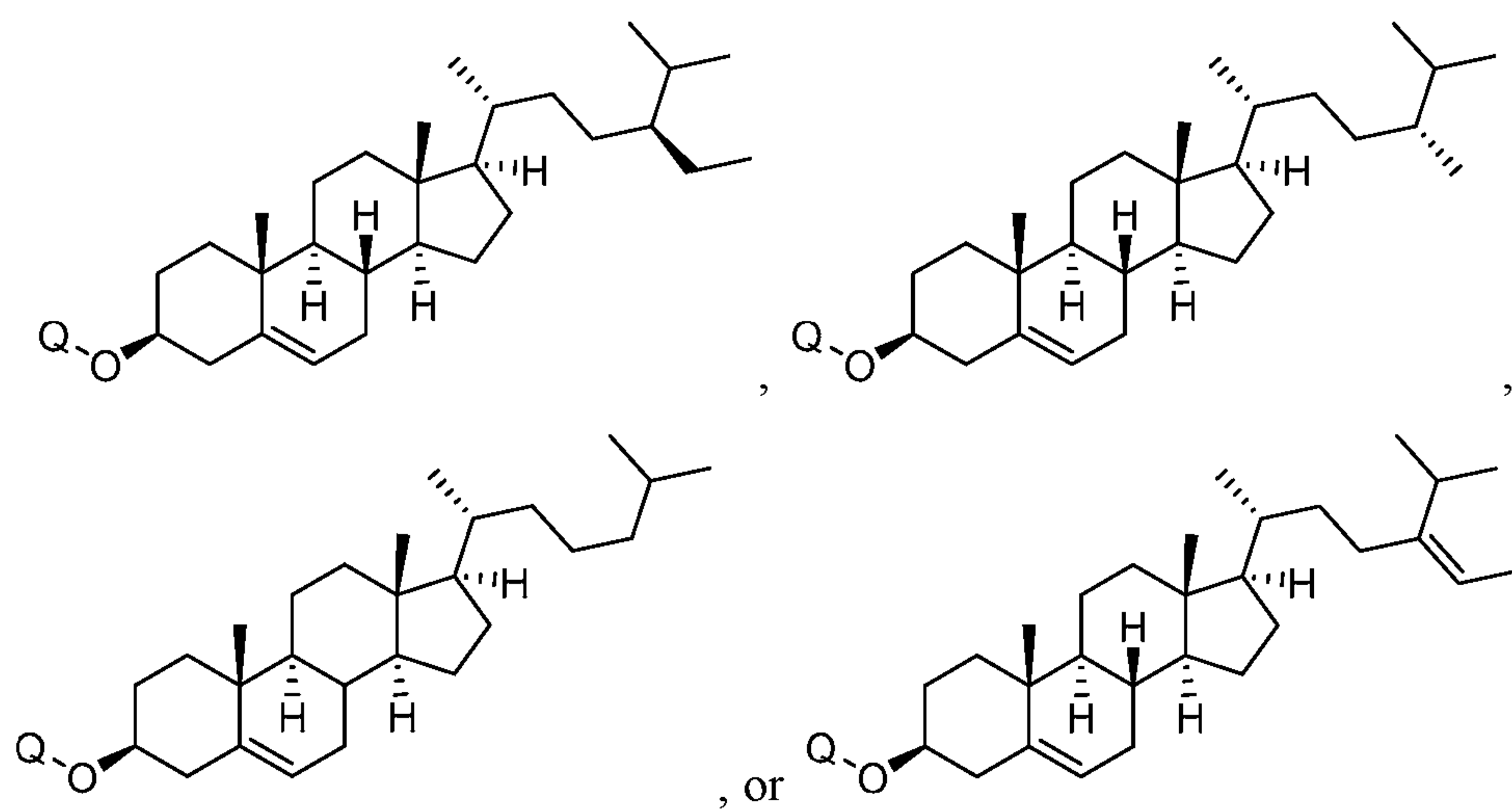
71. The lipid nanoparticle of any one of claims 68-70, wherein Q is



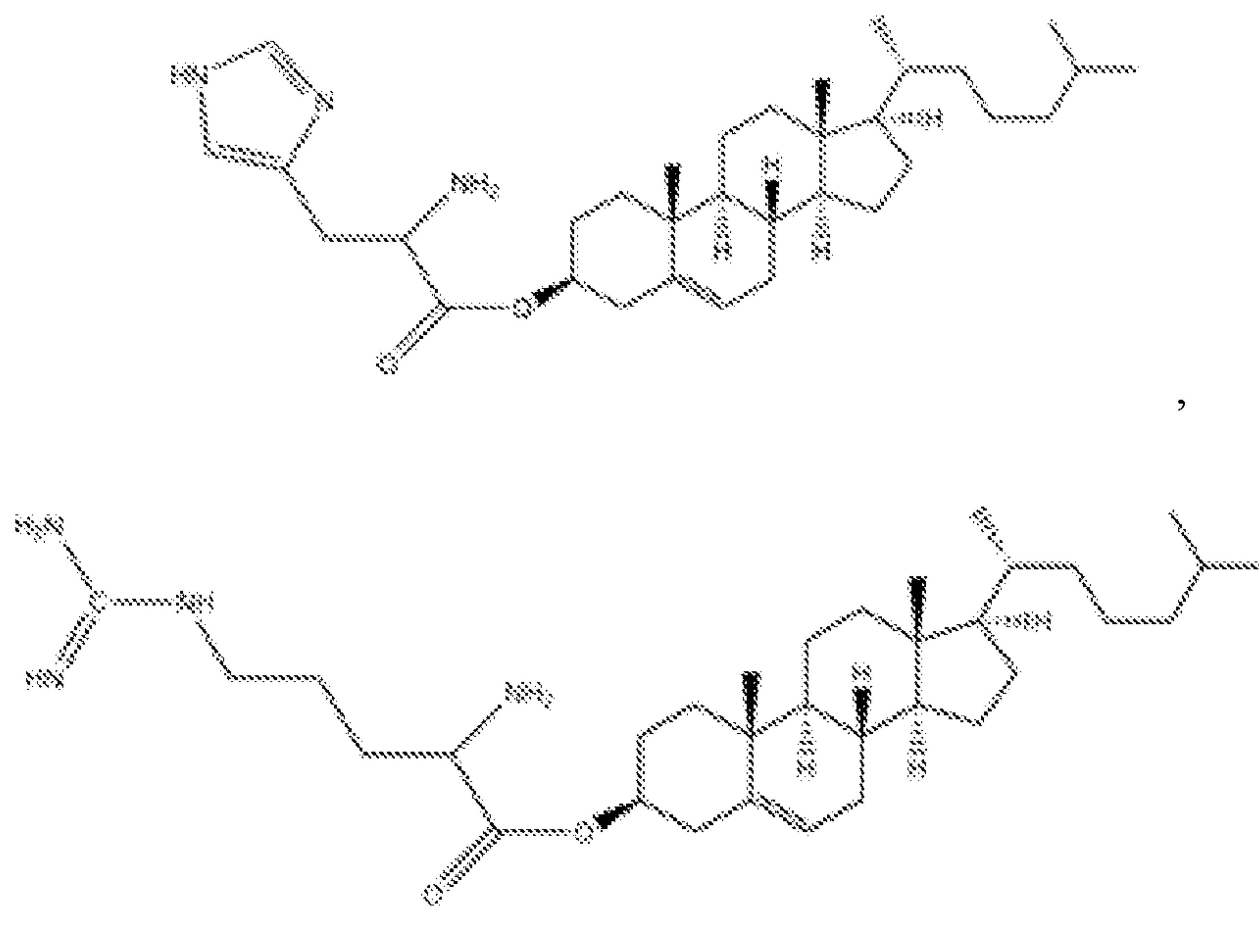
72. The lipid nanoparticle of any one of claims 68-71, wherein the cholesterol derivative has a formula

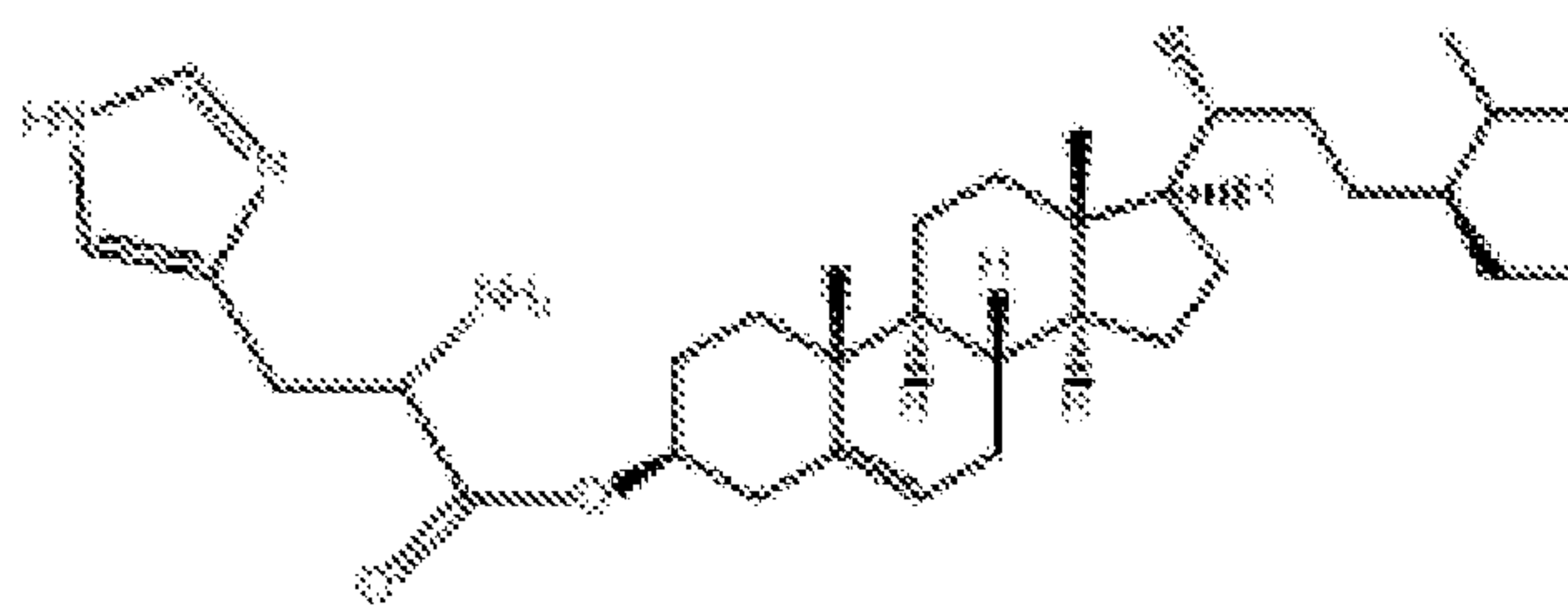
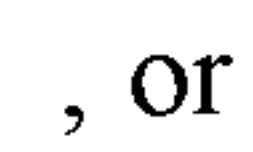


73. The lipid nanoparticle of any one of claims 68-72, wherein the cholesterol derivative has a formula



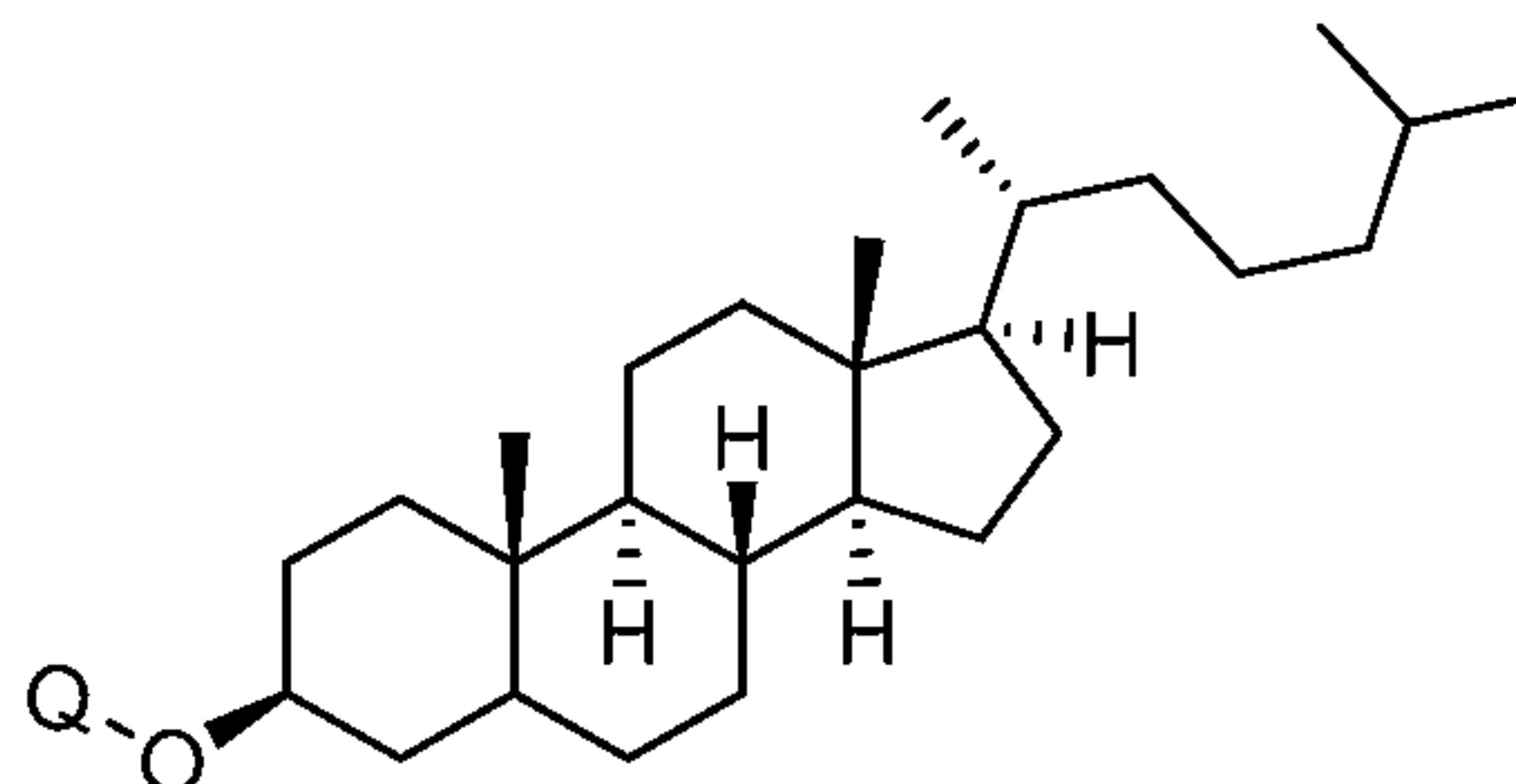
74. The lipid nanoparticle of any one of claims 68-73, wherein the cholesterol derivative has a formula



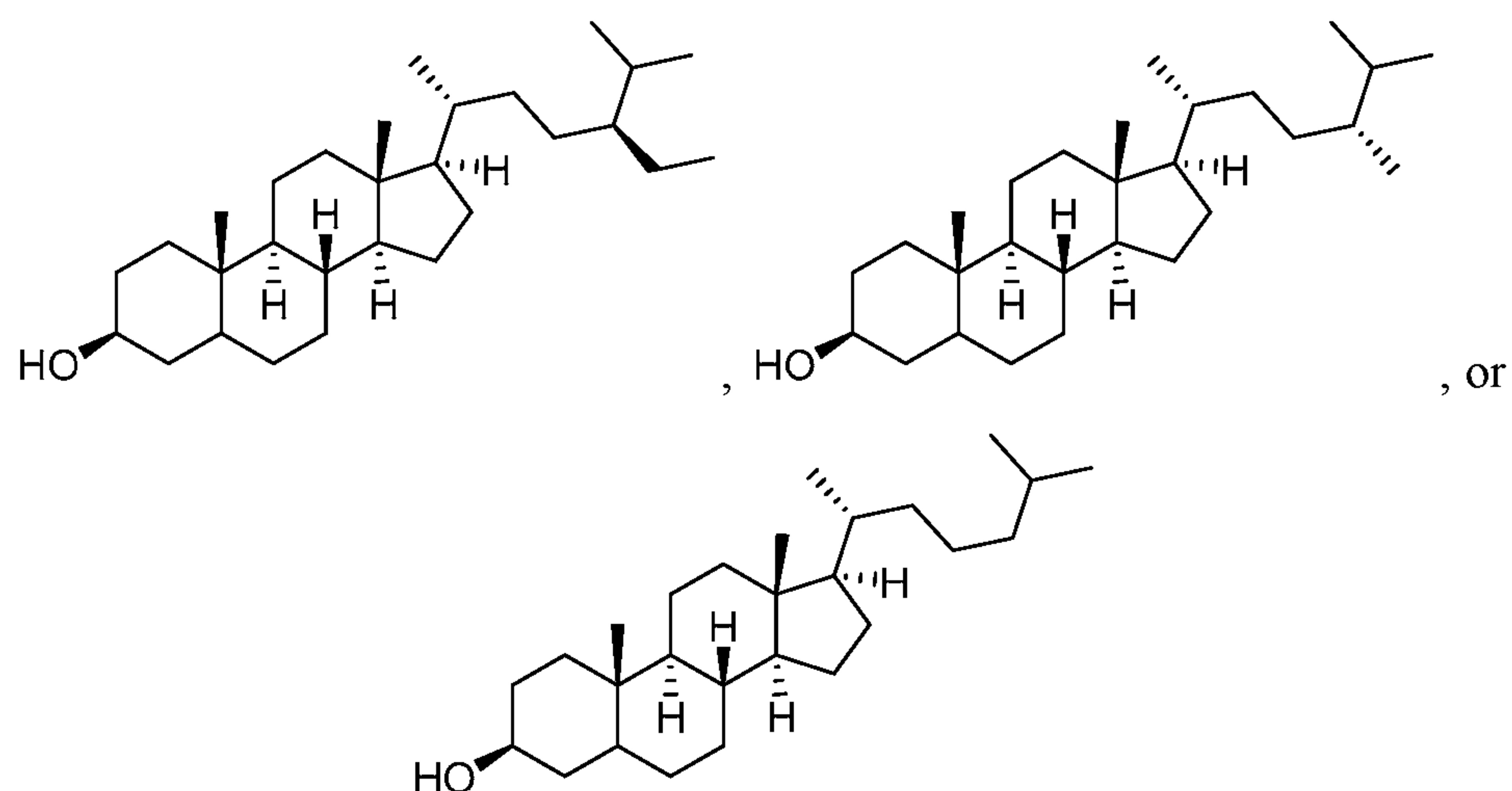


The chemical structure shows a steroid nucleus with four fused rings. At the 3-position, there is a substituent $Q-O$ attached via a wedge bond. At the 13-position, there is a methyl group attached via a wedge bond. At the 14-position, there is a hydrogen atom attached via a dashed bond. At the 17-position, there is a hydrogen atom attached via a wedge bond. At the 13-position, there is a substituent R^A attached via a wedge bond. At the 14-position, there is a hydrogen atom attached via a dashed bond.

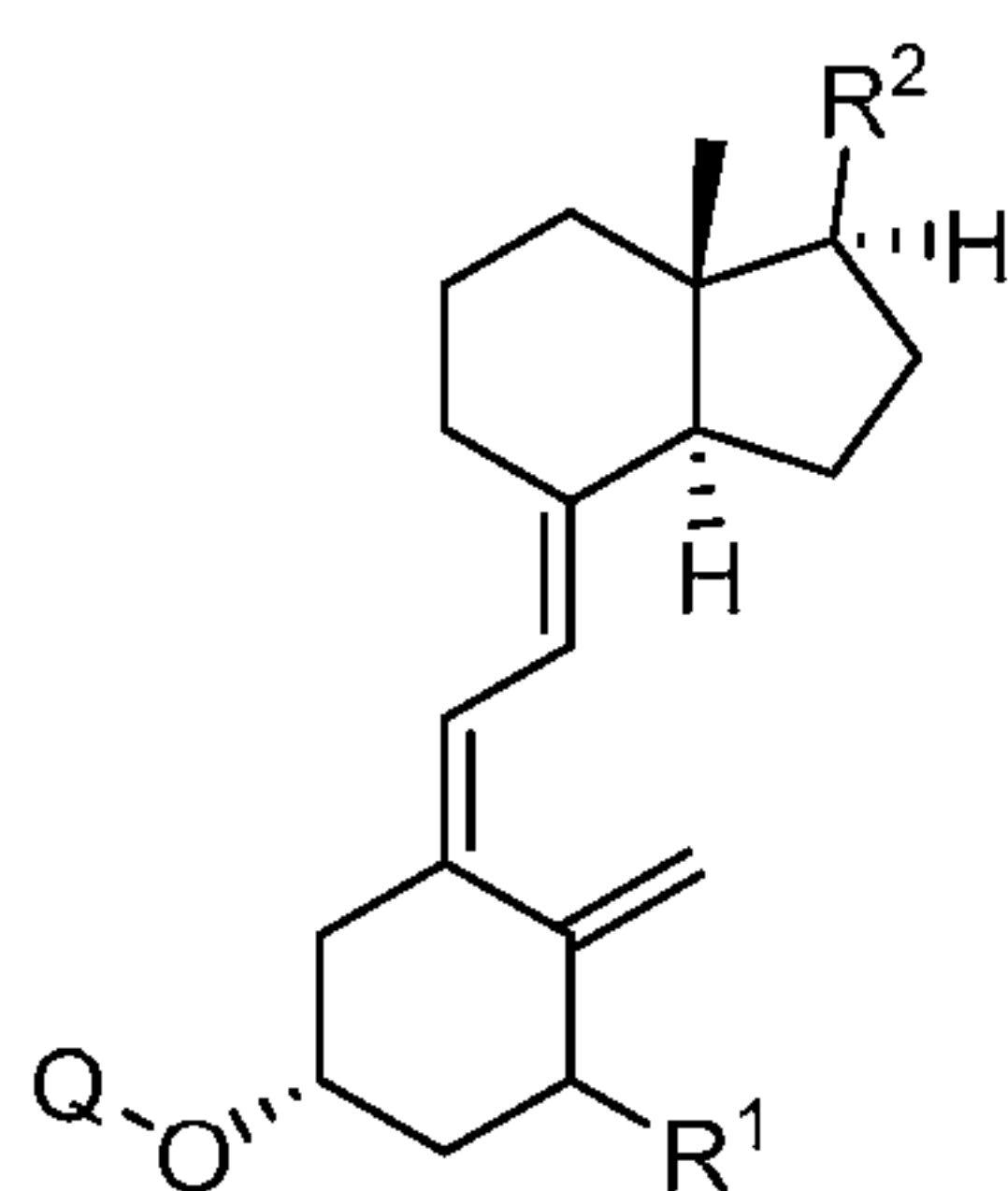
The image displays two chemical structures, labeled 1 and 2, which are steroid derivatives. Both structures feature a four-ring steroid nucleus. A side chain is attached to the D-ring, and a substituent Q is attached to the A-ring. The structures are identical, with the only difference being the label '1' on the left and '2' on the right.



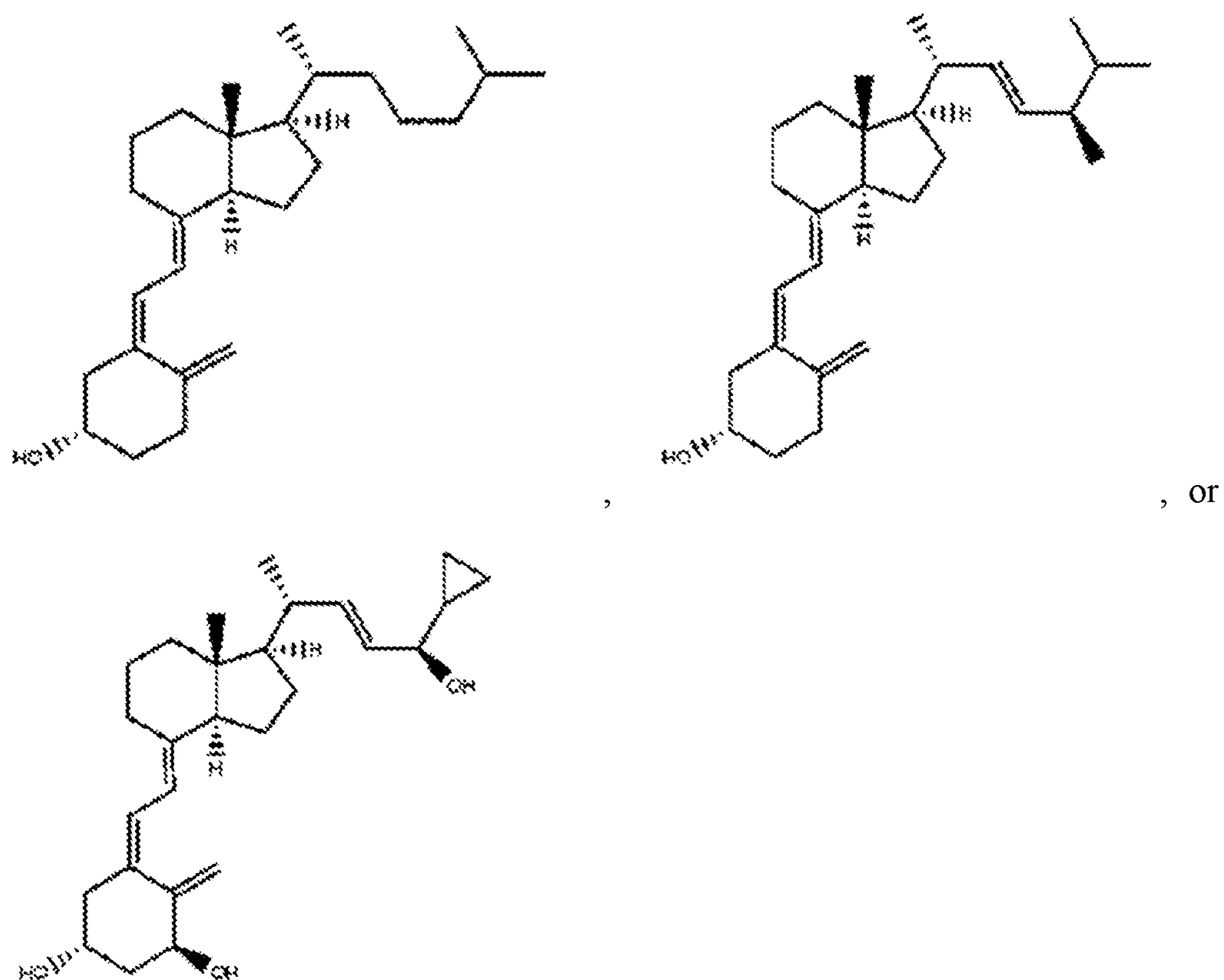
77. The lipid nanoparticle of claim 75 or 76, wherein the cholesterol derivative is



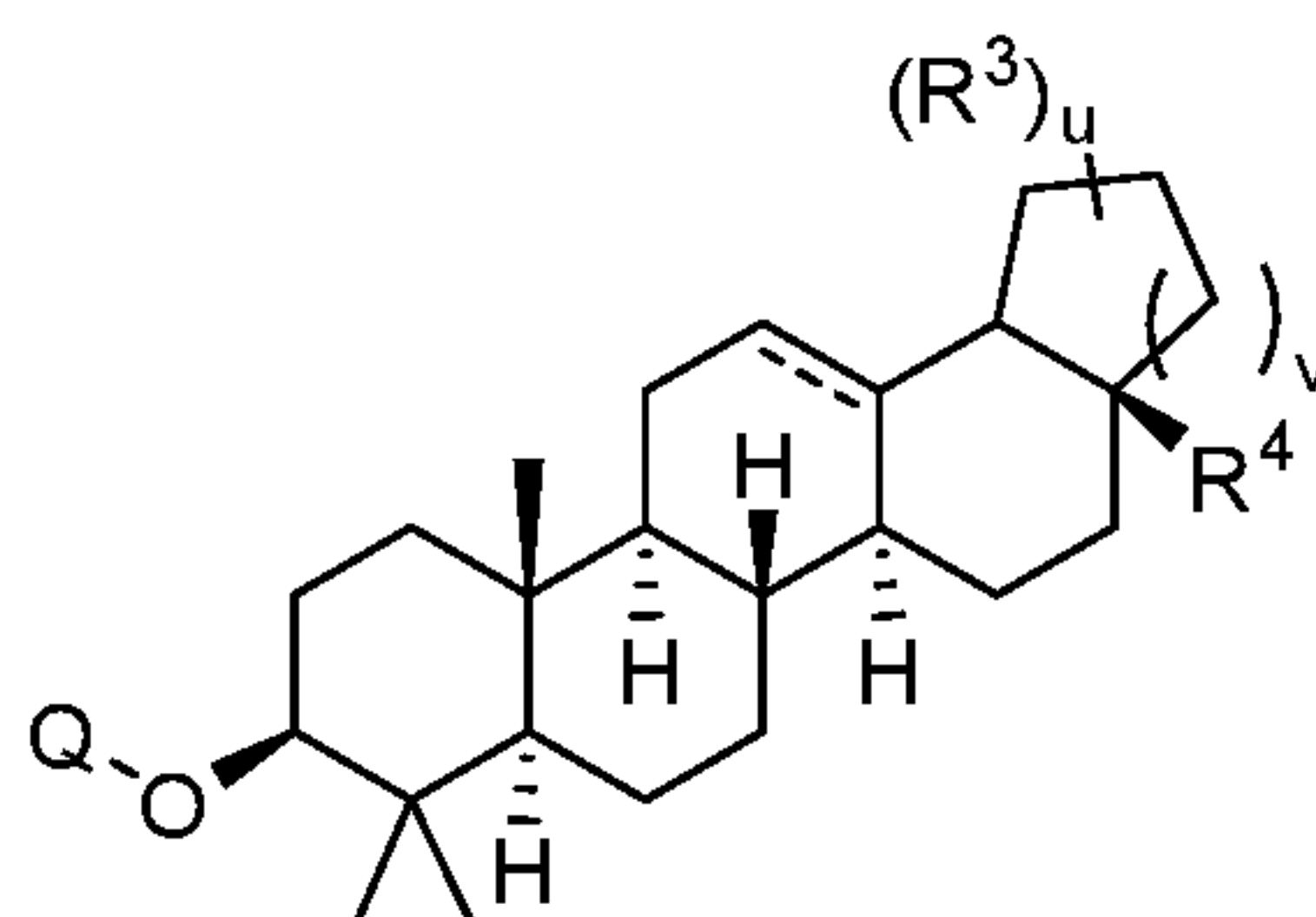
78. The lipid nanoparticle of any one of claims 68-71, wherein the cholesterol derivative has a formula



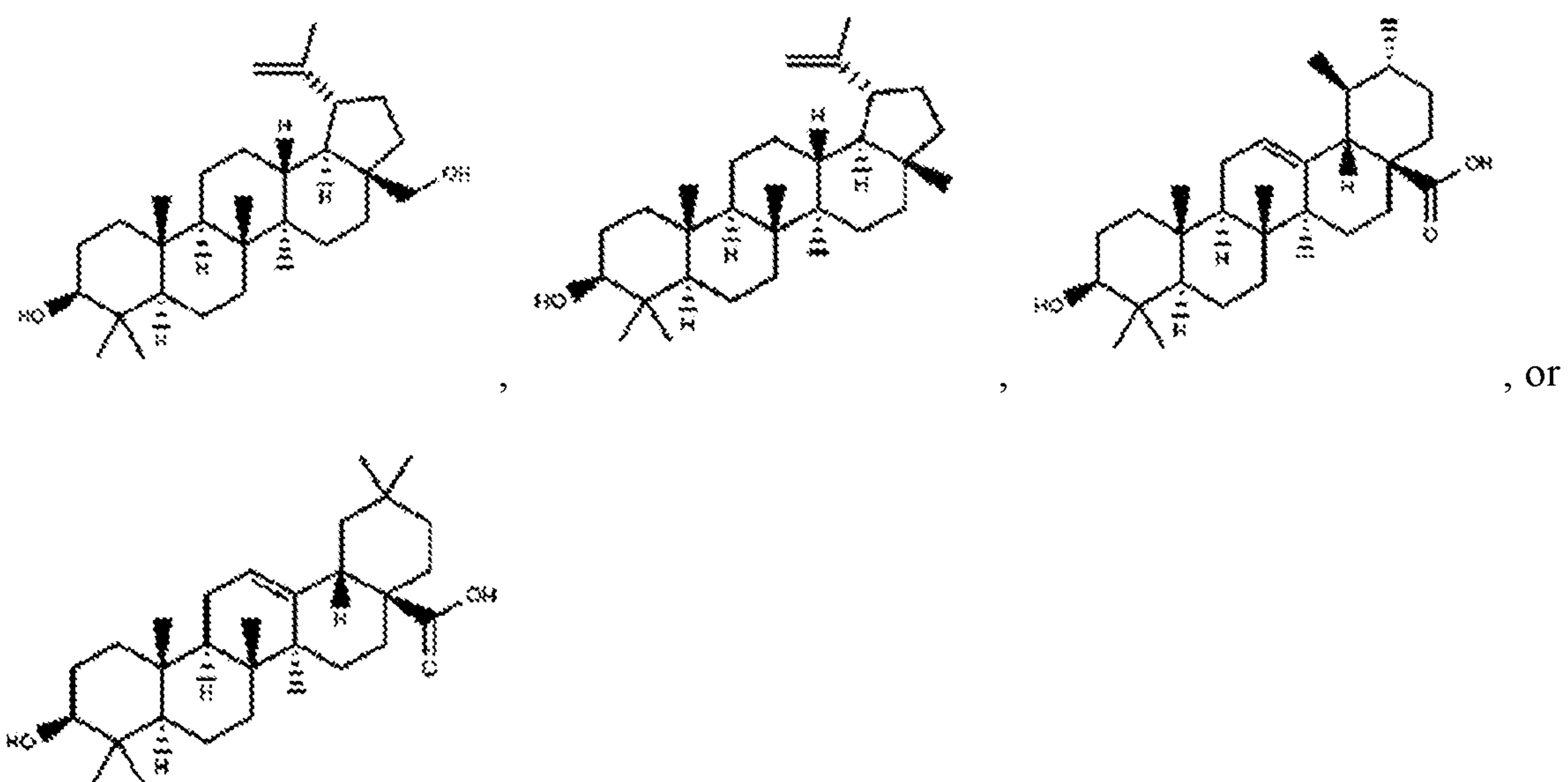
79. The lipid nanoparticle of claim 78, wherein the cholesterol derivative is



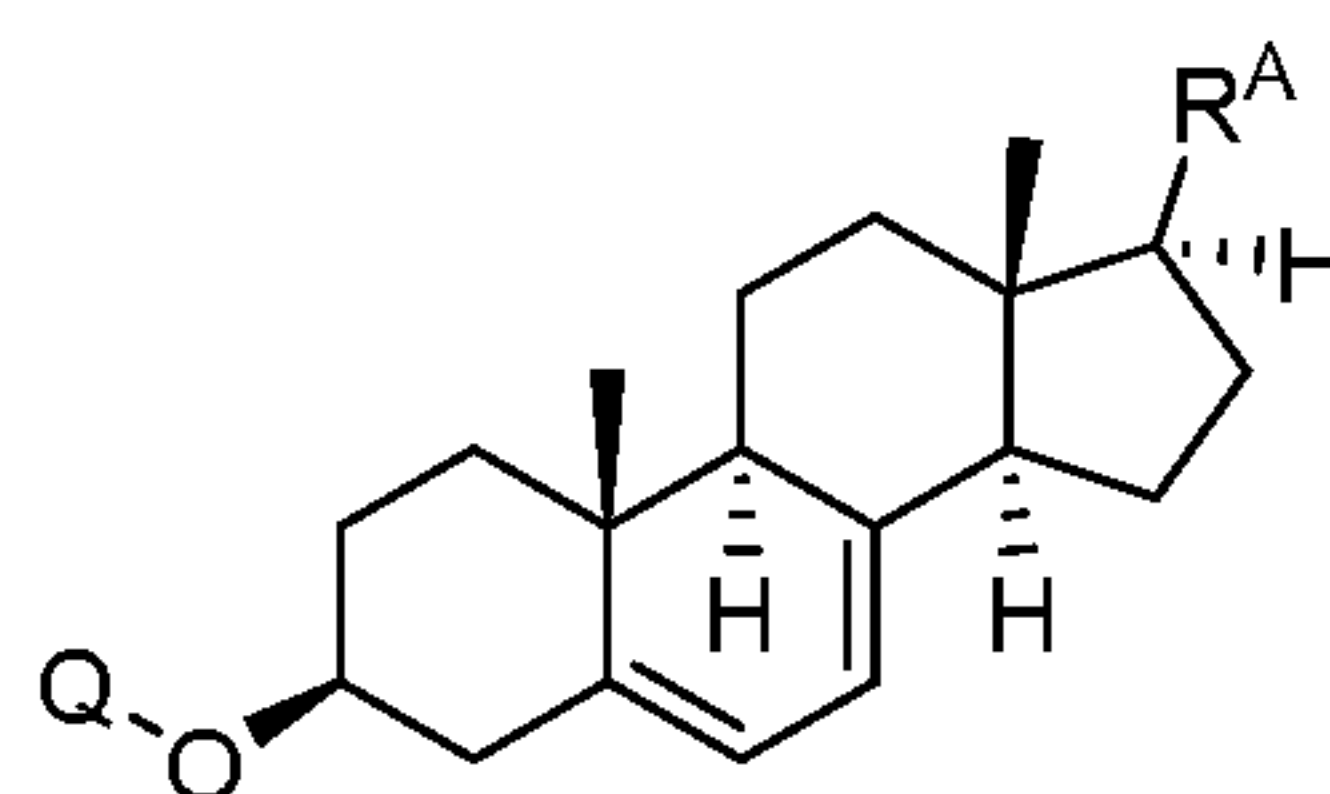
80. The lipid nanoparticle of any one of claims 68-71, wherein the cholesterol has a formula



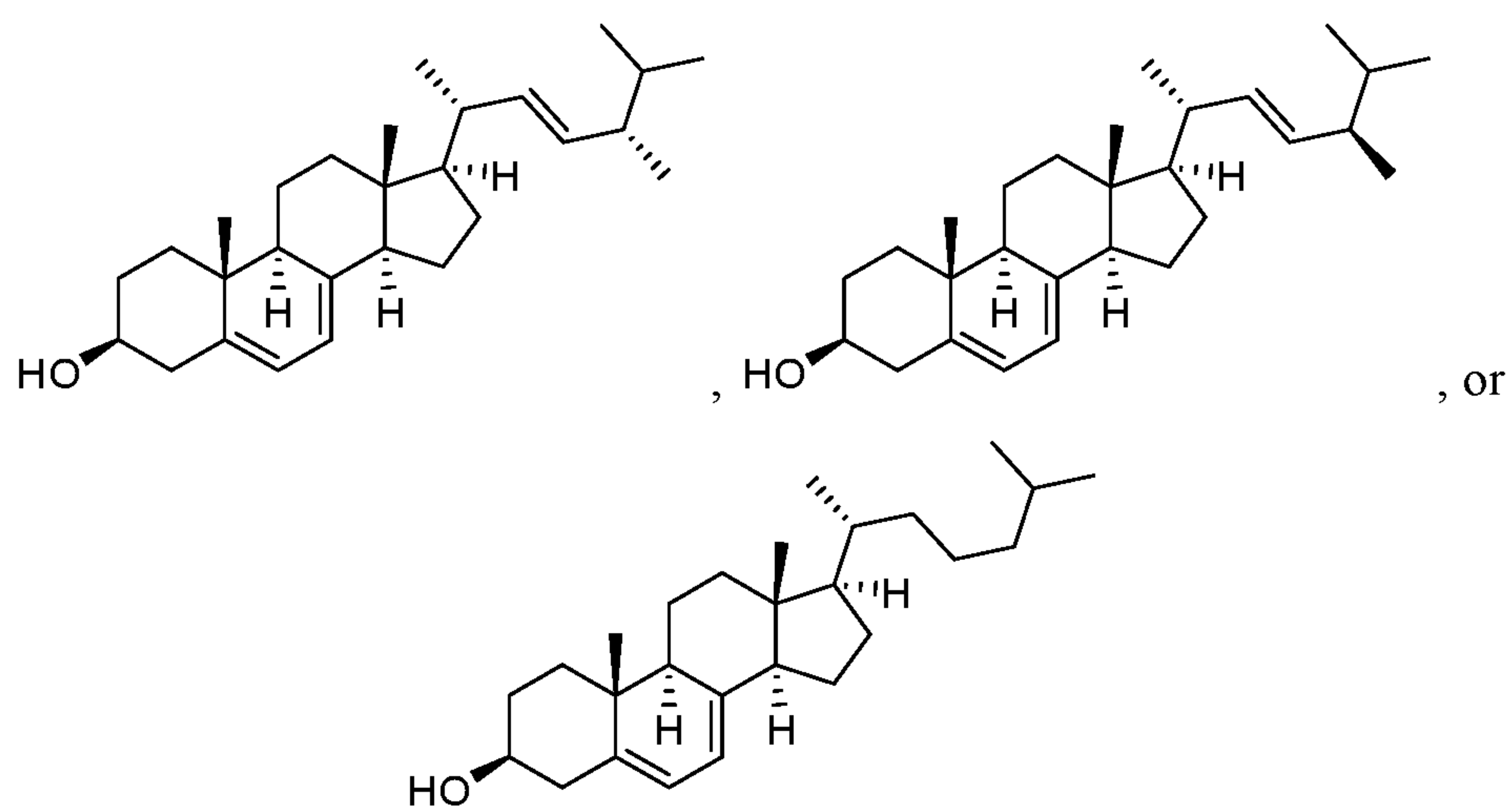
81. The lipid nanoparticle of claim 80, wherein the cholesterol derivative is



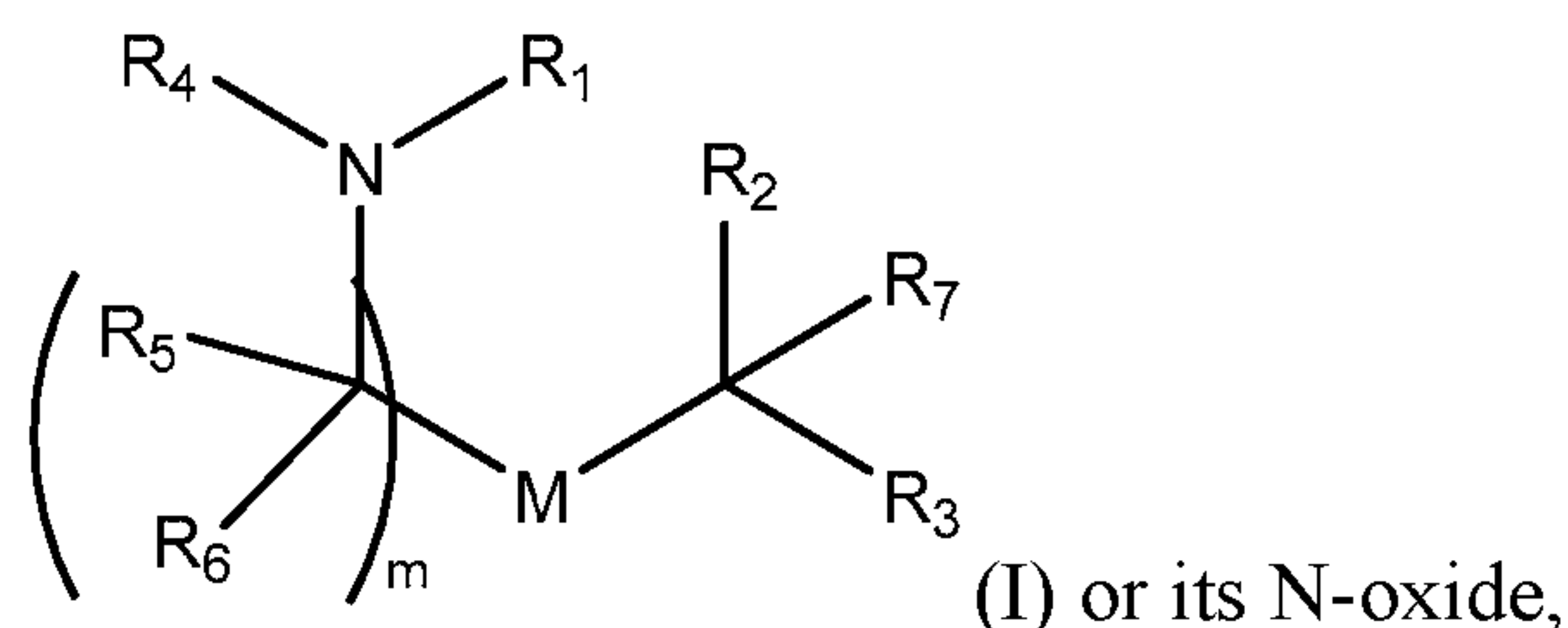
82. The lipid nanoparticle of any one of claims 68-71, wherein the cholesterol derivative has a formula



83. The lipid nanoparticle of claim 82, wherein the cholesterol derivative is



84. The nanoparticle composition of any one of claims 68-83, wherein the ionizable lipid is a compound of Formula (I):



or a salt or isomer thereof, wherein

R_1 is selected from the group consisting of C_{5-30} alkyl, C_{5-20} alkenyl, $-R^*YR''$, $-YR''$, and $-R''M'R'$;

R_2 and R_3 are independently selected from the group consisting of H, C_{1-14} alkyl, C_{2-14} alkenyl, $-R^*YR''$, $-YR''$, and $-R^*OR''$, or R_2 and R_3 , together with the atom to which they are attached, form a heterocycle or carbocycle;

R_4 is selected from the group consisting of hydrogen, a C_{3-6} carbocycle, $-(CH_2)_nQ$, $-(CH_2)_nCHQR$, $-CHQR$, $-CQ(R)_2$, and unsubstituted C_{1-6} alkyl, where Q is selected from a carbocycle, heterocycle, $-OR$, $-O(CH_2)_nN(R)_2$, $-C(O)OR$, $-OC(O)R$, $-CX_3$, $-CX_2H$, $-CXH_2$, $-CN$, $-N(R)_2$, $-C(O)N(R)_2$, $-N(R)C(O)R$, $-N(R)S(O)_2R$, $-N(R)C(O)N(R)_2$, $-N(R)C(S)N(R)_2$, $-N(R)R_8$, $-N(R)S(O)_2R_8$, $-O(CH_2)_nOR$, $-N(R)C(=NR_9)N(R)_2$, $-N(R)C(=CHR_9)N(R)_2$, $-OC(O)N(R)_2$, $-N(R)C(O)OR$, $-N(OR)C(O)R$, $-N(OR)S(O)_2R$, $-N(OR)C(O)OR$, $-N(OR)C(O)N(R)_2$, $-N(OR)C(S)N(R)_2$, $-N(OR)C(=NR_9)N(R)_2$, $-N(OR)C(=CHR_9)N(R)_2$, $-C(=NR_9)N(R)_2$, $-C(=NR_9)R$, $-C(O)N(R)OR$, and $-C(R)N(R)_2C(O)OR$, and each n is independently selected from 1, 2, 3, 4, and 5;

each R_5 is independently selected from the group consisting of C_{1-3} alkyl, C_{2-3} alkenyl, and H;

each R_6 is independently selected from the group consisting of C_{1-3} alkyl, C_{2-3} alkenyl, and H;

M and M' are independently selected from $-C(O)O-$, $-OC(O)-$, $-OC(O)-M''-C(O)O-$, $-C(O)N(R')$, $-N(R')C(O)-$, $-C(O)-$, $-C(S)-$, $-C(S)S-$, $-SC(S)-$, $-CH(OH)-$, $-P(O)(OR')O-$, $-S(O)_2-$, $-S-$, an aryl group, and a heteroaryl group, in which M'' is a bond, C_{1-13} alkyl or C_{2-13} alkenyl;

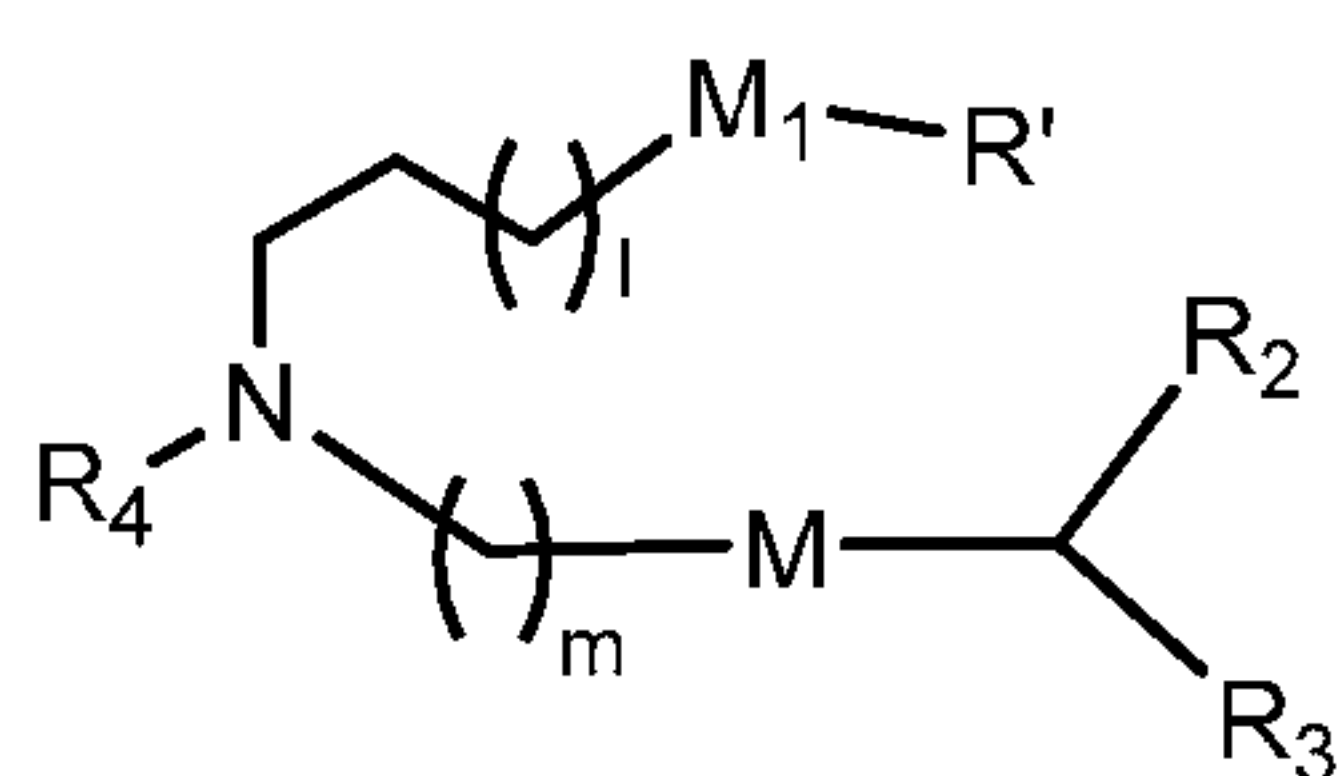
R_7 is selected from the group consisting of C_{1-3} alkyl, C_{2-3} alkenyl, and H;

R_8 is selected from the group consisting of C_{3-6} carbocycle and heterocycle;
 R_9 is selected from the group consisting of H, CN, NO_2 , C_{1-6} alkyl, -OR, $-S(O)_2R$, $-S(O)_2N(R)_2$, C_{2-6} alkenyl, C_{3-6} carbocycle and heterocycle;
each R is independently selected from the group consisting of C_{1-3} alkyl, C_{2-3} alkenyl, and H;
each R' is independently selected from the group consisting of C_{1-18} alkyl, C_{2-18} alkenyl, $-R^*YR''$, $-YR''$, and H;
each R'' is independently selected from the group consisting of C_{3-15} alkyl and C_{3-15} alkenyl;
each R^* is independently selected from the group consisting of C_{1-12} alkyl and C_{2-12} alkenyl;
each Y is independently a C_{3-6} carbocycle;
each X is independently selected from the group consisting of F, Cl, Br, and I; and
m is selected from 5, 6, 7, 8, 9, 10, 11, 12, and 13.

85. The nanoparticle composition of claim 84, wherein when R_4 is $-(CH_2)_nQ$, $-(CH_2)_nCHQR$, $-CHQR$, or $-CQ(R)_2$, then (i) Q is not $-N(R)_2$ when n is 1, 2, 3, 4 or 5, or (ii) Q is not 5, 6, or 7-membered heterocycloalkyl when n is 1 or 2.

86. The nanoparticle composition of claim 84 or 85, wherein R_1 is different from $-(CHR_5R_6)_m-M-CR_2R_3R_7$.

87. The nanoparticle composition of any one of claims 84-86, wherein the ionizable lipid is a compound of Formula (IA):

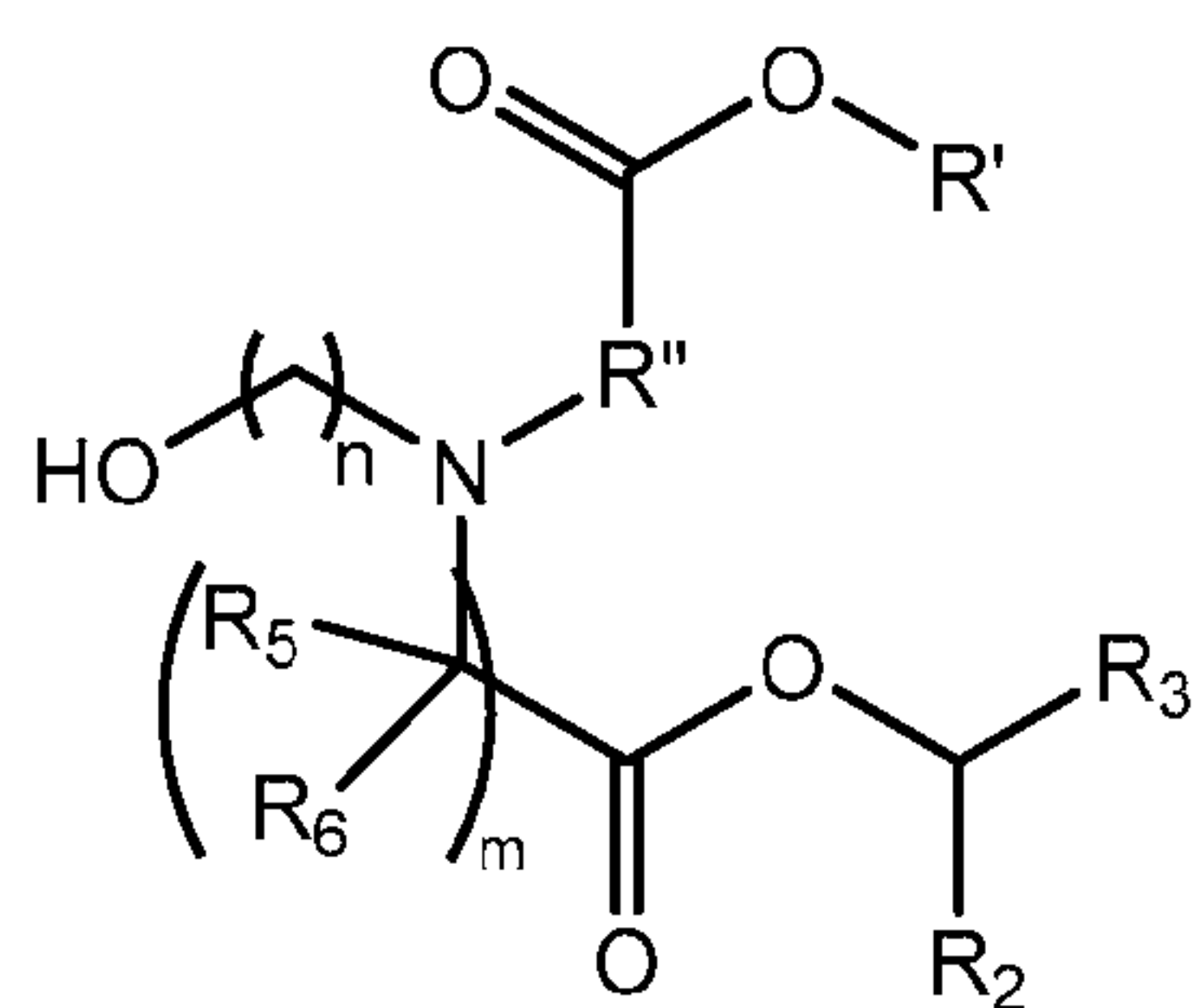


(IA) or its N-oxide,

or a salt or isomer thereof, wherein

l is selected from 1, 2, 3, 4, and 5;
 m is selected from 5, 6, 7, 8, and 9;
 M_1 is a bond or M' ;
 R_4 is hydrogen, unsubstituted C_{1-3} alkyl, or $-(CH_2)_nQ$, in which Q is OH, $-NHC(S)N(R)_2$, $-NHC(O)N(R)_2$, $-N(R)C(O)R$, $-N(R)S(O)_2R$, $-N(R)R_8$, $-N(R)S(O)_2R_8$,

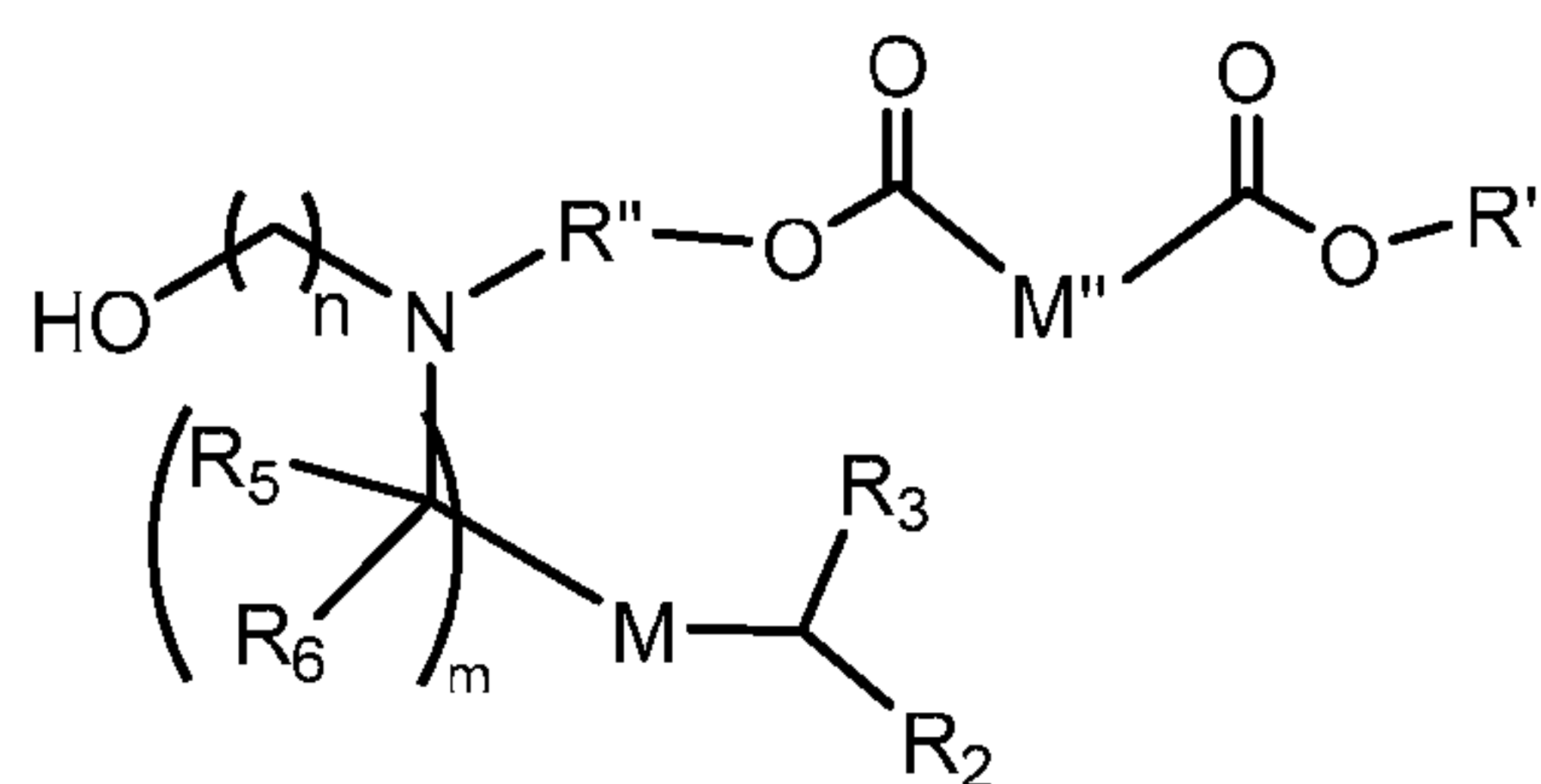
214



(IIId) or its N-oxide, or a salt or isomer thereof,

wherein R₂ and R₃ are independently selected from the group consisting of C₅₋₁₄ alkyl and C₅₋₁₄ alkenyl, and n is selected from 2, 3, and 4.

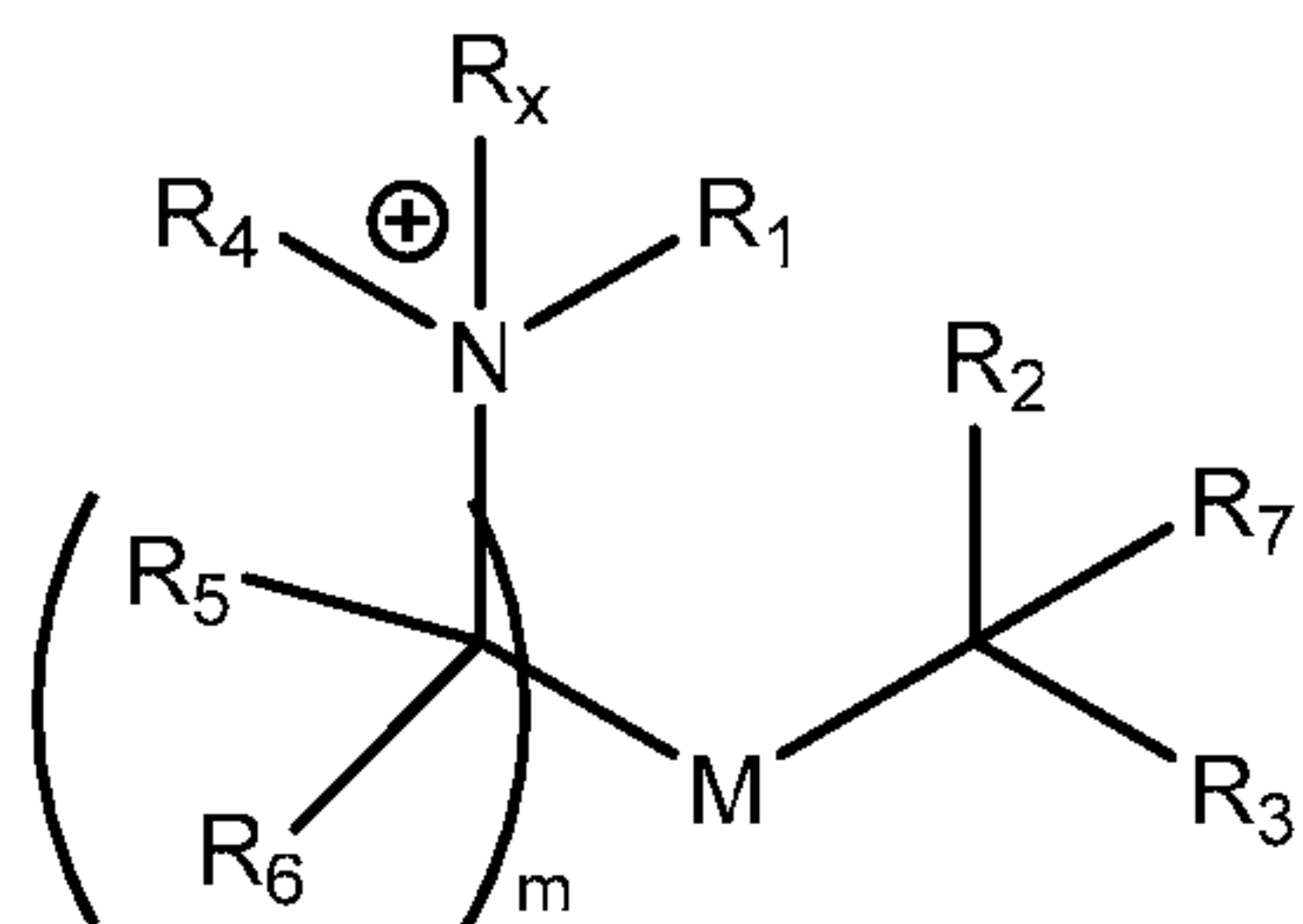
90. The nanoparticle composition of any one of claims 68-83, wherein the ionizable lipid is a compound of Formula (IIf):



(IIIf) or its N-oxide, or a salt or isomer thereof,

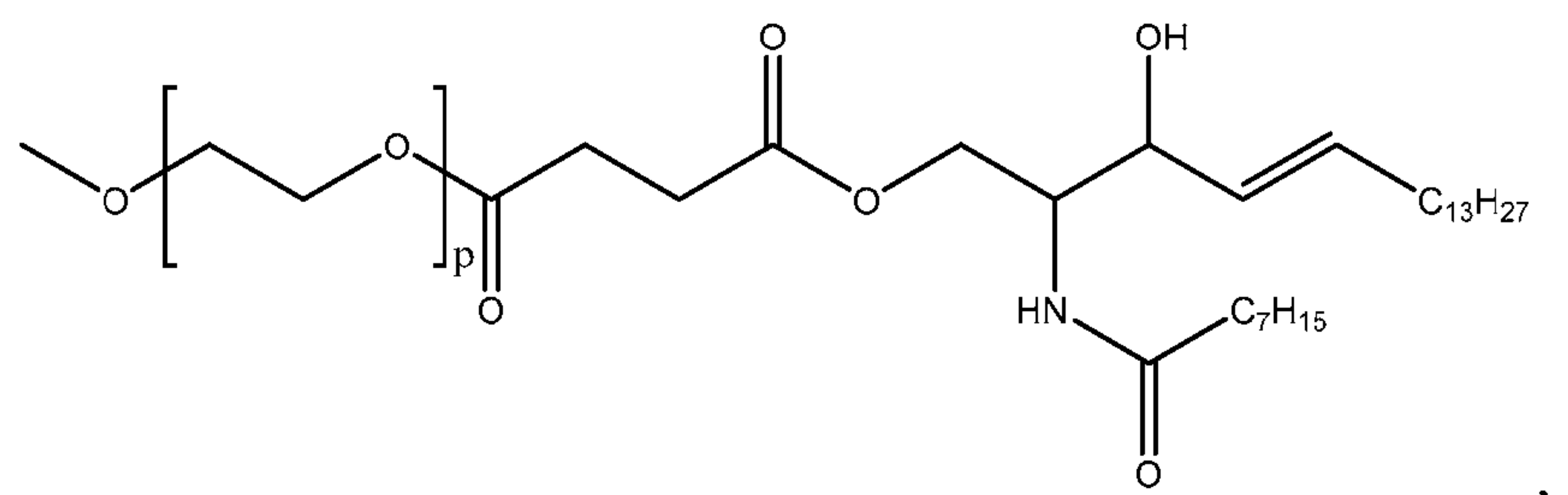
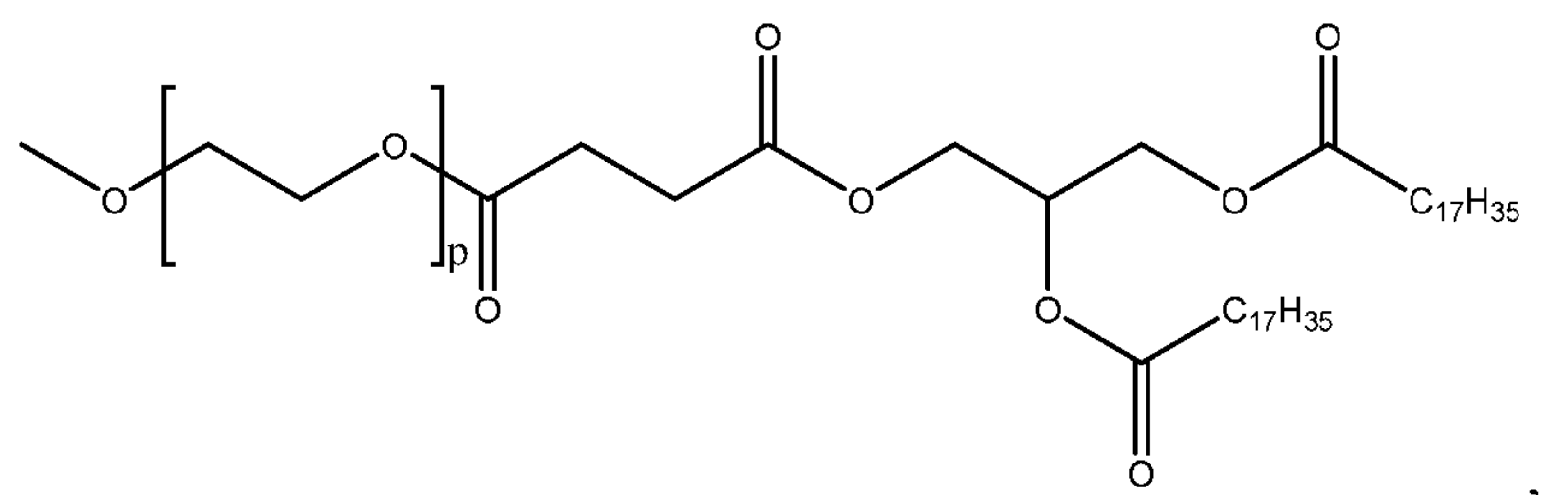
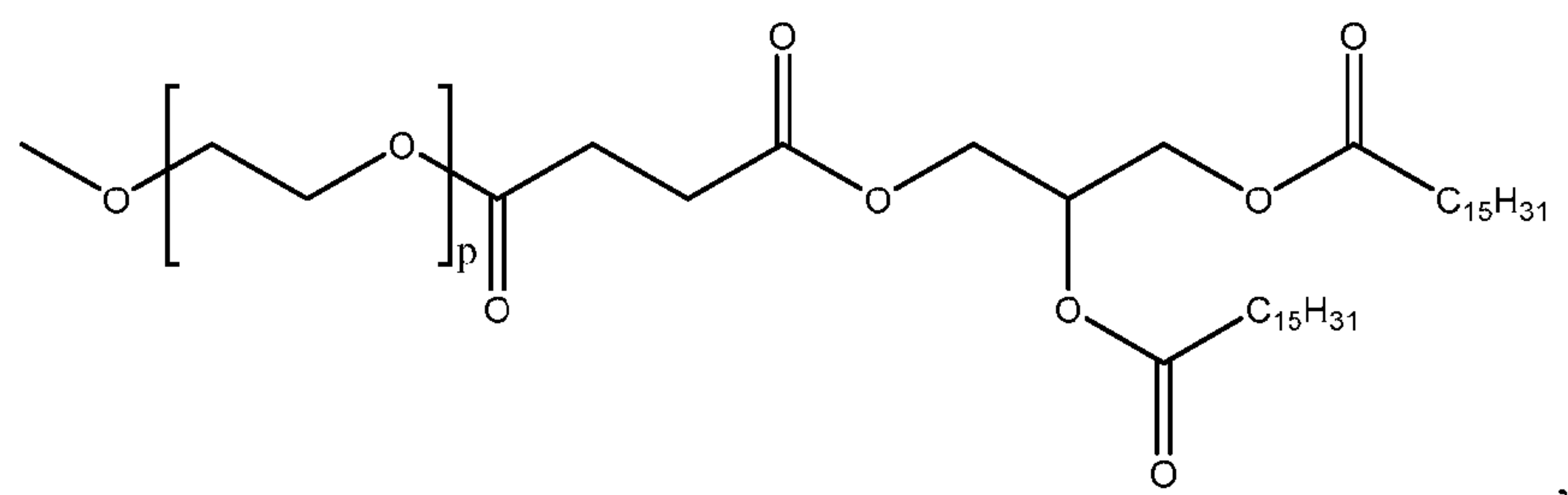
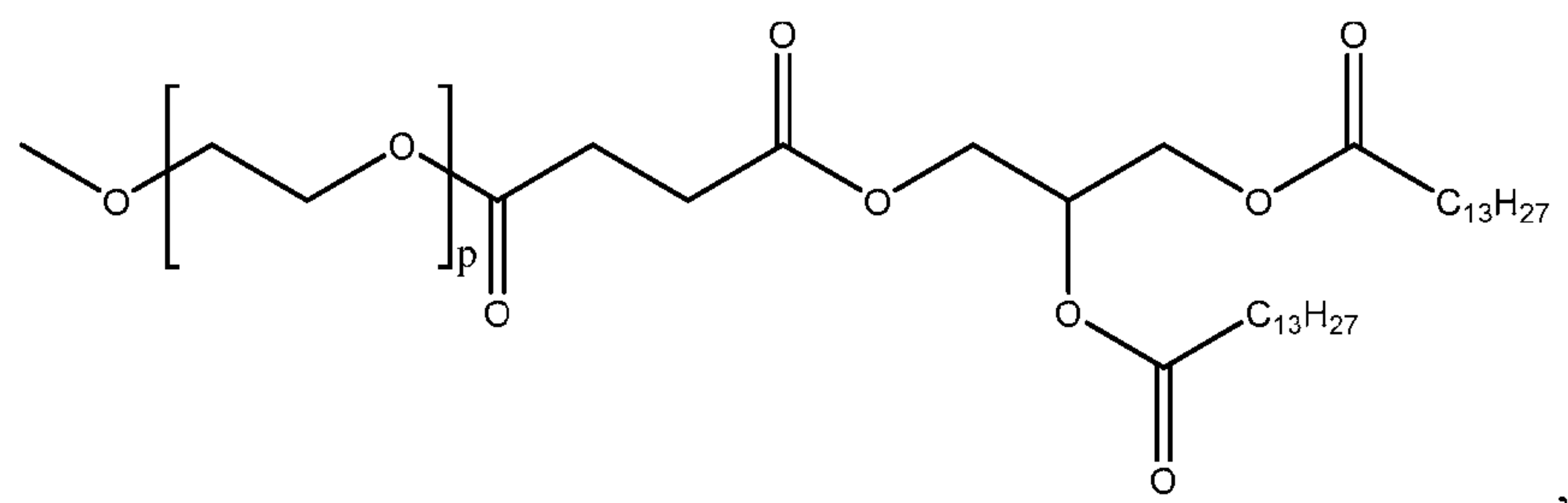
wherein M is -C(O)O- or -OC(O)-, M' is C₁₋₆ alkyl or C₂₋₆ alkenyl, R₂ and R₃ are independently selected from the group consisting of C₅₋₁₄ alkyl and C₅₋₁₄ alkenyl, and n is selected from 2, 3, and 4.

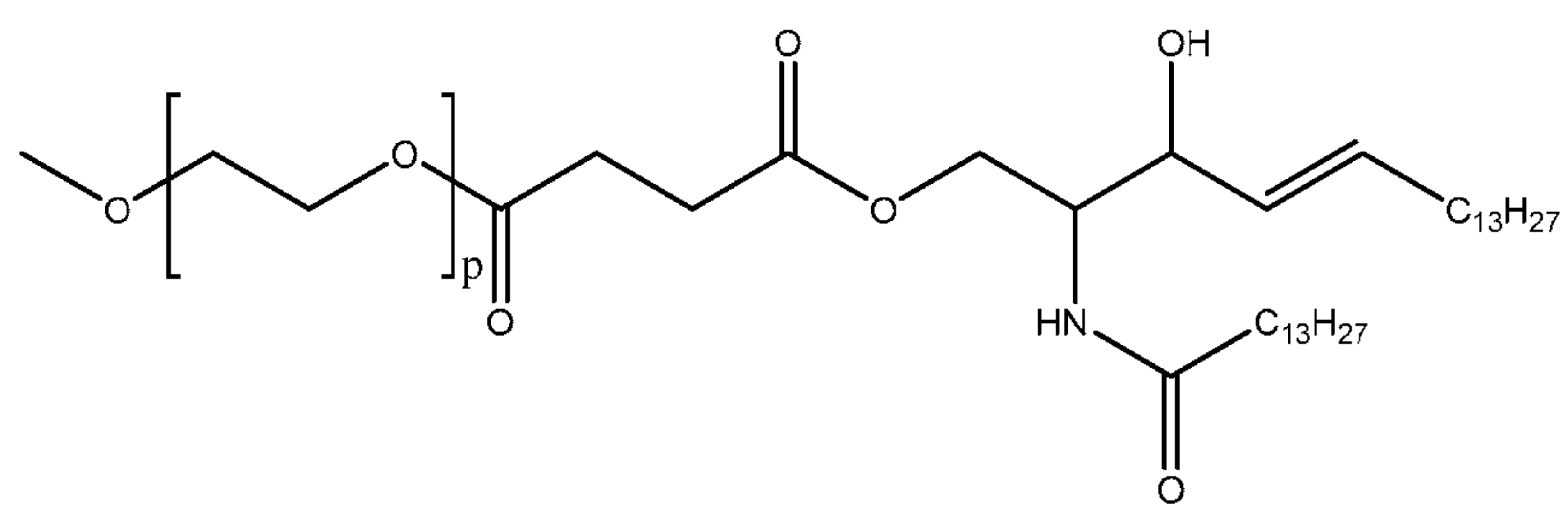
91. The nanoparticle composition of any one of claims 68-83, wherein the ionizable lipid is a compound of Formula (III):



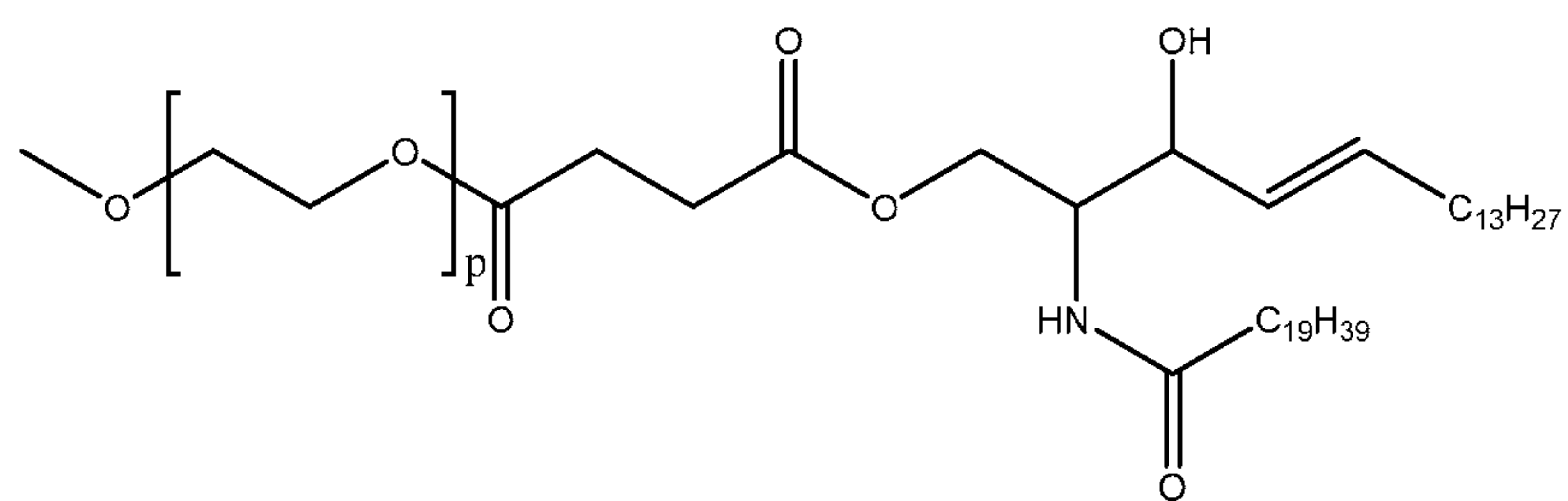
92. The lipid nanoparticle of any one of claims 68-0, wherein the surfactant is a PEG-diacylglycerol (PEG-DAG), PEG-ceramide (PEG-CER), or PEG-dialkyl glycerol.

93. The lipid nanoparticle of any one of claims 68-0, wherein the surfactant is selected from:

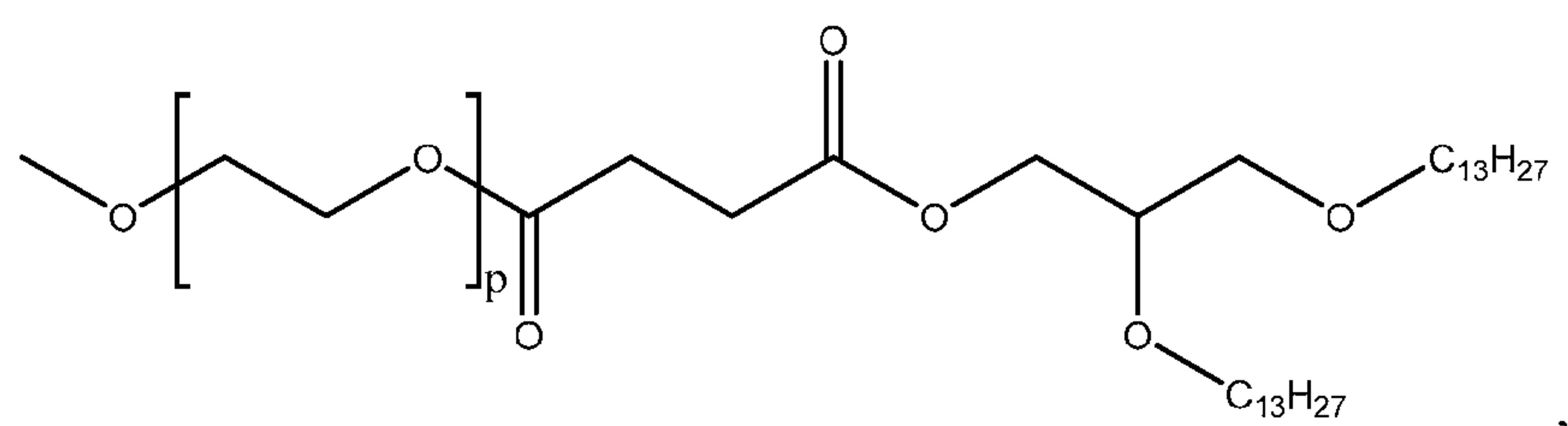




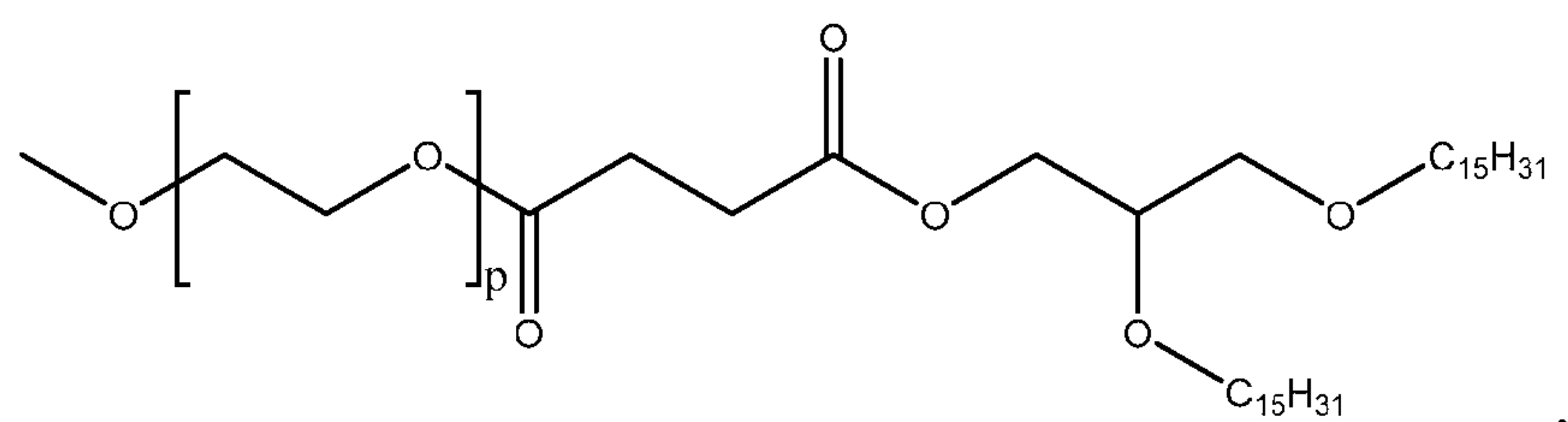
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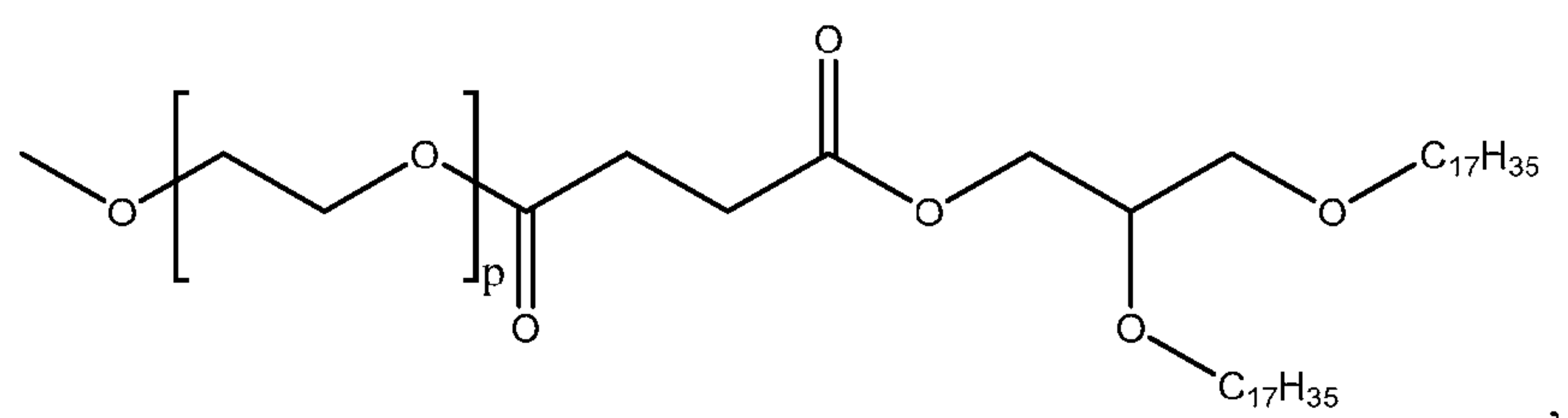
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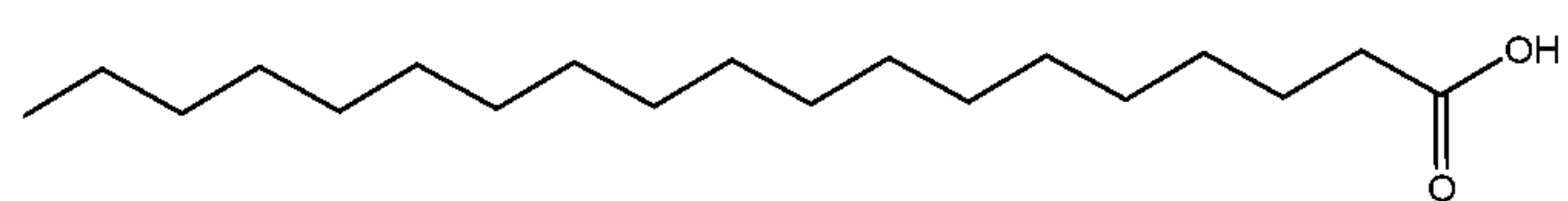
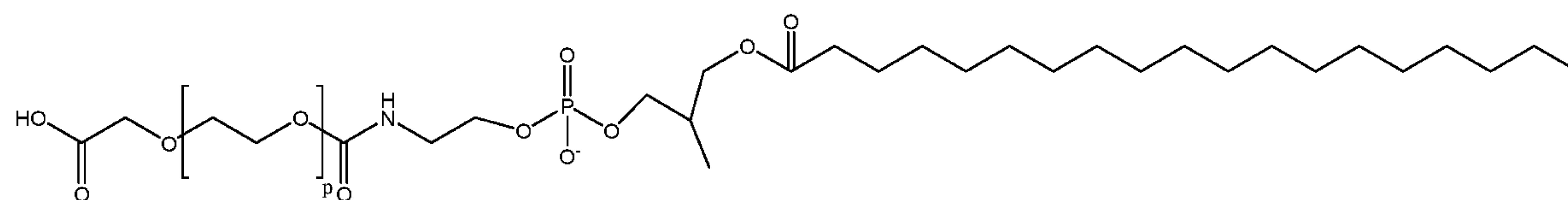
,



,



, and



;

wherein p is from 1 to 40.

94. The lipid nanoparticle of any one of claims 68-93, wherein the composition comprises about 45 mol % to about 65 mol % ionizable lipid, about 5 mol % to about 10 mol % phospholipid, about 25 mol % to about 35 mol % cholesterol derivative, and about 5 mol % to about 10 mol % surfactant.

95. The lipid nanoparticle of any one of claims 68-94, wherein the lipid nanoparticle has a nanoparticle size of from 80 nm to 150 nm.

96. The lipid nanoparticle of claim 95, wherein the nanoparticle size is from 90 nm to 130 nm.

97. A method for transfecting a cell, comprising:
contacting the cell with a lipid nanoparticle of any one of claims 68-96; and
incubating the cell for a time period sufficient for transfection to proceed.

98. The method of claim 97, wherein the time period sufficient for transfection to proceed is between about 1h and about 48h.

99. The method of claim 98, wherein the wherein the time period sufficient for transfection to proceed between is about 1h and about 5h, between about 6h and about 12h, between about 13h and about 24h, between about 25h and about 36h, or between about 37h and about 48h.

100. The method of claim 98, wherein the wherein the time period sufficient for transfection to proceed is about 1h, about 5h, about 10h, about 15h, about 20h, about 25h, about 30h, about 35h, about 40h, or about 45h.

101. The method of claim 98, wherein the wherein the time period sufficient for transfection to proceed is about 2h, about 6h, about 12h, about 18h, about 24h, about 36h, about 42h, or about 48h.

102. A method of treating a disease or disorder characterized by overexpression of a polypeptide in a subject, comprising administering to the subject the lipid nanoparticle of any one of claims 68-96, wherein the nucleic acid is capable of silencing or decreasing the expression of the polypeptide.

103. A method of treating a disease or disorder characterized by underexpression of a polypeptide in a subject, comprising administering to the subject the lipid nanoparticle of any one of claims 68-96, wherein the nucleic acid is capable of expressing or increasing the expression of the polypeptide.

104. A method for modulating the expression of a target polynucleotide or polypeptide, comprising contacting a cell with the lipid nanoparticle of any one of claims 68-96, wherein the nucleic acid is capable of modulating the expression of a target polynucleotide or polypeptide.

105. A method for making the lipid nanoparticle of any one of claims 68-96, comprising:
introducing a first stream comprising the nucleic acid in a first solvent into a device;
introducing a second stream comprising the cationic lipid, the phospholipid, the surfactant and the cholesterol derivative in a second solvent into the device;
flowing the first and second streams into a mixing region of the device for a time period sufficient for the first and second streams to mix to form a third stream comprising the lipid nanoparticle.

106. The method of claim 105, wherein the time period sufficient for the first and second streams to mix is between about 1h and about 48h.

107. The method of claim 106, wherein the wherein the time period sufficient for the first and second streams to mix is between about 1h and about 5h, between about 6h and about 12h, between about 13h and about 24h, between about 25h and about 36h, or between about 37h and about 48h.

108. The method of claim 106, wherein the wherein the time period sufficient for the first and second streams to mix is about 1h, about 5h, about 10h, about 15h, about 20h, about 25h, about 30h, about 35h, about 40h, or about 45h.

109. The method of claim 106, wherein the wherein the time period sufficient for the first and second streams to mix is about 2h, about 6h, about 12h, about 18h, about 24h, about 36h, about 42h, or about 48h.
110. The method of claim 106, wherein a volume ratio of the second stream to the first stream is 1:3.
111. The nanoparticle composition of any one of the preceding claims, for use in the treatment of a disease or disorder in a mammal in need thereof.
112. The nanoparticle composition of any one of the preceding claims, for use as a medicament for the treatment of a disease or disorder in a mammal in need thereof.
113. The use of a nanoparticle composition of any one of the preceding claims, in the manufacture of a medicament for the treatment of a disease or disorder in a mammal in need thereof.
114. The method, use, or nanoparticle composition for use of any one of the preceding claims, wherein the disease or disorder is characterized by underexpression of a polypeptide in the subject, and wherein the nucleic acid is capable of expressing or increasing the expression of the polypeptide.
115. The method, use, or nanoparticle composition for use of claim any one of the preceding claims, wherein the disease or disorder is characterized by overexpression of a polypeptide in the subject, and wherein the nucleic acid is capable of silencing or decreasing the expression of the polypeptide.
116. The method, use, or nanoparticle composition for use of claim any one of the preceding claims, wherein the disease or disorder is characterized by underexpression of a polypeptide in the subject, and wherein the nucleic acid is capable of expressing or increasing the expression of the polypeptide.

117. The method, use, or nanoparticle composition for use of any one of the preceding claims, wherein the subject is a mammal.

118. The method, use, or nanoparticle composition for use of any one of the preceding claims, wherein the mammal is a human.

119. The method, use, or nanoparticle composition for use of any one of the preceding claims, wherein the nanoparticle composition is administered intravenously, intramuscularly, intradermally, intrathecally, intraparenchymally, intravitreally, intraperitoneally, intratumorally, subcutaneously, intranasally, or by inhalation.

120. The method, use, or nanoparticle composition for use of any one of the preceding claims, wherein a dose of about 0.001 mg/kg to about 10 mg/kg of the therapeutic and/or prophylactic agent is administered to the mammal, or wherein the medicament comprises 0.001 mg/kg to about 10 mg/kg of the therapeutic and/or prophylactic agent.

121. The method, use, or nanoparticle composition for use of any one of the preceding claims, wherein the disease or disorder is characterized by dysfunctional or aberrant protein or polypeptide activity.

122. The method, use, or nanoparticle composition for use of any one of the preceding claims, wherein the disease or disorder is selected from the group consisting of infectious diseases, rare disease, lysosomal storage diseases, cancer and proliferative diseases, genetic diseases, autoimmune diseases, diabetes, neurodegenerative diseases, cardio- and reno-vascular diseases, and metabolic diseases.

123. The method of any one of the preceding claims, further comprising, prior to the contacting or administering step, pretreating said subject with one or more additional compounds, wherein pretreating comprises administering said one or more additional compounds to said subject.

124. The use or nanoparticle for use of any one of the preceding claims, wherein the subject has been pretreated with one or more additional compounds, wherein pretreating comprises administering said one or more additional compounds to said subject.

125. The method, use, or nanoparticle composition for use of claim 123 or 124, wherein said mammal is pretreated two weeks or fewer prior to the contacting or administering step.

126. The method, use, or nanoparticle composition for use of claim 123 or 124, wherein said mammal is pretreated one week or fewer prior to the contacting or administering step.

127. The method, use, or nanoparticle composition for use of claim 123 or 124, wherein said mammal is pretreated 24 or fewer hours prior to the contacting or administering step.

128. The method, use, or nanoparticle composition for use of claim 123 or 124, wherein said mammal is pretreated about one hour prior to the contacting or administering step.

129. The method, use, or nanoparticle composition for use of any one of the preceding claims, wherein said one or more additional compounds are selected from the group consisting of anti-inflammatory compounds, steroids, statins, estradiols, BTK inhibitors, S1P1 agonists, glucocorticoid receptor modulators (GRMs), leukotriene antagonists, and anti-histamines.

130. The method, use, or nanoparticle composition for use of any one of the preceding claims, wherein said one or more additional compounds are selected from the group consisting of dexamethasone, methotrexate, acetaminophen, MK-571, Montelukast, Zafirlukast, Pranlukast, an H1 receptor blocker, and an H2 receptor blocker.

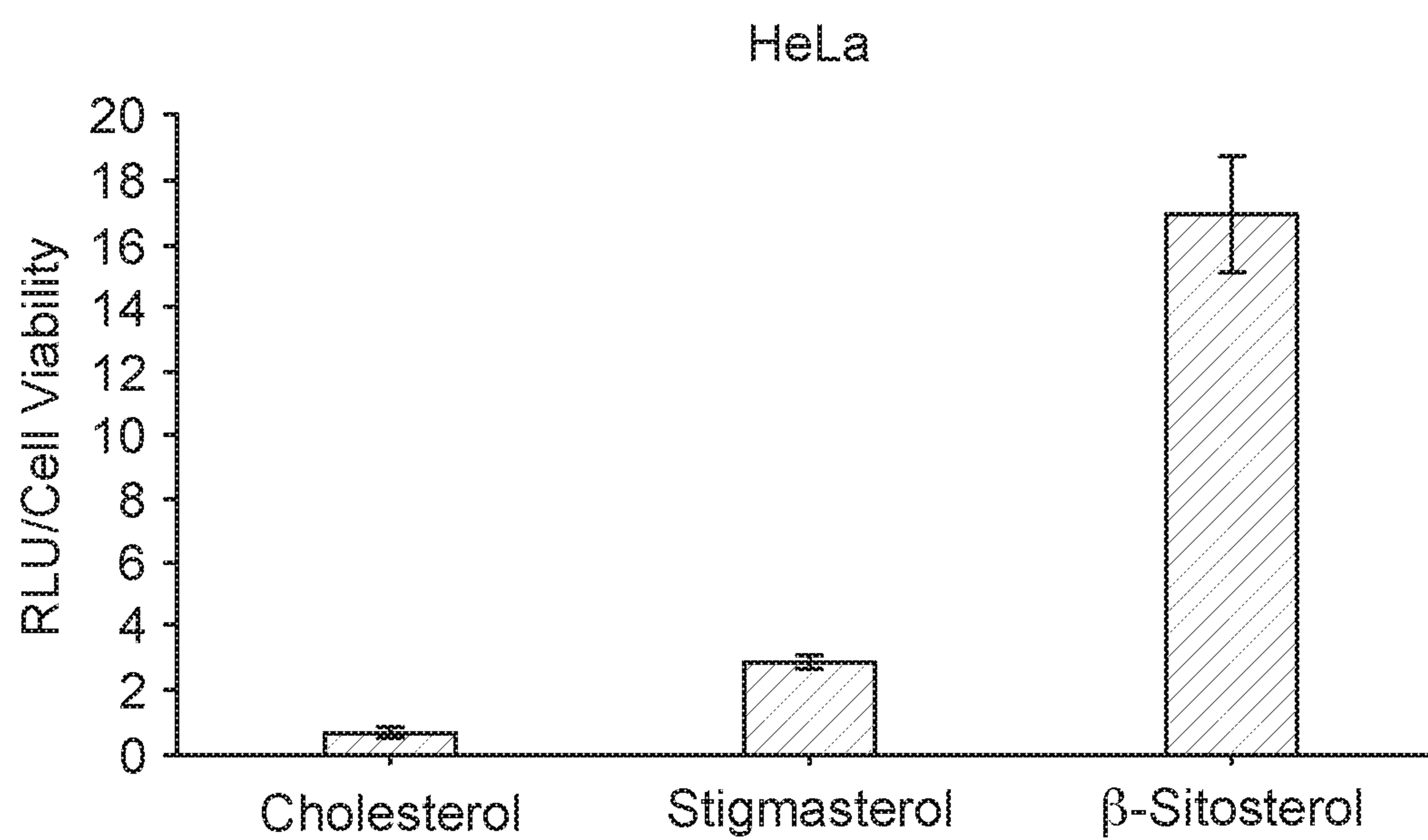
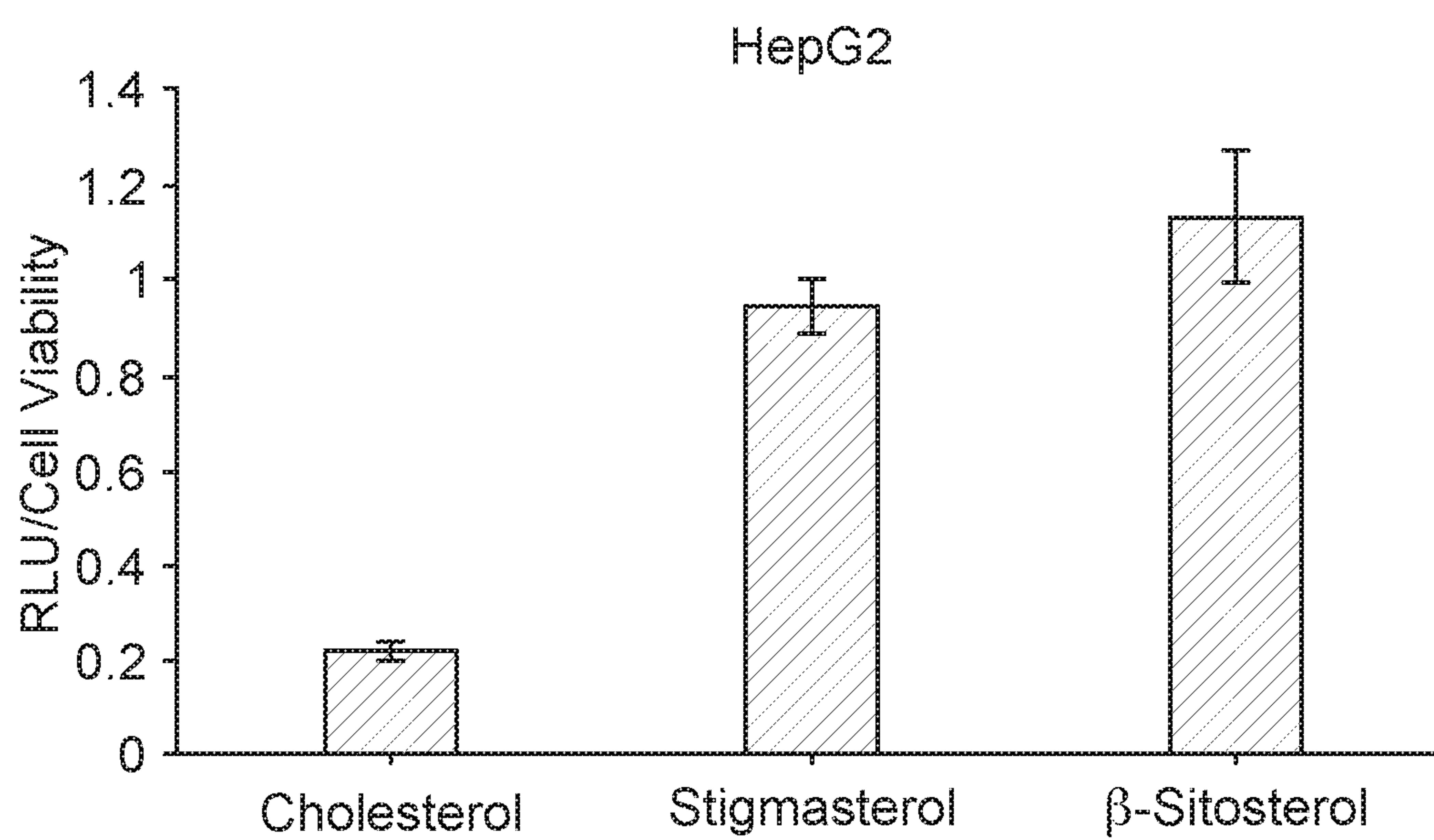
Fig. 1A**Fig. 1B**

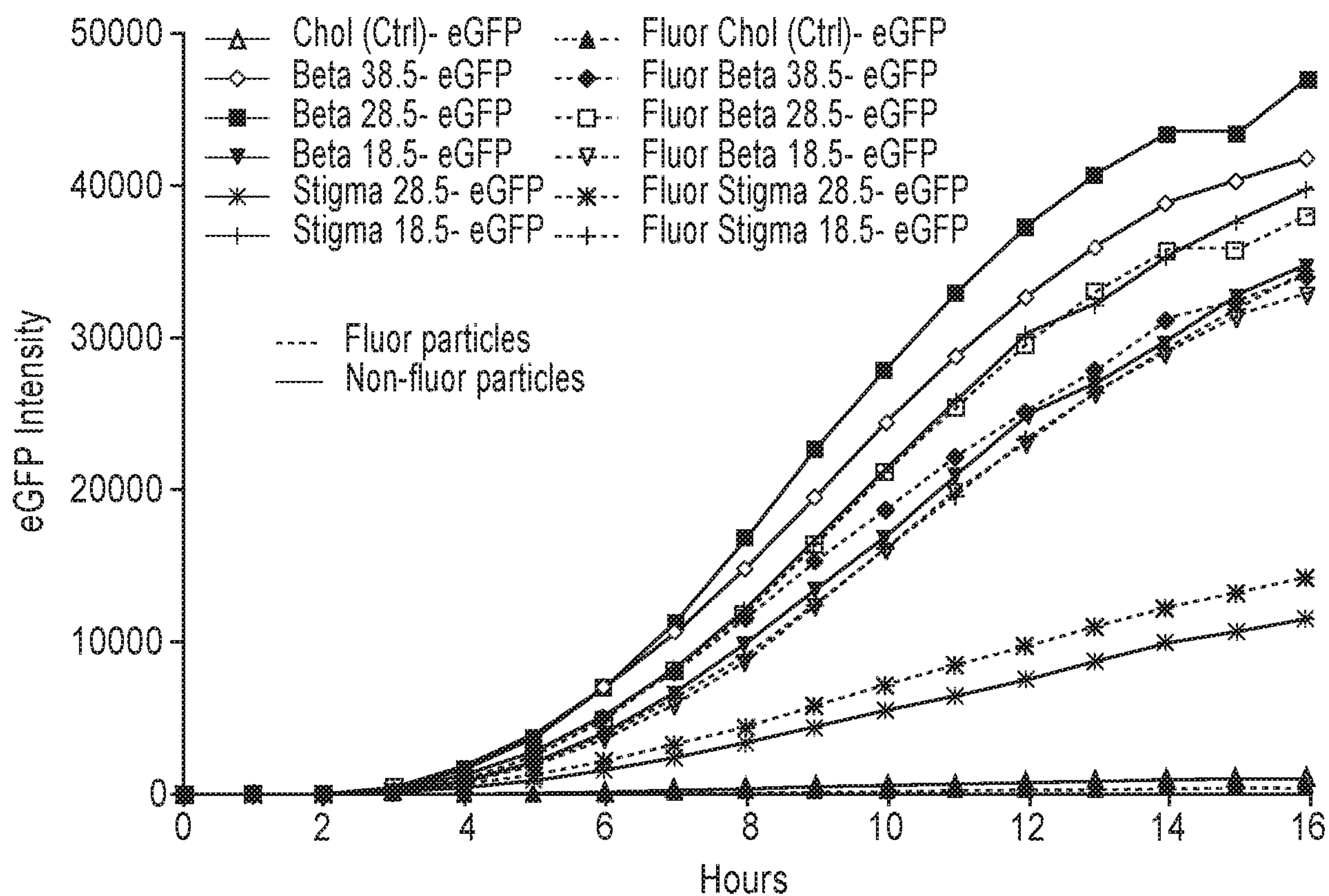
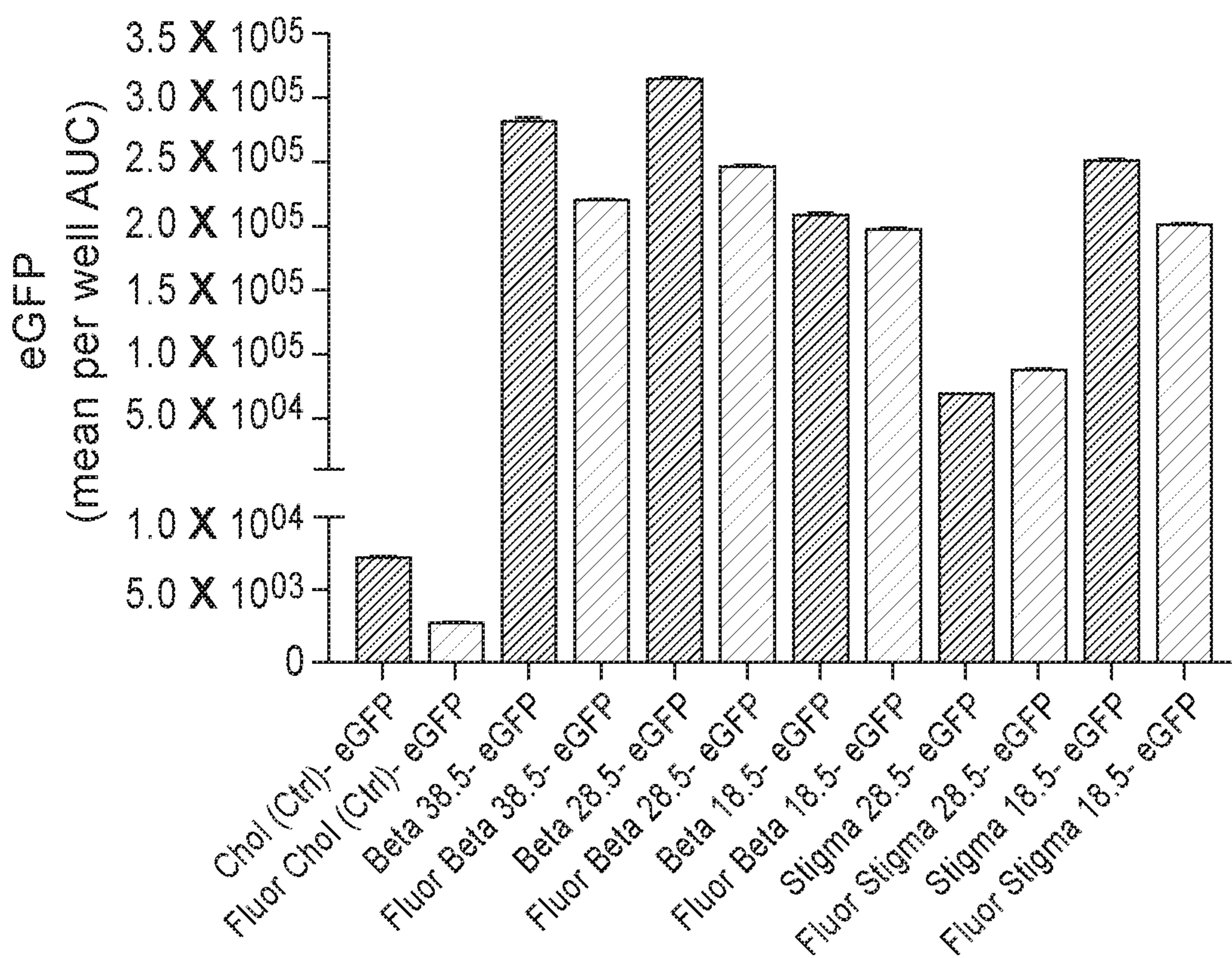
Fig. 2A**Fig. 2B**

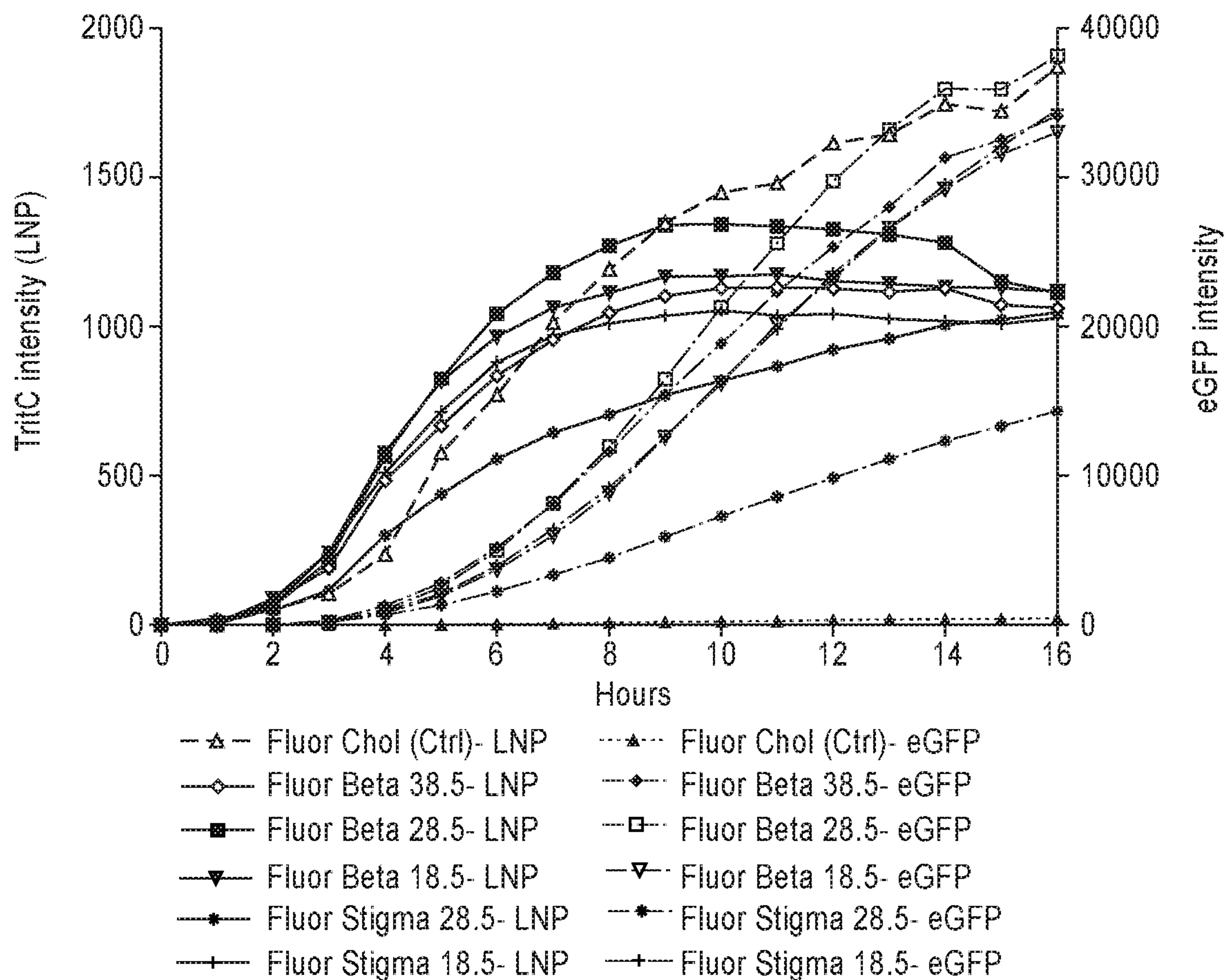
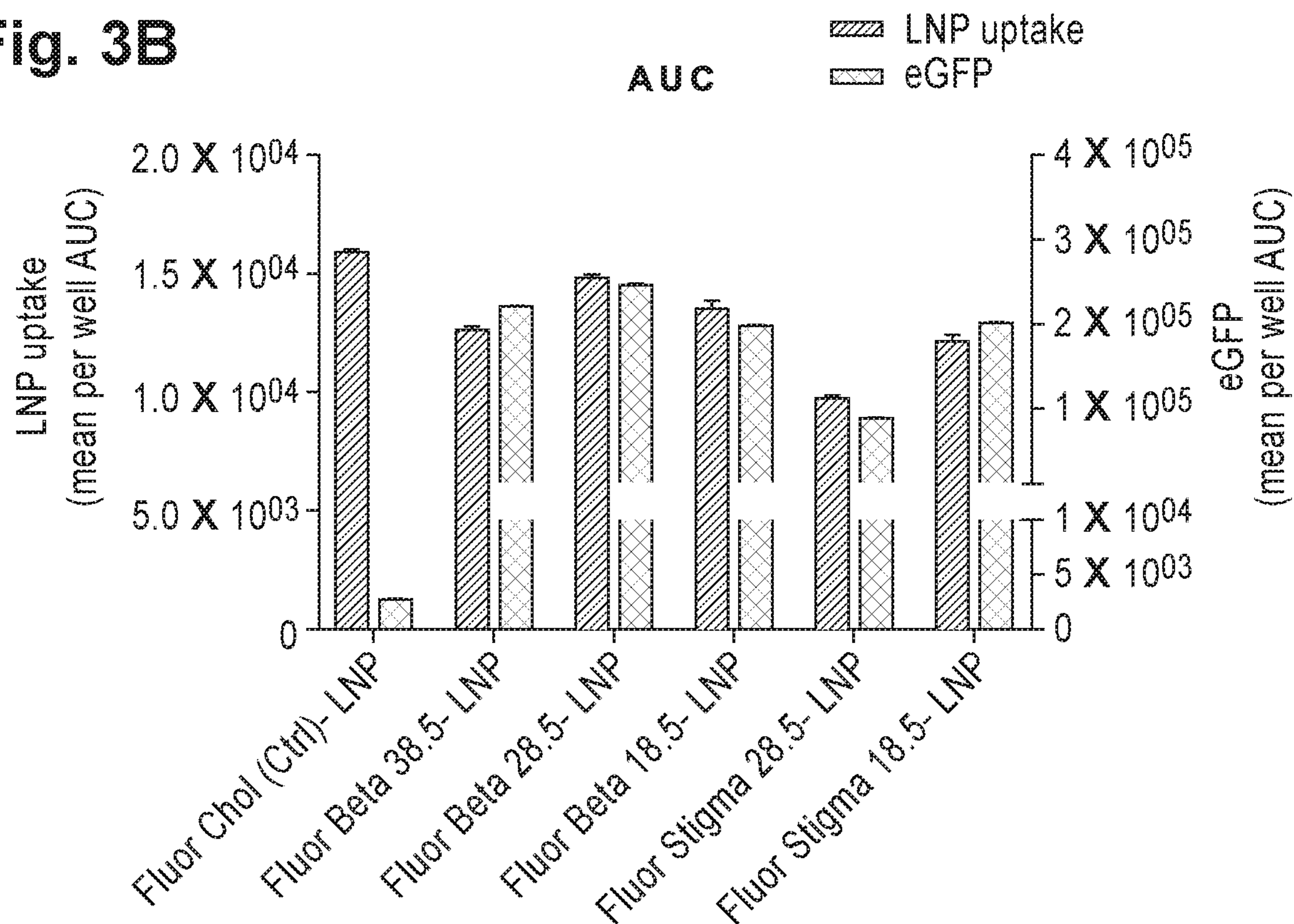
Fig. 3A**Fig. 3B**

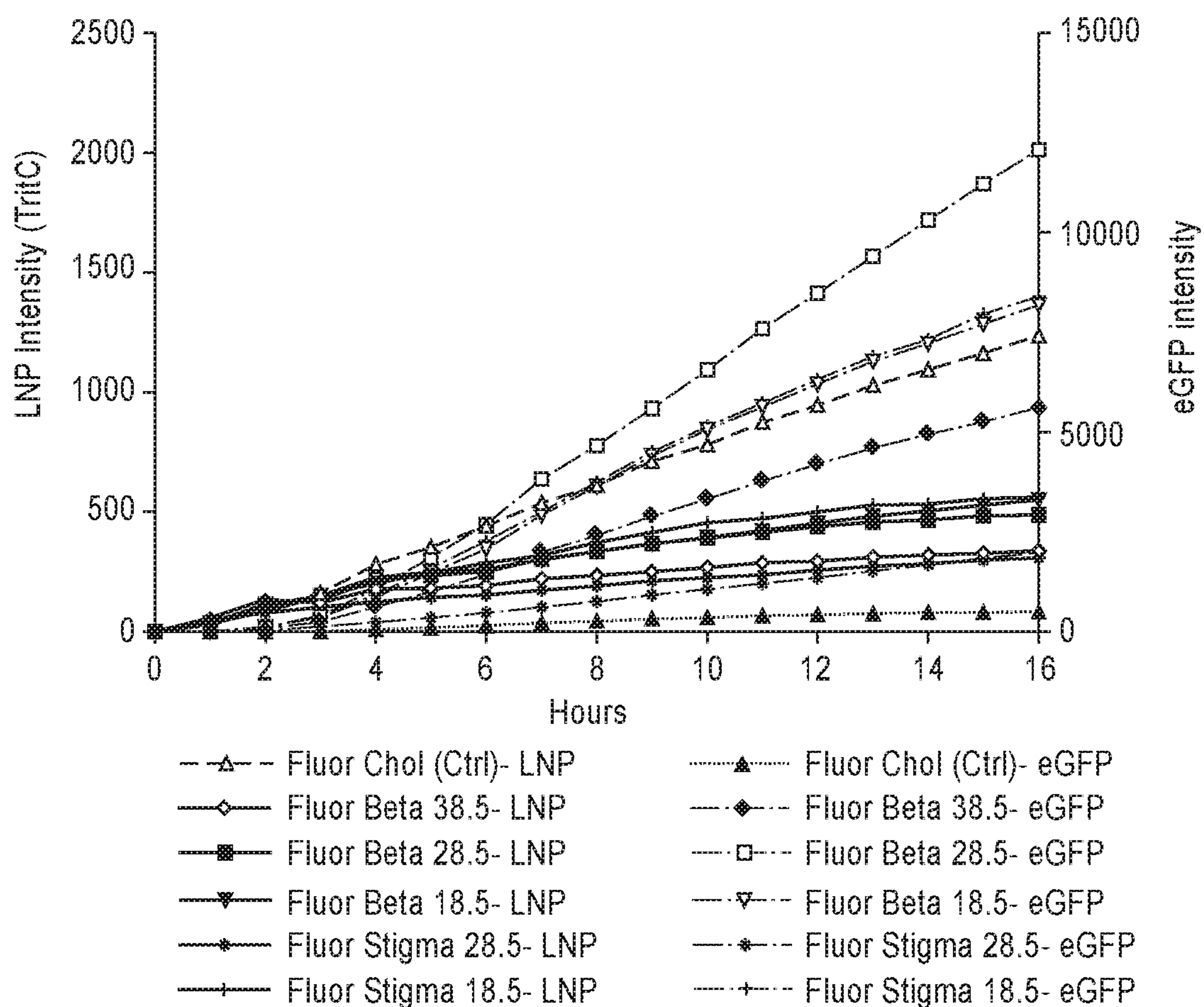
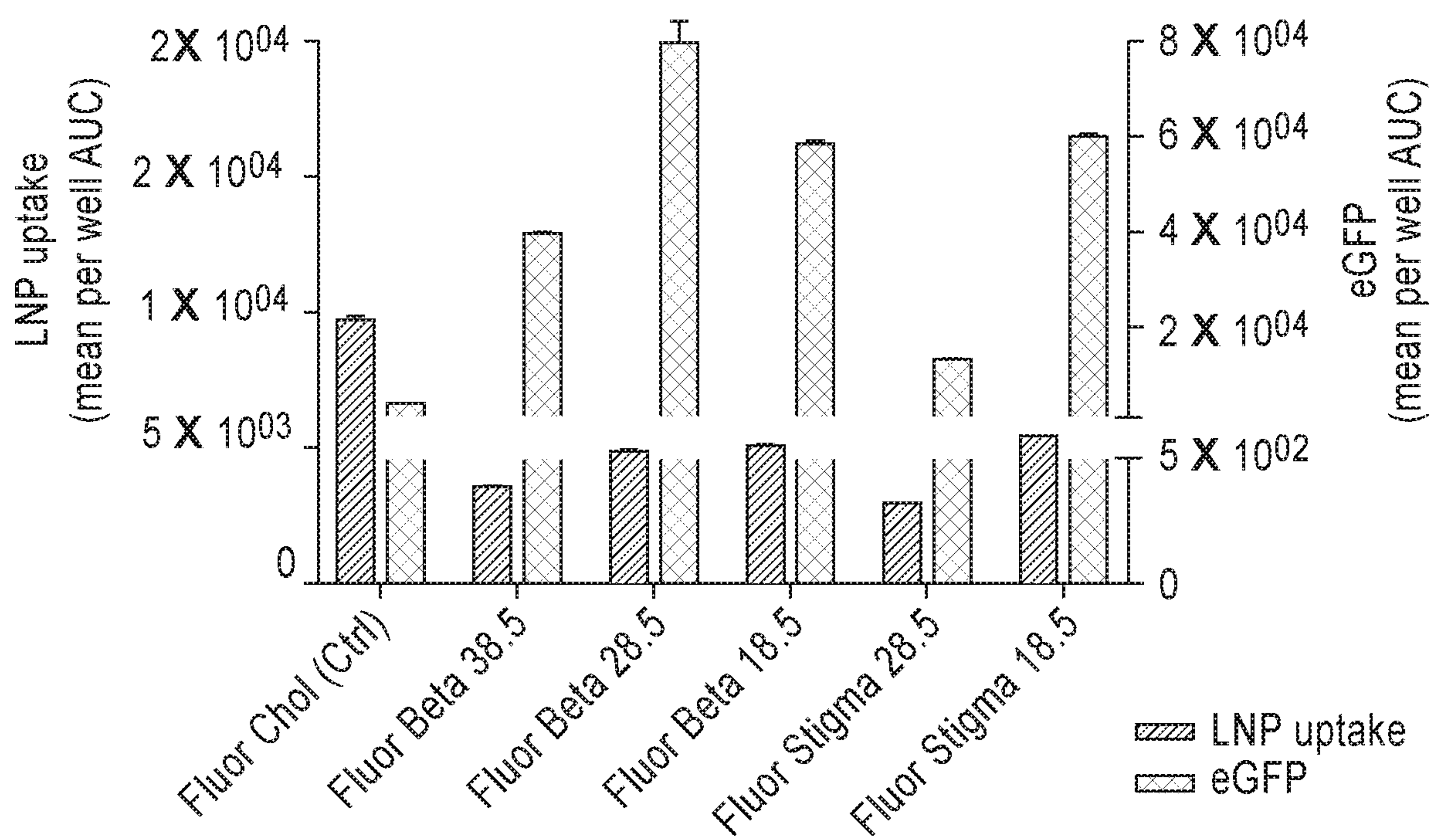
Fig. 4A**Fig. 4B**

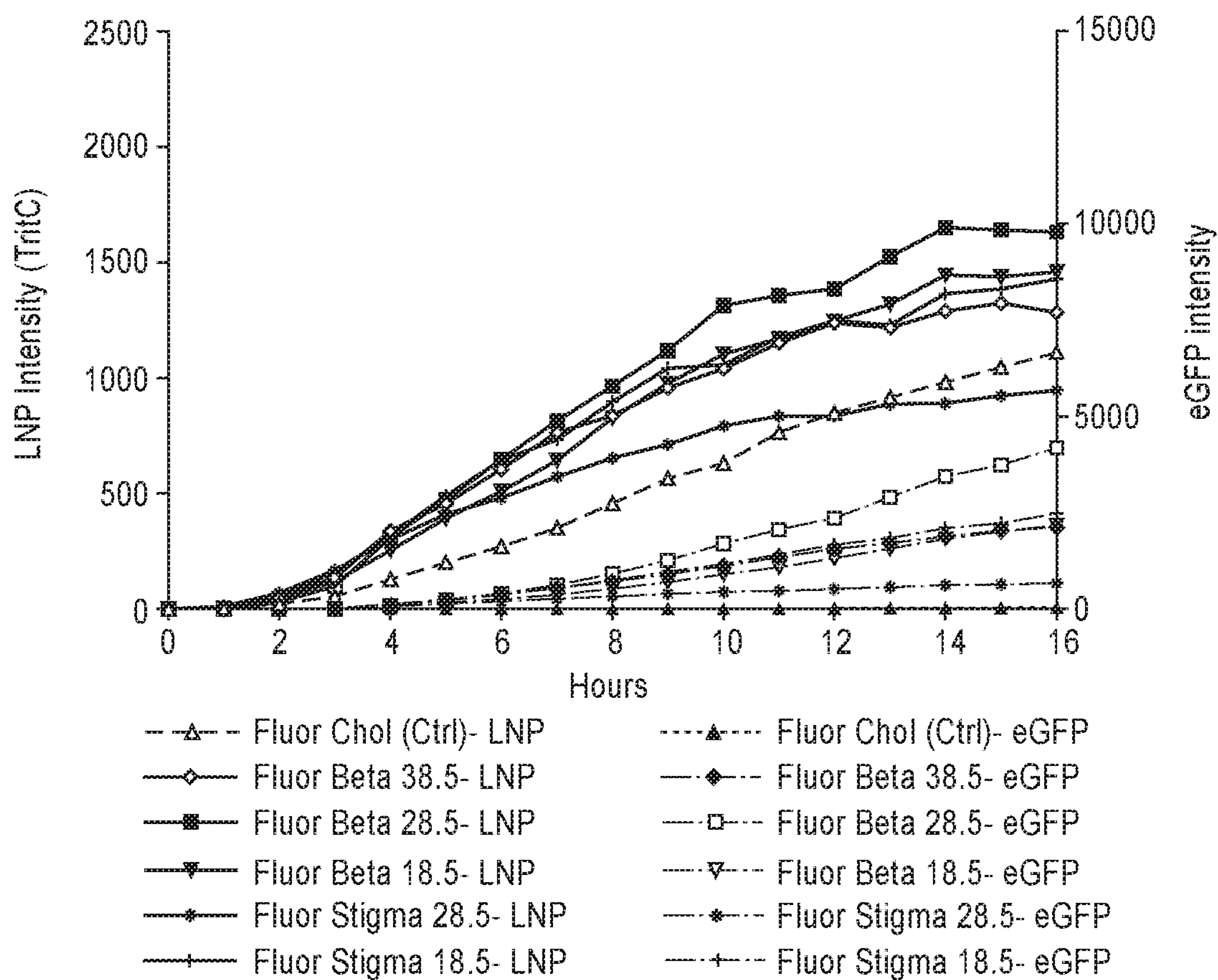
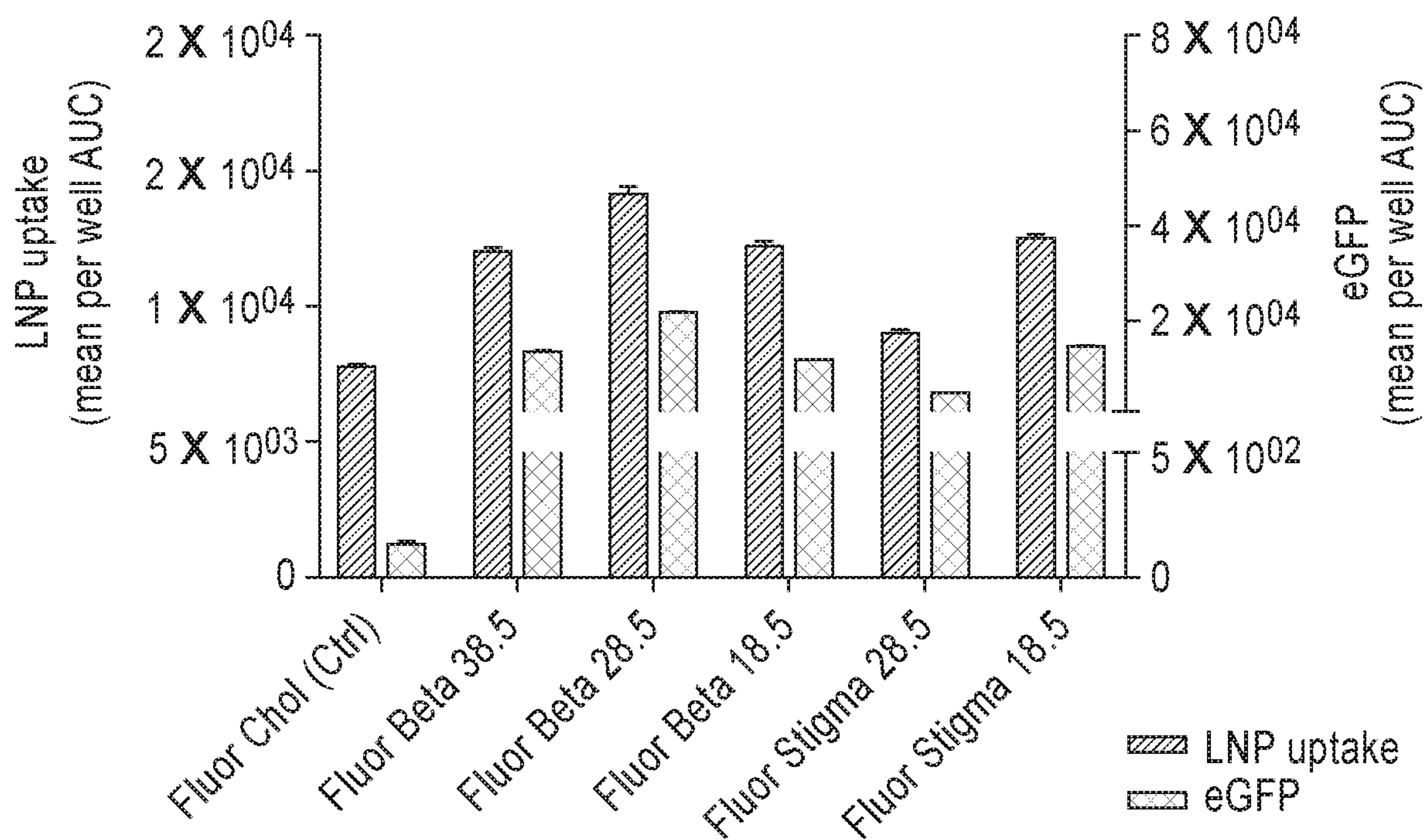
Fig. 5A**Fig. 5B**

Fig. 6A

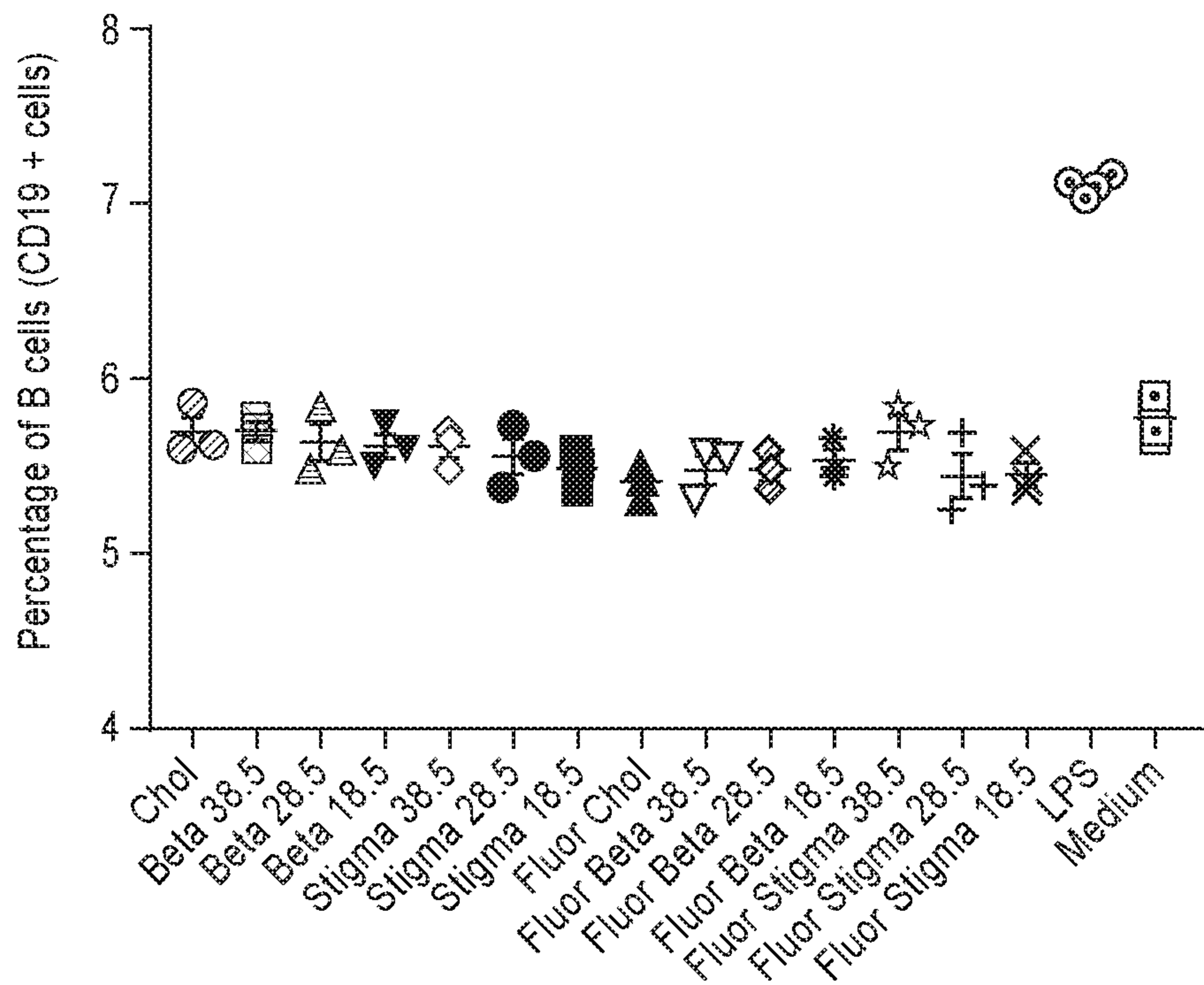


Fig. 6B

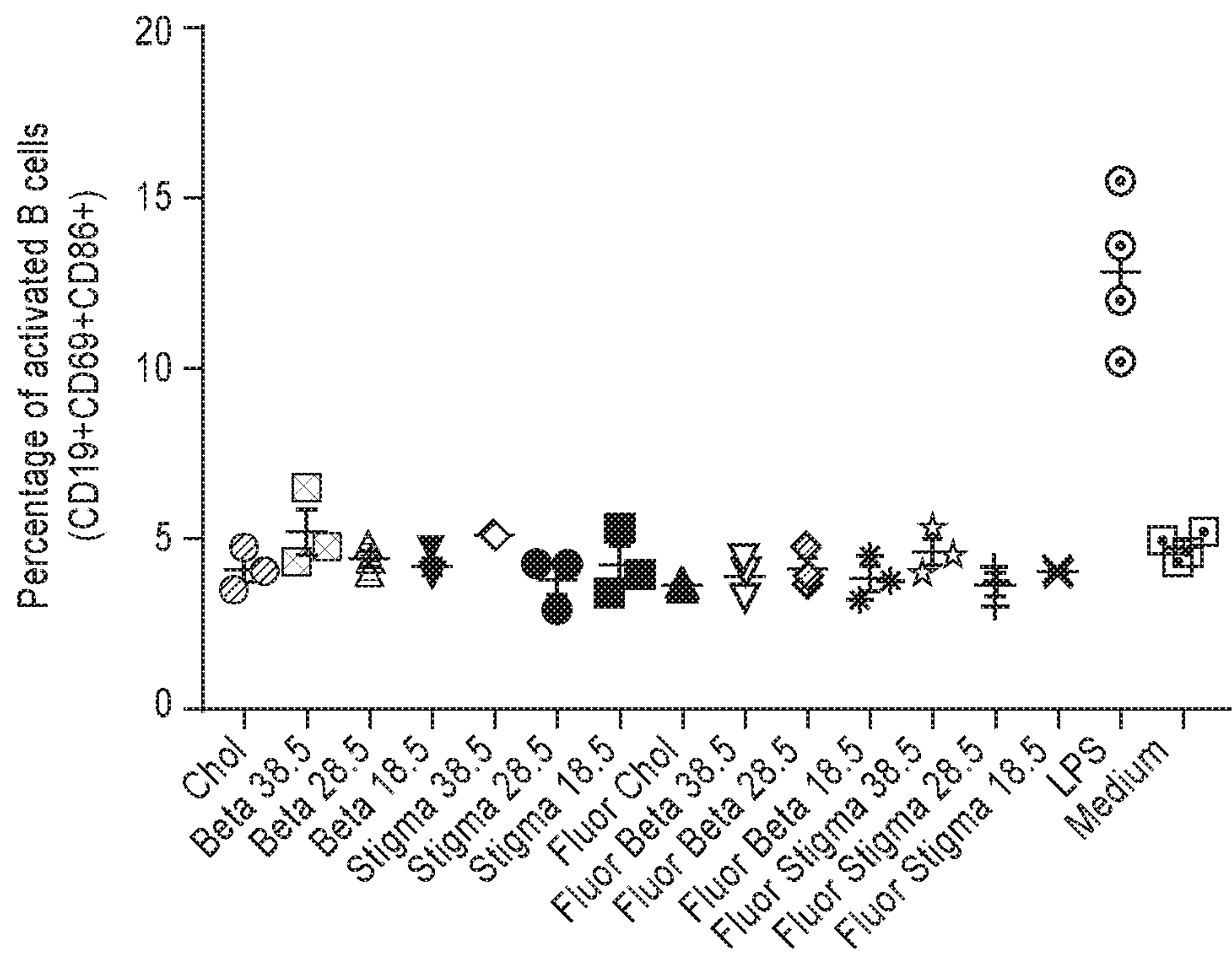
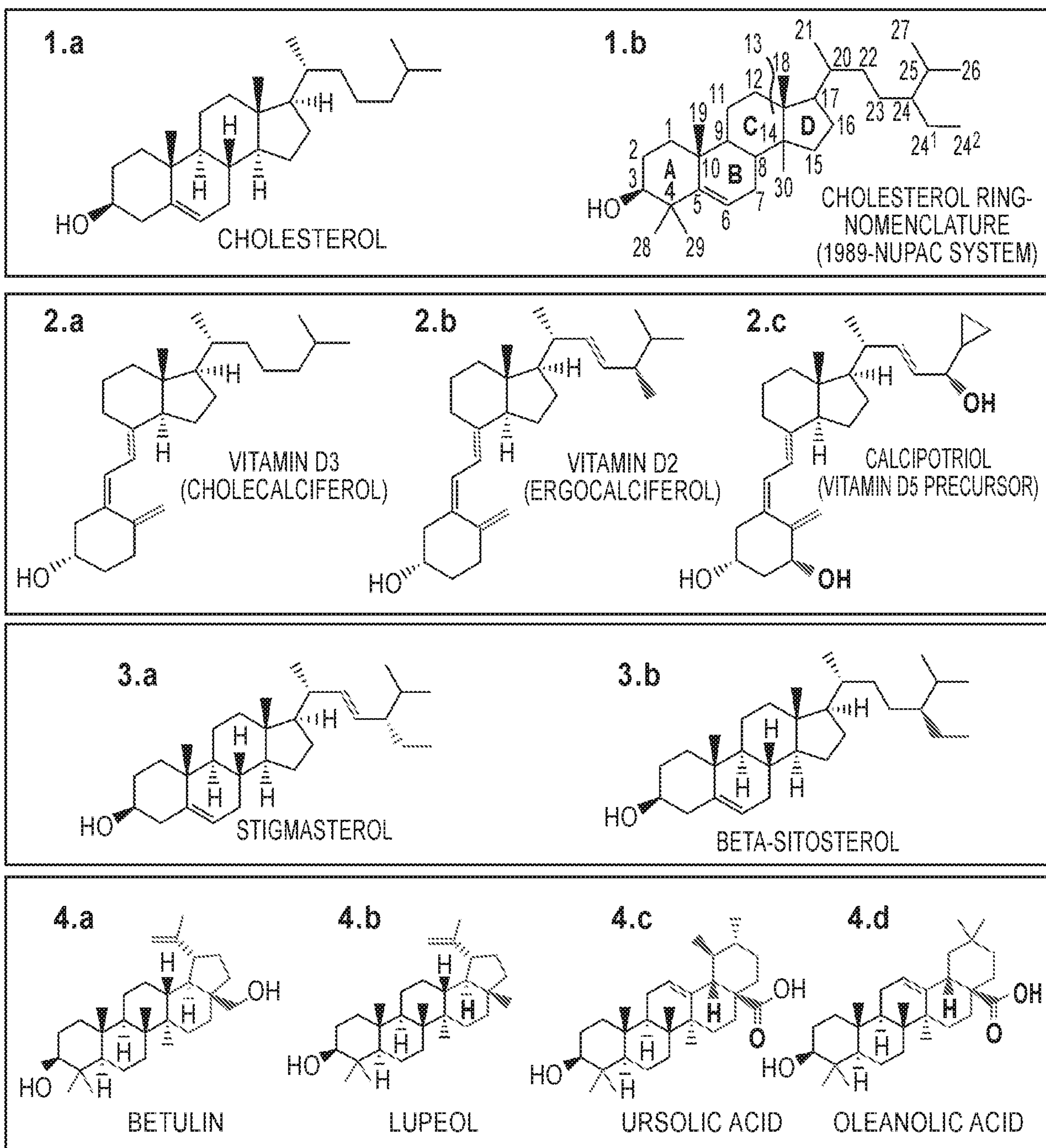


Fig. 7A

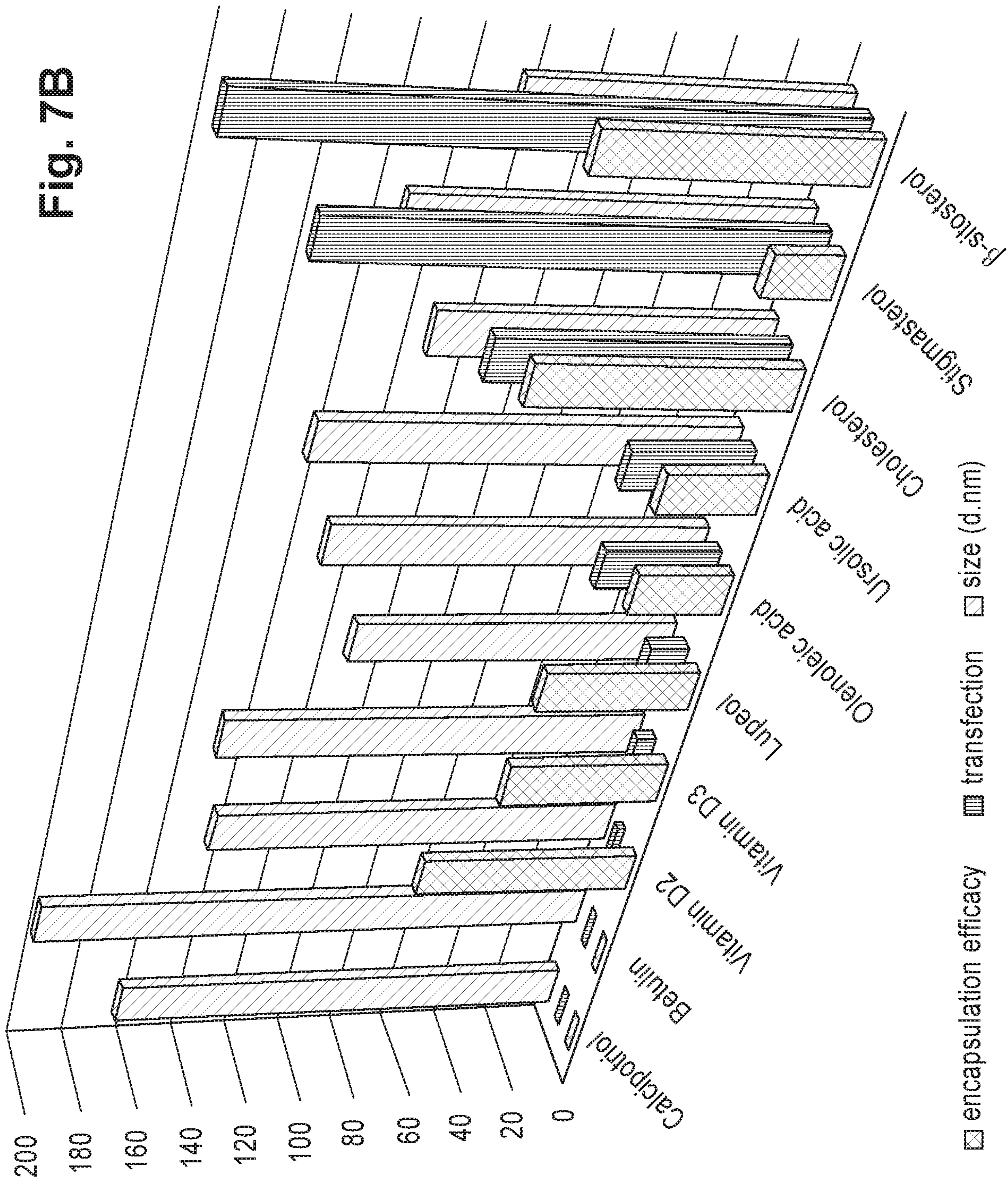


Fig. 7C

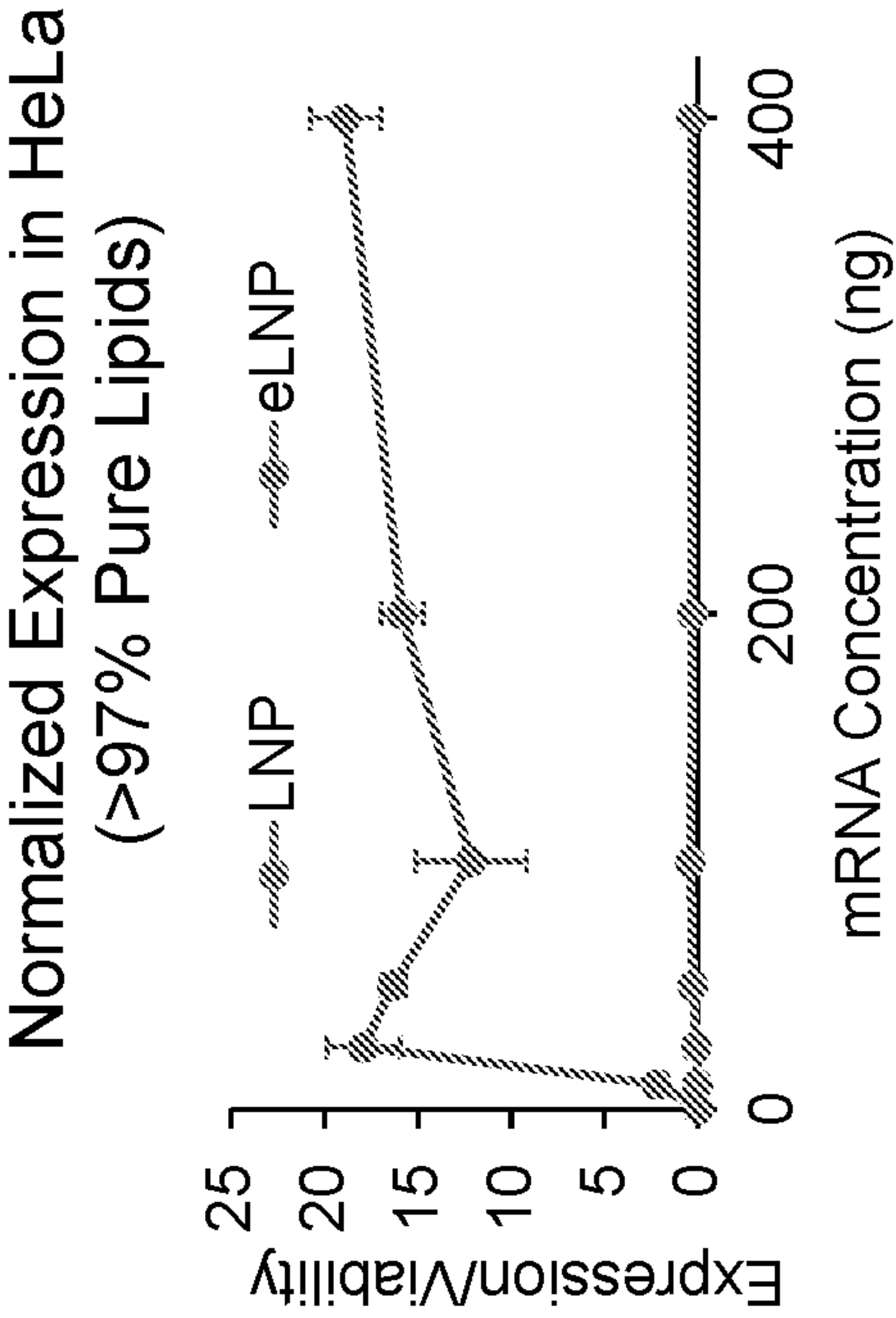
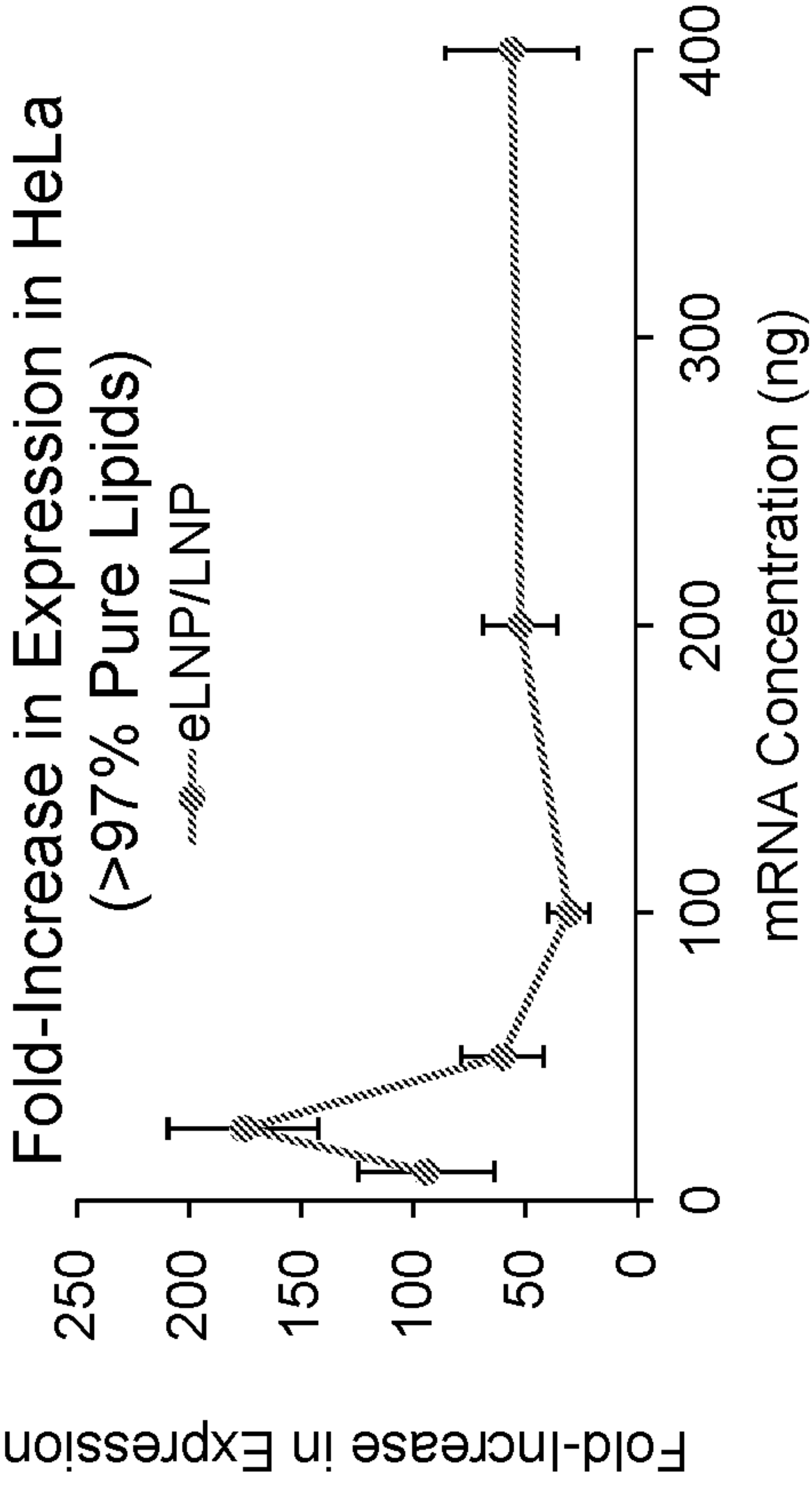


Fig. 7D



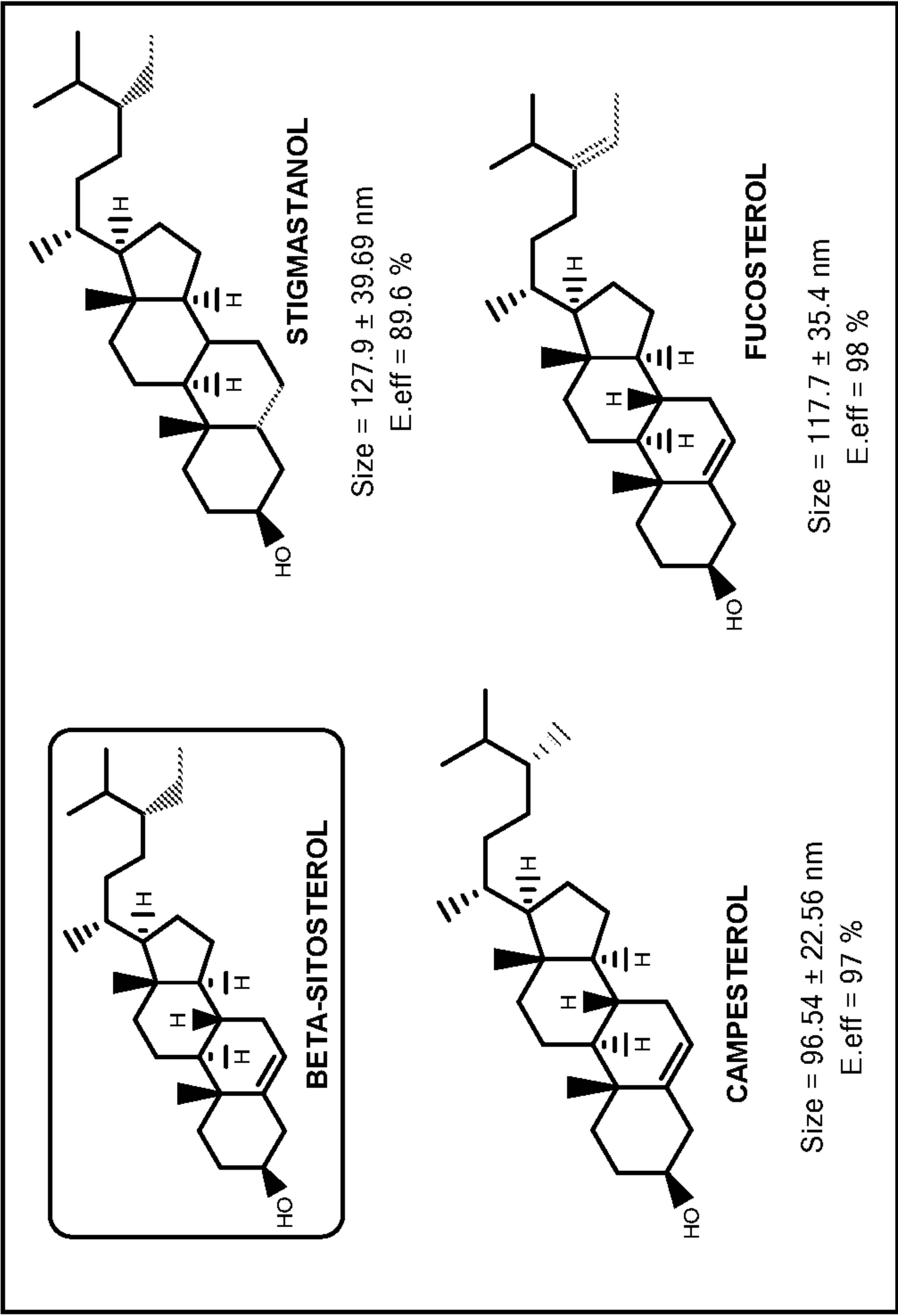
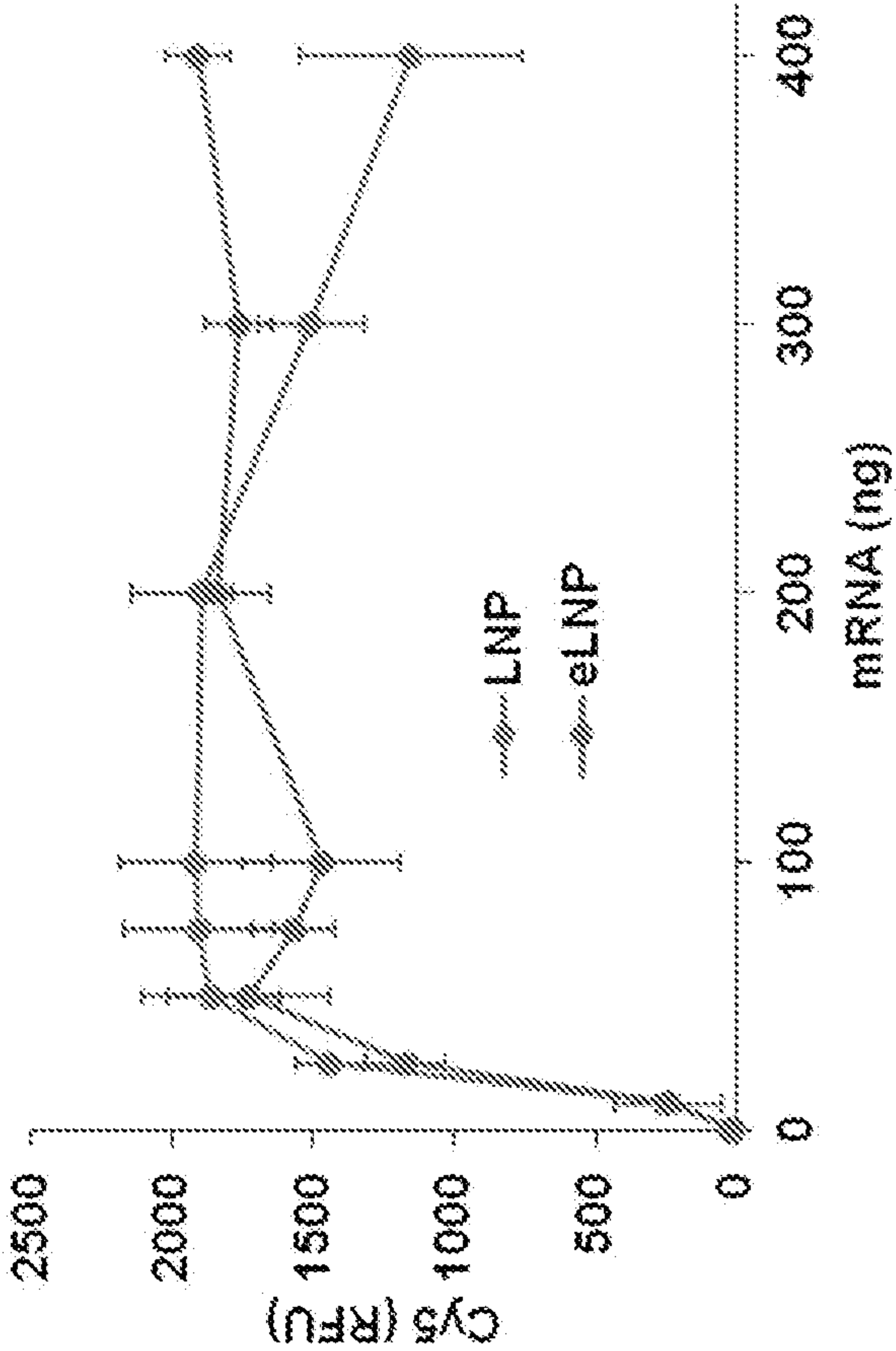


Fig. 7G

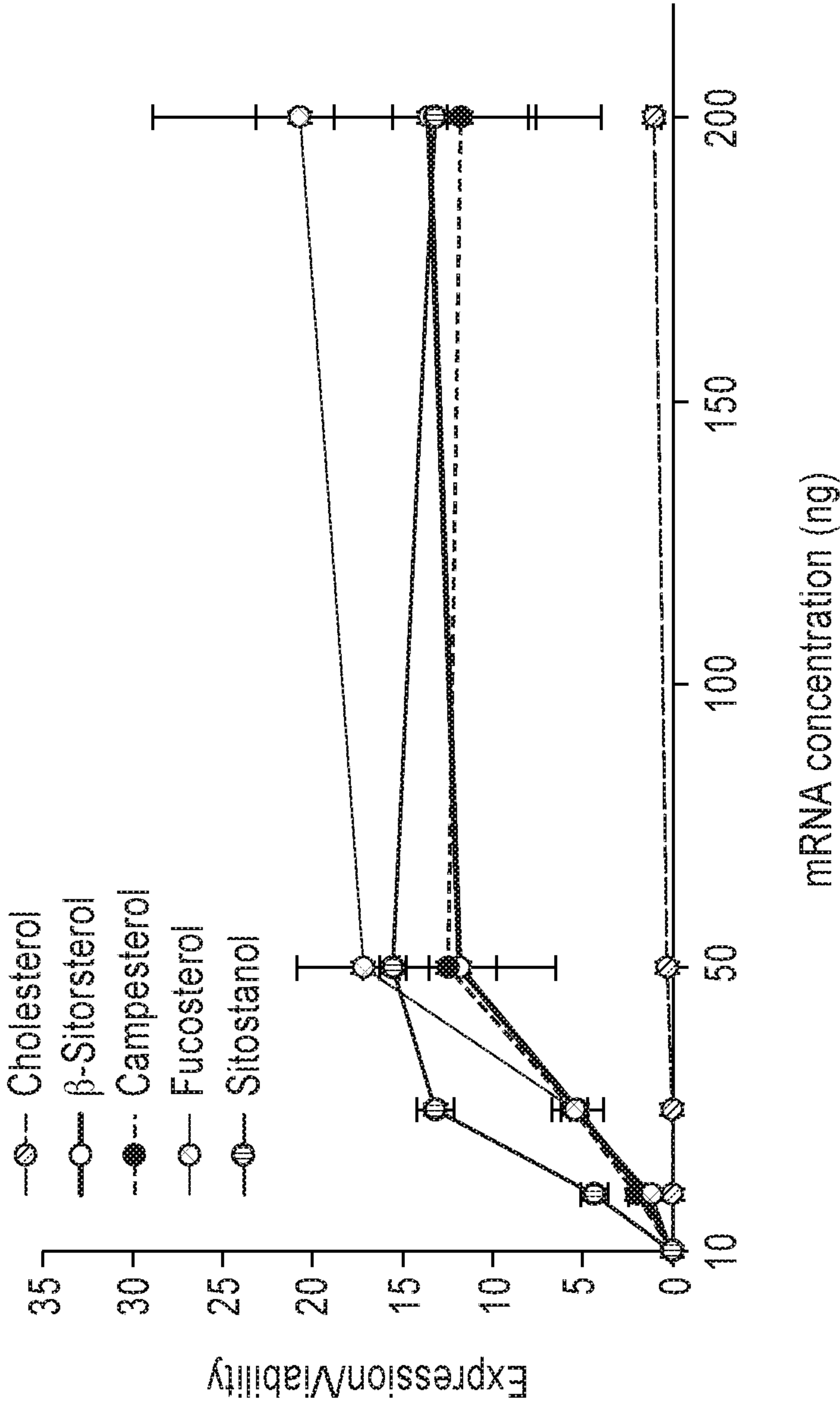


Fig. 7H

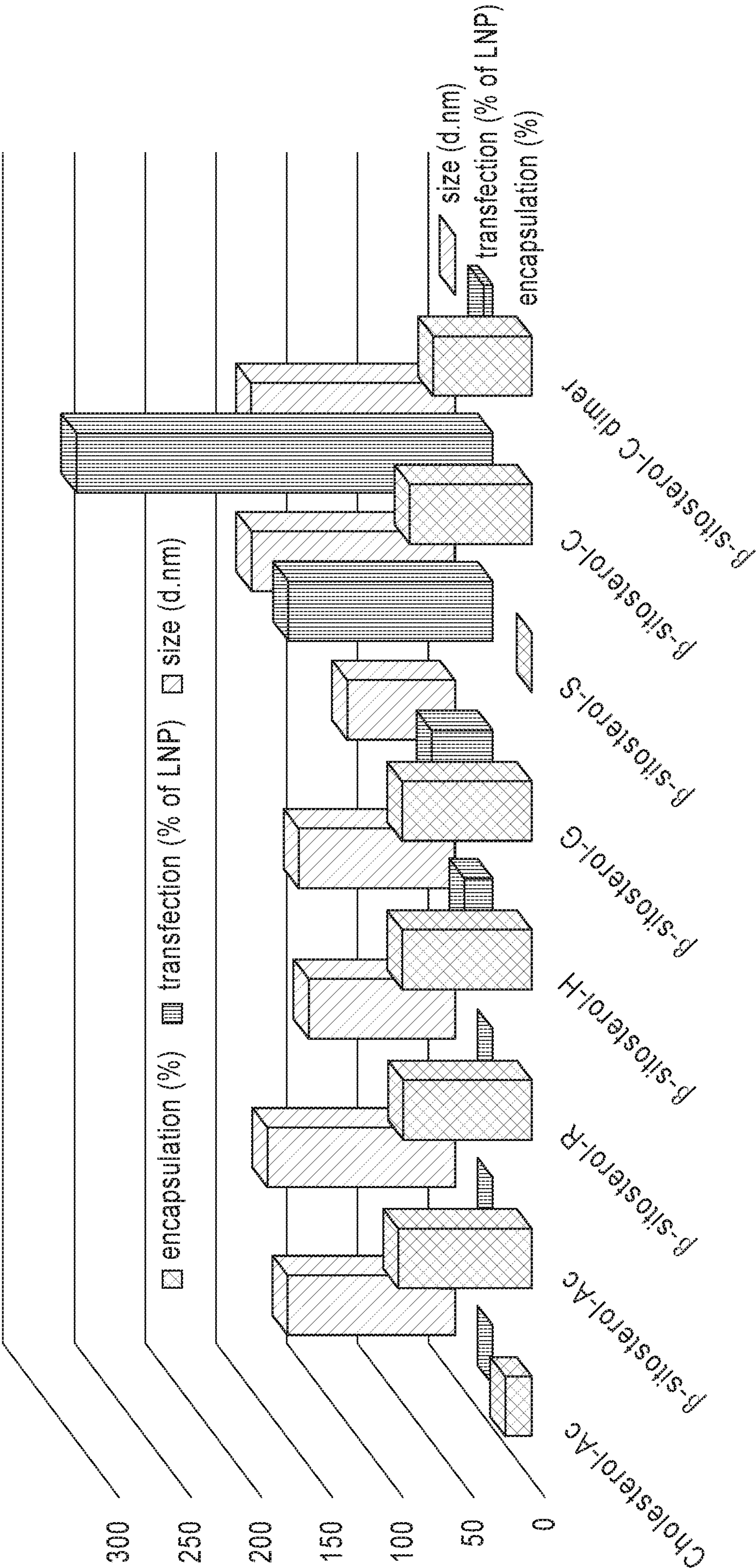


Fig. 8A

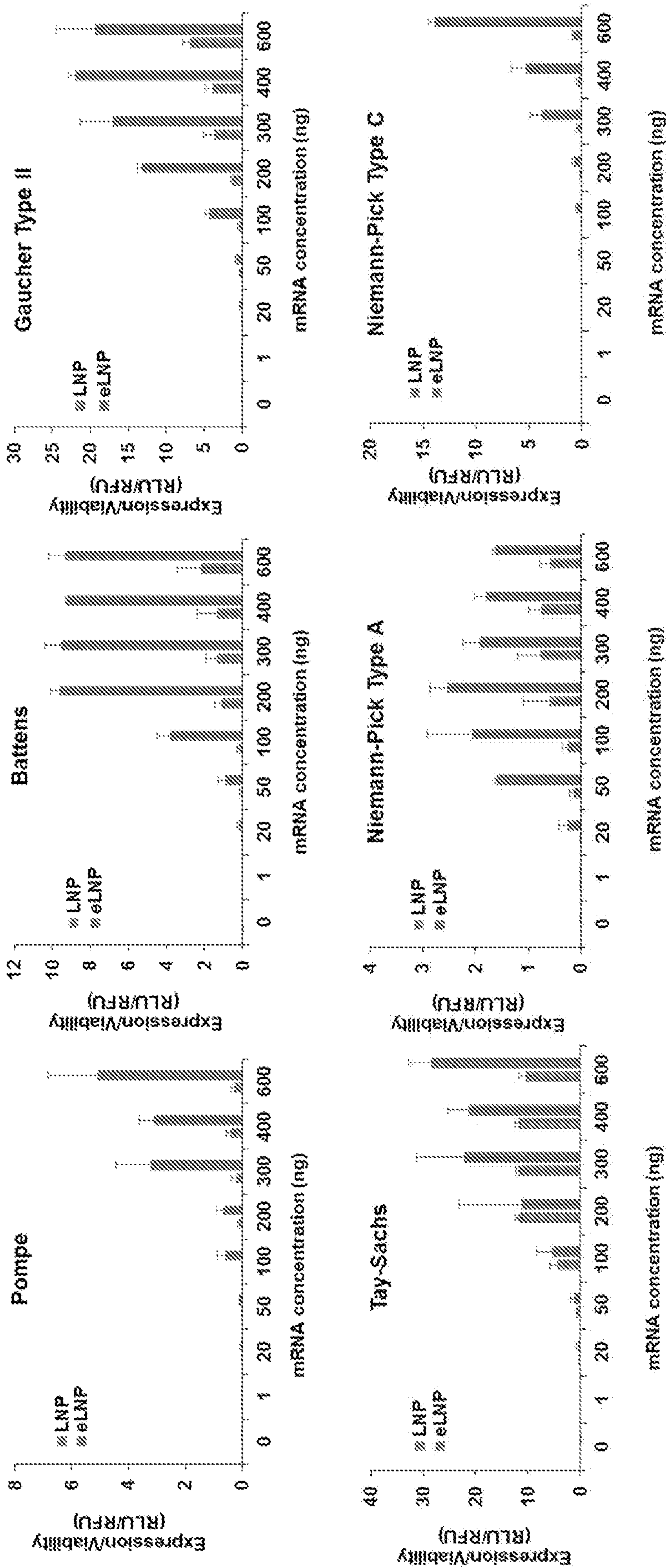


Fig. 8B

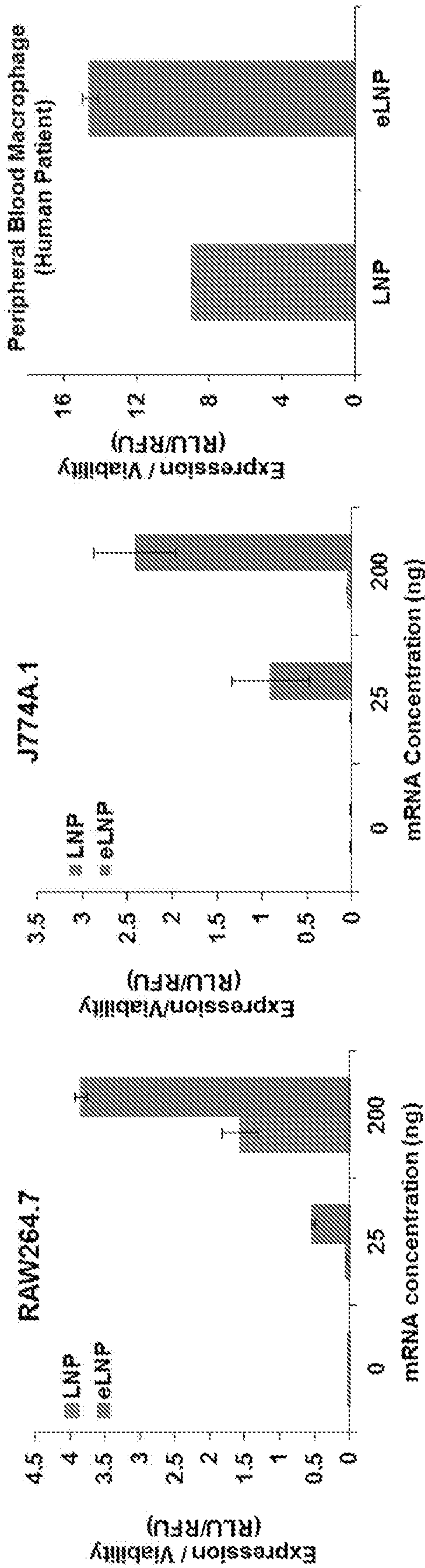


Fig. 8C

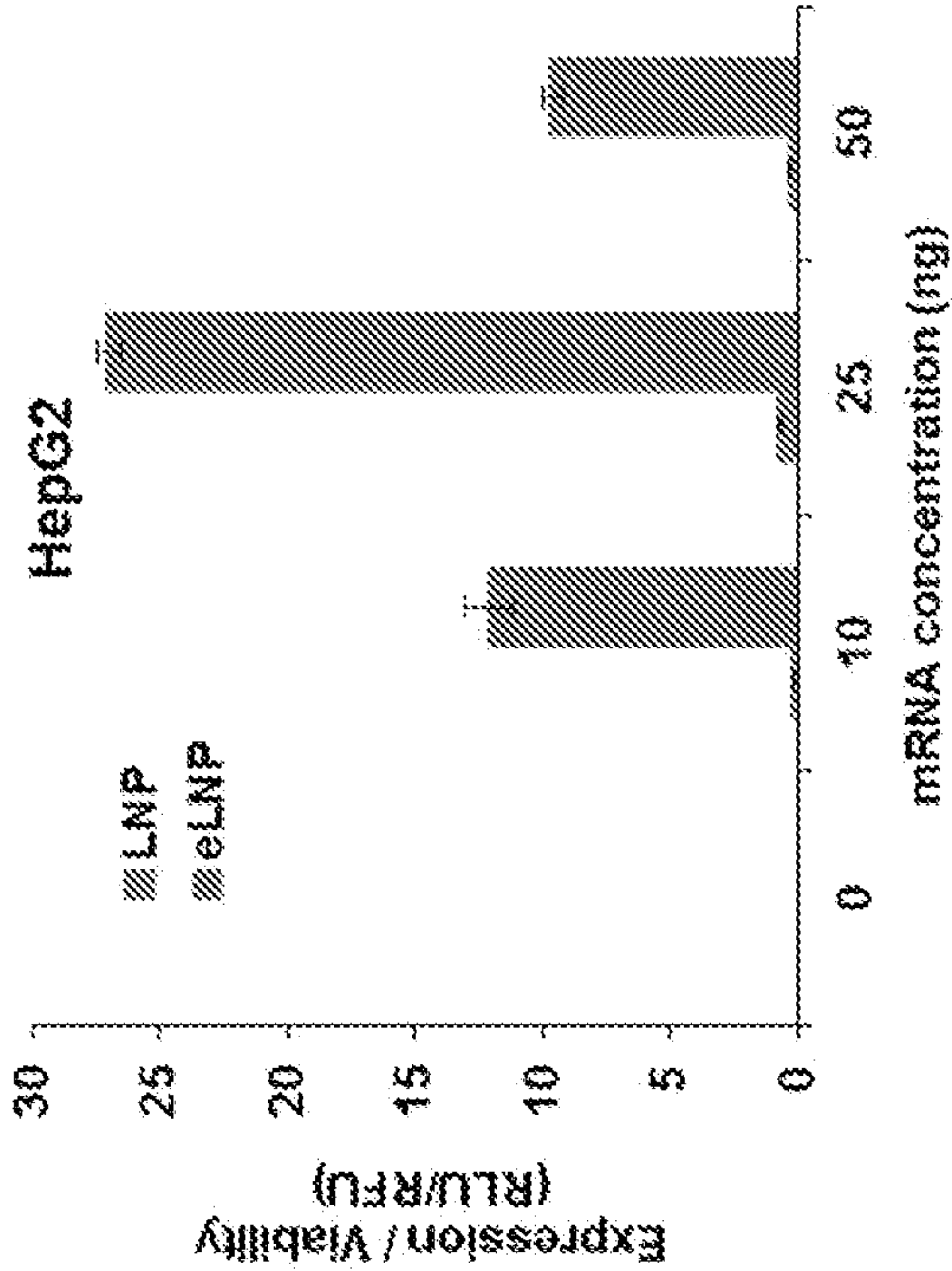


Fig. 9A

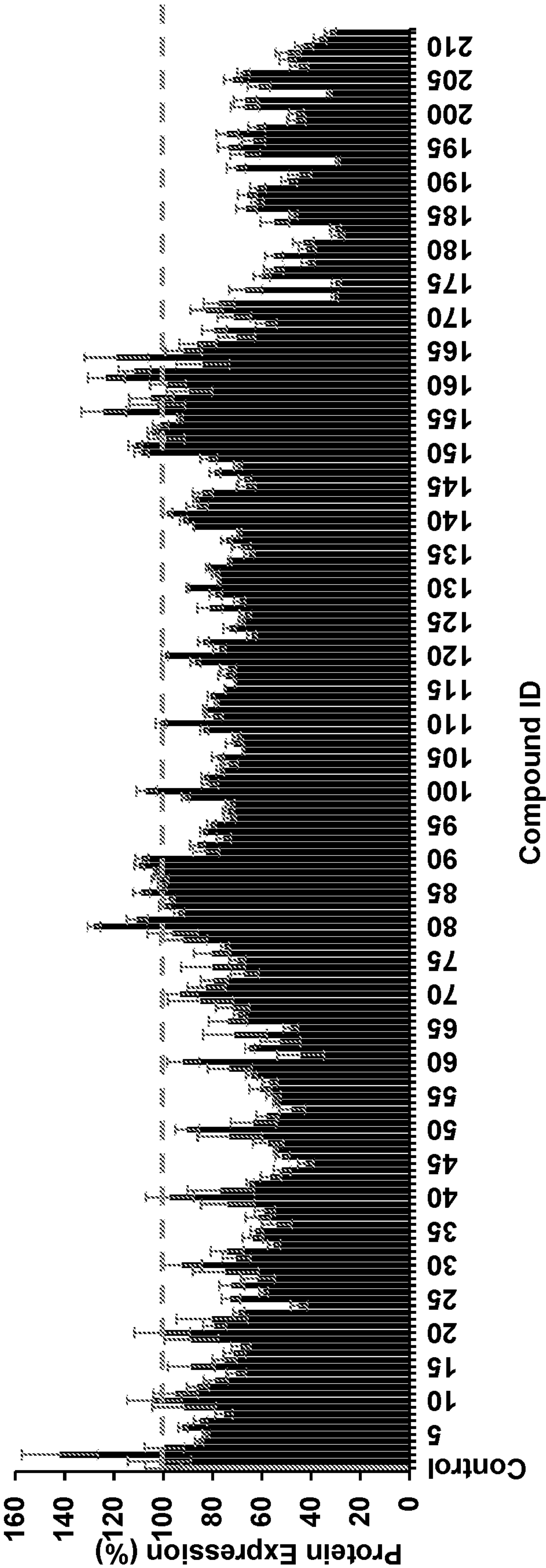


Fig. 9B

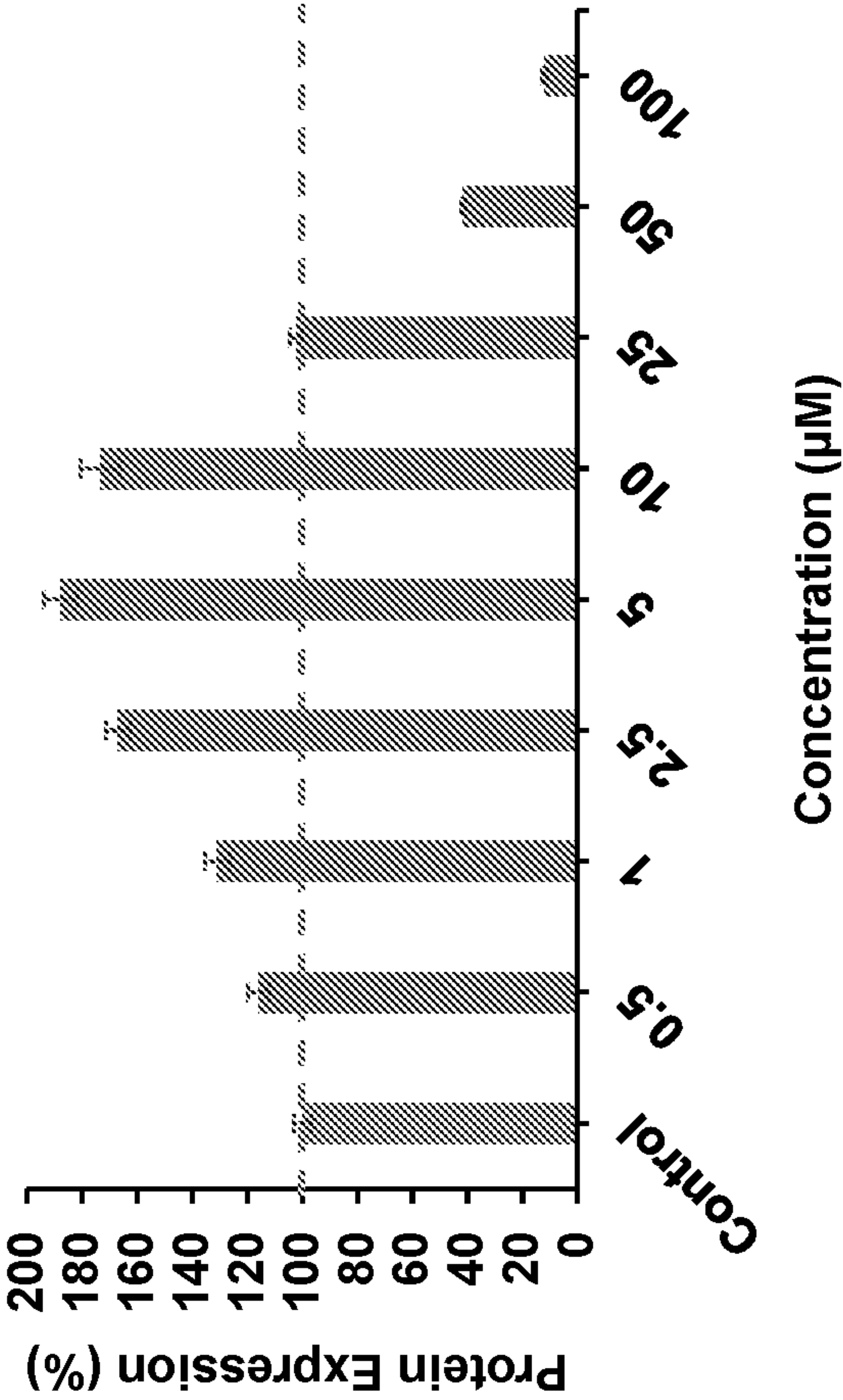


Fig. 9C

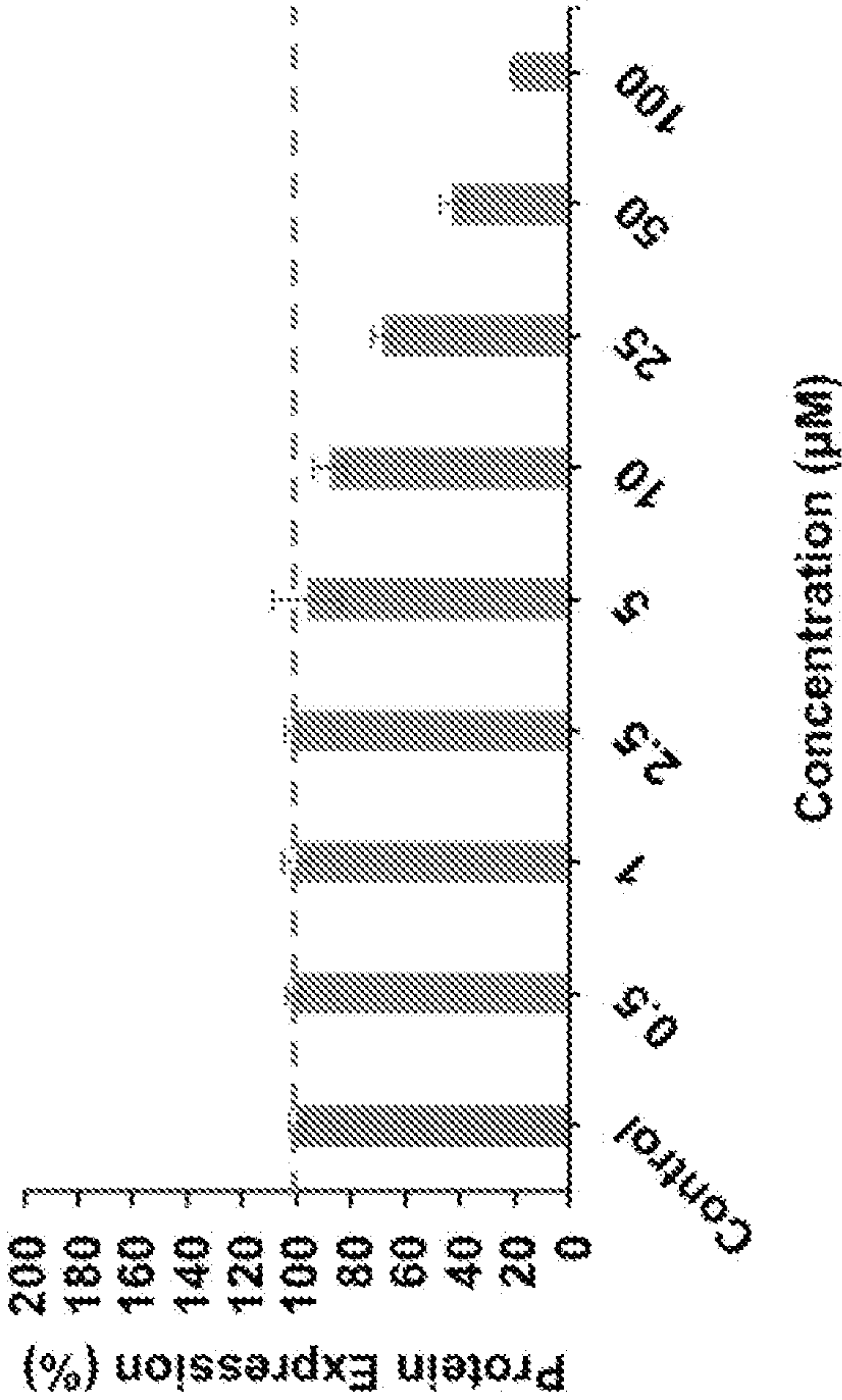


Fig. 9D

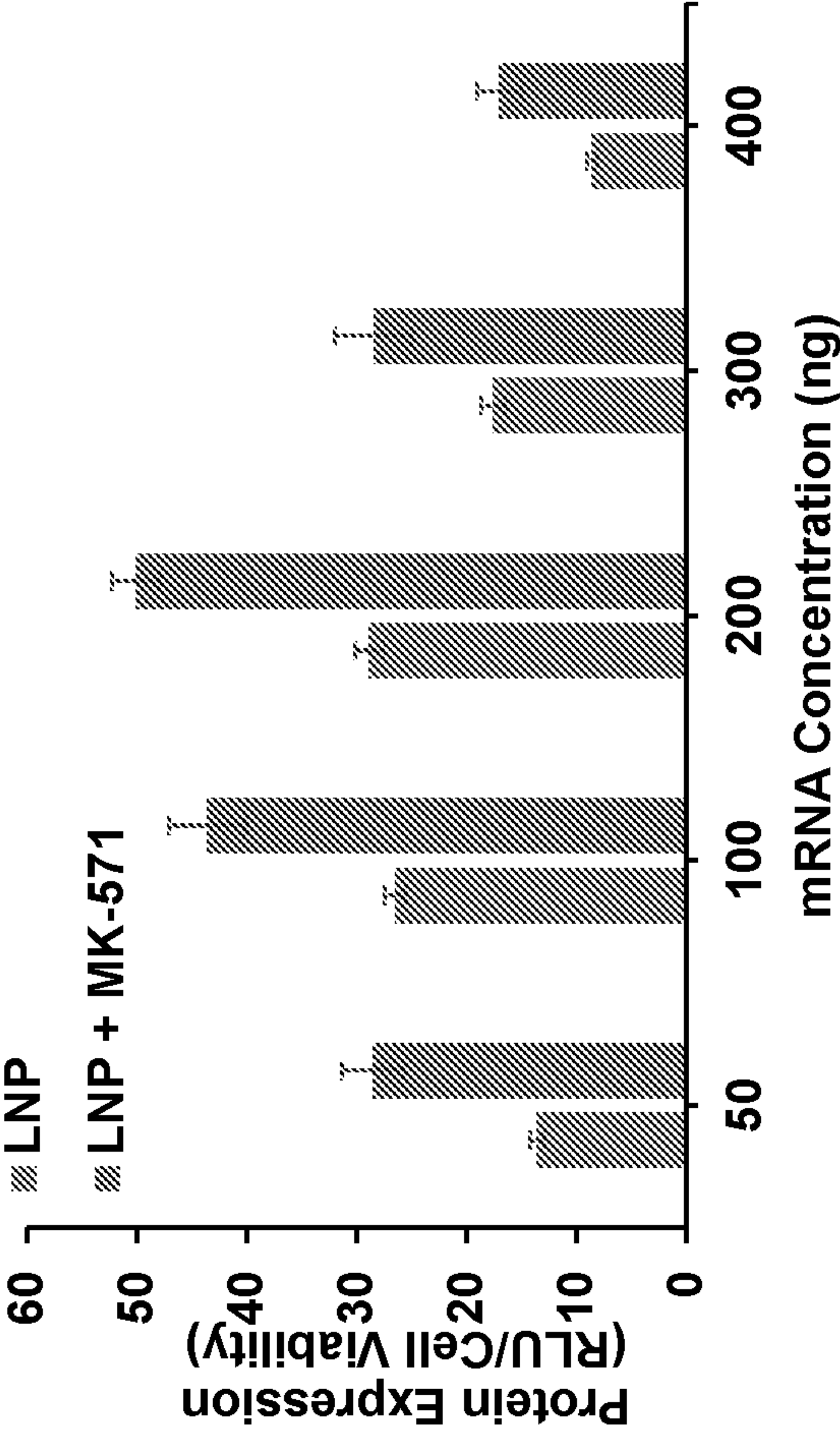


Fig. 9E

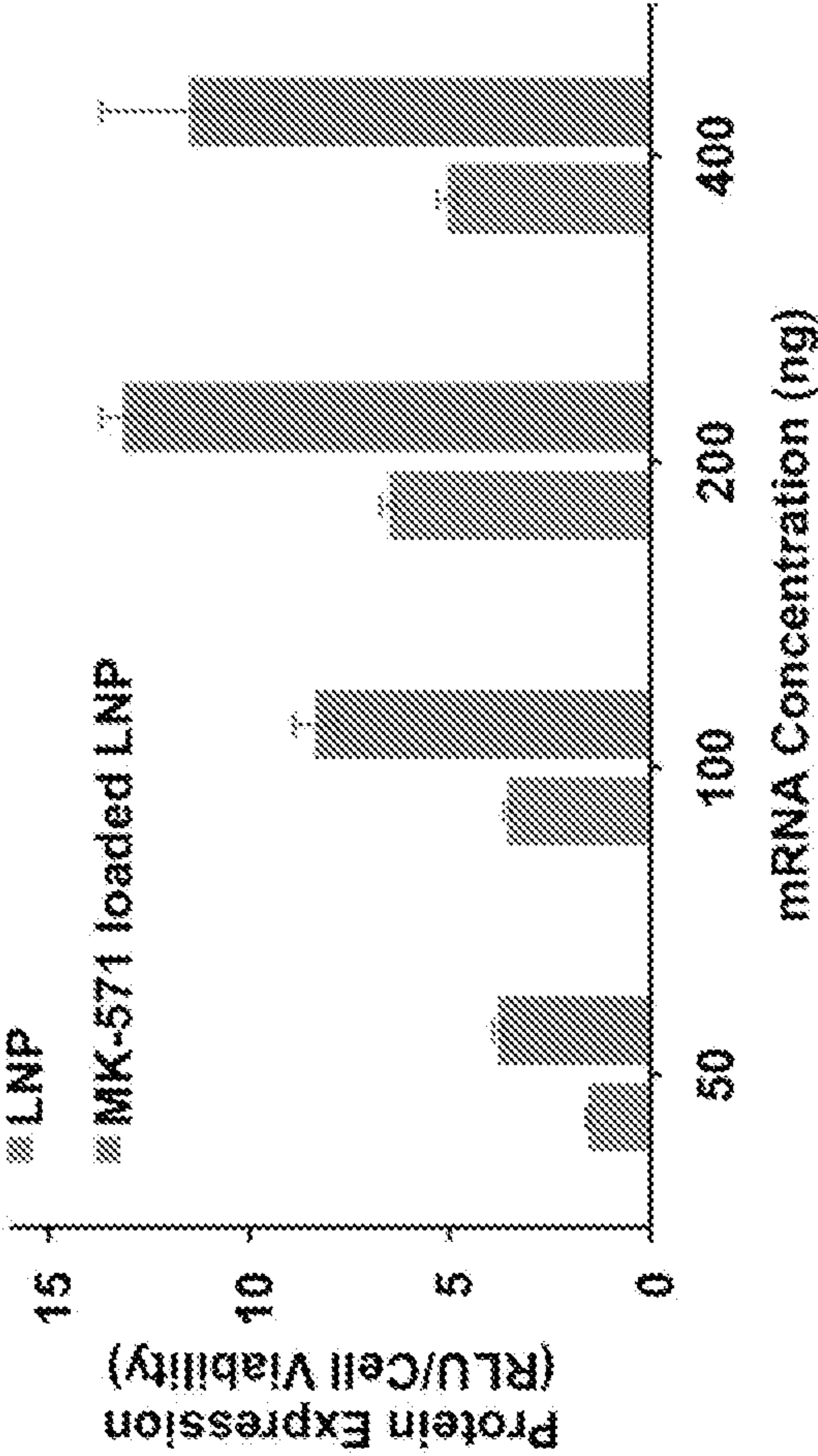


Fig. 9F

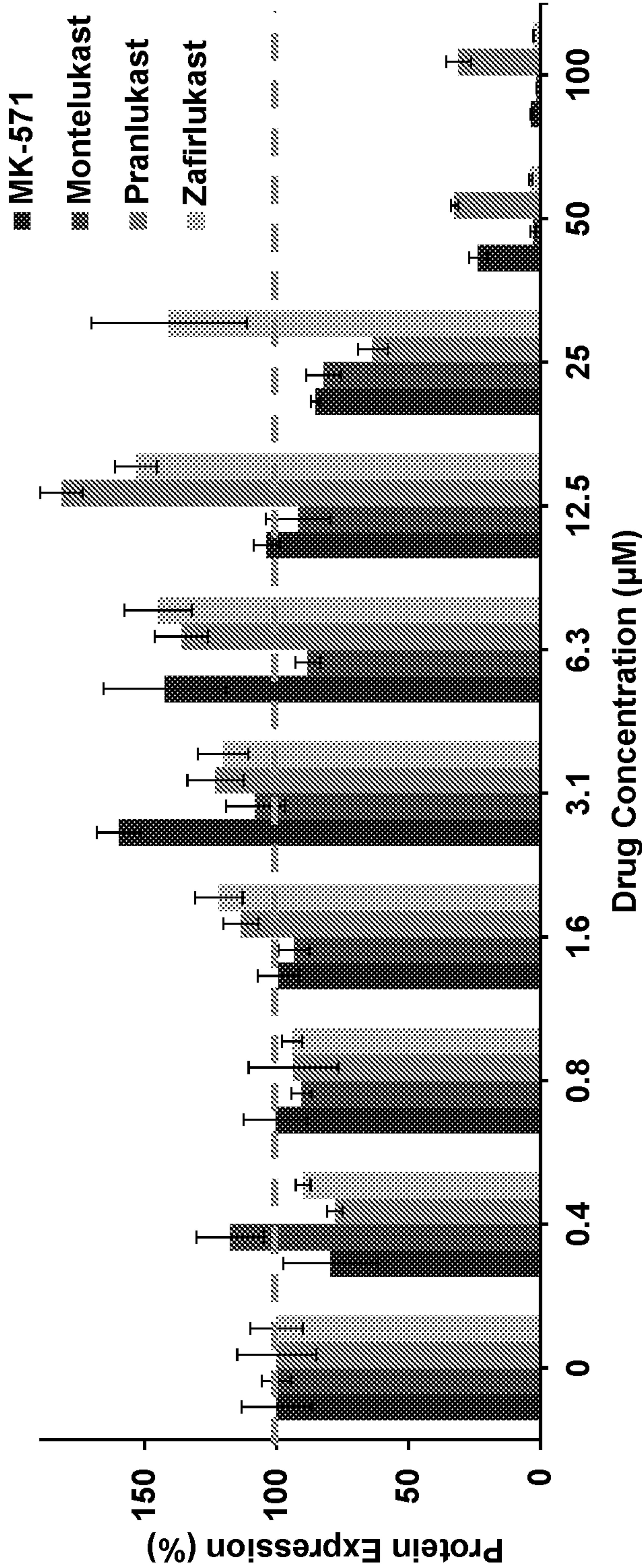


Fig. 1A

