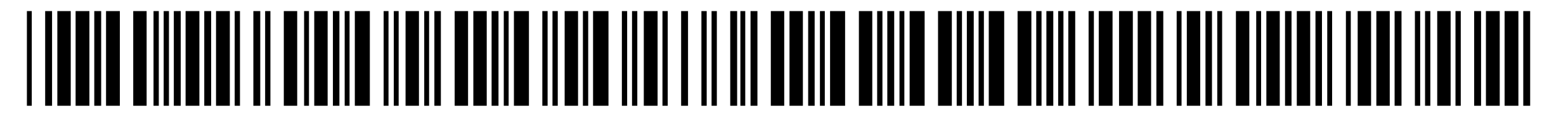


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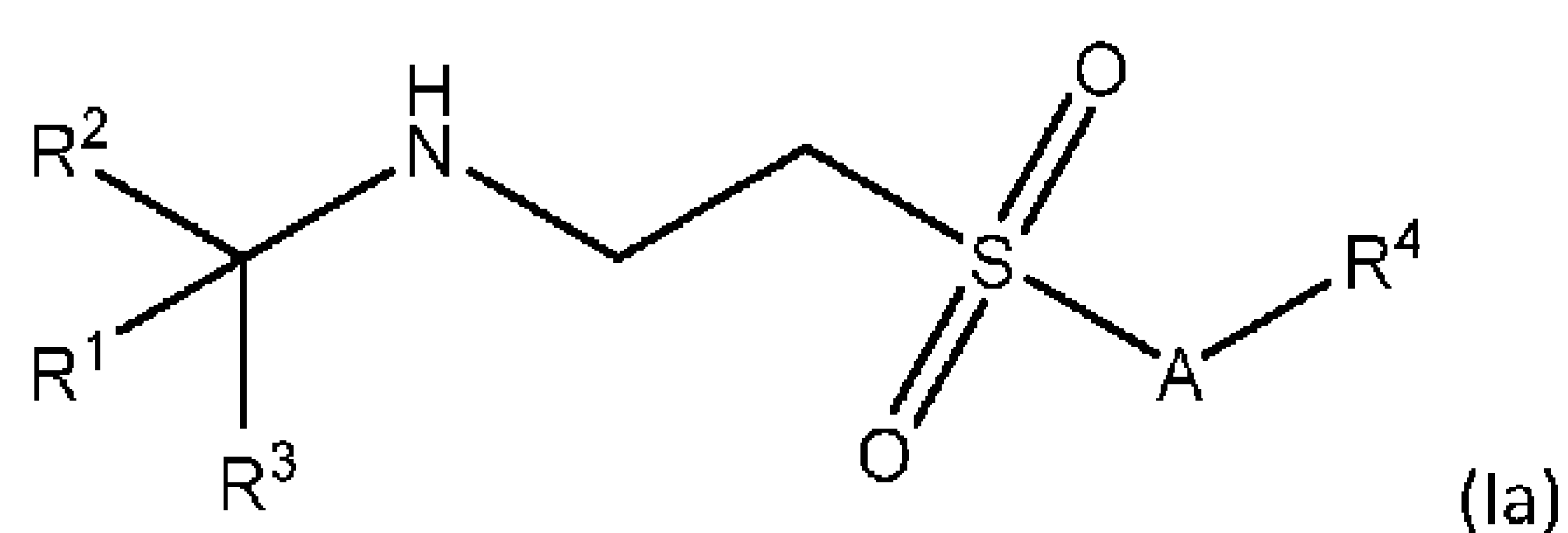
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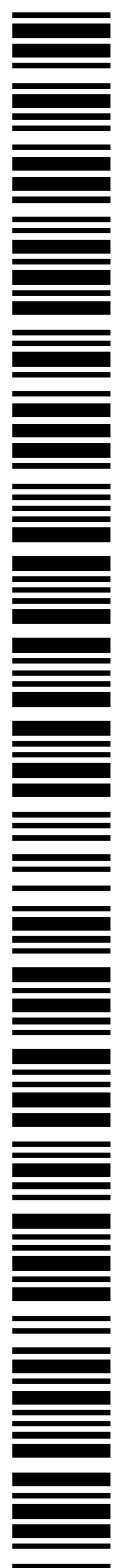
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(54) Title: TES-BASED CATIONIC LIPIDS



(57) Abstract: The present invention provides, in part, TES-based lipid compounds of Formula (1a), and sub-formulas thereof: or a pharmaceutically acceptable salt thereof. The compounds provided herein can be useful for delivery and expression of mRNA and encoded protein, e.g., as a component of liposomal delivery vehicle, and accordingly can be useful for treating various diseases, disorders and conditions, such as those associated with deficiency of one or more proteins.



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**TES-BASED CATIONIC LIPIDS****RELATED APPLICATIONS**

[001] This application claims priority to U.S. Provisional Application Serial Number 63/082,090, filed on September 23, 2020, the entire disclosure of which is hereby incorporated by reference.

**BACKGROUND**

[002] Delivery of nucleic acids has been explored extensively as a potential therapeutic option for certain disease states. In particular, messenger RNA (mRNA) therapy has become an increasingly important option for treatment of various diseases, including for those associated with deficiency of one or more proteins.

[003] Efficient delivery of liposome-encapsulated nucleic acids remains an active area of research. The cationic lipid component plays an important role in facilitating effective encapsulation of the nucleic acid during the loading of liposomes. In addition, cationic lipids may play an important role in the efficient release of the nucleic acid cargo from the liposome into the cytoplasm of a target cell. Various cationic lipids suitable for *in vivo* use have been discovered. However, there remains a need to identify lipids that can be synthesized efficiently and cheaply without the formation of potentially toxic by-products.

[004] "Good" buffers (or Good's buffers) are buffering agents for biochemical and biological research that were first selected and described by Norman Good and his colleagues (Good, N.E., et al. (1966) Hydrogen Ion Buffers for Biological Research. *Biochemistry* 5(2), 467-477). Most biological reactions take place near-neutral pH between 6 and 8. Good therefore reasoned that an ideal buffer for biochemical or biological applications would have a pKa value in this region to provide maximum buffering capacity. Additional selection criteria included high solubility, lack of toxicity, limited interference with biochemical reactions, very low absorbance between 240 nm and 700 nm, enzymatic and hydrolytic stability, minimal changes due to temperature and concentration, limited effects due to ionic or salt composition of the solution, limited interaction with mineral cations, and limited permeability of biological membranes.

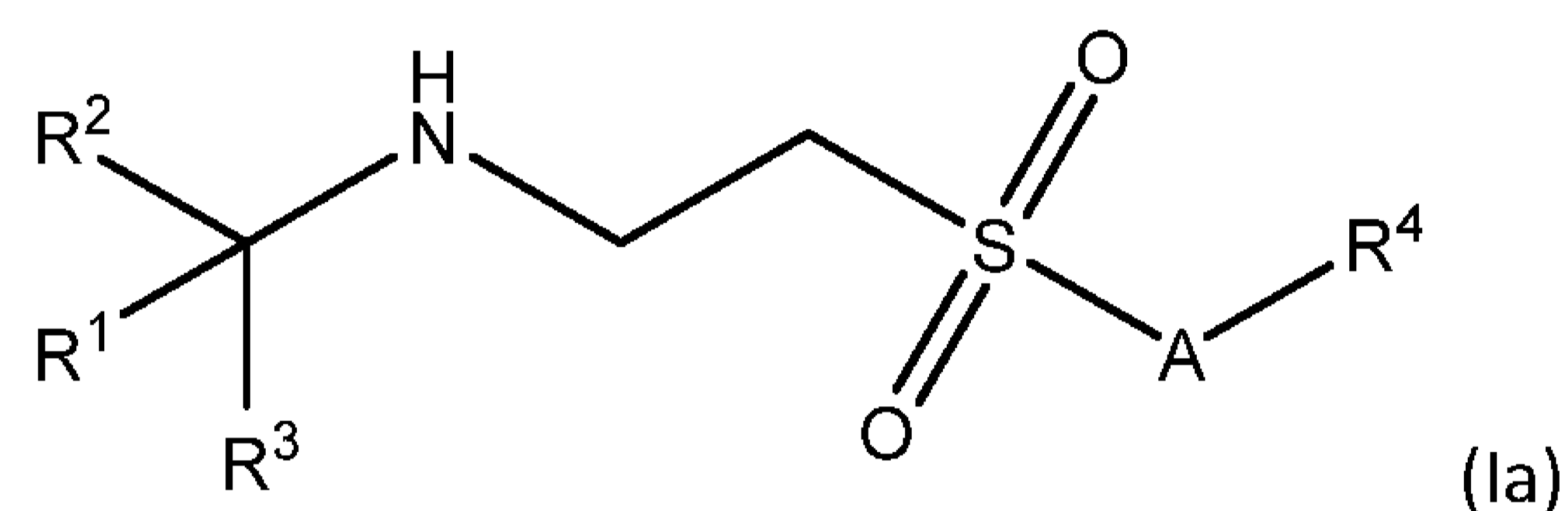
[005] The foregoing characteristics make "Good" buffers exceptionally good starting points for the synthesis of cationic lipids for use in *in vivo* settings. Many "Good" buffers remain crucial tools in modern biochemistry and biology laboratories and are therefore readily available at low cost.

## SUMMARY OF THE INVENTION

[006] The present invention provides, among other things, a novel class of cationic lipid compounds for *in vivo* delivery of therapeutic agents, such as nucleic acids. It is contemplated that these compounds are capable of highly effective *in vivo* delivery while maintaining a favorable toxicity profile.

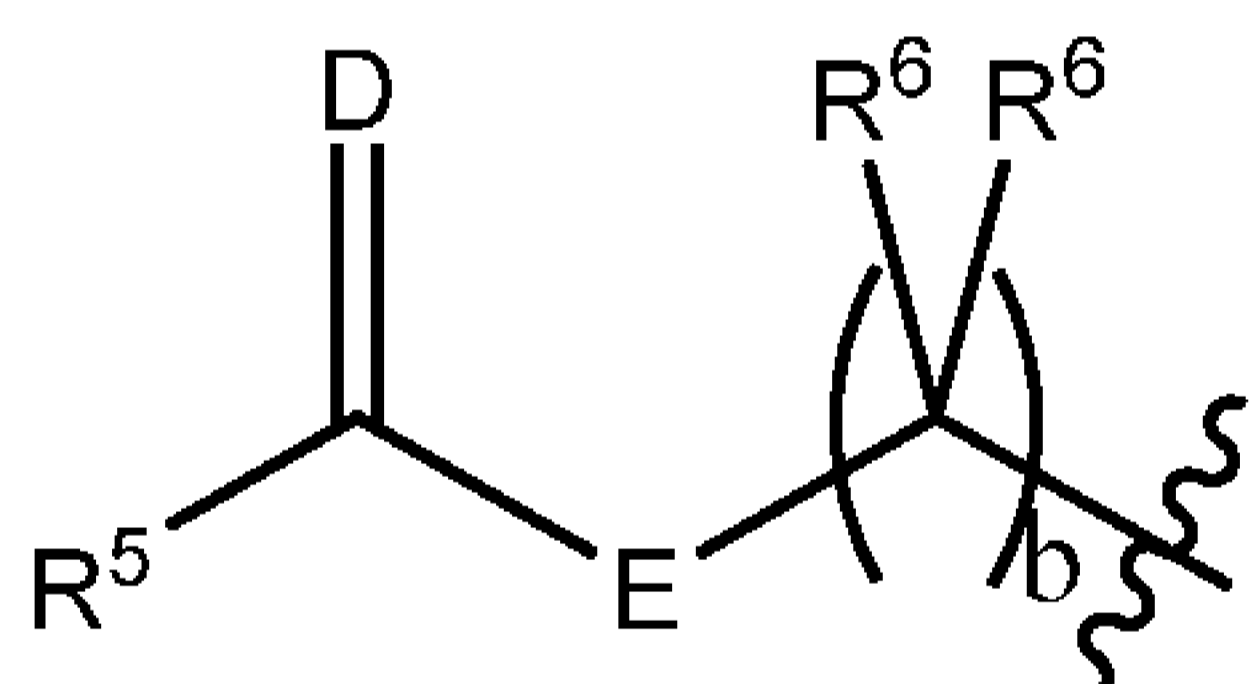
[007] The cationic lipids of the present invention can be synthesized from readily available starting reagents, such as such as "Good's" buffers (see Table 1). The cationic lipids of the present invention also have unexpectedly high encapsulation efficiencies. The cationic lipids of the present invention also comprise cleavable groups (e.g., esters and disulphides) that are contemplated to improve biodegradability and thus contribute to their favorable toxicity profile.

[008] In an aspect, provided herein are cationic lipids having a structure according to Formula (Ia):

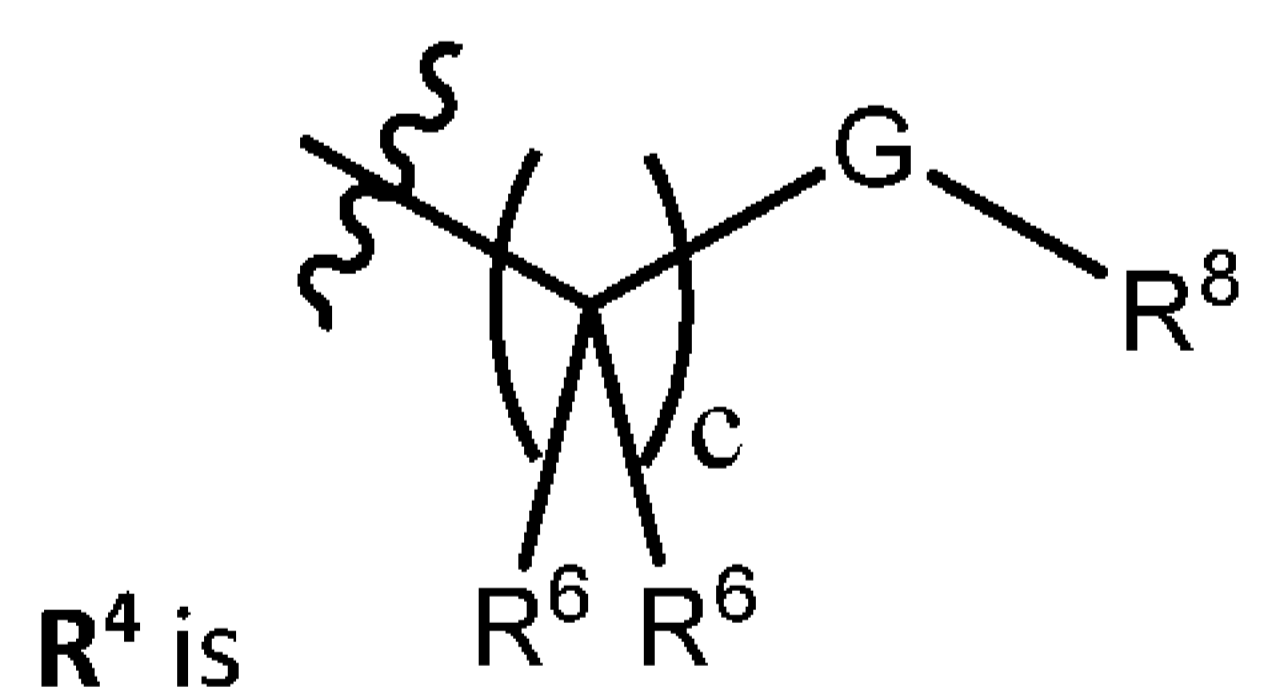


or a pharmaceutically acceptable salt thereof, wherein

$R^1$ ,  $R^2$  and  $R^3$  are each independently selected from:



, optionally substituted alkyl, optionally substituted alkenyl, optionally substituted alkynyl and optionally substituted acyl;



each  $R^5$  is independently selected from optionally substituted alkyl, optionally substituted alkenyl and optionally substituted alkynyl;

each  $R^6$  is independently selected from hydrogen, halogen, optionally substituted  $C_1$ - $C_6$  alkyl, and optionally substituted  $C_2$ - $C_6$  alkenyl;

$A$  is  $-NR^9-$  or  $-O-$ ;

$D$  is O or S;

$E$  and  $G$  are each independently selected from  $-NR^{10}-$ ,  $-O-$  and  $-S-$ ;

$R^8$ ,  $R^9$ , and  $R^{10}$  are each independently selected from hydrogen, optionally substituted  $C_1$ - $C_6$  alkyl and optionally substituted  $C_2$ - $C_6$  alkenyl;

each **b** is independently selected from 0, 1, 2, 3, 4, 5, 6, 7, 8, 9 and 10; and  
each **c** is independently selected from 1, 2, 3, 4, 5, 6, 7, 8, 9 and 10.

[009] In an aspect, provided herein are cationic lipids that are pharmaceutically acceptable salts of Formula (Ia).

[010] In an aspect, provided herein are compositions comprising the cationic lipid of the present invention or a pharmaceutically acceptable salt thereof, one or more non-cationic lipids, one or more cholesterol-based lipids and one or more PEG-modified lipid. In an aspect, the composition is a lipid nanoparticle, optionally a liposome.

[011] In an aspect, the compositions comprising the cationic lipids of the present invention may be used in therapy.

### BRIEF DESCRIPTION OF DRAWINGS

[012] FIG. 1 depicts *in vivo* protein production resulting from the delivery of mRNA (*i.e.*, FFL mRNA) using lipid nanoparticles comprising Compound **V**, **XII**, or **I** as described herein. As shown in this Figure, use of these compounds can result in high levels of *in vivo* protein production (*i.e.*, FFL protein) after administration.

### DETAILED DESCRIPTION OF CERTAIN EMBODIMENTS

#### **Definitions**

[013] In order for the present invention to be more readily understood, certain terms are first defined below. Additional definitions for the following terms and other terms are set forth throughout the specification. The publications and other reference materials referenced herein to describe the background of the invention and to provide additional detail regarding its practice are hereby incorporated by reference.

[014] *Amino acid*: As used herein, the term “amino acid,” in its broadest sense, refers to any compound and/or substance that can be incorporated into a polypeptide chain. In some embodiments, an amino acid has the general structure  $H_2N-C(H)(R)-COOH$ . In some embodiments, an amino acid is a naturally occurring amino acid. In some embodiments, an amino acid is a synthetic amino acid; in some embodiments, an amino acid is a d-amino acid; in some embodiments, an amino acid is an l-amino acid. “Standard amino acid” refers to any of the twenty standard l-amino acids commonly found in naturally occurring peptides. “Nonstandard amino acid” refers to any amino acid, other than the standard amino acids, regardless of whether it is prepared

synthetically or obtained from a natural source. As used herein, “synthetic amino acid” encompasses chemically modified amino acids, including but not limited to salts, amino acid derivatives (such as amides), and/or substitutions. Amino acids, including carboxy- and/or amino-terminal amino acids in peptides, can be modified by methylation, amidation, acetylation, protecting groups, and/or substitution with other chemical groups that can change the peptide’s circulating half-life without adversely affecting their activity. Amino acids may participate in a disulfide bond. Amino acids may comprise one or posttranslational modifications, such as association with one or more chemical entities (*e.g.*, methyl groups, acetate groups, acetyl groups, phosphate groups, formyl moieties, isoprenoid groups, sulfate groups, polyethylene glycol moieties, lipid moieties, carbohydrate moieties, biotin moieties, *etc.*). The term “amino acid” is used interchangeably with “amino acid residue,” and may refer to a free amino acid and/or to an amino acid residue of a peptide. It will be apparent from the context in which the term is used whether it refers to a free amino acid or a residue of a peptide.

**[015]** *Animal*: As used herein, the term “animal” refers to any member of the animal kingdom. In some embodiments, “animal” refers to humans, at any stage of development. In some embodiments, “animal” refers to non-human animals, at any stage of development. In certain embodiments, the non-human animal is a mammal (*e.g.*, a rodent, a mouse, a rat, a rabbit, a monkey, a dog, a cat, a sheep, a bovine, a primate, and/or a pig). In some embodiments, animals include, but are not limited to, mammals, birds, reptiles, amphibians, fish, insects, and/or worms. In some embodiments, an animal may be a transgenic animal, genetically-engineered animal, and/or a clone.

**[016]** *Approximately or about*: As used herein, the term “approximately” or “about,” as applied to one or more values of interest, refers 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).

**[017]** *Biologically active*: As used herein, the term “biologically active” refers to a characteristic of any agent that has activity in a biological system, and particularly in an organism. For instance, an agent that, when administered to an organism, has a biological effect on that organism, is considered to be biologically active.

**[018]** *Delivery*: As used herein, the term “delivery” encompasses both local and systemic delivery. For example, delivery of mRNA encompasses situations in which an mRNA is delivered to a target

tissue and the encoded protein is expressed and retained within the target tissue (also referred to as “local distribution” or “local delivery”), and situations in which an mRNA is delivered to a target tissue and the encoded protein is expressed and secreted into patient’s circulation system (*e.g.*, serum) and systematically distributed and taken up by other tissues (also referred to as “systemic distribution” or “systemic delivery”).

**[019]** *Expression*: As used herein, “expression” of a nucleic acid sequence refers to translation of an mRNA into a polypeptide, assemble multiple polypeptides into an intact protein (*e.g.*, enzyme) and/or post-translational modification of a polypeptide or fully assembled protein (*e.g.*, enzyme). In this application, the terms “expression” and “production,” and grammatical equivalents thereof, are used interchangeably.

**[020]** *Functional*: As used herein, a “functional” biological molecule is a biological molecule in a form in which it exhibits a property and/or activity by which it is characterized.

**[021]** *Half-life*: As used herein, the term “half-life” is the time required for a quantity such as nucleic acid or protein concentration or activity to fall to half of its value as measured at the beginning of a time period.

**[022]** *Helper lipid*: The term “helper lipid” as used herein refers to any neutral or zwitterionic lipid material including cholesterol. Without wishing to be held to a particular theory, helper lipids may add stability, rigidity, and/or fluidity within lipid bilayers/nanoparticles.

**[023]** *Improve, increase, or reduce*: As used herein, the terms “improve,” “increase,” or “reduce,” or grammatical equivalents, indicate values that are relative to a baseline measurement, such as a measurement in the same individual prior to initiation of the treatment described herein, or a measurement in a control subject (or multiple control subject) in the absence of the treatment described herein. A “control subject” is a subject afflicted with the same form of disease as the subject being treated, who is about the same age as the subject being treated.

**[024]** *In Vitro*: 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, *etc.*, rather than within a multi-cellular organism.

**[025]** *In Vivo*: As used herein, the term “*in vivo*” refers to events that occur within a multi-cellular organism, such as a human and a non-human animal. In the context of cell-based systems, the term may be used to refer to events that occur within a living cell (as opposed to, for example, *in vitro* systems).

**[026]** *Isolated*: As used herein, the term “isolated” refers to a substance and/or entity that has been (1) separated from at least some of the components with which it was associated when initially produced (whether in nature and/or in an experimental setting), and/or (2) produced, prepared,

and/or manufactured by the hand of man. isolated substances and/or entities may be separated from about 10%, about 20%, about 30%, about 40%, about 50%, about 60%, about 70%, about 80%, about 90%, about 91%, about 92%, about 93%, about 94%, about 95%, about 96%, about 97%, about 98%, about 99%, or more than about 99% of the other components with which they were initially associated. In some embodiments, isolated agents are about 80%, about 85%, about 90%, about 91%, about 92%, about 93%, about 94%, about 95%, about 96%, about 97%, about 98%, about 99%, or more than about 99% pure. As used herein, a substance is “pure” if it is substantially free of other components. As used herein, calculation of percent purity of isolated substances and/or entities should not include excipients (*e.g.*, buffer, solvent, water, *etc.*).

**[027]** *Liposome*: As used herein, the term “liposome” refers to any lamellar, multilamellar, or solid nanoparticle vesicle. Typically, a liposome as used herein can be formed by mixing one or more lipids or by mixing one or more lipids and polymer(s). In some embodiments, a liposome suitable for the present invention contains a cationic lipid(s) and optionally non-cationic lipid(s), optionally cholesterol-based lipid(s), and/or optionally PEG-modified lipid(s).

**[028]** *messenger RNA (mRNA)*: As used herein, the term “messenger RNA (mRNA)” or “mRNA” refers to a polynucleotide that encodes at least one polypeptide. mRNA as used herein encompasses both modified and unmodified RNA. The term “modified mRNA” related to mRNA comprising at least one chemically modified nucleotide. mRNA may contain one or more coding and non-coding regions. mRNA can be purified from natural sources, produced using recombinant expression systems and optionally purified, chemically synthesized, *etc.* Where appropriate, *e.g.*, in the case of chemically synthesized molecules, mRNA can comprise nucleoside analogs such as analogs having chemically modified bases or sugars, backbone modifications, *etc.* An mRNA sequence is presented in the 5' to 3' direction unless otherwise indicated. In some embodiments, an mRNA is or comprises natural nucleosides (*e.g.*, adenosine, guanosine, cytidine, uridine); nucleoside analogs (*e.g.*, 2-aminoadenosine, 2-thiothymidine, inosine, pyrrolo-pyrimidine, 3-methyl adenosine, 5-methylcytidine, C-5 propynyl-cytidine, C-5 propynyl-uridine, 2-aminoadenosine, C5-bromouridine, C5-fluorouridine, C5-iodouridine, C5-propynyl-uridine, C5-propynyl-cytidine, C5-methylcytidine, 2-aminoadenosine, 7-deazaadenosine, 7-deazaguanosine, 8-oxoadenosine, 8-oxoguanosine, O(6)-methylguanine, and 2-thiocytidine); chemically modified bases; biologically modified bases (*e.g.*, methylated bases); intercalated bases; modified sugars (*e.g.*, 2'-fluororibose, ribose, 2'-deoxyribose, arabinose, and hexose); and/or modified phosphate groups (*e.g.*, phosphorothioates and 5'-N-phosphoramidite linkages).

**[029]** *Nucleic acid*: As used herein, the term “nucleic acid,” in its broadest sense, refers to any compound and/or substance that is or can be incorporated into a polynucleotide chain. In some

embodiments, a nucleic acid is a compound and/or substance that is or can be incorporated into a polynucleotide chain via a phosphodiester linkage. In some embodiments, "nucleic acid" refers to individual nucleic acid residues (*e.g.*, nucleotides and/or nucleosides). In some embodiments, "nucleic acid" refers to a polynucleotide chain comprising individual nucleic acid residues. In some embodiments, "nucleic acid" encompasses RNA as well as single and/or double-stranded DNA and/or cDNA. In some embodiments, "nucleic acid" encompasses ribonucleic acids (RNA), including but not limited to any one or more of interference RNAs (RNAi), small interfering RNA (siRNA), short hairpin RNA (shRNA), antisense RNA (aRNA), messenger RNA (mRNA), modified messenger RNA (mmRNA), long non-coding RNA (lncRNA), micro-RNA (miRNA) multimeric coding nucleic acid (MCNA), polymeric coding nucleic acid (PCNA), guide RNA (gRNA) and CRISPR RNA (crRNA). In some embodiments, "nucleic acid" encompasses deoxyribonucleic acid (DNA), including but not limited to any one or more of single-stranded DNA (ssDNA), double-stranded DNA (dsDNA) and complementary DNA (cDNA). In some embodiments, "nucleic acid" encompasses both RNA and DNA. In embodiments, DNA may be in the form of antisense DNA, plasmid DNA, parts of a plasmid DNA, pre-condensed DNA, a product of a polymerase chain reaction (PCR), vectors (*e.g.*, P1, PAC, BAC, YAC, artificial chromosomes), expression cassettes, chimeric sequences, chromosomal DNA, or derivatives of these groups. In embodiments, RNA may be in the form of messenger RNA (mRNA), ribosomal RNA (rRNA), signal recognition particle RNA (7 SL RNA or SRP RNA), transfer RNA (tRNA), transfer-messenger RNA (tmRNA), small nuclear RNA (snRNA), small nucleolar RNA (snoRNA), SmY RNA, small Cajal body-specific RNA (scaRNA), guide RNA (gRNA), ribonuclease P (RNase P), Y RNA, telomerase RNA component (TERC), spliced leader RNA (SL RNA), antisense RNA (aRNA or asRNA), cis-natural antisense transcript (cis-NAT), CRISPR RNA (crRNA), long noncoding RNA (lncRNA), micro-RNA (miRNA), piwi-interacting RNA (piRNA), small interfering RNA (siRNA), transacting siRNA (tasiRNA), repeat associated siRNA (rasiRNA), 73K RNA, retrotransposons, a viral genome, a viroid, satellite RNA, or derivatives of these groups. In some embodiments, a nucleic acid is a mRNA encoding a protein such as an enzyme.

**[030]** *Patient:* As used herein, the term "patient" or "subject" refers to any organism to which a provided composition may be administered, *e.g.*, for experimental, diagnostic, prophylactic, cosmetic, and/or therapeutic purposes. Typical patients include animals (*e.g.*, mammals such as mice, rats, rabbits, non-human primates, and/or humans). In some embodiments, a patient is a human. A human includes pre- and post-natal forms.

**[031]** *Pharmaceutically acceptable:* The term "pharmaceutically acceptable," as used herein, refers to substances that, within the scope of sound medical judgment, are 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.

**[032]** *Pharmaceutically acceptable salt*: Pharmaceutically acceptable salts are well known in the art. For example, S. M. Berge *et al.*, describes pharmaceutically acceptable salts in detail in *J. Pharmaceutical Sciences* (1977) 66:1-19. Pharmaceutically acceptable salts of the compounds of this invention include those derived from suitable inorganic and organic acids and bases. Examples of pharmaceutically acceptable, nontoxic acid addition salts are salts of an amino group formed with inorganic acids such as hydrochloric acid, hydrobromic acid, phosphoric acid, sulfuric acid, and perchloric acid or with organic acids such as acetic acid, oxalic acid, maleic acid, tartaric acid, citric acid, succinic acid, or malonic acid, or by using other methods used in the art such as ion exchange. Other pharmaceutically acceptable salts include adipate, alginate, ascorbate, aspartate, benzenesulfonate, benzoate, bisulfate, borate, butyrate, camphorate, camphorsulfonate, citrate, cyclopentanepropionate, digluconate, dodecylsulfate, ethanesulfonate, formate, fumarate, glucoheptonate, glycerophosphate, gluconate, hemisulfate, heptanoate, hexanoate, 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, p-toluenesulfonate, undecanoate, valerate salts, and the like. Salts derived from appropriate bases include alkali metal, alkaline earth metal, ammonium and  $N^+(C_{1-4} \text{ alkyl})_4$  salts. Representative alkali or alkaline earth metal salts include sodium, lithium, potassium, calcium, magnesium, and the like. Further pharmaceutically acceptable salts include, when appropriate, nontoxic ammonium, quaternary ammonium, and amine cations formed using counterions such as halide, hydroxide, carboxylate, sulfate, phosphate, nitrate, sulfonate, and aryl sulfonate. Further pharmaceutically acceptable salts include salts formed from the quaternization of an amine using an appropriate electrophile, *e.g.*, an alkyl halide, to form a quaternized alkylated amino salt.

**[033]** *Systemic distribution or delivery*: As used herein, the terms “systemic distribution” or “systemic delivery,” or grammatical equivalents thereof, refer to a delivery or distribution mechanism or approach that affect the entire body or an entire organism. Typically, systemic distribution or delivery is accomplished via body’s circulation system, *e.g.*, blood stream. Compared to the definition of “local distribution or delivery.”

**[034]** *Subject*: As used herein, the term “subject” refers to a human or any non-human animal (*e.g.*, mouse, rat, rabbit, dog, cat, cattle, swine, sheep, horse or primate). A human includes pre- and post-natal forms. In many embodiments, a subject is a human being. A subject can be a patient,

which refers to a human presenting to a medical provider for diagnosis or treatment of a disease. The term “subject” is used herein interchangeably with “individual” or “patient.” A subject can be afflicted with or is susceptible to a disease or disorder but may or may not display symptoms of the disease or disorder.

**[035]** *Substantially*: As used herein, the term “substantially” refers to the qualitative condition of exhibiting total or near-total extent or degree of a characteristic or property of interest. One of ordinary skill in the biological arts will understand that biological and chemical phenomena rarely, if ever, go to completion and/or proceed to completeness or achieve or avoid an absolute result. The term “substantially” is therefore used herein to capture the potential lack of completeness inherent in many biological and chemical phenomena.

**[036]** *Target tissues*: As used herein, the term “target tissues” refers to any tissue that is affected by a disease to be treated. In some embodiments, target tissues include those tissues that display disease-associated pathology, symptom, or feature.

**[037]** *Therapeutically effective amount*: As used herein, the term “therapeutically effective amount” of a therapeutic agent means an amount that is sufficient, when administered to a subject suffering from or susceptible to a disease, disorder, and/or condition, to treat, diagnose, prevent, and/or delay the onset of the symptom(s) of the disease, disorder, and/or condition. It will be appreciated by those of ordinary skill in the art that a therapeutically effective amount is typically administered via a dosing regimen comprising at least one unit dose.

**[038]** *Treating*: As used herein, the term “treat,” “treatment,” or “treating” refers to any method used to partially or completely alleviate, ameliorate, relieve, inhibit, prevent, delay onset of, reduce severity of and/or reduce incidence of one or more symptoms or features of a particular disease, disorder, and/or condition. Treatment may be administered to a subject who does not exhibit signs of a disease and/or exhibits only early signs of the disease for the purpose of decreasing the risk of developing pathology associated with the disease.

#### **Chemical definitions**

**[039]** *Acyl*: As used herein, the term “acyl” refers to  $R^Z-(C=O)-$ , wherein  $R^Z$  is, for example, any alkyl, alkenyl, alkynyl, heteroalkyl or heteroalkylene.

**[040]** *Aliphatic*: As used herein, the term aliphatic refers to  $C_1-C_{50}$  hydrocarbons and includes both saturated and unsaturated hydrocarbons. An aliphatic may be linear, branched, or cyclic. For example,  $C_1-C_{20}$  aliphatics can include  $C_1-C_{20}$  alkyls (e.g., linear or branched  $C_1-C_{20}$  saturated alkyls),  $C_2-C_{20}$  alkenyls (e.g., linear or branched  $C_4-C_{20}$  dienyls, linear or branched  $C_6-C_{20}$  trienyls, and the like), and  $C_2-C_{20}$  alkynyls (e.g., linear or branched  $C_2-C_{20}$  alkynyls).  $C_1-C_{20}$  aliphatics can include  $C_3-C_{20}$  cyclic

aliphatics (*e.g.*, C<sub>3</sub>-C<sub>20</sub> cycloalkyls, C<sub>4</sub>-C<sub>20</sub> cycloalkenyls, or C<sub>8</sub>-C<sub>20</sub> cycloalkynyls). In certain embodiments, the aliphatic may comprise one or more cyclic aliphatic and/or one or more heteroatoms such as oxygen, nitrogen, or sulfur and may optionally be substituted with one or more substituents such as alkyl, halo, alkoxyl, hydroxy, amino, aryl, ether, ester or amide. An aliphatic group is unsubstituted or substituted with one or more substituent groups as described herein. For example, an aliphatic may be substituted with one or more (*e.g.*, 1, 2, 3, 4, 5, or 6 independently selected substituents) of halogen, -COR'', -CO<sub>2</sub>H, -CO<sub>2</sub>R'', -CN, -OH, -OR'', -OCOR', -OCO<sub>2</sub>R'', -NH<sub>2</sub>, -NHR'', -N(R'')<sub>2</sub>, -SR'' or -SO<sub>2</sub>R'', wherein each instance of R'' independently is C<sub>1</sub>-C<sub>20</sub> aliphatic (*e.g.*, C<sub>1</sub>-C<sub>20</sub> alkyl, C<sub>1</sub>-C<sub>15</sub> alkyl, C<sub>1</sub>-C<sub>10</sub> alkyl, or C<sub>1</sub>-C<sub>3</sub> alkyl). In embodiments, R'' independently is an unsubstituted alkyl (*e.g.*, unsubstituted C<sub>1</sub>-C<sub>20</sub> alkyl, C<sub>1</sub>-C<sub>15</sub> alkyl, C<sub>1</sub>-C<sub>10</sub> alkyl, or C<sub>1</sub>-C<sub>3</sub> alkyl). In embodiments, R'' independently is unsubstituted C<sub>1</sub>-C<sub>3</sub> alkyl. In embodiments, the aliphatic is unsubstituted. In embodiments, the aliphatic does not include any heteroatoms. *Alkyl*: As used herein, the term "alkyl" means acyclic linear and branched hydrocarbon groups, *e.g.* "C<sub>1</sub>-C<sub>30</sub> alkyl" refers to alkyl groups having 1-30 carbons. An alkyl group may be linear or branched. Examples of alkyl groups include, but are not limited to, methyl, ethyl, n-propyl, isopropyl, butyl, isobutyl, sec-butyl, tert-butyl, pentyl, isopentyl, tert-pentyl, hexyl, isohexyl, *etc.* The term "lower alkyl" means an alkyl group straight chain or branched alkyl having 1 to 6 carbon atoms. Other alkyl groups will be readily apparent to those of skill in the art given the benefit of the present disclosure. An alkyl group may be unsubstituted or substituted with one or more substituent groups as described herein. For example, an alkyl group may be substituted with one or more (*e.g.*, 1, 2, 3, 4, 5, or 6 independently selected substituents) of halogen, -COR'', -CO<sub>2</sub>H, -CO<sub>2</sub>R'', -CN, -OH, -OR'', -OCOR', -OCO<sub>2</sub>R'', -NH<sub>2</sub>, -NHR'', -N(R'')<sub>2</sub>, -SR'' or -SO<sub>2</sub>R'', wherein each instance of R'' independently is C<sub>1</sub>-C<sub>20</sub> aliphatic (*e.g.*, C<sub>1</sub>-C<sub>20</sub> alkyl, C<sub>1</sub>-C<sub>15</sub> alkyl, C<sub>1</sub>-C<sub>10</sub> alkyl, or C<sub>1</sub>-C<sub>3</sub> alkyl). In embodiments, R'' independently is an unsubstituted alkyl (*e.g.*, unsubstituted C<sub>1</sub>-C<sub>20</sub> alkyl, C<sub>1</sub>-C<sub>15</sub> alkyl, C<sub>1</sub>-C<sub>10</sub> alkyl, or C<sub>1</sub>-C<sub>3</sub> alkyl). In embodiments, R'' independently is unsubstituted C<sub>1</sub>-C<sub>3</sub> alkyl. In embodiments, the alkyl is substituted (*e.g.*, with 1, 2, 3, 4, 5, or 6 substituent groups as described herein). In embodiments, an alkyl group is substituted with a -OH group and may also be referred to herein as a "hydroxyalkyl" group, where the prefix denotes the -OH group and "alkyl" is as described herein.

**[041]** As used herein, "alkyl" also refers to a radical of a straight-chain or branched saturated hydrocarbon group having from 1 to 50 carbon atoms ("C<sub>1</sub>-C<sub>50</sub> alkyl"). In some embodiments, an alkyl group has 1 to 40 carbon atoms ("C<sub>1</sub>-C<sub>40</sub> alkyl"). In some embodiments, an alkyl group has 1 to 30 carbon atoms ("C<sub>1</sub>-C<sub>30</sub> alkyl"). In some embodiments, an alkyl group has 1 to 20 carbon atoms ("C<sub>1</sub>-C<sub>20</sub> alkyl"). In some embodiments, an alkyl group has 1 to 10 carbon atoms ("C<sub>1</sub>-C<sub>10</sub> alkyl"). In some embodiments, an alkyl group has 1 to 9 carbon atoms ("C<sub>1</sub>-C<sub>9</sub> alkyl"). In some embodiments, an alkyl

group has 1 to 8 carbon atoms ("C<sub>1</sub>-C<sub>8</sub> alkyl"). In some embodiments, an alkyl group has 1 to 7 carbon atoms ("C<sub>1</sub>-C<sub>7</sub> alkyl"). In some embodiments, an alkyl group has 1 to 6 carbon atoms ("C<sub>1</sub>-C<sub>6</sub> alkyl"). In some embodiments, an alkyl group has 1 to 5 carbon atoms ("C<sub>1</sub>-C<sub>5</sub> alkyl"). In some embodiments, an alkyl group has 1 to 4 carbon atoms ("C<sub>1</sub>-C<sub>4</sub> alkyl"). In some embodiments, an alkyl group has 1 to 3 carbon atoms ("C<sub>1</sub>-C<sub>3</sub> alkyl"). In some embodiments, an alkyl group has 1 to 2 carbon atoms ("C<sub>1</sub>-C<sub>2</sub> alkyl"). In some embodiments, an alkyl group has 1 carbon atom ("C<sub>1</sub> alkyl"). In some embodiments, an alkyl group has 2 to 6 carbon atoms ("C<sub>2</sub>-C<sub>6</sub> alkyl"). Examples of C<sub>1</sub>-C<sub>6</sub> alkyl groups include, without limitation, methyl (C<sub>1</sub>), ethyl (C<sub>2</sub>), n-propyl (C<sub>3</sub>), isopropyl (C<sub>3</sub>), n-butyl (C<sub>4</sub>), tert-butyl (C<sub>4</sub>), sec-butyl (C<sub>4</sub>), iso-butyl (C<sub>4</sub>), n-pentyl (C<sub>5</sub>), 3-pentanyl (C<sub>5</sub>), amyl (C<sub>5</sub>), neopentyl (C<sub>5</sub>), 3-methyl-2-butanyl (C<sub>5</sub>), tertiary amyl (C<sub>5</sub>), and n-hexyl (C<sub>6</sub>). Additional examples of alkyl groups include n-heptyl (C<sub>7</sub>), n-octyl (C<sub>8</sub>) and the like. Unless otherwise specified, each instance of an alkyl group is independently unsubstituted (an "unsubstituted alkyl") or substituted (a "substituted alkyl") with one or more substituents. In certain embodiments, the alkyl group is an unsubstituted C<sub>1</sub>-C<sub>50</sub> alkyl. In certain embodiments, the alkyl group is a substituted C<sub>1</sub>-C<sub>50</sub> alkyl.

**[042]** Affixing the suffix "-ene" to a group indicates the group is a divalent moiety, *e.g.*, arylene is the divalent moiety of aryl, and heteroarylene is the divalent moiety of heteroaryl.

**[043]** *Alkylene*: The term "alkylene," as used herein, represents a saturated divalent straight or branched chain hydrocarbon group and is exemplified by methylene, ethylene, isopropylene and the like. Likewise, the term "alkenylene" as used herein represents an unsaturated divalent straight or branched chain hydrocarbon group having one or more unsaturated carbon-carbon double bonds that may occur in any stable point along the chain, and the term "alkynylene" herein represents an unsaturated divalent straight or branched chain hydrocarbon group having one or more unsaturated carbon-carbon triple bonds that may occur in any stable point along the chain. In certain embodiments, an alkylene, alkenylene, or alkynylene group may comprise one or more cyclic aliphatic and/or one or more heteroatoms such as oxygen, nitrogen, or sulfur and may optionally be substituted with one or more substituents such as alkyl, halo, alkoxy, hydroxy, amino, aryl, ether, ester or amide. For example, an alkylene, alkenylene, or alkynylene may be substituted with one or more (*e.g.*, 1, 2, 3, 4, 5, or 6 independently selected substituents) of halogen, -COR'', -CO<sub>2</sub>H, -CO<sub>2</sub>R'', -CN, -OH, -OR'', -OCOR'', -OCO<sub>2</sub>R'', -NH<sub>2</sub>, -NHR'', -N(R'')<sub>2</sub>, -SR'' or -SO<sub>2</sub>R'', wherein each instance of R'' independently is C<sub>1</sub>-C<sub>20</sub> aliphatic (*e.g.*, C<sub>1</sub>-C<sub>20</sub> alkyl, C<sub>1</sub>-C<sub>15</sub> alkyl, C<sub>1</sub>-C<sub>10</sub> alkyl, or C<sub>1</sub>-C<sub>3</sub> alkyl). In embodiments, R'' independently is an unsubstituted alkyl (*e.g.*, unsubstituted C<sub>1</sub>-C<sub>20</sub> alkyl, C<sub>1</sub>-C<sub>15</sub> alkyl, C<sub>1</sub>-C<sub>10</sub> alkyl, or C<sub>1</sub>-C<sub>3</sub> alkyl). In embodiments, R'' independently is unsubstituted C<sub>1</sub>-C<sub>3</sub> alkyl. In certain embodiments, an alkylene, alkenylene, or alkynylene is unsubstituted. In certain embodiments, an alkylene, alkenylene, or alkynylene does not include any heteroatoms. *Alkenyl*: As

used herein, “alkenyl” means any linear or branched hydrocarbon chains having one or more unsaturated carbon-carbon double bonds that may occur in any stable point along the chain, *e.g.* “C<sub>2</sub>-C<sub>30</sub> alkenyl” refers to an alkenyl group having 2-30 carbons. For example, an alkenyl group includes prop-2-enyl, but-2-enyl, but-3-enyl, 2-methylprop-2-enyl, hex-2-enyl, hex-5-enyl, 2,3-dimethylbut-2-enyl, and the like. In embodiments, the alkenyl comprises 1, 2, or 3 carbon-carbon double bond. In embodiments, the alkenyl comprises a single carbon-carbon double bond. In embodiments, multiple double bonds (*e.g.*, 2 or 3) are conjugated. An alkenyl group may be unsubstituted or substituted with one or more substituent groups as described herein. For example, an alkenyl group may be substituted with one or more (*e.g.*, 1, 2, 3, 4, 5, or 6 independently selected substituents) of halogen, -COR'', -CO<sub>2</sub>H, -CO<sub>2</sub>R'', -CN, -OH, -OR'', -OCOR'', -OCO<sub>2</sub>R'', -NH<sub>2</sub>, -NHR'', -N(R'')<sub>2</sub>, -SR'' or -SO<sub>2</sub>R'', wherein each instance of R'' independently is C<sub>1</sub>-C<sub>20</sub> aliphatic (*e.g.*, C<sub>1</sub>-C<sub>20</sub> alkyl, C<sub>1</sub>-C<sub>15</sub> alkyl, C<sub>1</sub>-C<sub>10</sub> alkyl, or C<sub>1</sub>-C<sub>3</sub> alkyl). In embodiments, R'' independently is an unsubstituted alkyl (*e.g.*, unsubstituted C<sub>1</sub>-C<sub>20</sub> alkyl, C<sub>1</sub>-C<sub>15</sub> alkyl, C<sub>1</sub>-C<sub>10</sub> alkyl, or C<sub>1</sub>-C<sub>3</sub> alkyl). In embodiments, R'' independently is unsubstituted C<sub>1</sub>-C<sub>3</sub> alkyl. In embodiments, the alkenyl is unsubstituted. In embodiments, the alkenyl is substituted (*e.g.*, with 1, 2, 3, 4, 5, or 6 substituent groups as described herein). In embodiments, an alkenyl group is substituted with a -OH group and may also be referred to herein as a “hydroxyalkenyl” group, where the prefix denotes the -OH group and “alkenyl” is as described herein.

**[044]** As used herein, “alkenyl” also refers to a radical of a straight-chain or branched hydrocarbon group having from 2 to 50 carbon atoms and one or more carbon-carbon double bonds (*e.g.*, 1, 2, 3, or 4 double bonds) (“C<sub>2</sub>-C<sub>50</sub> alkenyl”). In some embodiments, an alkenyl group has 2 to 40 carbon atoms (“C<sub>2</sub>-C<sub>40</sub> alkenyl”). In some embodiments, an alkenyl group has 2 to 30 carbon atoms (“C<sub>2</sub>-C<sub>30</sub> alkenyl”). In some embodiments, an alkenyl group has 2 to 20 carbon atoms (“C<sub>2</sub>-C<sub>20</sub> alkenyl”). In some embodiments, an alkenyl group has 2 to 10 carbon atoms (“C<sub>2</sub>-C<sub>10</sub> alkenyl”). In some embodiments, an alkenyl group has 2 to 9 carbon atoms (“C<sub>2</sub>-C<sub>9</sub> alkenyl”). In some embodiments, an alkenyl group has 2 to 8 carbon atoms (“C<sub>2</sub>-C<sub>8</sub> alkenyl”). In some embodiments, an alkenyl group has 2 to 7 carbon atoms (“C<sub>2</sub>-C<sub>7</sub> alkenyl”). In some embodiments, an alkenyl group has 2 to 6 carbon atoms (“C<sub>2</sub>-C<sub>6</sub> alkenyl”). In some embodiments, an alkenyl group has 2 to 5 carbon atoms (“C<sub>2</sub>-C<sub>5</sub> alkenyl”). In some embodiments, an alkenyl group has 2 to 4 carbon atoms (“C<sub>2</sub>-C<sub>4</sub> alkenyl”). In some embodiments, an alkenyl group has 2 to 3 carbon atoms (“C<sub>2</sub>-C<sub>3</sub> alkenyl”). In some embodiments, an alkenyl group has 2 carbon atoms (“C<sub>2</sub> alkenyl”). The one or more carbon-carbon double bonds can be internal (such as in 2-butenyl) or terminal (such as in 1-butenyl). Examples of C<sub>2</sub>-C<sub>4</sub> alkenyl groups include, without limitation, ethenyl (C<sub>2</sub>), 1-propenyl (C<sub>3</sub>), 2-propenyl (C<sub>3</sub>), 1-butenyl (C<sub>4</sub>), 2-butenyl (C<sub>4</sub>), butadienyl (C<sub>4</sub>), and the like. Examples of C<sub>2</sub>-C<sub>6</sub> alkenyl groups include the aforementioned C<sub>2</sub>-C<sub>4</sub>

alkenyl groups as well as pentenyl (C<sub>5</sub>), pentadienyl (C<sub>5</sub>), hexenyl (C<sub>6</sub>), and the like. Additional examples of alkenyl include heptenyl (C<sub>7</sub>), octenyl (C<sub>8</sub>), octatrienyl (C<sub>8</sub>), and the like. Unless otherwise specified, each instance of an alkenyl group is independently unsubstituted (an “unsubstituted alkenyl”) or substituted (a “substituted alkenyl”) with one or more substituents. In certain embodiments, the alkenyl group is an unsubstituted C<sub>2</sub>-C<sub>50</sub> alkenyl. In certain embodiments, the alkenyl group is a substituted C<sub>2</sub>-C<sub>50</sub> alkenyl.

**[045]** *Alkynyl*: As used herein, “alkynyl” means any hydrocarbon chain of either linear or branched configuration, having one or more carbon-carbon triple bonds occurring in any stable point along the chain, *e.g.*, “C<sub>2</sub>-C<sub>30</sub> alkynyl”, refers to an alkynyl group having 2-30 carbons. Examples of an alkynyl group include prop-2-ynyl, but-2-ynyl, but-3-ynyl, pent-2-ynyl, 3-methylpent-4-ynyl, hex-2-ynyl, hex-5-ynyl, *etc.* In embodiments, an alkynyl comprises one carbon-carbon triple bond. An alkynyl group may be unsubstituted or substituted with one or more substituent groups as described herein. For example, an alkynyl group may be substituted with one or more (*e.g.*, 1, 2, 3, 4, 5, or 6 independently selected substituents) of halogen, -COR<sup>''</sup>, -CO<sub>2</sub>H, -CO<sub>2</sub>R<sup>''</sup>, -CN, -OH, -OR<sup>''</sup>, -OCOR<sup>''</sup>, -OCO<sub>2</sub>R<sup>''</sup>, -NH<sub>2</sub>, -NHR<sup>''</sup>, -N(R<sup>''</sup>)<sub>2</sub>, -SR<sup>''</sup> or -SO<sub>2</sub>R<sup>''</sup>, wherein each instance of R<sup>''</sup> independently is C<sub>1</sub>-C<sub>20</sub> aliphatic (*e.g.*, C<sub>1</sub>-C<sub>20</sub> alkyl, C<sub>1</sub>-C<sub>15</sub> alkyl, C<sub>1</sub>-C<sub>10</sub> alkyl, or C<sub>1</sub>-C<sub>3</sub> alkyl). In embodiments, R<sup>''</sup> independently is an unsubstituted alkyl (*e.g.*, unsubstituted C<sub>1</sub>-C<sub>20</sub> alkyl, C<sub>1</sub>-C<sub>15</sub> alkyl, C<sub>1</sub>-C<sub>10</sub> alkyl, or C<sub>1</sub>-C<sub>3</sub> alkyl). In embodiments, R<sup>''</sup> independently is unsubstituted C<sub>1</sub>-C<sub>3</sub> alkyl. In embodiments, the alkynyl is unsubstituted. In embodiments, the alkynyl is substituted (*e.g.*, with 1, 2, 3, 4, 5, or 6 substituent groups as described herein).

**[046]** As used herein, “alkynyl” also refers to a radical of a straight-chain or branched hydrocarbon group having from 2 to 50 carbon atoms and one or more carbon-carbon triple bonds (*e.g.*, 1, 2, 3, or 4 triple bonds) and optionally one or more double bonds (*e.g.*, 1, 2, 3, or 4 double bonds) (“C<sub>2</sub>-C<sub>50</sub> alkynyl”). An alkynyl group that has one or more triple bonds and one or more double bonds is also referred to as an “ene-yne”. In some embodiments, an alkynyl group has 2 to 40 carbon atoms (“C<sub>2</sub>-C<sub>40</sub> alkynyl”). In some embodiments, an alkynyl group has 2 to 30 carbon atoms (“C<sub>2</sub>-C<sub>30</sub> alkynyl”). In some embodiments, an alkynyl group has 2 to 20 carbon atoms (“C<sub>2</sub>-C<sub>20</sub> alkynyl”). In some embodiments, an alkynyl group has 2 to 10 carbon atoms (“C<sub>2</sub>-C<sub>10</sub> alkynyl”). In some embodiments, an alkynyl group has 2 to 9 carbon atoms (“C<sub>2</sub>-C<sub>9</sub> alkynyl”). In some embodiments, an alkynyl group has 2 to 8 carbon atoms (“C<sub>2</sub>-C<sub>8</sub> alkynyl”). In some embodiments, an alkynyl group has 2 to 7 carbon atoms (“C<sub>2</sub>-C<sub>7</sub> alkynyl”). In some embodiments, an alkynyl group has 2 to 6 carbon atoms (“C<sub>2</sub>-C<sub>6</sub> alkynyl”). In some embodiments, an alkynyl group has 2 to 5 carbon atoms (“C<sub>2</sub>-C<sub>5</sub> alkynyl”). In some embodiments, an alkynyl group has 2 to 4 carbon atoms (“C<sub>2</sub>-C<sub>4</sub> alkynyl”). In some embodiments, an alkynyl group has 2 to 3 carbon atoms (“C<sub>2</sub>-C<sub>3</sub> alkynyl”). In some embodiments, an alkynyl group has

2 carbon atoms (“C<sub>2</sub> alkynyl”). The one or more carbon-carbon triple bonds can be internal (such as in 2-butyne) or terminal (such as in 1-butyne). Examples of C<sub>2</sub>-C<sub>4</sub> alkynyl groups include, without limitation, ethynyl (C<sub>2</sub>), 1-propynyl (C<sub>3</sub>), 2-propynyl (C<sub>3</sub>), 1-butyne (C<sub>4</sub>), 2-butyne (C<sub>4</sub>), and the like. Examples of C<sub>2</sub>-C<sub>6</sub> alkenyl groups include the aforementioned C<sub>2</sub>-C<sub>4</sub> alkynyl groups as well as pentynyl (C<sub>5</sub>), hexynyl (C<sub>6</sub>), and the like. Additional examples of alkynyl include heptynyl (C<sub>7</sub>), octynyl (C<sub>8</sub>), and the like. Unless otherwise specified, each instance of an alkynyl group is independently unsubstituted (an “unsubstituted alkynyl”) or substituted (a “substituted alkynyl”) with one or more substituents. In certain embodiments, the alkynyl group is an unsubstituted C<sub>2</sub>-C<sub>50</sub> alkynyl. In certain embodiments, the alkynyl group is a substituted C<sub>2</sub>-C<sub>50</sub> alkynyl.

**[047]** *Aryl*: The term “aryl” used alone or as part of a larger moiety as in “aralkyl,” refers to a monocyclic, bicyclic, or tricyclic carbocyclic ring system having a total of six to fourteen ring members, wherein said ring system has a single point of attachment to the rest of the molecule, at least one ring in the system is aromatic and wherein each ring in the system contains 4 to 7 ring members. In embodiments, an aryl group has 6 ring carbon atoms (“C<sub>6</sub> aryl,” e.g., phenyl). In some embodiments, an aryl group has 10 ring carbon atoms (“C<sub>10</sub> aryl,” e.g., naphthyl such as 1-naphthyl and 2-naphthyl). In some embodiments, an aryl group has 14 ring carbon atoms (“C<sub>14</sub> aryl,” e.g., anthracyl). “Aryl” also includes ring systems wherein the aryl ring, as defined above, is fused with one or more carbocyclyl or heterocyclyl groups wherein the radical or point of attachment is on the aryl ring, and in such instances, the number of carbon atoms continue to designate the number of carbon atoms in the aryl ring system. Exemplary aryls include phenyl, naphthyl, and anthracene.

**[048]** As used herein, “aryl” also refers to a radical of a monocyclic or polycyclic (e.g., bicyclic or tricyclic) 4n+2 aromatic ring system (e.g., having 6, 10, or 14  $\pi$  electrons shared in a cyclic array) having 6-14 ring carbon atoms and zero heteroatoms provided in the aromatic ring system (“C<sub>6</sub>-C<sub>14</sub> aryl”). In some embodiments, an aryl group has 6 ring carbon atoms (“C<sub>6</sub> aryl”; e.g., phenyl). In some embodiments, an aryl group has 10 ring carbon atoms (“C<sub>10</sub> aryl”; e.g., naphthyl such as 1-naphthyl and 2-naphthyl). In some embodiments, an aryl group has 14 ring carbon atoms (“C<sub>14</sub> aryl”; e.g., anthracyl). “Aryl” also includes ring systems wherein the aryl ring, as defined above, is fused with one or more carbocyclyl or heterocyclyl groups wherein the radical or point of attachment is on the aryl ring, and in such instances, the number of carbon atoms continue to designate the number of carbon atoms in the aryl ring system. Unless otherwise specified, each instance of an aryl group is independently unsubstituted (an “unsubstituted aryl”) or substituted (a “substituted aryl”) with one or more substituents. In certain embodiments, the aryl group is an unsubstituted C<sub>6</sub>-C<sub>14</sub> aryl. In certain embodiments, the aryl group is a substituted C<sub>6</sub>-C<sub>14</sub> aryl.

[049] *Arylene*: The term “arylene” as used herein refers to an aryl group that is divalent (that is, having two points of attachment to the molecule). Exemplary arylenes include phenylene (*e.g.*, unsubstituted phenylene or substituted phenylene).

[050] *Carbocyclyl*: As used herein, “carbocyclyl” or “carbocyclic” refers to a radical of a non-aromatic cyclic hydrocarbon group having from 3 to 10 ring carbon atoms (“C<sub>3</sub>-C<sub>10</sub> carbocyclyl”) and zero heteroatoms in the non-aromatic ring system. In some embodiments, a carbocyclyl group has 3 to 8 ring carbon atoms (“C<sub>3</sub>-C<sub>8</sub> carbocyclyl”). In some embodiments, a carbocyclyl group has 3 to 7 ring carbon atoms (“C<sub>3</sub>-C<sub>7</sub> carbocyclyl”). In some embodiments, a carbocyclyl group has 3 to 6 ring carbon atoms (“C<sub>3</sub>-C<sub>6</sub> carbocyclyl”). In some embodiments, a carbocyclyl group has 4 to 6 ring carbon atoms (“C<sub>4</sub>-C<sub>6</sub> carbocyclyl”). In some embodiments, a carbocyclyl group has 5 to 6 ring carbon atoms (“C<sub>5</sub>-C<sub>6</sub> carbocyclyl”). In some embodiments, a carbocyclyl group has 5 to 10 ring carbon atoms (“C<sub>5</sub>-C<sub>10</sub> carbocyclyl”). Exemplary C<sub>3</sub>-C<sub>6</sub> carbocyclyl groups include, without limitation, cyclopropyl (C<sub>3</sub>), cyclopropenyl (C<sub>3</sub>), cyclobutyl (C<sub>4</sub>), cyclobutenyl (C<sub>4</sub>), cyclopentyl (C<sub>5</sub>), cyclopentenyl (C<sub>5</sub>), cyclohexyl (C<sub>6</sub>), cyclohexenyl (C<sub>6</sub>), cyclohexadienyl (C<sub>6</sub>), and the like. Exemplary C<sub>3</sub>-C<sub>8</sub> carbocyclyl groups include, without limitation, the aforementioned C<sub>3</sub>-C<sub>6</sub> carbocyclyl groups as well as cycloheptyl (C<sub>7</sub>), cycloheptenyl (C<sub>7</sub>), cycloheptadienyl (C<sub>7</sub>), cycloheptatrienyl (C<sub>7</sub>), cyclooctyl (C<sub>8</sub>), cyclooctenyl (C<sub>8</sub>), bicyclo[2.2.1]heptanyl (C<sub>7</sub>), bicyclo[2.2.2]octanyl (C<sub>8</sub>), and the like. Exemplary C<sub>3</sub>-C<sub>10</sub> carbocyclyl groups include, without limitation, the aforementioned C<sub>3</sub>-C<sub>8</sub> carbocyclyl groups as well as cyclononyl (C<sub>9</sub>), cyclononenyl (C<sub>9</sub>), cyclodecyl (C<sub>10</sub>), cyclodecenyl (C<sub>10</sub>), octahydro-1H-indenyl (C<sub>9</sub>), decahydronaphthalenyl (C<sub>10</sub>), spiro[4.5]decanyl (C<sub>10</sub>), and the like. As the foregoing examples illustrate, in certain embodiments, the carbocyclyl group is either monocyclic (“monocyclic carbocyclyl”) or polycyclic (*e.g.*, containing a fused, bridged or spiro ring system such as a bicyclic system (“bicyclic carbocyclyl”) or tricyclic system (“tricyclic carbocyclyl”)) and can be saturated or can contain one or more carbon-carbon double or triple bonds. “Carbocyclyl” also includes ring systems wherein the carbocyclyl ring, as defined above, is fused with one or more aryl or heteroaryl groups wherein the point of attachment is on the carbocyclyl ring, and in such instances, the number of carbons continue to designate the number of carbons in the carbocyclic ring system. Unless otherwise specified, each instance of a carbocyclyl group is independently unsubstituted (an “unsubstituted carbocyclyl”) or substituted (a “substituted carbocyclyl”) with one or more substituents. In certain embodiments, the carbocyclyl group is an unsubstituted C<sub>3</sub>-C<sub>10</sub> carbocyclyl. In certain embodiments, the carbocyclyl group is a substituted C<sub>3</sub>-C<sub>10</sub> carbocyclyl.

[051] In some embodiments, “carbocyclyl” or “carbocyclic” is referred to as a “cycloalkyl”, *i.e.*, a monocyclic, saturated carbocyclyl group having from 3 to 10 ring carbon atoms (“C<sub>3</sub>-C<sub>10</sub>

cycloalkyl"). In some embodiments, a cycloalkyl group has 3 to 8 ring carbon atoms ("C<sub>3</sub>-C<sub>8</sub> cycloalkyl"). In some embodiments, a cycloalkyl group has 3 to 6 ring carbon atoms ("C<sub>3</sub>-C<sub>6</sub> cycloalkyl"). In some embodiments, a cycloalkyl group has 4 to 6 ring carbon atoms ("C<sub>4</sub>-C<sub>6</sub> cycloalkyl"). In some embodiments, a cycloalkyl group has 5 to 6 ring carbon atoms ("C<sub>5</sub>-C<sub>6</sub> cycloalkyl"). In some embodiments, a cycloalkyl group has 5 to 10 ring carbon atoms ("C<sub>5</sub>-C<sub>10</sub> cycloalkyl"). Examples of C<sub>5</sub>-C<sub>6</sub> cycloalkyl groups include cyclopentyl (C<sub>5</sub>) and cyclohexyl (C<sub>6</sub>). Examples of C<sub>3</sub>-C<sub>6</sub> cycloalkyl groups include the aforementioned C<sub>5</sub>-C<sub>6</sub> cycloalkyl groups as well as cyclopropyl (C<sub>3</sub>) and cyclobutyl (C<sub>4</sub>). Examples of C<sub>3</sub>-C<sub>8</sub> cycloalkyl groups include the aforementioned C<sub>3</sub>-C<sub>6</sub> cycloalkyl groups as well as cycloheptyl (C<sub>7</sub>) and cyclooctyl (C<sub>8</sub>). Unless otherwise specified, each instance of a cycloalkyl group is independently unsubstituted (an "unsubstituted cycloalkyl") or substituted (a "substituted cycloalkyl") with one or more substituents. In certain embodiments, the cycloalkyl group is an unsubstituted C<sub>3</sub>-C<sub>10</sub> cycloalkyl. In certain embodiments, the cycloalkyl group is a substituted C<sub>3</sub>-C<sub>10</sub> cycloalkyl.

**[052]** *Halogen*: As used herein, the term "halogen" means fluorine, chlorine, bromine, or iodine.

**[053]** *Heteroalkyl*: The term "heteroalkyl" is meant a branched or unbranched alkyl, alkenyl, or alkynyl group having from 1 to 14 carbon atoms in addition to 1, 2, 3 or 4 heteroatoms independently selected from the group consisting of N, O, S, and P. Heteroalkyls include tertiary amines, secondary amines, ethers, thioethers, amides, thioamides, carbamates, thiocarbamates, hydrazones, imines, phosphodiester, phosphoramidates, sulfonamides, and disulfides. A heteroalkyl group may optionally include monocyclic, bicyclic, or tricyclic rings, in which each ring desirably has three to six members. Examples of heteroalkyls include polyethers, such as methoxymethyl and ethoxyethyl.

**[054]** *Heteroalkylene*: The term "heteroalkylene," as used herein, represents a divalent form of a heteroalkyl group as described herein.

**[055]** *Heteroaryl*: The term "heteroaryl," as used herein, is fully unsaturated heteroatom-containing ring wherein at least one ring atom is a heteroatom such as, but not limited to, nitrogen and oxygen.

**[056]** As used herein, "heteroaryl" also refers to a radical of a 5-14 membered monocyclic or polycyclic (e.g., bicyclic or tricyclic) 4n+2 aromatic ring system (e.g., having 6, 10, or 14  $\pi$  electrons shared in a cyclic array) having ring carbon atoms and 1 or more (e.g., 1, 2, 3, or 4 ring heteroatoms) ring heteroatoms provided in the aromatic ring system, wherein each heteroatom is independently selected from oxygen, sulfur, nitrogen, boron, silicon, and phosphorus ("5-14 membered heteroaryl"). In heteroaryl groups that contain one or more nitrogen atoms, the point of attachment can be a carbon or nitrogen atom, as valency permits. Heteroaryl polycyclic ring systems can include

one or more heteroatoms in one or both rings. "Heteroaryl" includes ring systems wherein the heteroaryl ring, as defined above, is fused with one or more carbocyclyl or heterocyclyl groups wherein the point of attachment is on the heteroaryl ring, and in such instances, the number of ring members continue to designate the number of ring members in the heteroaryl ring system.

"Heteroaryl" also includes ring systems wherein the heteroaryl ring, as defined above, is fused with one or more aryl groups wherein the point of attachment is either on the aryl or heteroaryl ring, and in such instances, the number of ring members designates the number of ring members in the fused polycyclic (aryl/heteroaryl) ring system. Polycyclic heteroaryl groups wherein one ring does not contain a heteroatom (e.g., indolyl, quinolinyl, carbazolyl, and the like) the point of attachment can be on either ring, i.e., either the ring bearing a heteroatom (e.g., 2-indolyl) or the ring that does not contain a heteroatom (e.g., 5-indolyl).

**[057]** In some embodiments, a heteroaryl group is a 5-10 membered aromatic ring system having ring carbon atoms and 1 or more (e.g., 1, 2, 3, or 4) ring heteroatoms provided in the aromatic ring system, wherein each heteroatom is independently selected from oxygen, sulfur, nitrogen, boron, silicon, and phosphorus ("5-10 membered heteroaryl"). In some embodiments, a heteroaryl group is a 5-8 membered aromatic ring system having ring carbon atoms and 1 or more (e.g., 1, 2, 3, or 4) ring heteroatoms provided in the aromatic ring system, wherein each heteroatom is independently selected from oxygen, sulfur, nitrogen, boron, silicon, and phosphorus ("5-8 membered heteroaryl"). In some embodiments, a heteroaryl group is a 5-6 membered aromatic ring system having ring carbon atoms and 1 or more (e.g., 1, 2, 3, or 4) ring heteroatoms provided in the aromatic ring system, wherein each heteroatom is independently selected from oxygen, sulfur, nitrogen, boron, silicon, and phosphorus ("5-6 membered heteroaryl"). In some embodiments, the 5-6 membered heteroaryl has 1 or more (e.g., 1, 2, or 3) ring heteroatoms selected from oxygen, sulfur, nitrogen, boron, silicon, and phosphorus. In some embodiments, the 5-6 membered heteroaryl has 1 or 2 ring heteroatoms selected from oxygen, sulfur, nitrogen, boron, silicon, and phosphorus. In some embodiments, the 5-6 membered heteroaryl has 1 ring heteroatom selected from oxygen, sulfur, nitrogen, boron, silicon, and phosphorus. Unless otherwise specified, each instance of a heteroaryl group is independently unsubstituted (an "unsubstituted heteroaryl") or substituted (a "substituted heteroaryl") with one or more substituents. In certain embodiments, the heteroaryl group is an unsubstituted 5-14 membered heteroaryl. In certain embodiments, the heteroaryl group is a substituted 5-14 membered heteroaryl.

**[058]** Exemplary 5-membered heteroaryl groups containing 1 heteroatom include, without limitation, pyrrolyl, furanyl and thiophenyl. Exemplary 5-membered heteroaryl groups containing 2 heteroatoms include, without limitation, imidazolyl, pyrazolyl, oxazolyl, isoxazolyl, thiazolyl, and

isothiazolyl. Exemplary 5-membered heteroaryl groups containing 3 heteroatoms include, without limitation, triazolyl, oxadiazolyl, and thiadiazolyl. Exemplary 5-membered heteroaryl groups containing 4 heteroatoms include, without limitation, tetrazolyl. Exemplary 6-membered heteroaryl groups containing 1 heteroatom include, without limitation, pyridinyl. Exemplary 6-membered heteroaryl groups containing 2 heteroatoms include, without limitation, pyridazinyl, pyrimidinyl, and pyrazinyl. Exemplary 6-membered heteroaryl groups containing 3 or 4 heteroatoms include, without limitation, triazinyl and tetrazinyl, respectively. Exemplary 7-membered heteroaryl groups containing 1 heteroatom include, without limitation, azepinyl, oxepinyl, and thiepinyl. Exemplary 5,6-bicyclic heteroaryl groups include, without limitation, indolyl, isoindolyl, indazolyl, benzotriazolyl, benzothiophenyl, isobenzothiophenyl, benzofuranyl, benzoisofuranyl, benzimidazolyl, benzoxazolyl, benzisoxazolyl, benzoxadiazolyl, benzthiazolyl, benzisothiazolyl, benzthiadiazolyl, indolizinyl, and purinyl. Exemplary 6,6-bicyclic heteroaryl groups include, without limitation, naphthyridinyl, pteridinyl, quinolinyl, isoquinolinyl, cinnolinyl, quinoxalinyl, phthalazinyl, and quinazolinyl. Exemplary tricyclic heteroaryl groups include, without limitation, phenanthridinyl, dibenzofuranyl, carbazolyl, acridinyl, phenothiazinyl, phenoxazinyl and phenazinyl.

**[059]** As used herein, “heterocyclyl” or “heterocyclic” refers to a radical of a 3- to 14-membered non-aromatic ring system having ring carbon atoms and 1 or more (e.g., 1, 2, 3, or 4) ring heteroatoms, wherein each heteroatom is independently selected from oxygen, sulfur, nitrogen, boron, silicon, and phosphorus (“3-14 membered heterocyclyl”). In heterocyclyl groups that contain one or more nitrogen atoms, the point of attachment can be a carbon or nitrogen atom, as valency permits. A heterocyclyl group can either be monocyclic (“monocyclic heterocyclyl”) or polycyclic (e.g., a fused, bridged or spiro ring system such as a bicyclic system (“bicyclic heterocyclyl”) or tricyclic system (“tricyclic heterocyclyl”)). and can be saturated or can contain one or more carbon-carbon double or triple bonds. Heterocyclyl polycyclic ring systems can include one or more heteroatoms in one or both rings. “Heterocyclyl” also includes ring systems wherein the heterocyclyl ring, as defined above, is fused with one or more carbocyclyl groups wherein the point of attachment is either on the carbocyclyl or heterocyclyl ring, or ring systems wherein the heterocyclyl ring, as defined above, is fused with one or more aryl or heteroaryl groups, wherein the point of attachment is on the heterocyclyl ring, and in such instances, the number of ring members continue to designate the number of ring members in the heterocyclyl ring system. Unless otherwise specified, each instance of heterocyclyl is independently unsubstituted (an “unsubstituted heterocyclyl”) or substituted (a “substituted heterocyclyl”) with one or more substituents. In certain embodiments, the heterocyclyl group is an unsubstituted 3-14 membered heterocyclyl. In certain embodiments, the heterocyclyl group is a substituted 3-14 membered heterocyclyl.

**[060]** In some embodiments, a heterocyclyl group is a 5-10 membered non-aromatic ring system having ring carbon atoms and 1 or more (e.g., 1, 2, 3, or 4) ring heteroatoms, wherein each heteroatom is independently selected from oxygen, sulfur, nitrogen, boron, silicon, and phosphorus ("5-10 membered heterocyclyl"). In some embodiments, a heterocyclyl group is a 5-8 membered non-aromatic ring system having ring carbon atoms and 1 or more (e.g., 1, 2, 3, or 4) ring heteroatoms, wherein each heteroatom is independently selected from oxygen, sulfur, nitrogen, boron, silicon, and phosphorus ("5-8 membered heterocyclyl"). In some embodiments, a heterocyclyl group is a 5-6 membered non-aromatic ring system having ring carbon atoms and 1 or more (e.g., 1, 2, 3, or 4) ring heteroatoms, wherein each heteroatom is independently selected from oxygen, sulfur, nitrogen, boron, silicon, and phosphorus ("5-6 membered heterocyclyl"). In some embodiments, the 5-6 membered heterocyclyl has 1 or more (e.g., 1, 2, or 3) ring heteroatoms selected from oxygen, sulfur, nitrogen, boron, silicon, and phosphorus. In some embodiments, the 5-6 membered heterocyclyl has 1 or 2 ring heteroatoms selected from oxygen, sulfur, nitrogen, boron, silicon, and phosphorus. In some embodiments, the 5-6 membered heterocyclyl has 1 ring heteroatom selected from oxygen, sulfur, nitrogen, boron, silicon, and phosphorus.

**[061]** Exemplary 3-membered heterocyclyl groups containing 1 heteroatom include, without limitation, azirdinyl, oxiranyl, thiorenlyl. Exemplary 4-membered heterocyclyl groups containing 1 heteroatom include, without limitation, azetidiny, oxetanyl and thietanyl. Exemplary 5-membered heterocyclyl groups containing 1 heteroatom include, without limitation, tetrahydrofuranyl, dihydrofuranyl, tetrahydrothiophenyl, dihydrothiophenyl, pyrrolidinyl, dihydropyrrolyl and pyrrolyl-2,5-dione. Exemplary 5-membered heterocyclyl groups containing 2 heteroatoms include, without limitation, dioxolanyl, oxathiolanyl and dithiolanyl. Exemplary 5-membered heterocyclyl groups containing 3 heteroatoms include, without limitation, triazoliny, oxadiazoliny, and thiadiazoliny. Exemplary 6-membered heterocyclyl groups containing 1 heteroatom include, without limitation, piperidinyl, tetrahydropyranyl, dihydropyridiny, and thianyl. Exemplary 6-membered heterocyclyl groups containing 2 heteroatoms include, without limitation, piperazinyl, morpholinyl, dithianyl, dioxanyl. Exemplary 6-membered heterocyclyl groups containing 2 heteroatoms include, without limitation, triazinanyl. Exemplary 7-membered heterocyclyl groups containing 1 heteroatom include, without limitation, azepanyl, oxepanyl and thiepanyl. Exemplary 8-membered heterocyclyl groups containing 1 heteroatom include, without limitation, azocanyl, oxecanyl and thiocanyl. Exemplary bicyclic heterocyclyl groups include, without limitation, indolinyl, isoindolinyl, dihydrobenzofuranyl, dihydrobenzothiényl, tetrahydrobenzothiényl, tetrahydrobenzofuranyl, tetrahydroindolyl, tetrahydroquinoliny, tetrahydroisoquinoliny, decahydroquinoliny, decahydroisoquinoliny, octahydrochromenyl, octahydroisochromenyl, decahydronaphthyridiny,

decahydro-1,8-naphthyridinyl, octahydropyrrolo[3,2-b]pyrrole, indolinyl, phthalimidyl, naphthalimidyl, chromanyl, chromenyl, 1H-benzo[e][1,4]diazepinyl, 1,4,5,7-tetrahydropyrano[3,4-b]pyrrolyl, 5,6-dihydro-4H-furo[3,2-b]pyrrolyl, 6,7-dihydro-5H-furo[3,2-b]pyranyl, 5,7-dihydro-4H-thieno[2,3-c]pyranyl, 2,3-dihydro-1H-pyrrolo[2,3-b]pyridinyl, 2,3-dihydrofuro[2,3-b]pyridinyl, 4,5,6,7-tetrahydro-1H-pyrrolo-[2,3-b]pyridinyl, 4,5,6,7-tetrahydrofuro[3,2-c]pyridinyl, 4,5,6,7-tetrahydrothieno[3,2-b]pyridinyl, 1,2,3,4-tetrahydro-1,6-naphthyridinyl, and the like.

**[062]** *Heterocycloalkyl*: The term “heterocycloalkyl,” as used herein, is a non-aromatic ring wherein at least one atom is a heteroatom such as, but not limited to, nitrogen, oxygen, sulfur, or phosphorus, and the remaining atoms are carbon. The heterocycloalkyl group can be substituted or unsubstituted.

**[063]** As understood from the above, alkyl, alkenyl, alkynyl, acyl, carbocyclyl, heterocyclyl, aryl, and heteroaryl groups, as defined herein, are, in certain embodiments, optionally substituted. Optionally substituted refers to a group which may be substituted or unsubstituted (e.g., “substituted” or “unsubstituted” alkyl, “substituted” or “unsubstituted” alkenyl, “substituted” or “unsubstituted” alkynyl, “substituted” or “unsubstituted” heteroalkyl, “substituted” or “unsubstituted” heteroalkenyl, “substituted” or “unsubstituted” heteroalkynyl, “substituted” or “unsubstituted” carbocyclyl, “substituted” or “unsubstituted” heterocyclyl, “substituted” or “unsubstituted” aryl or “substituted” or “unsubstituted” heteroaryl group. In general, the term “substituted” means that at least one hydrogen present on a group is replaced with a permissible substituent, e.g., a substituent which upon substitution results in a stable compound, e.g., a compound which does not spontaneously undergo transformation such as by rearrangement, cyclization, elimination, or other reaction. Unless otherwise indicated, a “substituted” group has a substituent at one or more substitutable positions of the group, and when more than one position in any given structure is substituted, the substituent is either the same or different at each position. The term “substituted” is contemplated to include substitution with all permissible substituents of organic compounds, any of the substituents described herein that results in the formation of a stable compound. The present invention contemplates any and all such combinations in order to arrive at a stable compound. For purposes of this invention, heteroatoms such as nitrogen may have hydrogen substituents and/or any suitable substituent as described herein which satisfy the valencies of the heteroatoms and results in the formation of a stable moiety.

**[064]** Exemplary carbon atom substituents include, but are not limited to, halogen, -CN, -NO<sub>2</sub>, -N<sub>3</sub>, -SO<sub>2</sub>, -SO<sub>3</sub>H, -OH, -OR<sup>aa</sup>, -ON(R<sup>bb</sup>)<sub>2</sub>, -N(R<sup>bb</sup>)<sub>2</sub>, -N(R<sup>bb</sup>)<sub>3</sub>+X<sup>-</sup>, -N(OR<sup>cc</sup>)R<sup>bb</sup>, -SeH, -SeR<sup>aa</sup>, -SH, -SR<sup>aa</sup>, -SSR<sup>cc</sup>, -C(=O)R<sup>aa</sup>, -CO<sub>2</sub>H, -CHO, -C(OR<sup>cc</sup>)<sub>2</sub>, -CO<sub>2</sub>R<sup>aa</sup>, -OC(=O)R<sup>aa</sup>, -OCO<sub>2</sub>R<sup>aa</sup>, -C(=O)N(R<sup>bb</sup>)<sub>2</sub>, -

OC(=O)N(R<sup>bb</sup>)<sub>2</sub>, -NR<sup>bb</sup>C(=O)R<sup>aa</sup>, -NR<sup>bb</sup>CO<sub>2</sub>R<sup>aa</sup>, -NR<sup>bb</sup>C(=O)N(R<sup>bb</sup>)<sub>2</sub>, -C(=NR<sup>bb</sup>)R<sup>aa</sup>, -C(=NR<sup>bb</sup>)OR<sup>aa</sup>, -OC(=NR<sup>bb</sup>)R<sup>aa</sup>, -OC(=NR<sup>bb</sup>)OR<sup>aa</sup>, -C(=NR<sup>bb</sup>)N(R<sup>bb</sup>)<sub>2</sub>, -OC(=NR<sup>bb</sup>)N(R<sup>bb</sup>)<sub>2</sub>, -NR<sup>bb</sup>C(=NR<sup>bb</sup>)N(R<sup>bb</sup>)<sub>2</sub>, -C(=O)NR<sup>bb</sup>SO<sub>2</sub>R<sup>aa</sup>, -NR<sup>bb</sup>SO<sub>2</sub>R<sup>aa</sup>, -SO<sub>2</sub>N(R<sup>bb</sup>)<sub>2</sub>, -SO<sub>2</sub>R<sup>aa</sup>, -SO<sub>2</sub>OR<sup>aa</sup>, -OSO<sub>2</sub>R<sup>aa</sup>, -S(=O)R<sup>aa</sup>, -OS(=O)R<sup>aa</sup>, -Si(R<sup>aa</sup>)<sub>3</sub> -OSi(R<sup>aa</sup>)<sub>3</sub> -C(=S)N(R<sup>bb</sup>)<sub>2</sub>, -C(=O)SR<sup>aa</sup>, -C(=S)SR<sup>aa</sup>, -SC(=S)SR<sup>aa</sup>, -SC(=O)SR<sup>aa</sup>, -OC(=O)SR<sup>aa</sup>, -SC(=O)OR<sup>aa</sup>, -SC(=O)R<sup>aa</sup>, -P(=O)<sub>2</sub>R<sup>aa</sup>, -OP(=O)<sub>2</sub>R<sup>aa</sup>, -P(=O)(R<sup>aa</sup>)<sub>2</sub>, -OP(=O)(R<sup>aa</sup>)<sub>2</sub>, -OP(=O)(OR<sup>cc</sup>)<sub>2</sub>, -P(=O)<sub>2</sub>N(R<sup>bb</sup>)<sub>2</sub>, -OP(=O)<sub>2</sub>N(R<sup>bb</sup>)<sub>2</sub>, -P(=O)(NR<sup>bb</sup>)<sub>2</sub>, -OP(=O)(NR<sup>bb</sup>)<sub>2</sub>, -NR<sup>bb</sup>P(=O)(OR<sup>cc</sup>)<sub>2</sub>, -NR<sup>bb</sup>P(=O)(NR<sup>bb</sup>)<sub>2</sub>, -P(R<sup>cc</sup>)<sub>2</sub>, -P(R<sup>cc</sup>)<sub>3</sub>, -OP(R<sup>cc</sup>)<sub>2</sub>, -OP(R<sup>cc</sup>)<sub>3</sub>, -B(R<sup>aa</sup>)<sub>2</sub>, -B(OR<sup>cc</sup>)<sub>2</sub>, -BR<sup>aa</sup>(OR<sup>cc</sup>), C<sub>1</sub>-C<sub>50</sub> alkyl, C<sub>2</sub>-C<sub>50</sub> alkenyl, C<sub>2</sub>-C<sub>50</sub> alkynyl, C<sub>3</sub>-C<sub>14</sub> carbocyclyl, 3-14 membered heterocyclyl, C<sub>6</sub>-C<sub>14</sub> aryl, and 5-14 membered heteroaryl, wherein each alkyl, alkenyl, alkynyl, carbocyclyl, heterocyclyl, aryl, and heteroaryl is independently substituted with 0, 1, 2, 3, 4, or 5 R<sup>dd</sup> groups; or two geminal hydrogens on a carbon atom are replaced with the group =O, =S, =NN(R<sup>bb</sup>)<sub>2</sub>, =NNR<sup>bb</sup>C(=O)R<sup>aa</sup>, =NNR<sup>bb</sup>C(=O)OR<sup>aa</sup>, =NNR<sup>bb</sup>S(=O)<sub>2</sub>R<sup>aa</sup>, =NR<sup>bb</sup>, or =NOR<sup>cc</sup>;

**[065]** each instance of R<sup>aa</sup> is, independently, selected from C<sub>1</sub>-C<sub>50</sub> alkyl, C<sub>2</sub>-C<sub>50</sub> alkenyl, C<sub>2</sub>-C<sub>50</sub> alkynyl, C<sub>3</sub>-C<sub>10</sub> carbocyclyl, 3-14 membered heterocyclyl, C<sub>6</sub>-C<sub>14</sub> aryl, and 5-14 membered heteroaryl, or two R<sup>aa</sup> groups are joined to form a 3-14 membered heterocyclyl or 5-14 membered heteroaryl ring, wherein each alkyl, alkenyl, alkynyl, carbocyclyl, heterocyclyl, aryl, and heteroaryl is independently substituted with 0, 1, 2, 3, 4, or 5 R<sup>dd</sup> groups;

**[066]** each instance of R<sup>bb</sup> is, independently, selected from hydrogen, -OH, -OR<sup>aa</sup>, -N(R<sup>cc</sup>)<sub>2</sub>, -CN, -C(=O)R<sup>aa</sup>, -C(=O)N(R<sup>cc</sup>)<sub>2</sub>, -CO<sub>2</sub>R<sup>aa</sup>, -SO<sub>2</sub>R<sup>aa</sup>, -C(=NR<sup>cc</sup>)OR<sup>aa</sup>, -C(=NR<sup>cc</sup>)N(R<sup>cc</sup>)<sub>2</sub>, -SO<sub>2</sub>N(R<sup>cc</sup>)<sub>2</sub>, -SO<sub>2</sub>R<sup>cc</sup>, -SO<sub>2</sub>OR<sup>cc</sup>, -SOR<sup>aa</sup>, -C(=S)N(R<sup>cc</sup>)<sub>2</sub>, -C(=O)SR<sup>cc</sup>, -C(=S)SR<sup>cc</sup>, -P(=O)<sub>2</sub>R<sup>aa</sup>, -P(=O)(R<sup>aa</sup>)<sub>2</sub>, -P(=O)<sub>2</sub>N(R<sup>cc</sup>)<sub>2</sub>, -P(=O)(NR<sup>cc</sup>)<sub>2</sub>, C<sub>1</sub>-C<sub>50</sub> alkyl, C<sub>2</sub>-C<sub>50</sub> alkenyl, C<sub>2</sub>-C<sub>50</sub> alkynyl, C<sub>3</sub>-C<sub>10</sub> carbocyclyl, 3-14 membered heterocyclyl, C<sub>6</sub>-C<sub>14</sub> aryl, and 5-14 membered heteroaryl, or two R<sup>bb</sup> groups, together with the heteroatom to which they are attached, form a 3-14 membered heterocyclyl or 5-14 membered heteroaryl ring, wherein each alkyl, alkenyl, alkynyl, carbocyclyl, heterocyclyl, aryl, and heteroaryl is independently substituted with 0, 1, 2, 3, 4, or 5 R<sup>dd</sup> groups;

**[067]** each instance of R<sup>cc</sup> is, independently, selected from hydrogen, C<sub>1</sub>-C<sub>50</sub> alkyl, C<sub>2</sub>-C<sub>50</sub> alkenyl, C<sub>2</sub>-C<sub>50</sub> alkynyl, C<sub>3</sub>-C<sub>10</sub> carbocyclyl, 3-14 membered heterocyclyl, C<sub>6</sub>-C<sub>14</sub> aryl, and 5-14 membered heteroaryl, or two R<sup>cc</sup> groups, together with the heteroatom to which they are attached, form a 3-14 membered heterocyclyl or 5-14 membered heteroaryl ring, wherein each alkyl, alkenyl, alkynyl, carbocyclyl, heterocyclyl, aryl, and heteroaryl is independently substituted with 0, 1, 2, 3, 4, or 5 R<sup>dd</sup> groups;

**[068]** each instance of R<sup>dd</sup> is, independently, selected from halogen, -CN, -NO<sub>2</sub>, -N<sub>3</sub>, -SO<sub>2</sub>H, -SO<sub>3</sub>H, -OH, -OR<sup>ee</sup>, -ON(R<sup>ff</sup>)<sub>2</sub>, -N(R<sup>ff</sup>)<sub>2</sub>, -N(R<sup>ff</sup>)<sub>3</sub>X<sup>-</sup>, -N(OR<sup>ee</sup>)R<sup>ff</sup>, -SH, -SR<sup>ee</sup>, -SSR<sup>ee</sup>, -C(=O)R<sup>ee</sup>, -CO<sub>2</sub>H, -CO<sub>2</sub>R<sup>ee</sup>, -OC(=O)R<sup>ee</sup>, -OCO<sub>2</sub>R<sup>ee</sup>, -C(=O)N(R<sup>ff</sup>)<sub>2</sub>, -OC(=O)N(R<sup>ff</sup>)<sub>2</sub>, -NR<sup>ff</sup>C(=O)R<sup>ee</sup>, -NR<sup>ff</sup>CO<sub>2</sub>R<sup>ee</sup>, -NR<sup>ff</sup>C(=O)N(R<sup>ff</sup>)<sub>2</sub>, -

C(=NR<sup>ff</sup>)OR<sup>ee</sup>, -OC(=NR<sup>ff</sup>)R<sup>ee</sup>, -OC(=NR<sup>ff</sup>)OR<sup>ee</sup>, -C(=NR<sup>ff</sup>)N(R<sup>ff</sup>)<sub>2</sub>, -OC(=NR<sup>ff</sup>)N(R<sup>ff</sup>)<sub>2</sub>, -NR<sup>ff</sup>C(=NR<sup>ff</sup>)N(R<sup>ff</sup>)<sub>2</sub>,  
 -NR<sup>ff</sup>SO<sub>2</sub>R<sup>ee</sup>, -SO<sub>2</sub>N(R<sup>ff</sup>)<sub>2</sub>, -SO<sub>2</sub>R<sup>ee</sup>, -SO<sub>2</sub>OR<sup>ee</sup>, -OSO<sub>2</sub>R<sup>ee</sup>, -S(=O)R<sup>ee</sup>, -Si(R<sup>ee</sup>)<sub>3</sub>, -OSi(R<sup>ee</sup>)<sub>3</sub>, -  
 C(=S)N(R<sup>ff</sup>)<sub>2</sub>, -C(=O)SR<sup>ee</sup>, -C(=S)SR<sup>ee</sup>, -SC(=S)SR<sup>ee</sup>, -P(=O)<sub>2</sub>R<sup>ee</sup>, -P(=O)(R<sup>ee</sup>)<sub>2</sub>, -OP(=O)(R<sup>ee</sup>)<sub>2</sub>, -  
 OP(=O)(OR<sup>ee</sup>)<sub>2</sub>, C<sub>1</sub>-C<sub>50</sub> alkyl, C<sub>2</sub>-C<sub>50</sub> alkenyl, C<sub>2</sub>-C<sub>50</sub> alkynyl, C<sub>3</sub>-C<sub>10</sub> carbocyclyl, 3-10 membered  
 heterocyclyl, C<sub>6</sub>-C<sub>10</sub> aryl, 5-10 membered heteroaryl, wherein each alkyl, alkenyl, alkynyl, carbocyclyl,  
 heterocyclyl, aryl, and heteroaryl is independently substituted with 0, 1, 2, 3, 4, or 5 R<sup>gg</sup> groups, or  
 two geminal R<sup>dd</sup> substituents can be joined to form =O or =S;

**[069]** each instance of R<sup>ee</sup> is, independently, selected from C<sub>1</sub>-C<sub>50</sub> alkyl, C<sub>2</sub>-C<sub>50</sub> alkenyl, C<sub>2</sub>-C<sub>50</sub>  
 alkynyl, C<sub>3</sub>-C<sub>10</sub> carbocyclyl, C<sub>6</sub>-C<sub>10</sub> aryl, 3-10 membered heterocyclyl, and 3-10 membered heteroaryl,  
 wherein each alkyl, alkenyl, alkynyl, carbocyclyl, heterocyclyl, aryl, and heteroaryl is independently  
 substituted with 0, 1, 2, 3, 4, or 5 R<sup>gg</sup> groups;

**[070]** each instance of R<sup>ff</sup> is, independently, selected from hydrogen, C<sub>1</sub>-C<sub>50</sub> alkyl, C<sub>2</sub>-C<sub>50</sub> alkenyl, C<sub>2</sub>-  
 C<sub>50</sub> alkynyl, C<sub>3</sub>-C<sub>10</sub> carbocyclyl, 3-10 membered heterocyclyl, C<sub>6</sub>-C<sub>10</sub> aryl and 5-10 membered  
 heteroaryl, or two R<sup>ff</sup> groups, together with the heteroatom to which they are attached, form a 3-14  
 membered heterocyclyl or 5-14 membered heteroaryl ring, wherein each alkyl, alkenyl, alkynyl,  
 carbocyclyl, heterocyclyl, aryl, and heteroaryl is independently substituted with 0, 1, 2, 3, 4, or 5 R<sup>gg</sup>  
 groups; and

**[071]** each instance of R<sup>gg</sup> is, independently, halogen, -CN, -NO<sub>2</sub>, -N<sub>3</sub>, -SO<sub>2</sub>H, -SO<sub>3</sub>H, -OH, -OC<sub>1</sub>-  
 C<sub>50</sub> alkyl, -ON(C<sub>1</sub>-C<sub>50</sub> alkyl)<sub>2</sub>, -N(C<sub>1</sub>-C<sub>50</sub> alkyl)<sub>2</sub>, -N(C<sub>1</sub>-C<sub>50</sub> alkyl)<sub>3</sub>+X<sup>-</sup>, -NH(C<sub>1</sub>-C<sub>50</sub> alkyl)<sub>2</sub>+X<sup>-</sup>, -NH<sub>2</sub>(C<sub>1</sub>-C<sub>50</sub>  
 alkyl)+X<sup>-</sup>, -NH<sub>3</sub>+X<sup>-</sup>, -N(OC<sub>1</sub>-C<sub>50</sub> alkyl)(C<sub>1</sub>-C<sub>50</sub> alkyl), -N(OH)(C<sub>1</sub>-C<sub>50</sub> alkyl), -NH(OH), -SH, -SC<sub>1</sub>-C<sub>50</sub> alkyl, -  
 SS(C<sub>1</sub>-C<sub>50</sub> alkyl), -C(=O)(C<sub>1</sub>-C<sub>50</sub> alkyl), -CO<sub>2</sub>H, -CO<sub>2</sub>(C<sub>1</sub>-C<sub>50</sub> alkyl), -OC(=O)(C<sub>1</sub>-C<sub>50</sub> alkyl), -OCO<sub>2</sub>(C<sub>1</sub>-C<sub>50</sub>  
 alkyl), -C(=O)NH<sub>2</sub>, -C(=O)N(C<sub>1</sub>-C<sub>50</sub> alkyl)<sub>2</sub>, -OC(=O)NH(C<sub>1</sub>-C<sub>50</sub> alkyl), -NHC(=O)(C<sub>1</sub>-C<sub>50</sub> alkyl), -N(C<sub>1</sub>-C<sub>50</sub>  
 alkyl)C(=O)(C<sub>1</sub>-C<sub>50</sub> alkyl), -NHCO<sub>2</sub>(C<sub>1</sub>-C<sub>50</sub> alkyl), -NHC(=O)N(C<sub>1</sub>-C<sub>50</sub> alkyl)<sub>2</sub>, -NHC(=O)NH(C<sub>1</sub>-C<sub>50</sub>  
 alkyl), -NHC(=O)NH<sub>2</sub>, -C(=NH)O(C<sub>1</sub>-C<sub>50</sub> alkyl), -OC(=NH)(C<sub>1</sub>-C<sub>50</sub> alkyl), -OC(=NH)OC<sub>1</sub>-C<sub>50</sub> alkyl, -  
 C(=NH)N(C<sub>1</sub>-C<sub>50</sub> alkyl)<sub>2</sub>, -C(=NH)NH(C<sub>1</sub>-C<sub>50</sub> alkyl), -C(=NH)NH<sub>2</sub>, -OC(=NH)N(C<sub>1</sub>-C<sub>50</sub>alkyl)<sub>2</sub>, -OC(NH)NH(C<sub>1</sub>-  
 C<sub>50</sub> alkyl), -OC(NH)NH<sub>2</sub>, -NHC(NH)N(C<sub>1</sub>-C<sub>50</sub> alkyl)<sub>2</sub>, -NHC(=NH)NH<sub>2</sub>, -NHCO<sub>2</sub>(C<sub>1</sub>-C<sub>50</sub> alkyl), -SO<sub>2</sub>N(C<sub>1</sub>-C<sub>50</sub>  
 alkyl)<sub>2</sub>, -SO<sub>2</sub>NH(C<sub>1</sub>-C<sub>50</sub> alkyl), -SO<sub>2</sub>NH<sub>2</sub>, -SO<sub>2</sub>(C<sub>1</sub>-C<sub>50</sub> alkyl), -SO<sub>2</sub>O(C<sub>1</sub>-C<sub>50</sub> alkyl), -OSO<sub>2</sub>(C<sub>1</sub>-C<sub>6</sub> alkyl), -SO(C<sub>1</sub>-  
 C<sub>6</sub> alkyl), -Si(C<sub>1</sub>-C<sub>50</sub> alkyl)<sub>3</sub>, -OSi(C<sub>1</sub>-C<sub>6</sub> alkyl)<sub>3</sub>, -C(=S)N(C<sub>1</sub>-C<sub>50</sub> alkyl)<sub>2</sub>, C(=S)NH(C<sub>1</sub>-C<sub>50</sub> alkyl), C(=S)NH<sub>2</sub>, -  
 C(=O)S(C<sub>1</sub>-C<sub>6</sub> alkyl), -C(=S)S(C<sub>1</sub>-C<sub>6</sub> alkyl), -SC(=S)S(C<sub>1</sub>-C<sub>6</sub> alkyl), -P(=O)<sub>2</sub>(C<sub>1</sub>-C<sub>50</sub> alkyl), -P(=O)(C<sub>1</sub>-C<sub>50</sub>  
 alkyl)<sub>2</sub>, -OP(=O)(C<sub>1</sub>-C<sub>50</sub> alkyl)<sub>2</sub>, -OP(=O)(OC<sub>1</sub>-C<sub>50</sub> alkyl)<sub>2</sub>, C<sub>1</sub>-C<sub>50</sub> alkyl, C<sub>2</sub>-C<sub>50</sub> alkenyl, C<sub>2</sub>-C<sub>50</sub> alkynyl, C<sub>3</sub>-C<sub>10</sub>  
 carbocyclyl, C<sub>6</sub>-C<sub>10</sub> aryl, 3-10 membered heterocyclyl, 5-10 membered heteroaryl; or two geminal R<sup>gg</sup>  
 substituents can be joined to form =O or =S; wherein X<sup>-</sup> is a counterion.

**[072]** As used herein, the term "halo" or "halogen" refers to fluorine (fluoro, -F), chlorine (chloro, -  
 Cl), bromine (bromo, -Br), or iodine (iodo, -I).

**[073]** As used herein, a “counterion” is a negatively charged group associated with a positively charged quarternary amine in order to maintain electronic neutrality. Exemplary counterions include halide ions (e.g., F<sup>-</sup>, Cl<sup>-</sup>, Br<sup>-</sup>, I<sup>-</sup>), NO<sub>3</sub><sup>-</sup>, ClO<sub>4</sub><sup>-</sup>, OH<sup>-</sup>, H<sub>2</sub>PO<sub>4</sub><sup>-</sup>, HSO<sub>4</sub><sup>-</sup>, sulfonate ions (e.g., methanesulfonate, trifluoromethanesulfonate, p-toluenesulfonate, benzenesulfonate, 10-camphor sulfonate, naphthalene-2-sulfonate, naphthalene-1-sulfonic acid-5-sulfonate, ethan-1-sulfonic acid-2-sulfonate, and the like), and carboxylate ions (e.g., acetate, ethanoate, propanoate, benzoate, glycerate, lactate, tartrate, glycolate, and the like).

**[074]** Nitrogen atoms can be substituted or unsubstituted as valency permits, and include primary, secondary, tertiary, and quarternary nitrogen atoms. Exemplary nitrogen atom substituents include, but are not limited to, hydrogen, -OH, -OR<sup>aa</sup>, -N(R<sup>cc</sup>)<sub>2</sub>, -CN, -C(=O)R<sup>aa</sup>, -C(=O)N(R<sup>cc</sup>)<sub>2</sub>, -CO<sub>2</sub>R<sup>aa</sup>, -SO<sub>2</sub>R<sup>aa</sup>, -C(=NR<sup>bb</sup>)R<sup>aa</sup>, -C(=NR<sup>cc</sup>)OR<sup>aa</sup>, -C(=NR<sup>cc</sup>)N(R<sup>cc</sup>)<sub>2</sub>, -SO<sub>2</sub>N(R<sup>cc</sup>)<sub>2</sub>, -SO<sub>2</sub>R<sup>cc</sup>, -SO<sub>2</sub>OR<sup>cc</sup>, -SOR<sup>aa</sup>, -C(=S)N(R<sup>cc</sup>)<sub>2</sub>, -C(=O)SR<sup>cc</sup>, -C(=S)SR<sup>cc</sup>, -P(=O)<sub>2</sub>R<sup>aa</sup>, -P(=O)(R<sup>aa</sup>)<sub>2</sub>, -P(=O)<sub>2</sub>N(R<sup>cc</sup>)<sub>2</sub>, -P(=O)(NR<sup>cc</sup>)<sub>2</sub>, C<sub>1</sub>-C<sub>50</sub> alkyl, C<sub>2</sub>-C<sub>50</sub> alkenyl, C<sub>2</sub>-C<sub>50</sub> alkynyl, C<sub>3</sub>-C<sub>10</sub> carbocyclyl, 3-14 membered heterocyclyl, C<sub>6</sub>-C<sub>14</sub> aryl, and 5-14 membered heteroaryl, or two R<sup>cc</sup> groups, together with the N atom to which they are attached, form a 3-14 membered heterocyclyl or 5-14 membered heteroaryl ring, wherein each alkyl, alkenyl, alkynyl, carbocyclyl, heterocyclyl, aryl, and heteroaryl is independently substituted with 0, 1, 2, 3, 4, or 5 R<sup>dd</sup> groups, and wherein R<sup>aa</sup>, R<sup>bb</sup>, R<sup>cc</sup> and R<sup>dd</sup> are as defined above.

**[075]** In certain embodiments, the substituent present on a nitrogen atom is a nitrogen protecting group (also referred to as an amino protecting group). Nitrogen protecting groups are well known in the art and include those described in detail in *Protecting Groups in Organic Synthesis*, T. W. Greene and P. G. M. Wuts, 3rd edition, John Wiley & Sons, 1999, incorporated herein by reference.

**[076]** For example, nitrogen protecting groups such as amide groups (e.g., -C(=O)R<sup>aa</sup>) include, but are not limited to, formamide, acetamide, chloroacetamide, trichloroacetamide, trifluoroacetamide, phenylacetamide, 3-phenylpropanamide, picolinamide, 3-pyridylcarboxamide, N-benzoylphenylalanyl derivative, benzamide, p-phenylbenzamide, o-nitrophenylacetamide, o-nitrophenoxyacetamide, acetoacetamide, (N'-dithiobenzoyloxyacylamino)acetamide, 3-(p-hydroxyphenyl)propanamide, 3-(o-nitrophenyl)propanamide, 2-methyl-2-(o-nitrophenoxy)propanamide, 2-methyl-2-(o-phenylazophenoxy)propanamide, 4-chlorobutanamide, 3-methyl-3-nitrobutanamide, o-nitrocinnamide, N-acetylmethionine derivative, o-nitrobenzamide and o-(benzoyloxymethyl)benzamide.

**[077]** Nitrogen protecting groups such as carbamate groups (e.g., -C(=O)OR<sup>aa</sup>) include, but are not limited to, methyl carbamate, ethyl carbamate, 9-fluorenylmethyl carbamate (Fmoc), 9-(2-sulfo)fluorenylmethyl carbamate, 9-(2,7-dibromo)fluorenylmethyl carbamate, 2,7-di-t-butyl-[9-(10,10-dioxo-10,10,10,10-tetrahydrothioxanthyl)]methyl carbamate (DBD-Tmoc), 4-

methoxyphenacyl carbamate (Phenoc), 2,2,2-trichloroethyl carbamate (Troc), 2-trimethylsilylethyl carbamate (Teoc), 2-phenylethyl carbamate (hZ), 1-(1-adamanty1)-1-methylethyl carbamate (Adpoc), 1,1-dimethyl-2-haloethyl carbamate, 1,1-dimethyl-2,2-dibromoethyl carbamate (DB-t-BOC), 1,1-dimethyl-2,2,2-trichloroethyl carbamate (TCBOC), 1-methyl-1-(4-biphenyl)ethyl carbamate (Bpoc), 1-(3,5-di-t-butylphenyl)-1-methylethyl carbamate (t-Bumeoc), 2-(2'-and 4'-pyridyl)ethyl carbamate (Pyoc), 2-(N,N-dicyclohexylcarboxamido)ethyl carbamate, t-butyl carbamate (BOC), 1-adamantyl carbamate (Adoc), vinyl carbamate (Voc), allyl carbamate (Alloc), 1-isopropylallyl carbamate (Ipaoc), cinnamyl carbamate (Coc), 4-nitrocinnamyl carbamate (Noc), 8-quinolyl carbamate, N-hydroxypiperidinyl carbamate, alkyldithio carbamate, benzyl carbamate (Cbz), p-methoxybenzyl carbamate (Moz), p-nitobenzyl carbamate, p-bromobenzyl carbamate, p-chlorobenzyl carbamate, 2,4-dichlorobenzyl carbamate, 4-methylsulfinylbenzyl carbamate (MsZ), 9-anthrylmethyl carbamate, diphenylmethyl carbamate, 2-methylthioethyl carbamate, 2-methylsulfonylethyl carbamate, 2-(p-toluenesulfonyl)ethyl carbamate, [2-(1,3-dithianyl)]methyl carbamate (Dmoc), 4-methylthiophenyl carbamate (Mtpc), 2,4-dimethylthiophenyl carbamate (Bmpc), 2-phosphonioethyl carbamate (Peoc), 2-triphenylphosphonioisopropyl carbamate (Ppoc), 1,1-dimethyl-2-cyanoethyl carbamate, m-chloro-p-acyloxybenzyl carbamate, p-(dihydroxyboryl)benzyl carbamate, 5-benzisoxazolymethyl carbamate, 2-(trifluoromethyl)-6-chromonylmethyl carbamate (Tcroc), m-nitrophenyl carbamate, 3,5-dimethoxybenzyl carbamate, o-nitrobenzyl carbamate, 3,4-dimethoxy-6-nitrobenzyl carbamate, phenyl(o-nitrophenyl)methyl carbamate, t-amyl carbamate, S-benzyl thiocarbamate, p-cyanobenzyl carbamate, cyclobutyl carbamate, cyclohexyl carbamate, cyclopentyl carbamate, cyclopropylmethyl carbamate, p-decyloxybenzyl carbamate, 2,2-dimethoxyacylvinyl carbamate, o-(N,N-dimethylcarboxamido)benzyl carbamate, 1,1-dimethyl-3-(N,N-dimethylcarboxamido)propyl carbamate, 1,1-dimethylpropynyl carbamate, di(2-pyridyl)methyl carbamate, 2-furanylmethyl carbamate, 2-iodoethyl carbamate, isoborynl carbamate, isobutyl carbamate, isonicotinyll carbamate, p-(p'-methoxyphenylazo)benzyl carbamate, 1-methylcyclobutyl carbamate, 1-methylcyclohexyl carbamate, 1-methyl-l-cyclopropylmethyl carbamate, 1-methyl-1(3,5-dimethoxyphenyl)ethyl carbamate, 1-methyl-1-(p-phenylazophenyl)ethyl carbamate, 1-methyl-l-phenylethyl carbamate, 1-methyl-1-(4-pyridyl)ethyl carbamate, phenyl carbamate, p-(phenylazo)benzyl carbamate, 2,4,6-tri-t-butylphenyl carbamate, 4-(trimethylammonium)benzyl carbamate, and 2,4,6-trimethylbenzyl carbamate.

**[078]** Nitrogen protecting groups such as sulfonamide groups (e.g., -S(=O)<sub>2</sub>R<sup>aa</sup>) include, but are not limited to, p-toluenesulfonamide (Ts), benzenesulfonamide, 2,3,6-trimethyl-4-methoxybenzenesulfonamide (Mtr), 2,4,6-trimethoxybenzenesulfonamide (Mtb), 2,6-dimethyl-4-methoxybenzenesulfonamide (Pme), 2,3,5,6-tetramethyl-4-methoxybenzenesulfonamide (Mte), 4-

methoxybenzenesulfonamide (Mbs), 2,4,6-trimethylbenzenesulfonamide (Mts), 2,6-dimethoxy-4-methylbenzenesulfonamide (iMds), 2,2,5,7,8-pentamethylchroman-6-sulfonamide (Pmc), methanesulfonamide (Ms),  $\beta$ -trimethylsilylethanesulfonamide (SES), 9-anthracenesulfonamide, 4-(4',8'-dimethoxynaphthylmethyl)benzenesulfonamide (DNMBS), benzylsulfonamide, trifluoromethylsulfonamide, and phenacylsulfonamide.

**[079]** Other nitrogen protecting groups include, but are not limited to, phenothiazinyl-(10)-acyl derivative, N'-p-toluenesulfonylaminoacyl derivative, N'-phenylaminothioacyl derivative, N-benzoylphenylalanyl derivative, N-acetylmethionine derivative, 4,5-diphenyl-3-oxazolin-2-one, N-phthalimide, N-dithiasuccinimide (Dts), N-2,3-diphenylmaleimide, N-2,5-dimethylpyrrole, N-1,1,4,4-tetramethyldisilylazacyclopentane adduct (STABASE), 5-substituted 1,3-dimethyl-1,3,5-triazacyclohexan-2-one, 5-substituted 1,3-dibenzyl-1,3,5-triazacyclohexan-2-one, 1-substituted 3,5-dinitro-4-pyridone, N-methylamine, N-allylamine, N-[2-(trimethylsilyl)ethoxy]methylamine (SEM), N-3-acetoxypropylamine, N-(1-isopropyl-4-nitro-2-oxo-3-pyrroline-3-yl)amine, quaternary ammonium salts, N-benzylamine, N-di(4-methoxyphenyl)methylamine, N-5-dibenzosuberonylamine, N-triphenylmethylamine (Tr), N-[(4-methoxyphenyl)diphenylmethyl]amine (MMTr), N-9-phenylfluorenylamine (PhF), N-2,7-dichloro-9-fluorenylmethyleneamine, N-ferrocenylmethylamino (Fcm), N-2-picolylamino N'-oxide, N-1,1-dimethylthiomethyleneamine, N-benzylideneamine, N-p-methoxybenzylideneamine, N-diphenylmethyleneamine, N-[(2-pyridyl)mesityl]methyleneamine, N-(N',N'-dimethylaminomethylene)amine, N,N'-isopropylidenediamine, N-p-nitrobenzylideneamine, N-salicylideneamine, N-5-chlorosalicylideneamine, N-(5-chloro-2-hydroxyphenyl)phenylmethyleneamine, N-cyclohexylideneamine, N-(5,5-dimethyl-3-oxo-1-cyclohexenyl)amine, N-borane derivative, N-diphenylborinic acid derivative, N-[phenyl(pentaacylchromium- or tungsten)acyl]amine, N-copper chelate, N-zinc chelate, N-nitroamine, N-nitrosoamine, amine N-oxide, diphenylphosphinamide (Dpp), dimethylthiophosphinamide (Mpt), diphenylthiophosphinamide (Ppt), dialkyl phosphoramidates, dibenzyl phosphoramidate, diphenyl phosphoramidate, benzenesulfenamide, o-nitrobenzenesulfenamide (Nps), 2,4-dinitrobenzenesulfenamide, pentachlorobenzenesulfenamide, 2-nitro-4-methoxybenzenesulfenamide, triphenylmethylsulfenamide, and 3-nitropyridinesulfenamide (Npys).

**[080]** In certain embodiments, the substituent present on an oxygen atom is an oxygen protecting group (also referred to as a hydroxyl protecting group). Oxygen protecting groups are well known in the art and include those described in detail in *Protecting Groups in Organic Synthesis*, T. W. Greene and P. G. M. Wuts, 3rd edition, John Wiley & Sons, 1999, incorporated herein by reference.

[081] Exemplary oxygen protecting groups include, but are not limited to, methyl, methoxymethyl (MOM), methylthiomethyl (MTM), t-butylthiomethyl, (phenyldimethylsilyl)methoxymethyl (SMOM), benzyloxymethyl (BOM), p-methoxybenzyloxymethyl (PMBM), (4-methoxyphenoxy)methyl (p-AOM), guaiacolmethyl (GUM), t-butoxymethyl, 4-pentenylloxymethyl (POM), siloxymethyl, 2-methoxyethoxymethyl (MEM), 2,2,2-trichloroethoxymethyl, bis(2-chloroethoxy)methyl, 2-(trimethylsilyl)ethoxymethyl (SEMOR), tetrahydropyranyl (THP), 3-bromotetrahydropyranyl, tetrahydrothiopyranyl, 1-methoxycyclohexyl, 4-methoxytetrahydropyranyl (MTHP), 4-methoxytetrahydrothiopyranyl, 4-methoxytetrahydrothiopyranyl S,S-dioxide, 1-[(2-chloro-4-methyl)phenyl]-4-methoxypiperidin-4-yl (CTMP), 1,4-dioxan-2-yl, tetrahydrofuran-2-yl, tetrahydrothiofuran-2-yl, 2,3,3a,4,5,6,7,7a-octahydro-7,8,8-trimethyl-4,7-methanobenzofuran-2-yl, 1-ethoxyethyl, 1-(2-chloroethoxy)ethyl, 1-methyl-1-methoxyethyl, 1-methyl-1-benzyloxyethyl, 1-methyl-1-benzyloxy-2-fluoroethyl, 2,2,2-trichloroethyl, 2-trimethylsilylethyl, 2-(phenylselenyl)ethyl, t-butyl, allyl, p-chlorophenyl, p-methoxyphenyl, 2,4-dinitrophenyl, benzyl (Bn), p-methoxybenzyl, 3,4-dimethoxybenzyl, o-nitrobenzyl, p-nitrobenzyl, p-halobenzyl, 2,6-dichlorobenzyl, p-cyanobenzyl, p-phenylbenzyl, 2-picolyl, 4-picolyl, 3-methyl-2-picolyl N-oxido, diphenylmethyl, p,p'-dinitrobenzhydryl, 5-dibenzosuberonyl, triphenylmethyl,  $\alpha$ -naphthylidiphenylmethyl, p-methoxyphenyldiphenylmethyl, di(p-methoxyphenyl)phenylmethyl, tri(p-methoxyphenyl)methyl, 4-(4'-bromophenoxy)phenyldiphenylmethyl, 4,4',4''-tris(4,5-dichlorophthalimidophenyl)methyl, 4,4',4''-tris(levulinoyloxyphenyl)methyl, 4,4',4''-tris(benzoyloxyphenyl)methyl, 3-(imidazol-1-yl)bis(4',4''-dimethoxyphenyl)methyl, 1,1-bis(4-methoxyphenyl)-1'-pyrenylmethyl, 9-anthryl, 9-(9-phenyl)xanthenyl, 9-(9-phenyl-10-oxo)anthryl, 1,3-benzodisulfuran-2-yl, benzoisothiazolyl S,S-dioxido, trimethylsilyl (TMS), triethylsilyl (TES), triisopropylsilyl (TIPS), dimethylisopropylsilyl (IPDMS), diethylisopropylsilyl (DEIPS), dimethylhexylsilyl, t-butyl dimethylsilyl (TBDMS), t-butyl diphenylsilyl (TBDPS), tribenzylsilyl, tri-p-xylylsilyl, triphenylsilyl, diphenylmethylsilyl (DPMS), t-butylmethoxyphenylsilyl (TBMPS), formate, benzoylformate, acetate, chloroacetate, dichloroacetate, trichloroacetate, trifluoroacetate, methoxyacetate, triphenylmethoxyacetate, phenoxyacetate, p-chlorophenoxyacetate, 3-phenylpropionate, 4-oxopentanoate (levulinate), 4,4-(ethylenedithio)pentanoate (levulinoyldithioacetal), pivaloate, adamantate, crotonate, 4-methoxycrotonate, benzoate, p-phenylbenzoate, 2,4,6-trimethylbenzoate (mesitoate), alkyl methyl carbonate, 9-fluorenylmethyl carbonate (Fmoc), alkyl ethyl carbonate, alkyl 2,2,2-trichloroethyl carbonate (Troc), 2-(trimethylsilyl)ethyl carbonate (TMSEC), 2-(phenylsulfonyl)ethyl carbonate (Psec), 2-(triphenylphosphonio)ethyl carbonate (Peoc), alkyl isobutyl carbonate, alkyl vinyl carbonate, alkyl allyl carbonate, alkyl p-nitrophenyl carbonate, alkyl benzyl carbonate, alkyl p-methoxybenzyl carbonate, alkyl 3,4-dimethoxybenzyl carbonate, alkyl o-nitrobenzyl carbonate, alkyl

p-nitrobenzyl carbonate, alkyl S-benzyl thiocarbonate, 4-ethoxy-1-naphthyl carbonate, methyl dithiocarbonate, 2-iodobenzoate, 4-azidobutyrate, 4-nitro-4-methylpentanoate, o-(dibromomethyl)benzoate, 2-formylbenzenesulfonate, 2-(methylthiomethoxy)ethyl, 4-(methylthiomethoxy)butyrate, 2-(methylthiomethoxymethyl)benzoate, 2,6-dichloro-4-methylphenoxyacetate, 2,6-dichloro-4-(1,1,3,3-tetramethylbutyl)phenoxyacetate, 2,4-bis(1,1-dimethylpropyl)phenoxyacetate, chlorodiphenylacetate, isobutyrate, monosuccinoate, (E)-2-methyl-2-butenate, o-(methoxyacyl)benzoate,  $\alpha$ -naphthoate, nitrate, alkyl N,N,N',N'-tetramethylphosphorodiamidate, alkyl N-phenylcarbamate, borate, dimethylphosphinothioyl, alkyl 2,4-dinitrophenylsulfenate, sulfate, methanesulfonate (mesylate), benzylation, and tosylate (Ts).

**[082]** In certain embodiments, the substituent present on a sulfur atom is a sulfur protecting group (also referred to as a thiol protecting group). Sulfur protecting groups are well known in the art and include those described in detail in *Protecting Groups in Organic Synthesis*, T. W. Greene and P. G. M. Wuts, 3rd edition, John Wiley & Sons, 1999, incorporated herein by reference.

**[083]** Exemplary sulfur protecting groups include, but are not limited to, alkyl, benzyl, p-methoxybenzyl, 2,4,6-trimethylbenzyl, 2,4,6-trimethoxybenzyl, o-hydroxybenzyl, p-hydroxybenzyl, o-acetoxybenzyl, p-acetoxybenzyl, p-nitrobenzyl, 4-picolyl, 2-quinolinylmethyl, 2-picolyl N-oxido, 9-anthrylmethyl, 9-fluorenylmethyl, xanthenyl, ferrocenylmethyl, diphenylmethyl, bis(4-methoxyphenyl)methyl, 5-dibenzosuberonyl, triphenylmethyl, diphenyl-4-pyridylmethyl, phenyl, 2,4-dinitrophenyl, t-butyl, 1-adamantyl, methoxymethyl (MOM), isobutoxymethyl, benzyloxymethyl, 2-tetrahydropyranyl, benzylthiomethyl, phenylthiomethyl, thiazolidino, acetamidomethyl, trimethylacetamidomethyl, benzamidomethyl, allyloxycarbonylaminomethyl, phenylacetamidomethyl, phthalimidomethyl, acetylmethyl, carboxymethyl, cyanomethyl, (2-nitro-1-phenyl)ethyl, 2-(2,4-dinitrophenyl)ethyl, 2-cyanoethyl, 2-(Trimethylsilyl)ethyl, 2,2-bis(carboethoxy)ethyl, (1-m-nitrophenyl-2-benzoyl)ethyl, 2-phenylsulfonyl, 2-(4-methylphenylsulfonyl)-2-methylprop-2-yl, acetyl, benzoyl, trifluoroacetyl, N-[[[p-biphenyl]isopropoxy]carbonyl]-N-methyl]- $\gamma$ -aminothiobutyrate, 2,2,2-trichloroethoxycarbonyl, t-butoxycarbonyl, benzyloxycarbonyl, p-methoxybenzyloxycarbonyl, N-ethyl, N-methoxymethyl, sulfonate, sulfenylthiocarbonate, 3-nitro-2-pyridinesulfonyl sulfide, oxathiolone.

### ***Compounds of the Invention***

**[084]** Liposomal-based vehicles are considered an attractive carrier for therapeutic agents and remain subject to continued development efforts. While liposomal-based vehicles that comprise certain lipid components have shown promising results with regard to encapsulation, stability and site localization, there remains a great need for improvement of liposomal-based delivery systems.

For example, a significant drawback of liposomal delivery systems relates to the construction of liposomes that have sufficient cell culture or *in vivo* stability to reach desired target cells and/or intracellular compartments, and the ability of such liposomal delivery systems to efficiently release their encapsulated materials to such target cells.

**[085]** In particular, there remains a need for improved lipids compounds that demonstrate improved pharmacokinetic properties and which are capable of delivering macromolecules, such as nucleic acids, to a wide variety cell types and tissues with enhanced efficiency. Importantly, there also remains a particular need for novel lipid compounds that are characterized as having reduced toxicity and are capable of efficiently delivering encapsulated nucleic acids and polynucleotides to targeted cells, tissues and organs.

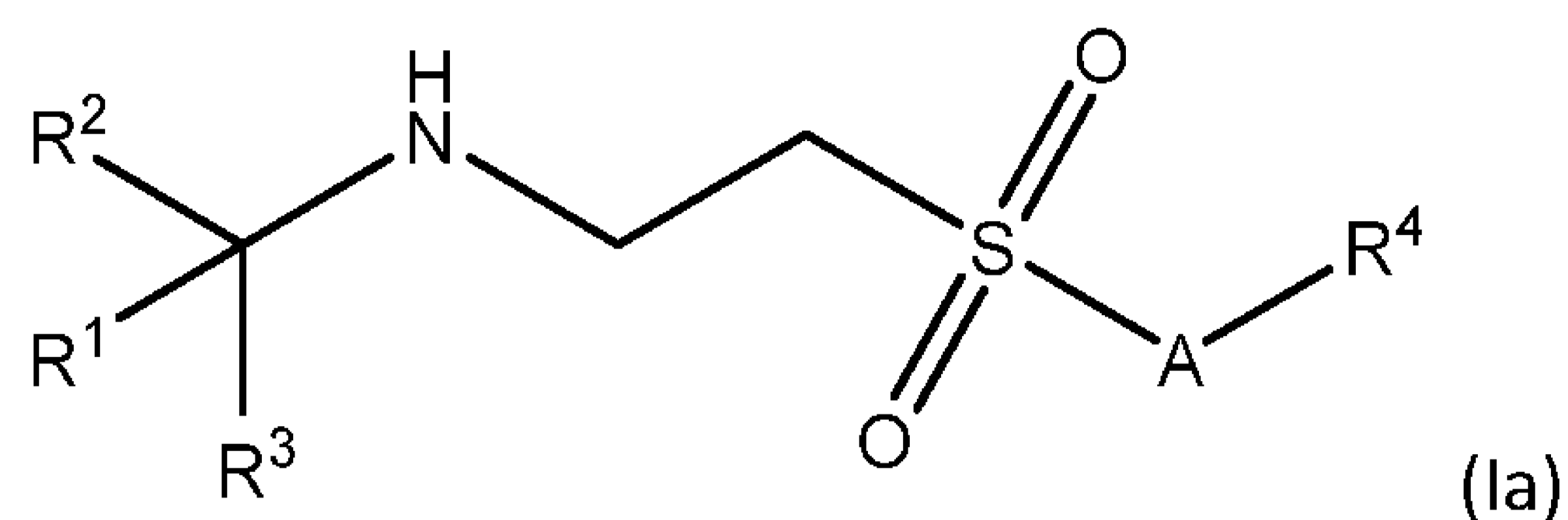
**[086]** Described herein a novel class of cationic lipid compounds for improved *in vivo* delivery of therapeutic agents, such as nucleic acids. In particular, a cationic lipid described herein may be used, optionally with other lipids, to formulate a lipid-based nanoparticle (*e.g.*, liposome) for encapsulating therapeutic agents, such as nucleic acids (*e.g.*, DNA, siRNA, mRNA, microRNA) for therapeutic use.

**[087]** In embodiments, compounds of the invention as described herein can provide one or more desired characteristics or properties. That is, in certain embodiments, compounds of the invention as described herein can be characterized as having one or more properties that afford such compounds advantages relative to other similarly classified lipids. For example, compounds disclosed herein can allow for the control and tailoring of the properties of liposomal compositions (*e.g.*, lipid nanoparticles) of which they are a component. In particular, compounds disclosed herein can be characterized by enhanced transfection efficiencies and their ability to provoke specific biological outcomes. Such outcomes can include, for example enhanced cellular uptake, endosomal/lysosomal disruption capabilities and/or promoting the release of encapsulated materials (*e.g.*, polynucleotides) intracellularly. Additionally, the compounds disclosed herein have advantageous pharmacokinetic properties, biodistribution, and efficiency (*e.g.*, due to the different disassociate rates of the polymer group used).

**[088]** The present application demonstrates that not only are the cationic lipids of the present invention synthetically tractable from readily available starting materials, but they also have unexpectedly high encapsulation efficiencies.

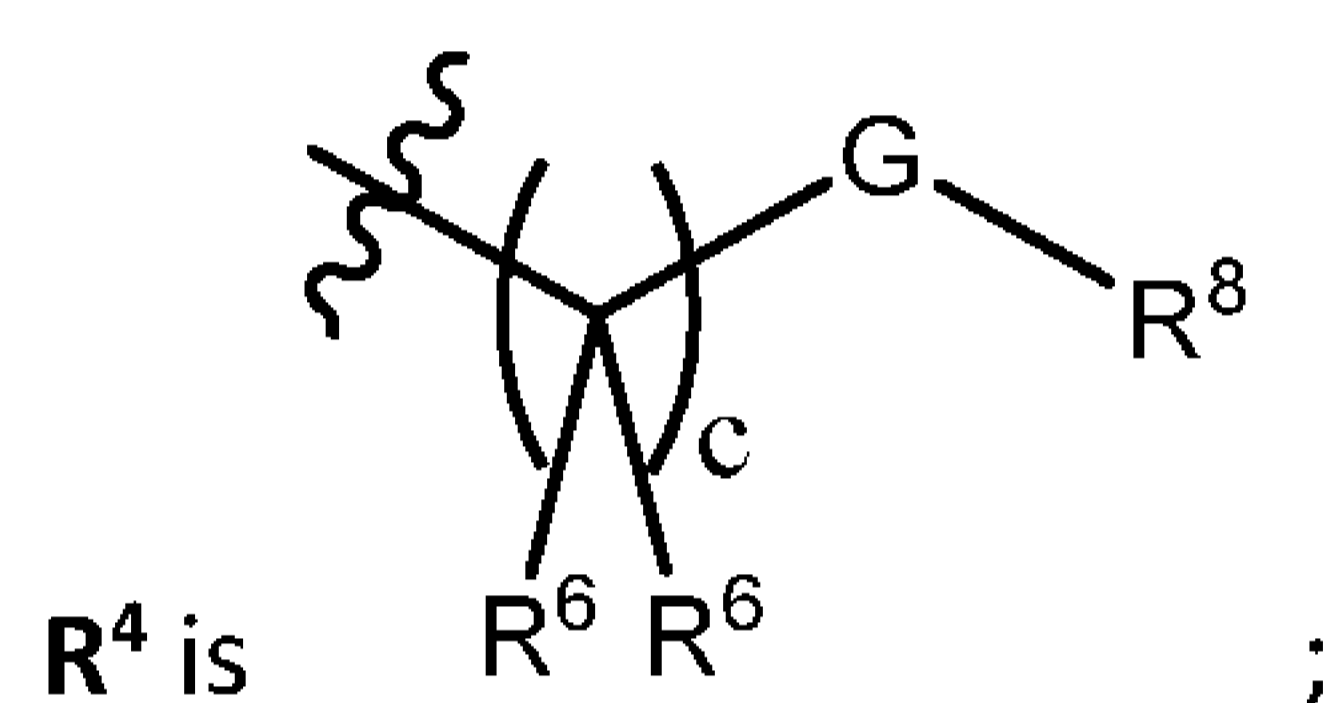
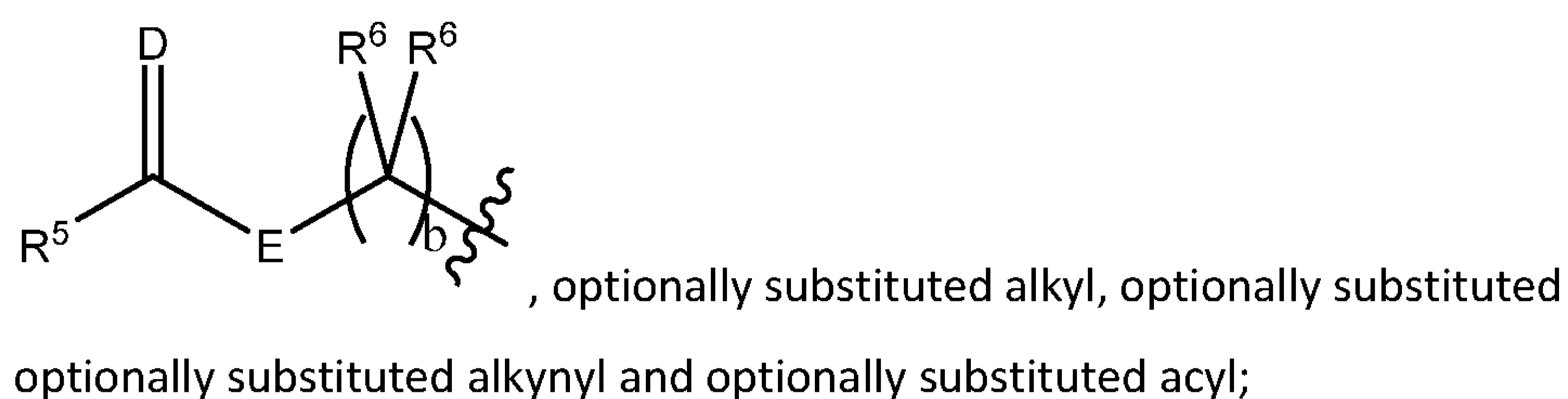
**[089]** Additionally, the cationic lipids of the present invention have cleavable groups such as ester groups and disulphides. These cleavable groups (*e.g.* esters and disulphides) are contemplated to improve biodegradability and thus contribute to their favorable toxicity profile.

[090] Provided herein are compounds which are cationic lipids. For example, the cationic lipids of the present invention include compounds having a structure according to Formula (Ia):



or a pharmaceutically acceptable salt thereof, wherein

$R^1$ ,  $R^2$  and  $R^3$  are each independently selected from:



each  $R^5$  is independently selected from optionally substituted alkyl, optionally substituted alkenyl and optionally substituted alkynyl;

each  $R^6$  is independently selected from hydrogen, halogen, optionally substituted  $C_1$ - $C_6$  alkyl, and optionally substituted  $C_2$ - $C_6$  alkenyl;

**A** is  $-NR^9-$  or  $-O-$ ;

**D** is O or S;

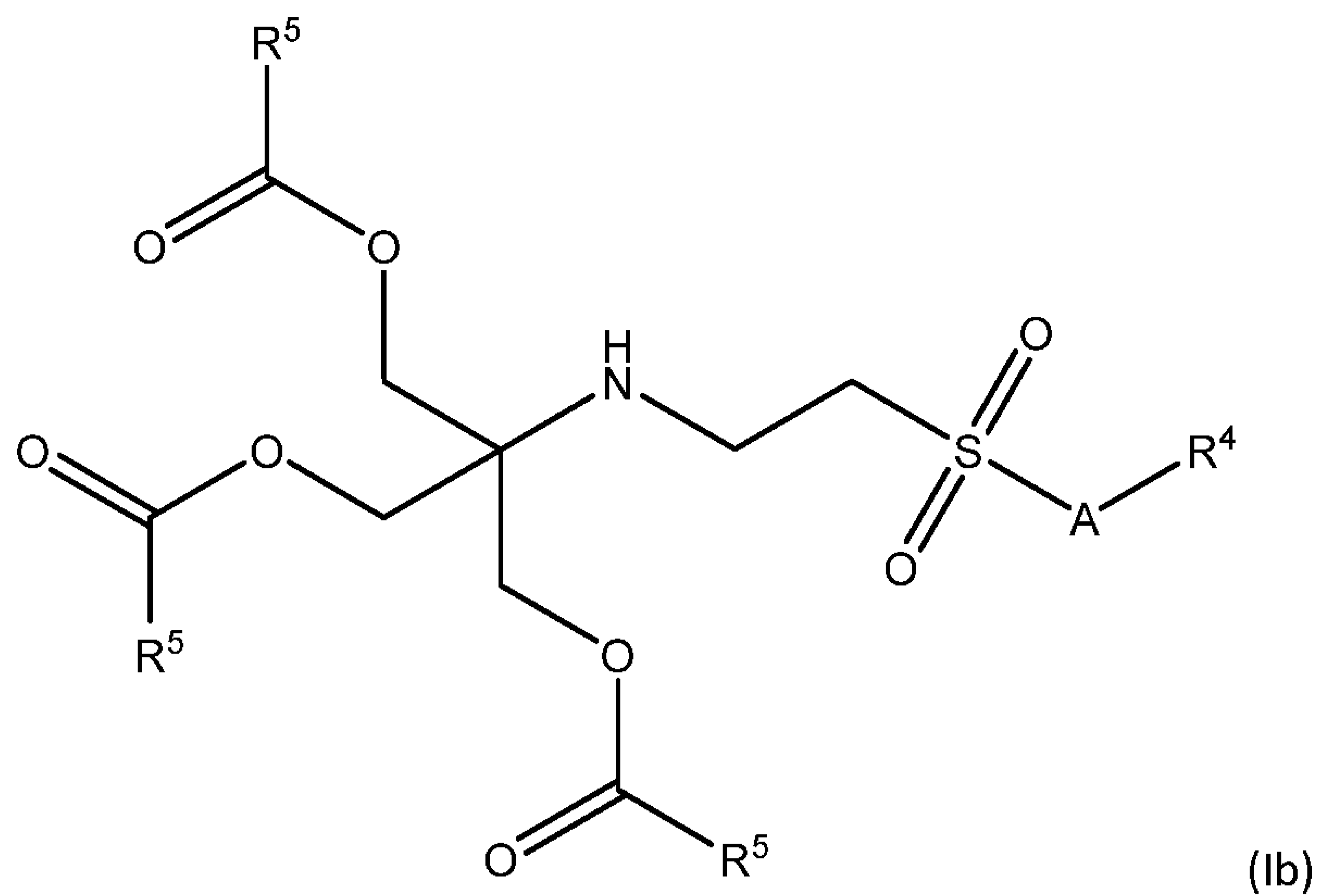
**E** and **G** are each independently selected from  $-NR^{10}-$ ,  $-O-$  and  $-S-$ ;

$R^8$ ,  $R^9$ , and  $R^{10}$  are each independently selected from hydrogen, optionally substituted  $C_1$ - $C_6$  alkyl and optionally substituted  $C_2$ - $C_6$  alkenyl;

each **b** is independently selected from 0, 1, 2, 3, 4, 5, 6, 7, 8, 9 and 10; and

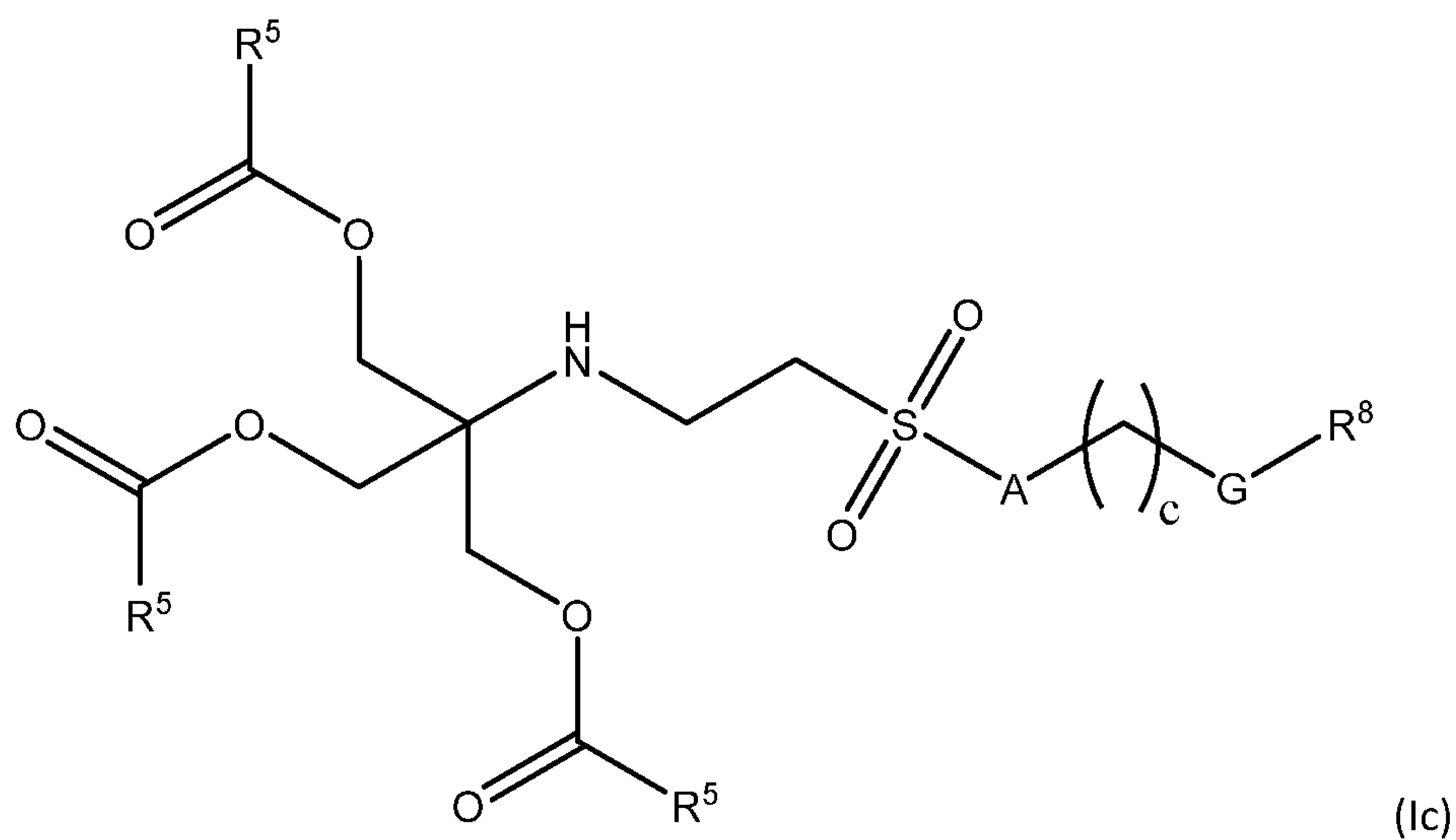
each **c** is independently selected from 1, 2, 3, 4, 5, 6, 7, 8, 9 and 10.

[091] In embodiments, the cationic lipids of the present invention include compounds having a structure according to Formula (Ib):



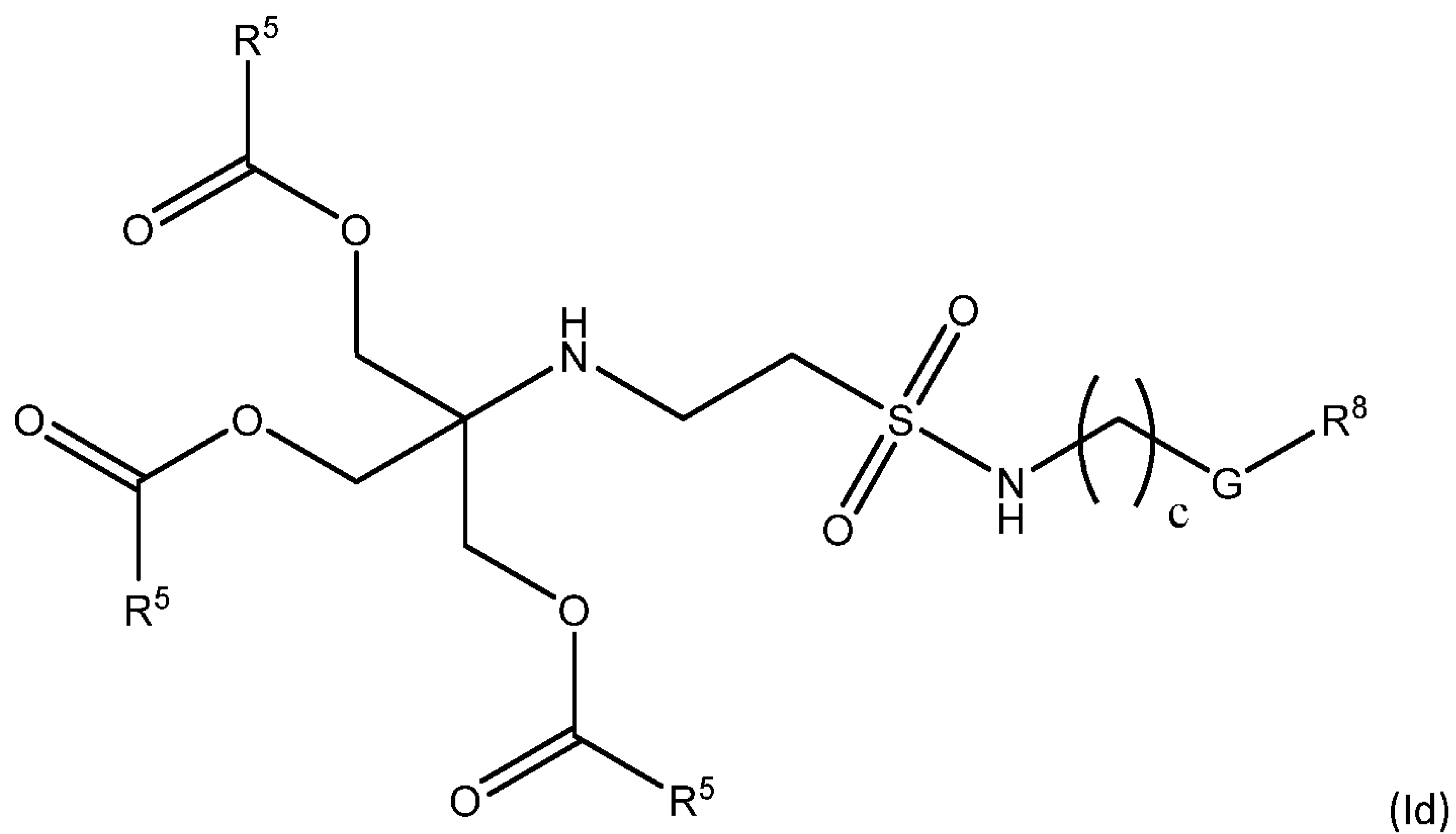
or a pharmaceutically acceptable salt thereof, wherein  $R^5$ , A and  $R^4$  are as defined in Formula (Ia).

[092] In embodiments, the cationic lipids of the present invention include compounds having a structure according to Formula (Ic):



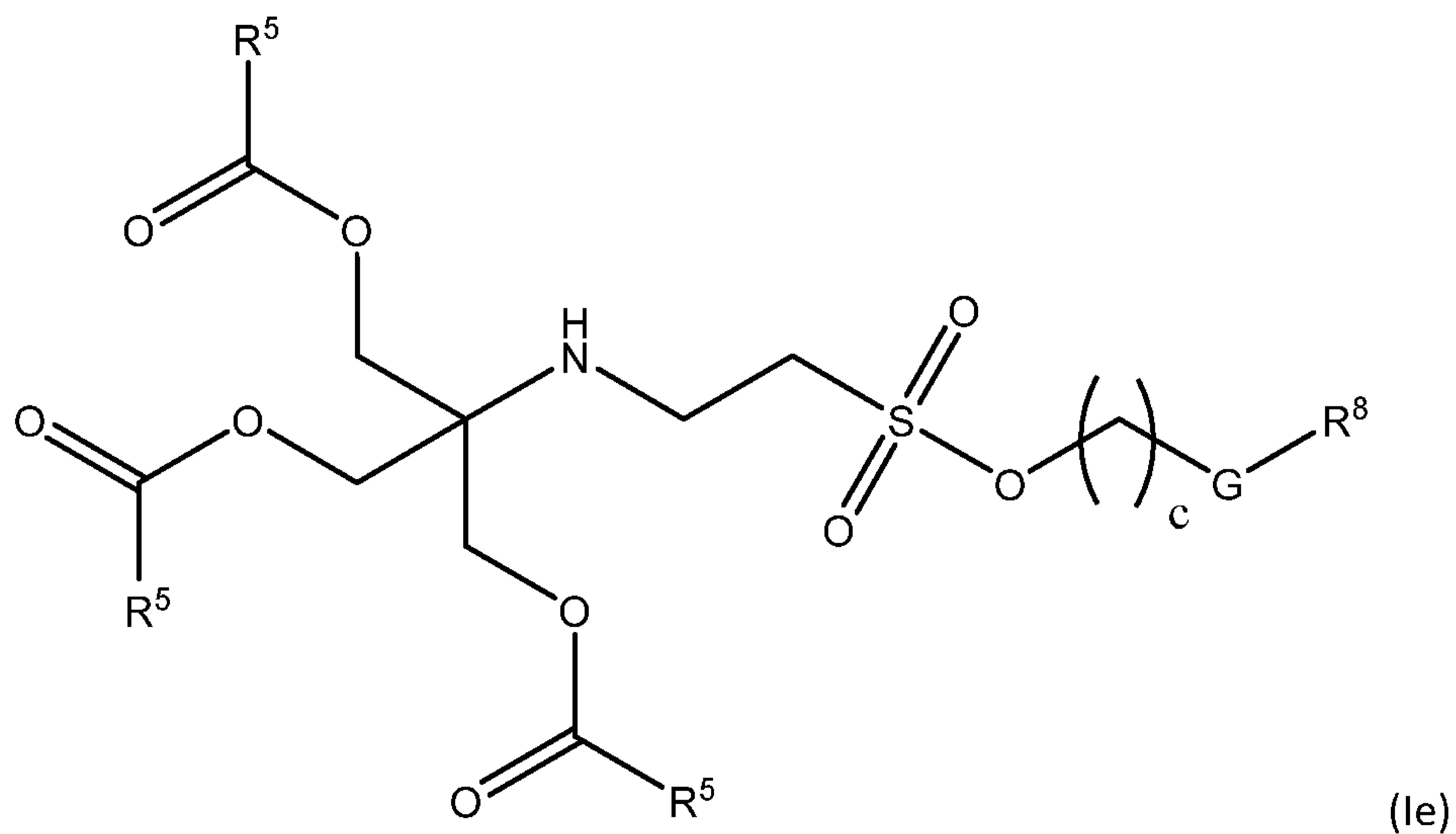
or a pharmaceutically acceptable salt thereof, wherein  $R^5$ , A, c, G and  $R^8$  are as defined in Formula (Ia).

[093] In embodiments, the cationic lipids of the present invention include compounds having a structure according to Formula (Id):



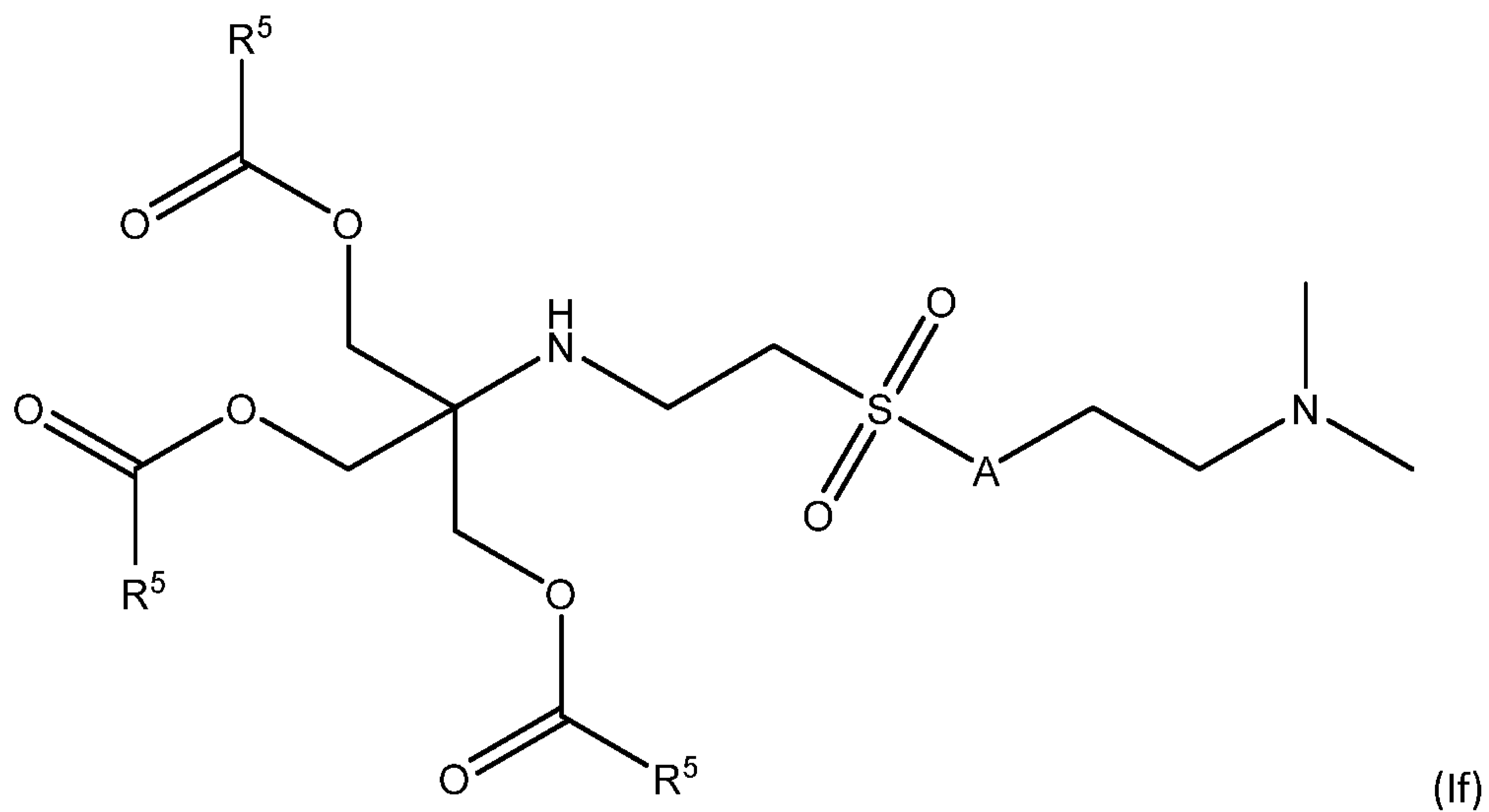
or a pharmaceutically acceptable salt thereof, wherein  $R^5$ ,  $c$ ,  $G$  and  $R^8$  are as defined in Formula (Ia).

[094] In embodiments, the cationic lipids of the present invention include compounds having a structure according to Formula (Ie):



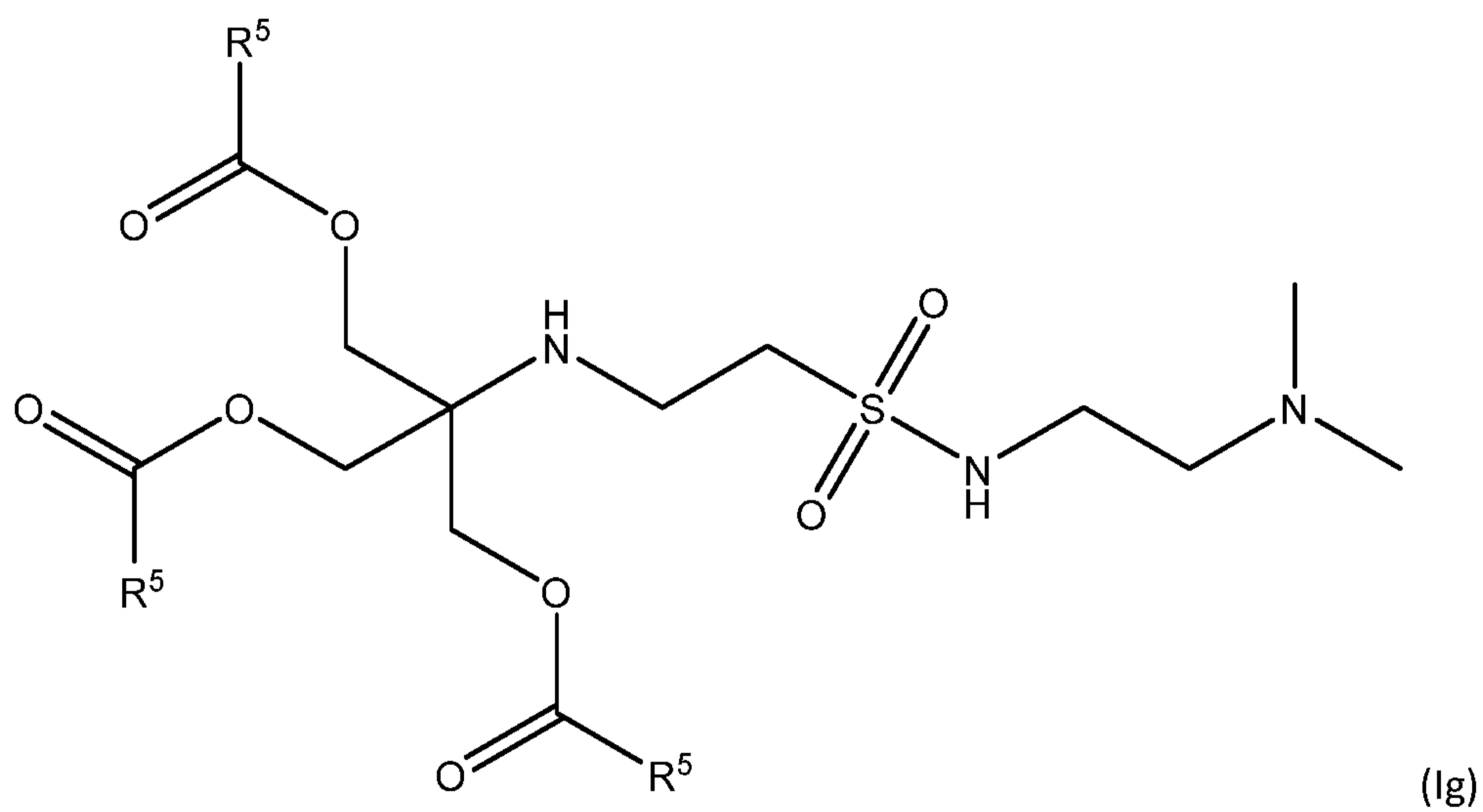
or a pharmaceutically acceptable salt thereof, wherein  $R^5$ ,  $c$ ,  $G$  and  $R^8$  are as defined in Formula (Ia).

[095] In embodiments, the cationic lipids of the present invention include compounds having a structure according to Formula (If):



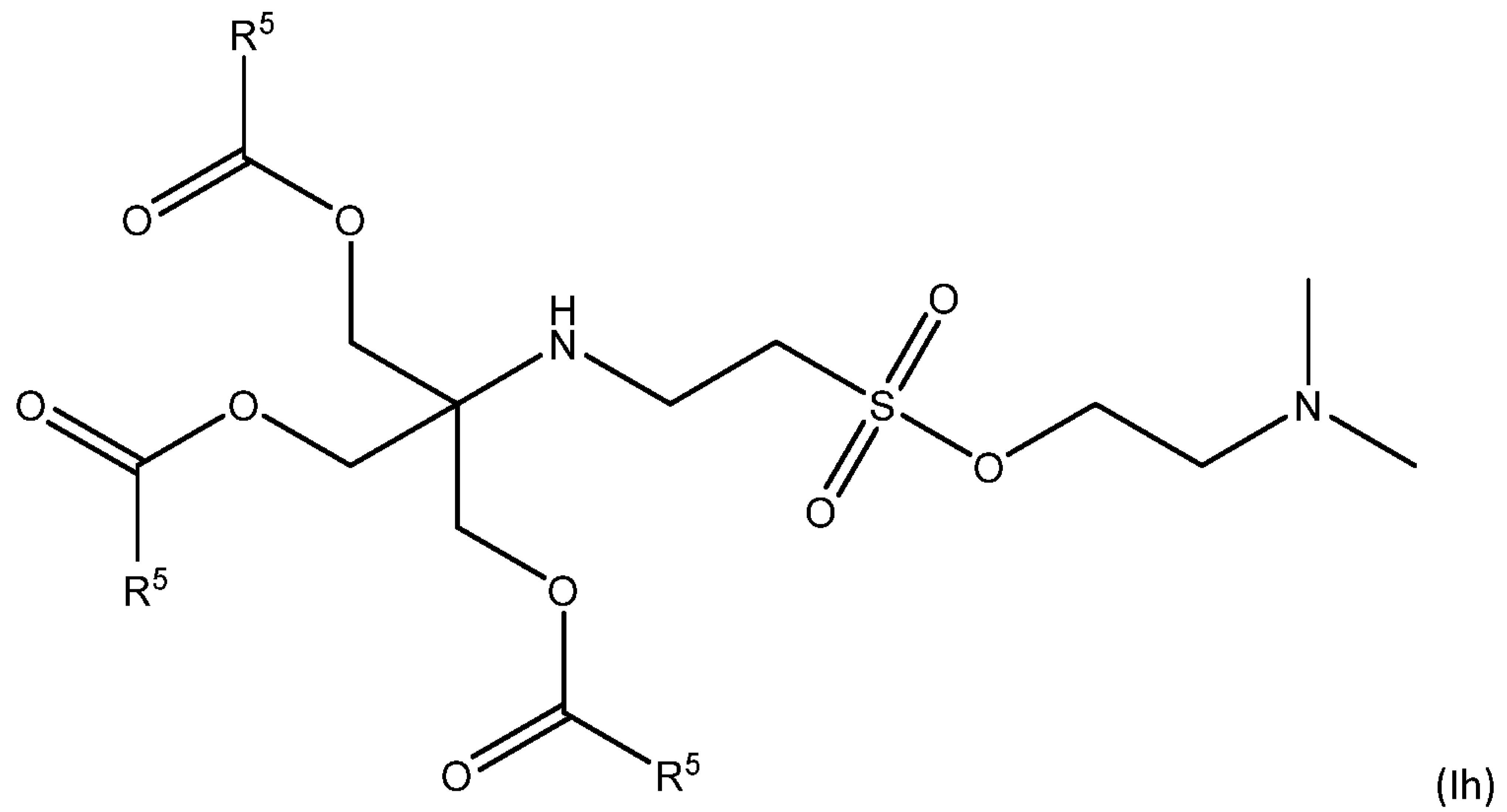
or a pharmaceutically acceptable salt thereof, wherein R<sup>5</sup> and A are as defined in Formula (Ia).

[096] In embodiments, the cationic lipids of the present invention include compounds having a structure according to Formula (Ig):



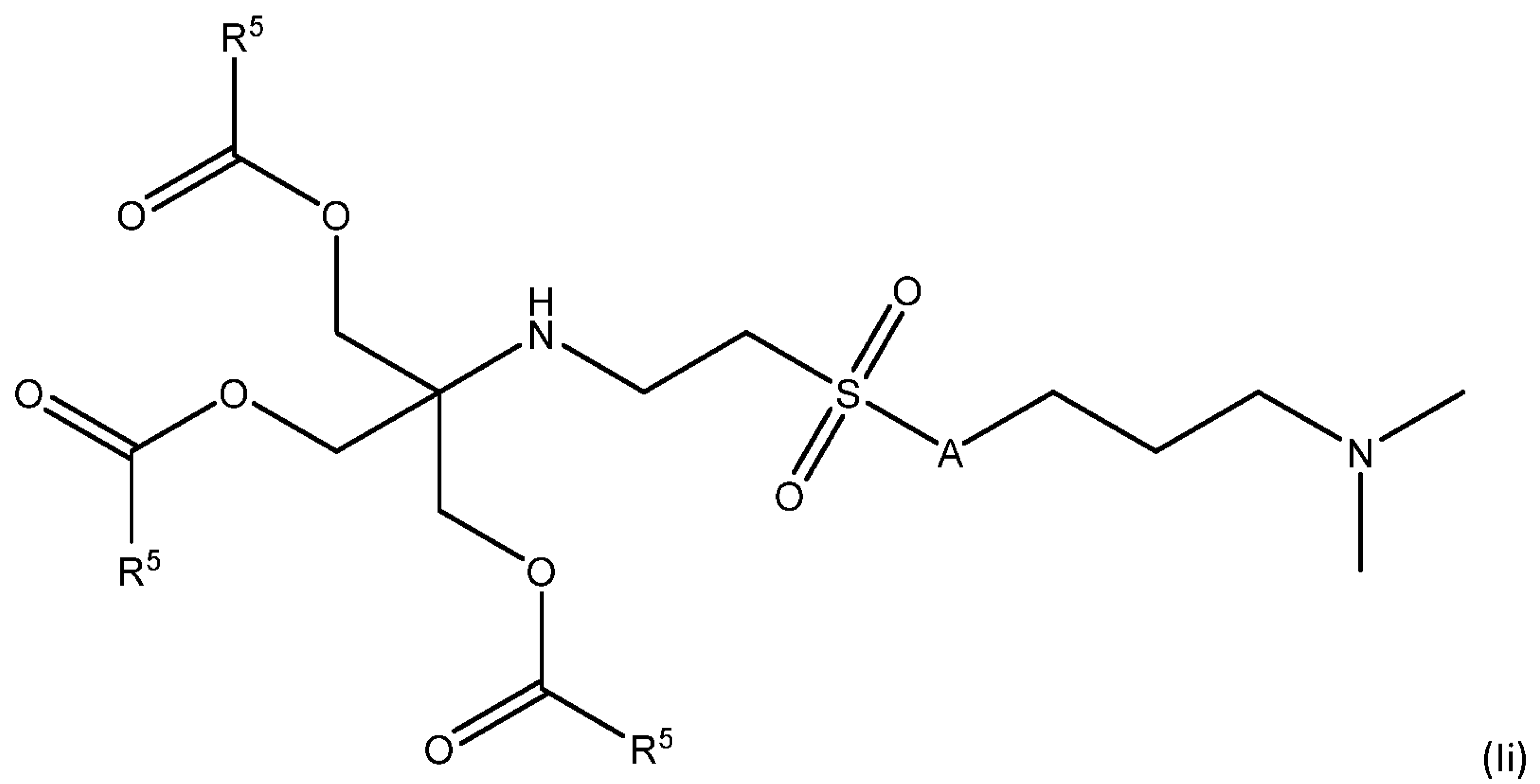
or a pharmaceutically acceptable salt thereof, wherein R<sup>5</sup> is as defined in Formula (Ia).

[097] In embodiments, the cationic lipids of the present invention include compounds having a structure according to Formula (Ih):



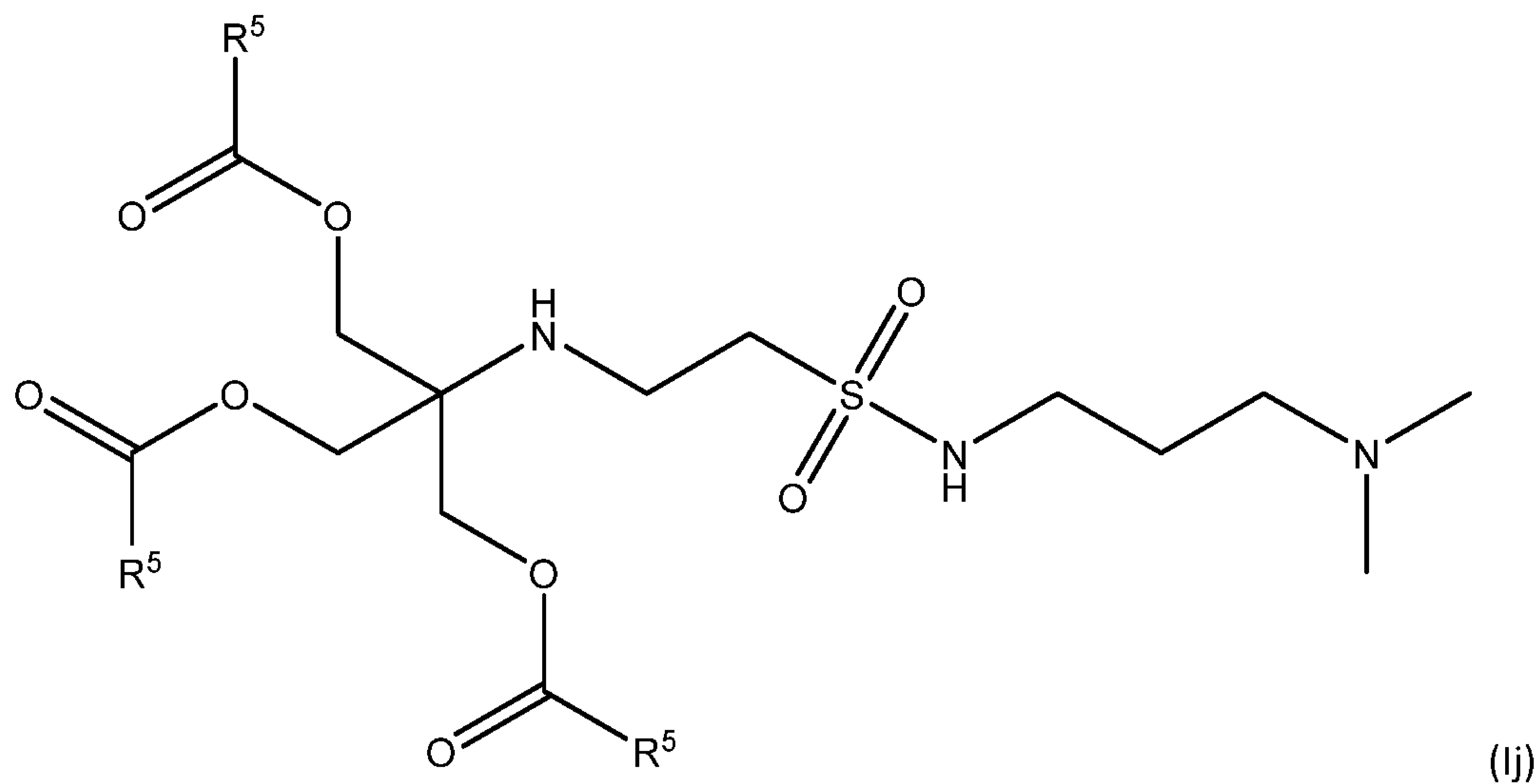
or a pharmaceutically acceptable salt thereof, wherein R<sup>5</sup> is as defined in Formula (Ia).

[098] In embodiments, the cationic lipids of the present invention include compounds having a structure according to Formula (Ii):



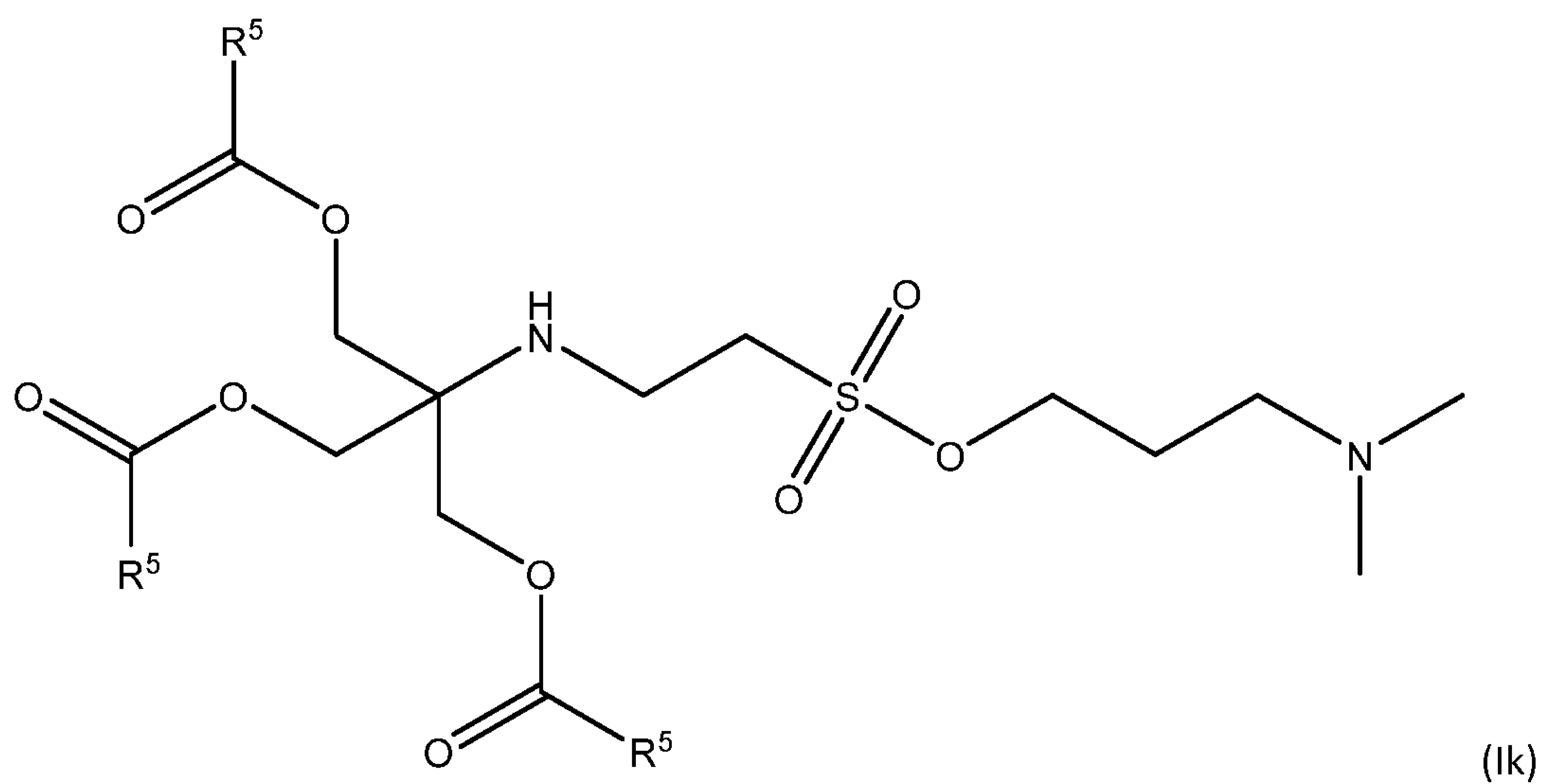
or a pharmaceutically acceptable salt thereof, wherein R<sup>5</sup> and A are as defined in Formula (Ia).

[099] In embodiments, the cationic lipids of the present invention include compounds having a structure according to Formula (Ij):



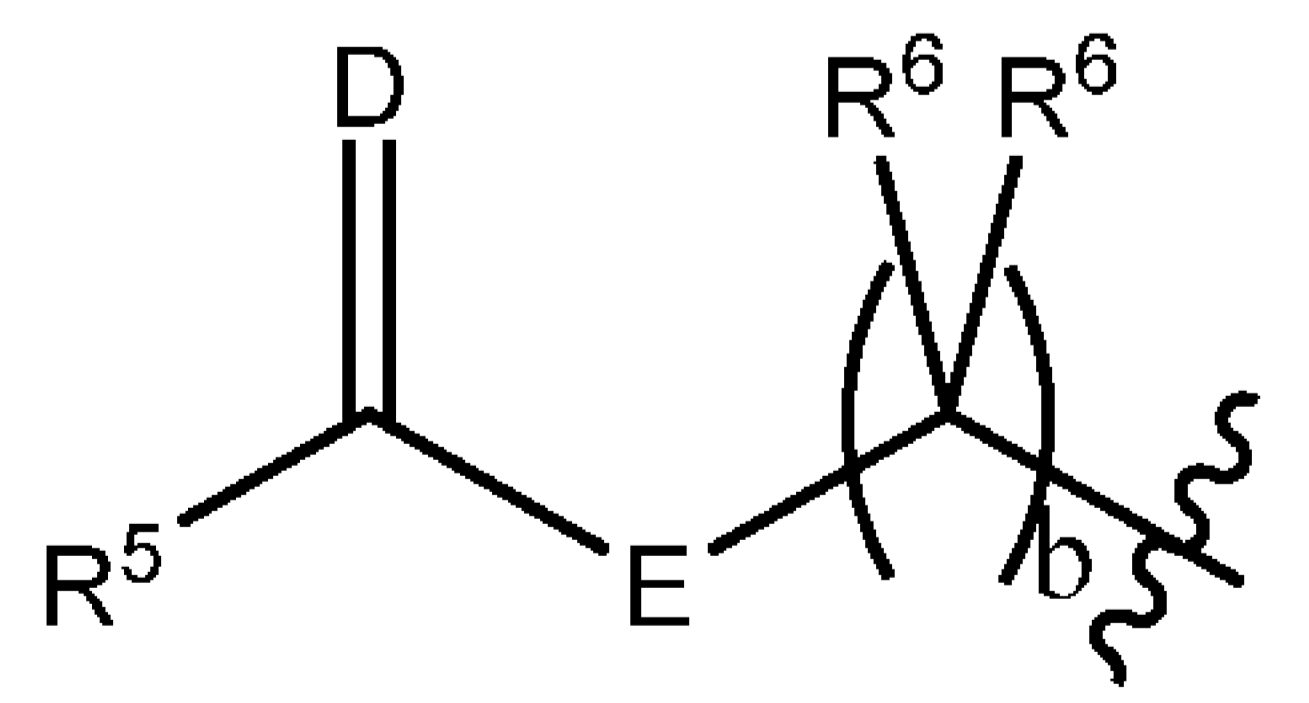
or a pharmaceutically acceptable salt thereof, wherein R<sup>5</sup> is as defined in Formula (Ia).

[0100] In embodiments, the cationic lipids of the present invention include compounds having a structure according to Formula (Ik):

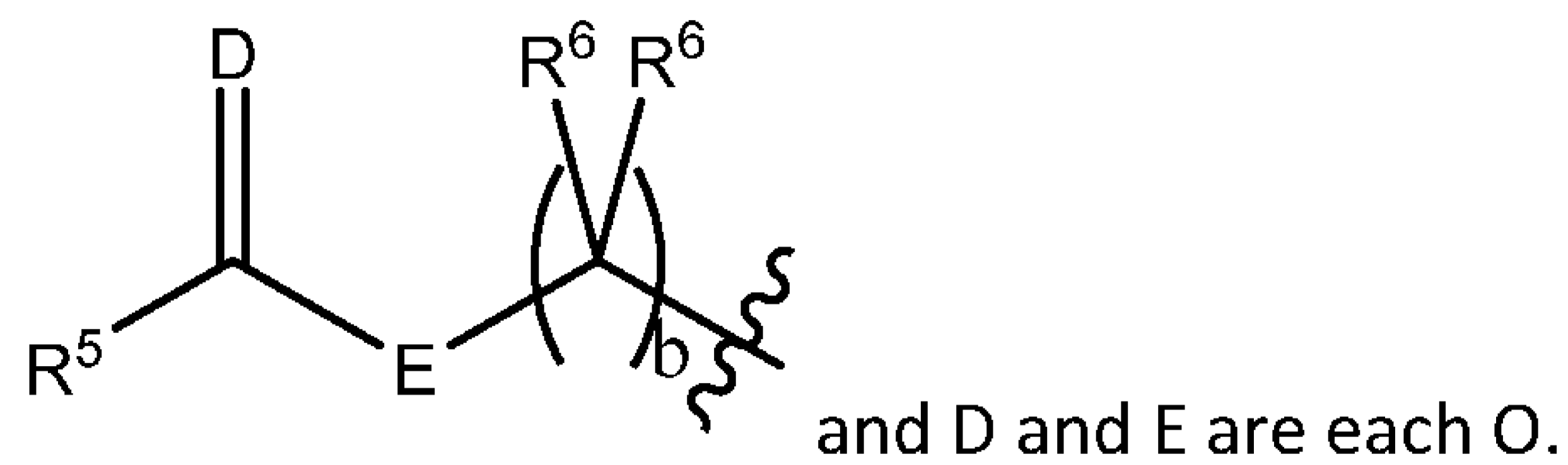


or a pharmaceutically acceptable salt thereof, wherein R<sup>5</sup> is as defined in Formula (Ia).

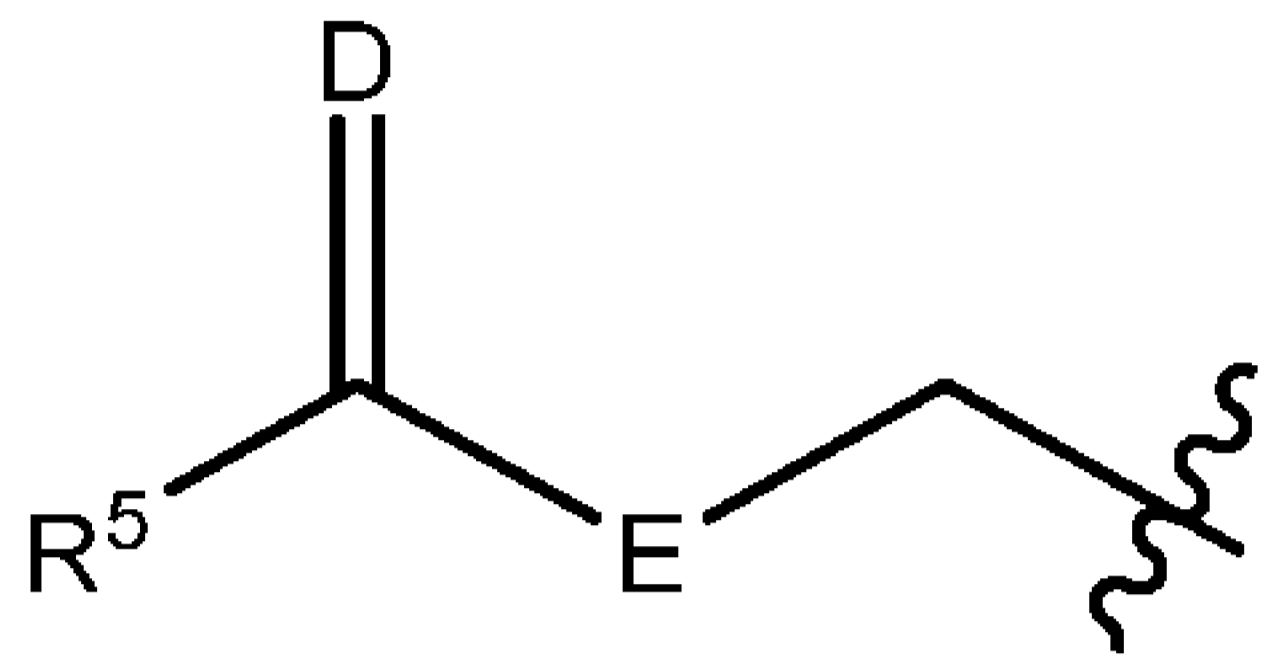
[0101] In embodiments (e.g. compounds of Formula (Ia)) R<sup>1</sup>, R<sup>2</sup> and R<sup>3</sup> are each independently



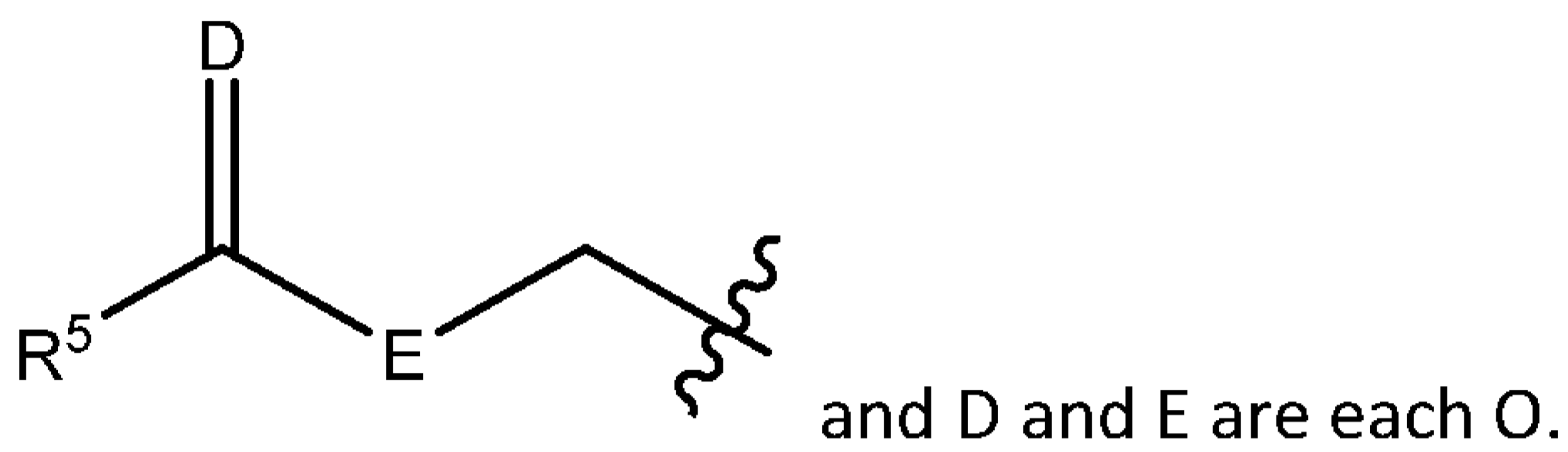
[0102] In embodiments, (e.g. compounds of Formula (Ia))  $R^1$ ,  $R^2$  and  $R^3$  are each independently



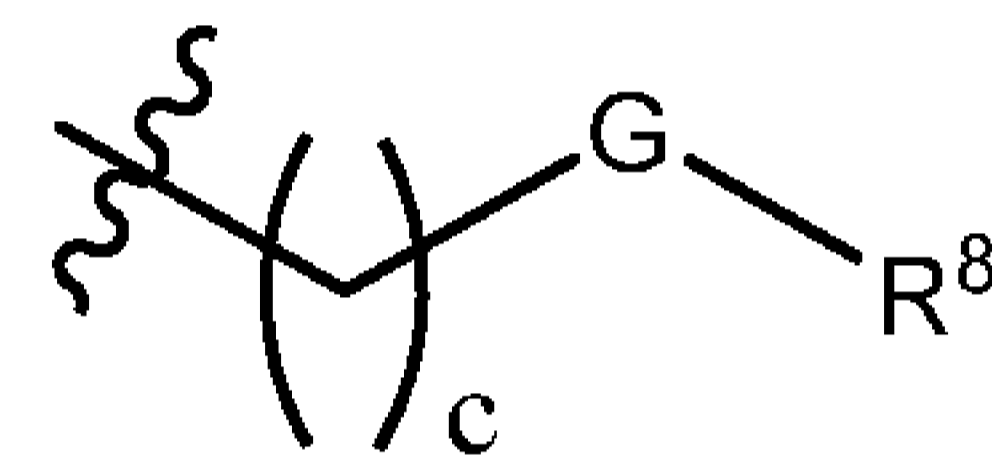
[0103] In embodiments (e.g. compounds of Formula (Ia)),  $R^1$ ,  $R^2$  and  $R^3$  are each independently



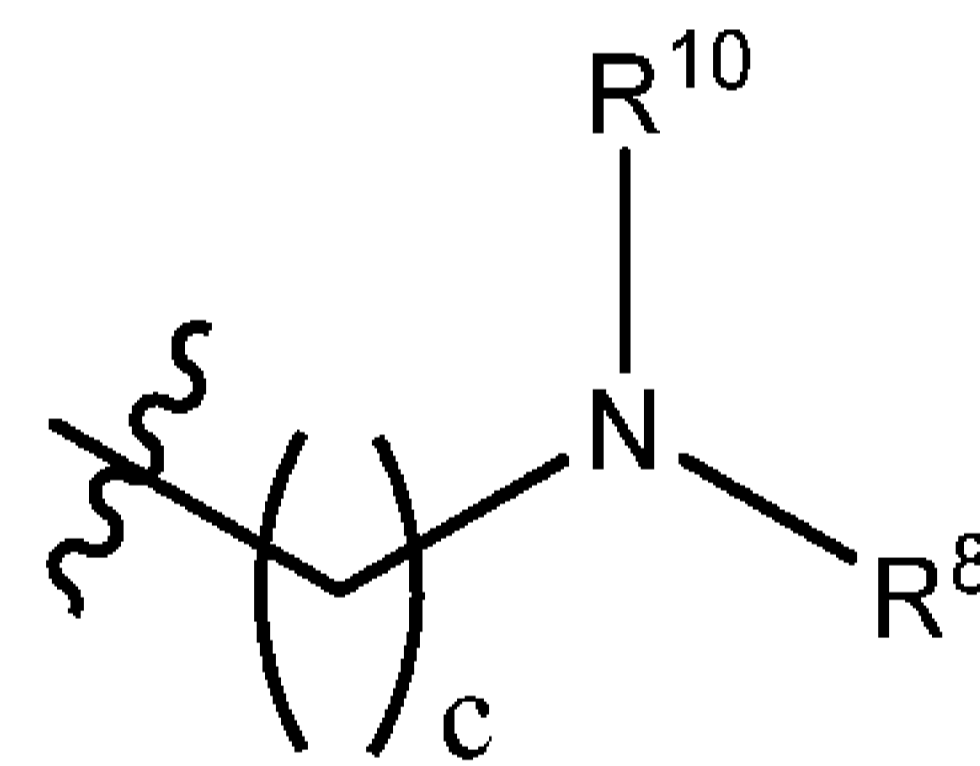
[0104] In embodiments, (e.g. compounds of Formula (Ia))  $R^1$ ,  $R^2$  and  $R^3$  are each independently



[0105] In embodiments (e.g. compounds of Formula (Ia) or (Ib)),  $R^4$  is

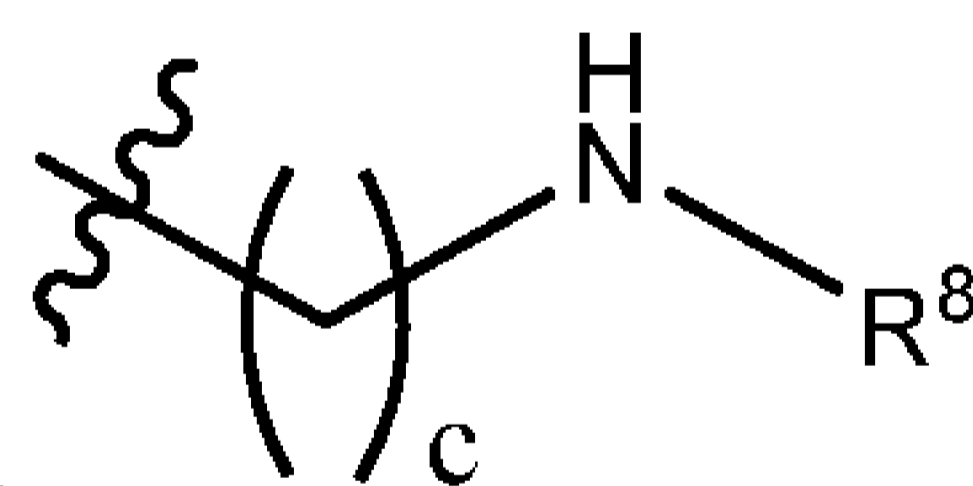


embodiments (e.g. compounds of Formula (Ia) or (Ib)),  $R^4$  is



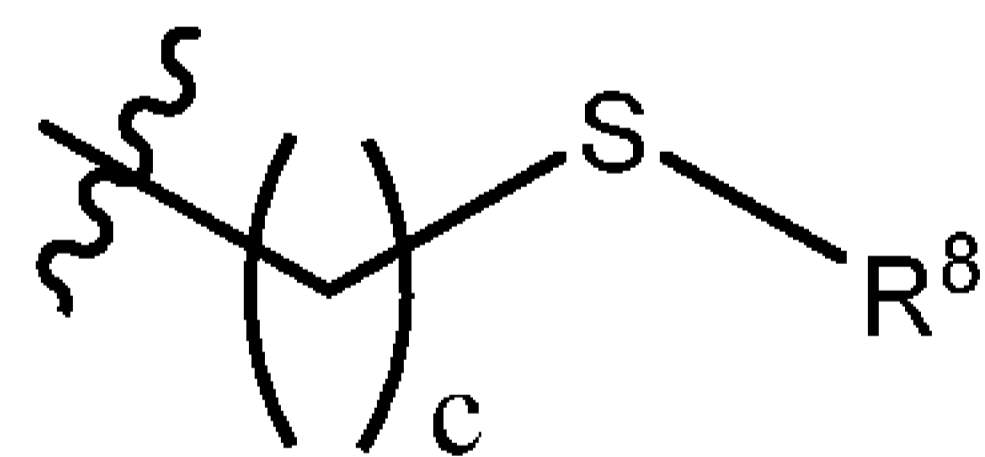
. In embodiments

(e.g. compounds of Formula (Ia) or (Ib)),  $R^4$  is



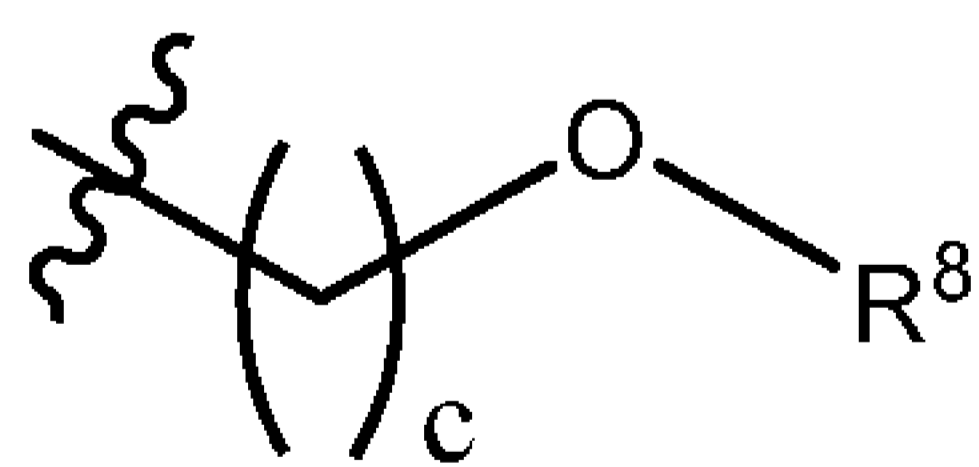
. In embodiments (e.g. compounds

of Formula (Ia) or (Ib)),  $R^4$  is



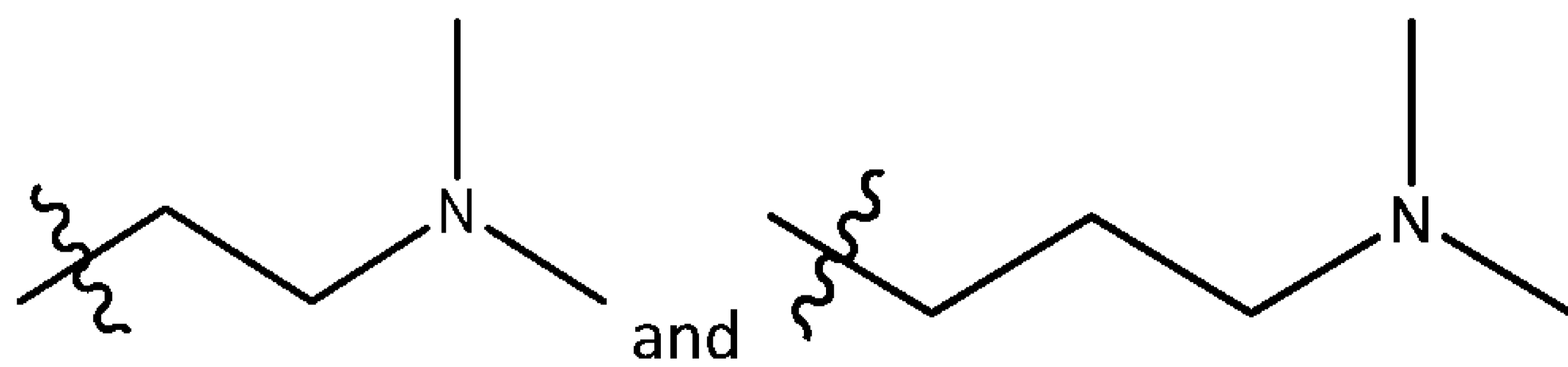
. In embodiments (e.g. compounds of Formula (Ia) or

(Ib)),  $R^4$  is

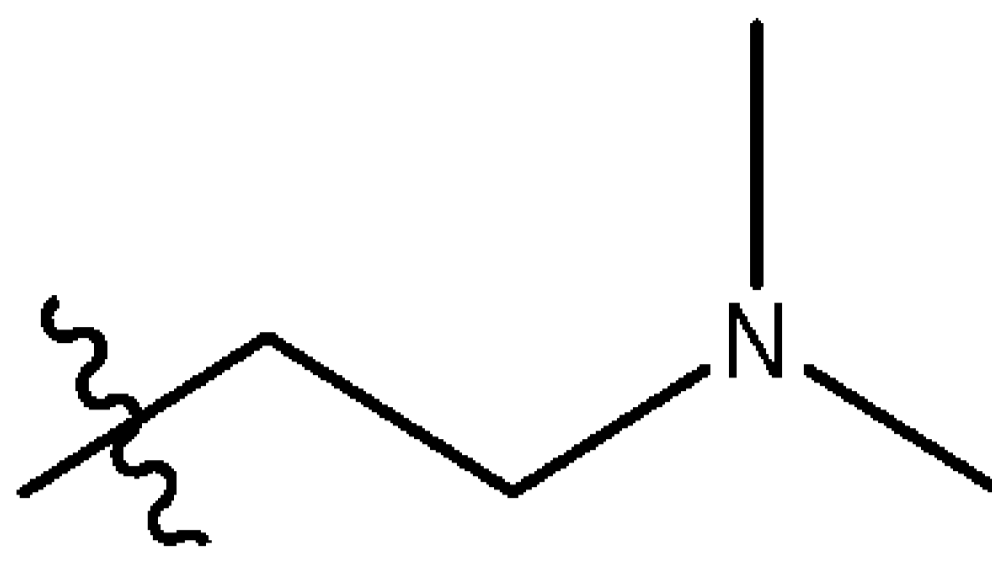


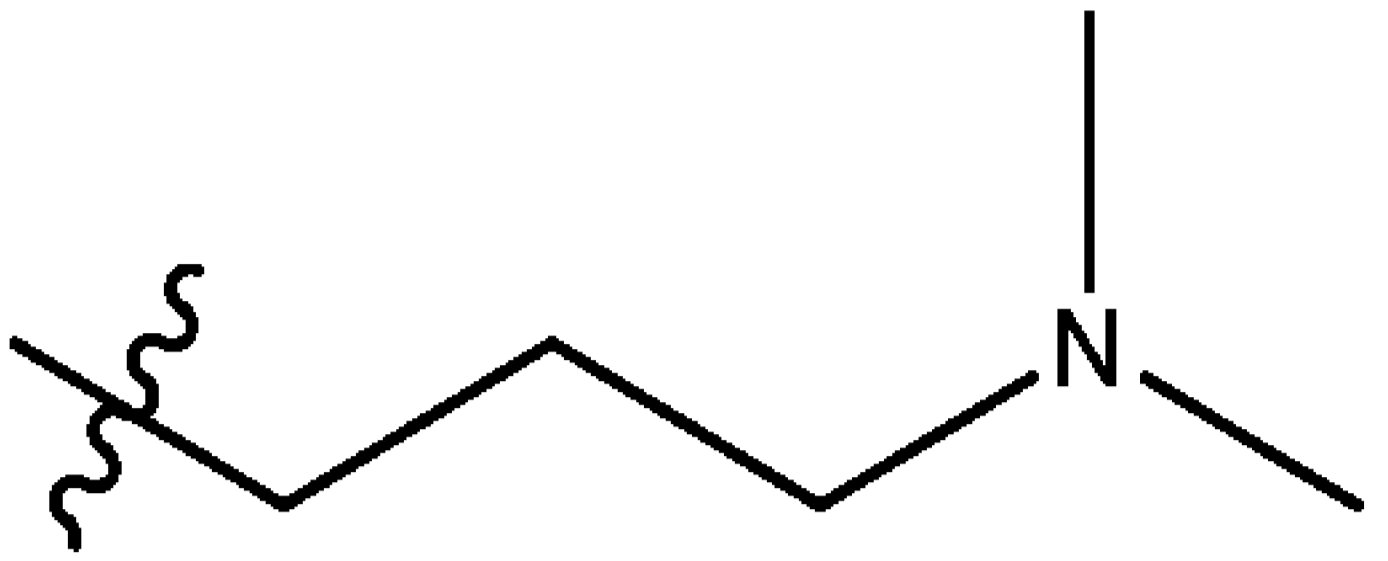
. In embodiments (e.g. compounds of Formula (Ia) or (Ib)),  $R^4$  is

selected from



. In embodiments (e.g.

compounds of Formula (Ia) or (Ib)),  $R^4$  is . In embodiments (e.g. compounds of

Formula (Ia) or (Ib)),  $R^4$  is .

**[0106]** In embodiments, each  $R^5$  is independently selected from optionally substituted  $C_1$ - $C_{50}$  alkyl, optionally substituted  $C_2$ - $C_{50}$  alkenyl, and optionally substituted  $C_2$ - $C_{50}$  alkynyl. In embodiments, each  $R^5$  is independently selected from optionally substituted  $C_1$ - $C_{40}$  alkyl, optionally substituted  $C_2$ - $C_{40}$  alkenyl, and optionally substituted  $C_2$ - $C_{40}$  alkynyl. In embodiments, each  $R^5$  is independently selected from optionally substituted  $C_1$ - $C_{30}$  alkyl, optionally substituted  $C_2$ - $C_{30}$  alkenyl, and optionally substituted  $C_2$ - $C_{30}$  alkynyl. In embodiments, each  $R^5$  is independently selected from optionally substituted  $C_1$ - $C_{20}$  alkyl, optionally substituted  $C_2$ - $C_{20}$  alkenyl, and optionally substituted  $C_2$ - $C_{20}$  alkynyl. In embodiments, each  $R^5$  is independently selected from optionally substituted  $C_1$ - $C_{10}$  alkyl, optionally substituted  $C_2$ - $C_{10}$  alkenyl, and optionally substituted  $C_2$ - $C_{10}$  alkynyl.

**[0107]** In embodiments, each  $R^5$  is independently selected from optionally substituted  $C_5$ - $C_{50}$  alkyl, optionally substituted  $C_5$ - $C_{50}$  alkenyl, and optionally substituted  $C_5$ - $C_{50}$  alkynyl. In embodiments, each  $R^5$  is independently selected from optionally substituted  $C_5$ - $C_{40}$  alkyl, optionally substituted  $C_5$ - $C_{40}$  alkenyl, and optionally substituted  $C_5$ - $C_{40}$  alkynyl. In embodiments, each  $R^5$  is independently selected from optionally substituted  $C_5$ - $C_{30}$  alkyl, optionally substituted  $C_5$ - $C_{30}$  alkenyl, and optionally substituted  $C_5$ - $C_{30}$  alkynyl. In embodiments, each  $R^5$  is independently selected from optionally substituted  $C_5$ - $C_{20}$  alkyl, optionally substituted  $C_5$ - $C_{20}$  alkenyl, and optionally substituted  $C_5$ - $C_{20}$  alkynyl. In embodiments, each  $R^5$  is independently selected from optionally substituted  $C_5$ - $C_{10}$  alkyl, optionally substituted  $C_5$ - $C_{10}$  alkenyl, and optionally substituted  $C_5$ - $C_{10}$  alkynyl.

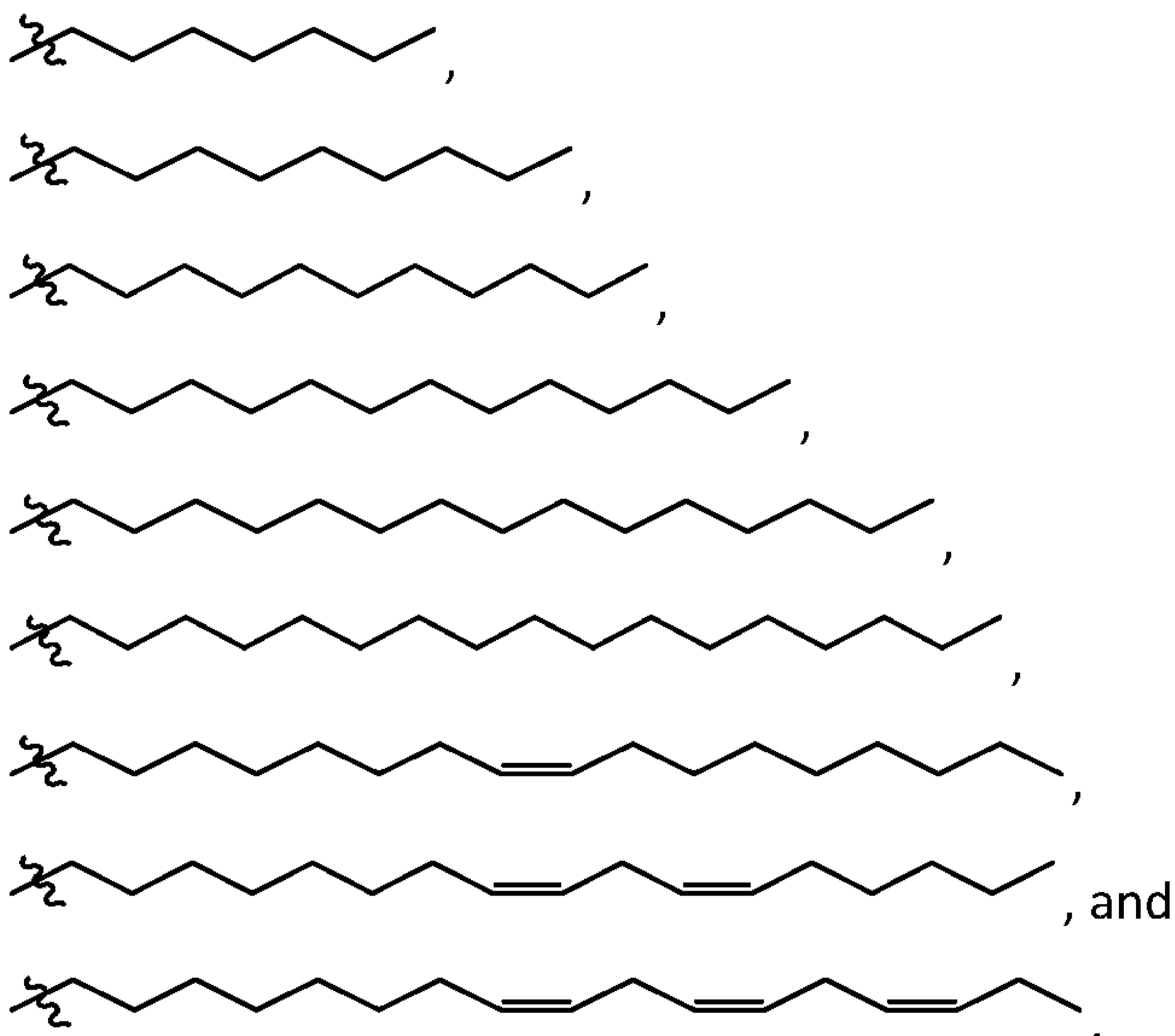
**[0108]** In embodiments, each  $R^5$  is optionally substituted alkyl. In embodiments, each  $R^5$  is optionally substituted  $C_5$ - $C_{50}$  alkyl. In embodiments, each  $R^5$  is optionally substituted  $C_5$ - $C_{40}$  alkyl. In embodiments, each  $R^5$  is optionally substituted  $C_5$ - $C_{30}$  alkyl. In embodiments, each  $R^5$  is optionally substituted  $C_5$ - $C_{25}$  alkyl. In embodiments, each  $R^5$  is optionally substituted  $C_5$ - $C_{20}$  alkyl. In embodiments, each  $R^5$  is optionally substituted  $C_8$ - $C_{16}$  alkyl.

**[0109]** In embodiments, each  $R^5$  is optionally substituted alkenyl. In embodiments, each  $R^5$  is optionally substituted  $C_5$ - $C_{50}$  alkenyl. In embodiments, each  $R^5$  is optionally substituted  $C_5$ - $C_{40}$  alkenyl. In embodiments, each  $R^5$  is optionally substituted  $C_5$ - $C_{30}$  alkenyl. In embodiments, each  $R^5$  is optionally substituted  $C_5$ - $C_{25}$  alkenyl. In embodiments, each  $R^5$  is optionally substituted  $C_5$ - $C_{20}$  alkenyl. In embodiments, each  $R^5$  is optionally substituted  $C_8$ - $C_{16}$  alkenyl.

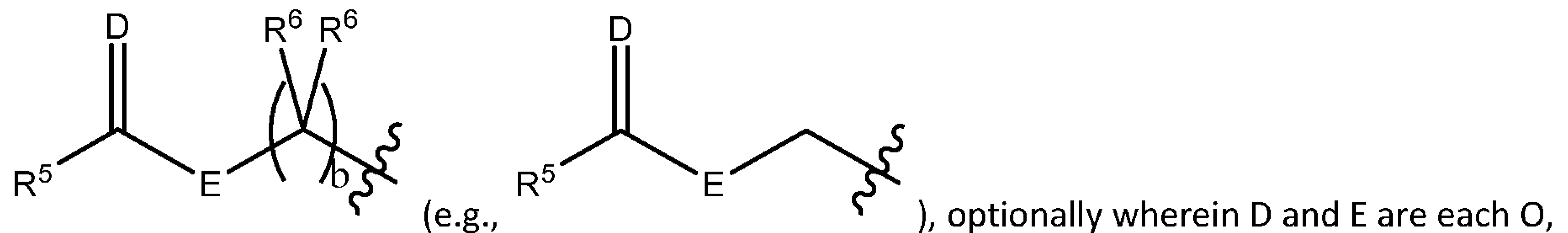
[0110] In embodiments, each  $R^5$  is optionally substituted alkynyl. In embodiments, each  $R^5$  is optionally substituted  $C_5$ - $C_{50}$  alkynyl. In embodiments, each  $R^5$  is optionally substituted  $C_5$ - $C_{40}$  alkynyl. In embodiments, each  $R^5$  is optionally substituted  $C_5$ - $C_{30}$  alkynyl. In embodiments, each  $R^5$  is optionally substituted  $C_5$ - $C_{25}$  alkynyl. In embodiments, each  $R^5$  is optionally substituted  $C_5$ - $C_{20}$  alkynyl. In embodiments, each  $R^5$  is optionally substituted  $C_8$ - $C_{16}$  alkynyl.

[0111] In embodiments, each  $R^5$  is independently selected from optionally substituted alkyl and optionally substituted alkenyl.

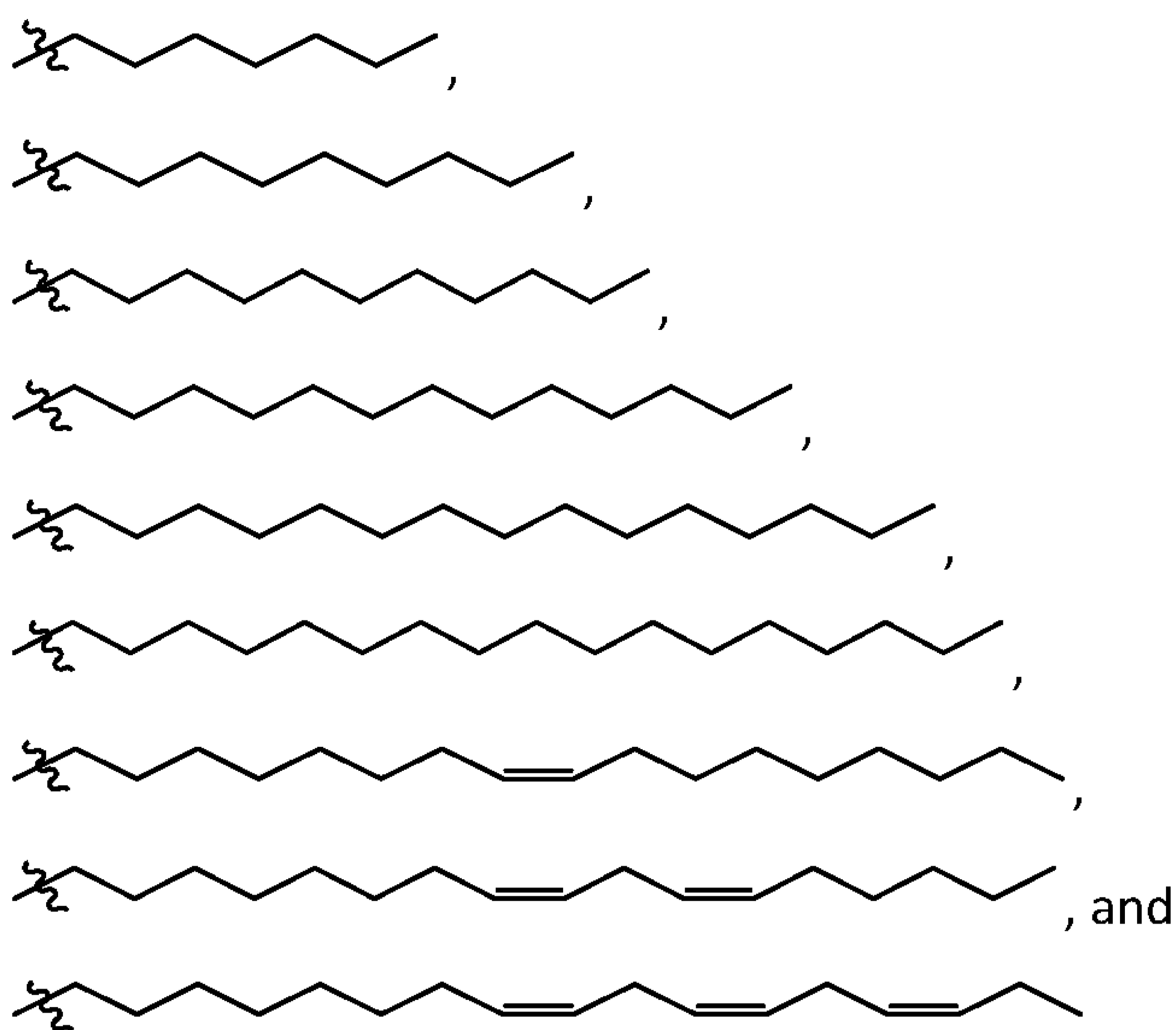
[0112] In embodiments, each  $R^5$  is independently selected from:



[0113] In embodiments,  $R^1$ ,  $R^2$  and  $R^3$  are each independently selected from:



and each  $R^5$  is independently selected from:



[0114] In embodiments (e.g. compounds of Formula (Ia), or (Ib))  $R^6$  is hydrogen;

[0115] In embodiments (e.g. compounds of Formula (Ia), (Ib), (Ic), (If), or (Ii))  $A$  is  $-NH-$  or  $-O-$ . In embodiments (e.g. compounds of Formula (Ia), (Ib), (Ic), (If), or (Ii)),  $A$  is  $-NH-$ . In embodiments (e.g. compounds of Formula (Ia), (Ib), (Ic), (If), or (Ii)),  $A$  is  $-O-$ .

[0116] In embodiments,  $D$  is O. In embodiments,  $D$  is S.

[0117] In embodiments,  $E$  is  $-NR^{10}-$ . In embodiments,  $E$  is  $-O-$ . In embodiments,  $E$  is  $-S-$ . In embodiments,  $G$  is  $-NR^{10}-$ . In embodiments,  $G$  is  $-O-$ . In embodiments,  $G$  is  $-S-$ .

[0118] In embodiments  $R^8$  is H. In embodiments,  $R^8$  is optionally substituted  $C_1-C_6$  alkyl. In embodiments,  $R^8$  is optionally substituted  $C_1-C_5$  alkyl. In embodiments,  $R^8$  is optionally substituted  $C_1-C_4$  alkyl. In embodiments,  $R^8$  is optionally substituted  $C_1-C_3$  alkyl. In embodiments,  $R^8$  is optionally substituted  $C_1-C_2$  alkyl. In embodiments,  $R^8$  is optionally substituted  $C_1$  alkyl. In embodiments,  $R^8$  is methyl.

[0119] In embodiments,  $R^8$  is optionally substituted  $C_2-C_6$  alkenyl. In embodiments,  $R^8$  is optionally substituted  $C_2-C_5$  alkenyl. In embodiments,  $R^8$  is optionally substituted  $C_2-C_4$  alkenyl. In embodiments,  $R^8$  is optionally substituted  $C_2-C_3$  alkenyl. In embodiments,  $R^8$  is optionally substituted  $C_2$  alkenyl.

[0120] In embodiments,  $R^9$  is hydrogen.

[0121] In embodiments,  $R^9$  is optionally substituted  $C_1-C_6$  alkyl. In embodiments,  $R^9$  is optionally substituted  $C_1-C_5$  alkyl. In embodiments,  $R^9$  is optionally substituted  $C_1-C_4$  alkyl. In embodiments,  $R^9$  is optionally substituted  $C_1-C_3$  alkyl. In embodiments,  $R^9$  is optionally substituted  $C_1-C_2$  alkyl. In embodiments,  $R^9$  is methyl.

[0122] In embodiments,  $R^9$  is optionally substituted  $C_2-C_6$  alkenyl. In embodiments,  $R^9$  is optionally substituted  $C_2-C_5$  alkenyl. In embodiments,  $R^9$  is optionally substituted  $C_2-C_4$  alkenyl. In

embodiments,  $R^9$  is optionally substituted  $C_2$ - $C_3$  alkenyl. In embodiments,  $R^9$  is optionally substituted  $C_2$  alkenyl.

[0123] In embodiments, each  $R^{10}$  is independently selected from hydrogen and optionally substituted  $C_1$ - $C_6$  alkyl. In embodiments, each  $R^{10}$  is independently selected from hydrogen and optionally substituted  $C_1$ - $C_5$  alkyl. In embodiments, each  $R^{10}$  is independently selected from hydrogen and optionally substituted  $C_1$ - $C_4$  alkyl. In embodiments, each  $R^{10}$  is independently selected from hydrogen and optionally substituted  $C_1$ - $C_3$  alkyl. In embodiments, each  $R^{10}$  is independently selected from hydrogen and optionally substituted  $C_1$ - $C_2$  alkyl. In embodiments, each  $R^{10}$  is independently selected from hydrogen and optionally substituted  $C_1$  alkyl. In embodiments, each  $R^{10}$  is independently selected from hydrogen and methyl.

[0124] In embodiments, each  $R^{10}$  is independently selected from hydrogen and optionally substituted  $C_2$ - $C_6$  alkenyl. In embodiments, each  $R^{10}$  is independently selected from hydrogen and optionally substituted  $C_2$ - $C_5$  alkenyl. In embodiments, each  $R^{10}$  is independently selected from hydrogen and optionally substituted  $C_2$ - $C_4$  alkenyl. In embodiments, each  $R^{10}$  is independently selected from hydrogen and optionally substituted  $C_2$ - $C_3$  alkenyl. In embodiments, each  $R^{10}$  is independently selected from hydrogen and optionally substituted  $C_2$  alkenyl.

[0125] In embodiments  $G$  is  $NR^{10}$  and both  $R^8$  and  $R^{10}$  are the same. In some embodiments  $R^8$  and  $R^{10}$  and both selected from H and optionally substituted  $C_1$ - $C_6$  alkyl. In some embodiments  $R^8$  and  $R^{10}$  and each methyl.

[0126] In embodiments, for any preceding embodiment with the integer  $b$ ,  $b$  is 1, 2, 3, 4, or 5. In embodiments, for any preceding embodiment with the integer  $b$ ,  $b$  is 1, 2, 3, or 4. In embodiments, for any preceding embodiment with the integer  $b$ ,  $b$  is 1, 2, or 3. In embodiments, for any preceding embodiment with the integer  $b$ ,  $b$  is 1 or 2. In embodiments, for any preceding embodiment with the integer  $b$ ,  $b$  is 1.

[0127] In embodiments, for any preceding embodiment with the integer  $c$ ,  $c$  is 1, 2, 3, 4, or 5. In embodiments, for any preceding embodiment with the integer  $c$ ,  $c$  is 1, 2, 3, or 4. In embodiments, for any preceding embodiment with the integer  $c$ ,  $c$  is 1, 2, or 3. In embodiments, for any preceding embodiment with the integer  $c$ ,  $c$  is 2 or 3. In embodiments, for any preceding embodiment with the integer  $c$ ,  $c$  is 2. In embodiments, for any preceding embodiment with the integer  $c$ ,  $c$  is 3.

[0128] In embodiments, the substituents are not optionally substituted.

[0129] In embodiments, the cationic lipids of the present invention have any one of the structures in Table A, or a pharmaceutically acceptable salt thereof.

[0130] In embodiments, a composition comprising the cationic lipid of any one of the preceding embodiments, one or more non-cationic lipids, one or more cholesterol-based lipids and one or

more PEG-modified lipid is provided. In embodiments, this composition is a lipid nanoparticle. In embodiments, the one or more cationic lipid(s) constitute(s) about 30 mol %-60 mol % of the lipid nanoparticle. In embodiments, the one or more non-cationic lipid(s) constitute(s) 10 mol%-50 mol% of the lipid nanoparticle. In embodiments, the one or more PEG-modified lipid(s) constitute(s) 1 mol%-10 mol% of the lipid nanoparticle. In embodiments, the cholesterol-based lipid constitutes 10 mol%-50 mol% of the lipid nanoparticle. In embodiments, the lipid nanoparticle encapsulates a nucleic acid, optionally an mRNA encoding a peptide or protein. In embodiments, the lipid nanoparticles have an encapsulation percentage for mRNA of at least 70%. In embodiments, the lipid nanoparticles have an encapsulation percentage for mRNA of at least 75%. In embodiments, the lipid nanoparticles have an encapsulation percentage for mRNA of at least 80%. In embodiments, the lipid nanoparticles have an encapsulation percentage for mRNA of at least 85%. In embodiments, the lipid nanoparticles have an encapsulation percentage for mRNA of at least 90%. In embodiments, the lipid nanoparticles have an encapsulation percentage for mRNA of at least 95%.

**[0131]** In embodiments, the composition of any one of the preceding embodiments is for use in therapy.

**[0132]** In embodiments, the composition of any one of the preceding embodiments is for use in a method of treating or preventing a disease amenable to treatment or prevention by the peptide or protein encoded by the mRNA, optionally wherein the disease is (a) a protein deficiency, optionally wherein the protein deficiency affects the liver, lung, brain or muscle, (b) an autoimmune disease, (c) an infectious disease, or (d) cancer.

**[0133]** In embodiments, the composition is administered intravenously, intrathecally or intramuscularly, or by pulmonary delivery, optionally through nebulization.

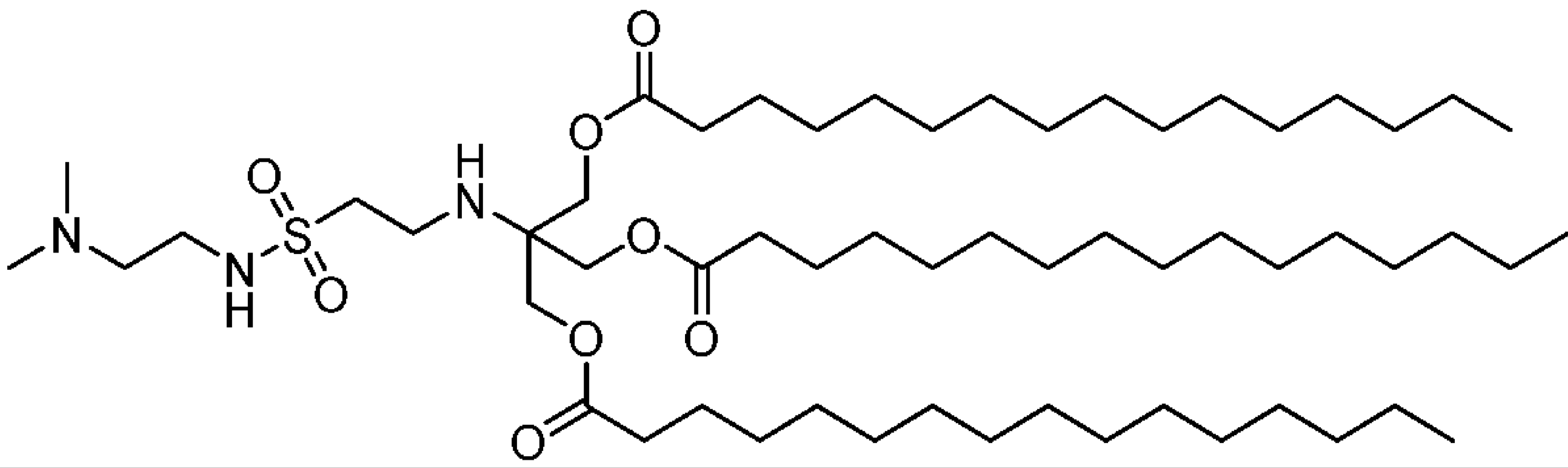
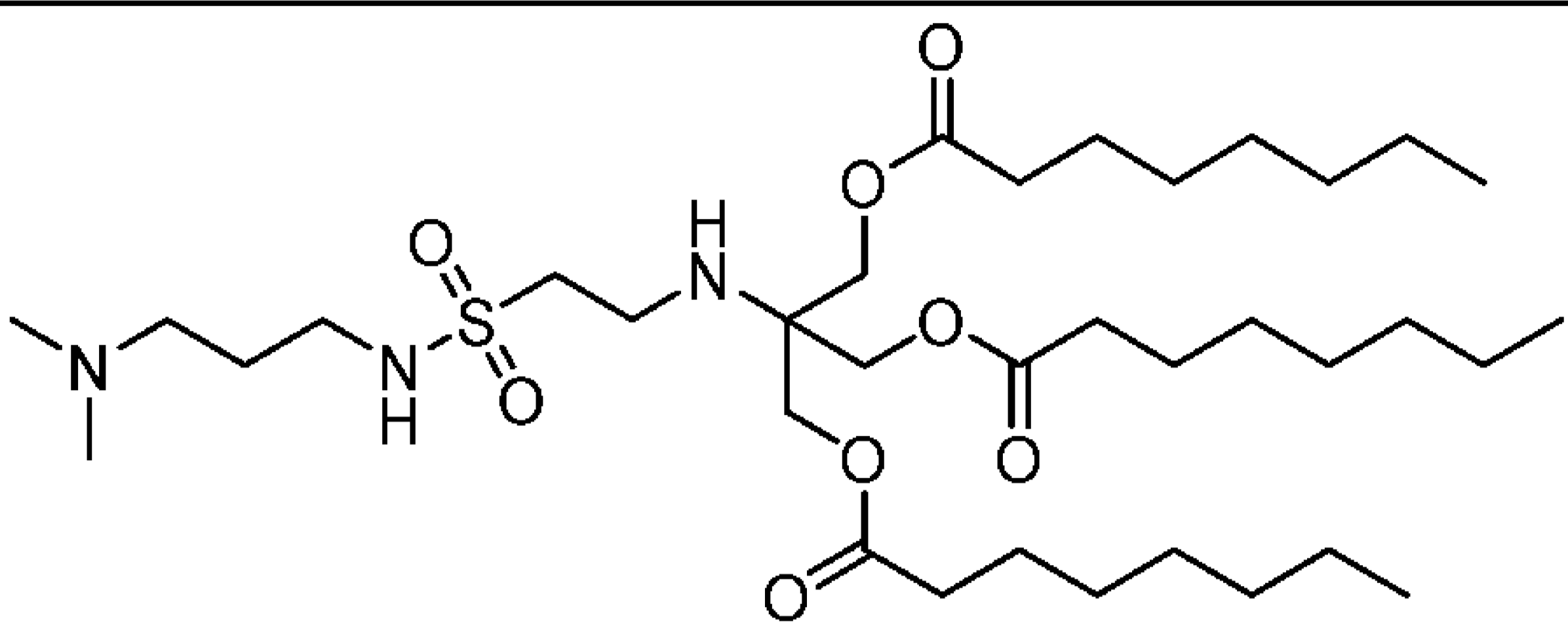
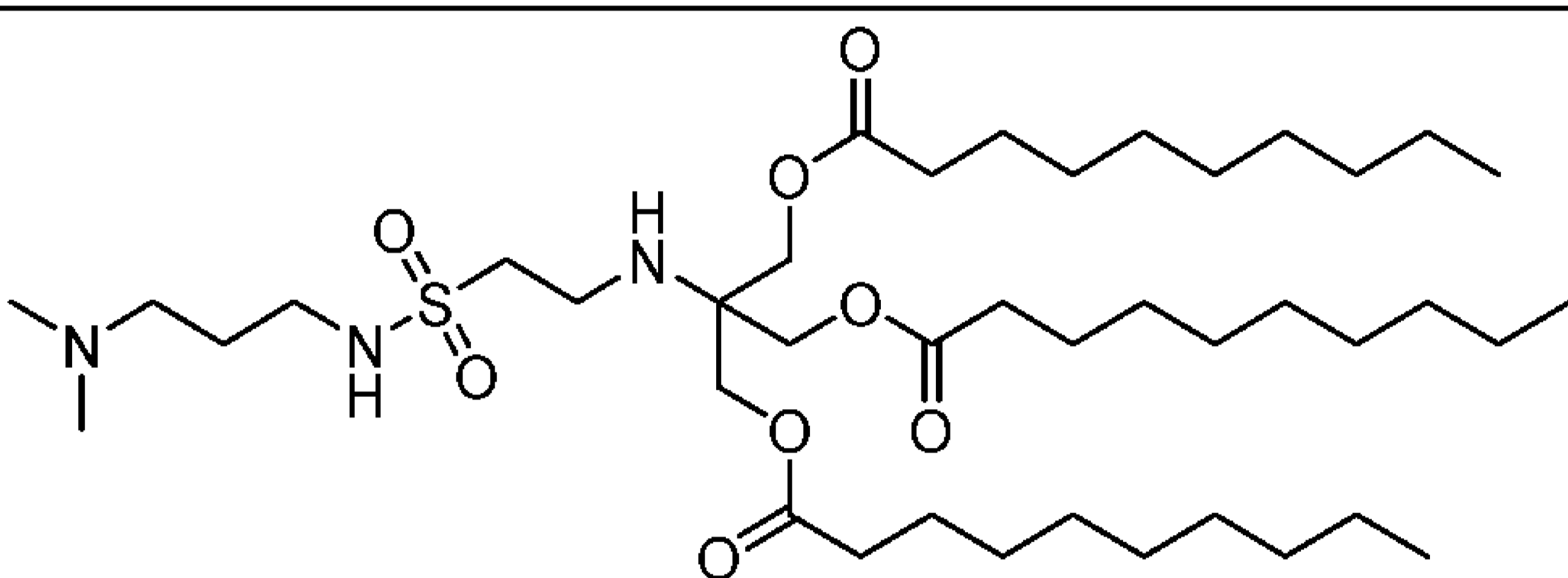
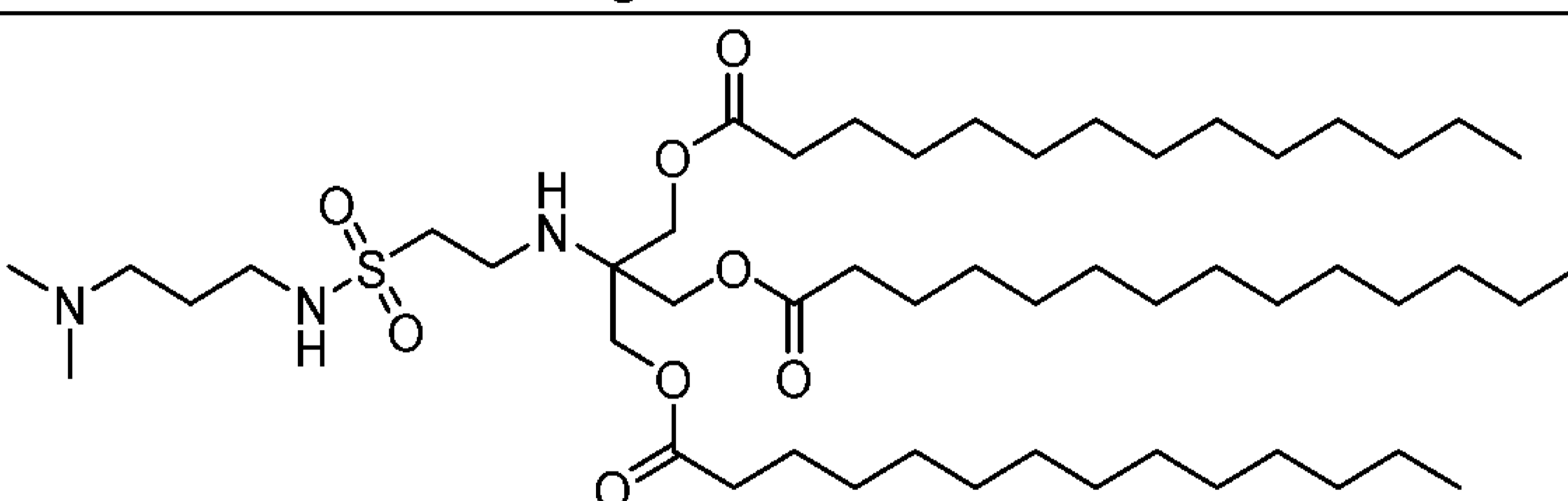
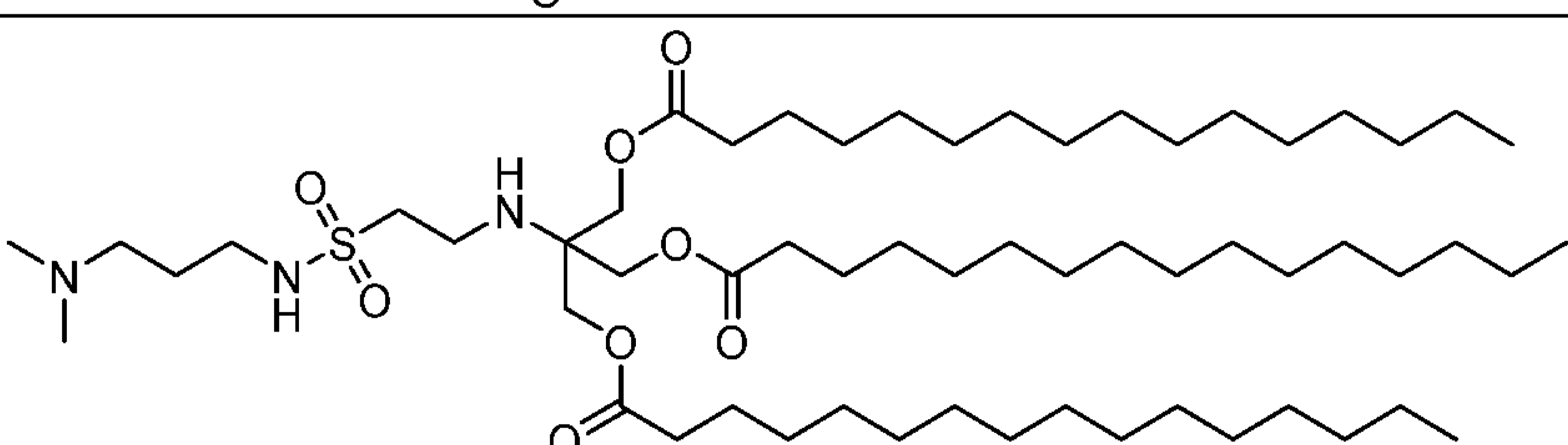
#### Exemplary Compounds

**[0134]** In embodiments, the cationic lipid of the present invention include compounds selected from those depicted in Table A, or a pharmaceutically acceptable salt thereof.

**[0135]** Exemplary compounds include those described in **Table A**, or a pharmaceutically acceptable salt thereof.

Compound No.	<b>Table A:</b> TES-based cationic lipids
I	

<p>II</p>	
<p>III</p>	
<p>IV</p>	
<p>V</p>	
<p>VI</p>	
<p>VII</p>	
<p>VIII</p>	

IX	
X	
XI	
XII	
XIII	

[0136] Any of the compounds identified in Table A above may be provided in the form of a pharmaceutically acceptable salt and such salts are intended to be encompassed by the present invention.

[0137] The compounds of the invention as described herein can be prepared according to methods known in the art, including the exemplary syntheses of the Examples provided herein.

### ***Nucleic Acids***

[0138] The compounds of the invention as described herein can be used to prepare compositions useful for the delivery of nucleic acids.

#### Synthesis of Nucleic Acids

[0139] Nucleic acids according to the present invention may be synthesized according to any known methods. For example, mRNAs according to the present invention may be synthesized *in vitro*

transcription (IVT). Briefly, IVT is typically performed with a linear or circular DNA template containing a promoter, a pool of ribonucleotide triphosphates, a buffer system that may include DTT and magnesium ions, and an appropriate RNA polymerase (*e.g.*, T3, T7, mutated T7 or SP6 RNA polymerase), DNase I, pyrophosphatase, and/or RNase inhibitor. The exact conditions will vary according to the specific application.

**[0140]** In some embodiments, for the preparation of mRNA according to the invention, a DNA template is transcribed *in vitro*. A suitable DNA template typically has a promoter, for example a T3, T7, mutated T7 or SP6 promoter, for *in vitro* transcription, followed by desired nucleotide sequence for desired mRNA and a termination signal.

**[0141]** Desired mRNA sequence(s) according to the invention may be determined and incorporated into a DNA template using standard methods. For example, starting from a desired amino acid sequence (*e.g.*, an enzyme sequence), a virtual reverse translation is carried out based on the degenerated genetic code. Optimization algorithms may then be used for selection of suitable codons. Typically, the G/C content can be optimized to achieve the highest possible G/C content on one hand, taking into the best possible account the frequency of the tRNAs according to codon usage on the other hand. The optimized RNA sequence can be established and displayed, for example, with the aid of an appropriate display device and compared with the original (wild-type) sequence. A secondary structure can also be analyzed to calculate stabilizing and destabilizing properties or, respectively, regions of the RNA.

#### Modified mRNA

**[0142]** In some embodiments, mRNA according to the present invention may be synthesized as unmodified or modified mRNA. Modified mRNA comprise nucleotide modifications in the RNA. A modified mRNA according to the invention can thus include nucleotide modification that are, for example, backbone modifications, sugar modifications or base modifications. In some embodiments, mRNAs may be synthesized from naturally occurring nucleotides and/or nucleotide analogues (modified nucleotides) including, but not limited to, purines (adenine (A), guanine (G)) or pyrimidines (thymine (T), cytosine (C), uracil (U)), and as modified nucleotides analogues or derivatives of purines and pyrimidines, such as *e.g.*, 1-methyl-adenine, 2-methyl-adenine, 2-methylthio-N-6-isopentenyl-adenine, N6-methyl-adenine, N6-isopentenyl-adenine, 2-thio-cytosine, 3-methyl-cytosine, 4-acetyl-cytosine, 5-methyl-cytosine, 2,6-diaminopurine, 1-methyl-guanine, 2-methyl-guanine, 2,2-dimethyl-guanine, 7-methyl-guanine, inosine, 1-methyl-inosine, pseudouracil (5-uracil), dihydro-uracil, 2-thio-uracil, 4-thio-uracil, 5-carboxymethylaminomethyl-2-thio-uracil, 5-(carboxyhydroxymethyl)-uracil, 5-fluoro-uracil, 5-bromo-uracil, 5-carboxymethylaminomethyl-uracil, 5-methyl-2-thio-uracil, 5-methyl-uracil, N-uracil-5-oxyacetic acid methyl ester, 5-

methylaminomethyl-uracil, 5-methoxyaminomethyl-2-thio-uracil, 5'-methoxycarbonylmethyl-uracil, 5-methoxy-uracil, uracil-5-oxyacetic acid methyl ester, uracil-5-oxyacetic acid (v), 1-methyl-pseudouracil, queuosine, beta-D-mannosyl-queuosine, wybutoxosine, and phosphoramidates, phosphorothioates, peptide nucleotides, methylphosphonates, 7-deazaguanosine, 5-methylcytosine and inosine. The preparation of such analogues is known to a person skilled in the art *e.g.*, from the U.S. Pat. No. 4,373,071, U.S. Pat. No. 4,401,796, U.S. Pat. No. 4,415,732, U.S. Pat. No. 4,458,066, U.S. Pat. No. 4,500,707, U.S. Pat. No. 4,668,777, U.S. Pat. No. 4,973,679, U.S. Pat. No. 5,047,524, U.S. Pat. No. 5,132,418, U.S. Pat. No. 5,153,319, U.S. Pat. Nos. 5,262,530 and 5,700,642, the disclosures of which are incorporated by reference in their entirety.

### ***Pharmaceutical Formulations of Cationic Lipids and Nucleic Acids***

**[0143]** In certain embodiments, the compounds of the invention as described herein, as well as pharmaceutical and liposomal compositions comprising such lipids, can be used in formulations to facilitate the delivery of encapsulated materials (*e.g.*, one or more polynucleotides such as mRNA) to, and subsequent transfection of one or more target cells. For example, in certain embodiments cationic lipids described herein (and compositions such as liposomal compositions comprising such lipids) are characterized as resulting in one or more of receptor-mediated endocytosis, clathrin-mediated and caveolae-mediated endocytosis, phagocytosis and macropinocytosis, fusogenicity, endosomal or lysosomal disruption and/or releasable properties that afford such compounds advantages relative other similarly classified lipids.

**[0144]** According to the present invention, a nucleic acid, *e.g.*, mRNA encoding a protein (*e.g.*, a full length, fragment or portion of a protein) as described herein may be delivered via a delivery vehicle comprising a compound of the invention as described herein.

**[0145]** As used herein, the terms "delivery vehicle," "transfer vehicle," "nanoparticle," or grammatical equivalents thereof, are used interchangeably.

**[0146]** For example, the present invention provides a composition (*e.g.*, a pharmaceutical composition) comprising a compound described herein and one or more polynucleotides. A composition (*e.g.*, a pharmaceutical composition) may further comprise one or more cationic lipids, one or more non-cationic lipids, one or more cholesterol-based lipids and/or one or more PEG-modified lipids.

**[0147]** In certain embodiments a composition exhibits an enhanced (*e.g.*, increased) ability to transfect one or more target cells. Accordingly, also provided herein are methods of transfecting one or more target cells. Such methods generally comprise the step of contacting the one or more target cells with the cationic lipids and/or pharmaceutical compositions disclosed herein (*e.g.*, a liposomal formulation comprising a compound described herein encapsulating one or more

polynucleotides) such that the one or more target cells are transfected with the materials encapsulated therein (*e.g.*, one or more polynucleotides). As used herein, the terms “transfect” or “transfection” refer to the intracellular introduction of one or more encapsulated materials (*e.g.*, nucleic acids and/or polynucleotides) into a cell (*e.g.*, into a target cell). The introduced polynucleotide may be stably or transiently maintained in the target cell. The term “transfection efficiency” refers to the relative amount of such encapsulated material (*e.g.*, polynucleotides) up-taken by, introduced into, and/or expressed by the target cell which is subject to transfection. In practice, transfection efficiency may be estimated by the amount of a reporter polynucleotide product produced by the target cells following transfection. In certain embodiments, the compounds and pharmaceutical compositions described herein demonstrate high transfection efficiencies thereby improving the likelihood that appropriate dosages of the encapsulated materials (*e.g.*, one or more polynucleotides) will be delivered to the site of pathology and subsequently expressed, while at the same time minimizing potential systemic adverse effects or toxicity associated with the compound or their encapsulated contents.

**[0148]** Following transfection of one or more target cells by, for example, the polynucleotides encapsulated in the one or more lipid nanoparticles comprising the pharmaceutical or liposomal compositions disclosed herein, the production of the product (*e.g.*, a polypeptide or protein) encoded by such polynucleotide may be stimulated and the capability of such target cells to express the polynucleotide and produce, for example, a polypeptide or protein of interest is enhanced. For example, transfection of a target cell by one or more compounds or pharmaceutical compositions encapsulating mRNA will enhance (*i.e.*, increase) the production of the protein or enzyme encoded by such mRNA.

**[0149]** Further, delivery vehicles described herein (*e.g.*, liposomal delivery vehicles) may be prepared to preferentially distribute to other target tissues, cells or organs, such as the heart, lungs, kidneys, spleen. In embodiments, the lipid nanoparticles of the present invention may be prepared to achieve enhanced delivery to the target cells and tissues. For example, polynucleotides (*e.g.*, mRNA) encapsulated in one or more of the compounds or pharmaceutical and liposomal compositions described herein can be delivered to and/or transfect targeted cells or tissues. In some embodiments, the encapsulated polynucleotides (*e.g.*, mRNA) are capable of being expressed and functional polypeptide products produced (and in some instances excreted) by the target cell, thereby conferring a beneficial property to, for example the target cells or tissues. Such encapsulated polynucleotides (*e.g.*, mRNA) may encode, for example, a hormone, enzyme, receptor, polypeptide, peptide or other protein of interest.

### Liposomal Delivery Vehicles

[0150] In some embodiments, a composition is a suitable delivery vehicle. In embodiments, a composition is a liposomal delivery vehicle, *e.g.*, a lipid nanoparticle.

[0151] The terms “liposomal delivery vehicle” and “liposomal composition” are used interchangeably.

[0152] Enriching liposomal compositions with one or more of the cationic lipids disclosed herein may be used as a means of improving (*e.g.*, reducing) the toxicity or otherwise conferring one or more desired properties to such enriched liposomal composition (*e.g.*, improved delivery of the encapsulated polynucleotides to one or more target cells and/or reduced *in vivo* toxicity of a liposomal composition). Accordingly, also contemplated are pharmaceutical compositions, and in particular liposomal compositions, that comprise one or more of the cationic lipids disclosed herein.

[0153] Thus, in certain embodiments, the compounds of the invention as described herein may be used as a component of a liposomal composition to facilitate or enhance the delivery and release of encapsulated materials (*e.g.*, one or more therapeutic agents) to one or more target cells (*e.g.*, by permeating or fusing with the lipid membranes of such target cells).

[0154] As used herein, liposomal delivery vehicles, *e.g.*, lipid nanoparticles, are usually characterized as microscopic vesicles having an interior aqua space sequestered from an outer medium by a membrane of one or more bilayers. Bilayer membranes of liposomes are typically formed by amphiphilic molecules, such as lipids of synthetic or natural origin that comprise spatially separated hydrophilic and hydrophobic domains (Lasic, Trends Biotechnol., 16: 307-321, 1998). Bilayer membranes of the liposomes can also be formed by amphiphilic polymers and surfactants (*e.g.*, polymerosomes, niosomes, *etc.*). In the context of the present invention, a liposomal delivery vehicle typically serves to transport a desired mRNA to a target cell or tissue.

[0155] In certain embodiments, such compositions (*e.g.*, liposomal compositions) are loaded with or otherwise encapsulate materials, such as for example, one or more biologically-active polynucleotides (*e.g.*, mRNA).

[0156] In embodiments, a composition (*e.g.*, a pharmaceutical composition) comprises an mRNA encoding a protein, encapsulated within a liposome. In embodiments, a liposome comprises one or more cationic lipids, one or more non-cationic lipids, one or more cholesterol-based lipids and one or more PEG-modified lipids, and wherein at least one cationic lipid is a compound of the invention as described herein. In embodiments, a composition comprises an mRNA encoding for a protein (*e.g.*, any protein described herein). In embodiments, a composition comprises an mRNA encoding for cystic fibrosis transmembrane conductance regulator (CFTR) protein. In embodiments, a composition comprises an mRNA encoding for ornithine transcarbamylase (OTC) protein.

[0157] In embodiments, a composition (*e.g.*, a pharmaceutical composition) comprises a nucleic acid encapsulated within a liposome, wherein the liposome comprises a compound described herein.

[0158] In embodiments, a nucleic acid is an mRNA encoding a peptide or protein. In embodiments, an mRNA encodes a peptide or protein for use in the delivery to or treatment of the lung of a subject or a lung cell (*e.g.*, an mRNA encodes cystic fibrosis transmembrane conductance regulator (CFTR) protein). In embodiments, an mRNA encodes a peptide or protein for use in the delivery to or treatment of the liver of a subject or a liver cell (*e.g.*, an mRNA encodes ornithine transcarbamylase (OTC) protein). Still other exemplary mRNAs are described herein.

[0159] In embodiments, a liposomal delivery vehicle (*e.g.*, a lipid nanoparticle) can have a net positive charge.

[0160] In embodiments, a liposomal delivery vehicle (*e.g.*, a lipid nanoparticle) can have a net negative charge.

[0161] In embodiments, a liposomal delivery vehicle (*e.g.*, a lipid nanoparticle) can have a net neutral charge.

[0162] In embodiments, a lipid nanoparticle that encapsulates a nucleic acid (*e.g.*, mRNA encoding a peptide or protein) comprises one or more compounds of the invention as described herein.

[0163] For example, the amount of a compound of the invention as described herein in a composition can be described as a percentage (“wt%”) of the combined dry weight of all lipids of a composition (*e.g.*, the combined dry weight of all lipids present in a liposomal composition).

[0164] In embodiments of the pharmaceutical compositions described herein, a compound of the invention as described herein is present in an amount that is about 0.5 wt% to about 30 wt% (*e.g.*, about 0.5 wt% to about 20 wt%) of the combined dry weight of all lipids present in a composition (*e.g.*, a liposomal composition).

[0165] In embodiments, a compound of the invention as described herein is present in an amount that is about 1 wt% to about 30 wt%, about 1 wt% to about 20 wt%, about 1 wt% to about 15 wt%, about 1 wt% to about 10 wt%, or about 5 wt% to about 25 wt% of the combined dry weight of all lipids present in a composition (*e.g.*, a liposomal composition). In embodiments, a compound of the invention as described herein is present in an amount that is about 0.5 wt% to about 5 wt%, about 1 wt% to about 10 wt%, about 5 wt% to about 20 wt%, or about 10 wt% to about 20 wt% of the combined dry weight of all lipids present in a composition such as a liposomal delivery vehicle.

[0166] In embodiments, the amount of a compound of the invention as described herein is present in an amount that is at least about 5 wt%, about 10 wt%, about 15 wt%, about 20 wt%, about 25 wt%, about 30 wt%, about 35 wt%, about 40 wt%, about 45 wt%, about 50 wt%, about 55 wt%,

about 60 wt%, about 65 wt%, about 70 wt%, about 75 wt%, about 80 wt%, about 85 wt%, about 90 wt%, about 95 wt%, about 96 wt%, about 97 wt%, about 98 wt%, or about 99 wt% of the combined dry weight of total lipids in a composition (*e.g.*, a liposomal composition).

**[0167]** In embodiments, the amount of a compound of the invention as described herein is present in an amount that is no more than about 5 wt%, about 10 wt%, about 15 wt%, about 20 wt%, about 25 wt%, about 30 wt%, about 35 wt%, about 40 wt%, about 45 wt%, about 50 wt%, about 55 wt%, about 60 wt%, about 65 wt%, about 70 wt%, about 75 wt%, about 80 wt%, about 85 wt%, about 90 wt%, about 95 wt%, about 96 wt%, about 97 wt%, about 98 wt%, or about 99 wt% of the combined dry weight of total lipids in a composition (*e.g.*, a liposomal composition).

**[0168]** In embodiments, a composition (*e.g.*, a liposomal delivery vehicle such as a lipid nanoparticle) comprises about 0.1 wt% to about 20 wt% (*e.g.*, about 0.1 wt% to about 15 wt%) of a compound described herein. In embodiments, a delivery vehicle (*e.g.*, a liposomal delivery vehicle such as a lipid nanoparticle) comprises about 0.5 wt%, about 1 wt%, about 3 wt%, about 5 wt%, or about 10 wt% of a compound described herein. In embodiments, a delivery vehicle (*e.g.*, a liposomal delivery vehicle such as a lipid nanoparticle) comprises up to about 0.5 wt%, about 1 wt%, about 3 wt%, about 5 wt%, about 10 wt%, about 15 wt%, or about 20 wt% of a compound described herein. In embodiments, the percentage results in an improved beneficial effect (*e.g.*, improved delivery to targeted tissues such as the liver or the lung).

**[0169]** The amount of a compound of the invention as described herein in a composition also can be described as a percentage (“mol%”) of the combined molar amounts of total lipids of a composition (*e.g.*, the combined molar amounts of all lipids present in a liposomal delivery vehicle).

**[0170]** In embodiments of pharmaceutical compositions described herein, a compound of the invention as described herein is present in an amount that is about 0.5 mol% to about 50 mol% (*e.g.*, about 0.5 mol% to about 20 mol%) of the combined molar amounts of all lipids present in a composition such as a liposomal delivery vehicle.

**[0171]** In embodiments, a compound of the invention as described herein is present in an amount that is about 0.5 mol% to about 5 mol%, about 1 mol% to about 10 mol%, about 5 mol% to about 20 mol%, about 10 mol% to about 20 mol%, about 15 mol% to about 30 mol%, about 20 mol% to about 35 mol%, about 25 mol% to about 40 mol%, about 30 mol% to about 45 mol%, about 35 mol% to about 50 mol%, about 40 mol% to about 55 mol %, or about 45 mol% to about 60 mol% of the combined molar amounts of all lipids present in a composition such as a liposomal delivery vehicle. In embodiments, a compound of the invention as described herein is present in an amount that is about 1 mol% to about 60 mol%, 1 mol% to about 50 mol%, 1 mol% to about 40 mol%, 1 mol% to about 30 mol%, about 1 mol% to about 20 mol%, about 1 mol% to about 15 mol%, about 1 mol% to

about 10 mol%, about 5 mol% to about 55 mol%, about 5 mol% to about 45 mol%, about 5 mol% to about 35 mol% or about 5 mol% to about 25 mol% of the combined molar amounts of all lipids present in a composition such as a liposomal delivery vehicle

**[0172]** In certain embodiments, a compound of the invention as described herein can comprise from about 0.1 mol% to about 50 mol%, or from 0.5 mol% to about 50 mol%, or from about 1 mol% to about 50 mol%, or from about 5 mol% to about 50 mol%, or from about 10 mol% to about 50 mol%, or from about 15 mol% to about 50 mol%, or from about 20 mol% to about 50 mol%, or from about 25 mol% to about 50 mol%, or from about 30 mol% to about 50 mol%, of the total amount of lipids in a composition (*e.g.*, a liposomal delivery vehicle).

**[0173]** In certain embodiments, a compound of the invention as described herein can comprise greater than about 0.1 mol%, or greater than about 0.5 mol%, or greater than about 1 mol%, greater than about 5 mol%, greater than about 10 mol%, greater than about 20 mol%, greater than about 30 mol%, or greater than about 40 mol% of the total amount of lipids in the lipid nanoparticle.

**[0174]** In certain embodiments, a compound as described can comprise less than about 60 mol%, or less than about 55 mol%, or less than about 50 mol%, or less than about 45 mol%, or less than about 40 mol%, or less than about 35 mol %, less than about 30 mol%, or less than about 25 mol%, or less than about 10 mol%, or less than about 5 mol%, or less than about 1 mol% of the total amount of lipids in a composition (*e.g.*, a liposomal delivery vehicle).

**[0175]** In embodiments, the amount of a compound of the invention as described herein is present in an amount that is at least about 5 mol%, about 10 mol%, about 15 mol%, about 20 mol%, about 25 mol%, about 30 mol%, about 35 mol%, about 40 mol%, about 45 mol%, about 50 mol%, about 55 mol%, about 60 mol%, about 65 mol%, about 70 mol%, about 75 mol%, about 80 mol%, about 85 mol%, about 90 mol%, about 95 mol%, about 96 mol%, about 97 mol%, about 98 mol%, or about 99 mol% of the combined molar amounts of total lipids in a composition (*e.g.*, a liposomal composition).

**[0176]** In embodiments, the amount of a compound of the invention as described herein is present in an amount that is no more than about 5 mol%, about 10 mol%, about 15 mol%, about 20 mol%, about 25 mol%, about 30 mol%, about 35 mol%, about 40 mol%, about 45 mol%, about 50 mol%, about 55 mol%, about 60 mol%, about 65 mol%, about 70 mol%, about 75 mol%, about 80 mol%, about 85 mol%, about 90 mol%, about 95 mol%, about 96 mol%, about 97 mol%, about 98 mol%, or about 99 mol% of the combined molar amounts of total lipids in a composition (*e.g.*, a liposomal composition).

**[0177]** In embodiments, the percentage results in an improved beneficial effect (*e.g.*, improved delivery to targeted tissues such as the liver or the lung).

**[0178]** In a typical embodiment, a composition of the invention (*e.g.*, a liposomal composition) comprises one or more cationic lipids, one or more non-cationic lipids, one or more cholesterol-based lipids, and one or more PEG-modified lipids, wherein at least one cationic lipid is a compound of the invention as described herein. For example, a composition suitable for practicing the invention has four lipid components comprising a compound of the invention as described herein as the cationic lipid component, a non-cationic lipid, a cholesterol-based lipid and a PEG-modified lipid. The non-cationic lipid may be DOPE or DEPE. The cholesterol-based lipid may be cholesterol. The PEG-modified lipid may be DMG-PEG2K.

**[0179]** In further embodiments, pharmaceutical (*e.g.*, liposomal) compositions comprise one or more of a PEG-modified lipid, a non-cationic lipid and a cholesterol lipid. In other embodiments, such pharmaceutical (*e.g.*, liposomal) compositions comprise: one or more PEG-modified lipids; one or more non-cationic lipids; and one or more cholesterol lipids. In yet further embodiments, such pharmaceutical (*e.g.*, liposomal) compositions comprise: one or more PEG-modified lipids and one or more cholesterol lipids.

**[0180]** In embodiments, a composition (*e.g.*, lipid nanoparticle) that encapsulates a nucleic acid (*e.g.*, mRNA encoding a peptide or protein) comprises one or more compounds of the invention as described herein and one or more lipids selected from the group consisting of a cationic lipid, a non-cationic lipid, and a PEGylated lipid.

**[0181]** In embodiments, a composition (*e.g.*, lipid nanoparticle) that encapsulates a nucleic acid (*e.g.*, mRNA encoding a peptide or protein) comprises one or more compound of the invention as described herein; one or more lipids selected from the group consisting of a cationic lipid, a non-cationic lipid, and a PEGylated lipid; and further comprises a cholesterol-based lipid. Typically, such a composition has four lipid components comprising a compound of the invention as described herein as the cationic lipid component, a non-cationic lipid (*e.g.*, DOPE), a cholesterol-based lipid (*e.g.*, cholesterol) and a PEG-modified lipid (*e.g.*, DMG-PEG2K).

**[0182]** In embodiments, a lipid nanoparticle that encapsulates a nucleic acid (*e.g.*, mRNA encoding a peptide or protein) comprises one or more compounds of the invention as described herein, as well as one or more lipids selected from the group consisting of a cationic lipid, a non-cationic lipid, a PEGylated lipid, and a cholesterol-based lipid.

**[0183]** According to various embodiments, the selection of cationic lipids, non-cationic lipids and/or PEG-modified lipids which comprise the lipid nanoparticle, as well as the relative molar ratio of such lipids to each other, is based upon the characteristics of the selected lipid(s), the nature of the intended target cells, the characteristics of the mRNA to be delivered. Additional considerations

include, for example, the saturation of the alkyl chain, as well as the size, charge, pH, pKa, fusogenicity and toxicity of the selected lipid(s). Thus, the molar ratios may be adjusted accordingly.

#### *Cationic Lipids*

**[0184]** In addition to any of the compounds of the invention as described herein, a composition may comprise one or more additional cationic lipids.

**[0185]** In some embodiments, liposomes may comprise one or more additional cationic lipids. As used herein, the phrase “cationic lipid” refers to any of a number of lipid species that have a net positive charge at a selected pH, such as physiological pH. Several cationic lipids have been described in the literature, many of which are commercially available.

**[0186]** Suitable additional cationic lipids for use in the compositions include the cationic lipids as described in the literature.

#### *Helper Lipids*

**[0187]** Compositions (*e.g.*, liposomal compositions) may also comprise one or more helper lipids. Such helper lipids include non-cationic lipids. As used herein, the phrase “non-cationic lipid” refers to any neutral, zwitterionic or anionic lipid. As used herein, the phrase “anionic lipid” refers to any of a number of lipid species that carry a net negative charge at a selected pH, such as physiological pH. Non-cationic lipids include, but are not limited to, distearoylphosphatidylcholine (DSPC), dioleoylphosphatidylcholine (DOPC), dipalmitoylphosphatidylcholine (DPPC), dioleoylphosphatidylglycerol (DOPG), dipalmitoylphosphatidylglycerol (DPPG), dioleoylphosphatidylethanolamine (DOPE), 1,2-Dierucoyl-sn-glycero-3-phosphoethanolamine (DEPE), palmitoyloleoylphosphatidylcholine (POPC), palmitoyloleoyl-phosphatidylethanolamine (POPE), dioleoyl-phosphatidylethanolamine 4-(N-maleimidomethyl)-cyclohexane-1-carboxylate (DOPE-mal), dipalmitoyl phosphatidyl ethanolamine (DPPE), dimyristoylphosphoethanolamine (DMPE), distearoyl-phosphatidyl-ethanolamine (DSPE), 16-O-monomethyl PE, 16-O-dimethyl PE, 18-1-trans PE, 1-stearoyl-2-oleoyl-phosphatidylethanolamine (SOPE), or a mixture thereof. A non-cationic or helper lipid suitable for practicing the invention is dioleoylphosphatidylethanolamine (DOPE). Alternatively, 1,2-Dierucoyl-sn-glycero-3-phosphoethanolamine (DEPE) can be used as a non-cationic or helper lipid.

**[0188]** In some embodiments, a non-cationic lipid is a neutral lipid, *i.e.*, a lipid that does not carry a net charge in the conditions under which the composition is formulated and/or administered.

**[0189]** In some embodiments, a non-cationic lipid may be present in a molar ratio (mol%) of about 5% to about 90%, about 5% to about 70%, about 5% to about 50%, about 5% to about 40%, about 5% to about 30%, about 10% to about 70%, about 10% to about 50%, or about 10% to about 40% of

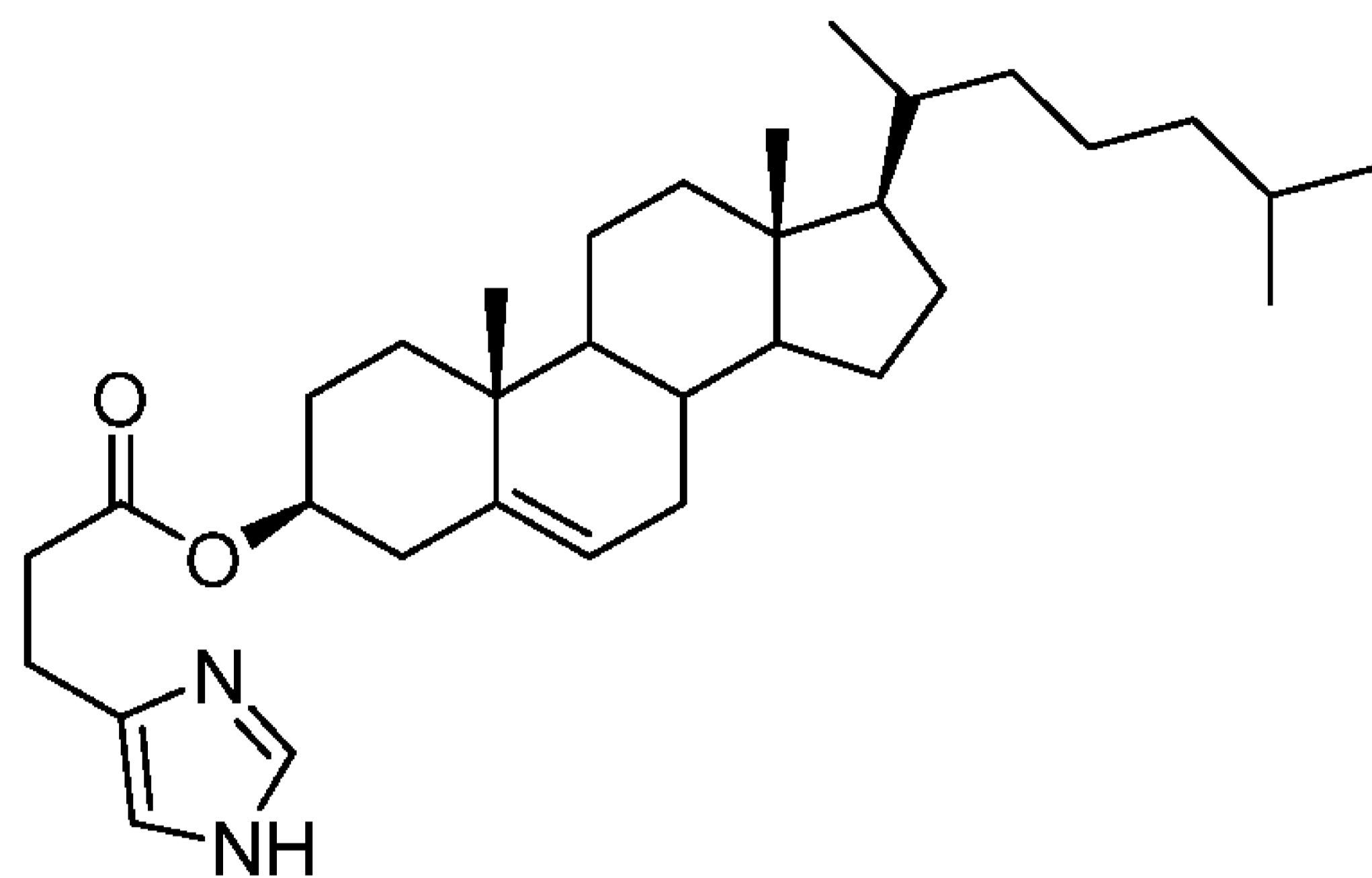
the total lipids present in a composition. In some embodiments, total non-cationic lipids may be present in a molar ratio (mol%) of about 5% to about 90%, about 5% to about 70%, about 5% to about 50%, about 5% to about 40%, about 5% to about 30%, about 10 % to about 70%, about 10% to about 50%, or about 10% to about 40% of the total lipids present in a composition. In some embodiments, the percentage of non-cationic lipid in a liposome may be greater than about 5 mol%, greater than about 10 mol%, greater than about 20 mol%, greater than about 30 mol%, or greater than about 40 mol%. In some embodiments, the percentage total non-cationic lipids in a liposome may be greater than about 5 mol%, greater than about 10 mol%, greater than about 20 mol%, greater than about 30 mol%, or greater than about 40 mol%. In some embodiments, the percentage of non-cationic lipid in a liposome is no more than about 5 mol%, no more than about 10 mol%, no more than about 20 mol%, no more than about 30 mol%, or no more than about 40 mol%. In some embodiments, the percentage total non-cationic lipids in a liposome may be no more than about 5 mol%, no more than about 10 mol%, no more than about 20 mol%, no more than about 30 mol%, or no more than about 40 mol%.

**[0190]** In some embodiments, a non-cationic lipid may be present in a weight ratio (wt%) of about 5% to about 90%, about 5% to about 70%, about 5% to about 50%, about 5% to about 40%, about 5% to about 30%, about 10 % to about 70%, about 10% to about 50%, or about 10% to about 40% of the total lipids present in a composition. In some embodiments, total non-cationic lipids may be present in a weight ratio (wt%) of about 5% to about 90%, about 5% to about 70%, about 5% to about 50%, about 5% to about 40%, about 5% to about 30%, about 10 % to about 70%, about 10% to about 50%, or about 10% to about 40% of the total lipids present in a composition. In some embodiments, the percentage of non-cationic lipid in a liposome may be greater than about 5 wt%, greater than about 10 wt%, greater than about 20 wt%, greater than about 30 wt%, or greater than about 40 wt%. In some embodiments, the percentage total non-cationic lipids in a liposome may be greater than about 5 wt%, greater than about 10 wt%, greater than about 20 wt%, greater than about 30 wt%, or greater than about 40 wt%. In some embodiments, the percentage of non-cationic lipid in a liposome is no more than about 5 wt%, no more than about 10 wt%, no more than about 20 wt%, no more than about 30 wt%, or no more than about 40 wt%. In some embodiments, the percentage total non-cationic lipids in a liposome may be no more than about 5 wt%, no more than about 10 wt%, no more than about 20 wt%, no more than about 30 wt%, or no more than about 40 wt%.

#### *Cholesterol-based Lipids*

**[0191]** In some embodiments, a composition (*e.g.*, a liposomal composition) comprises one or more cholesterol-based lipids. For example, a suitable cholesterol-based lipid for practicing the invention

is cholesterol. Other suitable cholesterol-based lipids include, for example, DC-Chol (N,N-dimethyl-N-ethylcarboxamidocholesterol), 1,4-bis(3-N-oleylamino-propyl)piperazine (Gao, *et al.* Biochem. Biophys. Res. Comm. 179, 280 (1991); Wolf *et al.* BioTechniques 23, 139 (1997); U.S. Pat. No. 5,744,335), or imidazole cholesterol ester (ICE), which has the following structure,



**[0192]** In some embodiments, a cholesterol-based lipid may be present in a molar ratio (mol%) of about 1% to about 30%, or about 5% to about 20% of the total lipids present in a liposome. In some embodiments, the percentage of cholesterol-based lipid in the lipid nanoparticle may be greater than about 5 mol%, greater than about 10 mol%, greater than about 20 mol%, greater than about 30 mol%, or greater than about 40 mol%. In some embodiments, the percentage of cholesterol-based lipid in the lipid nanoparticle may be no more than about 5 mol%, no more than about 10 mol%, no more than about 20 mol%, no more than about 30 mol%, or no more than about 40 mol%.

**[0193]** In some embodiments, a cholesterol-based lipid may be present in a weight ratio (wt%) of about 1% to about 30%, or about 5% to about 20% of the total lipids present in a liposome. In some embodiments, the percentage of cholesterol-based lipid in the lipid nanoparticle may be greater than about 5 wt%, greater than about 10 wt%, greater than about 20 wt%, greater than about 30 wt%, or greater than about 40 wt%. In some embodiments, the percentage of cholesterol-based lipid in the lipid nanoparticle may be no more than about 5 wt%, no more than about 10 wt%, no more than about 20 wt%, no more than about 30 wt%, or no more than about 40 wt%.

#### *PEGylated Lipids*

**[0194]** In some embodiments, a composition (*e.g.*, a liposomal composition) comprises one or more further PEGylated lipids. A suitable PEG-modified or PEGylated lipid for practicing the invention is 1,2-dimyristoyl-rac-glycero-3-methoxypolyethylene glycol-2000 (DMG-PEG2K).

**[0195]** For example, the use of polyethylene glycol (PEG)-modified phospholipids and derivatized lipids such as derivatized ceramides (PEG-CER), including N-octanoyl-sphingosine-1-[succinyl(methoxy polyethylene glycol)-2000] (C8 PEG-2000 ceramide) is also contemplated by the present invention in combination with one or more of compounds of the invention as described herein and, in some embodiments, other lipids together which comprise the liposome. In some

embodiments, particularly useful exchangeable lipids are PEG-ceramides having shorter acyl chains (*e.g.*, C<sub>14</sub> or C<sub>18</sub>).

**[0196]** Contemplated further PEG-modified lipids (also referred to herein as a PEGylated lipid, which term is interchangeable with PEG-modified lipid) include, but are not limited to, a polyethylene glycol chain of up to 5 kDa in length covalently attached to a lipid with alkyl chain(s) of C<sub>6</sub>-C<sub>20</sub> length. In some embodiments, a PEG-modified or PEGylated lipid is PEGylated cholesterol or PEG-2K. The addition of such components may prevent complex aggregation and may also provide a means for increasing circulation lifetime and increasing the delivery of the lipid-nucleic acid composition to the target cell, (Klibanov *et al.* (1990) FEBS Letters, 268 (1): 235-237), or they may be selected to rapidly exchange out of the formulation *in vivo* (see U.S. Pat. No. 5,885,613).

**[0197]** Further PEG-modified phospholipid and derivatized lipids of the present invention may be present in a molar ratio (mol%) from about 0% to about 10%, about 0.5% to about 10%, about 1% to about 10%, about 2% to about 10%, or about 3% to about 5% of the total lipid present in the composition (*e.g.*, a liposomal composition).

#### ***Pharmaceutical Formulations and Therapeutic Uses***

**[0198]** Compounds of the invention as described herein may be used in the preparation of compositions (*e.g.*, to construct liposomal compositions) that facilitate or enhance the delivery and release of encapsulated materials (*e.g.*, one or more therapeutic polynucleotides) to one or more target cells (*e.g.*, by permeating or fusing with the lipid membranes of such target cells).

**[0199]** For example, when a liposomal composition (*e.g.*, a lipid nanoparticle) comprises or is otherwise enriched with one or more of the compounds disclosed herein, the phase transition in the lipid bilayer of the one or more target cells may facilitate the delivery of the encapsulated materials (*e.g.*, one or more therapeutic polynucleotides encapsulated in a lipid nanoparticle) into the one or more target cells.

**[0200]** Similarly, in certain embodiments compounds of the invention as described herein may be used to prepare liposomal vehicles that are characterized by their reduced toxicity *in vivo*. In certain embodiments, the reduced toxicity is a function of the high transfection efficiencies associated with the compositions disclosed herein, such that a reduced quantity of such composition may administered to the subject to achieve a desired therapeutic response or outcome.

**[0201]** Thus, pharmaceutical formulations comprising a compound described and nucleic acids provided by the present invention may be used for various therapeutic purposes. To facilitate delivery of nucleic acids *in vivo*, a compound described herein and nucleic acids can be formulated in combination with one or more additional pharmaceutical carriers, targeting ligands or stabilizing reagents. In some embodiments, a compound described herein can be formulated via pre-mixed

lipid solution. In other embodiments, a composition comprising a compound described herein can be formulated using post-insertion techniques into the lipid membrane of the nanoparticles.

Techniques for formulation and administration of drugs may be found in "Remington's Pharmaceutical Sciences," Mack Publishing Co., Easton, Pa., latest edition.

**[0202]** Suitable routes of administration include, for example, oral, rectal, vaginal, transmucosal, pulmonary including intratracheal or inhaled, or intestinal administration; parenteral delivery, including intradermal, transdermal (topical), intramuscular, subcutaneous, intramedullary injections, as well as intrathecal, direct intraventricular, intravenous, intraperitoneal, or intranasal. In particular embodiments, the intramuscular administration is to a muscle selected from the group consisting of skeletal muscle, smooth muscle and cardiac muscle. In some embodiments the administration results in delivery of the nucleic acids to a muscle cell. In some embodiments the administration results in delivery of the nucleic acids to a hepatocyte (*i.e.*, liver cell).

**[0203]** A common route for administering a liposomal composition of the invention may be intravenous delivery, in particular when treating metabolic disorders, especially those affecting the liver (e.g., ornithine transcarbamylase (OTC) deficiency). Alternatively, depending on the disease or disorder to be treated, the liposomal composition may be administered via pulmonary delivery (e.g., for the treatment of cystic fibrosis). For vaccination, a liposomal composition of the invention is typically administered intramuscularly. Diseases or disorders affecting the eye may be treated by administering a liposomal composition of the invention intravitreally.

**[0204]** Alternatively or additionally, pharmaceutical formulations of the invention may be administered in a local rather than systemic manner, for example, via injection of the pharmaceutical formulation directly into a targeted tissue (e.g., in a sustained release formulation). Local delivery can be affected in various ways, depending on the tissue to be targeted. Exemplary tissues in which delivered mRNA may be delivered and/or expressed include, but are not limited to the liver, kidney, heart, spleen, serum, brain, skeletal muscle, lymph nodes, skin, and/or cerebrospinal fluid. In embodiments, the tissue to be targeted is the liver. For example, aerosols containing compositions of the present invention can be inhaled (for nasal, tracheal, or bronchial delivery); compositions of the present invention can be injected into the site of injury, disease manifestation, or pain, for example; compositions can be provided in lozenges for oral, tracheal, or esophageal application; can be supplied in liquid, tablet or capsule form for administration to the stomach or intestines, can be supplied in suppository form for rectal or vaginal application; or can even be delivered to the eye by use of creams, drops, or even injection.

**[0205]** Compositions described herein can comprise mRNA encoding peptides including those described herein (*e.g.*, a polypeptide such as a protein).

[0206] In embodiments, a mRNA encodes a polypeptide.

[0207] In embodiments, a mRNA encodes a protein.

[0208] Exemplary peptides encoded by mRNA (*e.g.*, exemplary proteins encoded by mRNA) are described herein.

[0209] The present invention provides methods for delivering a composition having full-length mRNA molecules encoding a peptide or protein of interest for use in the treatment of a subject, *e.g.*, a human subject or a cell of a human subject or a cell that is treated and delivered to a human subject.

### ***Delivery Methods***

[0210] The route of delivery used in the methods of the invention allows for non-invasive, self-administration of the compounds of the invention. In some embodiments, the methods involve intratracheal or pulmonary administration by aerosolization, nebulization, or instillation of a compositions comprising mRNA encoding a therapeutic protein in a suitable transfection or lipid carrier vehicles as described above. In some embodiments, the protein is encapsulated with a liposome. In some embodiments, the liposome comprises a lipid, which is a compound of the invention. As used herein below, administration of a compound of the invention includes administration of a composition comprising a compound of the invention.

[0211] Although the local cells and tissues of the lung represent a potential target capable of functioning as a biological depot or reservoir for production and secretion of the protein encoded by the mRNA, applicants have discovered that administration of the compounds of the invention to the lung via aerosolization, nebulization, or instillation results in the distribution of even non-secreted proteins outside the lung cells. Without wishing to be bound by any particular theory, it is contemplated that nanoparticle compositions of the invention pass, through the lung airway-blood barrier, resulting in translation of the intact nanoparticle to non-lung cells and tissues, such as, *e.g.*, the heart, the liver, the spleen, where it results in the production of the encoded protein in these non-lung tissues. Thus, the utility of the compounds of the invention and methods of the invention extend beyond production of therapeutic protein in lung cells and tissues of the lung and can be used to delivery to non-lung target cells and/or tissues. They are useful in the management and treatment of a large number of diseases, and in particular peripheral diseases which result from both secreted and non-secreted protein and/or enzyme deficiencies (*e.g.*, one or more lysosomal storage disorders). In certain embodiments, the compounds of the invention, used in the methods of the invention result in the distribution of the mRNA encapsulated nanoparticles and production of the encoded protein in the liver, spleen, heart, and/or other non-lung cells. For example, administration of the compounds of the invention, by aerosolization, nebulization, or instillation to

the lung will result in the composition itself and its protein product (*e.g.*, functional beta galactosidase protein) will be detectable in both the local cells and tissues of the lung, as well as in peripheral target cells, tissues and organs as a result of translocation of the mRNA and delivery vehicle to non-lung cells.

**[0212]** In certain embodiments, the compounds of the invention may be employed in the methods of the invention to specifically target peripheral cells or tissues. Following the pulmonary delivery, it is contemplated the compounds of the invention cross the lung airway-blood barrier and distribute into cells other than the local lung cells. Accordingly, the compounds disclosed herein may be administered to a subject by way of the pulmonary route of administration, using a variety of approach known by those skilled in the art (*e.g.*, by inhalation), and distribute to both the local target cells and tissues of the lung, as well as in peripheral non-lung cells and tissues (*e.g.*, cells of the liver, spleen, kidneys, heart, skeletal muscle, lymph nodes, brain, cerebrospinal fluid, and plasma). As a result, both the local cells of the lung and the peripheral non-lung cells can serve as biological reservoirs or depots capable of producing and/or secreting a translation product encoded by one or more polynucleotides. Accordingly, the present invention is not limited to the treatment of lung diseases or conditions, but rather can be used as a non-invasive means of facilitating the delivery of polynucleotides, or the production of enzymes and proteins encoded thereby, in peripheral organs, tissues and cells (*e.g.*, hepatocytes) which would otherwise be achieved only by systemic administration. Exemplary peripheral non-lung cells include, but are not limited to, hepatocytes, epithelial cells, hematopoietic cells, epithelial cells, endothelial 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.

**[0213]** Following administration of the composition to the subject, the protein product encoded by the mRNA (*e.g.*, a functional protein or enzyme) is detectable in the peripheral target tissues for at least about one to seven days or longer following administration of the compound to the subject. The amount of protein product necessary to achieve a therapeutic effect will vary depending on the condition being treated, the protein encoded, and the condition of the patient. For example, the protein product may be detectable in the peripheral target tissues at a concentration (*e.g.*, a therapeutic concentration) of at least 0.025-1.5  $\mu\text{g/ml}$  (*e.g.*, at least 0.050  $\mu\text{g/ml}$ , at least 0.075  $\mu\text{g/ml}$ , at least 0.1  $\mu\text{g/ml}$ , at least 0.2  $\mu\text{g/ml}$ , at least 0.3  $\mu\text{g/ml}$ , at least 0.4  $\mu\text{g/ml}$ , at least 0.5  $\mu\text{g/ml}$ , at least 0.6  $\mu\text{g/ml}$ , at least 0.7  $\mu\text{g/ml}$ , at least 0.8  $\mu\text{g/ml}$ , at least 0.9  $\mu\text{g/ml}$ , at least 1.0  $\mu\text{g/ml}$ , at least 1.1  $\mu\text{g/ml}$ , at least 1.2  $\mu\text{g/ml}$ , at least 1.3  $\mu\text{g/ml}$ , at least 1.4  $\mu\text{g/ml}$ , or at least 1.5  $\mu\text{g/ml}$ ), for at least

about 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 35, 40, 45 days or longer following administration of the compound to the subject.

**[0214]** It has been demonstrated that nucleic acids can be delivered to the lungs by intratracheal administration of a liquid suspension of the compound and inhalation of an aerosol mist produced by a liquid nebulizer or the use of a dry powder apparatus such as that described in U.S. patent 5,780,014, incorporated herein by reference.

**[0215]** In certain embodiments, the compounds of the invention may be formulated such that they may be aerosolized or otherwise delivered as a particulate liquid or solid prior to or upon administration to the subject. Such compounds may be administered with the assistance of one or more suitable devices for administering such solid or liquid particulate compositions (such as, *e.g.*, an aerosolized aqueous solution or suspension) to generate particles that are easily respirable or inhalable by the subject. In some embodiments, such devices (*e.g.*, a metered dose inhaler, jet-nebulizer, ultrasonic nebulizer, dry-powder-inhalers, propellant-based inhaler or an insufflator) facilitate the administration of a predetermined mass, volume or dose of the compositions (*e.g.*, about 0.5 mg/kg of mRNA per dose) to the subject. For example, in certain embodiments, the compounds of the invention are administered to a subject using a metered dose inhaler containing a suspension or solution comprising the compound and a suitable propellant. In certain embodiments, the compounds of the invention may be formulated as a particulate powder (*e.g.*, respirable dry particles) intended for inhalation. In certain embodiments, compositions of the invention formulated as respirable particles are appropriately sized such that they may be respirable by the subject or delivered using a suitable device (*e.g.*, a mean D50 or D90 particle size less than about 500 $\mu$ m, 400 $\mu$ m, 300 $\mu$ m, 250 $\mu$ m, 200 $\mu$ m, 150 $\mu$ m, 100 $\mu$ m, 75 $\mu$ m, 50 $\mu$ m, 25 $\mu$ m, 20 $\mu$ m, 15 $\mu$ m, 12.5 $\mu$ m, 10 $\mu$ m, 5 $\mu$ m, 2.5 $\mu$ m or smaller). In yet other embodiments, the compounds of the invention are formulated to include one or more pulmonary surfactants (*e.g.*, lamellar bodies). In some embodiments, the compounds of the invention are administered to a subject such that a concentration of at least 0.05 mg/kg, at least 0.1 mg/kg, at least 0.5 mg/kg, at least 1.0 mg/kg, at least 2.0 mg/kg, at least 3.0 mg/kg, at least 4.0 mg/kg, at least 5.0 mg/kg, at least 6.0 mg/kg, at least 7.0 mg/kg, at least 8.0 mg/kg, at least 9.0 mg/kg, at least 10 mg/kg, at least 15 mg/kg, at least 20 mg/kg, at least 25 mg/kg, at least 30 mg/kg, at least 35 mg/kg, at least 40 mg/kg, at least 45 mg/kg, at least 50 mg/kg, at least 55 mg/kg, at least 60 mg/kg, at least 65 mg/kg, at least 70 mg/kg, at least 75 mg/kg, at least 80 mg/kg, at least 85 mg/kg, at least 90 mg/kg, at least 95 mg/kg, or at least 100 mg/kg body weight is administered in a single dose. In some embodiments, the compounds of the invention are administered to a subject such that a total amount of at least 0.1 mg, at least 0.5 mg, at least 1.0 mg, at least 2.0 mg, at least 3.0 mg, at least 4.0 mg, at least 5.0 mg, at least 6.0 mg, at

least 7.0 mg, at least 8.0 mg, at least 9.0 mg, at least 10 mg, at least 15 mg, at least 20 mg, at least 25 mg, at least 30 mg, at least 35 mg, at least 40 mg, at least 45 mg, at least 50 mg, at least 55 mg, at least 60 mg, at least 65 mg, at least 70 mg, at least 75 mg, at least 80 mg, at least 85 mg, at least 90 mg, at least 95 mg or at least 100 mg mRNA is administered in one or more doses.

Synthesis of Compounds of the Invention

[0216] The cationic lipid MC3 is the current gold standard for *in vivo* delivery of *e.g.* siRNA (see WO2010/144740). However, the synthesis of this lipid involves a six-step process and requires handling of a Grignard reagent. In contrast, the present invention provides cationic lipids that can be prepared from readily available starting reagents, such as TES (N-[Tris(hydroxymethyl)methyl]-2-aminoethanesulfonic acid) (see Table 1 below). These starting reagents can be coupled to cationic headgroups and lipid tails using coupling reactions, such as sulfonylation, acetylation and alkylation (see for example, Table 2 below).

Table 1

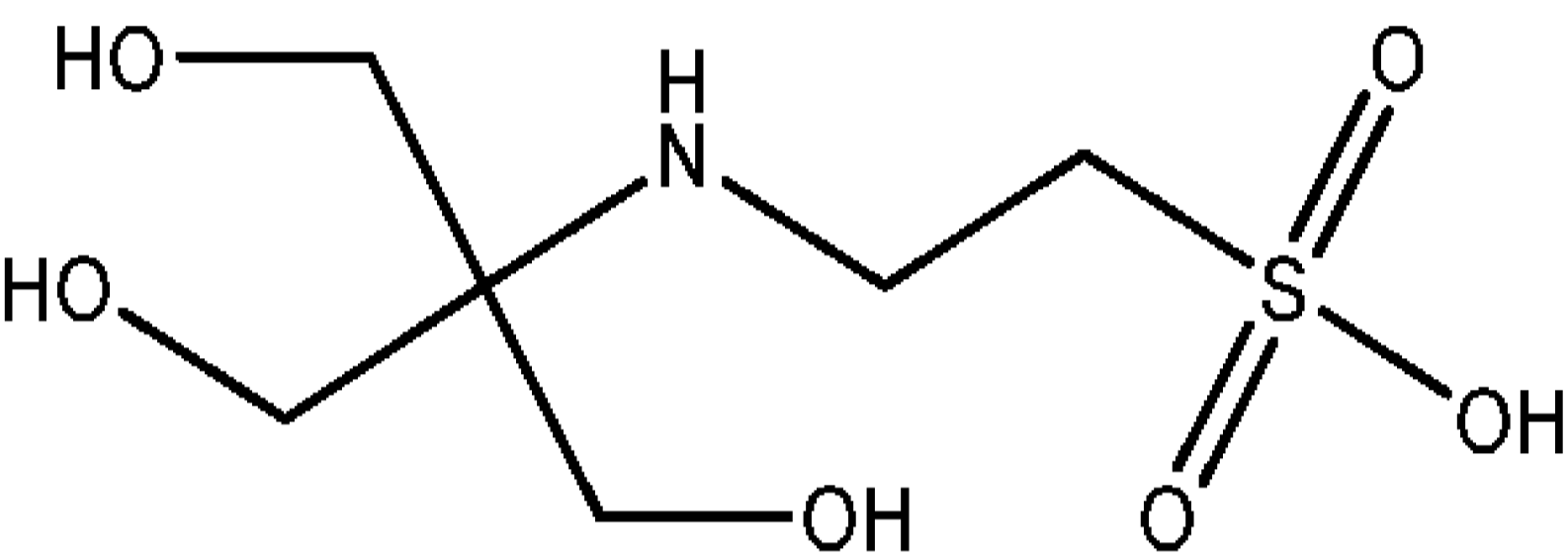
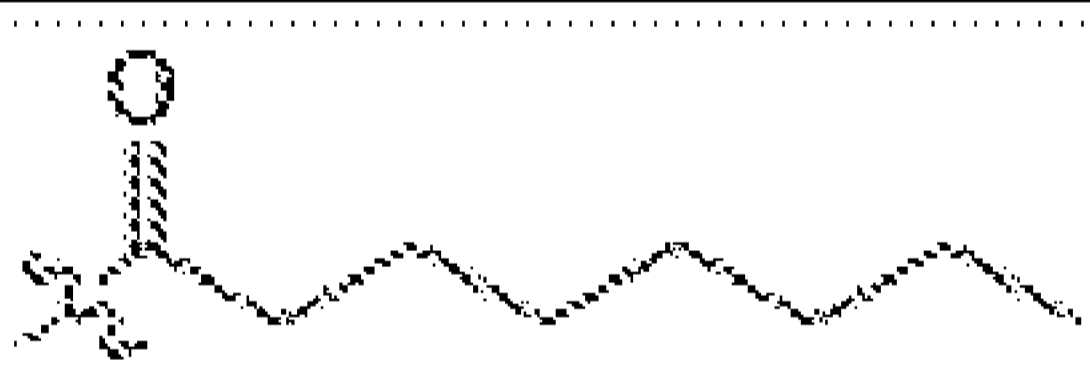
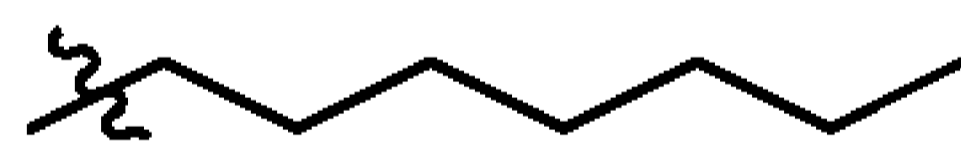
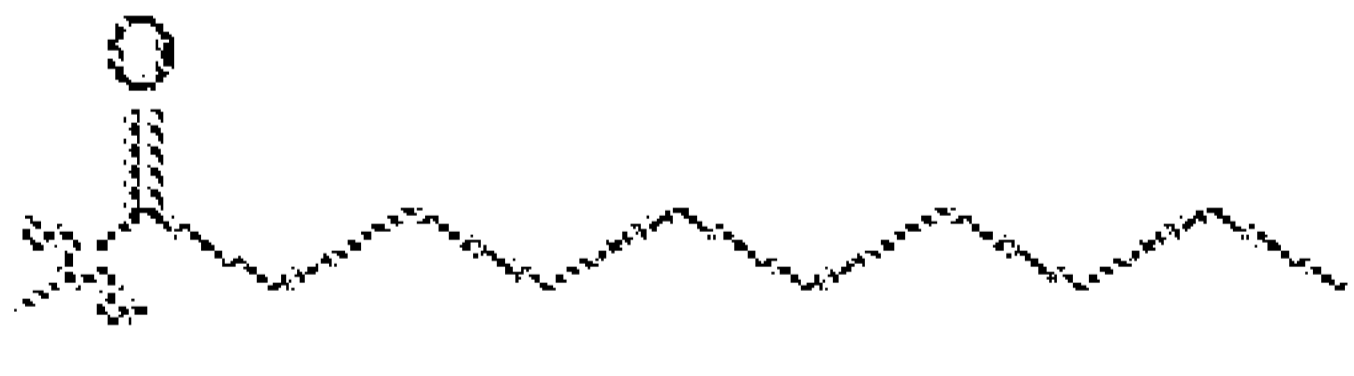


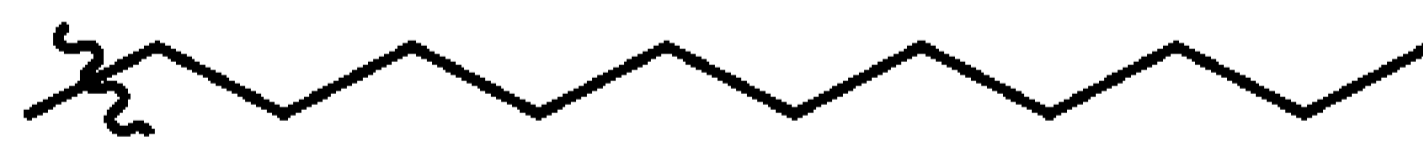
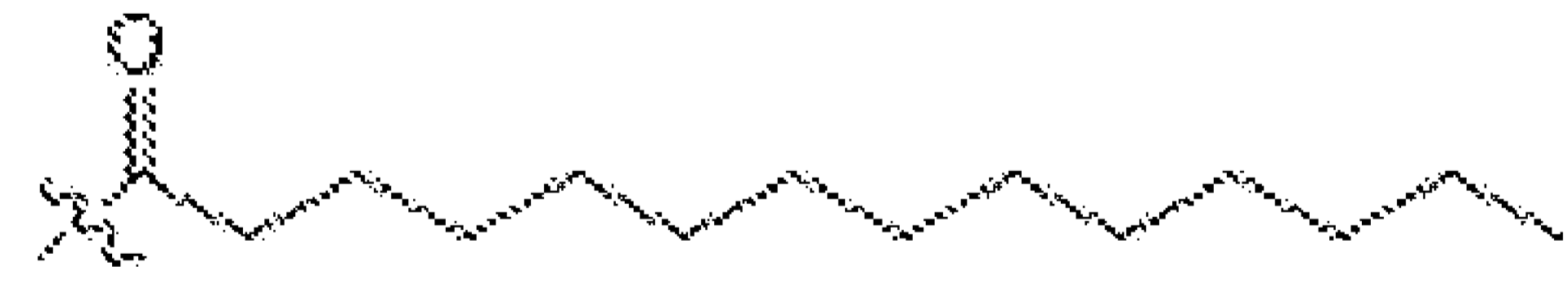

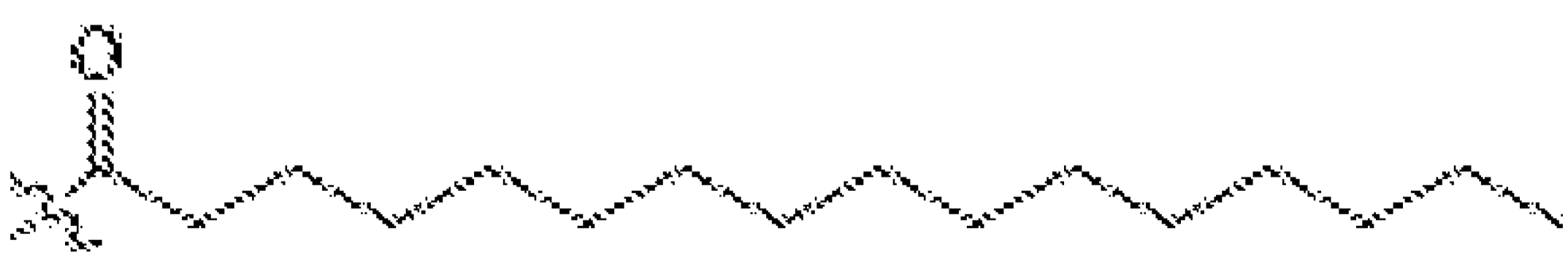



"Good" Buffer name	Structure
TES	

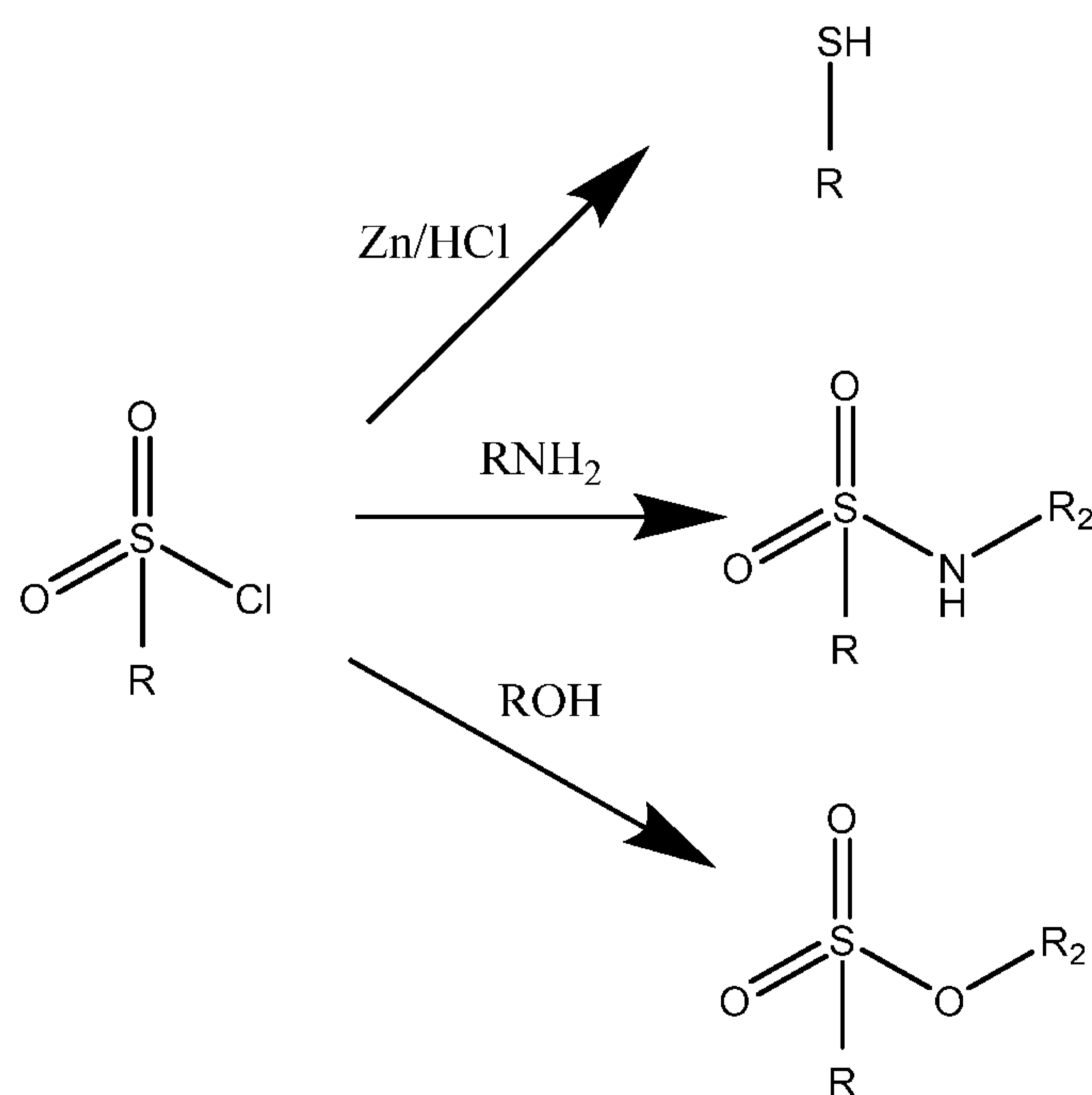
Table 2: Examples of lipid chains that are suitable for the present invention:

Carbon Chain	Full chain	R <sup>5</sup> in compounds of the invention
Caprylic (C8)		
Capric (C10)		
Lauric (C12)		
Myristic (C14)		
Palmitic (C16)		
Stearic (C18)		

Oleic (C18:) (9Z)		
Linoleic (C18:2) (9Z, 12Z)		
Linolenic (C18:3) (9Z, 12Z, 15Z)		

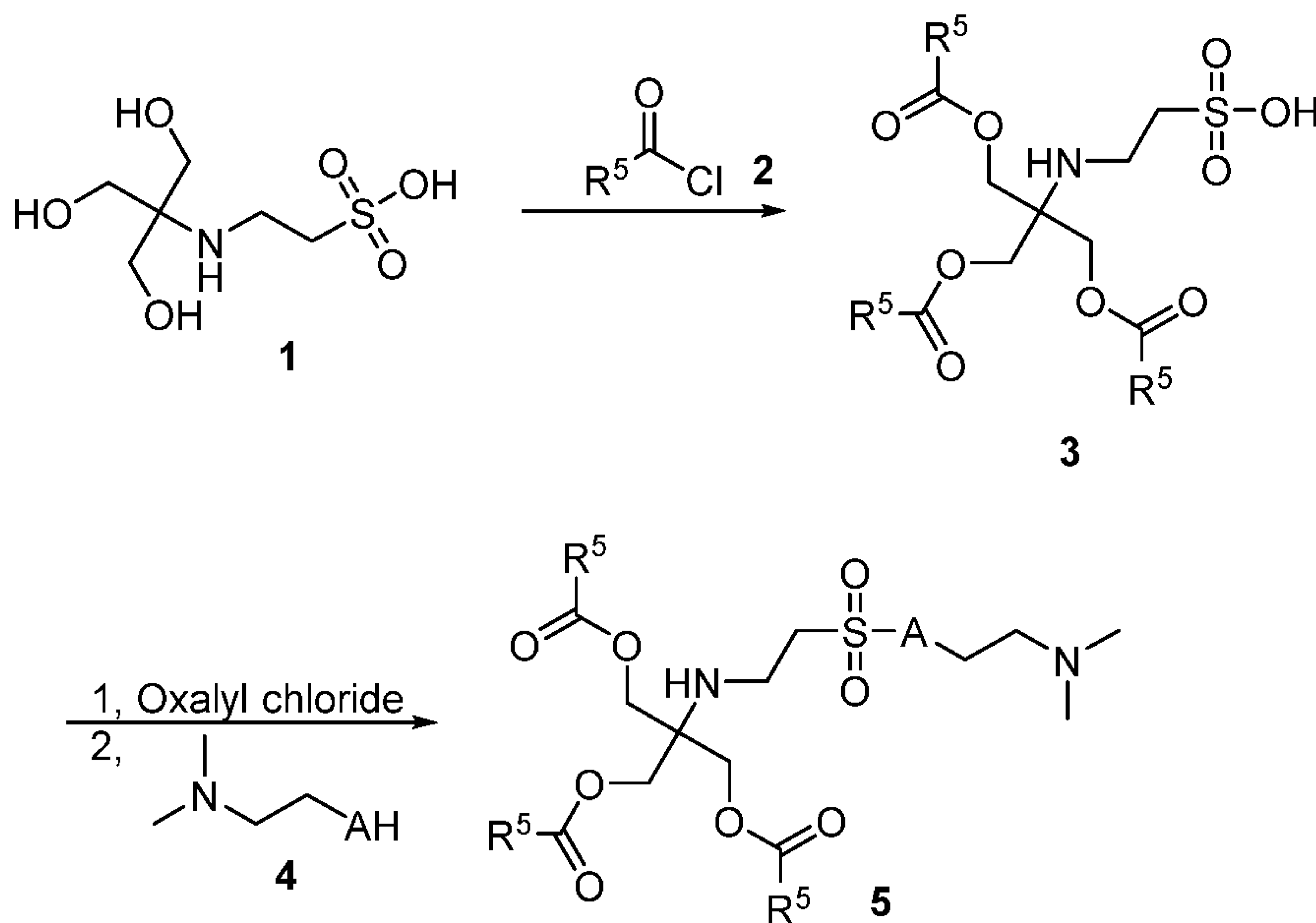
**[0217]** In embodiments, a cationic lipid described herein can be prepared by conjugating a “Good’s” Buffer with a lipid, for example the carboxylic acid of a lipid, under suitable conditions. Exemplary lipid chains are described in **Table 2**. Accordingly, suitable cationic lipids include those resulting from any combination of the precursors described in **Table 1** and **Table 2**.

**[0218]** In some embodiments, the sulfonic acid groups of compounds, such as “Good’s” buffers can be derivatized by forming a sulfonyl chloride using reagents, such as oxalyl chloride. The resulting sulfonyl chloride can undergo a number of reactions, including but not limited to reduction with Zn/HCl to form the corresponding thiol and coupling to nucleophiles, such as amines and alcohols to form the corresponding sulfonamides and sulfonates (see for example, **Scheme 1** below):



**[0219]** Using the chemistry outlined in **Scheme 1** it is possible to derivatise the sulfonic acid starting reagents with a range of suitable cationic lipid head groups and lipid chains.

[0220] For example, a cationic lipid according to the present invention (compound 3) can be synthesized by reacting TES (compound 1) with an acyl chloride (compound 2) in a first step. A cationic head group, such as compound 4, can then be added using oxalyl chloride in a second step to form the lipid 5 (see for example, **Scheme 2**).



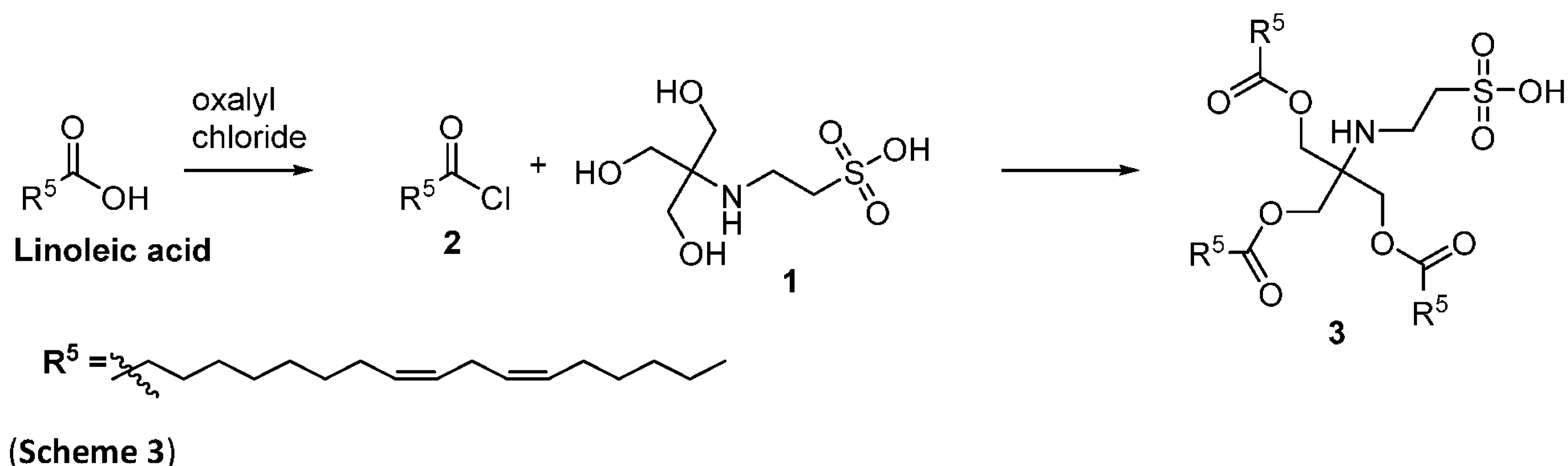
[0221] The compounds of the invention as described herein can be prepared according to methods known in the art, including the exemplary syntheses of the Examples provided herein.

### EXAMPLES

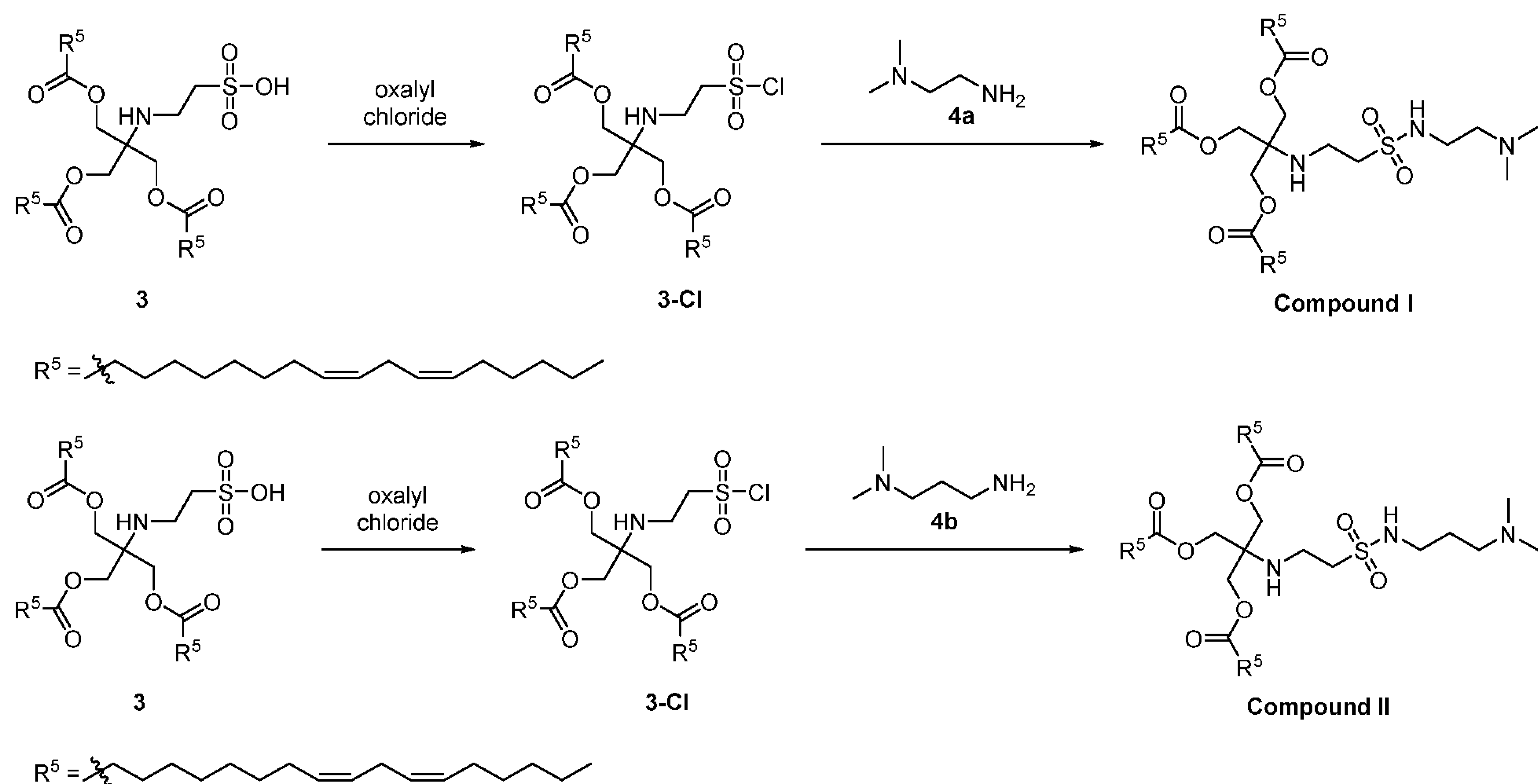
[0222] While certain compounds, compositions and methods of the present invention have been described with specificity in accordance with certain embodiments, the following examples serve only to illustrate the compounds of the invention and are not intended to limit the same.

#### Example 1: General synthesis scheme for TES-based cationic lipids

[0223] For example, the compounds of the invention may be prepared according to **Scheme 3**:



[0224] Linoleic acid is treated with a chlorinating reagent such as oxalyl chloride to provide the acyl chloride compound 2. Reaction of compound 2 with a nucleophilic compound, such as the buffer compound 1, affords compound 3.



[0225] Compound 3 is treated with a chlorinating agent such as oxalyl chloride to provide the electrophilic compound 3-Cl. Reaction of 3-Cl with a nucleophile such as compound 4a or 4b then affords compounds I and II respectively (see **Scheme 4** above).

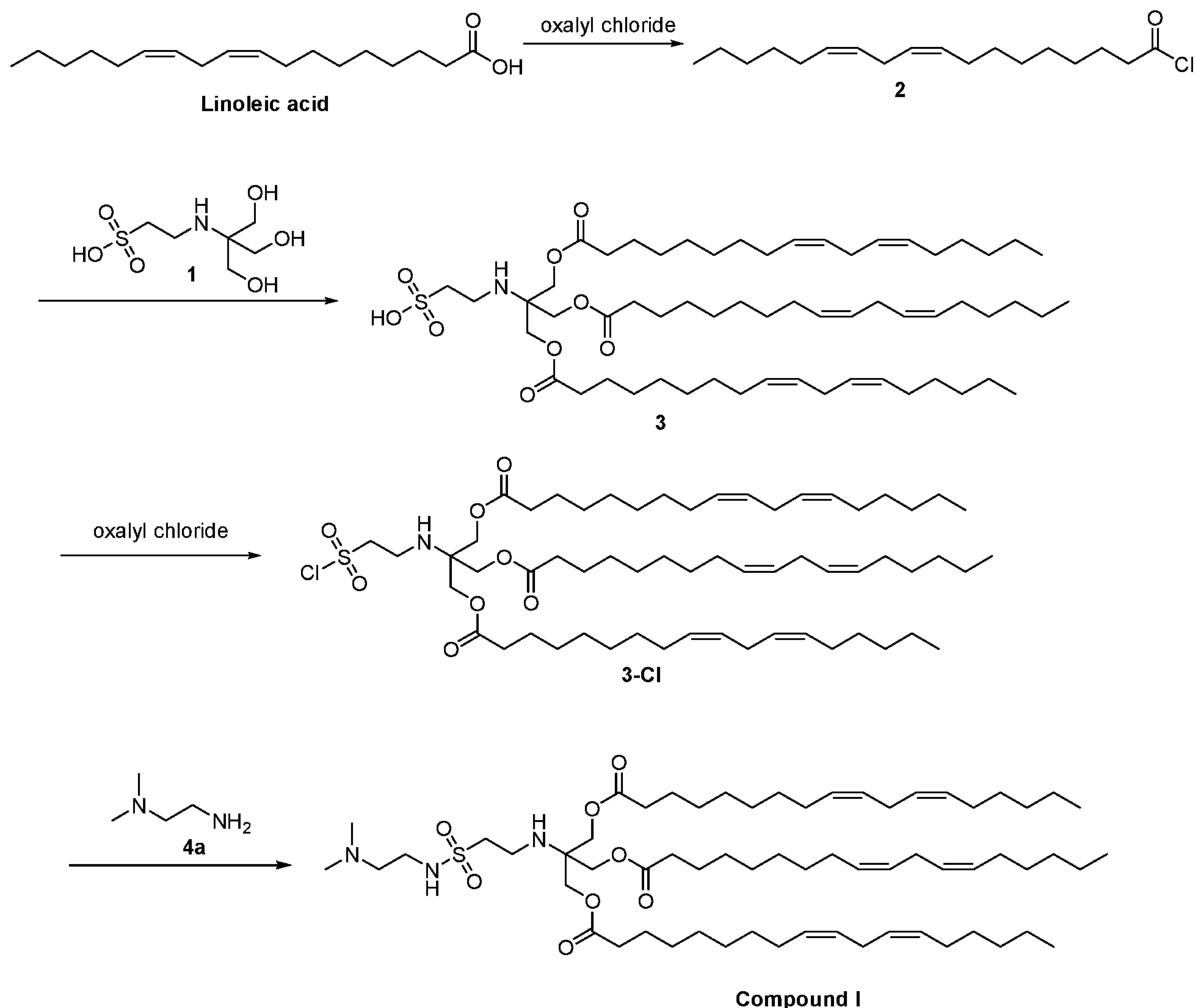
[0226] The lipids according to **Schemes 3 & 4** were prepared using the following reaction conditions:

SM	Product	Reaction Conditions	Scale	Yield
<b>Linoleic acid</b>	<b>2</b>	Oxalyl chloride, DMF DCM	1.0 g of <b>linoleic acid</b>	-
<b>1 &amp; 2</b>	<b>3</b>	Dimethylacetamide + N-Methylmorpholine	200 mg of <b>1</b>	562 mg 47% yield
<b>3</b>	<b>3-Cl</b>	Oxalyl chloride, DMF DCM	200 mg of <b>3</b>	-
<b>3-Cl &amp; 4b</b>	<b>Compound II</b>	DCM	200 mg of <b>3-Cl</b>	105 mg (49% over 2 steps)

3-Cl & 4a	Compound I	DCM	200 mg of 3-Cl	136 mg (62% yield over 2 steps)
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Example 2: Specific synthesis scheme for TES-based cationic lipids

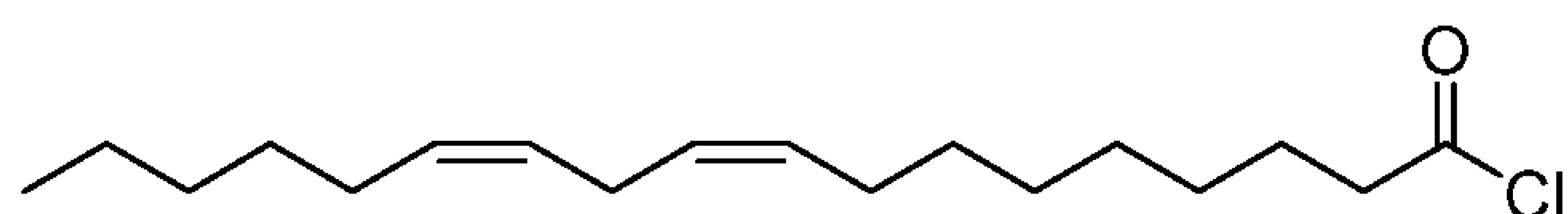
[0227] Scheme 5 was used to prepare compound I, as illustrated below:



(Scheme 5)

[0228] In particular, compound I was prepared according to **Scheme 5** using the following synthesis steps:

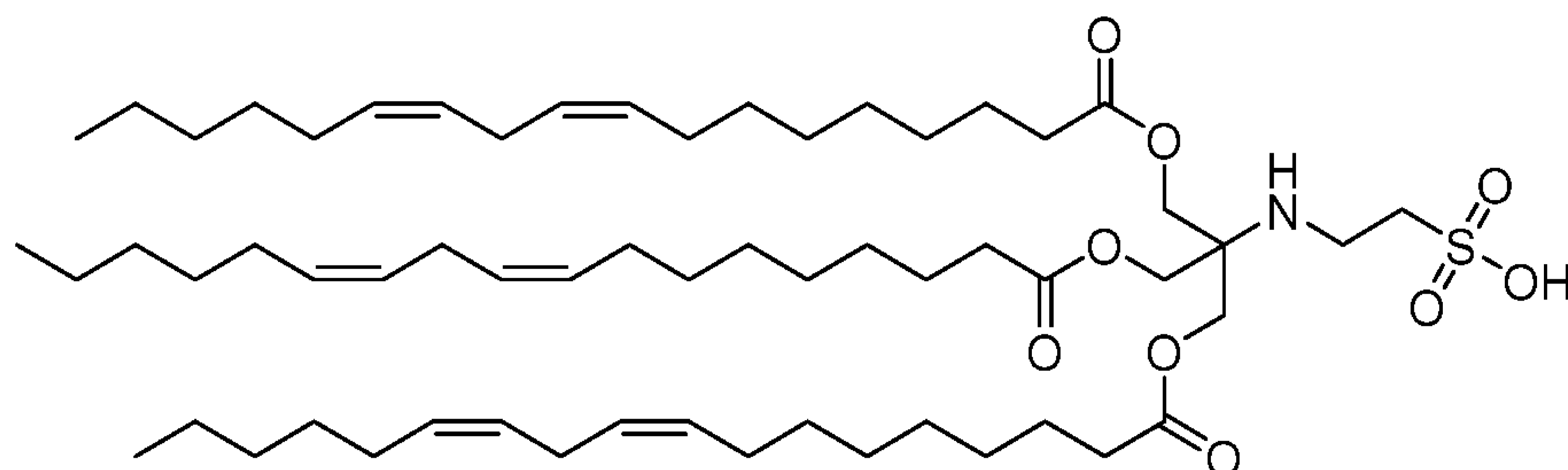
Synthesis of (9Z,12Z)-Octadeca-9,12-dienoyl chloride (2)



[0229] To a solution of Linolenic acid (1.0 g, 3.6 mmol) in 10 mL dichloromethane at 0 °C, was added *N,N*-dimethylformamide (0.1 mL) and oxalyl chloride (1.2 mL, 14.3 mmol). The reaction mixture was

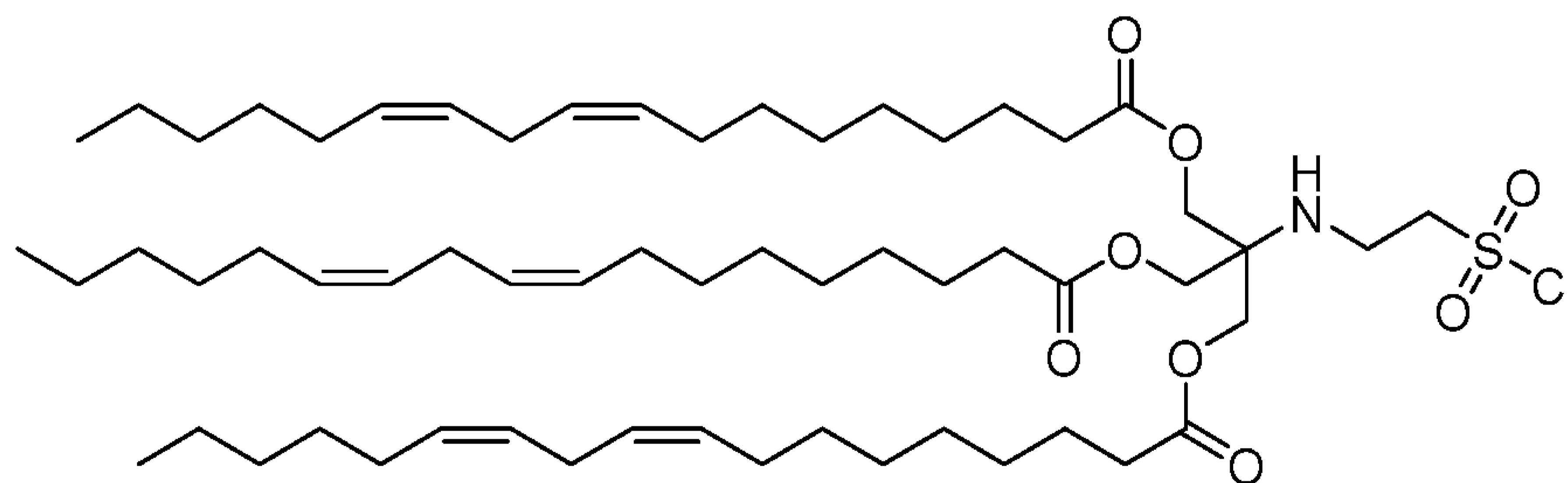
warmed to room temperature and stirred for 3 h. The solvent was removed to the under reduced pressure, and the crude was used in next step without further purification.

**Synthesis of 2-((1,3-Bis(((9Z,12Z)-octadeca-9,12-dienoyl)oxy)-2-(((9Z,12Z)-octadeca-9,12-dienoyl)oxy)methyl)propan-2-yl)amino)ethane-1-sulfonic acid (3)**



**[0230]** To a solution of (9Z,12Z)-octadeca-9,12-dienoyl chloride **2** (1.1 g, 3.6 mmol) in anhydrous *N,N*-dimethylacetamide (5.0 mL) and *N*-methyl morpholine (3.0 mL), was added 2-((1,3-dihydroxy-2-(hydroxymethyl)propan-2-yl)amino)ethane-1-sulfonic acid (**1, TES**) (200 mg, 0.87 mmol). The reaction mixture was heated to 55 °C for 3 h. MS analysis showed the formation of desired product. The reaction mixture was cooled to room temperature, diluted with water (100 mL) and extracted with dichloromethane (2 x 100 mL). The combined organic layer was washed with saturated brine (100 mL) and dried over anhydrous sodium sulfate. The solvent was removed under vacuum, and the residue was purified by column chromatography (40 g SiO<sub>2</sub>: 0 to 10% methanol in dichloromethane gradient) to obtain 2-((1,3-bis(((9Z,12Z)-octadeca-9,12-dienoyl)oxy)-2-(((9Z,12Z)-octadeca-9,12-dienoyl)oxy)methyl)propan-2-yl)amino)ethane-1-sulfonic acid as colorless solid (562 mg, 47% yield).

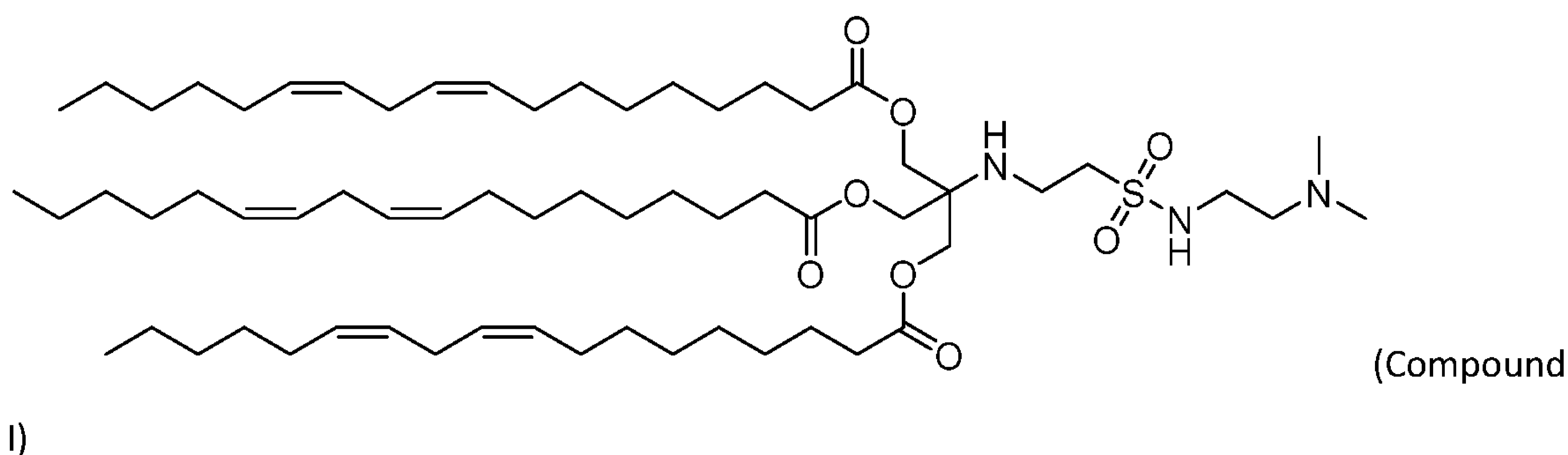
**Synthesis of 2-((2-(Chlorosulfonyl)ethyl)amino)-2-(((9Z,12Z)-octadeca-9,12-dienoyl)oxy)methyl)propane-1,3-diyl (9Z,9'Z,12Z,12'Z)-bis(octadeca-9,12-dienoate) (3-Cl)**



**[0231]** To a solution of 2-((1,3-bis(((9Z,12Z)-octadeca-9,12-dienoyl)oxy)-2-(((9Z,12Z)-octadeca-9,12-dienoyl)oxy)methyl)propan-2-yl)amino)ethane-1-sulfonic acid **3** (210 mg, 0.82 mmol) in anhydrous dichloromethane (5.0 mL) at 0 °C was added *N,N*-dimethylformamide (0.05 mL) and oxalyl chloride (0.08 mL, 2.1 mmol). The reaction mixture was warmed to room temperature and stirred for 3 h. The solvent was removed to the dryness under reduced pressure to give 2-((2-(chlorosulfonyl)ethyl)amino)-2-(((9Z,12Z)-octadeca-9,12-dienoyl)oxy)methyl)propane-1,3-diyl

(9Z,9'Z,12Z,12'Z)-bis(octadeca-9,12-dienoate), which was used in next step without further purification.

**Synthesis of 2-((2-(N-(2-(dimethylamino)ethyl)sulfamoyl)ethyl)amino)-2-(((9Z,12Z)-octadeca-9,12-dienoyl)oxy)methyl)propane-1,3-diyl (9Z,9'Z,12Z,12'Z)-bis(octadeca-9,12-dienoate) (Compound I)**



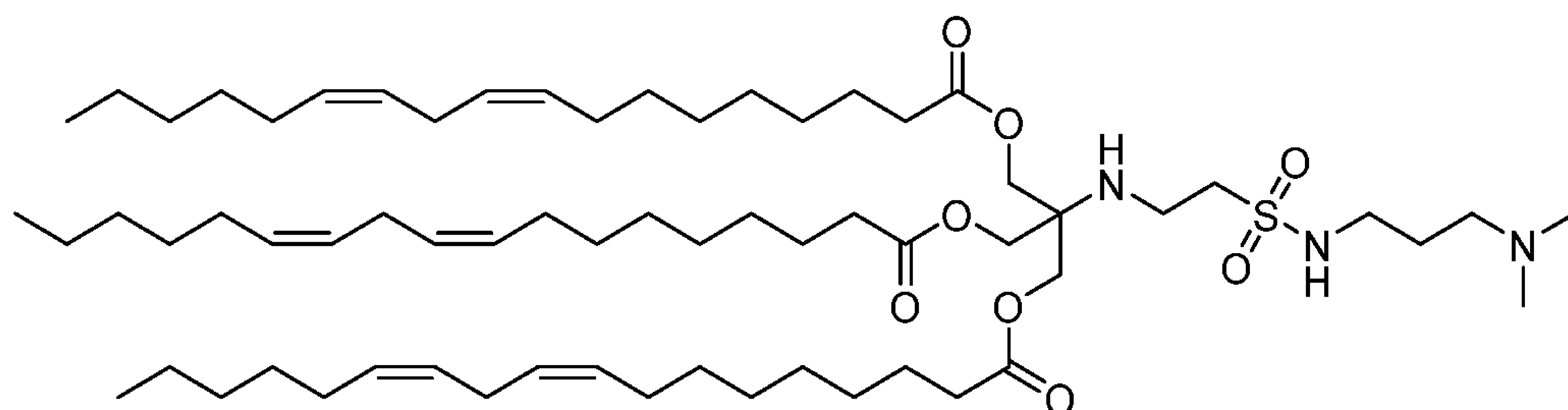
**[0232]** To a solution of 2-((2-(chlorosulfonyl)ethyl)amino)-2-(((9Z,12Z)-octadeca-9,12-dienoyl)oxy)methyl)propane-1,3-diyl (9Z,9'Z,12Z,12'Z)-bis(octadeca-9,12-dienoate) 3-Cl (210 mg, 0.82 mmol) in anhydrous dichloromethane (5.0 mL) at 0 °C was added *N*<sup>1</sup>,*N*<sup>1</sup>-dimethylethane-1,2-diamine (182 mg, 2.1 mmol). The reaction mixture was warmed to room temperature and stirred for 3 h. The reaction was quenched by addition of water, and the mixture was extracted with dichloromethane (2 x 100 mL). The combined organic layer was washed with saturated brine (100 mL) and dried over anhydrous sodium sulfate. The solvent was removed, and the crude was purified by column chromatography (40 g SiO<sub>2</sub>: 0 to 15% methanol in dichloromethane gradient) to obtain 2-((2-(N-(2-(dimethylamino)ethyl)sulfamoyl)ethyl)amino)-2-(((9Z,12Z)-octadeca-9,12-dienoyl)oxy)methyl)propane-1,3-diyl (9Z,9'Z,12Z,12'Z)-bis(octadeca-9,12-dienoate) as yellow oil (139 mg, 62% yield).

**[0233]** <sup>1</sup>H NMR (300 MHz, Chloroform-*d*) δ 5.26-5.44 (m, 12H), 4.09 (s, 6H), 3.06-3.18 (m, 6H), 2.75 (t, 6H), 2.47 (t, 2H), 2.32 (t, 6H), 2.24 (s, 6H), 2.00-2.10 (m, 12H), 1.52-1.65 (m, 4H), 1.20-1.40 (m, 44H), 0.88 (t, 9H).

**[0234]** APCI-MS analysis: Calculated C<sub>64</sub>H<sub>115</sub>N<sub>3</sub>O<sub>8</sub>S, [M+H] = 1186.7, observed = 1186.8.

**[0235]** All other cationic lipids were prepared following the above representative procedure in similar yields.

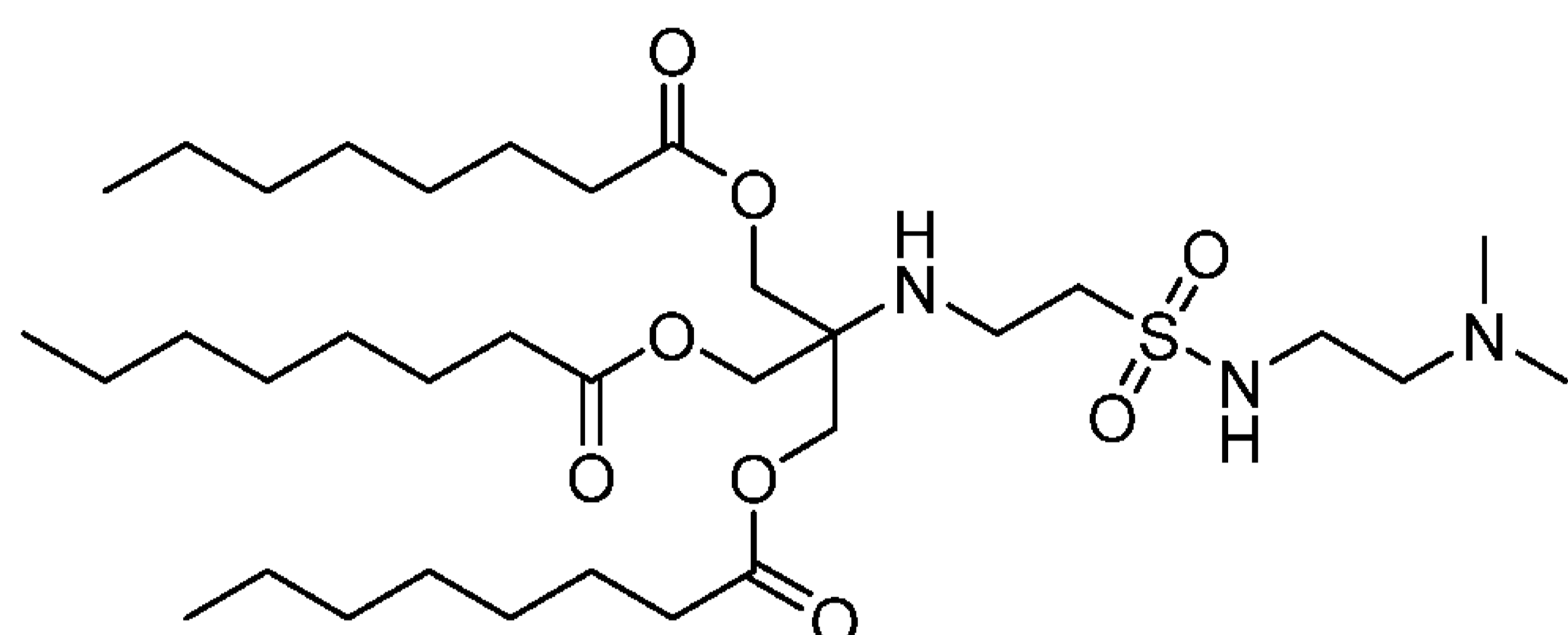
**Analytical data for 2-((2-(N-(3-(dimethylamino)propyl)sulfamoyl)ethyl)amino)-2-(((9Z,12Z)-octadeca-9,12-dienoyl)oxy)methyl)propane-1,3-diyl (9Z,9'Z,12Z,12'Z)-bis(octadeca-9,12-dienoate) (Compound II)**



[0236]  $^1\text{H NMR}$  (300 MHz, Chloroform- $d$ )  $\delta$  5.24-5.42 (m, 12H), 4.08 (s, 6H), 3.17 (t, 2H), 3.06 (bs, 4H), 2.75 (t, 6H), 2.43 (t, 2H), 2.31 (t, 6H), 2.23 (s, 6H), 1.98-2.08 (m, 12H), 1.70 (quint, 2H), 1.52-1.63 (m, 4H), 1.17-1.45 (m, 44H), 0.87 (t, 9H).

[0237] APCI-MS analysis: Calculated  $\text{C}_{65}\text{H}_{117}\text{N}_3\text{O}_8\text{S}$ ,  $[\text{M}+\text{H}] = 1100.7$ , observed = 1100.8.

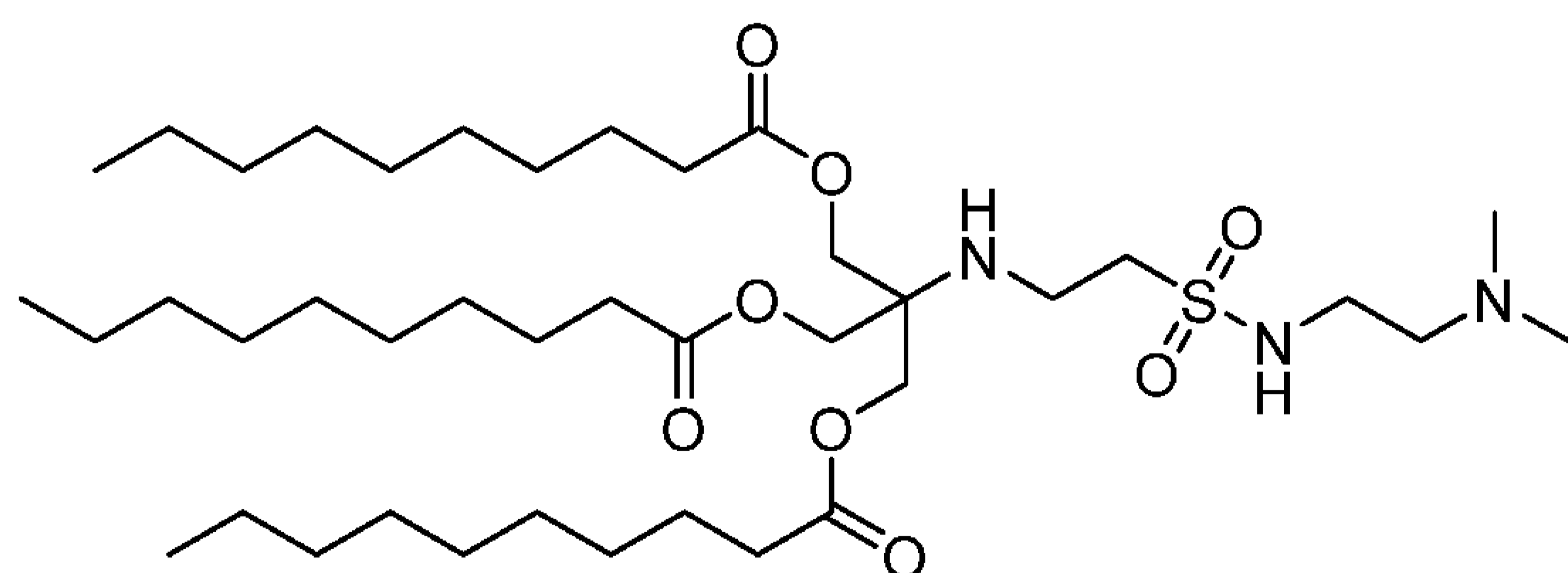
**Analytical data for 2-((2-(N-(2-(Dimethylamino)ethyl)sulfamoyl)ethyl)amino)-2-((octanoyloxy)methyl)propane-1,3-diyl dioctanoate (Compound V)**



[0238]  $^1\text{H NMR}$  (300 MHz, Chloroform- $d$ )  $\delta$  4.09 (s, 6H), 3.05-3.18 (m, 6H), 2.44 (t, 2H), 2.32 (t, 6H), 2.22 (s, 6H), 1.54-1.65 (m, 6H), 1.20-1.40 (m, 24H), 0.86 (t, 9H).

[0239] APCI-MS analysis: Calculated  $\text{C}_{34}\text{H}_{67}\text{N}_3\text{O}_8\text{S}$ ,  $[\text{M}+\text{H}] = 678.4$ , observed = 678.5.

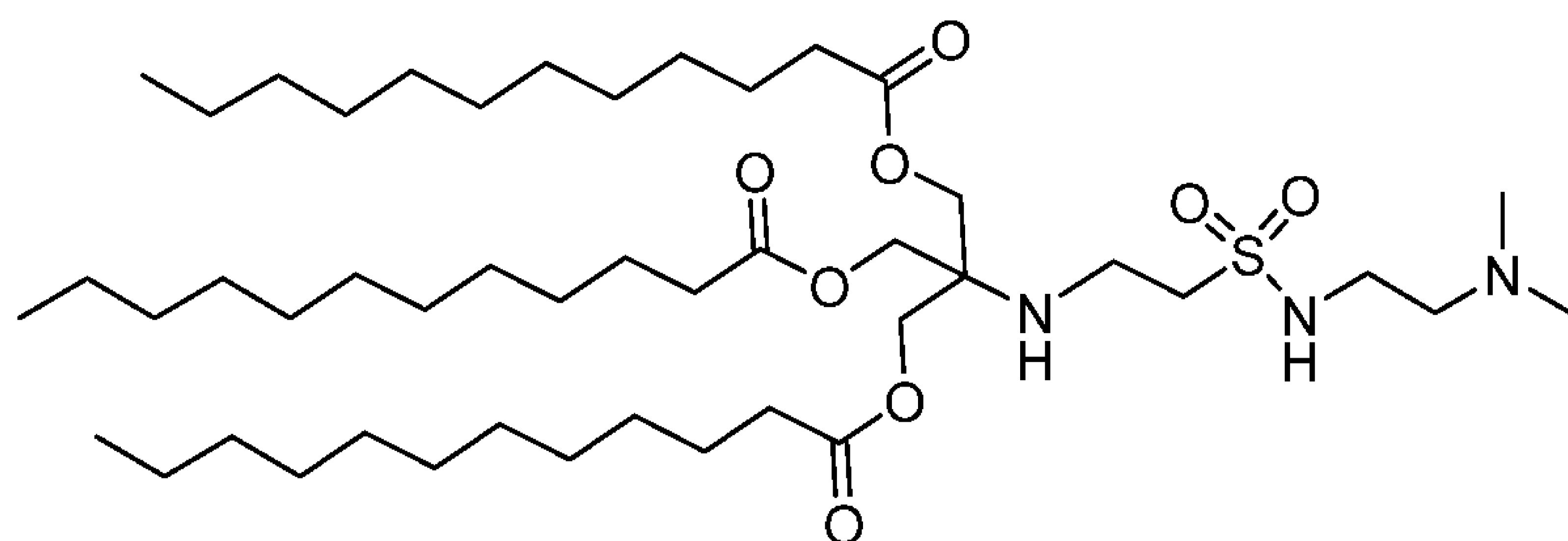
**Analytical data for 2-((Decanoyloxy)methyl)-2-((2-(N-(2-(Dimethylamino)ethyl)sulfamoyl)ethyl)amino)propane-1,3-diyl bis(decanoate) (Compound VI)**



[0240]  $^1\text{H NMR}$  (300 MHz, Chloroform- $d$ )  $\delta$  4.08 (s, 6H), 3.04-3.16 (m, 6H), 2.45 (t, 2H), 2.31 (t, 6H), 2.23 (s, 6H), 1.52-1.65 (m, 6H), 1.20-1.40 (m, 38H), 0.86 (t, 9H).

[0241] APCI-MS analysis: Calculated  $\text{C}_{40}\text{H}_{79}\text{N}_3\text{O}_8\text{S}$ ,  $[\text{M}+\text{H}] = 762.4$ , observed = 762.5.

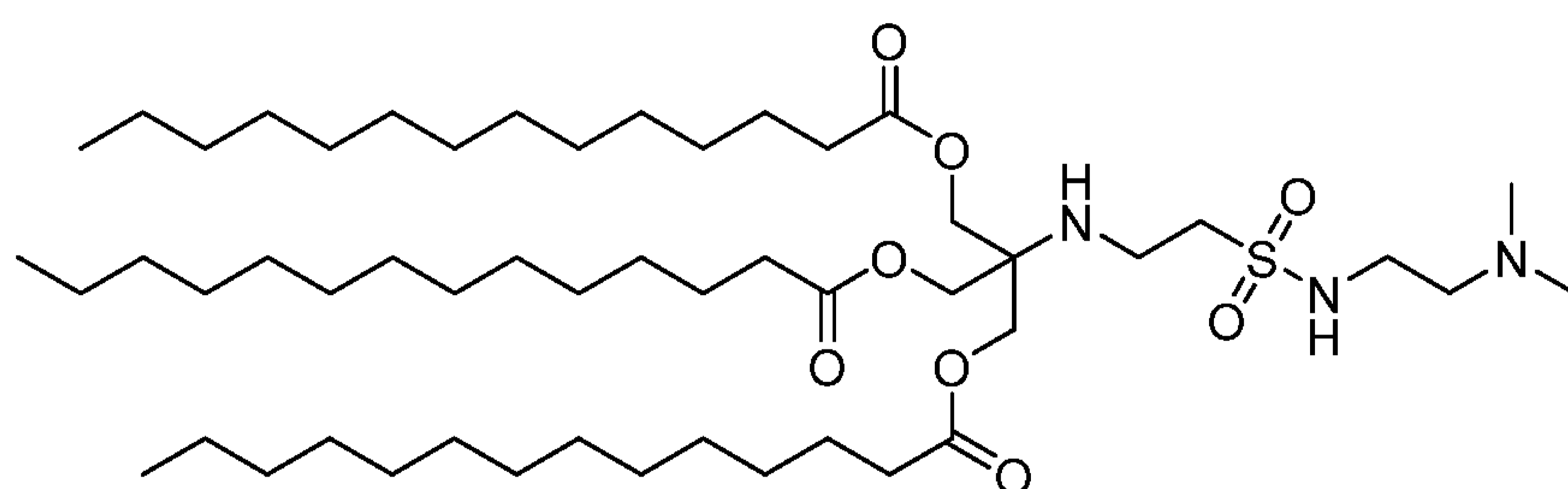
**Analytical data for 2-((2-(N-(2-(Dimethylamino)ethyl)sulfamoyl)ethyl)amino)-2-((dodecanoyloxy)methyl)propane-1,3-diyl didodecanoate (Compound VII)**



[0242]  $^1\text{H NMR}$  (300 MHz, Chloroform- $d$ )  $\delta$  4.08 (s, 6H), 3.04-3.19 (m, 6H), 2.46 (t, 2H), 2.32 (t, 6H), 2.23 (s, 6H), 1.52-1.66 (m, 6H), 1.16-1.34 (m, 50H), 0.86 (t, 9H).

[0243] APCI-MS analysis: Calculated  $\text{C}_{46}\text{H}_{91}\text{N}_3\text{O}_8\text{S}$ ,  $[\text{M}+\text{H}] = 846.6$ , observed = 846.7.

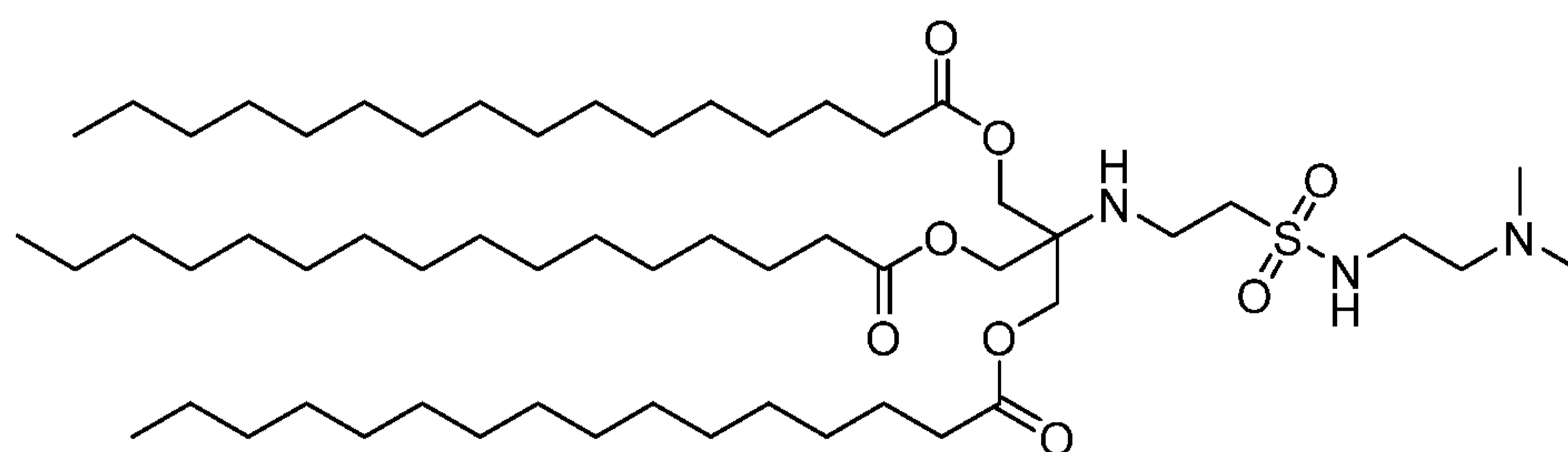
**Analytical data for 2-((2-(N-(2-(Dimethylamino)ethyl)sulfamoyl)ethyl)amino)-2-((tetradecanoyloxy)methyl)propane-1,3-diyl ditetradecanoate (Compound VIII)**



[0244]  $^1\text{H NMR}$  (300 MHz, Chloroform- $d$ )  $\delta$  4.07 (s, 6H), 3.15 (t, 2H), 2.98-3.12 (m, 4H), 2.46 (t, 2H), 2.30 (t, 6H), 2.23 (s, 6H), 1.50-1.64 (m, 6H), 1.16-1.34 (m, 62H), 0.86 (t, 9H).

[0245] APCI-MS analysis: Calculated  $\text{C}_{52}\text{H}_{103}\text{N}_3\text{O}_8\text{S}$ ,  $[\text{M}+\text{H}] = 930.7$ , observed = 930.6.

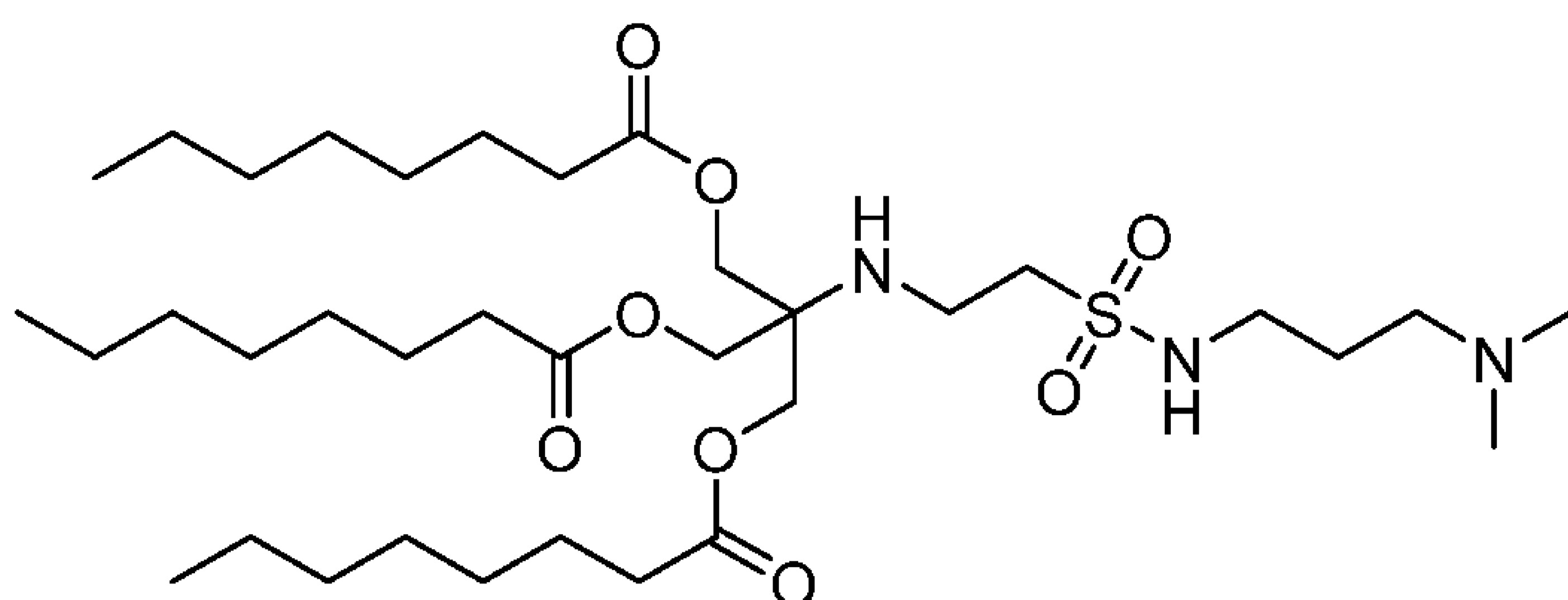
**Analytical data for 2-((2-(N-(2-(Dimethylamino)ethyl)sulfamoyl)ethyl)amino)-2-((palmitoyloxy)methyl)propane-1,3-diyl dipalmitate (Compound IX)**



[0246]  $^1\text{H NMR}$  (300 MHz, Chloroform- $d$ )  $\delta$  4.09 (s, 6H), 3.15 (t, 2H), 2.98-3.12 (m, 4H), 2.48 (t, 2H), 2.32 (t, 6H), 2.25 (s, 6H), 1.53-1.64 (m, 6H), 1.16-1.34 (m, 74H), 0.86 (t, 9H).

[0247] APCI-MS analysis: Calculated  $\text{C}_{58}\text{H}_{115}\text{N}_3\text{O}_8\text{S}$ ,  $[\text{M}+\text{H}] = 1014.8$ , observed = 1014.7.

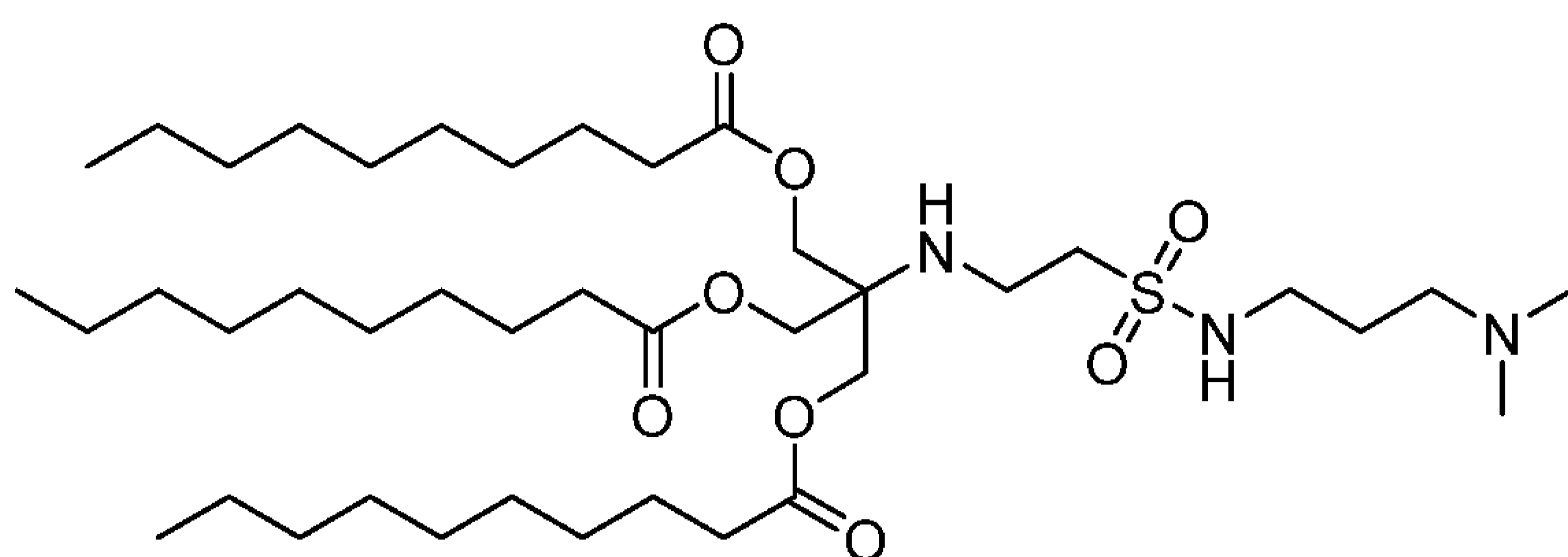
**Analytical data for 2-((2-(N-(3-(Dimethylamino)propyl)sulfamoyl)ethyl)amino)-2-((octanoyloxy)methyl)propane-1,3-diyl dioctanoate (Compound X)**



[0248]  $^1\text{H NMR}$  (300 MHz, Chloroform- $d$ )  $\delta$  4.08 (s, 6H), 3.18 (t, 2H), 3.02-3.12 (m, 4H), 2.48 (t, 2H), 2.31 (t, 6H), 2.27 (s, 6H), 1.73 (quint, 2H), 1.52-1.65 (m, 6H), 1.20-1.40 (m, 24H), 0.86 (t, 9H).

[0249] APCI-MS analysis: Calculated  $\text{C}_{35}\text{H}_{69}\text{N}_3\text{O}_8\text{S}$ ,  $[\text{M}+\text{H}] = 692.4$ , observed = 692.5.

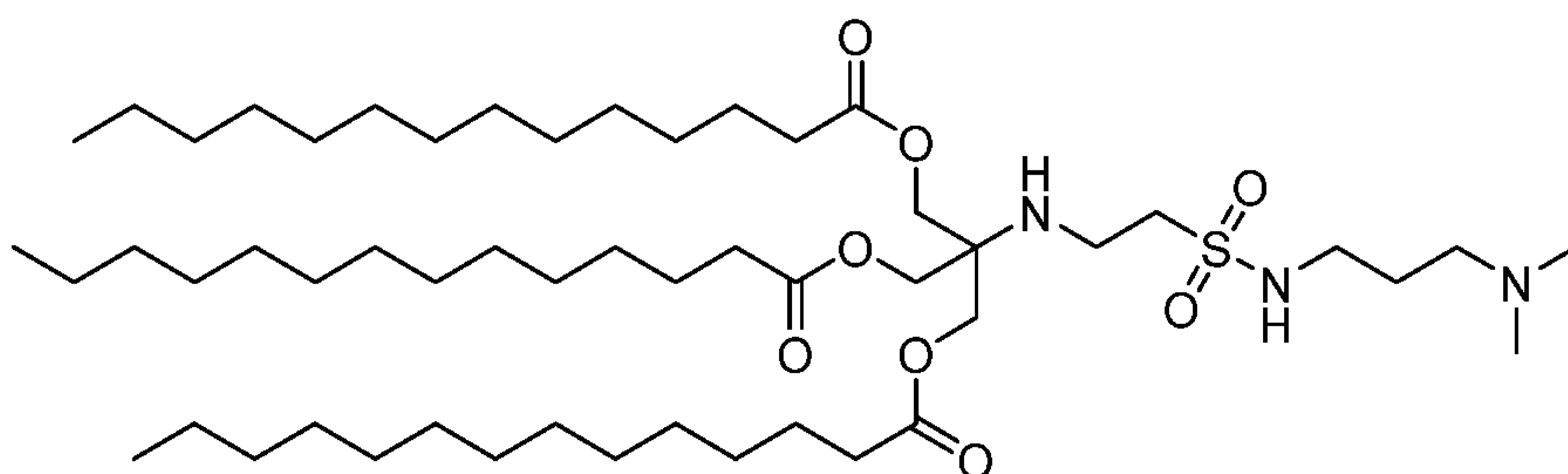
**Analytical data for 2-((Decanoyloxy)methyl)-2-((2-(N-(3-(dimethylamino)propyl)sulfamoyl)ethyl)amino)propane-1,3-diyl bis(decanoate) (Compound XI)**



[0250]  $^1\text{H NMR}$  (300 MHz, Chloroform- $d$ )  $\delta$  4.09 (s, 6H), 3.18 (t, 2H), 3.04-3.14 (m, 4H), 2.48 (t, 2H), 2.32 (t, 6H), 2.26 (s, 6H), 1.73 (quint, 2H), 1.52-1.65 (m, 6H), 1.16-1.38 (m, 38H), 0.86 (t, 9H).

[0251] APCI-MS analysis: Calculated  $\text{C}_{41}\text{H}_{81}\text{N}_3\text{O}_8\text{S}$ ,  $[\text{M}+\text{H}] = 776.4$ , observed = 776.5.

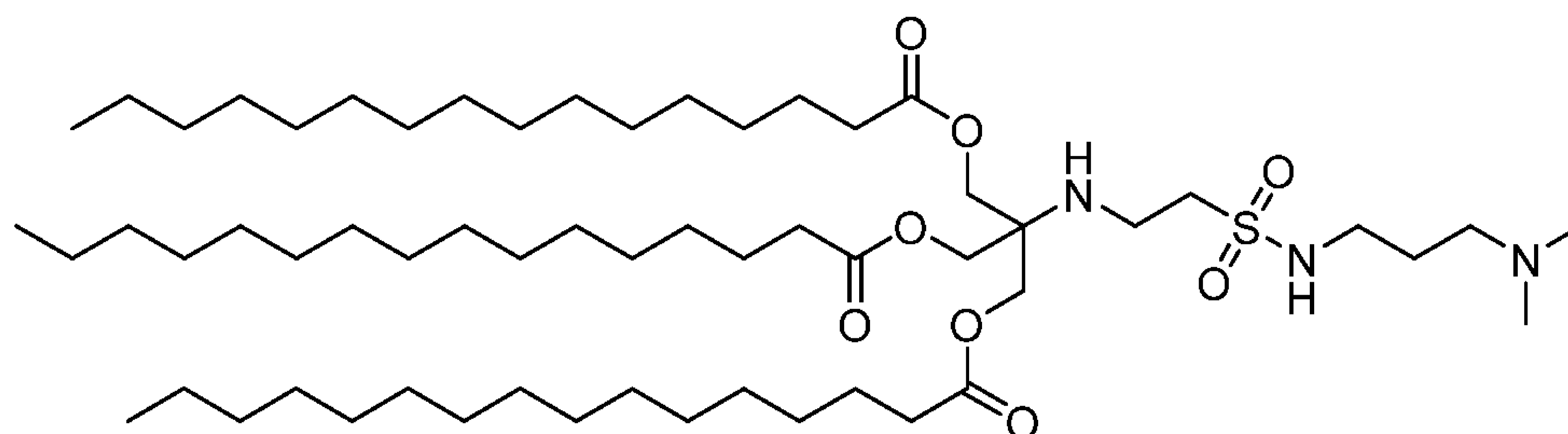
**Analytical data for 2-((2-(N-(3-(Dimethylamino)propyl)sulfamoyl)ethyl)amino)-2-((tetradecanoyloxy)methyl)propane-1,3-diyl ditetradecanoate (Compound XII)**



[0252]  $^1\text{H NMR}$  (300 MHz, Chloroform- $d$ )  $\delta$  4.06 (s, 6H), 3.15 (t, 2H), 3.04-3.12 (m, 4H), 2.47 (t, 2H), 2.29 (t, 6H), 2.25 (s, 6H), 1.71 (quint, 2H), 1.50-1.64 (m, 6H), 1.16-1.38 (m, 62H), 0.84 (t, 9H).

[0253] APCI-MS analysis: Calculated  $\text{C}_{53}\text{H}_{105}\text{N}_3\text{O}_8\text{S}$ ,  $[\text{M}+\text{H}] = 944.7$ , observed = 944.7.

**Analytical data for 2-((2-(N-(3-(Dimethylamino)propyl)sulfamoyl)ethyl)amino)-2-((palmitoyloxy)methyl)propane-1,3-diyl dipalmitate (Compound XIII)**



[0254]  $^1\text{H}$  NMR (300 MHz, Chloroform- $d$ )  $\delta$  4.09 (s, 6H), 3.22 (t, 2H), 3.04-3.14 (m, 4H), 2.66 (t, 2H), 2.41 (s, 6H), 2.32 (t, 6H), 1.82 (quint, 2H), 1.54-1.66 (m, 6H), 1.16-1.38 (m, 74H), 0.86 (t, 9H).

[0255] APCI-MS analysis: Calculated  $\text{C}_{59}\text{H}_{117}\text{N}_3\text{O}_8\text{S}$ ,  $[\text{M}+\text{H}] = 1028.8$ , observed = 1028.7.

### Example 3: Lipid Nanoparticle Formulation

[0256] Cationic lipids described herein can be used in the preparation of lipid nanoparticles according to methods known in the art. For example, suitable methods include methods described in International Publication No. WO 2018/089801, which is hereby incorporated by reference in its entirety.

[0257] One exemplary process for lipid nanoparticle formulation is *Process A* of WO 2018/089801 (see, e.g., Example 1 and Figure 1 of WO 2018/089801). *Process A* (“A”) relates to a conventional method of encapsulating mRNA by mixing mRNA with a mixture of lipids, without first pre-forming the lipids into lipid nanoparticles. In an exemplary process, an ethanol lipid solution and an aqueous buffered solution of mRNA were prepared separately. A solution of mixture of lipids (cationic lipid, helper lipids, zwitterionic lipids, PEG lipids etc.) was prepared by dissolving lipids in ethanol. The mRNA solution was prepared by dissolving the mRNA in citrate buffer. Then, these two solutions were mixed using a pump system. In some instances, the two solutions were mixed using a gear pump system. In certain embodiments, the two solutions were mixing using a ‘T’ junction (or “Y” junction). The mixture was then purified by diafiltration with a TFF process. The resultant formulation concentrated and stored at 2-8 °C until further use.

[0258] A second exemplary process for lipid nanoparticle formulation is *Process B* of WO 2018/089801 (see, e.g., Example 2 and Figure 2 of WO 2018/089801). *Process B* (“B”) refers to a process of encapsulating messenger RNA (mRNA) by mixing pre-formed lipid nanoparticles with mRNA. A range of different conditions, such as varying temperatures (i.e., heating or not heating the mixture), buffers, and concentrations, may be employed in *Process B*. In an exemplary process, lipids dissolved in ethanol and citrate buffer were mixed using a pump system. The instantaneous mixing of the two streams resulted in the formation of empty lipid nanoparticles, which was a self-assembly process. The resultant formulation mixture was empty lipid nanoparticles in citrate buffer containing alcohol. The formulation was then subjected to a TFF purification process wherein buffer exchange occurred. The resulting suspension of pre-formed empty lipid nanoparticles was then

mixed with mRNA using a pump system. For certain cationic lipids, heating the solution post-mixing resulted in a higher percentage of lipid nanoparticles containing mRNA and a higher total yield of mRNA.

[0259] Lipid nanoparticle formulations of **Table 3** were prepared by Process A. All of the lipid nanoparticle formulations comprised hEPO mRNA and the different lipids in following mol % ratios: Cationic Lipid: DMG-PEG2000; Cholesterol: DOPE = 40:5:25:30.

**Table 3. Exemplary lipid nanoparticle formulations**

mRNA	Formulation Composition	Process	N/P	Size (nm)	PDI	Encapsulation %
FFL	<b>Compound I:</b> DMG- PEG2000:Cholesterol:DOPE	A	4	65.2	0.23	72
FFL	<b>Compound V:</b> DMG- PEG2000:Cholesterol:DOPE	A	4	83.4	0.14	87
FFL	<b>Compound XII:</b> DMG- PEG2000:Cholesterol:DOPE	A	4	89.5	0.16	85

Example 4: Delivery of Firefly Luciferase (FFL) mRNA by intratracheal administration

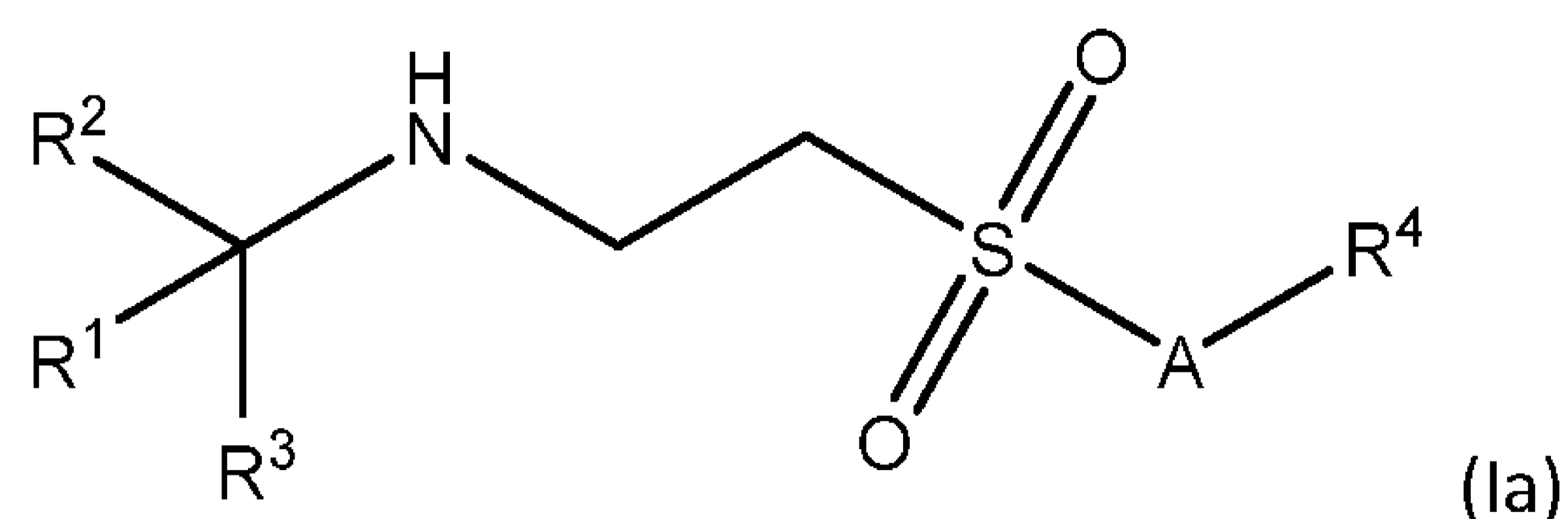
[0260] Lipid nanoparticle formulations listed in **Table 3** comprising FFL mRNA, cationic lipid, DMG-PEG2000, cholesterol and DOPE were administered to male CD1 mice (6-8 weeks old) by a single intratracheal aerosol administration via a Microsprayer® (50ul/animal) while under anesthesia. At approximately 24 hours post-dose, the animals were dosed with luciferin at 150 mg/kg (60 mg/ml) by intraperitoneal injection at 2.5ml/kg. After 5-15 minutes, all animals were imaged using an IVIS imaging system to measure luciferase production in the lung. **Figure 1** shows that lipid nanoparticles comprising the cationic lipids described herein are effective in delivering FFL mRNA *in vivo* based on positive luciferase activity.

[0261] From the foregoing description, one skilled in the art can easily ascertain the essential characteristics of this invention, and without departing from the spirit and scope thereof, can make various changes and modifications of the invention to adapt it to various usages and conditions.

[0262] All references, patents or applications, U.S. or foreign, cited in the application are hereby incorporated by reference as if written herein in their entireties. Where any inconsistencies arise, material literally disclosed herein controls.

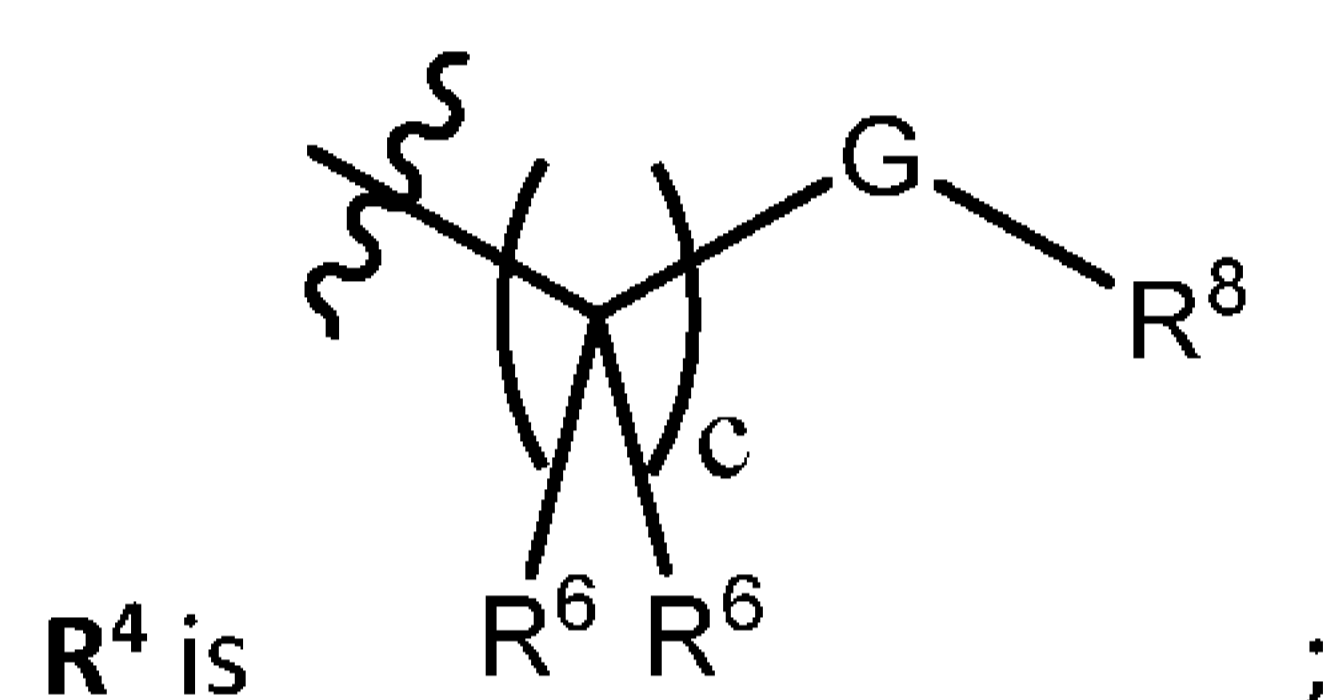
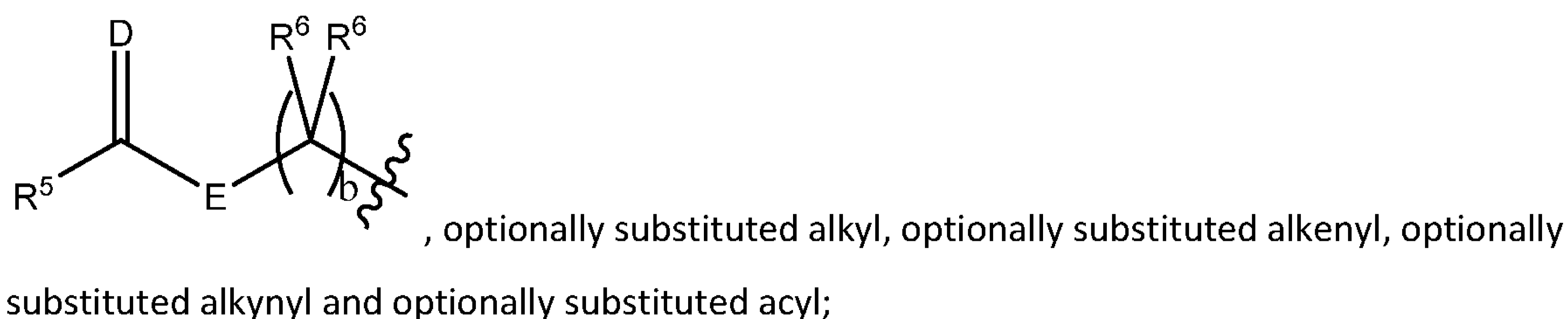
## CLAIMS

1. A compound having a structure according to Formula (Ia):



or a pharmaceutically acceptable salt thereof, wherein

$R^1$ ,  $R^2$  and  $R^3$  are each independently selected from:



each  $R^5$  is independently selected from optionally substituted alkyl, optionally substituted alkenyl and optionally substituted alkynyl;

each  $R^6$  is independently selected from hydrogen, halogen, optionally substituted  $C_1$ - $C_6$  alkyl, and optionally substituted  $C_2$ - $C_6$  alkenyl;

**A** is  $-NR^9-$  or  $-O-$ ;

**D** is O or S;

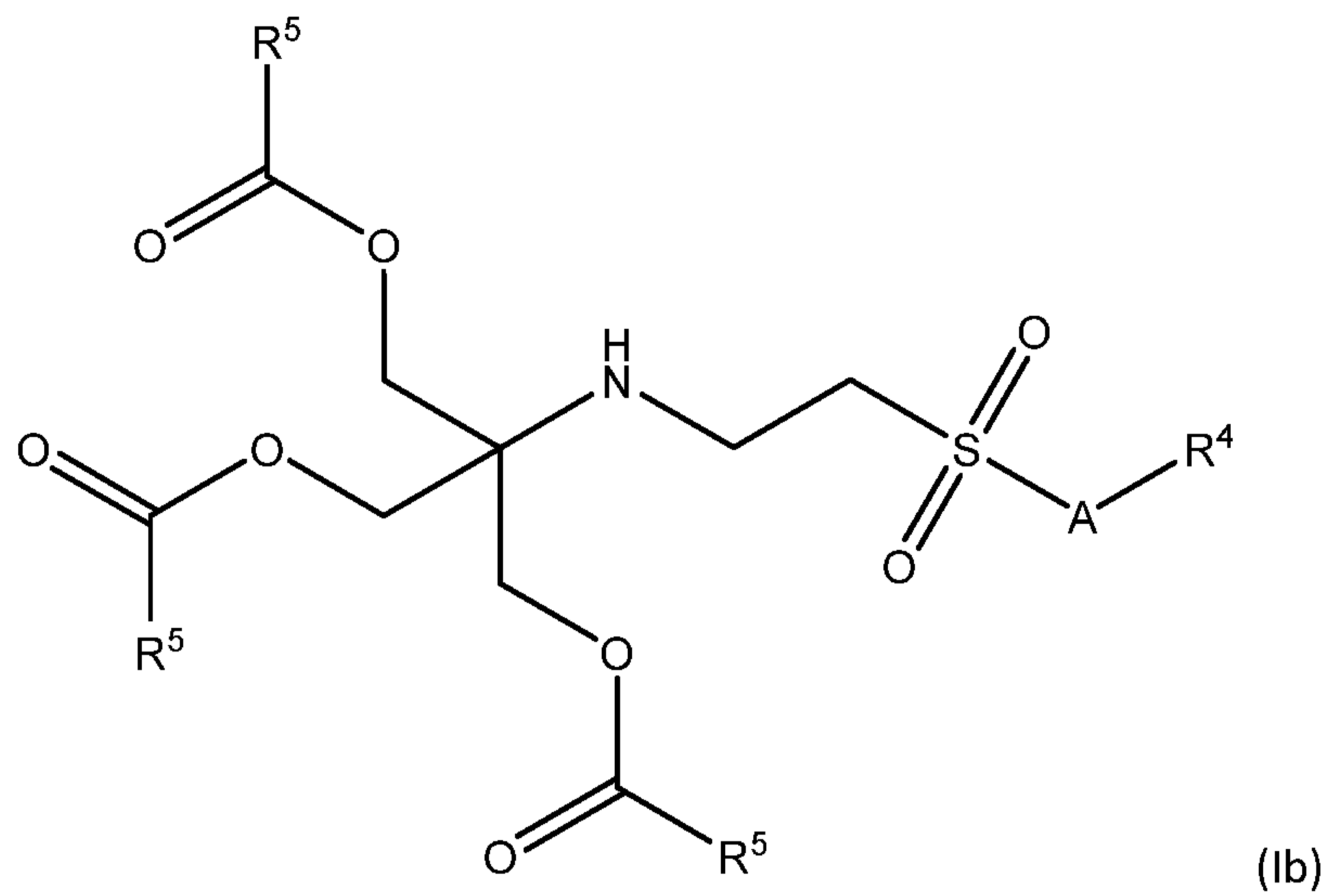
**E** and **G** are each independently selected from  $-NR^{10}-$ ,  $-O-$  and  $-S-$ ;

$R^8$ ,  $R^9$ , and  $R^{10}$  are each independently selected from hydrogen, optionally substituted  $C_1$ - $C_6$  alkyl and optionally substituted  $C_2$ - $C_6$  alkenyl;

each **b** is independently selected from 0, 1, 2, 3, 4, 5, 6, 7, 8, 9 and 10; and

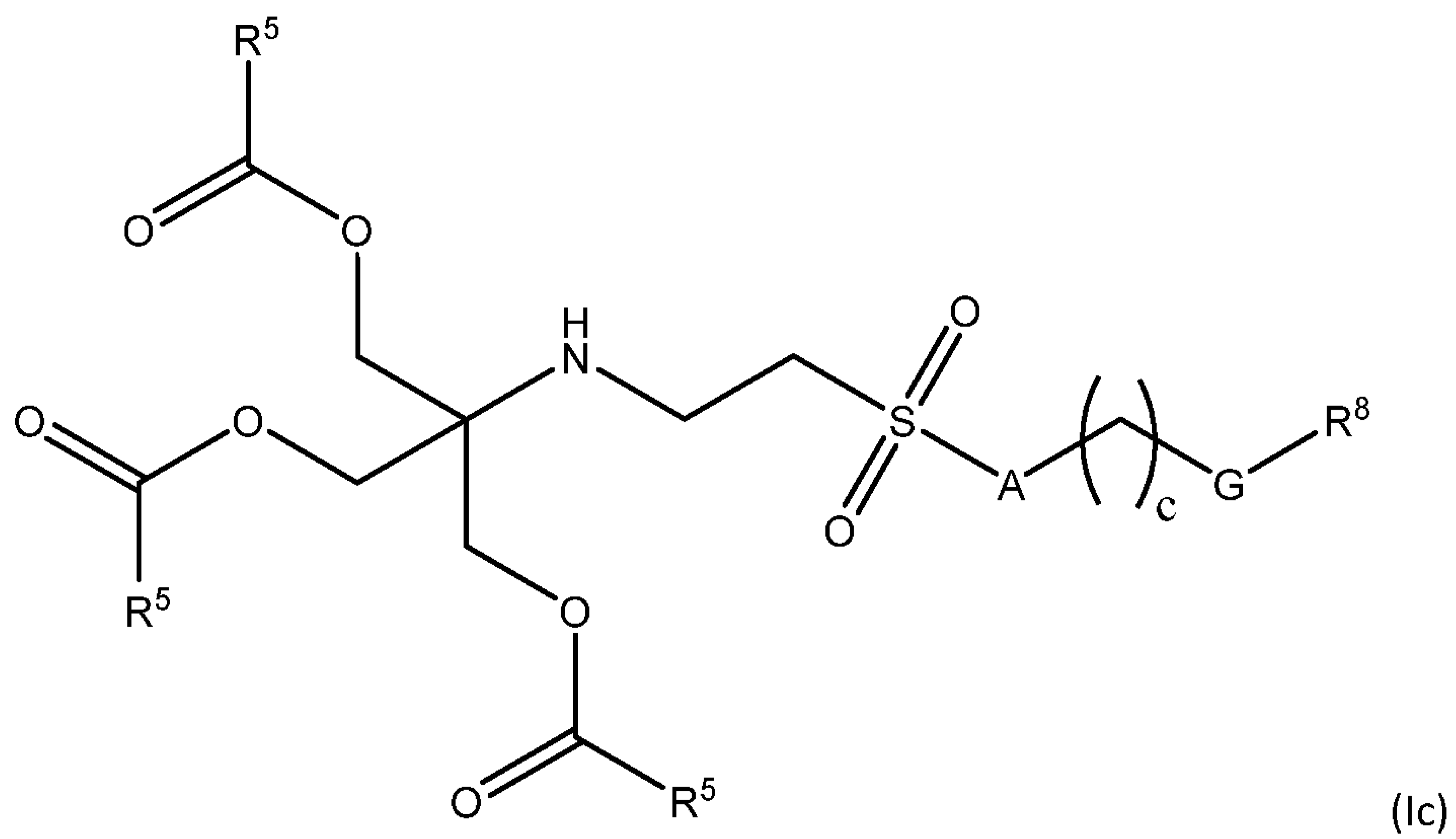
each **c** is independently selected from 1, 2, 3, 4, 5, 6, 7, 8, 9 and 10.

2. The compound of claim 1, wherein the compound has a structure according to Formula (Ib):



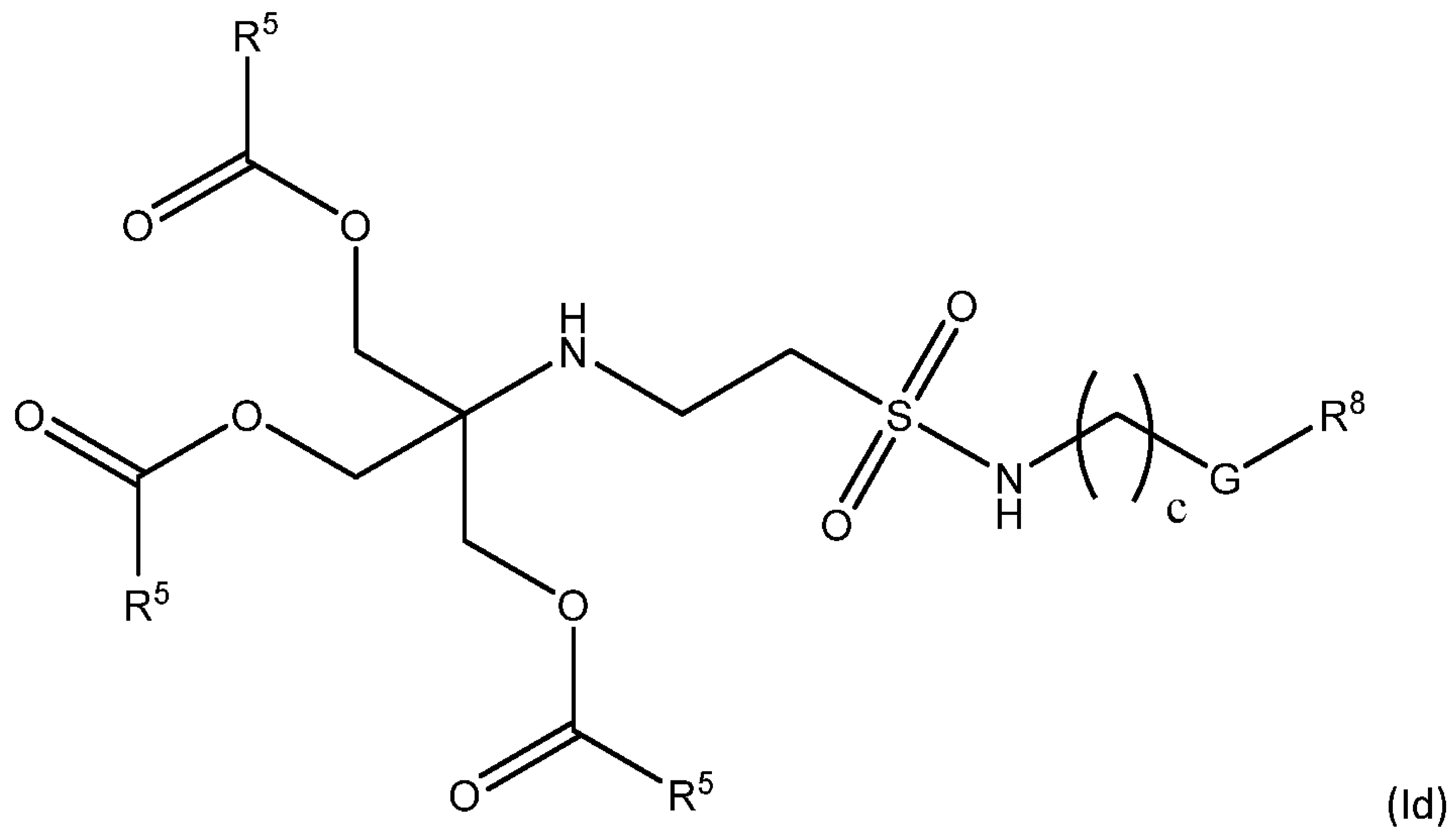
or a pharmaceutically acceptable salt thereof.

3. The compound of any one of claims 1 or 2, wherein the compound has a structure according to Formula (Ic):



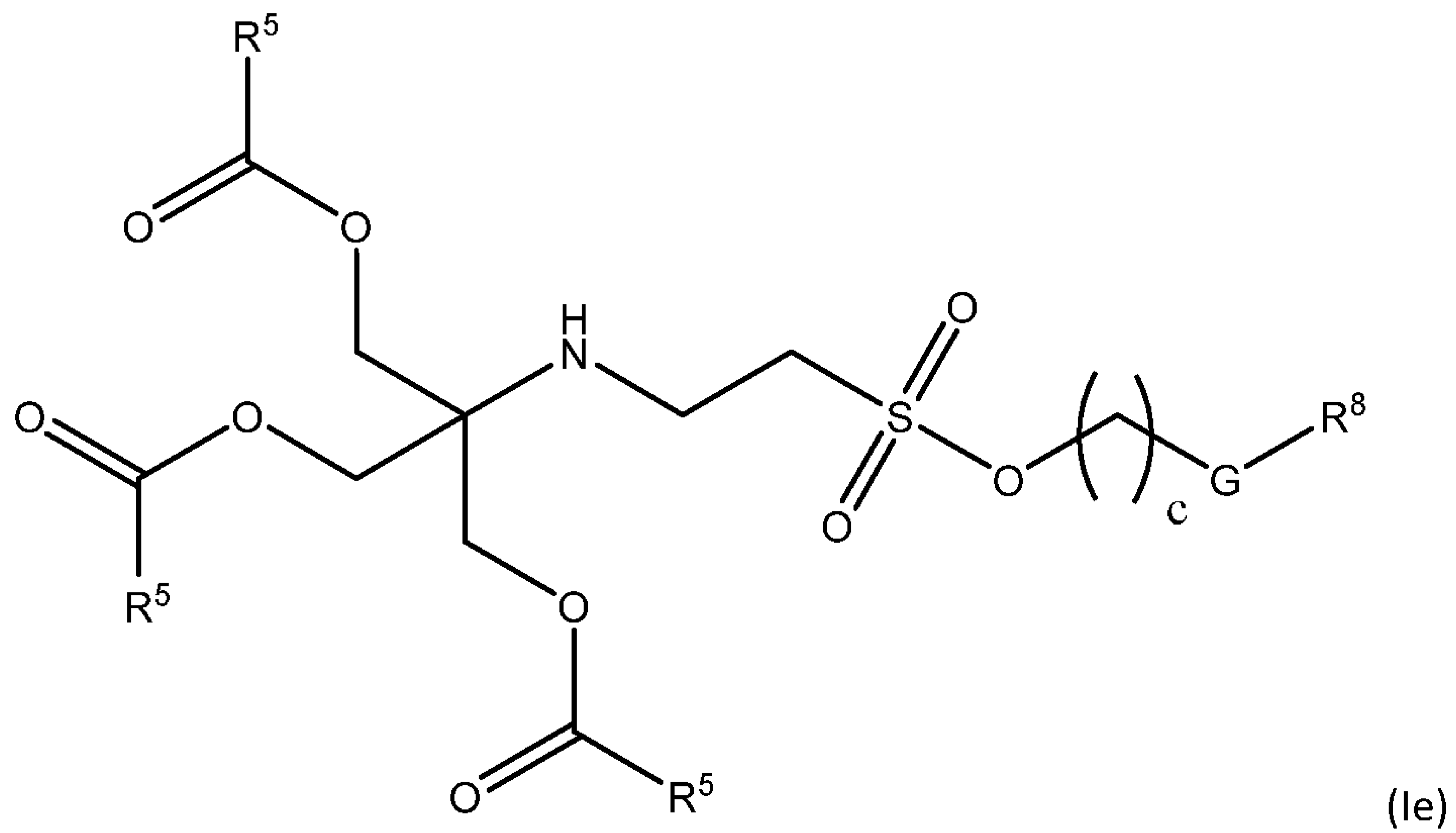
or a pharmaceutically acceptable salt thereof.

4. The compound of any one of claims 1-3, wherein the compound has a structure according to Formula (Id):



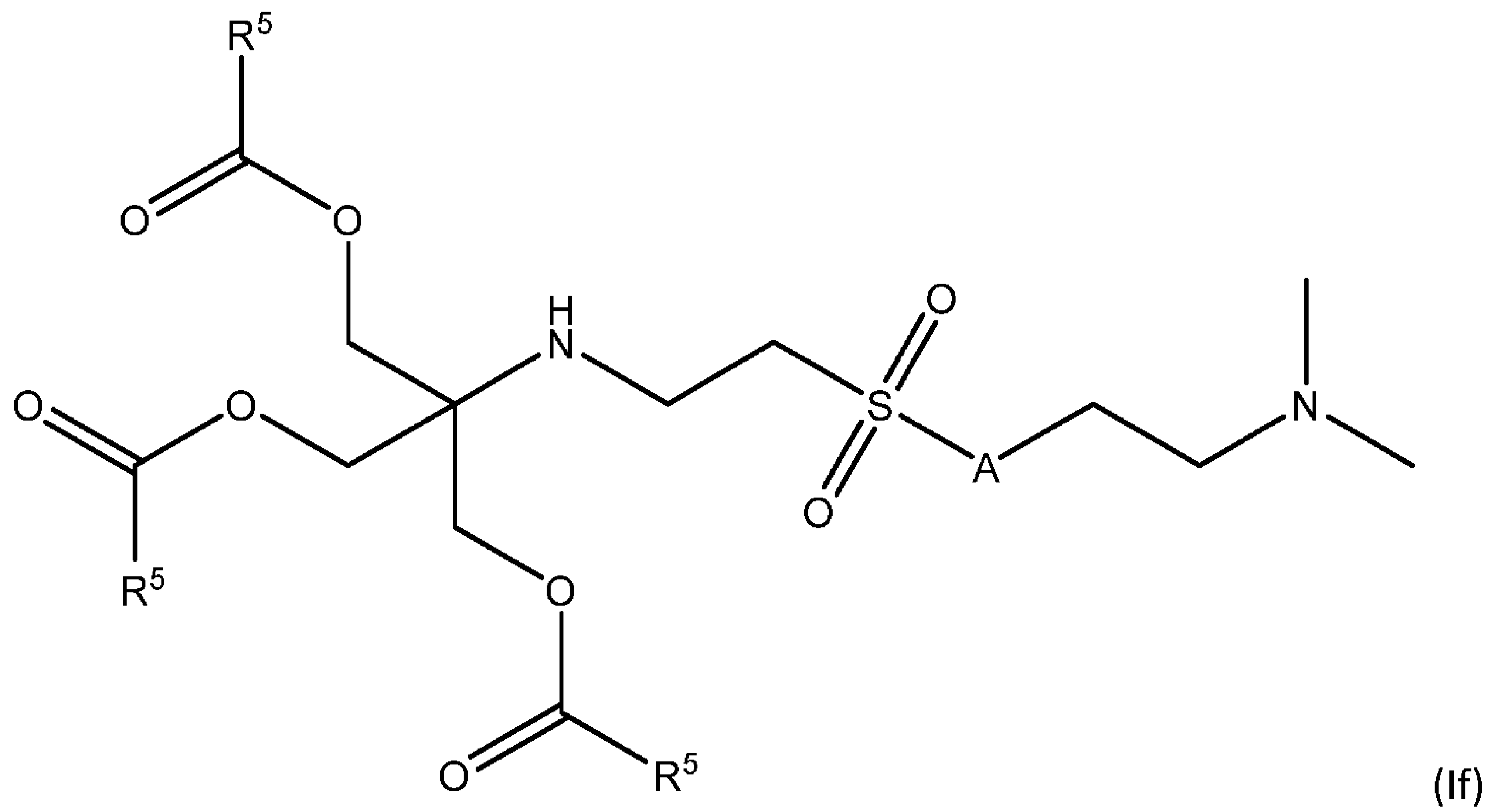
or a pharmaceutically acceptable salt thereof.

5. The compound of any one of claims 1-3, wherein the compound has a structure according to Formula (Ie):



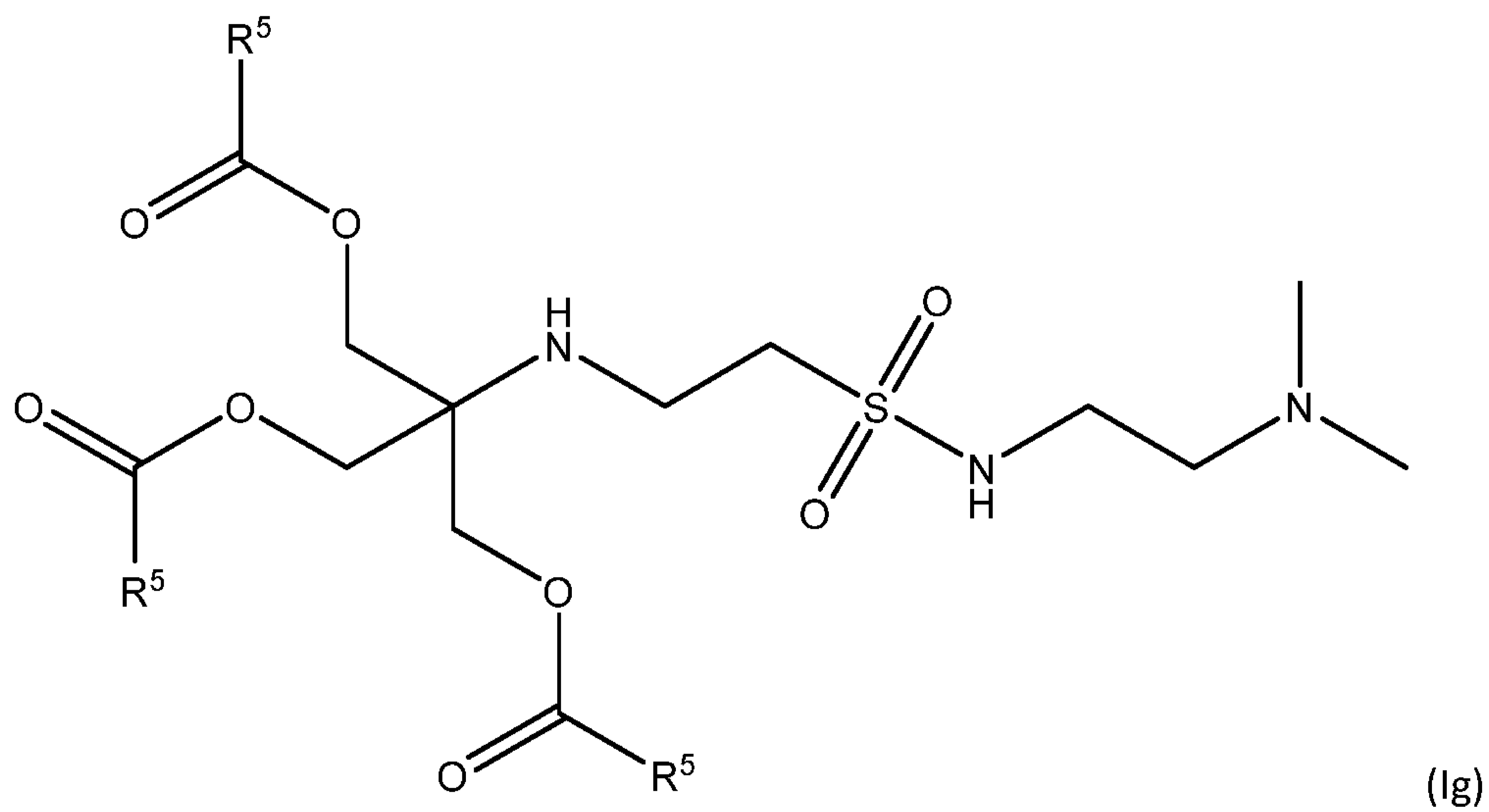
or a pharmaceutically acceptable salt thereof.

6. The compound of any one of claims 1-3, wherein the compound has a structure according to Formula (If):



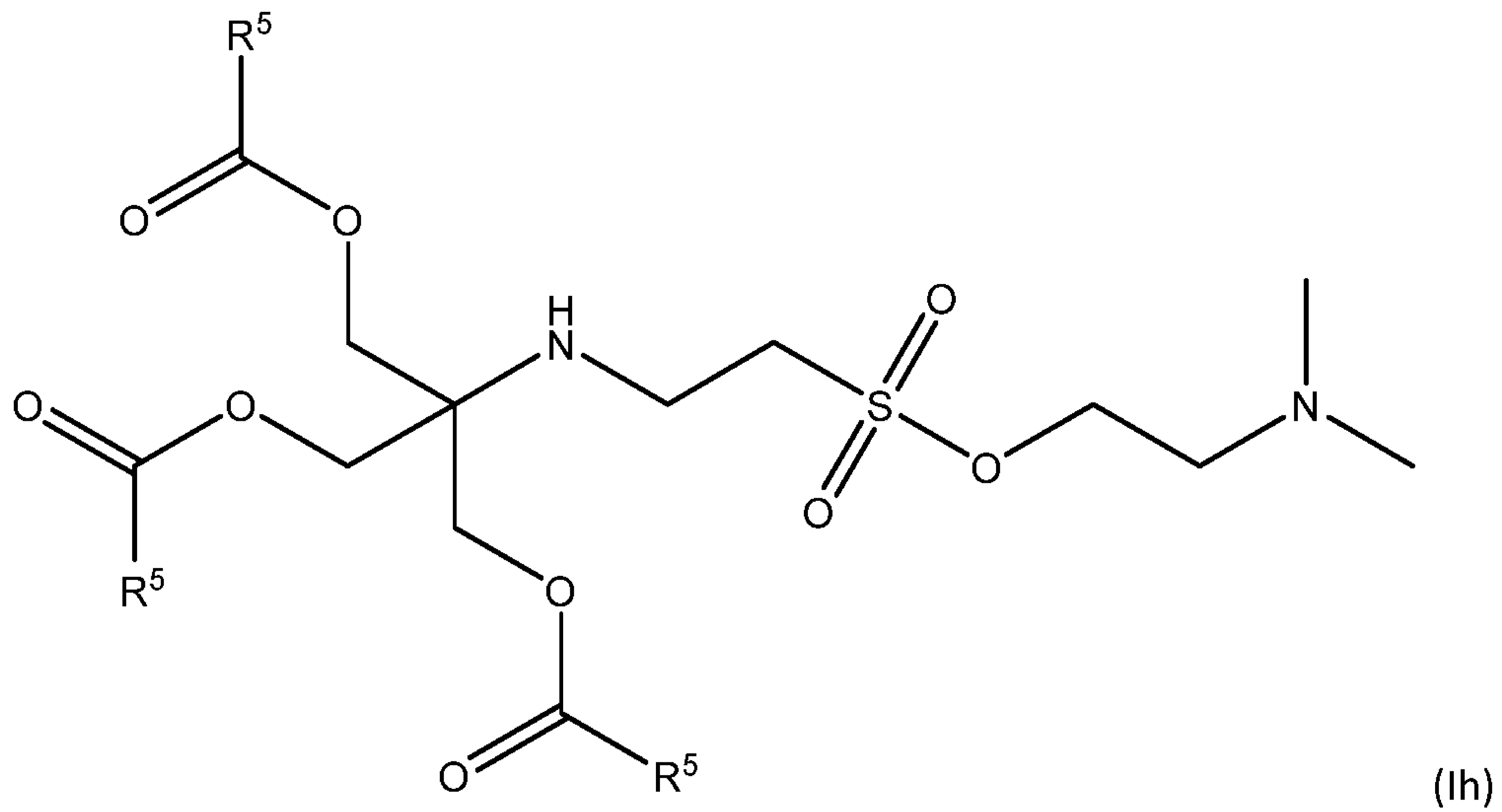
or a pharmaceutically acceptable salt thereof.

7. The compound of claim 6, wherein the compound has a structure according to Formula (Ig):



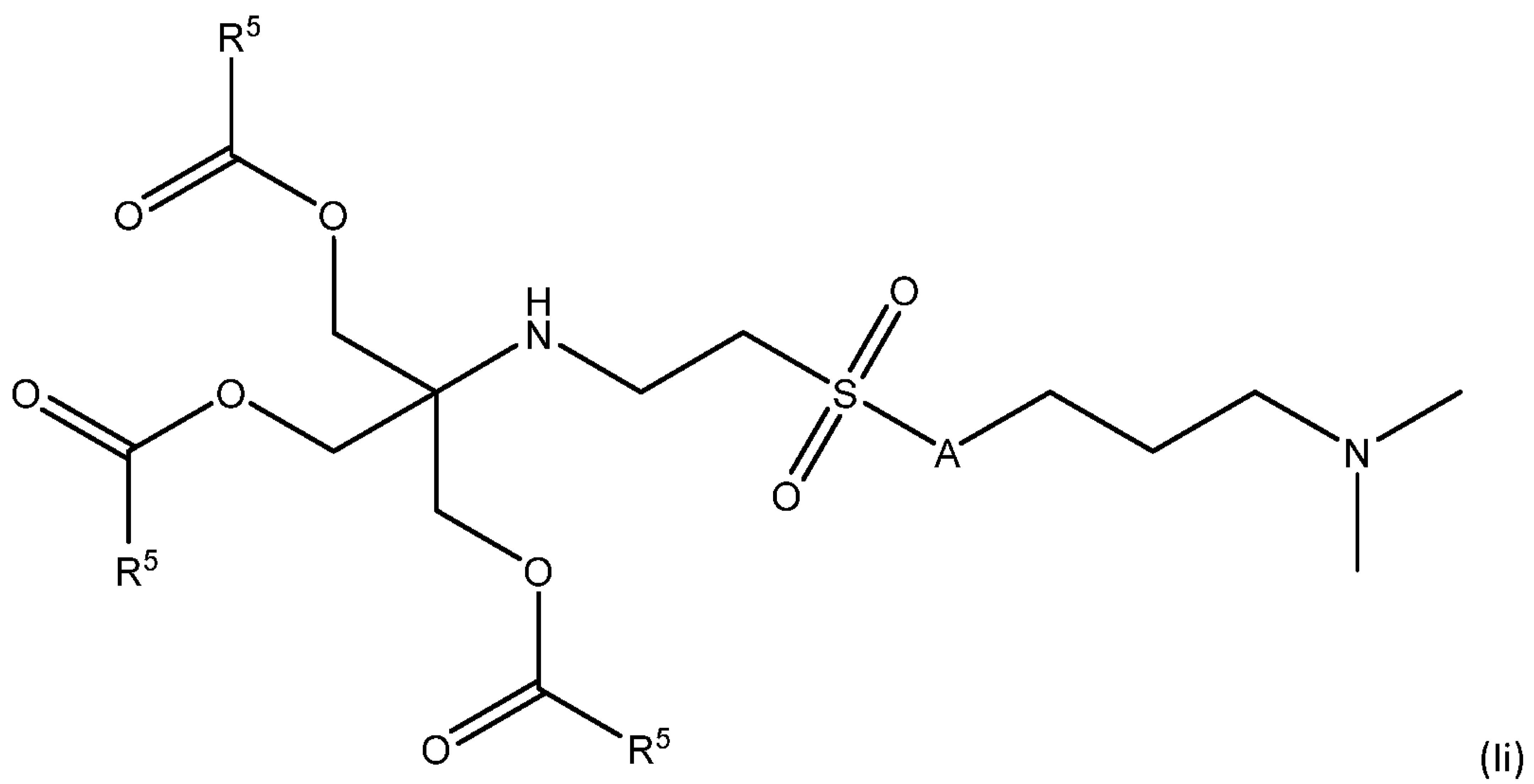
or a pharmaceutically acceptable salt thereof.

8. The compound of claim 6, wherein the compound has a structure according to Formula (Ih):



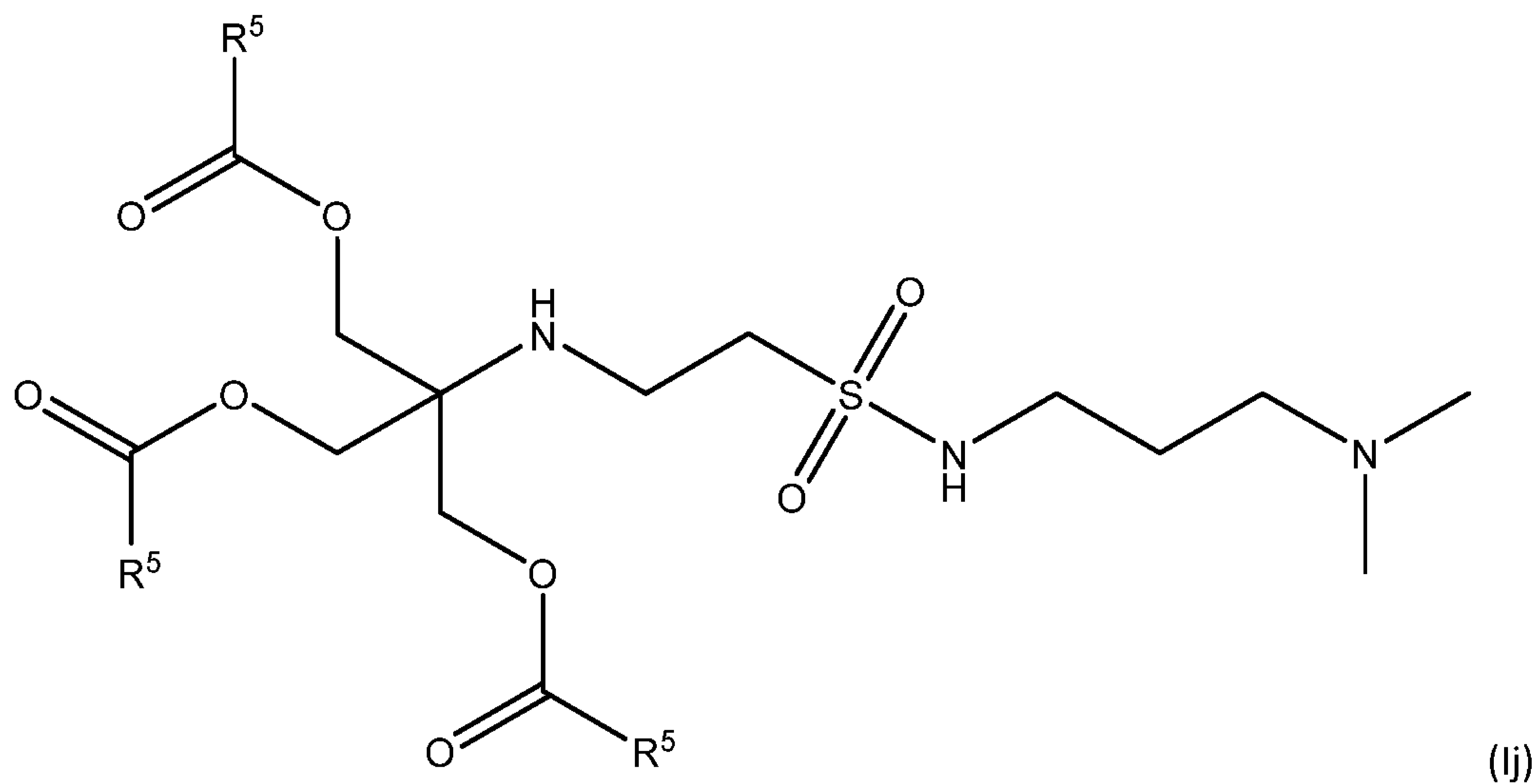
or a pharmaceutically acceptable salt thereof.

9. The compound according to any one of claims 1-3, wherein the compound has a structure according to Formula (Ii):



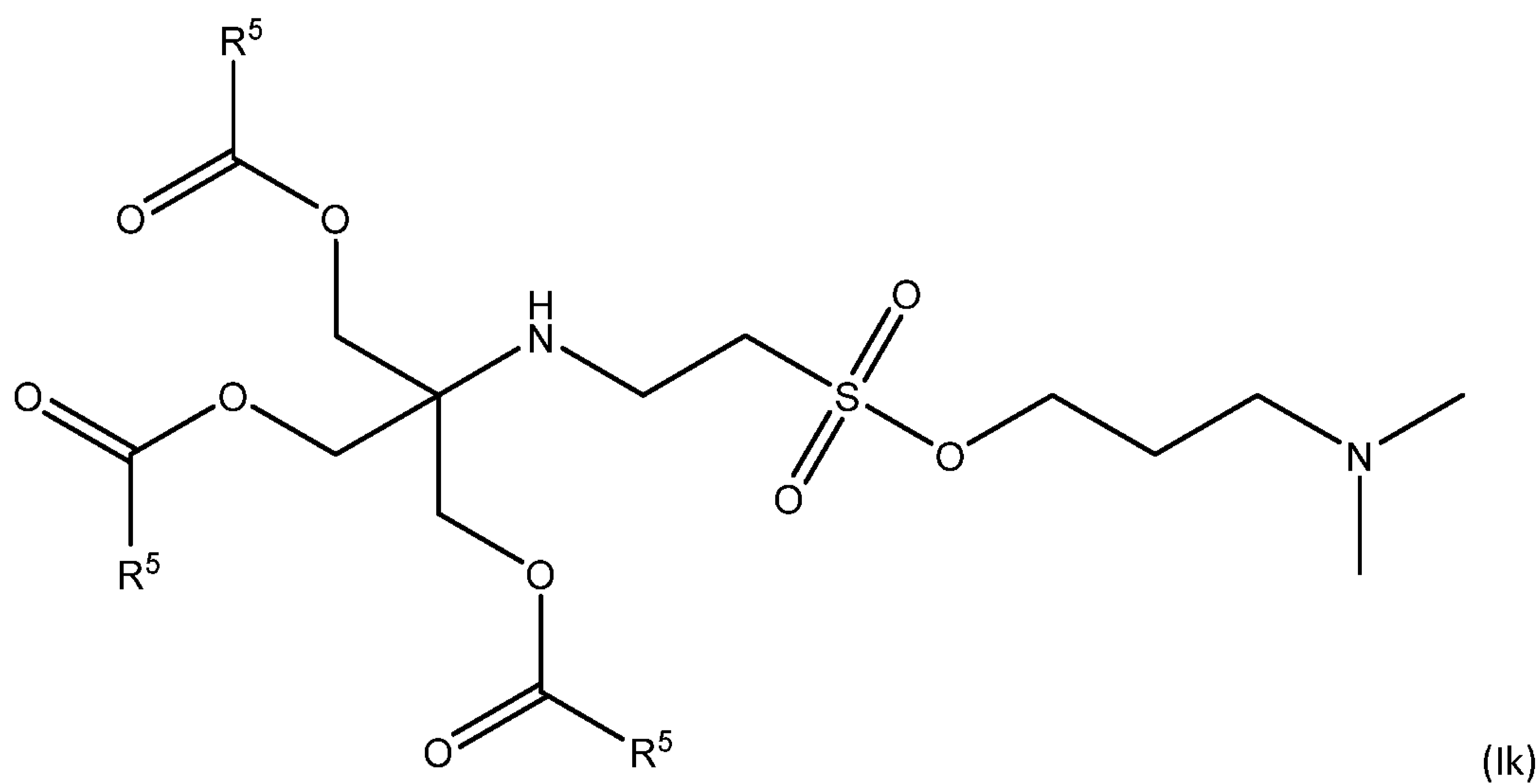
or a pharmaceutically acceptable salt thereof.

10. The compound according to claim 9, wherein the compound has a structure according to Formula (lj):



or a pharmaceutically acceptable salt thereof.

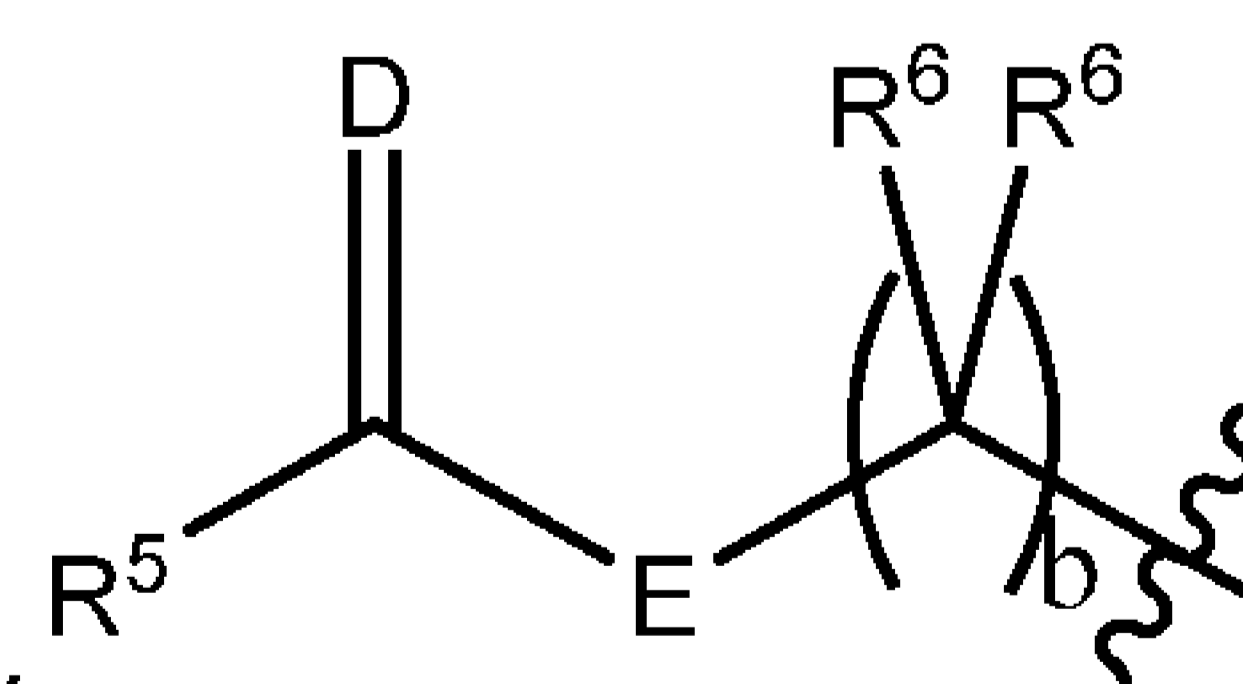
11. The compound according to claim 9, wherein the compound has a structure according to Formula (lk):



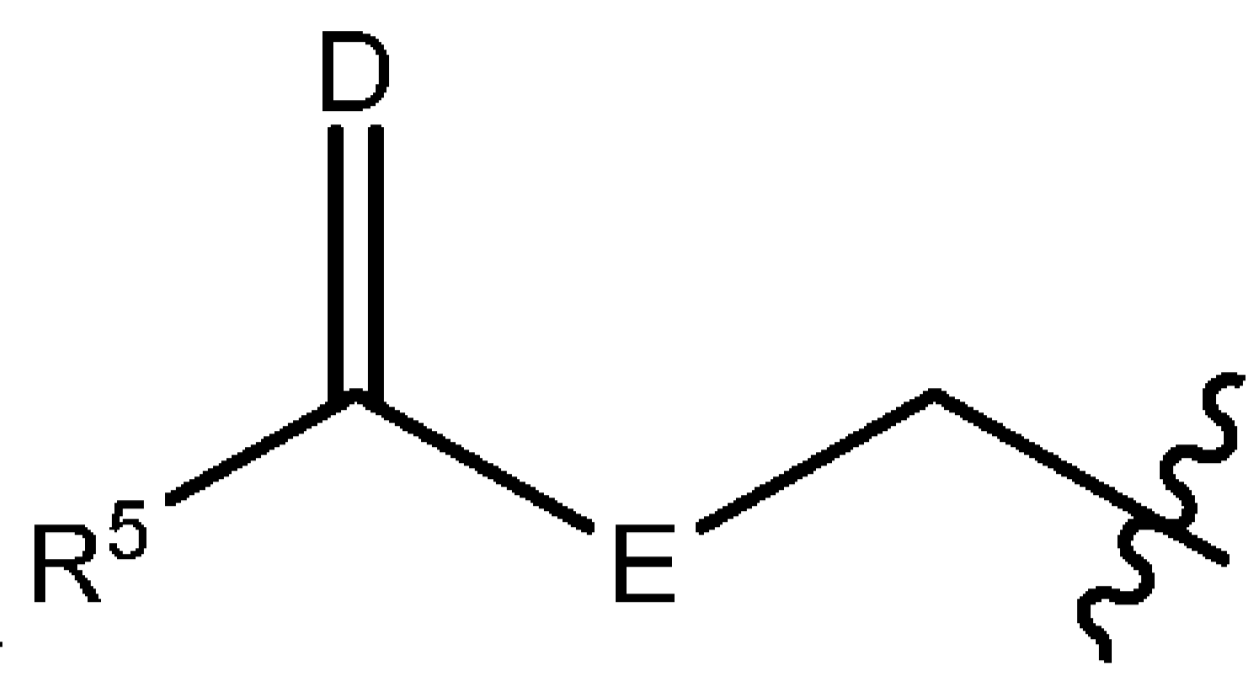
or a pharmaceutically acceptable salt thereof.

12. The compound according to any one of the preceding claims or a pharmaceutically

acceptable salt thereof, wherein  $R^1$ ,  $R^2$  and  $R^3$  are each independently



13. The compound according to any one of the preceding claims or a pharmaceutically acceptable salt thereof,

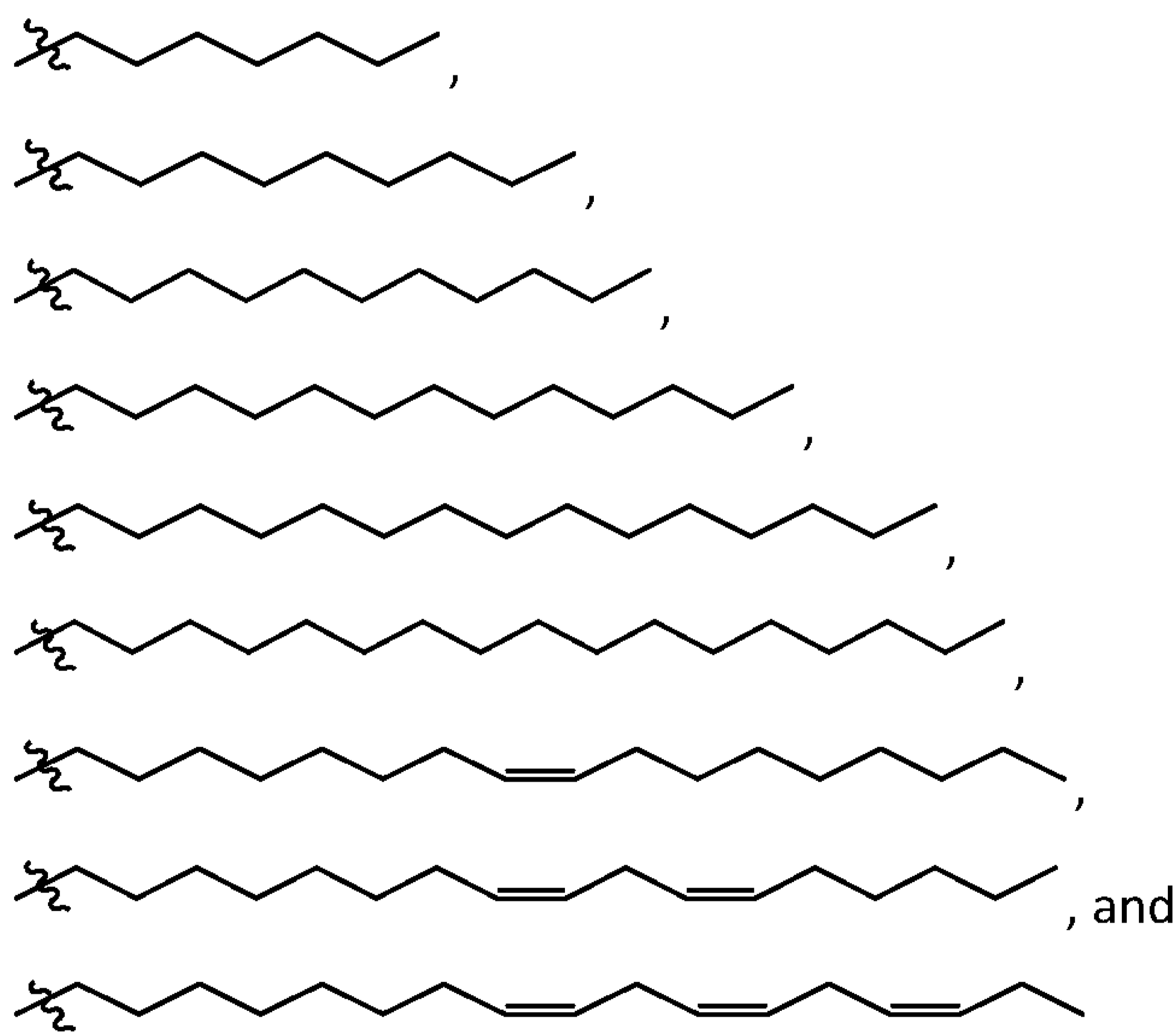


wherein  $R^1$ ,  $R^2$  and  $R^3$  are each independently

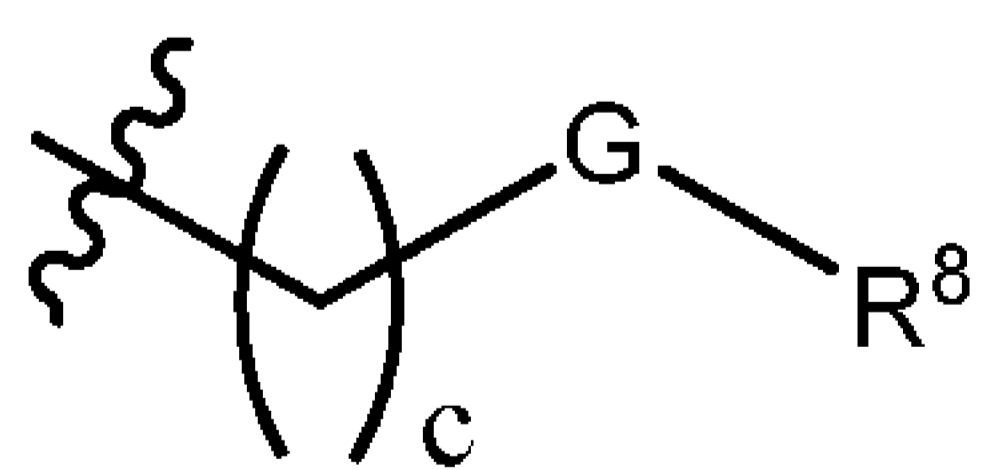
14. The compound according to any one of claims 12 or 13 or a pharmaceutically acceptable salt thereof, wherein **D** and **E** are each O.

15. The compound according to any one of the preceding claims or a pharmaceutically acceptable salt thereof, wherein each  $R^5$  is independently selected from optionally substituted alkyl and optionally substituted alkenyl.

16. The compound according to any one of the preceding claims or a pharmaceutically acceptable salt thereof, wherein each  $R^5$  is independently selected from:

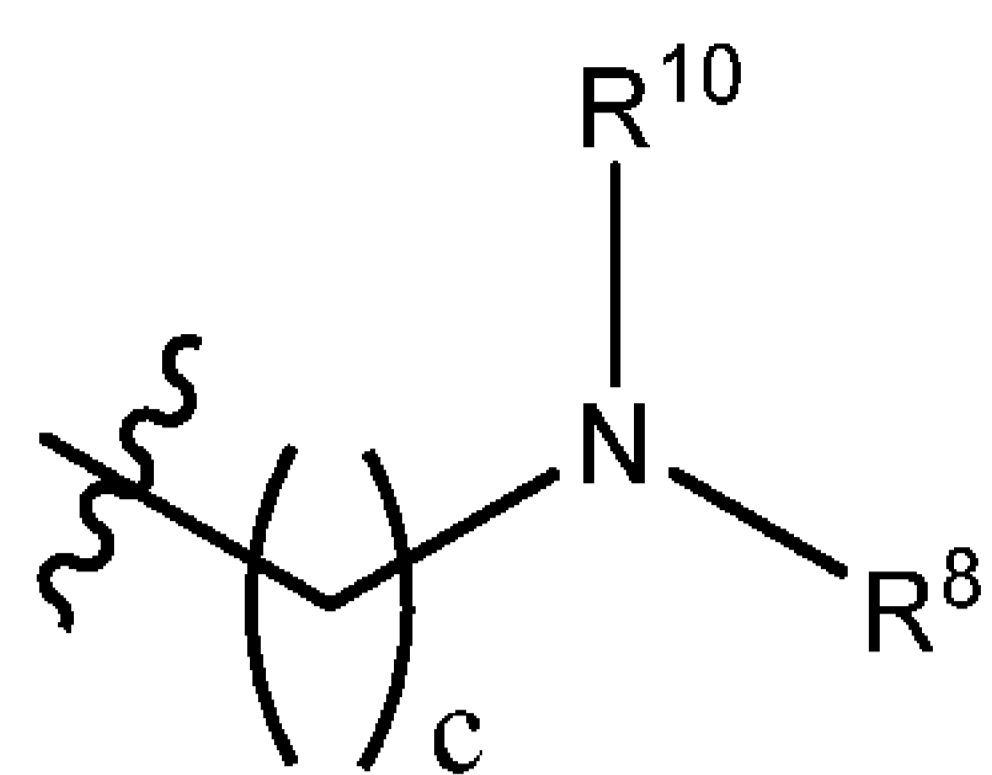


17. The compound of any one of the preceding claims or a pharmaceutically acceptable salt thereof,



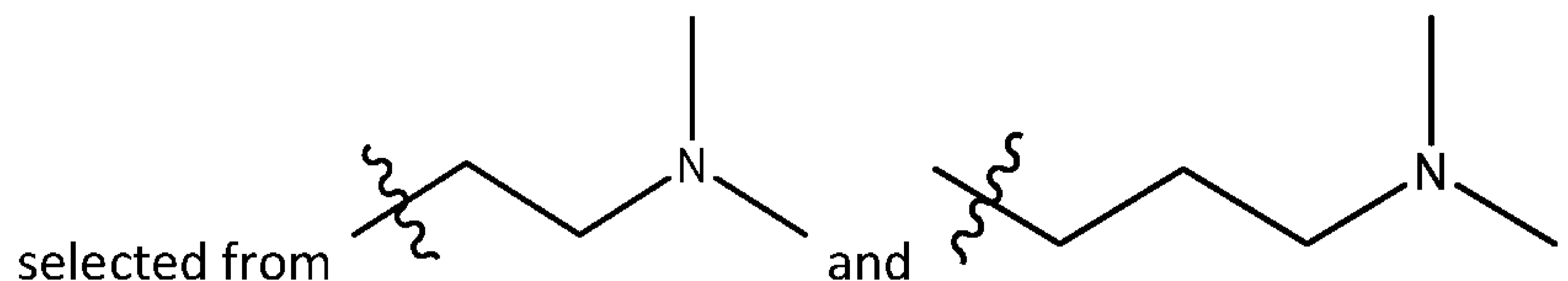
thereof, wherein  $R^4$  is

18. The compound of any one of the preceding claims or a pharmaceutically acceptable salt

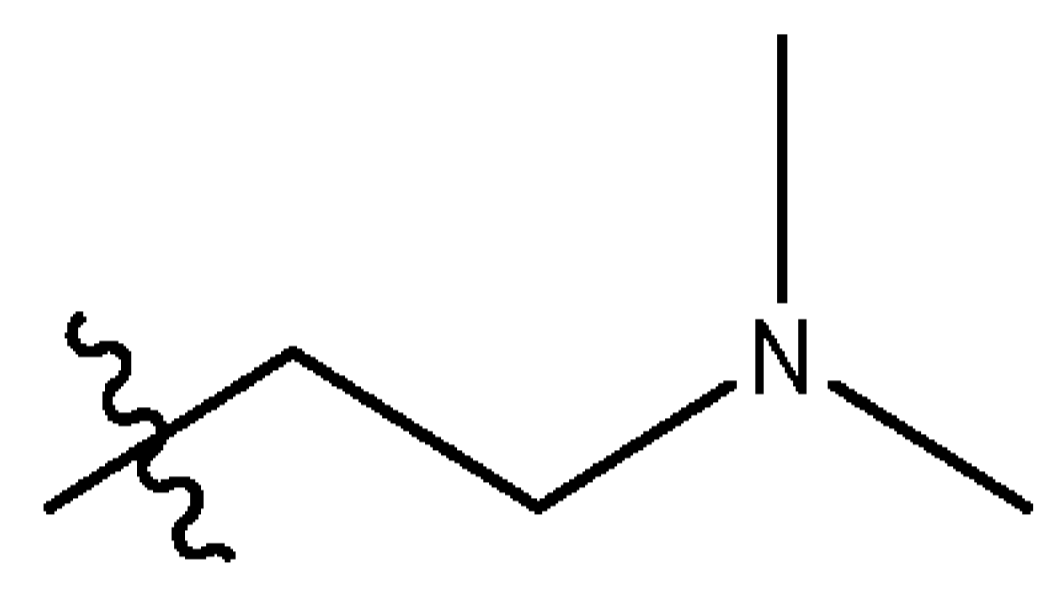


thereof, wherein  $R^4$  is

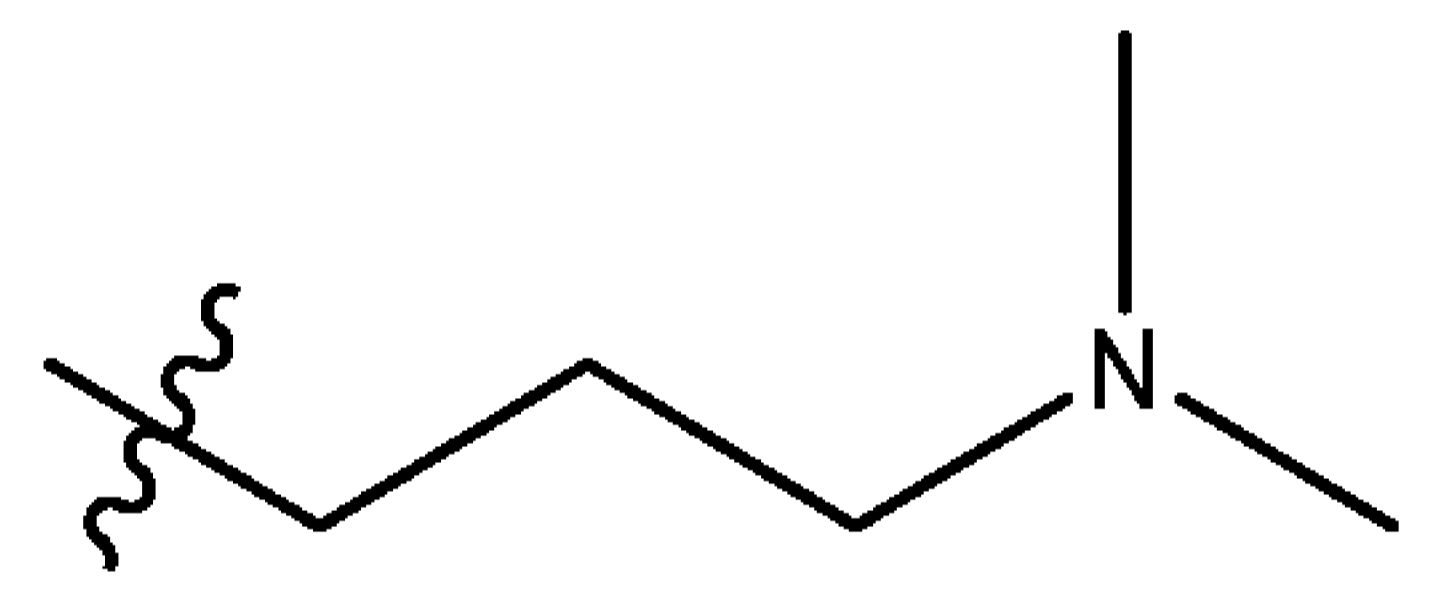
19. The compound of claim 18, or a pharmaceutically acceptable salt thereof, wherein  $R^4$  is



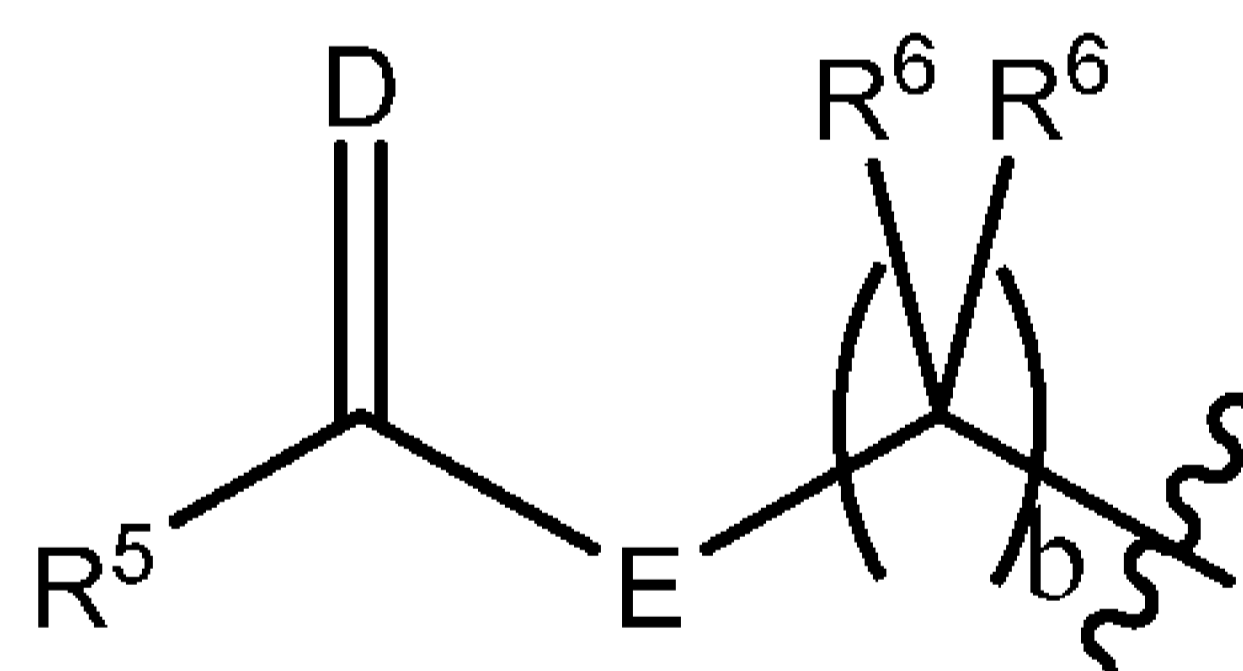
20. The compound of claim 19 or a pharmaceutically acceptable salt thereof, wherein  $R^4$  is



21. The compound of claim 19 or a pharmaceutically acceptable salt thereof, wherein  $R^4$  is

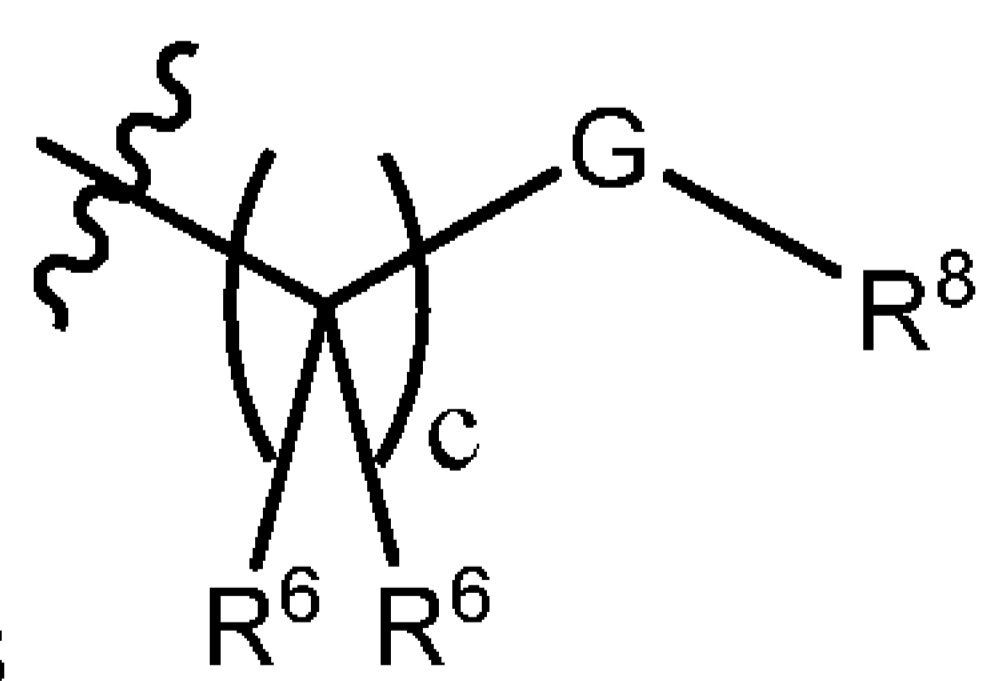


22. The compound of any one of the preceding claims or a pharmaceutically acceptable salt thereof, wherein  $R^1$ ,  $R^2$  and  $R^3$  are each independently:



and wherein  $b$  is 1.

23. The compound of any one of the preceding claims or a pharmaceutically acceptable salt

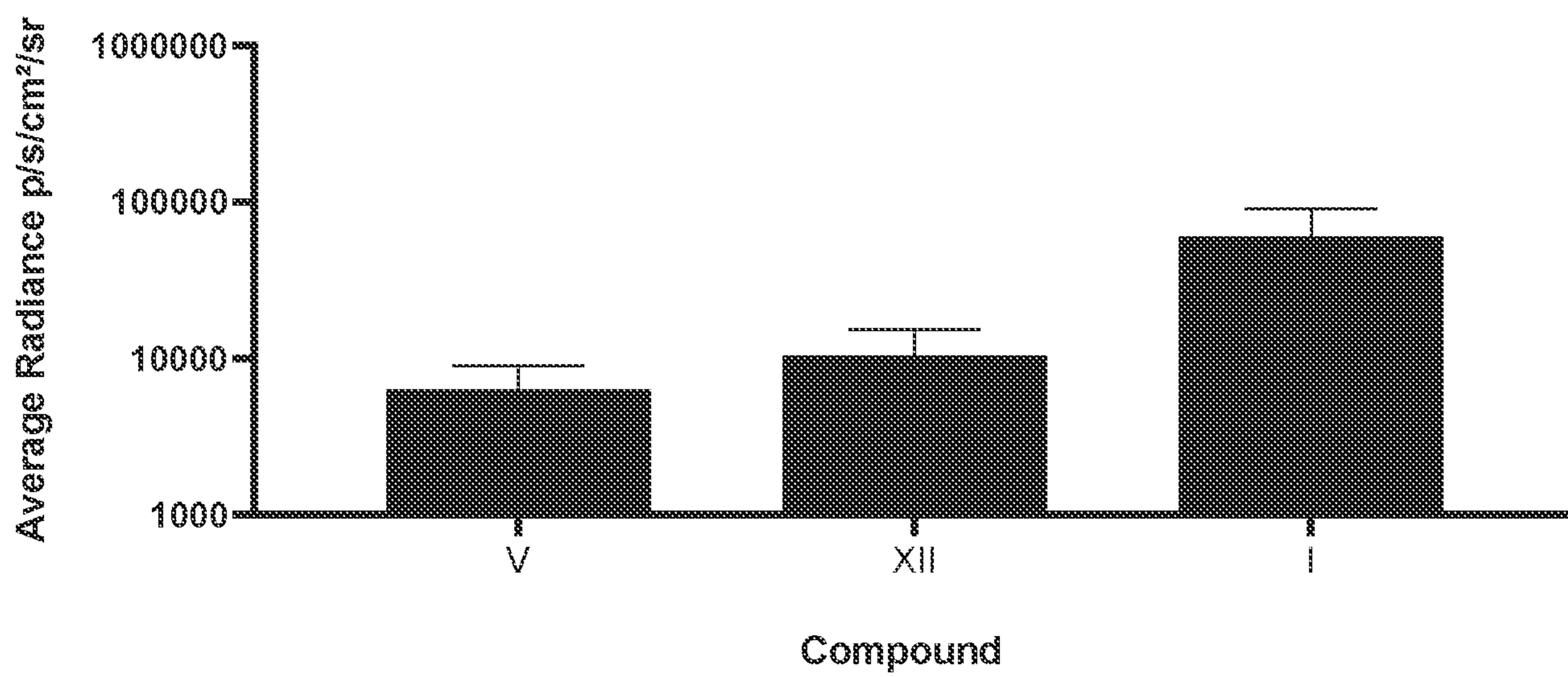


thereof, wherein  $R^4$  is

and wherein  $c$  is 2 or 3.

24. The compound of any one of the preceding claims or a pharmaceutically acceptable salt thereof, wherein **A** is **NR<sup>9</sup>**, optionally wherein **R<sup>9</sup>** is H.
25. The compound of any one of claims 1 to 23 or a pharmaceutically acceptable salt thereof, wherein **A** is O.
26. A compound selected from those listed in Table A or a pharmaceutically acceptable salt thereof.
27. A composition comprising the cationic lipid of any one of the preceding claims, one or more non-cationic lipids, one or more cholesterol-based lipids and one or more PEG-modified lipids.
28. The composition of claim 27, wherein the composition is a lipid nanoparticle, optionally a liposome.
29. The composition of claim 28, wherein the one or more cationic lipid(s) constitute(s) about 30 mol %-60 mol % of the lipid nanoparticle.
30. The composition of any one of claims 28 or 29, wherein the one or more non-cationic lipid(s) constitute(s) 10 mol %-50 mol % of the lipid nanoparticle.
31. The composition of any one of claims 28-30, wherein the one or more PEG-modified lipid(s) constitute(s) 1 mol %-10 mol % of the lipid nanoparticle.
32. The composition of any one of claims 28-31, wherein the cholesterol-based lipid constitutes 10 mol %-50 mol% of the lipid nanoparticle.
33. The composition of any one of claims 28-32, wherein the lipid nanoparticle encapsulates a nucleic acid, optionally an mRNA encoding a peptide or protein.
34. The composition of any one of claims 28-32, wherein the lipid nanoparticle encapsulates an mRNA encoding a peptide or protein.

35. The composition of claim 34, wherein the lipid nanoparticles have an encapsulation percentage for mRNA of
- (i) at least 70%;
  - (ii) at least 75%;
  - (iii) at least 80%;
  - (iv) at least 85%;
  - (v) at least 90%; or
  - (vi) at least 95%.
36. The composition of any one of claims 34-35 for use in therapy.
37. The composition of any one of claims 34-36 for use in a method of treating or preventing a disease amenable to treatment or prevention by the peptide or protein encoded by the mRNA, optionally wherein the disease is (a) a protein deficiency, optionally wherein the protein deficiency affects the liver, lung, brain or muscle, (b) an autoimmune disease, (c) an infectious disease, or (d) cancer.
38. The composition for use according to claim 36 or 37, wherein the composition is administered intravenously, intrathecally or intramuscularly, or by pulmonary delivery, optionally through nebulization.
39. A method for treating or preventing a disease wherein said method comprises administering to a subject in need thereof the composition of any one of claims 34-35 and wherein the disease is amenable to treatment or prevention by the peptide or protein encoded by the mRNA, optionally wherein the disease is (a) a protein deficiency, optionally wherein the protein deficiency affects the liver, lung, brain or muscle, (b) an autoimmune disease, (c) an infectious disease, or (d) cancer.
40. The method of claim 39, wherein the composition is administered intravenously, intrathecally or intramuscularly, or by pulmonary delivery, optionally through nebulization.



**FIG. 1**