



(12) **DEMANDE DE BREVET CANADIEN**  
**CANADIAN PATENT APPLICATION**

(13) **A1**

(86) Date de dépôt PCT/PCT Filing Date: 2016/06/30  
(87) Date publication PCT/PCT Publication Date: 2017/01/12  
(85) Entrée phase nationale/National Entry: 2018/01/05  
(86) N° demande PCT/PCT Application No.: US 2016/040370  
(87) N° publication PCT/PCT Publication No.: 2017/007677  
(30) Priorité/Priority: 2015/07/07 (US62/189,473)

(51) Cl.Int./Int.Cl. *C09K 15/32*(2006.01),  
*C08K 5/00*(2006.01), *H01B 1/12*(2006.01)

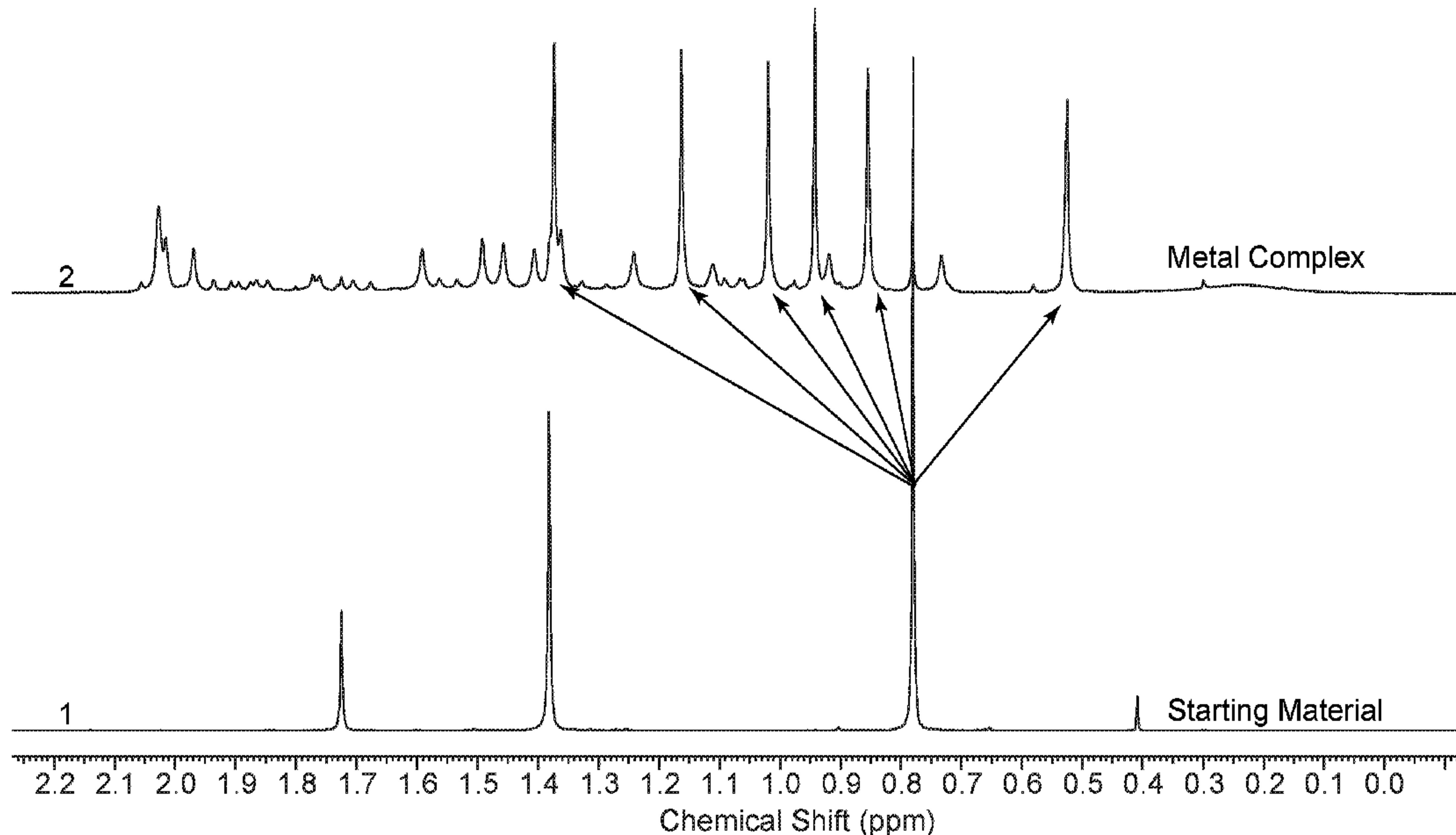
(71) Demandeur/Applicant:  
3M INNOVATIVE PROPERTIES COMPANY, US

(72) Inventeurs/Inventors:  
SCHULTZ, NATHAN E., US;  
LI, FUMING B., US;  
VOLP, KELLY A., US;  
MCCORMICK, MARK, US

(74) Agent: SMART & BIGGAR

(54) Titre : SELS PHENOLATES DE BENZOTRIAZOLE SUBSTITUÉS ET COMPOSITIONS ANTIOXYDANTES  
FORMÉES A PARTIR DE CEUX-CI

(54) Title: SUBSTITUTED BENZOTRIAZOLE PHENOLATE SALTS AND ANTIOXIDANT COMPOSITIONS FORMED  
THEREFROM



**Fig. 1**

(57) Abrégé/Abstract:

A class of antioxidant compositions include benzotriazole phenolate salts with substituents either ortho to the phenol hydroxide group and/or para to the phenol hydroxide group can be prepared from substituted benzotriazole phenols. The ortho substituent group can be a simple hydrocarbon, alkoxy or amino group, or the ortho substituent group can be a linking group, linking the benzotriazole phenolate to another benzotriazole phenolate group.

## (12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization

International Bureau



(10) International Publication Number

WO 2017/007677 A1

(43) International Publication Date  
12 January 2017 (12.01.2017)(51) International Patent Classification:  
*C09K 15/32* (2006.01)      *C08K 5/00* (2006.01)  
*H01B 1/12* (2006.01)(21) International Application Number:  
PCT/US2016/040370(22) International Filing Date:  
30 June 2016 (30.06.2016)(25) Filing Language:  
English(26) Publication Language:  
English(30) Priority Data:  
62/189,473      7 July 2015 (07.07.2015)      US

(71) Applicant: 3M INNOVATIVE PROPERTIES COMPANY [US/US]; 3M Center, Post Office Box 33427, Saint Paul, Minnesota 55133-3427 (US).

(72) Inventors: SCHULTZ, Nathan E.; 3M Center, Post Office Box 33427, Saint Paul, Minnesota 55133-3427 (US). LI, Fuming B.; 3M Center, Post Office Box 33427, Saint Paul, Minnesota 55133-3427 (US). VOLP, Kelly A.; 3M Center, Post Office Box 33427, Saint Paul, Minnesota 55133-3427 (US). MCCORMICK, Mark; 3M Center, Post Office Box 33427, Saint Paul, Minnesota 55133-3427 (US).

(74) Agents: OLOFSON, Jeffrey M. et al.; 3M Center, Office of Intellectual Property Counsel, 3M Center, Saint Paul, Minnesota 55133-3427 (US).

(81) Designated States (unless otherwise indicated, for every kind of national protection available): AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JP, KE, KG, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States (unless otherwise indicated, for every kind of regional protection available): ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

## Published:

— with international search report (Art. 21(3))

(54) Title: SUBSTITUTED BENZOTRIAZOLE PHENOLATE SALTS AND ANTIOXIDANT COMPOSITIONS FORMED THEREFROM

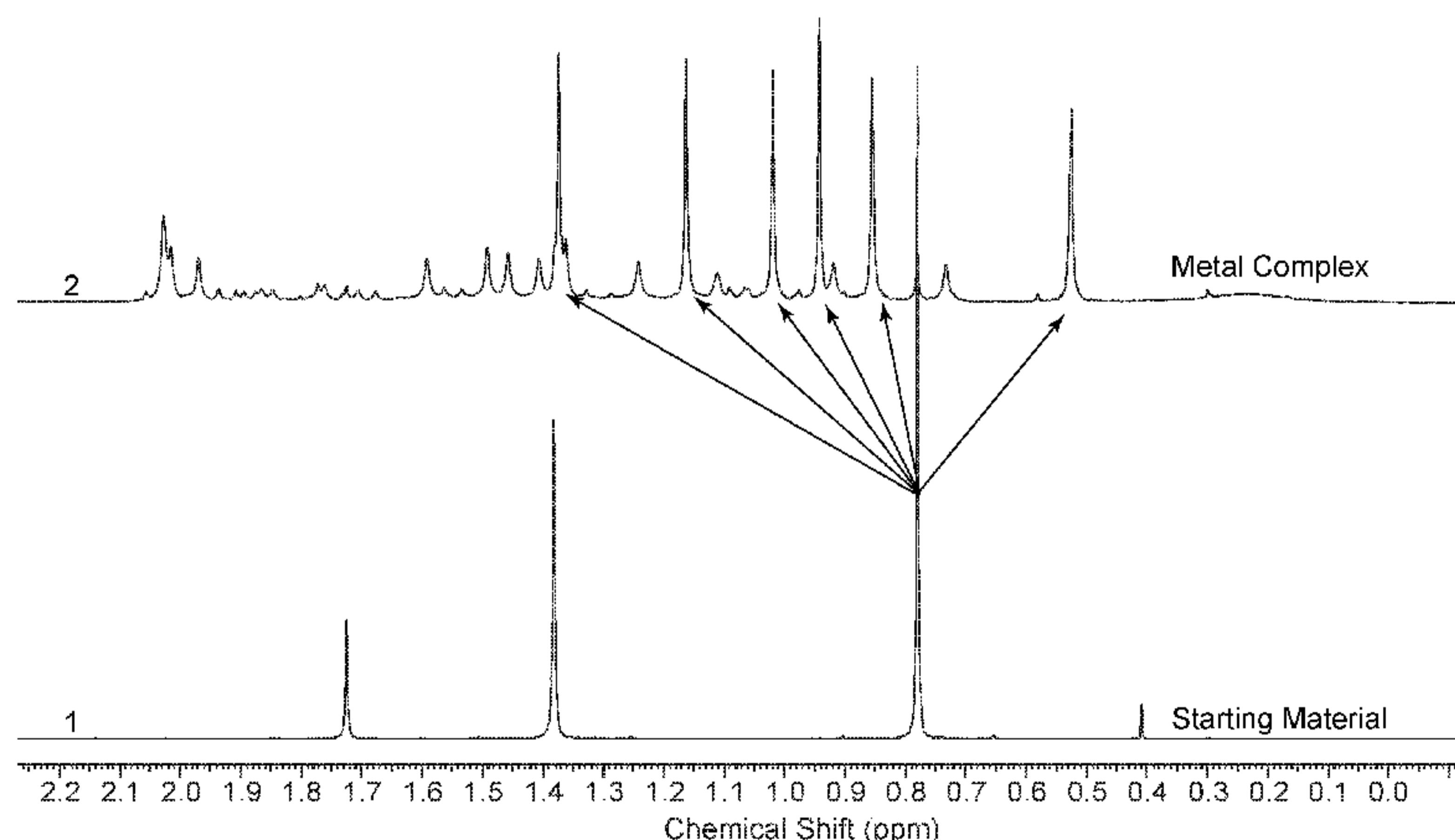


Fig. 1

(57) Abstract: A class of antioxidant compositions include benzotriazole phenolate salts with substituents either ortho to the phenol hydroxide group and/or para to the phenol hydroxide group can be prepared from substituted benzotriazole phenols. The ortho substituent group can be a simple hydrocarbon, alkoxy or amino group, or the ortho substituent group can be a linking group, linking the benzotriazole phenolate to another benzotriazole phenolate group.

WO 2017/007677 A1

## SUBSTITUTED BENZOTRIAZOLE PHENOLATE SALTS AND ANTIOXIDANT COMPOSITIONS FORMED THEREFROM

### Field of the Disclosure

5 This disclosure relates to substituted benzotriazole phenolate salts and antioxidant compositions formed from them.

### Background

10 Phenols are a class of chemical compounds having a hydroxyl group directly bonded to an aromatic hydrocarbon group. Phenolates are the anionic salts of phenols in which a proton has been removed from the hydroxyl group of the phenol. A wide variety of phenolics, as compounds that contain a phenol group are called, are known. Some phenolics are produced by plants in nature and others have been synthetically designed for a variety of chemical uses.

15 One class of phenolics are 2-(2-hydroxyphenyl)benzotriazoles or benzotriazole phenols. Benzotriazole phenols are an important class of UV absorbers, and in some cases, can absorb in the visible range as well. These compounds are often used as additives in materials and can even be incorporated into the polymeric structures via a polymerizable substituent on the benzotriazole phenol structure.

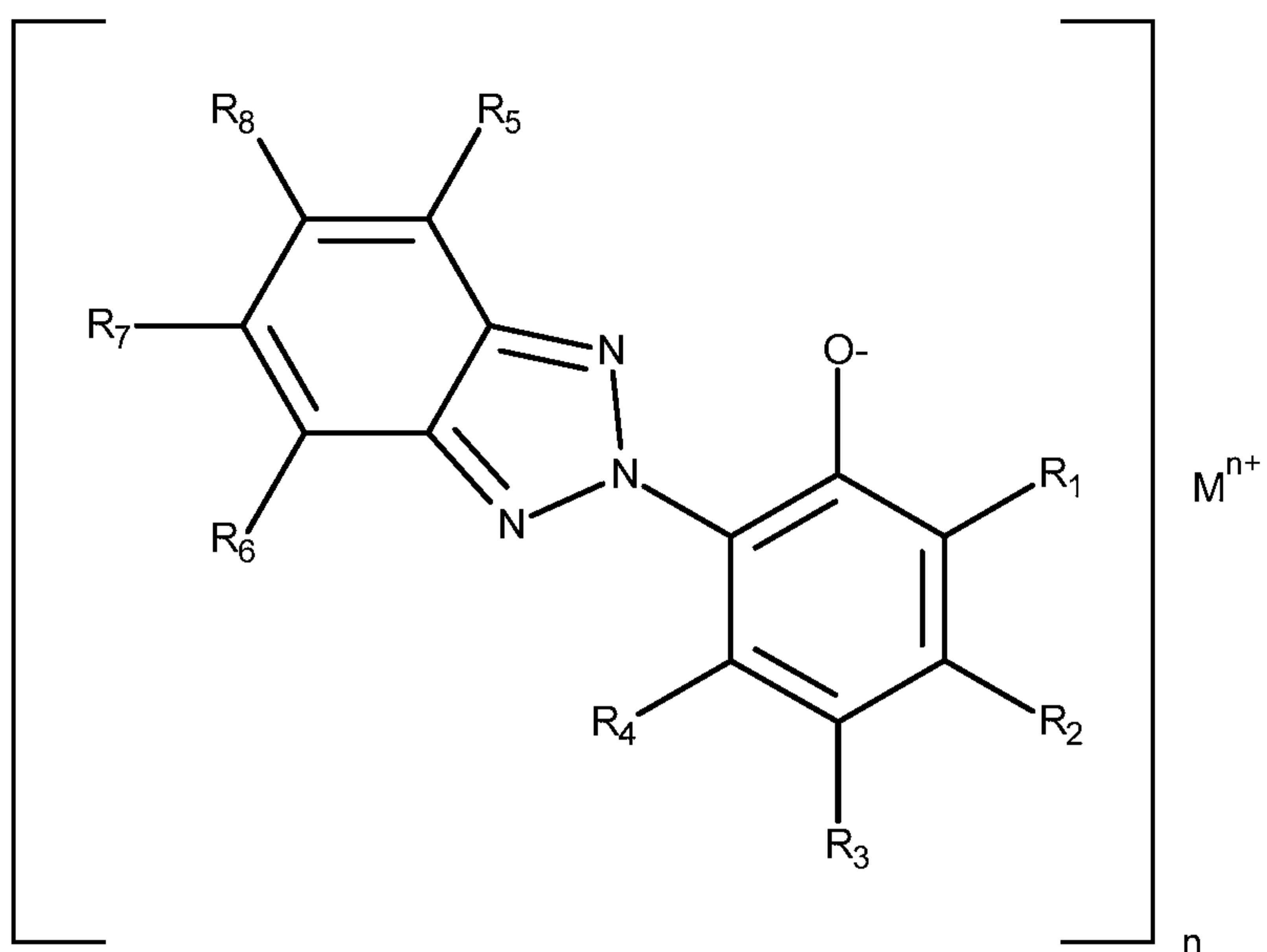
20 In addition to the usefulness of the benzotriazole phenols themselves, the benzotriazole phenols can also be used as synthons to form benzotriazole phenolate salts that are also useful. For example in EP Patent Publication No. 351,732, the use of a variety of benzotriazole phenolate salts are used as the essential ingredient to give high crystallization rates in polyester polymer compositions.

25 The need remains for substituted benzotriazole phenolate salts.

### Summary

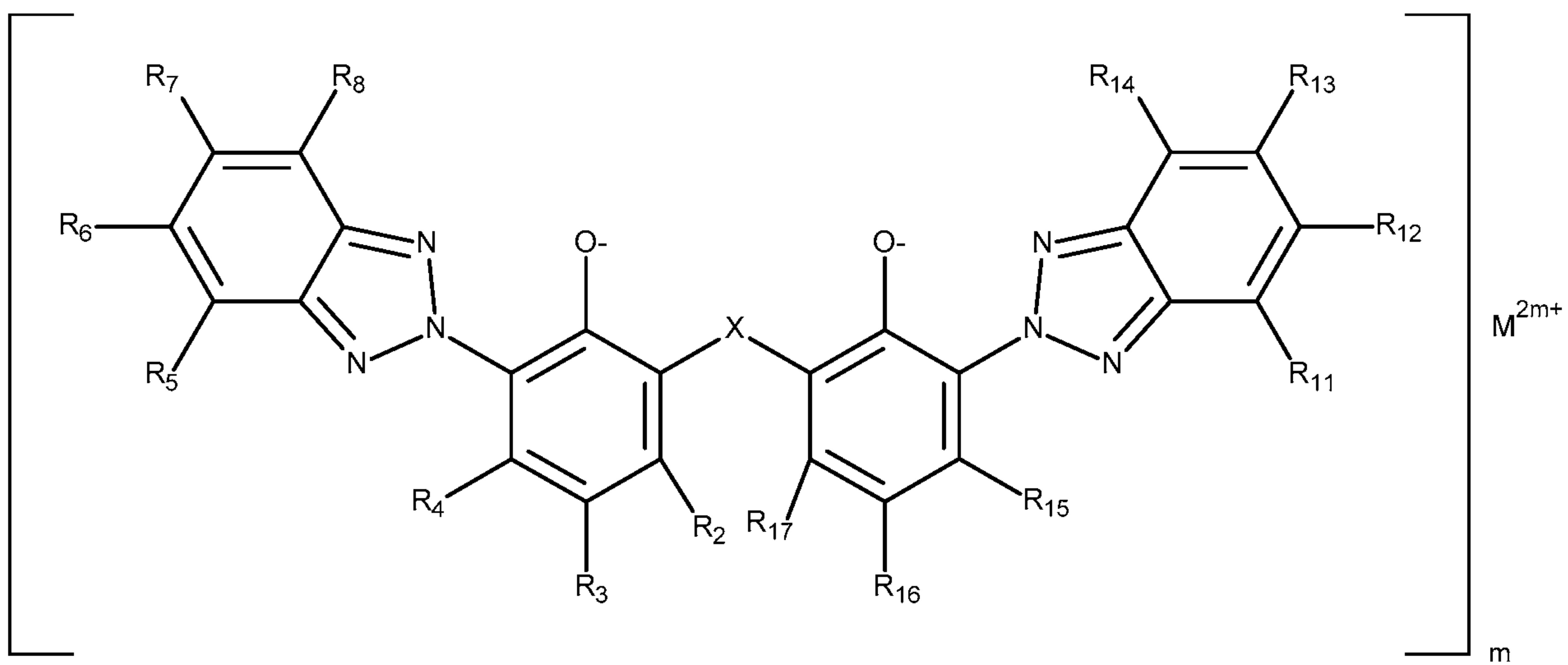
Disclosed herein are substituted benzotriazole phenolate salts, and antioxidant compositions comprising these substituted benzotriazole phenolate salts. In some 30 embodiments, the antioxidant composition comprises one or more macromolecular salt compositions, the macromolecular salt composition comprising an assembly of metal salts

comprising repeat units of a substituted benzotriazole phenolate anion and a metal cation with the structure:



where each R<sup>1</sup>, R<sup>2</sup>, R<sup>3</sup>, R<sup>4</sup>, R<sup>5</sup>, R<sup>6</sup>, R<sup>7</sup>, and R<sup>8</sup>, independently comprises a hydrogen atom, an alkyl group, an alkenyl group, an aryl group, a halogen atom, or a substituted heteroatom group comprising a -B(OR<sup>18</sup>)(OR<sup>19</sup>), a -SiR<sup>20</sup><sub>3</sub>, a -CH<sub>2</sub>-R<sup>9</sup>, an -O-R<sup>9</sup>, a -N-R<sup>9</sup>R<sup>10</sup>, a -S-R<sup>9</sup>, a -S(O)-R<sup>9</sup>, or a -S(O)<sub>2</sub>-R<sup>9</sup> group, where S(O) is a sulfinyl group S=O, and S(O)<sub>2</sub> is a sulfonyl group O=S=O, R<sup>9</sup> comprises a hydrogen atom, an alkyl group, an alkenyl group, an aryl group, or a heteroatom-containing group comprising one or more oxygen, nitrogen, sulfur, or phosphorous atoms, wherein the -B(OR<sup>18</sup>)(OR<sup>19</sup>), -SiR<sup>20</sup><sub>3</sub>, -CH<sub>2</sub>-R<sup>9</sup>, -O-R<sup>9</sup>, -N-R<sup>9</sup>R<sup>10</sup>, -S-R<sup>9</sup>, -S(O)-R<sup>9</sup>, or -S(O)<sub>2</sub>-R<sup>9</sup> group may be neutral or anionic, and R<sup>10</sup> comprises a hydrogen atom, an alkyl group, an alkenyl group, an aryl group, or a heteroatom-containing group comprising one or more oxygen, nitrogen, sulfur, or phosphorous atoms, or R<sup>9</sup> and R<sup>10</sup> together with the atoms connecting form a heterocyclic ring structure, R<sup>18</sup> and R<sup>19</sup> are independently hydrogen atoms, alkyl groups or R<sup>18</sup> and R<sup>19</sup> together with the atoms connecting form a heterocyclic ring structure, each R<sup>20</sup> independently comprises an alkyl group; n is an integer of 1-4; and M comprises a metal atom with a valency of n; and the macromolecular assembly comprises 2-4 repeat units.

In other embodiments, the repeat unit of the macromolecular salt has the structure:



where X comprises a -CH<sub>2</sub>-, -O-, -S-, -S(O)-, -S(O)<sub>2</sub>-, or -NR<sup>10</sup>- linking group where R<sup>10</sup> comprises a hydrogen atom, an alkyl group, or an aryl group, each R<sup>2</sup>, R<sup>3</sup>, R<sup>4</sup>, R<sup>5</sup>, R<sup>6</sup>, R<sup>7</sup>, R<sup>8</sup>, R<sup>11</sup>, R<sup>12</sup>, R<sup>13</sup>, R<sup>14</sup>, R<sup>15</sup>, R<sup>16</sup>, and R<sup>17</sup>, independently comprises a hydrogen atom, an alkyl group, an alkenyl group, an aryl group, or a halogen atom; m = 0.5, 1, or 2; M is a metal ion with a valency of 2m such that M is lithium sodium or potassium when m = 0.5; M is calcium, magnesium, or cobalt, when m = 1; and M is vanadium or titanium when m = 2.

10

### Brief Description of the Drawings

The present application may be more completely understood in consideration of the following detailed description of various embodiments of the disclosure in connection with the accompanying drawings.

15

Figure 1 shows a view of NMR data for a precursor and for an embodiment of an article of this disclosure.

### Detailed Description

One class of useful phenolics are 2-(2-hydroxyphenyl)benzotriazoles or benzotriazole phenols. Benzotriazole phenols are an important class of UV absorbers, and in some cases, can absorb in the visible range as well. These compounds are often used as additives in materials, particularly polymeric materials, and can be used as synthons to

prepare benzotriazole phenolate salts, which can also be useful as additives in materials, especially polymeric materials.

Phenols such as benzotriazole phenols are known to be absorbers of light, especially UV (ultraviolet) light, but also in some instances visible light. A number of 5 benzotriazole phenols are commercially available as light stabilizers, that is to say for incorporation into polymeric matrices to protect the matrices from damage by UV light.

Disclosed herein are substituted benzotriazole phenolate salts which have a wide variety of desirable properties. The substituted benzotriazole phenolate salts have 10 antioxidant properties. That is to say that incorporation of the phenolate salts into polymeric matrices protects that matrices from oxidation. This is very different from the light stabilization properties of the phenols. This antioxidant property can be measured in a variety of ways as will be described in greater detail in the Examples section below. The ability of these salts to provide protection from oxidation is a very useful property, as well as one that is not expected for this class of materials.

15 In addition, the substituted benzotriazole phenolate salts also have the unexpected property of fluorescence. Fluorescence is a well understood property in which the material absorbs electromagnetic radiation of one wavelength and emits electromagnetic radiation of different, typically longer, wavelength. In the present disclosure, the substituted benzotriazole phenolate salts absorb light of UV wavelengths and emits light 20 in the visible range of wavelengths. This property has a wide range of uses, particularly when the fluorescent material is dispersed within a polymeric matrix. For example, a wide variety of safety and security items utilize this property from signs and other safety articles where the fluorescence enhances the visibility of the safety articles, to security articles which can use the fluorescence for verification (the presence of fluorescence in a 25 security document allows for verification of the authenticity of the security document by exposure to UV light and observation of the fluorescence). The fluorescence of the substituted benzotriazole phenolate salts is surprising in view of the fact that the phenols from which the salts are prepared are not fluorescent.

Another property of these substituted benzotriazole phenolate salts is their 30 usefulness as charge enhancing additives for electret materials. This property is more fully disclosed in the copending application Attorney Docket No. 75916US002 filed on the same day as the present application.

The substituted benzotriazole phenolate salts of this disclosure are not simple salts of the type [anion][cation] such as one would expect for this type of salt. Rather, the salts are macromolecular salt compositions comprising an assembly of metal salts having repeat units of a substituted benzotriazole phenolate anion and metal cation(s) with the general structure: {[anion][cation]}<sub>a</sub> where a is an integer of from two to four. The methods in which this macromolecular composition has been verified will be described in greater detail in the Examples section. Nuclear magnetic resonance (NMR) spectra verifies that the macromolecular structure is present in solution.

The terms “a”, “an”, and “the” are used interchangeably with “at least one” to mean one or more of the elements being described.

The term “alkyl” refers to a monovalent group that is a radical of an alkane, which is a saturated hydrocarbon. The alkyl can be linear, branched, cyclic, or combinations thereof and typically has 1 to 20 carbon atoms. In some embodiments, the alkyl group contains 1 to 18, 1 to 12, 1 to 10, 1 to 8, 1 to 6, or 1 to 4 carbon atoms. Examples of alkyl groups include, but are not limited to, methyl, ethyl, n-propyl, isopropyl, n-butyl, isobutyl, tert-butyl (t-butyl), n-pentyl, n-hexyl, cyclohexyl, n-heptyl, n-octyl, and ethylhexyl.

The term “alkenyl” refers to a monovalent group that is a radical of an alkene, which is a hydrocarbon with at least one carbon-carbon double bond. The alkenyl can be linear, branched, cyclic, or combinations thereof and typically contains 2 to 20 carbon atoms. In some embodiments, the alkenyl contains 2 to 18, 2 to 12, 2 to 10, 4 to 10, 4 to 8, 2 to 8, 2 to 6, or 2 to 4 carbon atoms. Exemplary alkenyl groups include ethenyl, n-propenyl, and n-butenyl.

The term “alkaryl” as used herein refers to aryl substituted alkyl group of the general structure -R<sup>a</sup>-Ar, where R<sup>a</sup> is an alkylene group and Ar is an aryl group. An example of an alkaryl group is a benzyl group -CH<sub>2</sub>-Ph.

The term “heteroatom substituted” refers to an alkyl, aryl or other group which contains heteroatoms. These heteroatoms may be pendant atoms, for example, halogens such as fluorine, chlorine, bromine, or iodine or catenary atoms such as nitrogen, oxygen, boron, or sulfur.

The term “alkoxy” refers to a group with the general structure -O-R, where R is an alkyl group. The term “aryloxy” refers to a group with the general structure -O-R, where

R is an aryl group. In some instances, the term alkoxy is used generically to describe both alkoxy and aryloxy groups.

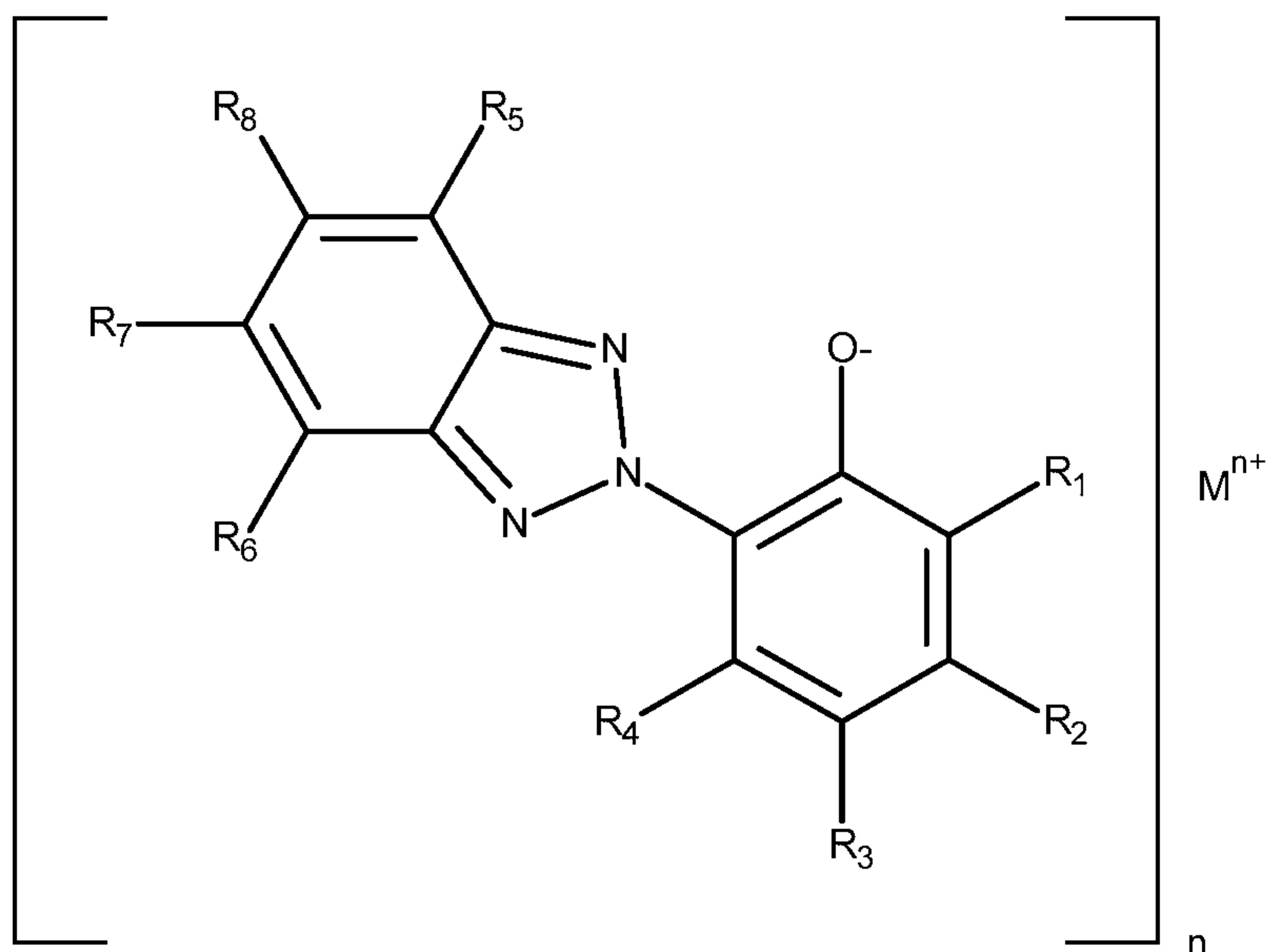
The term “aryl” refers to an aromatic carbocyclic group that is a radical containing 1 to 5 rings which may be connected or fused. The aryl group may be substituted with alkyl or heteroalkyl groups. Examples of aryl groups include phenyl groups, naphthalene groups and anthracene groups.

The terms “room temperature” and “ambient temperature” are used interchangeably to mean temperatures in the range of 20°C to 25°C.

Unless otherwise indicated, all numbers expressing feature sizes, amounts, and physical properties used in the specification and claims are to be understood as being modified in all instances by the term “about.” Accordingly, unless indicated to the contrary, the numbers set forth are approximations that can vary depending upon the desired properties using the teachings disclosed herein.

Disclosed herein are compositions of matter comprising salts of substituted benzotriazole phenolate anions and metal cations that are macromolecular salts, and antioxidant compositions comprising one or more macromolecular salts of substituted benzotriazole phenols.

Among the compositions disclosed herein are compositions of matter comprising macromolecular salts of a substituted benzotriazole phenolate anion and a metal cation with repeating units with the structure of Formula I:



## Formula I

In Formula I, at least one of R<sup>1</sup> and R<sup>3</sup> comprises a substituent group, that is to say a group other than a hydrogen atom. In many embodiments, both R<sup>1</sup> and R<sup>3</sup> comprise substituent groups. In some embodiments R<sup>1</sup> is not substituted i.e. R<sup>1</sup> comprises a hydrogen atom, in many other embodiments R<sup>1</sup> is a substituent group or another linked benzotriazole phenol group, as will be described in greater detail below.

In embodiments where R<sup>1</sup> is not substituted (i.e. is a hydrogen atom), R<sup>3</sup> comprises an alkyl, alkoxy or aryloxy group comprising 1-20 carbon atoms, and each R<sup>2</sup>, R<sup>4</sup>, R<sup>5</sup>, R<sup>6</sup>, R<sup>7</sup>, and R<sup>8</sup>, independently comprises a hydrogen atom, an alkyl group, an alkenyl group, an aryl group, or a halogen atom. In one embodiment, R<sup>1</sup> comprises a hydrogen atom, R<sup>3</sup> comprises an alkyl group with one carbon atom, and each R<sup>2</sup>, R<sup>4</sup>, R<sup>5</sup>, R<sup>6</sup>, R<sup>7</sup>, and R<sup>8</sup>, independently comprises a hydrogen atom. In another embodiment, R<sup>1</sup> comprises a hydrogen atom, R<sup>3</sup> comprises an alkoxy group comprising 4 carbon atoms, and each R<sup>2</sup>, R<sup>4</sup>, R<sup>5</sup>, R<sup>6</sup>, R<sup>7</sup>, and R<sup>8</sup>, independently comprises a hydrogen atom.

In a wide variety of embodiments R<sup>1</sup> comprises a substituent group. In these embodiments, R<sup>1</sup> comprises a halogen atom, an alkyl or substituted alkyl group, an alkenyl group, or a group comprising an -O-R<sup>9</sup>, a -N-R<sup>9</sup>R<sup>10</sup>, a -B(OR<sup>18</sup>)(OR<sup>19</sup>), or a -SiR<sup>20</sup><sub>3</sub>. In these embodiments R<sup>9</sup> comprises a hydrogen atom, an alkyl group, an alkenyl group, an aryl group, or a heteroatom-containing group comprising one or more oxygen, nitrogen, sulfur, or phosphorous atoms, and R<sup>10</sup> comprises a hydrogen atom, an alkyl group, an alkenyl group, an aryl group, or a heteroatom-containing group comprising one or more oxygen, nitrogen, sulfur, or phosphorous atoms, or R<sup>9</sup> and R<sup>10</sup> together with the atoms connecting form a heterocyclic ring structure, each R<sup>18</sup> and R<sup>19</sup> is independently a hydrogen atom, an alkyl group, an aryl group, or R<sup>18</sup> and R<sup>19</sup> together with the atoms connecting form a heterocyclic ring structure, each R<sup>20</sup> group is an alkyl group, and each R<sup>2</sup>, R<sup>3</sup>, R<sup>4</sup>, R<sup>5</sup>, R<sup>6</sup>, R<sup>7</sup>, and R<sup>8</sup>, independently comprises a hydrogen atom, an alkyl group, an alkenyl group, an aryl group, or a halogen atom. Each of these embodiments will be described in greater detail below.

In some embodiments, R<sup>1</sup> comprises a relatively small substituent group, one which is of smaller molecular weight and/or steric size relative to the benzotriazole phenol base molecule. In other embodiments, the R<sup>1</sup> group is a substituent group that is comparable in size and/or steric size to the benzotriazole phenol base molecule, and is in

fact another benzotriazole phenol linked to the benzotriazole phenol base molecule by an oxygen-based, nitrogen-based, or carbon-based linking group. Examples of the first type, where  $R^1$  comprises a relatively small substituent group, will be presented first.

5 In some embodiments,  $R^1$  comprises a halogen atom. Suitable halogen atoms include fluorine, bromine, chlorine and iodine. Bromine (Br) and chlorine (Cl) are particularly suitable.

10 In some embodiments,  $R^1$  comprises an alkyl group, an alkenyl group, or a substituted alkyl group. When  $R^1$  comprises an alkyl group typically  $R^1$  comprises an alkyl group with 1-6 carbon atoms, in one particular embodiment  $R^1$  comprises an alkyl group with 4 carbon atoms, generally a tert-butyl group, and  $R^3$  is an alkyl group with 4 carbon atoms, typically a tert-butyl group. When  $R^1$  comprises an alkenyl group typically 15  $R^1$  comprises an alkenyl group with 1-6 carbon atoms, in one particular embodiment  $R^1$  comprises an alkenyl group with 3 carbon atoms, generally a propenyl group, and  $R^3$  is an alkyl group with 1 carbon atom, typically a methyl group. When  $R^1$  comprises a substituted alkyl group typically  $R^1$  comprises an aryl substituted alkyl group with 1-12 carbon atoms, in one particular embodiment  $R^1$  comprises an substituted alkyl group with 10 carbon atoms, a 2,2-dimethyl-3-phenyl group, and  $R^3$  is an alkyl group with 8 carbon atoms, typically an iso-octyl group.

20 In some embodiments, where  $R^1$  comprises an  $-O-R^9$  group wherein  $R^9$  comprises an alkyl group with 1-20 carbon atoms, or an aryl group. In many of these embodiments,  $R^3$  is also a substituent group, typically  $R^3$  is an alkyl group with 1-20 carbon atoms.

25 In some embodiments,  $R^9$  comprises an alkyl group with 1-6 carbon atoms, in one particular embodiment  $R^9$  comprises an alkyl group with 4 carbon atoms, and  $R^3$  is an alkyl group with 8 carbon atoms, typically an iso-octyl group.

In other embodiments,  $R^9$  comprises an aryl group comprising a substituted phenyl group. In some particular embodiments,  $R^9$  comprises a 3-methyl phenyl group or a 4-methyl phenyl group, and  $R^3$  is an alkyl group with 8 carbon atoms, typically an iso-octyl group.

30 In another group of embodiments,  $R^1$  comprises an  $-N-R^9R^{10}$  group. In some of these embodiments,  $R^9$  comprises an alkyl group with 1-20 carbon atoms, or an aryl group. In these embodiments,  $R^{10}$  independently comprises a hydrogen atom or alkyl

group with 1-6 carbon atoms. In many of these embodiments,  $R^3$  is also a substituent group, typically  $R^3$  is an alkyl group with 1-20 carbon atoms.

5 In some embodiments,  $R^9$  comprises an alkyl group with 1-6 carbon atoms, or an aryl group comprising a 4-alkyl substituted phenyl group, wherein the alkyl substituted group has 1-6 carbon atoms, and  $R^{10}$  comprises a hydrogen atom.

10 In one particular embodiment,  $R^9$  comprises an alkyl group with 1 carbon atom (a methyl group),  $R^{10}$  comprises a hydrogen atom, and  $R^3$  is an alkyl group with 8 carbon atoms, typically an iso-octyl group. In one particular embodiment,  $R^9$  comprises an alkyl group with 6 carbon atoms,  $R^{10}$  comprises a hydrogen atom, and  $R^3$  is an alkyl group with 8 carbon atoms, typically an iso-octyl group. In yet another particular embodiment,  $R^9$  comprises a 4-alkyl substituted phenyl group, wherein the alkyl substituted group has 6 carbon atoms (i.e. the group comprises a 4-hexyl phenyl group),  $R^{10}$  comprises a hydrogen atom, and  $R^3$  is an alkyl group with 8 carbon atoms, typically an iso-octyl group.

15 In another particular embodiment,  $R^1$  comprises a  $-B(OH)_2$  group, in other embodiments  $R^1$  comprises  $-B(-O-C(Me)_2-C(Me)_2-O-)$ , and  $R^3$  is an alkyl group with 8 carbon atoms, typically an iso-octyl group.

In another particular embodiment,  $R^1$  comprises a  $-SiR^{20}_3$  group where  $R^{20}$  comprises an alkyl group with 1-6 carbon atoms, in some embodiments  $R^{20}$  comprises 3 carbon atoms, typically  $R^{20}$  comprises an isopropyl group.

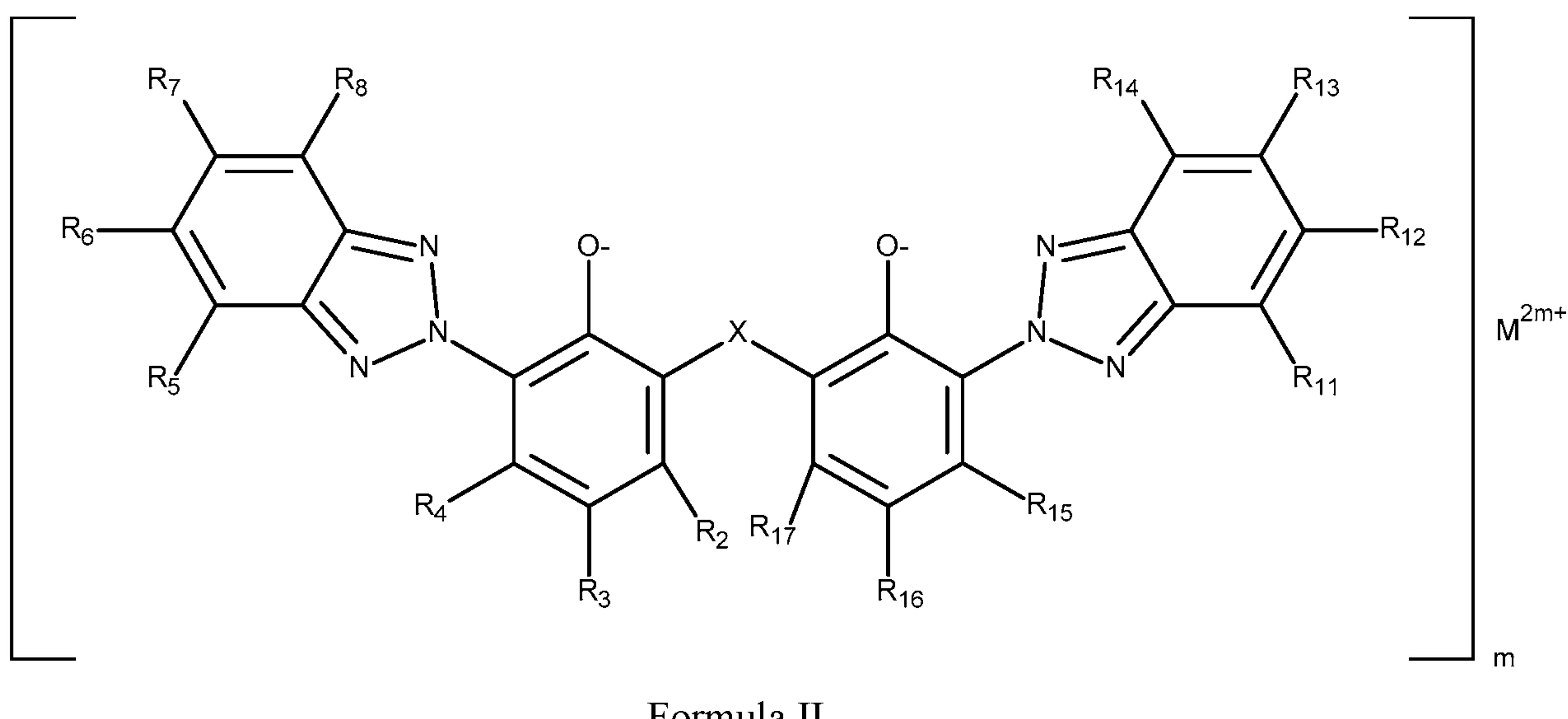
20 In Formula I,  $M$  is a main group or transition metal ion with a valency of  $n$ , and  $n$  also describes the stoichiometry of the anionic portion of the salt. Typically  $n$  is an integer of 1-4. If  $n$  is 1, the metal salt  $M$  is a monovalent metal ion and the stoichiometry of the anionic portion is 1. If  $n$  is 2, the metal salt  $M$  is a divalent metal ion and the stoichiometry of the anionic portion is 2, meaning that two anions are present per  $M$  ion. 25 Typically, the cationic portion of the macromolecular salt,  $M$ , is a metallic cation with a valency of 1 or 2. In embodiments where  $M$  is monovalent, the  $M$  is lithium, sodium or potassium. In embodiments where  $M$  is divalent, there are two equivalents of the anionic portion in the macromolecular salt, and  $M$  is calcium, magnesium, or cobalt. In some embodiments,  $M$  is a tetravalent metal ion ( $n = 4$ ) or titanium or vanadium.

30 The salt shown in Formula I is a macromolecular salt, by which it is meant that it is not a simple anion and cation combination, but is a more complex assembly of anions and cations. The salt shown in Formula I is a repeat unit, and the salt comprises from 2 to 4

repeat units. The stoichiometry of the salt (as defined by the value of n) is different from the macromolecular nature of the salt. The stoichiometry merely refers to the charge balance of the salt, whereas the macromolecular nature of the salt refers to the presence of an extended assembly of salts. As was described above, a simple anion-cation salt would 5 be of the type: [anion][cation], whereas the salts of this disclosure are macromolecular salts of the type: {[anion][cation]}<sub>a</sub>, where a is an integer of from 2 to 4.

As will be explained in greater detail in the Examples section, NMR (nuclear magnetic resonance) can be used to show that the salts are macromolecular assemblies in solution. This NMR evidence is also shown in Figure 1. To summarize, a characteristic 10 alkyl group on the phenol from which the salt is made shows a single peak. Upon formation of the salt, the single peak forms multiple peaks, demonstrating that the characteristic alkyl group is not a single peak as would be anticipated for a simple [anion][cation] salt. The presence of multiple peaks shows that the characteristic alkyl group on the anion experiences slightly different environments because the anions are part 15 of the macromolecular assembly. Analysis of NMR Diffusion measurements can be used to determine the number of repeat units in the macromolecular assembly (the value of a shown above), which is generally 2-4.

As mentioned above, in other embodiments the R<sup>1</sup> group is a substituent group that is comparable in size and/or steric size to the benzotriazole phenolate base molecule, and 20 is in fact another benzotriazole phenolate linked to the benzotriazole phenolate base molecule by an oxygen, nitrogen-based, carbon-based, or sulfur-based linking group. Examples of this second type of compound are described by Formula II below:



The structure of Formula II can be viewed as compound of Formula I where the R<sup>1</sup> group is an -X-R<sup>9</sup> group an X is a linking group comprising an -O-, -NR<sup>10</sup>-, -S-, -S(O)-, -S(O)<sub>2</sub>-, or -CH<sub>2</sub>-, where S(O) is a sulfinyl group S=O, S(O)<sub>2</sub> is a sulfonyl group O=S=O, and where R<sup>10</sup> comprises a hydrogen atom, an alkyl group, or an aryl group. The R<sup>9</sup> group in these embodiments is another benzotriazole phenolate group, which may be the same or different from the base benzotriazole phenolate group. In these embodiments, each R<sup>2</sup>, R<sup>3</sup>, R<sup>4</sup>, R<sup>5</sup>, R<sup>6</sup>, R<sup>7</sup>, R<sup>8</sup>, R<sup>11</sup>, R<sup>12</sup>, R<sup>13</sup>, R<sup>14</sup>, R<sup>15</sup>, R<sup>16</sup>, and R<sup>17</sup>, independently comprises a hydrogen atom, an alkyl group, an alkenyl group, an aryl group, or a halogen atom.

In Formula II, M is a metal ion with a valency of 2m, and m also describes the stoichiometry of the anionic portion of the salt. In this instance, m can be a non-integer number, selected from 0.5, 1.0, or 2. If m is 0.5, the metal salt M is monovalent metal (2m = 1) and the stoichiometry of the anionic portion is 0.5 (i.e. one half the anionic portion per M, or 2 M ions per 1 anionic portion). If m is 1, the metal salt M is a divalent metal ion and the stoichiometry of the anionic portion is 1. If m is 2, the metal salt M is a tetravalent metal ion and the stoichiometry of the anionic portion is 2, meaning that two anions are present per M ion. Typically, the cationic portion of the macromolecular salt, M, is a metallic cation with a valency of 1 or 2. In embodiments where M is monovalent, the M is lithium, sodium or potassium. In embodiments where M is divalent, M is calcium, magnesium, or cobalt. In some embodiments, M is a tetravalent metal ion (m = 2) or titanium or vanadium.

In some embodiments of the compounds of Formula II, X comprises an -NR<sup>10</sup>- linking group where R<sup>10</sup> comprises a hydrogen atom, or an alkyl group comprising 1-3 carbon atoms. Typically in these embodiments, the R<sup>3</sup> and R<sup>16</sup> groups are substituent groups, where R<sup>3</sup> and R<sup>16</sup> each comprise an alkyl group with 1-20 carbon atoms. 5 Typically, each R<sup>2</sup>, R<sup>4</sup>, R<sup>5</sup>, R<sup>6</sup>, R<sup>7</sup>, R<sup>8</sup>, R<sup>11</sup>, R<sup>12</sup>, R<sup>13</sup>, R<sup>14</sup>, R<sup>15</sup>, and R<sup>17</sup>, is a hydrogen atom.

In one particular embodiment, X comprises an -NR<sup>10</sup>- linking group where R<sup>10</sup> comprises a hydrogen atom, the R<sup>3</sup> and R<sup>16</sup> groups are alkyl groups with 8 carbon atoms, typically iso-octyl groups, and each R<sup>2</sup>, R<sup>4</sup>, R<sup>5</sup>, R<sup>6</sup>, R<sup>7</sup>, R<sup>8</sup>, R<sup>11</sup>, R<sup>12</sup>, R<sup>13</sup>, R<sup>14</sup>, R<sup>15</sup>, and R<sup>17</sup>, is a hydrogen atom.

10 In another particular embodiment, X comprises an -NR<sup>10</sup>- linking group where R<sup>10</sup> comprises an alkyl group with 1 carbon atom (a methyl group), the R<sup>3</sup> and R<sup>16</sup> groups are alkyl groups with 8 carbon atoms, typically iso-octyl groups, and each R<sup>2</sup>, R<sup>4</sup>, R<sup>5</sup>, R<sup>6</sup>, R<sup>7</sup>, R<sup>8</sup>, R<sup>11</sup>, R<sup>12</sup>, R<sup>13</sup>, R<sup>14</sup>, R<sup>15</sup>, and R<sup>17</sup>, is a hydrogen atom.

15 In some embodiments of the compounds of Formula II, X comprises an -O- linking group. Typically in these embodiments, the R<sup>3</sup> and R<sup>16</sup> groups are substituent groups, where R<sup>3</sup> and R<sup>16</sup> each comprise an alkyl group with 1-20 carbon atoms. Typically, each R<sup>2</sup>, R<sup>4</sup>, R<sup>5</sup>, R<sup>6</sup>, R<sup>7</sup>, R<sup>8</sup>, R<sup>11</sup>, R<sup>12</sup>, R<sup>13</sup>, R<sup>14</sup>, R<sup>15</sup>, and R<sup>17</sup>, is a hydrogen atom.

20 In one particular embodiment, X comprises an -O- linking group, the R<sup>3</sup> and R<sup>16</sup> groups are alkyl groups with 8 carbon atoms, typically iso-octyl groups, and each R<sup>2</sup>, R<sup>4</sup>, R<sup>5</sup>, R<sup>6</sup>, R<sup>7</sup>, R<sup>8</sup>, R<sup>11</sup>, R<sup>12</sup>, R<sup>13</sup>, R<sup>14</sup>, R<sup>15</sup>, and R<sup>17</sup>, is a hydrogen atom.

In some embodiments of the compounds of Formula II, X comprises a -S- linking group. Typically in these embodiments, the R<sup>3</sup> and R<sup>16</sup> groups are substituent groups, where R<sup>3</sup> and R<sup>16</sup> each comprise an alkyl group with 1-20 carbon atoms. Typically, each R<sup>2</sup>, R<sup>4</sup>, R<sup>5</sup>, R<sup>6</sup>, R<sup>7</sup>, R<sup>8</sup>, R<sup>11</sup>, R<sup>12</sup>, R<sup>13</sup>, R<sup>14</sup>, R<sup>15</sup>, and R<sup>17</sup>, is a hydrogen atom.

25 In one particular embodiment, X comprises a -S- linking group, the R<sup>3</sup> and R<sup>16</sup> groups are alkyl groups with 8 carbon atoms, typically iso-octyl groups, and each R<sup>2</sup>, R<sup>4</sup>, R<sup>5</sup>, R<sup>6</sup>, R<sup>7</sup>, R<sup>8</sup>, R<sup>11</sup>, R<sup>12</sup>, R<sup>13</sup>, R<sup>14</sup>, R<sup>15</sup>, and R<sup>17</sup>, is a hydrogen atom.

30 In some embodiments, X comprises a methylene group -CH<sub>2</sub>- . Typically in these embodiments, the R<sup>3</sup> and R<sup>16</sup> groups are substituent groups, where R<sup>3</sup> and R<sup>16</sup> each comprise an alkyl group with 1-20 carbon atoms. Typically, each R<sup>2</sup>, R<sup>4</sup>, R<sup>5</sup>, R<sup>6</sup>, R<sup>7</sup>, R<sup>8</sup>, R<sup>11</sup>, R<sup>12</sup>, R<sup>13</sup>, R<sup>14</sup>, R<sup>15</sup>, and R<sup>17</sup>, is a hydrogen atom. In a particular embodiment, R<sup>3</sup> and

R<sup>16</sup> each comprise an iso-octyl group. The phenol from which this salt is prepared is commercially available from BASF as TINUVIN 360.

The macromolecular nature of the salt compositions was unexpected and has been shown to be present in solution. The methodology for confirming the macromolecular nature of these salts is described in greater detail in the Examples section below. While not wishing to be bound by theory, it is believed that the unexpected macromolecular structure of the salt composition also impacts the other unexpected properties of these salts, especially their anti-oxidant activity and their fluorescence.

Also disclosed are a new class of antioxidant compositions. These antioxidant compositions comprise at least one of the macromolecular salts described above. These antioxidant compositions are useful in a wide range of applications. Among these applications are the addition of these compositions to polymeric matrices. A wide range of matrices are suitable as are described in copending application Attorney Docket No. 76177US002 filed on the same day as the present application.

One particular application for which these salts, macromolecular salts, and antioxidant compositions have been shown to be particularly suitable is as charge additives in electret articles. This is described in copending application Attorney Docket No. 75916US002 filed on the same day as the present application.

Descriptions for the preparation of the substituted benzotriazole phenolate salts and the antioxidant compositions prepared from them are described in detail below in the Examples section.

### Examples

These examples are merely for illustrative purposes only and are not meant to be limiting on the scope of the appended claims. All parts, percentages, ratios, etc. in the examples and the rest of the specification are by weight, unless noted otherwise. Solvents were Alfa Aesar (ChemSeal grade) and were used with no further purification. Solvents that were used in separations, isolations, chromatography, and other general use were obtained from EMD (Omnisolv Grade).

The following abbreviations are used throughout the Examples: M =molar; min = minutes; h = hours; equiv = equivalents; x = times; g = grams; mg = milligrams; mmol = millimoles; L = liters; mL = milliliters; rt = room temperature; aq = aqueous; RBF = round

bottom flask.

### Materials.

The following is a table of commercially available materials and reagents that were used.

5

Compound	Supplier
<b>Bases</b>	
sodium ethoxide (ca. 20% in Ethanol)	TCI America
sodium tert-butoxide	TCI America
n-butyllithium (1.6M in hexanes)	Sigma-Aldrich
potassium carbonate	EMD Millipore
cesium carbonate	Alfa Aesar
potassium hydroxide	EMD Millipore
triethylamine	Sigma-Aldrich
sodium bicarbonate	Sigma-Aldrich
ammonium chloride	VWR
<b>Oxidants</b>	
1,3-Dibromo-5,5-dimethylhydantoin	Alfa Aesar
hydrogen peroxide, 30%	J.T. Baker
urea hydrogen peroxide adduct	Alfa Aesar
m-chloroperoxybenzoic acid	Alfa Aesar
<b>Ligands</b>	
2-(Dicyclohexylphosphino)-2',4',6'-tri-i-propyl-1,1'-biphenyl (XPhos)	Strem
2-(Di-t-butylphosphino)-3-methoxy-6-methyl-2'-4'-6'-tri-i-propyl-1,1'-biphenyl (RockPhos)	Strem
2-(Di-t-butylphosphino)-3,6-dimethoxy-2',4',6'-tri-i-propyl-1,1'-biphenyl ( <i>t</i> -buBrettPhos)	Strem
1,1'-bis(diphenylphosphino)ferrocene	Strem
<b>Catalysts</b>	
tris(dibenzylideneacetone)dipalladium	Strem
palladium acetate	TCI America

allylpalladium(II) chloride dimer	Lancaster
copper acetate	Alfa Aesar
Methanesulfonato(2-(di-t-butylphosphino)-3,6-dimethoxy-2',4',6'-tri-i-propyl-1,1'-biphenyl)(2'-amino-1,1'-biphenyl-2-yl)palladium(II) (XPhos Precatalyst)	Strem
Methanesulfonato(2-(di-t-butylphosphino)-3-methoxy-6-methyl-2',4',6'-tri-i-propyl-1,1'-biphenyl)(2'-amino-1,1'-biphenyl-2-yl)palladium(II) (RockPhos Precatalyst)	Strem
Methanesulfonato(2-(di-t-butylphosphino)-3,6-dimethoxy-2',4',6'-tri-i-propyl-1,1'-biphenyl)(2'-amino-1,1'-biphenyl-2-yl)palladium(II) (t-BuBrettPhos Precatalyst)	Strem
<b>Reagents</b>	
p-tolylboronic acid	Aldrich Chemical
trimethylborate	Alfa Aesar
iodomethane	Alfa Aesar
triisopropylchlorosilane	Alfa Aesar
boron tribromide	Sigma-Aldrich
thionyl chloride	Alfa Aesar
trifluoromethanesulfonic anhydride	Oakwood
2-(2H-Benzotriazol-2-yl)-4-(1,1,3,3-tetramethylbutyl)phenol	TCI America
m-cresol	Alfa Aesar
n-butanol	Sigma-Aldrich
methylamine hydrochloride	Aldrich Chemical
4-n-hexylaniline	Alfa Aesar
hexylamine	Alfa Aesar
ammonia (0.5M in dioxane)	Sigma Aldrich

scandium triflate	Strem
4-methylbenzenethiol toluene	Alfa Aesar
potassium thioacetate	Alfa Aesar
3,5-bis(trifluoromethyl)aniline	Alfa Aesar
1-bromo-4-(heptadecafluoroctyl)benzene	Sigma Aldrich
1-iodooctadecane	Alfa Aesar

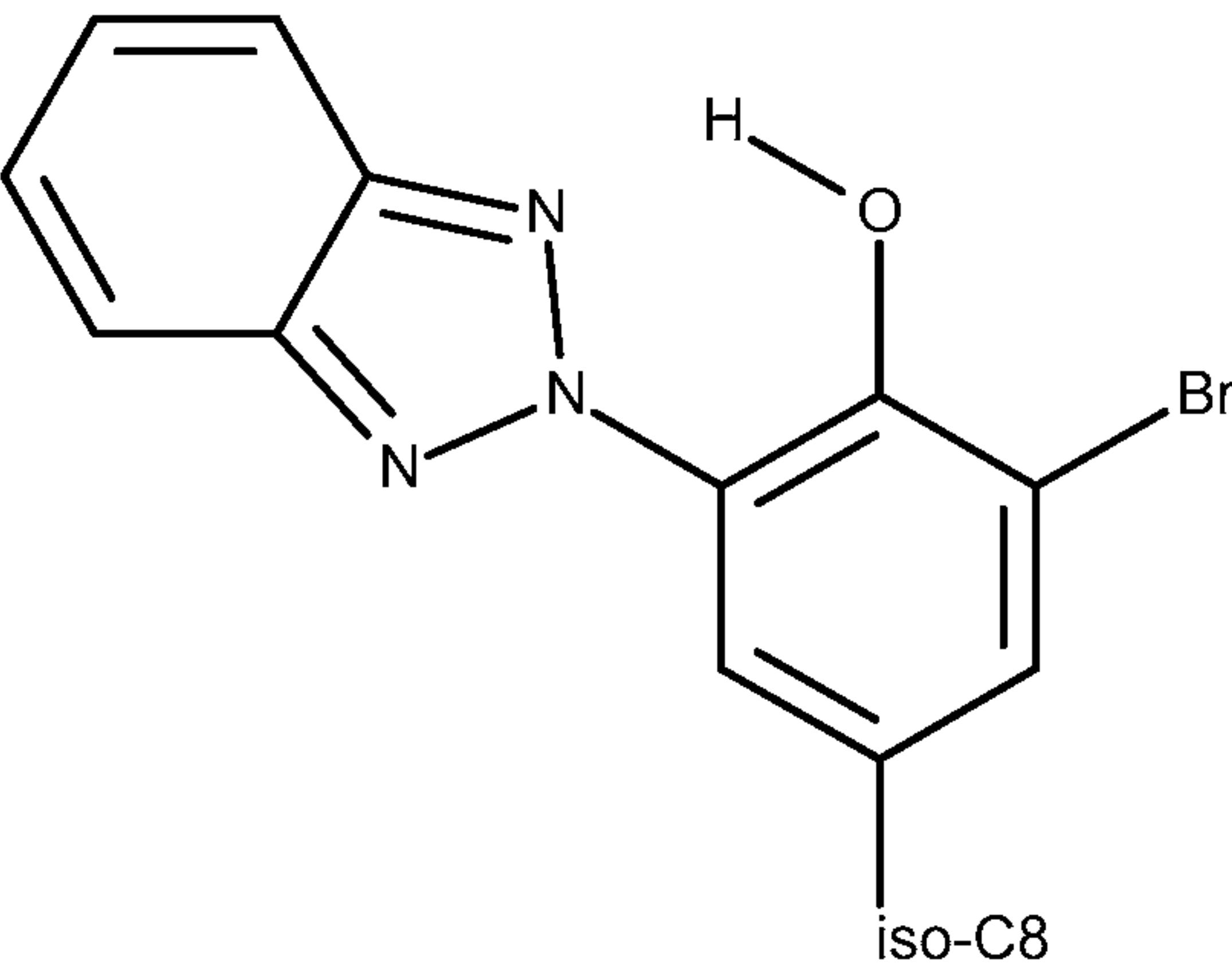
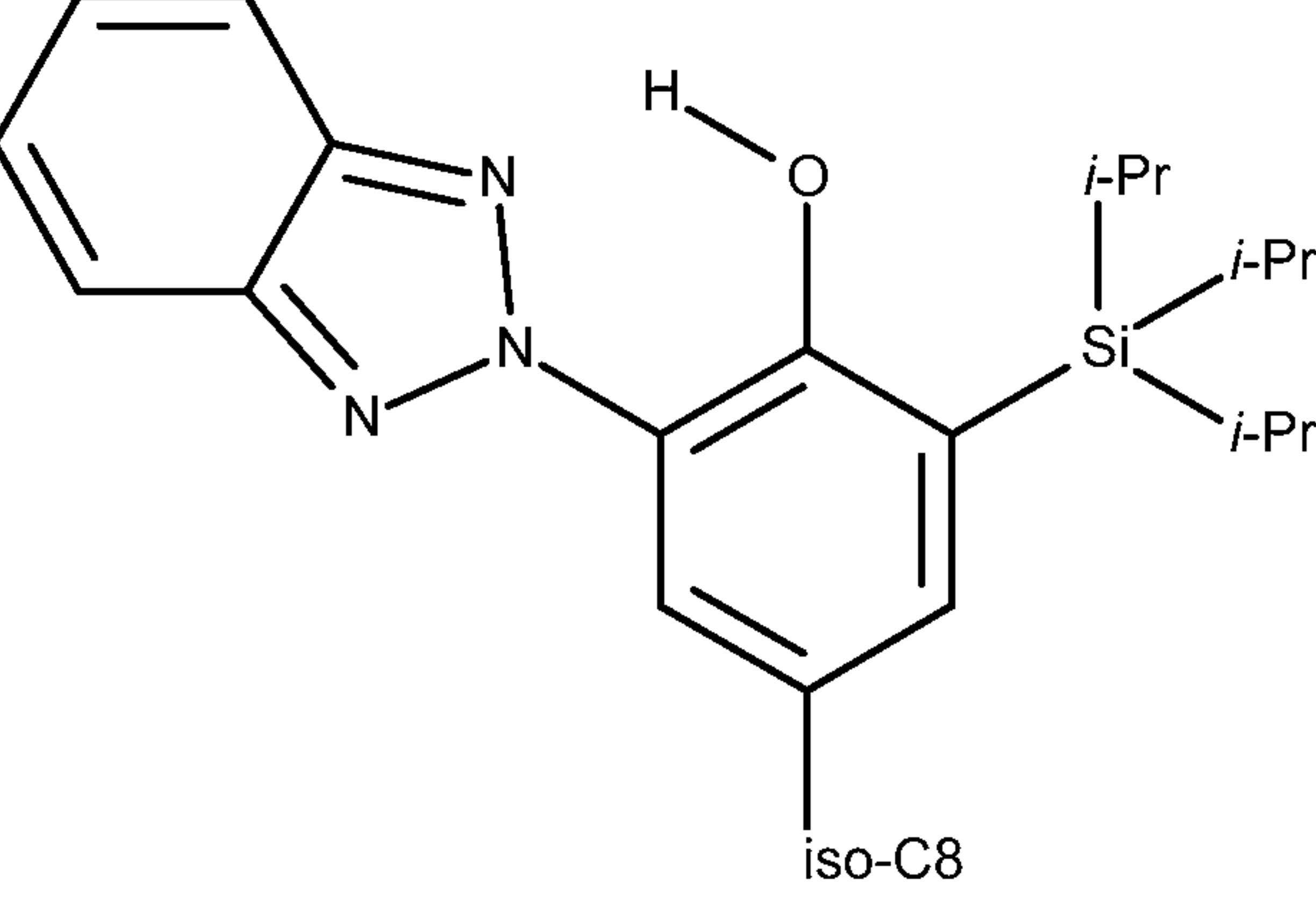
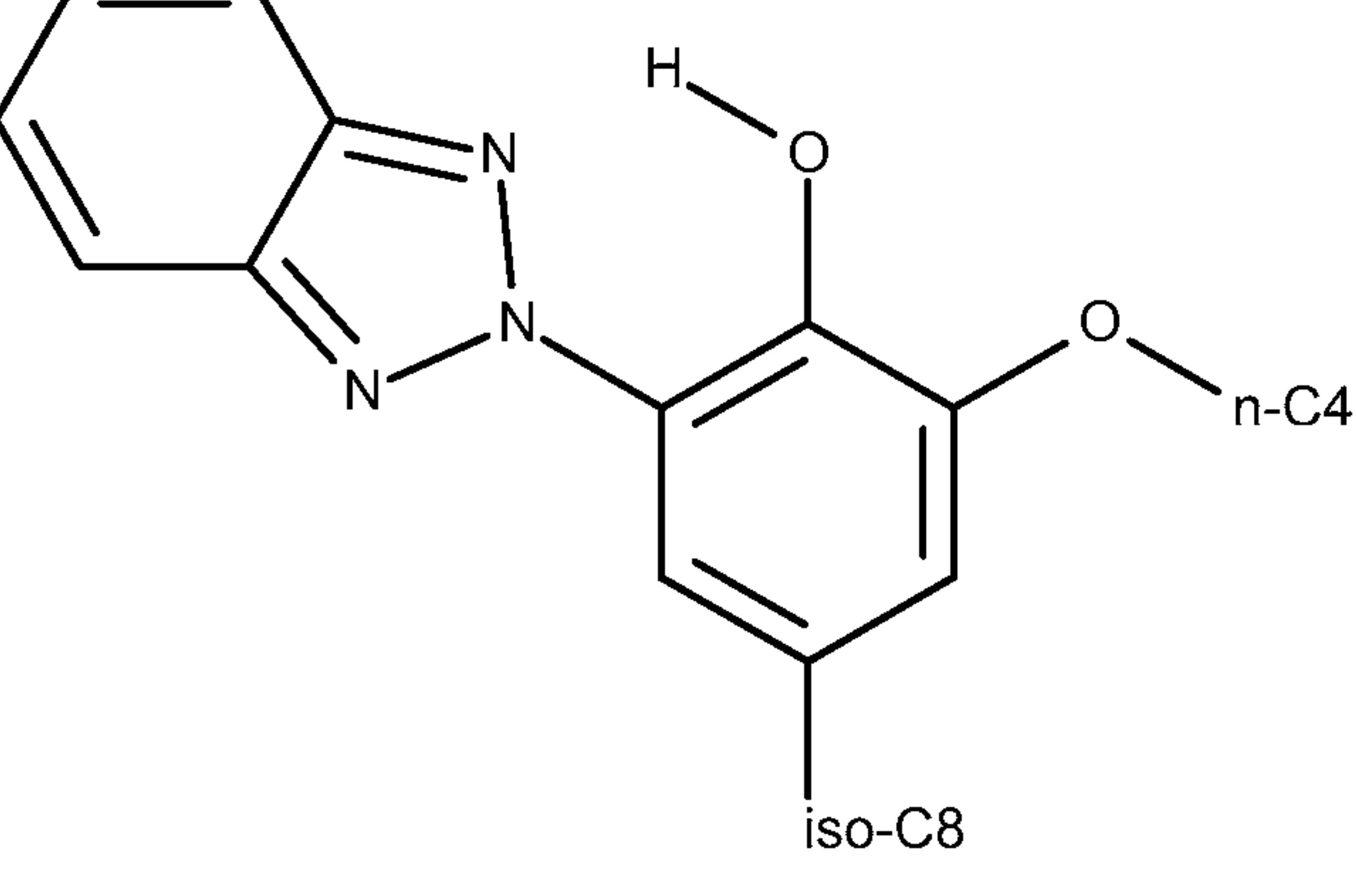
### Structural Formulas of Phenol and Protected Phenol (Ether) Compounds Disclosed.

5 The table below presents a summary of the structural formulas for the phenol compounds used in this application to prepare phenolate salts. The phenols are either commercially available or prepared in the Synthesis Examples below.

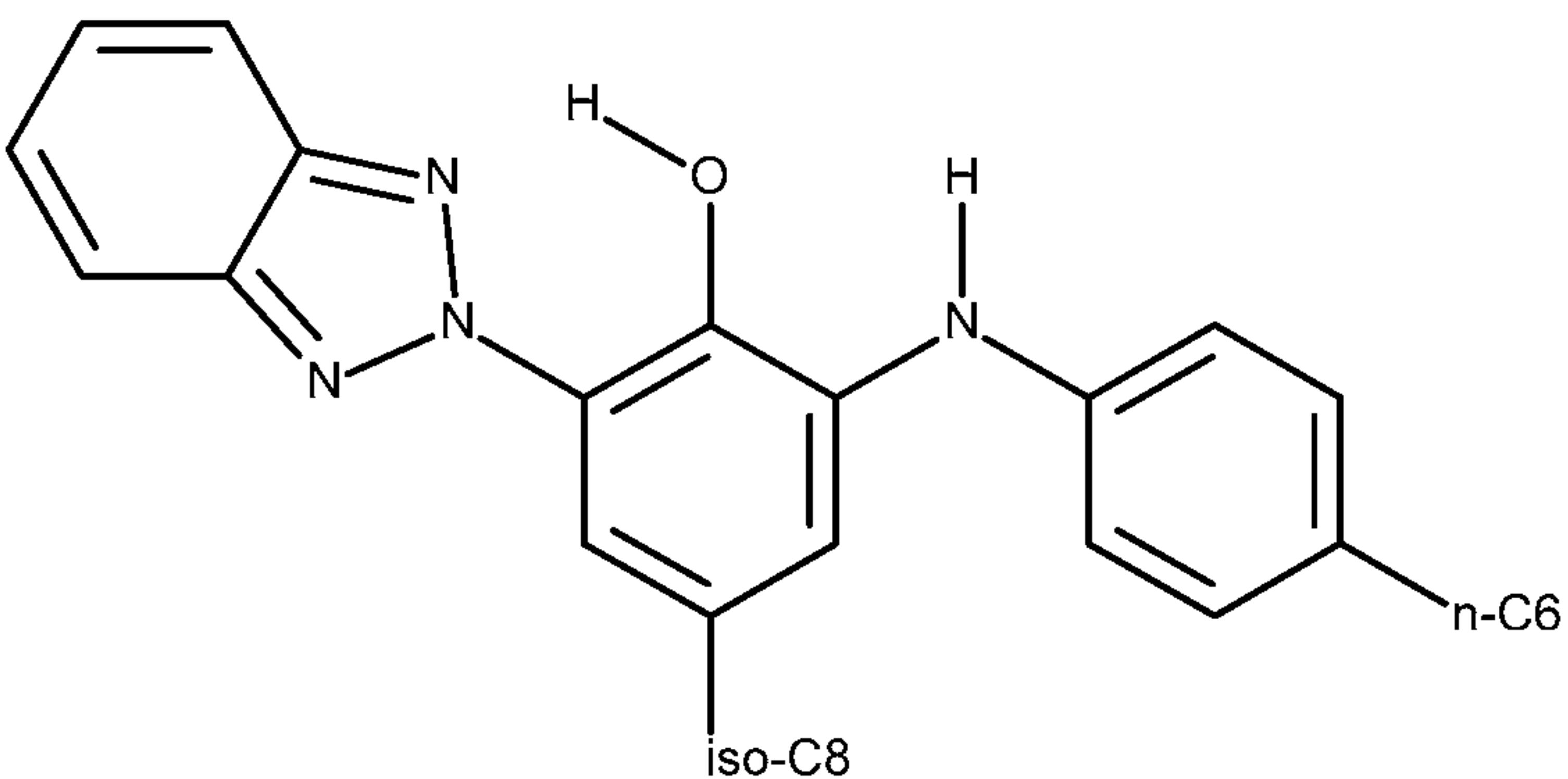
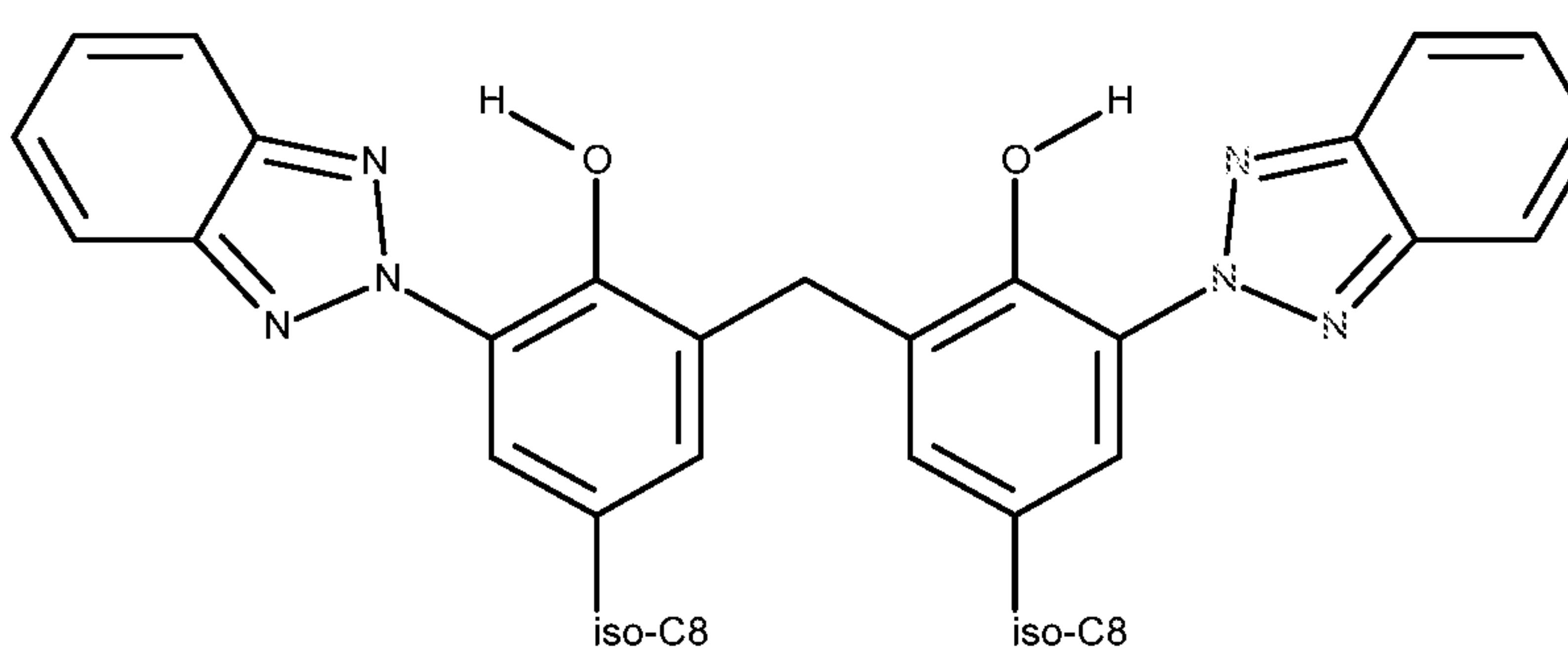
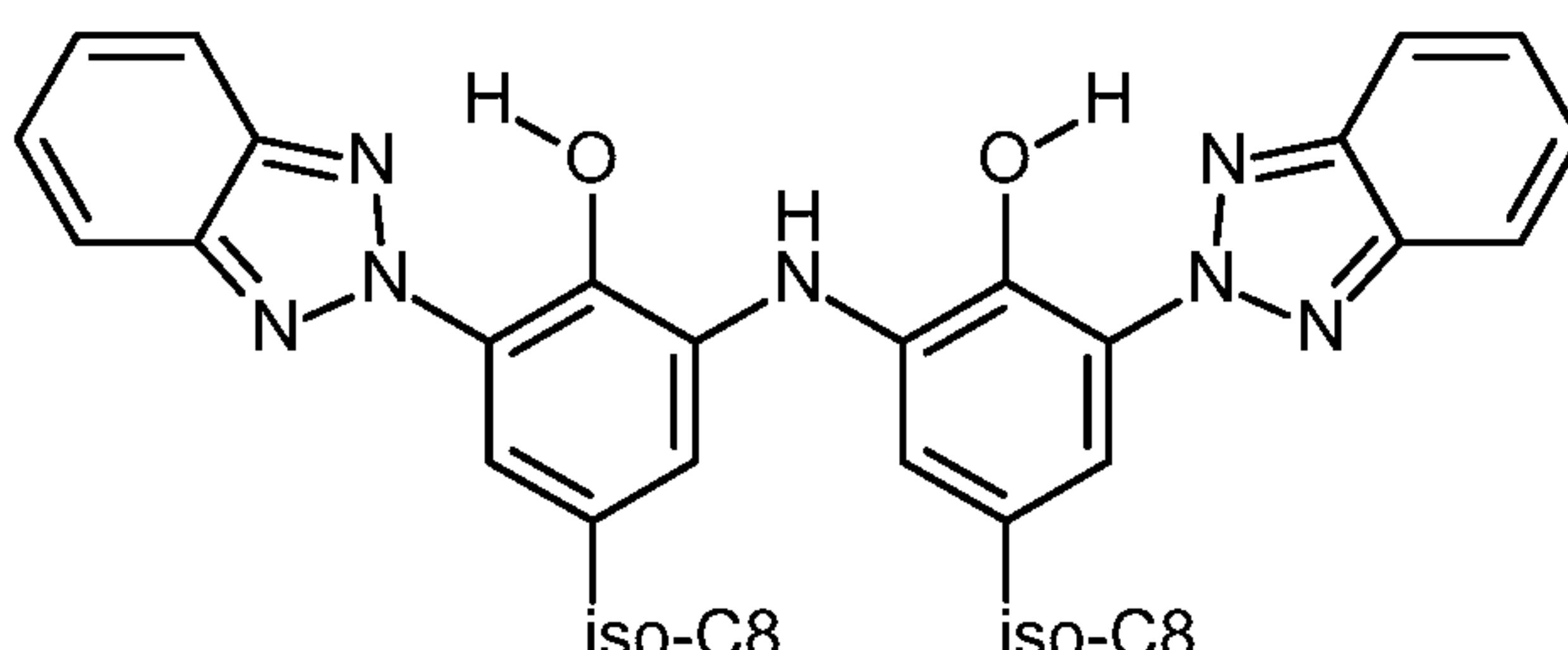
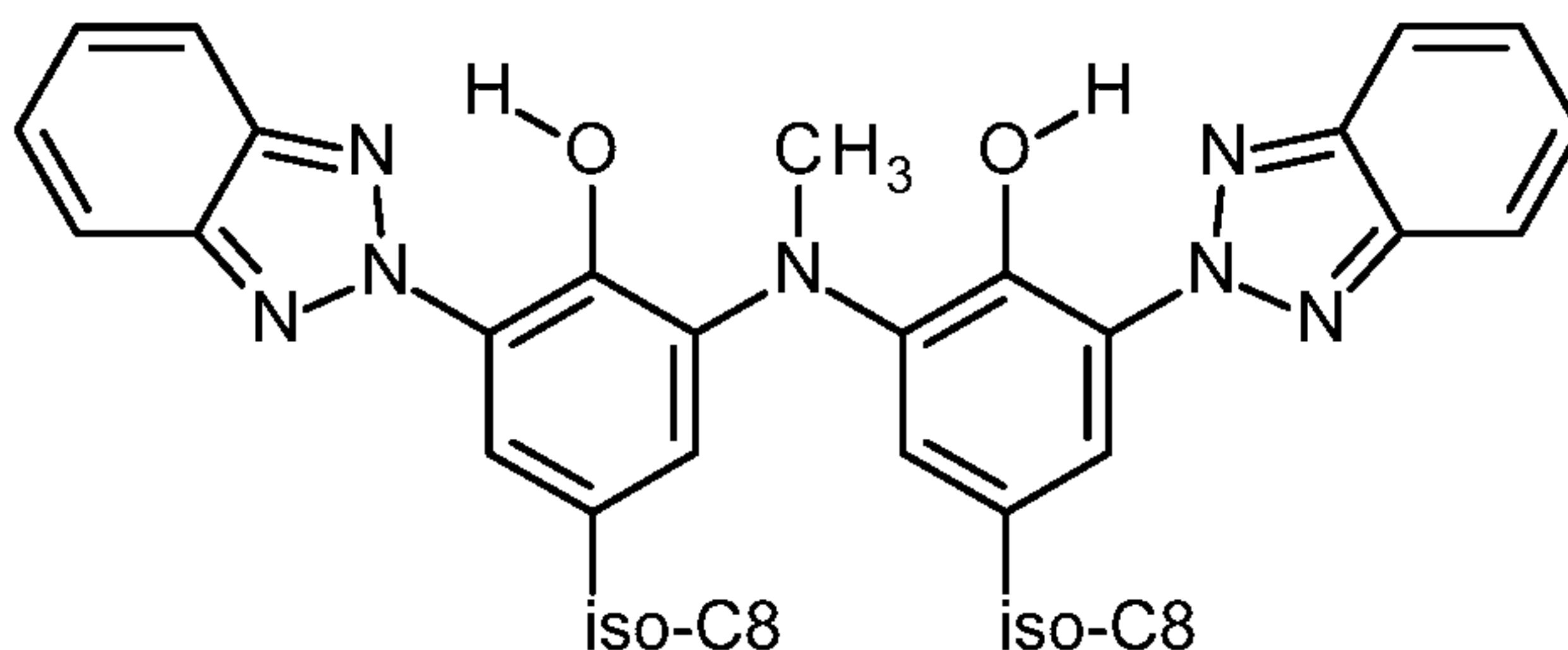
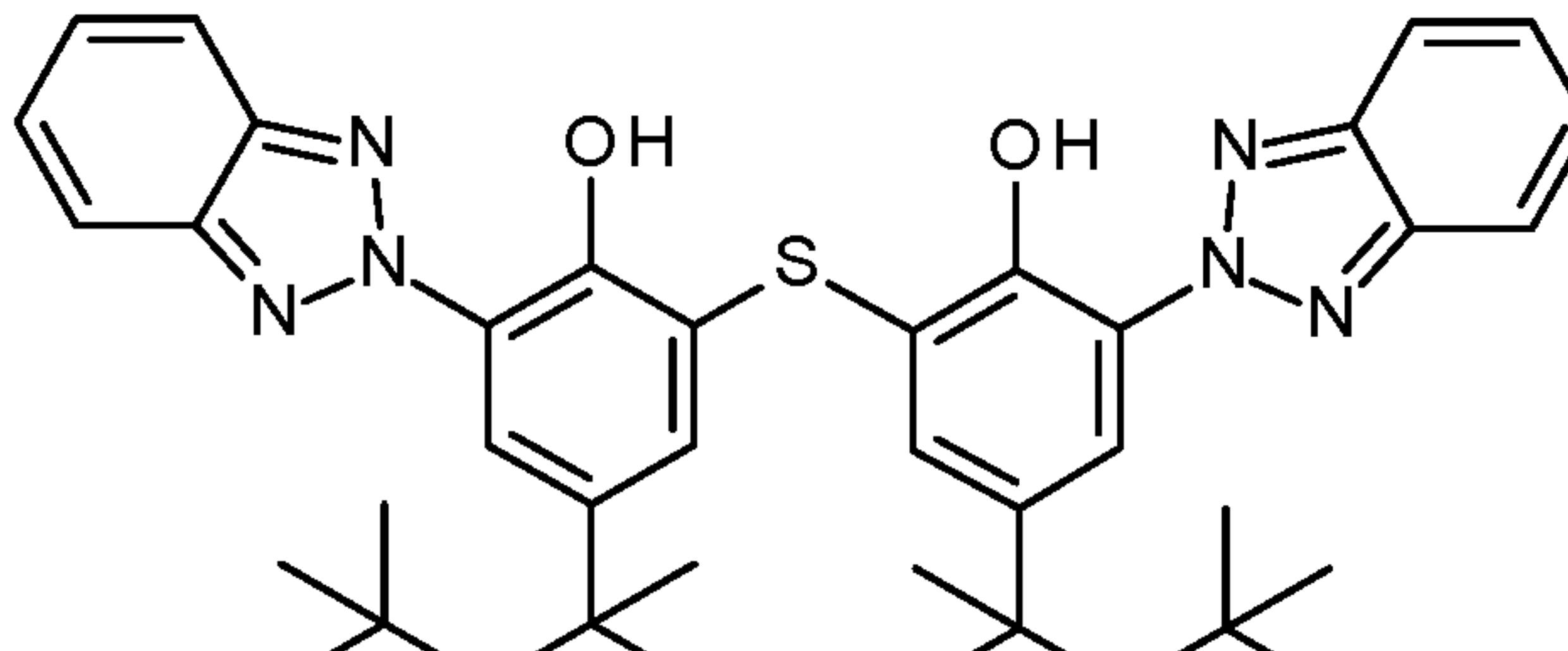
Table A: Listing of Phenol Structures

Name	Source	Structure
Ether-1	Synthesis Example SE2	
Phenol-1	Commercially available	

Phenol-2	Commercially Available	
Phenol-3	Synthesis Example SE1	
Phenol-4	Commercially Available	

Phenol-5	Synthesis Example SE2	
Phenol-6	Synthesis Example SE3	
Phenol-7	Synthesis Example SE4	

Phenol-8	Synthesis Example SE5	
Phenol-9	Synthesis Example SE6	
Phenol-10	Commercially Available	

Phenol-11	Synthesis Example SE7	
Phenol-12	Commercially Available	
Phenol-13	Synthesis Example SE8	
Phenol-14	Synthesis Example SE9	
Phenol-15	Synthesis Example SE10	

Phenol-16	Commercially Available	
Phenol-17	Synthesis Example SE11	
Phenol-18	Synthesis Example SE12	
Phenol-19	Synthesis Example SE13	
Phenol-20	Synthesis Example SE14	
Phenol-21	Synthesis Example SE15	

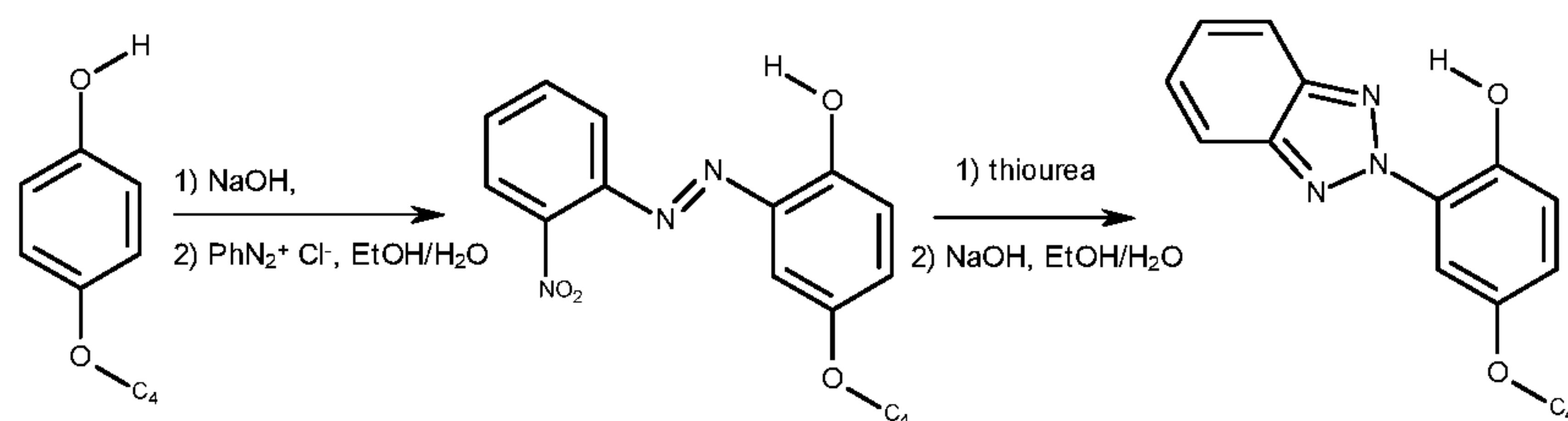
Phenol-22	Synthesis Example SE16	
Phenol-23	Synthesis Example SE17	
Phenol-24	Synthesis Example SE18	

### General Synthesis of Phenols

In the examples below automated flash chromatography (AFC) was carried out using an ISOLERA system available from Biotage, Inc, Charlottesville, Virginia, USA. For these purifications Biotage SNAP Ultra silica columns were used with a hexane/ethyl acetate gradient mixture.

All intermediates and products were confirmed using  $^1\text{H}$  and  $^{13}\text{C}$  Nuclear Magnetic Resonance (NMR) on a 500MHz Bruker instrument. In some cases HRMS was also obtained.

A specialized reaction was used to prepare Phenol-3 as shown in Synthesis Example SE1 below, for the other phenols synthesized, General Reaction Scheme I was followed.

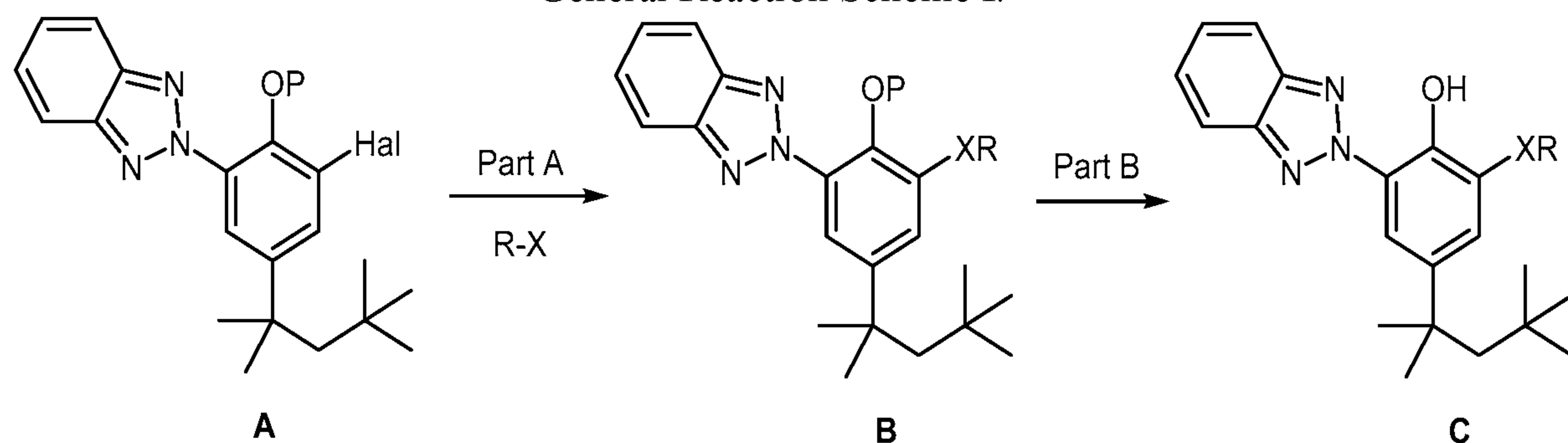


The diazo compound above as synthesized following standard diazotization procedure (WO08131921; *Bioorg. Med. Chem. Lett.* **2010**, *20*, 4193–4195.), followed by reductive cyclization to give Phenol-3.

A General Reaction Scheme I is presented below which was followed to prepare the a number of phenols used to prepare the phenolate salts of this disclosure. Specific details are provided for each Synthesis Example.

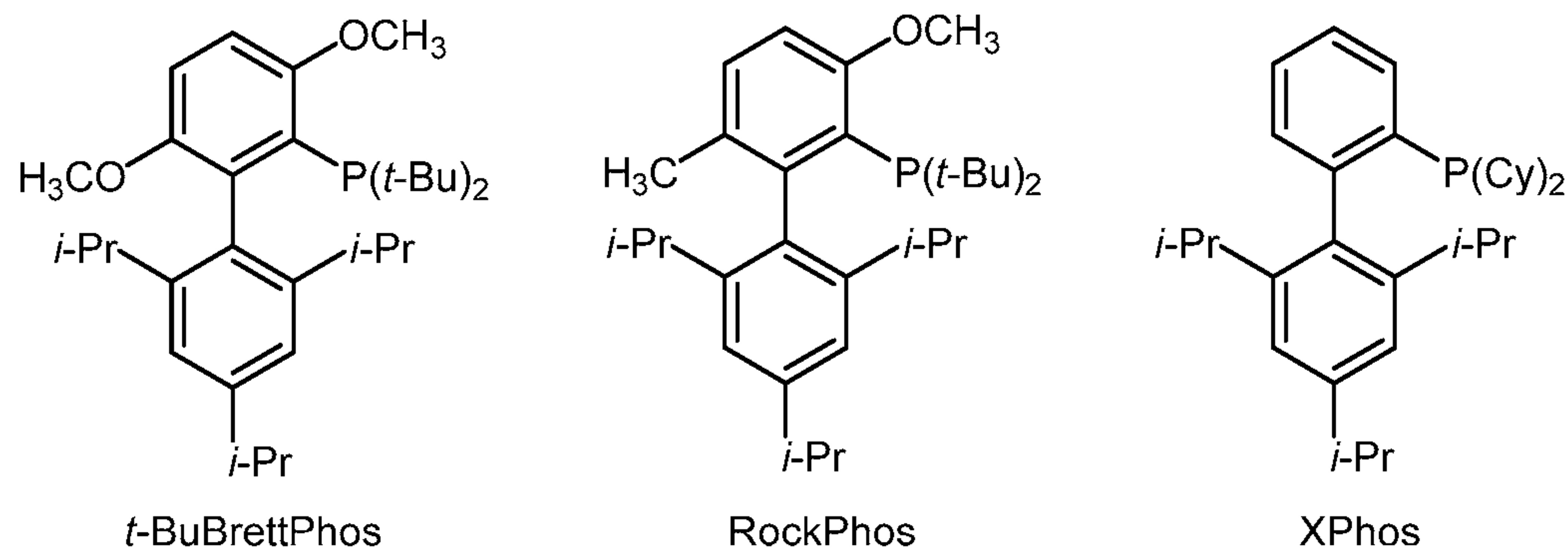
10

## General Reaction Scheme I.



Part A: Cross-Coupling. Protected phenol **A** is subjected to cross-coupling conditions with either a palladium or copper catalyst. For specific reaction conditions, see each individual example.

*Palladium Catalysis (Buchwald-Hartwig cross-coupling):* Buchwald, Hartwig, and coworkers have reported in the literature a transformation in which aryl halides can be converted to heteroatoms by use of a palladium catalyst and a bulky phosphine ligand. The following commercially available ligands (developed by Buchwald) have been used to synthesize benzotriazole phenolic analogs in which a heteroatom has been introduced in the ortho position (see compound **B**). These ligands can also be purchased already complexed to the palladium catalyst and are referred to as precatalysts.

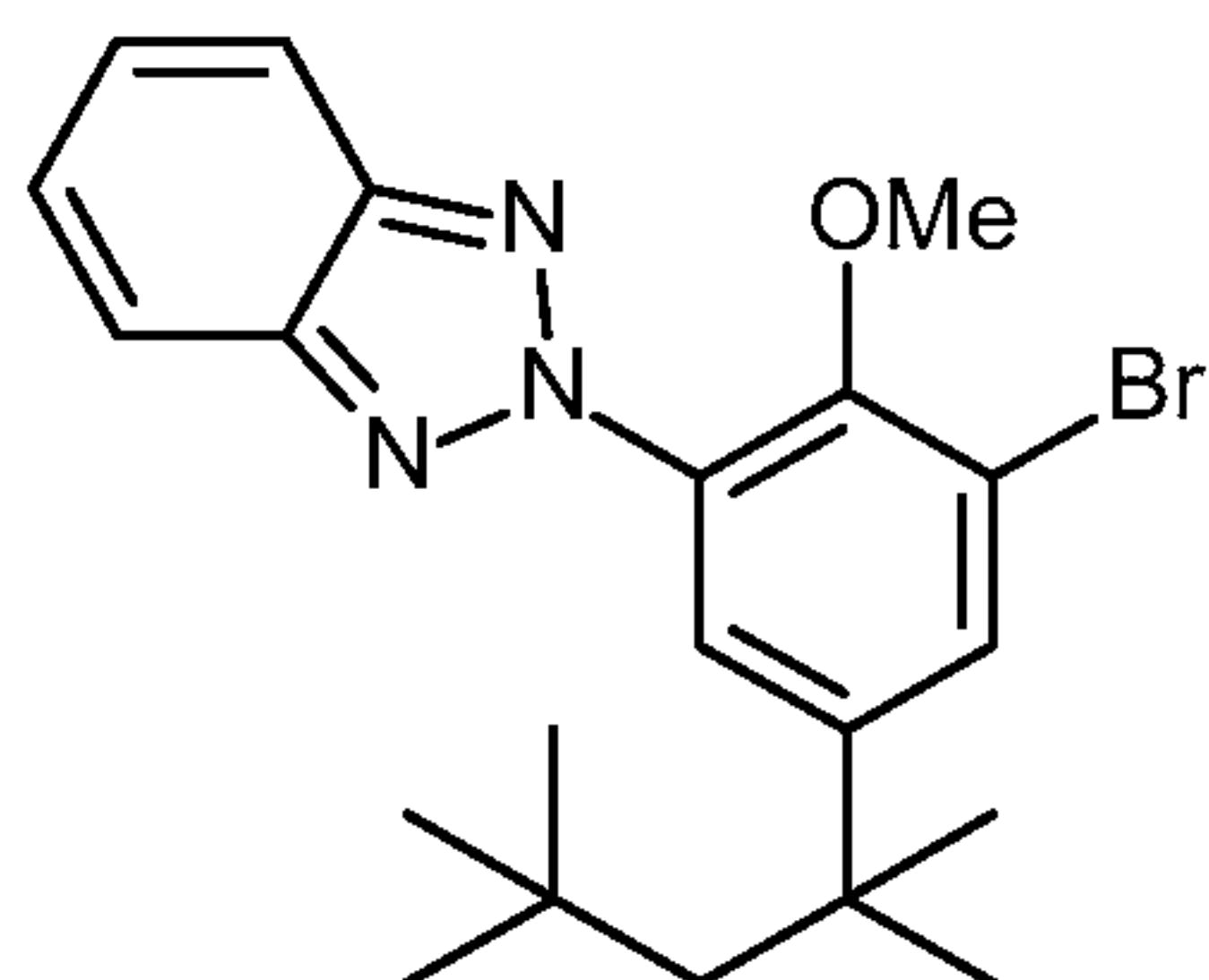


*Copper Catalysis (Chan-Evans-Lam coupling):* Copper can also be used to effect cross-coupling reactions between arylboronic acids and phenols, anilines, or arylthiols. This is considered to be a modification of the Ullmann condensation, as described in

Part B: Deprotection of Methyl Ether. The methoxy ether benzotriazole (**B**, P = Me) was dissolved in dichloromethane (0.1 M) and cooled to -78°C while stirring under N<sub>2</sub>. Boron tribromide (1 equivalent per protected phenol) was added dropwise and the reaction mixture allowed to slowly warm to room temperature. When the reaction was complete (analysis by TLC), water was added dropwise and the mixture was stirred for 10 min. The organic layer was separated and the aqueous layer extracted with DCM (2x). The combined organic layers were washed with saturated aqueous NaHCO<sub>3</sub> and brine, dried (Na<sub>2</sub>SO<sub>4</sub> or MgSO<sub>4</sub>), filtered and concentrated. The residue was purified (SiO<sub>2</sub>) to give products in 78-98% yield.

Note that in the following Synthesis Examples, compounds that are referred to as “Ethers” are protected phenols, meaning that the -OH group is instead a “protected hydroxyl group” i.e. a -OCH<sub>3</sub> group, which is deprotected to reform the phenolic hydroxyl group.

## *Synthesis Example SE2: Ether-1 and Phenol-5*



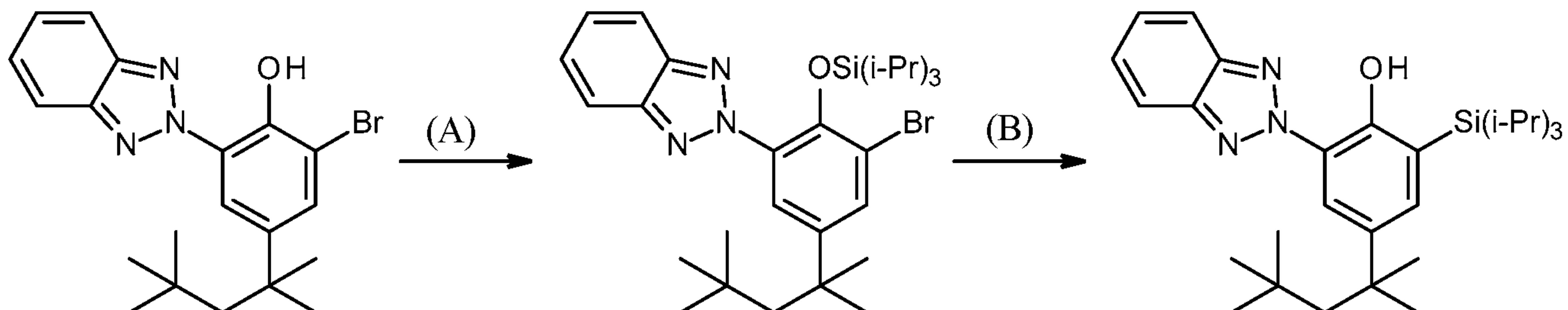
Part A: Bromination. 2-(2H-Benzotriazol-2-yl)-4-(1,1,3,3-tetramethylbutyl)phenol (100 g, 309 mmol) was placed in a 1 L round bottom flask fitted with a stir bar and dissolved in chloroform (500 mL). To this was added 1,3-dibromo-5,5-dimethylhydantoin (DBDMH) (45.95 g, 161 mmol) and the mixture stirred rt overnight. After such time, the mixture was filtered and concentrated to give a dark red residue. The residue was recrystallized from dichloromethane/ethanol to obtain white crystals. Multiple recrystallizations of the mother liquor yielded 113 g of pure product (91% yield) of Phenol-5.

Part B: Methylation. The reaction product from Part A was placed in a 1 L round bottom flask fitted with a stir bar and dissolved in acetonitrile (400 mL). Potassium carbonate (20.70 g, 150 mmol) was added followed by iodomethane (3.3 mL, 52.5 mmol). The mixture stirred rt overnight. After such time, the reaction mixture was partially concentrated, diluted with ethyl acetate and filtered over celite. The solution was concentrated, giving a thick beige oil, which eventually solidified over time to give 20.8 g (quantitative yield) of product of Ether 1.

*Synthesis Example SE3: Phenol-6*

2-(2H-1,2,3-benzotriazol-2-yl)-6-((triisopropylsilyl)oxy)-4-(2,4,4-trimethylpentan-2-

yl)phenol



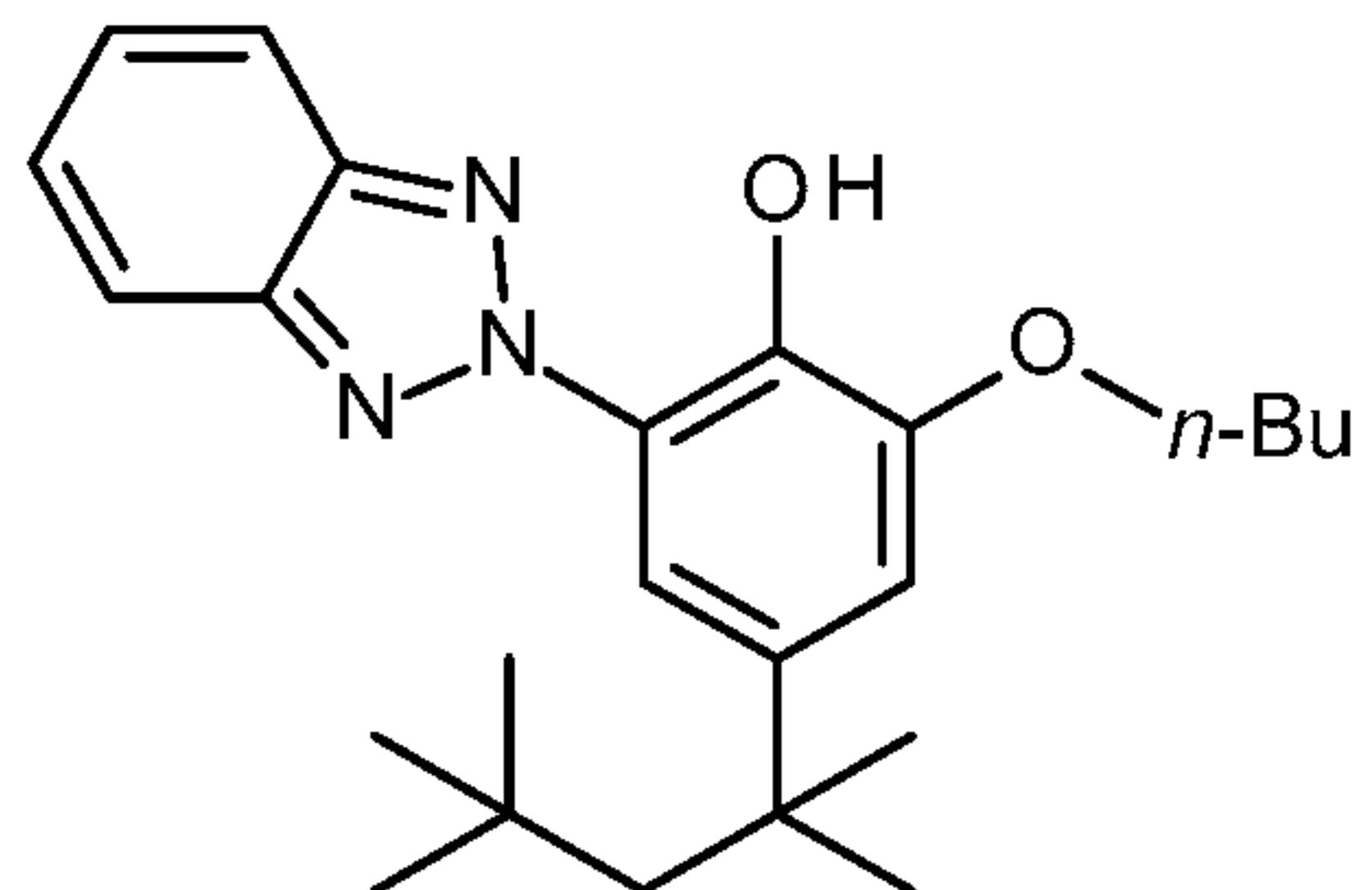
Part A. The reaction product from Synthesis Example SE2 was silylated with triisopropylchlorosilane (TIPS-Cl) following standard procedures.

Part B. The reaction product from Part A (1.57 g, 2.81 mmol) was placed into a round bottom flask containing a stir bar and charged with N<sub>2</sub>. THF (20 mL) was added and the flask cooled to -78°C. n-Butyl lithium (1.8 mL, 2.81 mmol) was added and the mixture was allowed to slowly warm to rt and stir for 3 h. After such time, the reaction was quenched with saturated ammonium chloride and the product extracted with EtOAc (3x). The combined organic layers were washed with brine, dried and filtered. The crude residue was purified by AFC to give a colorless solid (0.74 g, 55% yield).

10

*Synthesis Example SE4: Phenol-7*

2-(2H-1,2,3-benzotriazol-2-yl)-6-butoxy-4-(2,4,4-trimethylpentan-2-yl)phenol



15

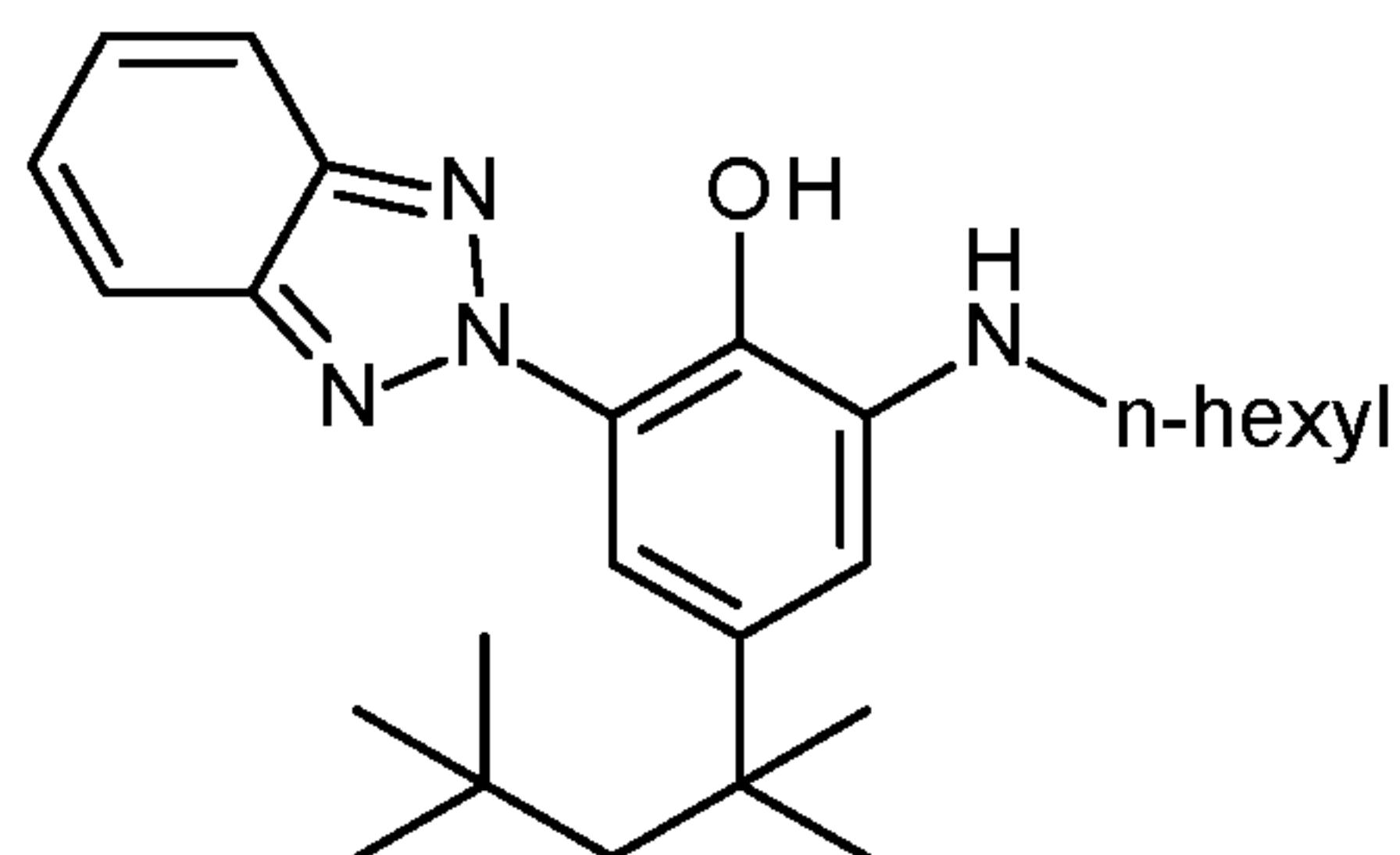
20

Into three flame dried 40-dram vials, each equipped with a stir bar and activated 4Å molecular sieves was placed Ether 1 prepared in Synthesis Example SE1, (4.179 g, 10.04 mmol), cesium carbonate (4.91 g, 15.06 mmol), allylpalladium chloride dimer (18.4 mg, 0.5 mol %), and RockPhos ligand (23.4 mg, 0.5 mol %). Each vial was fitted with a septa cap and evacuated and backfilled with N<sub>2</sub> (3x). Toluene (10 mL), followed by anhydrous n-butanol (1.8 mL, 20.08 mmol) was added to each vial. The vials were placed on a ChemGlass reaction block and heated to 100 °C for 72 h. After such time, the reaction mixtures were combined, filtered over celite, and concentrated. The crude residue was purified via flash column chromatography to give a pale yellow solid (9.80 g, 79% yield). Following Part B (General Reaction Scheme I), the free phenol was isolated as a beige solid after purification by flash column chromatography (8.50 g, 85% yield).

25

*Synthesis Example SE5: Phenol-8*

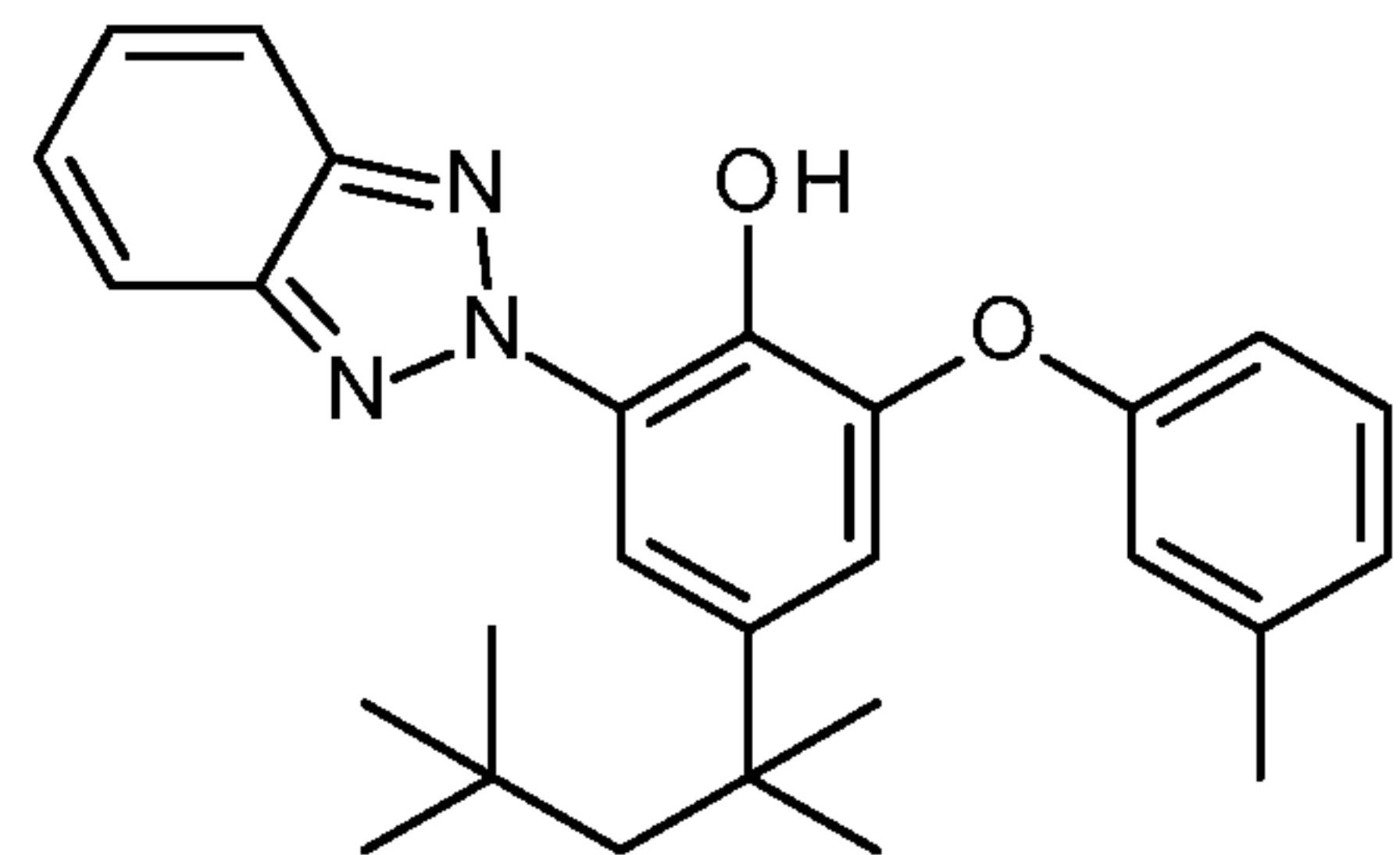
2-(2H-benzo[d][1,2,3]triazol-2-yl)-6-(hexylamino)-4-(2,4,4-trimethylpentan-2-yl)phenol



5 Into three flame dried vials equipped with a stir bar was placed Ether 1 prepared in Synthesis Example SE1, (1.66 g, 4 mmol), tris(dibenzylideneacetone)dipalladium(0) (73.3 mg, 0.08 mmol), XPhos ligand (95.3 mg, 0.2 mmol), sodium *tert*-butoxide (538 mg, 5.6 mmol), and 1-hexylamine (0.74 mL, 5.6 mmol). The vial was fitted with a septa cap and evacuated and backfilled with N<sub>2</sub>. Dioxane (20 mL) was added and the reaction was heated to 130 °C for 16 h. After such time, the mixtures were cooled to rt, combined, diluted with EtOAc and filtered over celite. The residue was purified via AFC. A beige solid was isolated (3.88 g, 74% yield). Following Part B (General Reaction Scheme I),  
10 gave the free phenol as a yellow solid (3.32, 88% yield).

*Synthesis Example SE6: Phenol-9*

2-(2H-1,2,3-benzotriazol-2-yl)-6-(*m*-tolyloxy)-4-(2,4,4-trimethylpentan-2-yl)phenol

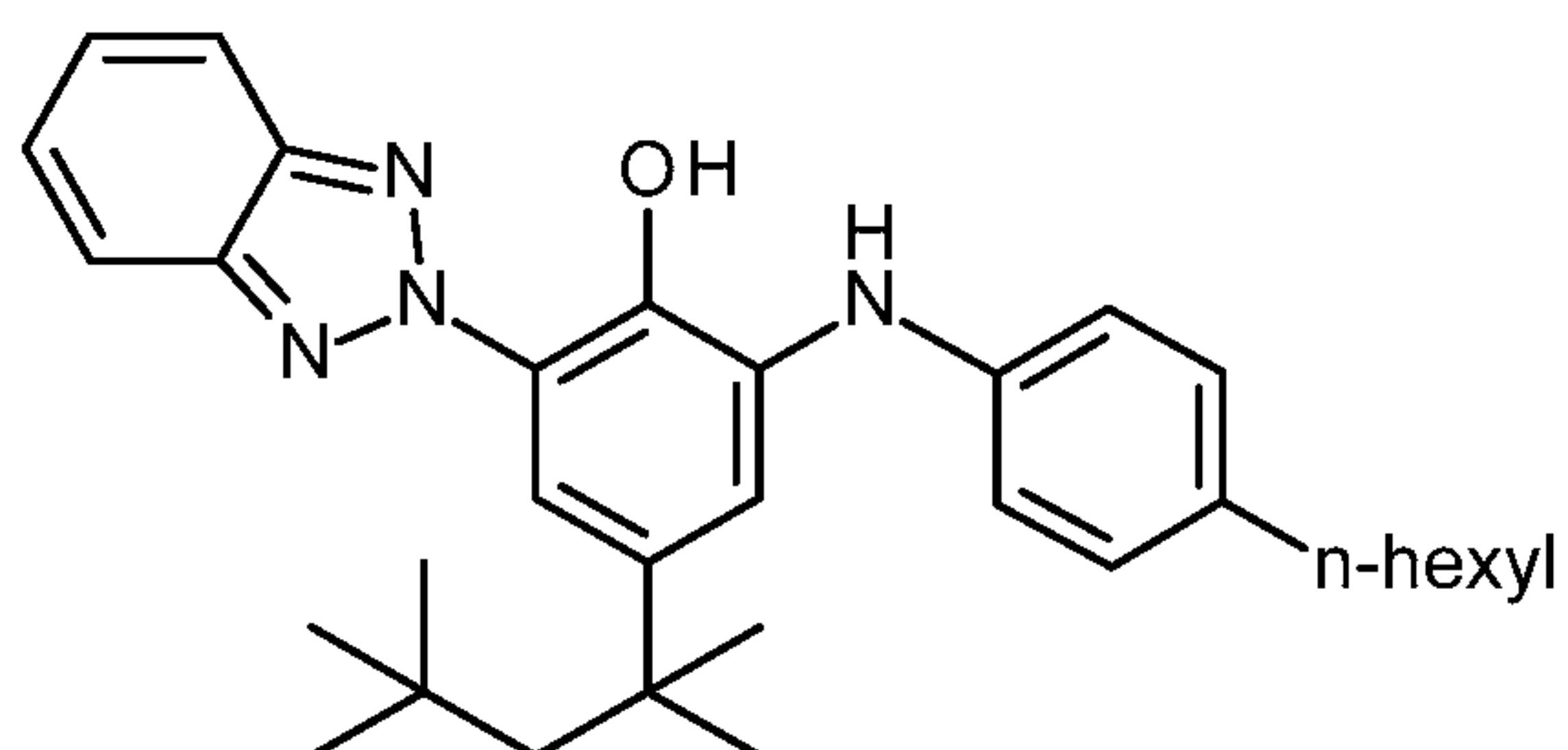


15 Into two flame dried 40-dram vials, each equipped with a stir bar and activated 4 Å mol sieves was placed Ether 1 prepared in Synthesis Example SE1, (4.16 g, 10 mmol), potassium phosphate (4.25 g, 20 mmol), palladium(II) acetate (45 mg, 2 mol %), and RockPhos ligand (93 mg, 2 mol %). Each vial was fitted with a septa cap and evacuated and backfilled with N<sub>2</sub> (3x). Toluene (10 mL), followed by *m*-cresol (1.3 mL, 12 mmol)  
20 was added to each vial. The vials were placed on a ChemGlass reaction block and heated to 100°C for 16 h. After such time, the reaction mixtures were combined, filtered over celite, and concentrated. The crude residue was purified via flash column chromatography to give a beige solid (7.07 g, 80% yield). Following Part B (General Reaction Scheme I),

the free phenol was isolated as a beige solid after purification by flash column chromatography (6.50 g, 98% yield).

*Synthesis Example SE7: Phenol-11*

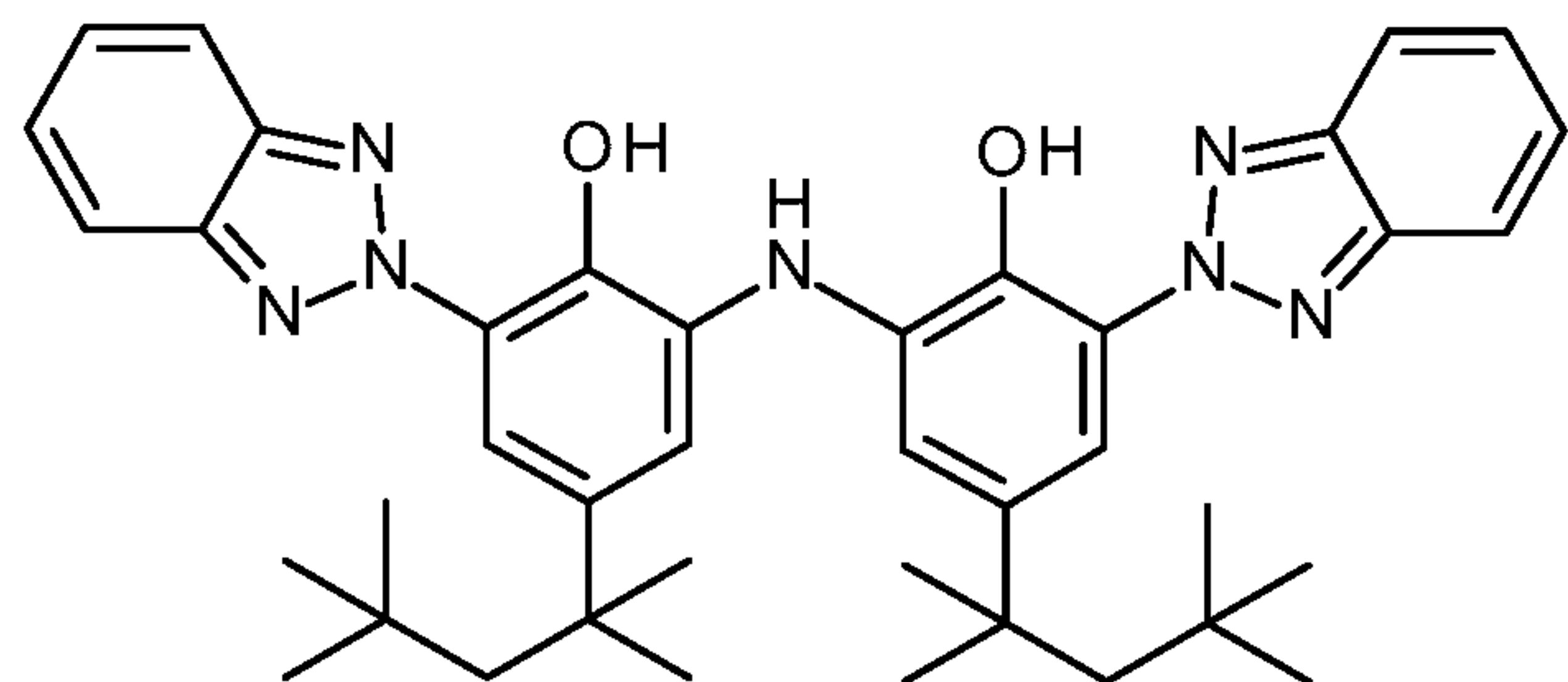
5 2-(2H-benzo[d][1,2,3]triazol-2-yl)-6-((4-hexylphenyl)amino)-4-(2,4,4-trimethylpentan-2-yl)phenol



10 Into three flame dried vials equipped with a stir bar was placed Ether 1 prepared in Synthesis Example SE1, (1.66 g, 4 mmol), tris(dibenzylideneacetone)dipalladium(0) (73.3 mg, 0.08 mmol), XPhos ligand (95.3 mg, 0.2 mmol), sodium *tert*-butoxide (538 mg, 5.6 mmol), and 4-hexylaniline (1 mL, 5.6 mmol). The vial was fitted with a septa cap and evacuated and backfilled with N<sub>2</sub>. Dioxane (20 mL) was added and the reaction was heated to 130 °C for 16 h. After such time, the mixtures were cooled to rt, combined, diluted with EtOAc and filtered over celite. The residue was purified via AFC. A beige solid was isolated (3.88 g, 74% yield). Following Part B (General Reaction Scheme I), gave the free phenol as a yellow solid (4.67 g, 96% yield).

*Synthesis Example SE8: Phenol-13*

6,6'-azanediylbis(2-(2H-benzo[d][1,2,3]triazol-2-yl)-4-(2,4,4-trimethylpentan-2-yl)phenol)



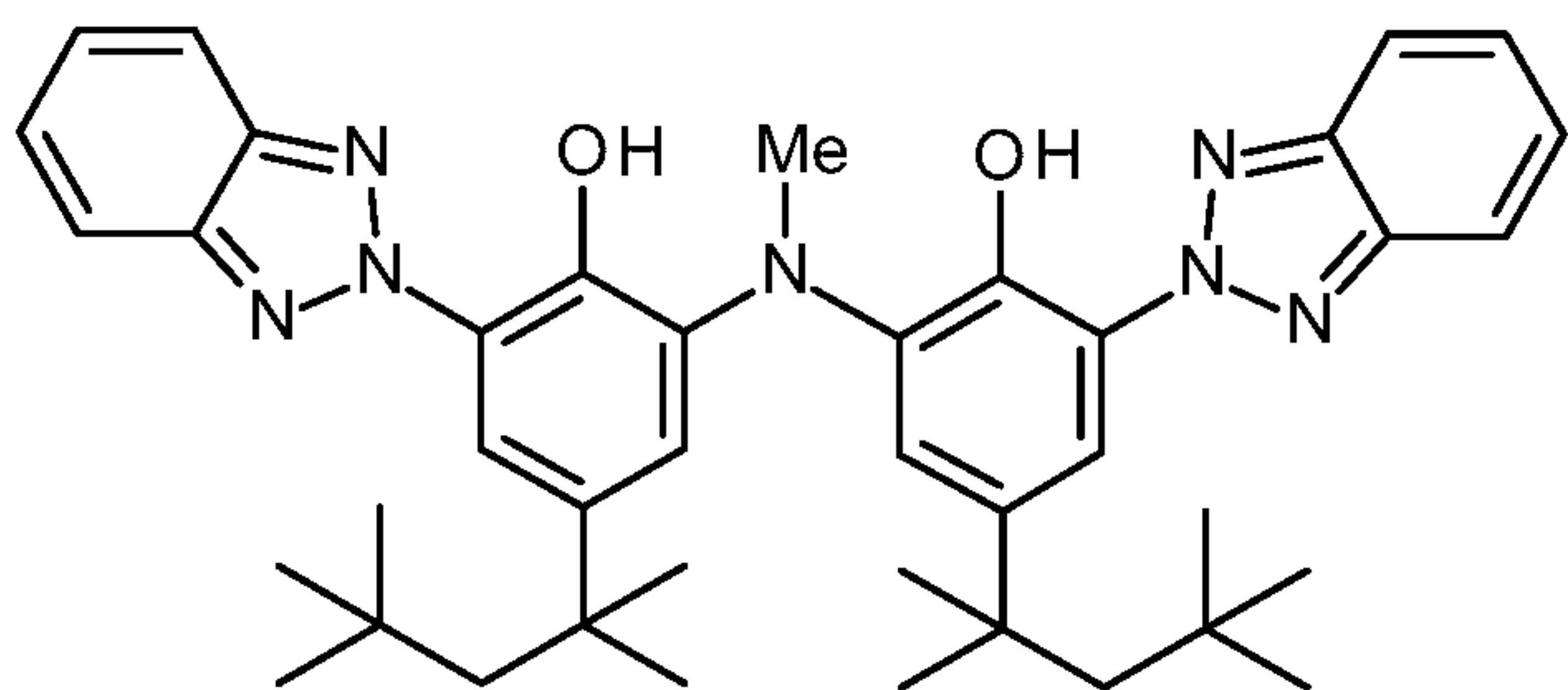
20 Part A. To an oven-dried Schlenk flask fitted with a stir bar was added 4Å molecular sieves, sodium *tert*-butoxide (23.37 mmol, 2.25 g), Pd<sub>2</sub>(dba)<sub>3</sub> (0.33 mmol, 306 mg), XPhos (0.83 mmol, 398 mg) and Ether 1 prepared in Synthesis Example SE1, (16.69 mmol, 6.95 g). The flask was then evacuated and flushed with N<sub>2</sub> (3x) and ammonia in dioxane (0.5 M, 100 mL) was added via cannula. The Schlenk flask was closed and heated to 130 °C

for 16 h. After such time, the reaction mixture was diluted with EtOAc, filtered, and concentrated. The crude oil was purified via flash column chromatography to give a beige solid.

5 Part B. The product of Part A was dissolved in dichloromethane (150 mL) and cooled to -78°C while stirring under N<sub>2</sub>. Boron tribromide (17.10 mmol, 1.6 mL) was added dropwise and the reaction mixture allowed to slowly warm to rt. When the reaction was complete (analysis by TLC), water was added dropwise and the mixture was stirred for 10 min. The organic layer was separated and the aqueous layer extracted with DCM (2x).  
10 The combined organic layers were washed with saturated aqueous NaHCO<sub>3</sub> and brine, dried (Na<sub>2</sub>SO<sub>4</sub> or MgSO<sub>4</sub>), filtered and concentrated. The residue was recrystallized from hot acetone to give a yellow crystalline solid (3.38 g, 61% yield from Ether 1).

*Synthesis Example SE9: Phenol-14*

15 6,6'-(methylazanediyl)bis(2-(2H-benzo[d][1,2,3]triazol-2-yl)-4-(2,4,4-trimethylpentan-2-yl)phenol)



20 Part A. The reaction product from Synthesis Example SE6, Part A (12.79 mmol, 8.8 g) was dissolved in dimethylformamide (120 mL) and to this, sodium hydride (14.07 mmol, 0.56 g) was added under a stream of N<sub>2</sub> at rt. The mixture was stirred 10 min and then iodomethane (14.07 mmol, 0.88 mL) was added and stirring continued for another 2 h. The reaction was quenched with saturated aq ammonium chloride and extracted with EtOAc (3X). The combined organic layers were washed with water and then brine, dried with Na<sub>2</sub>SO<sub>4</sub>, filtered and concentrated. No further purification was performed.

25

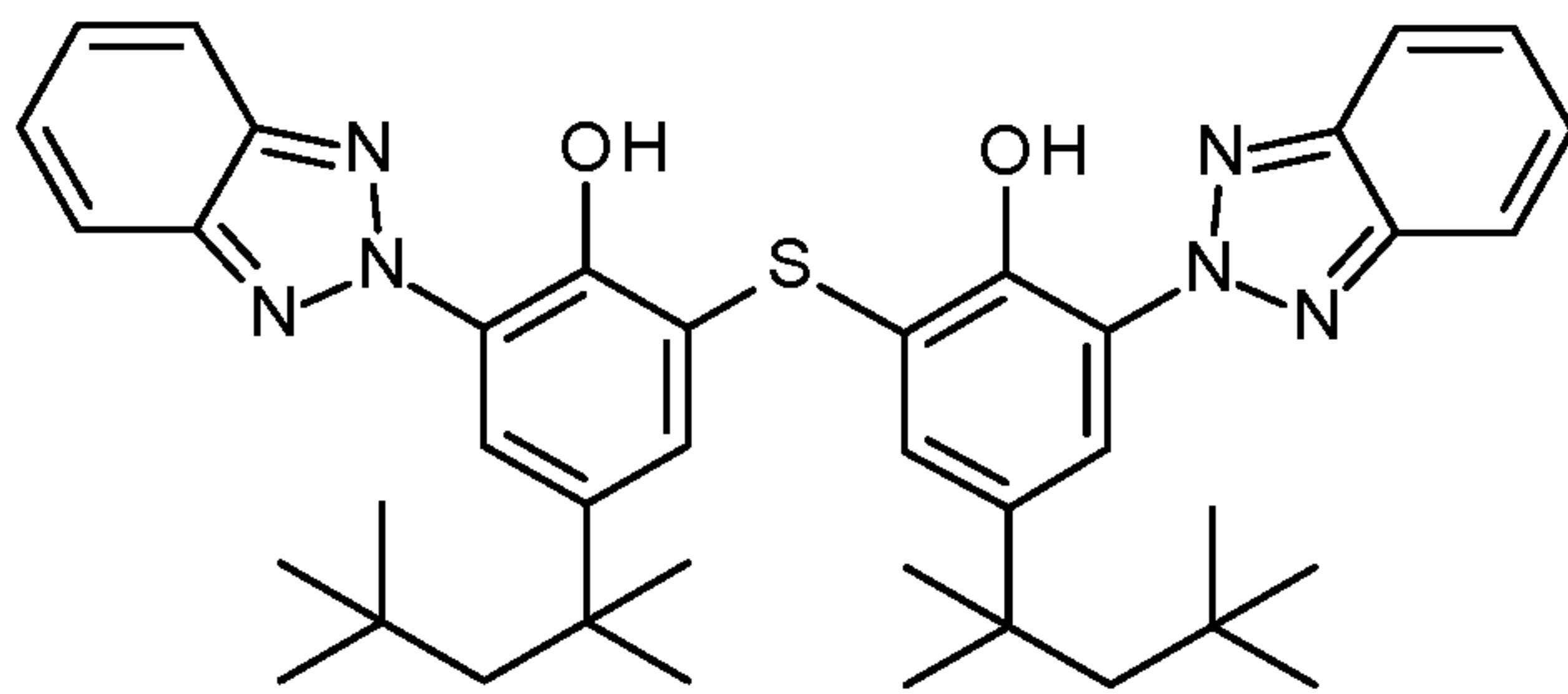
Part B. The product of Part B was dissolved in dichloromethane (150 mL) and cooled to -78°C while stirring under N<sub>2</sub>. Boron tribromide (17.10 mmol, 1.6 mL) was added dropwise and the reaction mixture allowed to slowly warm to rt. When the reaction was complete (analysis by TLC), water was added dropwise and the mixture was stirred for 10

min. The organic layer was separated and the aqueous layer extracted with DCM (2x). The combined organic layers were washed with saturated aqueous NaHCO<sub>3</sub> and brine, dried (Na<sub>2</sub>SO<sub>4</sub> or MgSO<sub>4</sub>), filtered and concentrated. The residue was recrystallized from hot acetone to give a yellow crystalline solid (6.74 g, 60% yield from Ether 1).

5

*Synthesis Example SE10: Phenol-15*

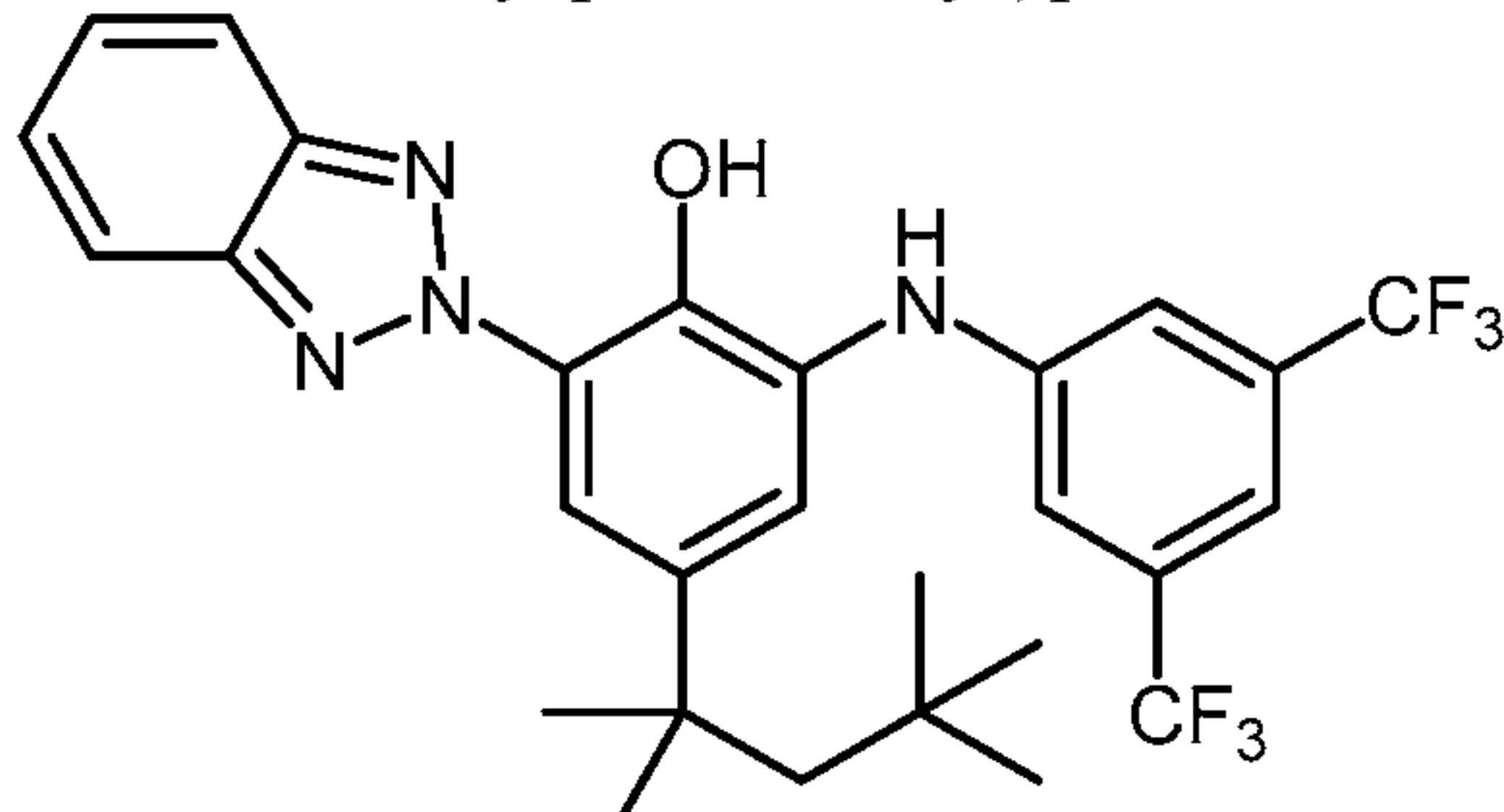
6,6'-thiobis(2-(2H-benzo[d][1,2,3]triazol-2-yl)-4-(2,4,4-trimethylpentan-2-yl)phenol)



To a flame dried vial equipped with a stir bar was placed 3-bromo-2-methoxy-5-(2,4,4-trimethylpentan-2-yl)phenyl)-2H-1,2,3-benzotriazole (0.416 g, 1 mmol), potassium thioacetate (0.057 g, 0.5 mmol), Tris(dibenzylideneacetone)dipalladium(0) (0.023 g, 0.025 mmol), 1,1'-Bis(diphenylphosphino)ferrocene (0.028 g, 0.05 mmol) and potassium phosphate (0.127 g, 0.6 mmol). The vial was then evacuated and flushed with N<sub>2</sub> (3x) and toluene (0.5 mL) and acetone (0.25 mL) was added. The reaction mixture was stirred for 72 h at 130 °C. After such time, the mixture was cooled, filtered, and purified by flash column chromatography to obtain 5 as a white solid (0.240 g, 68% yield). Following the procedure from Example 10, Part B, the product was obtained as a white solid (0.230 g, 99% yield).

*Synthesis Example SE11: Phenol 17*

20 2-(2H-benzotriazol-2-yl)-6-((3,5-bis(trifluoromethyl)phenyl)amino)-4-(2,4,4-trimethylpentan-2-yl)phenol

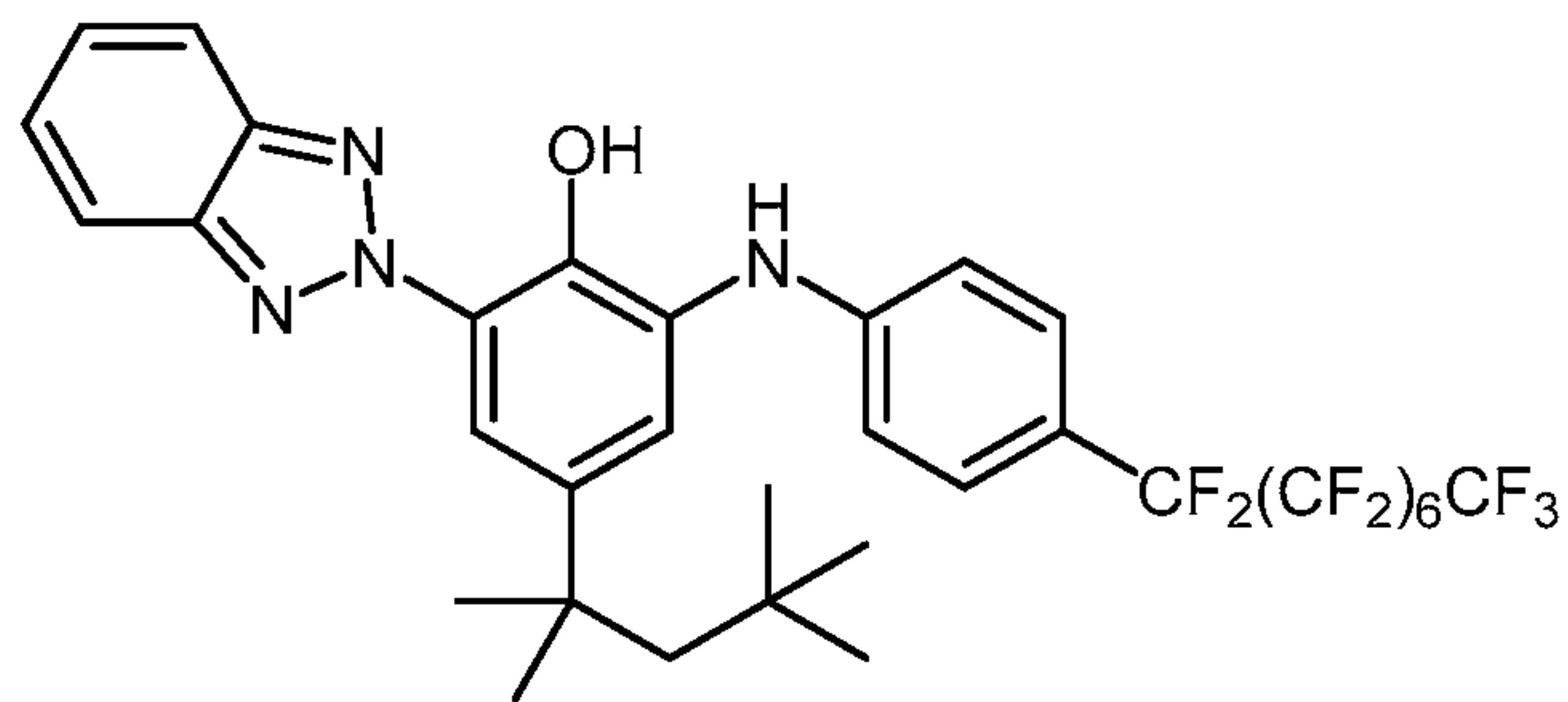


Into a 250 mL Schlenk flask equipped with a stir bar was placed Ether-1 from SE2, (20.0 g, 48.03 mmol), tris(dibenzylideneacetone)dipalladium(0) (1.04 g, 1.14 mmol), XPhos

ligand (1.35 g, 2.75 mmol), sodium *tert*-butoxide (7.63 g, 79.4 mmol), and 3,5-bis(trifluoromethyl)aniline (8 mL, 51.36 mmol). The Schlenk flask evacuated and backfilled with N<sub>2</sub>. Dioxane (200 mL) was added and the reaction was heated to 130 °C for 16 h. After such time, the mixture was cooled to rt, diluted with EtOAc, filtered over 5 celite and concentrated. The residue was purified via AFC. A brown solid was isolated (26.8 g, 98% yield). Following Part B (General Reaction Scheme I), gave the free phenol as a yellow solid (21.3 g, 82% yield).

#### Synthesis Example SE12: Phenol 18

10 2-(2H-triazol-2-yl)-6-((4-(perfluoroctyl)phenyl)amino)-4-(2,4,4-trimethylpentan-2-yl)phenol

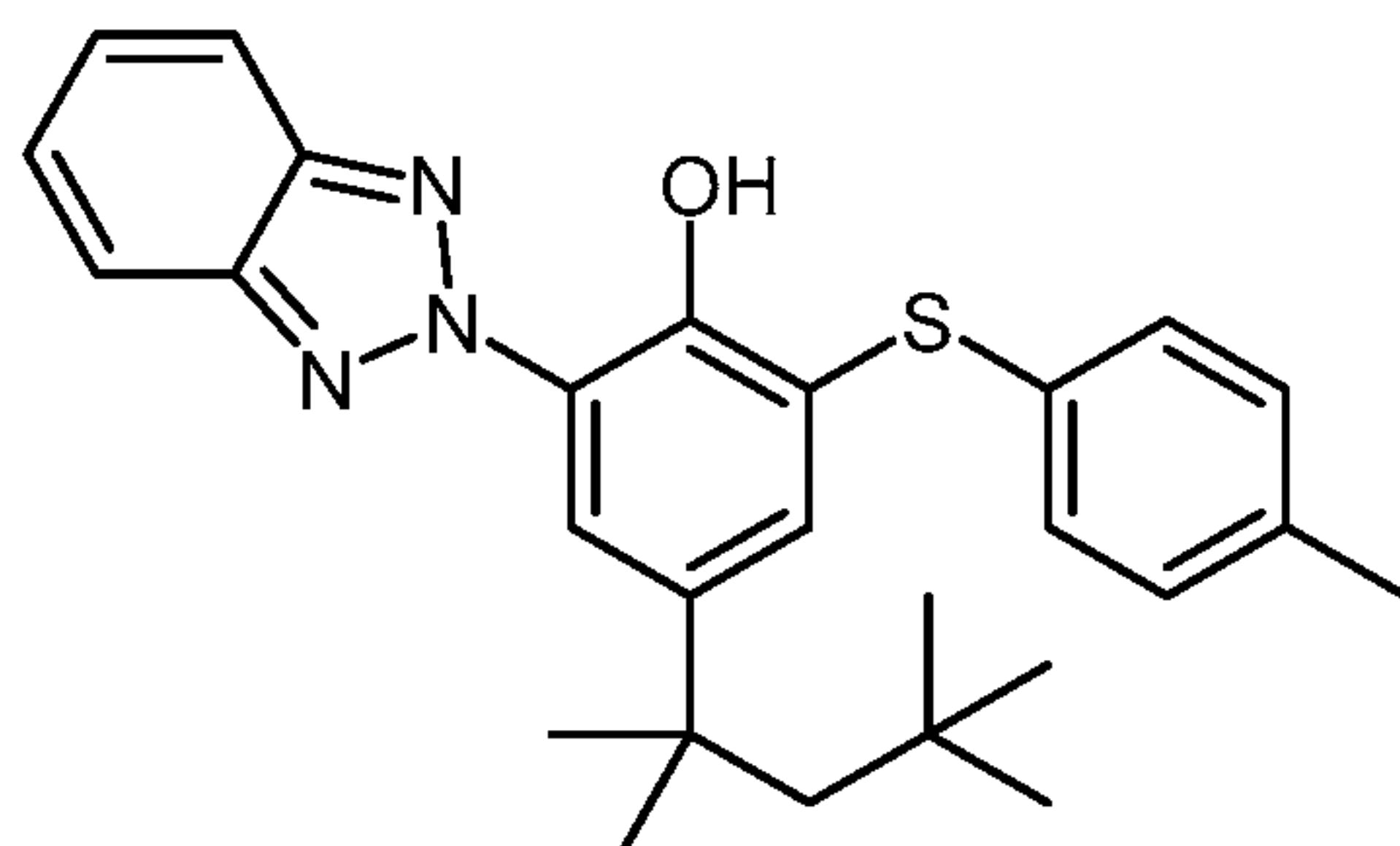


15 Into two flame dried 40-dram vials, each equipped with a stir bar was placed the aniline side product (3-(2H-benzo[d][1,2,3]triazol-2-yl)-2-methoxy-5-(2,4,4-trimethylpentan-2-yl)aniline ) from SE8, Part A (1.162 g, 3.30 mmol), 1-bromo-4-(heptadecafluoroctyl)benzene (2.0 g, 3.30 mmol), tris(dibenzylideneacetone)dipalladium(0) (60.4 mg, 0.066 mmol), XPhos ligand (80 mg, 0.163 mmol), and sodium *tert*-butoxide (444 mg, 4.62 mmol). Each vial was fitted with a septa cap and evacuated and backfilled with N<sub>2</sub>. Dioxane (20 mL) was added to each vial 20 and the vials were placed on a ChemGlass reaction block and heated to 130 °C for 16 h. After such time, the mixtures were cooled to rt, diluted with EtOAc, combined, and filtered over celite and concentrated. The residue was purified via AFC. A brown solid was isolated (4.41 g, 79% yield). Following Part B (General Reaction Scheme I), gave the free phenol as a yellow solid (3.41 g, 79% yield).

25

#### Synthesis Example SE13: Phenol 19

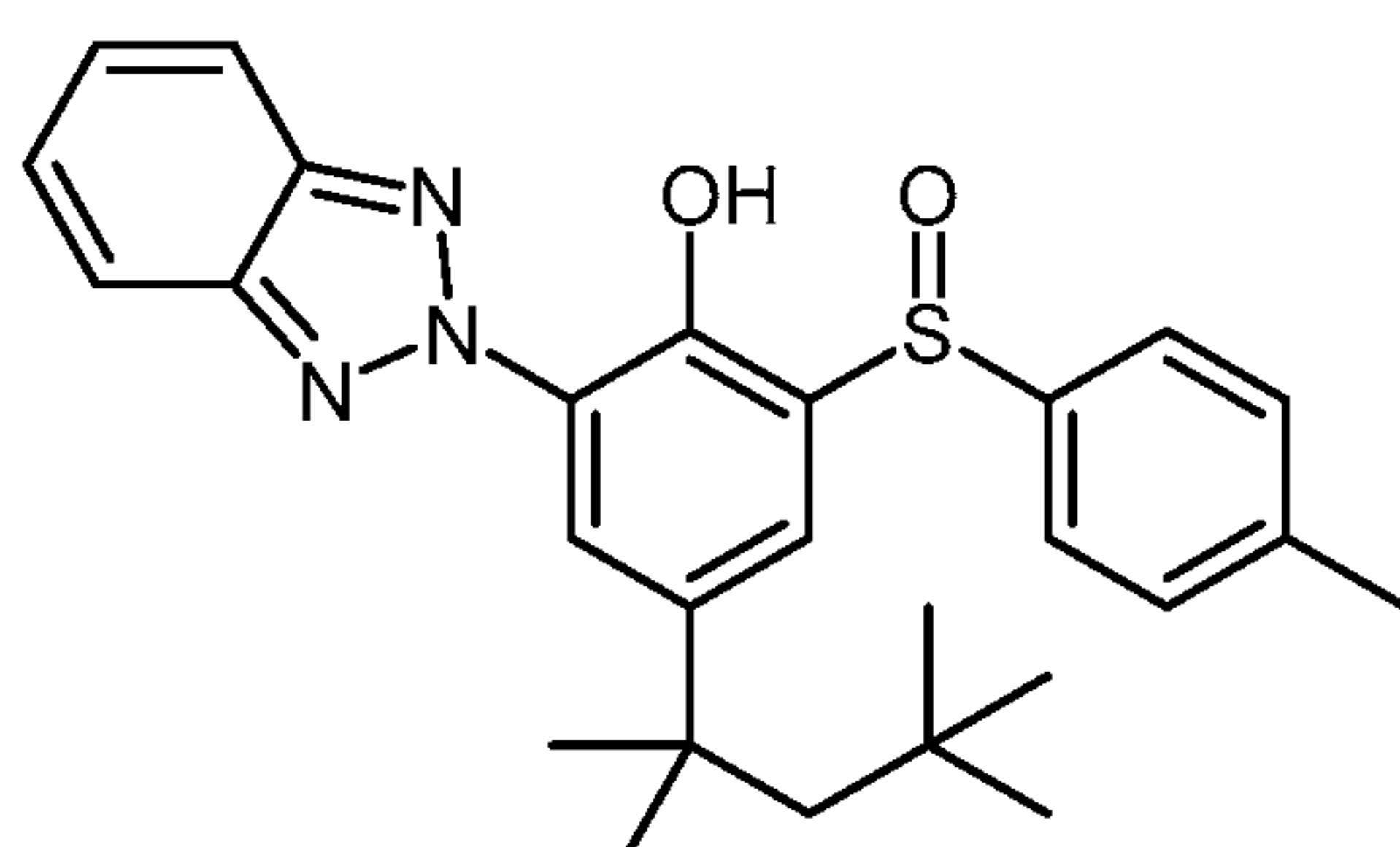
2-(2H-benzotriazol-2-yl)-6-(p-tolylthio)-4-(2,4,4-trimethylpentan-2-yl)phenol  
benzotriazole



5 Into a flame dried vial equipped with a stir bar was placed 2-(2H-benzo[1,2,3]triazol-2-yl)-6-bromo-4-(2,4-dimethylpentan-2-yl)phenol (2.88 g, 6.92 mmol), tris(dibenzylideneacetone)dipalladium(0) (0.317 g, 0.346 mmol), 1,1'bis(diphenylphospino)ferrocene (0.383 g, 0.692 mmol), potassium phosphate (1.76 g 8.30 mmol), and 4-methylbenzenethiol toluene (1.031 g, 8.30 mmol). The vial was fitted with a septa cap and evacuated and backfilled with N<sub>2</sub>. Toluene (14 mL) was added and the reaction was heated to 110 °C for 16 h. After such time, the mixtures were cooled to 10 rt, combined, diluted with EtOAc and filtered over celite. The residue was purified via AFC. A beige solid was isolated (3.09 g, 97% yield). Following Part B (General Reaction Scheme I), gave the free phenol as an ivory-colored solid (2.70 g, 90% yield).

Synthesis Example SE14: Phenol 20

## 2-(2H-benzotriazol-2-yl)-6-(p-tolylsulfinyl)-4-(2,4,4-trimethylpentan-2-yl)phenol

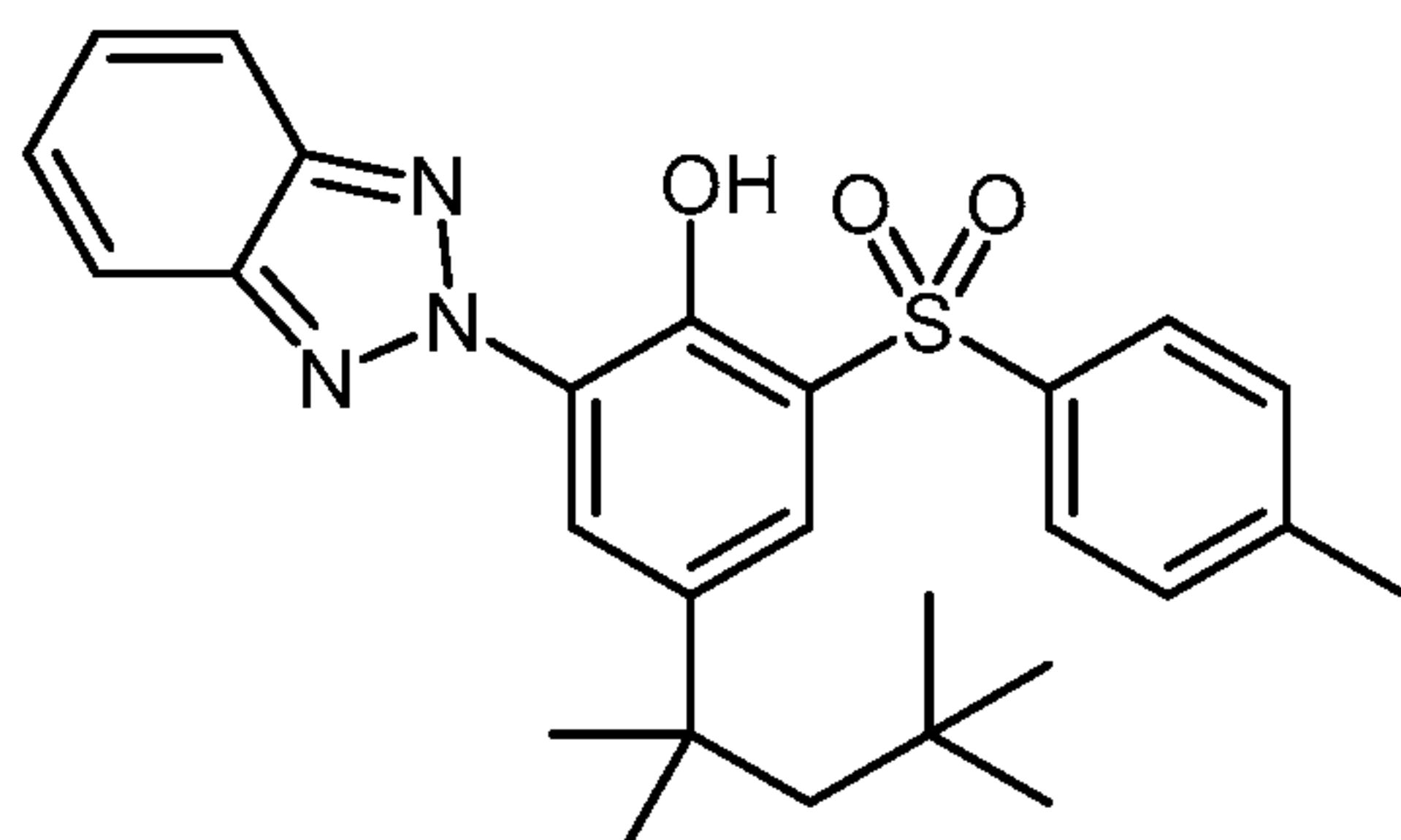


The following was adapted from a literature procedure (Org Lett. 2003, 5, 235). Aryl sulfide from SE13 (1.2 g, 2.69 mmol) was added to a vial equipped with a stir bar. Ethanol (7 mL) and hydrogen peroxide (30%, 1.5 mL) were added and N<sub>2</sub> was bubbled through the mixture for several minutes. Scandium triflate (0.265 g, 0.539 mmol) was added and the mixture allowed to stir rt overnight. After such time, the reaction was quenched with H<sub>2</sub>O

(2 mL) and filtered. The filtrate was purified by AFC and a white solid was obtained (0.764 g, 61% yield). Another 0.167 g of recrystallized product from the mother liquor was obtained for a total of 0.931 g (75% yield) of product.

Synthesis Example SE15: Phenol 21

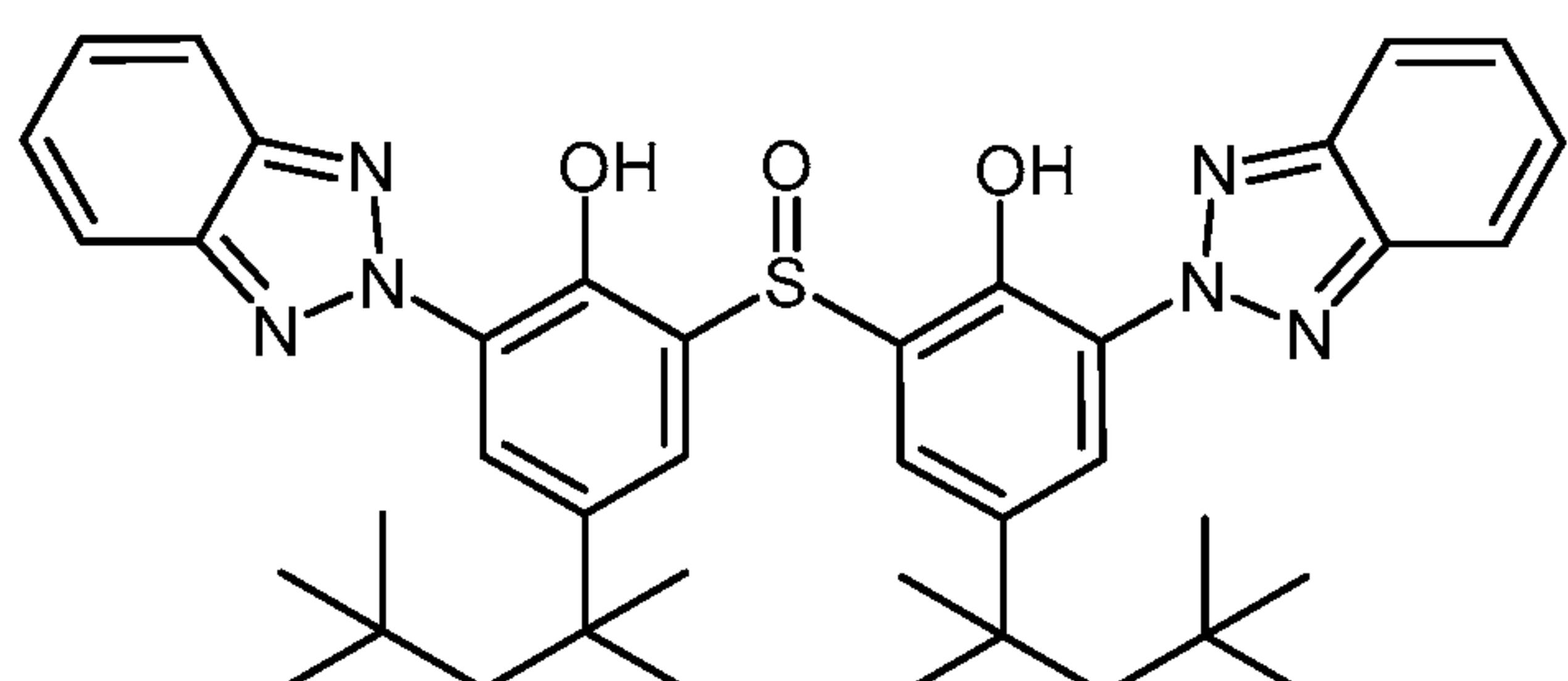
5 2-(2H-benzotriazol-2-yl)-6-tosyl-4-(2,4,4-trimethylpentan-2-yl)phenol



Aryl sulfide from SE13 (1.5 g, 3.366 mmol) was dissolved in dichloromethane (17 mL) in a vial equipped with a stir bar. M-Chloroperoxybenzoic acid, 50 wt % (2.56 g, 7.40 mmol) was added and the reaction stirred until complete by TLC. The reaction was then 10 quenched with sat'd aqueous NaHCO<sub>3</sub> and the organic layer separated, dried (Na<sub>2</sub>SO<sub>4</sub>), filtered, and concentrated. It was purified by washing with EtOAc and filtering. A white solid was obtained (1.34 g, 83% yield).

Synthesis Example SE16: Phenol 22

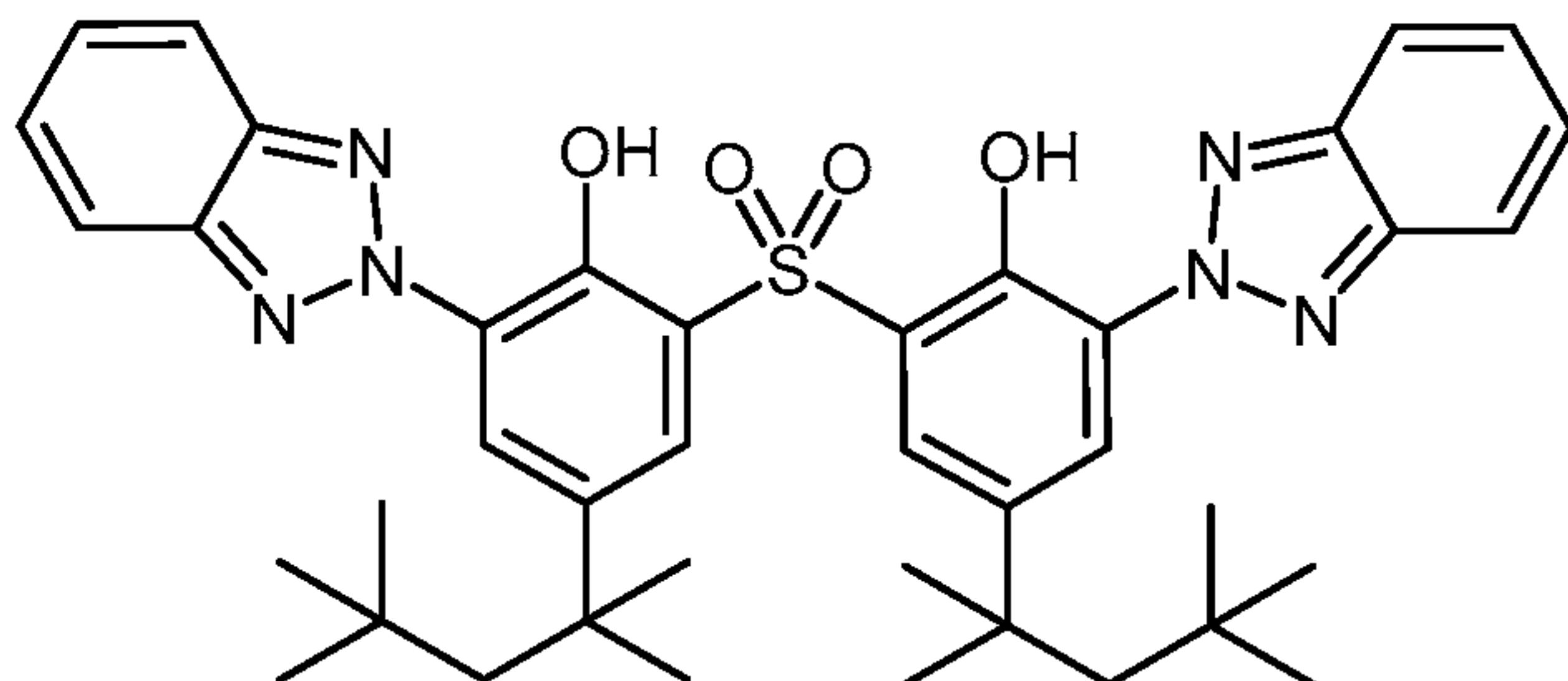
15 6,6'-thiobis(2-(2H-benzo[d][1,2,3]triazol-2-yl)-4-(2,4,4-trimethylpentan-2-yl)phenol)



6,6'-Thiobis(2-(2H-benzotriazol-2-yl)-4-(2,4,4-trimethylpentan-2-yl)phenol) from SE10 was oxidized using a literature procedure (Org Lett, 1999, 1, 189). 6,6'-Thiobis(2-(2H-benzotriazol-2-yl)-4-(2,4,4-trimethylpentan-2-yl)phenol) (7.39 mmol, 5.0 g) was dissolved 20 in ethanol (5 mL) along with scandium triflate (0.74 mmol, 364 mg) and hydrogen peroxide-urea adduct (8.5 mmol, 820 mg). The reaction stirred at 80 °C overnight and the white precipitate was filtered and washed with water and ethanol. A 2:1 mixture of the sulfoxide:sulfone was isolated (4.18 g, 81% yield).

## Synthesis Example SE17: Phenol 23

6,6'-sulfonylbis(2-(2H-benzotriazol-2-yl)-4-(2,4,4-trimethylpentan-2-yl)phenol)

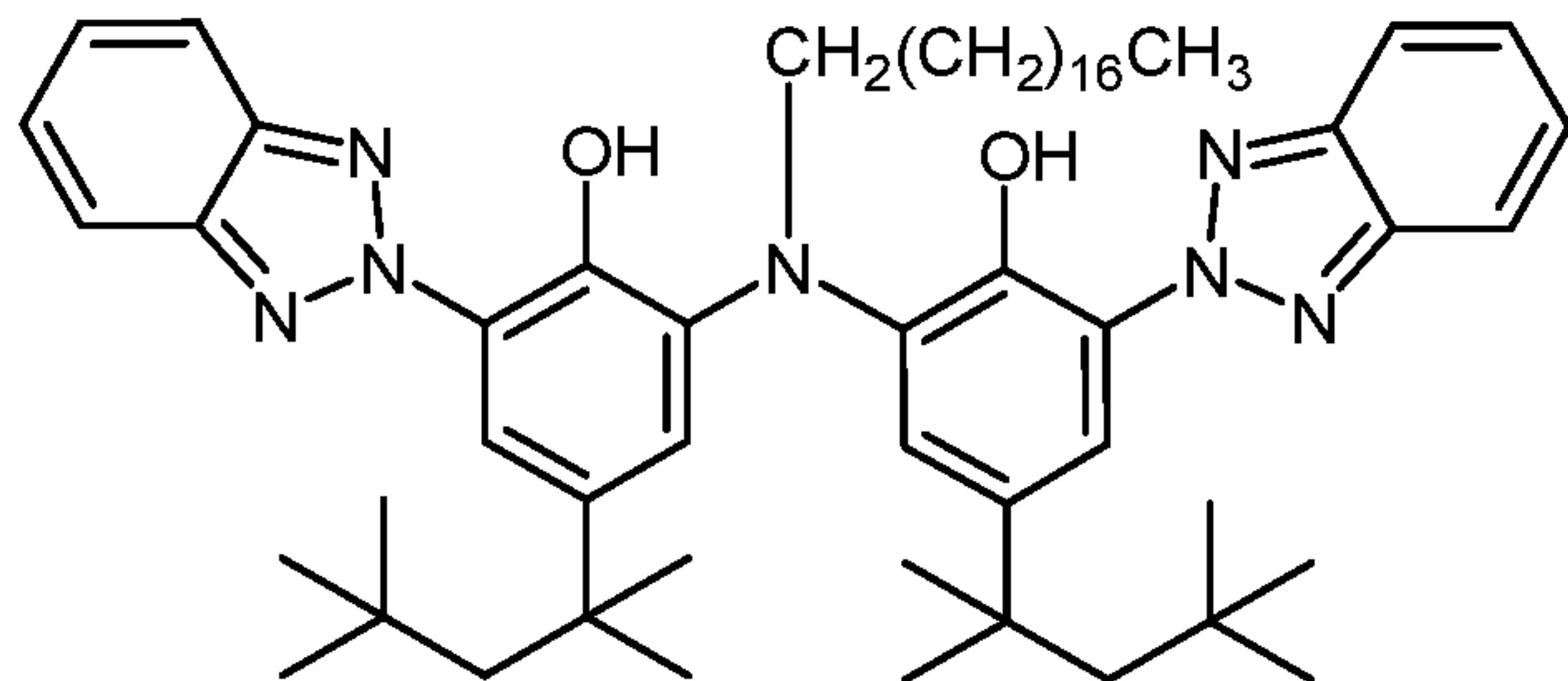


5

6,6'-Sulfonylbis(2-(2H-benzotriazol-2-yl)-4-(2,4,4-trimethylpentan-2-yl)phenol) was synthesized in a similar fashion as Example 24. Aryl sulfide from SE10 (4.5 g, 6.6 mmol) was dissolved in dichloromethane (33 mL) in a flask equipped with a stir bar. m-Chloroperoxybenzoic acid, 50 wt % (7.40 mmol, 5.05 g) was added and the reaction stirred until complete by TLC. The reaction was then quenched with saturated aqueous  $\text{NaHCO}_3$  and the organic layer separated, dried ( $\text{Na}_2\text{SO}_4$ ), filtered, and concentrated. It was purified by washing with  $\text{EtOAc}$  and filtering. A white solid was obtained (2.9 g, 62% yield).

## Synthesis Example SE18: Phenol 24

15 6,6'-(octadecylazanediy1)bis(2-(2H-benzotriazol-2-yl)-4-(2,4,4-trimethylpentan-2-yl)phenol)



Part A. The reaction product from part A of SE8, (4.0 g, 5.81 mmol) was dissolved in dimethylformamide (60 mL) and to this, sodium hydride (6.40 mmol, 256 mg) was added under a stream of  $\text{N}_2$  at rt. The mixture was stirred 10 min and then 1-iodooctadecane (6.40 mmol, 2.43 g) was added and stirring continued for another 2 h. The reaction was quenched with saturated aq ammonium chloride and extracted with  $\text{EtOAc}$  (3X). The combined organic layers were washed with water and then brine, dried with  $\text{Na}_2\text{SO}_4$ , filtered and concentrated. No further purification was performed.

Part B. The product of Part A was dissolved in dichloromethane (40 mL) and cooled to a temperature of -78°C while stirring under N<sub>2</sub>. Boron tribromide (12.20 mmol, 1.2 mL) was added dropwise and the reaction mixture allowed to slowly warm to rt. When the 5 reaction was complete (analysis by TLC), water was added dropwise and the mixture was stirred for 10 min. The organic layer was separated and the aqueous layer extracted with DCM (2x). The combined organic layers were washed with saturated aqueous NaHCO<sub>3</sub> and brine, dried (Na<sub>2</sub>SO<sub>4</sub> or MgSO<sub>4</sub>), filtered and concentrated to give a viscous oil (5.16 g, 97% yield).

10

### General Synthesis of Phenolate Salts

The above described phenols were used to prepare phenolate salts using one of the synthetic routes described below. The reagents used to prepare the salts are shown in Tables A and B and the phenolate salts formed are summarized in Table 1 below.

15

### Synthetic Procedures

#### *Alkoxide Route*

20 Phenolic starting material is added to THF at 10 – 40% in a two-necked RBF equipped with a magnetic stir bar, condenser and addition funnel. The solution is stirred and heated to reflux until all of the phenolic starting material is dissolved under nitrogen. A stoichiometric amount of metal alkoxide stock solution is added dropwise from the addition funnel to the RBF under nitrogen. The solution is refluxed from 1 to 36 hours. The solution is stripped with reduced pressure, and the recovered powder is dried in under vacuum.

25

#### *Hydride Route*

Anhydrous methanol is added to a dry, three-necked RBF equipped with a magnetic stir bar, reflux condenser, nitrogen inlet, and a stoppered port. The metal hydride is added to the RBF and refluxed under nitrogen for 30 minutes. The amount of hydride is used is added in 1 – 5 % stoichiometric excess relative to the phenol being used, and the amount 30 of phenol used is typically between 10 – 50% solids. After 30 minutes, the reaction is allowed to cool to room temperature and a stoichiometric amount of phenol is added to the reaction by unstoppering the third port and adding the phenol in portions with a spatula.

The reaction mixture is restoppered and stirred under nitrogen for 24 hours, at which point the reaction mixture is vacuum filtered and dried under vacuum. We have also prepared hypostoichiometric compounds where less than the stoichiometric amount of cation is used and hyperstoichiometric amounts where a stoichiometric excess amount of cation is used.

5

### *Metal Route*

The metal in its zero oxidation state was stirred with an alcohol in one flask, while the phenol was stirred in an appropriate organic solvent in a separate flask. A typical solvent was toluene. The solutions are combined into one flask once the metal was fully digested 10 by the alcohol. The resulting precipitate was vacuum filtered, washed with methanol, and dried under vacuum.

### *Alternative Routes*

Other alternative routes can be envisioned for making these complexes. These routes 15 could include reacting the phenols with an organometallic, such as butyl lithium.

## **Materials**

The following is a table of commercially available materials and reagents that were used to prepare the phenolate salts

20 Table B: Listing of reagents used to prepare phenolate salts

Material	Source	Supplied Form
CaH <sub>2</sub>	MP Biomedicals	Powder
Mg(OCH <sub>3</sub> ) <sub>2</sub>	Sigma-Aldrich	Powder
Ca(OCH <sub>3</sub> ) <sub>2</sub>	Sigma-Aldrich	Powder
Li(OCH <sub>3</sub> )	Sigma-Aldrich	2.2 M in methanol
Na(OCH <sub>2</sub> CH <sub>3</sub> )	Alfa-Aesar	21% w/v in ethanol
K(OCH <sub>3</sub> )	Sigma-Aldrich	25% in methanol
Tetraethyl orthotitanate	TCI America	Liquid
Co(II) (OCH <sub>2</sub> CH <sub>2</sub> OCH <sub>3</sub> ) <sub>2</sub>	Alfa-Aesar	5% w/v in methoxyethanol
Ca metal, granules	Alfa-Aesar	Granules

Methoxyethanol	Alfa-Aesar	Liquid
----------------	------------	--------

Table C: Listing of phenols used in preparing phenolate salts

Phenol	Trade Name	Source
Phenol-1	TINUVIN P	BASF
Phenol-2	----	Sigma-Aldrich
Phenol-3	----	Synthesis Example SE3 5
Phenol-4	TINUVIN 327	BASF
Phenol-5	----	Synthesis Example SE2
Phenol-6	----	Synthesis Example SE3 10
Phenol-7	----	Synthesis Example SE4
Phenol-8	----	Synthesis Example SE5
Phenol-9	----	Synthesis Example SE6 15
Phenol-10	TINUVIN 234	BASF
Phenol-11	----	Synthesis Example SE7
Phenol-12	TINUVIN 360	BASF 20
Phenol-13	----	Synthesis Example SE8
Phenol-14	----	Synthesis Example SE9
Phenol-15	----	Synthesis Example SE10 25
Phenol-16	CGL 136	CIBA
Phenol-17	----	Synthesis Example SE11
Phenol-18	----	Synthesis Example SE12 30
Phenol-19	----	Synthesis Example SE13
Phenol-20	----	Synthesis Example SE14 35
Phenol-21	----	Synthesis Example SE15
Phenol-22	----	Synthesis Example SE16 40
Phenol-23	----	Synthesis Example SE17
Phenol-24	----	Synthesis Example SE18

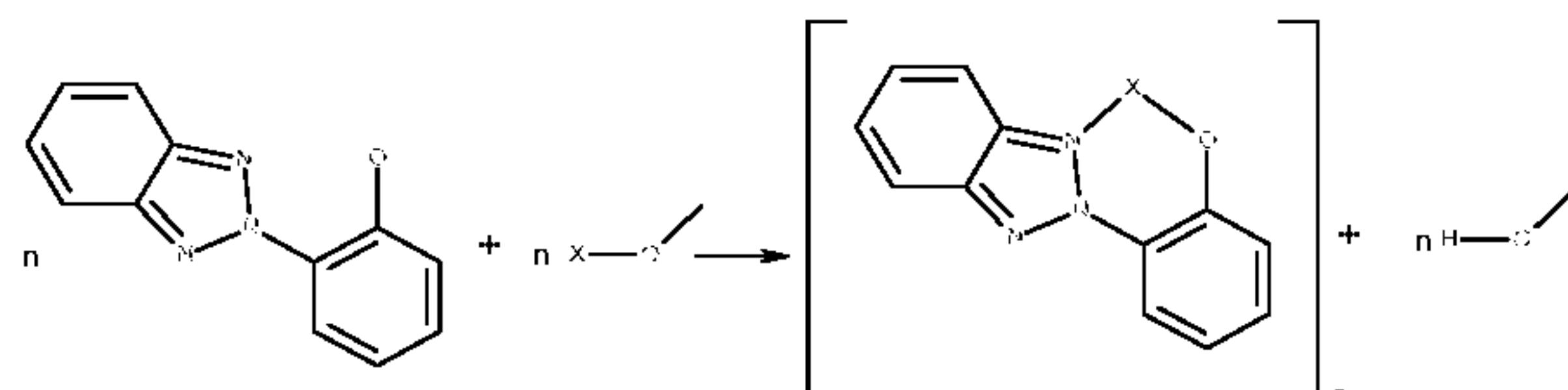
**Table 1. Metal Salts**

Material	Phenolate	Cation
Complex-1	Phenol-1	Na

Complex-2	Phenol-1	K
Complex-3	Phenol-2	Na
Complex-4	Phenol-3	K
Complex-5	Phenol-4	Na
Complex-6	Phenol-5	Na
Complex-7	Phenol-6	Na
Complex-8	Phenol-7	Na
Complex-9	Phenol-8	Na
Complex-10	Phenol-9	Na
Complex-11	Phenol-10	Na
Complex-12	Phenol-10	K
Complex-13	Phenol-11	Na
Complex-14	Phenol-12	Li
Complex-15	Phenol-12	Na
Complex-16	Phenol-12	Mg
Complex-17 <sup>a</sup>	Phenol-12	Ca
Complex-18 <sup>b</sup>	Phenol-12	Ca
Complex-19	Phenol-12	Co
Complex-20 <sup>c</sup>	Phenol-12	Ca
Complex 21	Phenol-12	K
Complex-22	Phenol-13	Ca
Complex-23	Phenol-13	Na
Complex-24	Phenol-14	Ca
Complex-25	Phenol-14	Na
Complex-26	Phenol-15	Ca
Complex-27	Phenol-15	Na
Complex-28	Phenol-16	Na
Complex-29	Phenol-17	Na
Complex-30	Phenol-18	Na
Complex-31	Phenol-19	Na
Complex-32	Phenol-20	Na
Complex-33	Phenol-21	Na
Complex-34	Phenol-22	Ca
Complex-35	Phenol-22	Na
Complex-36	Phenol-23	Ca
Complex-37	Phenol-23	Na
Complex-38 <sup>c</sup>	Phenol-23	Ca
Complex-39	Phenol-24	Ca

<sup>a</sup> Synthesized by the hydride route; <sup>b</sup> Synthesized by the alkoxide route; <sup>c</sup> Synthesized by the metal route

As described above, an unexpected feature of these salt compounds is that they form multi-metal centered complexes comprised of one, two, three, or more phenolates. We refer to these compounds as macromolecular salt compositions. For simplicity, the macromolecular salt compositions are referred to as monomers, dimers, trimers, etc, using the standard macromolecular nomenclature. To demonstrate this feature, the heats of reaction,  $\Delta H_{rxn}$ , were computed for several model compounds using the following generalized reaction scheme:

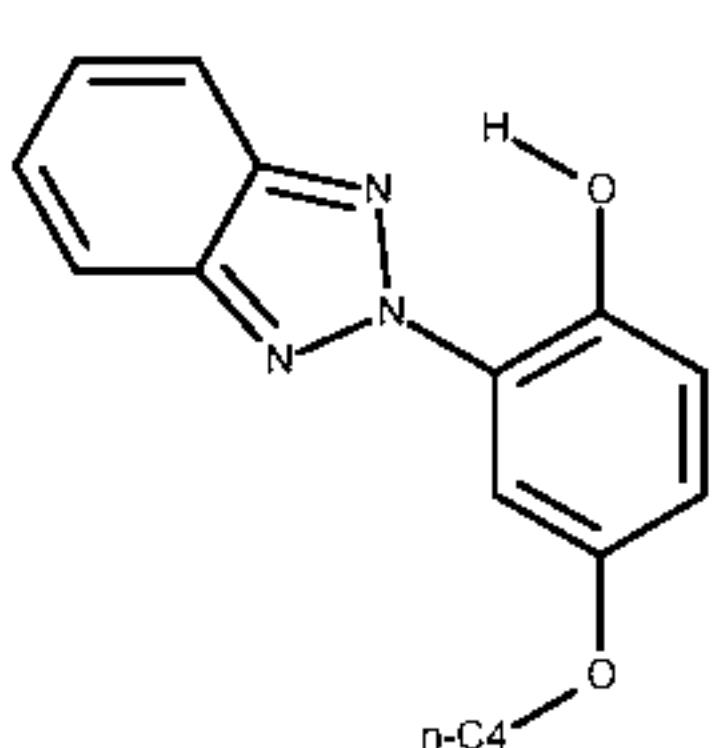
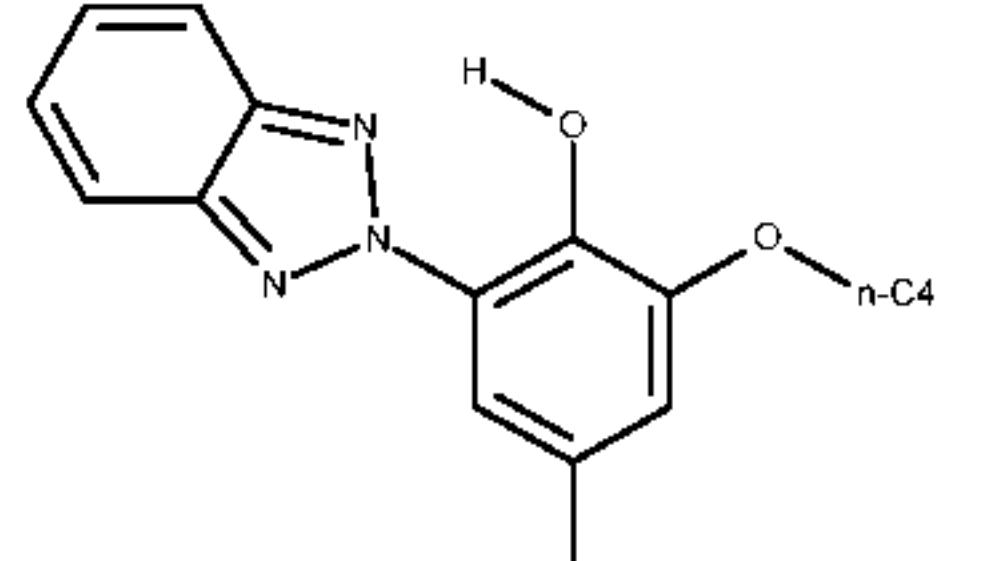
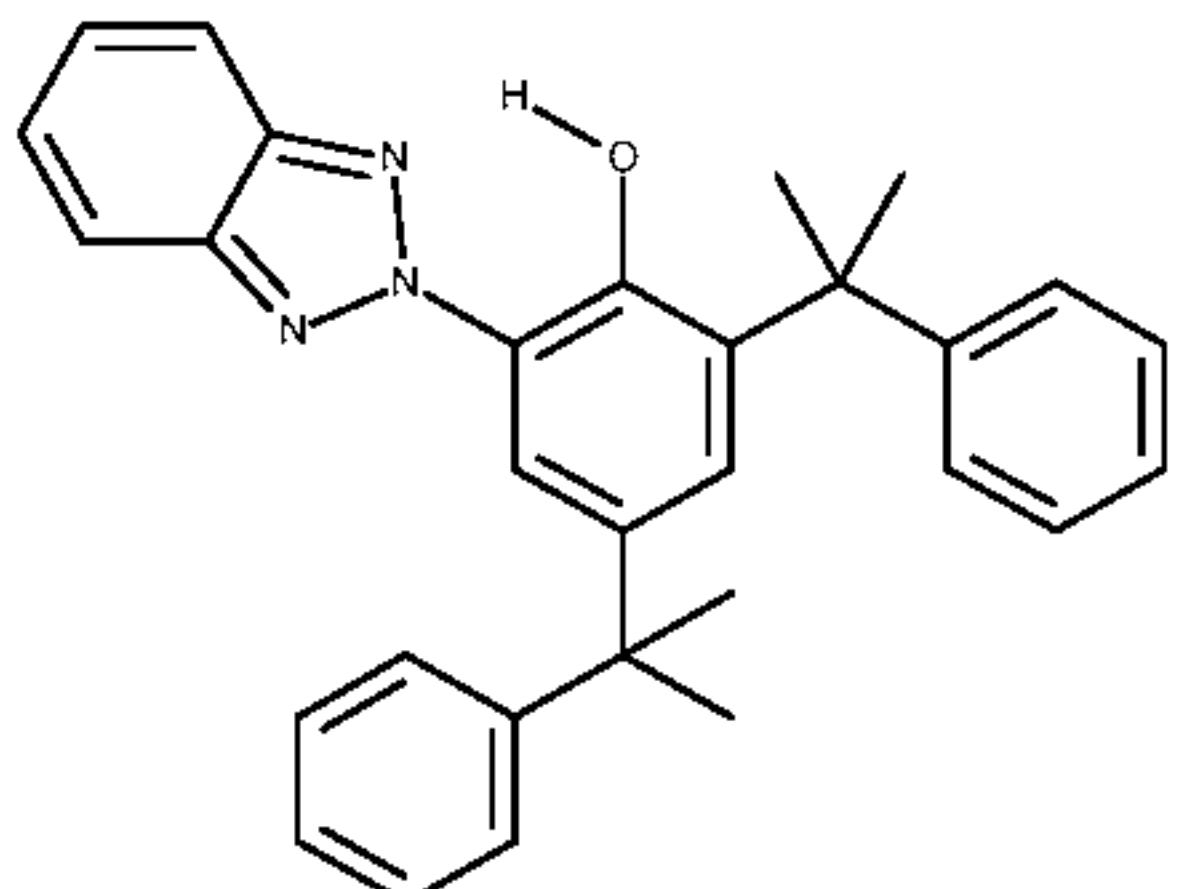
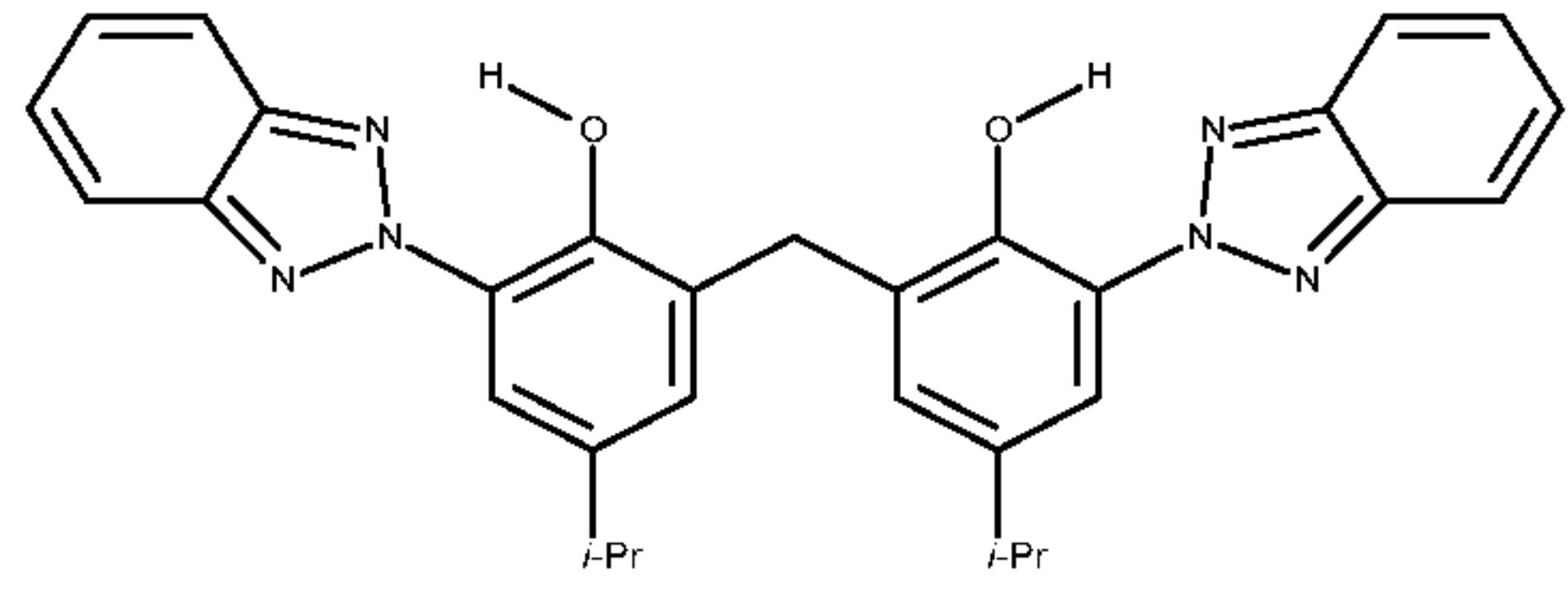
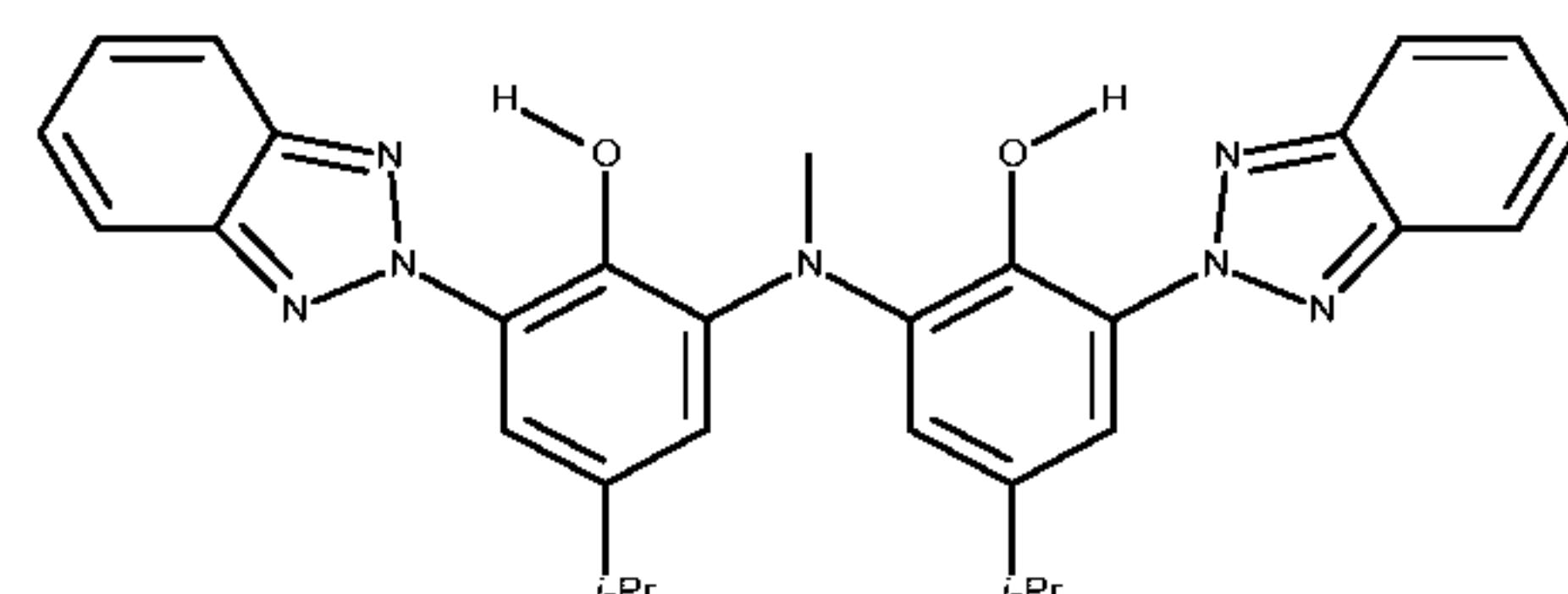


10

The heats of reaction were calculated by first optimizing the structures with the B3LYP density functional and MIDI! basis set followed by a frequency calculation to verify that the structure is a local minima. The geometry was further refined by optimizing with the B3LYP density functional and 6-31G(d,p) basis set. The heats of reaction are computed from the B3LYP/6-31G(d,p) electronic energies. The reported heats of reaction have been normalized to the number of metal centers. All computations were run with NWChem 6.5 (M. Valiev, E.J. Bylaska, N. Govind, K. Kowalski, T.P. Straatsma, H.J.J. van Dam, D. Wang, J. Nieplocha, E. Apra, T.L. Windus, W.A. de Jong, "NWChem: a comprehensive and scalable open-source solution for large scale molecular simulations" *Comput. Phys. Commun.* **181**, 1477, 2010). The results are reported in Table 2.

Table 2. Computed heats of reactions in kcal/mol

Model Compound	Metal	$\Delta H_{rxn}$			
		Monomer	Dimer	Trimer	Tetramer
	Na	23.6	47.6	51.3	51.5
	K	23.1	43.2	48.5	47.4

	Na	24.3	46.8	52.5	49.7
	Na	25.0	54.9	58.2	55.5
	Na	31.9	55.4	45.3	
	K	33.0	51.1	45.8	
	Na	36.3	47.7	51.3	
	Ca	15.9	56.6	59.2	
	Ca	19.0	53.1	56.7	

## NMR Data

### Sample Prep:

The deuterated solvents used in this study were tetrahydrofuran (THF) or benzene. 5 The solvent was chosen based on the solubility of both the parent phenol and metal complex. Additionally, the solvents should not disrupt the bonding by replacing a ligand in the complex. The concentration of the prepared samples was kept low such that the solute concentration has a negligible effect on the viscosity of the deuterated solvent selected. If the viscosity of the deuterated solvent was low (most organic solvents), the 10 sample was prepared in a 3 mm NMR tube rather than the 5 mm NMR tube to eliminate convection in the tube.

### Measurement and Data Processing:

The Diffusion measurements were carried out on either the Bruker 500 MHz or Bruker 600 MHz NMR spectrometers. The gradients were suitably calibrated using a deuterated water sample. The standard Bruker 2D-DOSY sequence ledpgp2s was used. For non-polymeric samples, the default settings of  $\Delta = 75$  ms and  $\delta = 3$  ms are sufficient. 5 If the size of the complex or aggregate is expected to have a radius  $> 1$  nm, then increasing  $\Delta$  may be necessary. For a description of the DOSY pulse sequence, refer to Antalek, B., *Concepts in Magnetic Resonance*, **14**(4), 225-258 (2002).

The data was processed using Bruker Top Spin software. This is most suitable if there isn't spectral overlap between the compound of interest and residual monomer or 10 another impurity in the sample. Selecting an exponential fit with a single component for each data point worked very well. The diffusion coefficient of the water or the main deuterated solvent can be used as internal controls from sample to sample to ensure there hasn't been a large viscosity change of the solution compared to the neat deuterated solvent. The diffusion coefficient of the analyte is measured in  $\text{m}^2/\text{s}$ .

15 The diffusion spectra of the starting material and the phenolate complex can be overlaid to easily visualize the difference in the diffusion coefficients.

The proton spectra for many of the complexes are quite different from the starting material. The first difference was the disappearance of the OH proton observed in the starting material at about 12 ppm.

20 Also observed in the proton spectra is a splitting of many of the resonances. For example the 2 t-butyl groups on the iso-C8 groups are a single resonance in the starting material with a peak at about 0.78 ppm. Upon reaction to form a metal complex, this resonance is often seen to split. In this example (Shown in Figure 1) the resonance splits into 6 distinct narrow peaks. This is the result of different t-butyl groups on different 25 molecules experience distinct magnetic environments. Exchange NMR experiments were carried out, but no chemical exchange among the multiple t-butyl resonances in complex was observed using NOESY experiments.

30 Aggregation numbers were calculated using an empirical relationship. The diffusion coefficients are plotted versus the molecular weight on a log-log plot. According to several references, there should be a linear relationship if the molecules have similar fractal exponents (Augé, S. et al.; *J. Phys. Chem. B*, **113**, 1914-1918, (2009). Neufeld, R., Stalke, D.; *Chem. Sci.*, DOI:10.1039/c5sc00670h, (2015).).

The linear regression results in empirical formulas relating the Log of the molecular weight to the log of the diffusion coefficient in Benzene:

$$\text{Log M} = -(1/0.73825) * (\text{Log D} + 6.99798)$$

And in THF:

5       $\text{Log M} = -(1/0.66235) * (\text{Log D} + 7.11205)$

These relationships are used to estimate the molecular weight of the phenolate complexes formed. The results are reported in Table 3.

Table 3: Diffusion coefficients and estimated size of complex.

Structure	Solvent	log D	estimated size
Phenol 1	THF	-8.698	1
Complex 1	THF	-8.936	3
Complex 2	THF	-8.978	3
Phenol 2	THF	-8.743	1
Complex 3	THF	-8.916	2
Phenol 3	THF	-8.764	1
Complex 4	THF	-9.016	3
Phenol 4	THF	-8.847	1
Complex 5	THF	-8.913	2
Phenol 5	Benzene	-8.932	1
Complex 6	Benzene	-9.194	2
Phenol 7	THF	-8.88	1
Complex 8	THF	-9.14	3
Phenol 8	THF	-8.92	1
Complex 9	THF	-9.06	2
Phenol 9	THF	-8.80	1
Complex 10	THF	-9.18	2
Phenol 10	Benzene	-9.006	1
Complex 11	Benzene	-9.101	2
Complex 12	Benzene	-9.142	2
Phenol 11	THF	-8.948	1
Complex 13	THF	-9.075	2
Phenol 12	Benzene	-9.098	1

Complex 14	Benzene	-9.371	3
Complex 15	Benzene	-9.293	2
Complex 17	Benzene	-9.390	3
Complex 18	Benzene	-9.389	3
Complex 19	Benzene	-9.425	3
Phenol 13	Benzene	-9.087	1
Complex 23	Benzene	-9.278	2
Complex 22	Benzene	-9.476	3
Phenol 14	Benzene	-9.103	1
Complex 25	Benzene	-9.297	2
Phenol 15	Benzene	-9.099	1
Complex 26	Benzene	-9.357	2
Complex 27	Benzene	-9.269	2
Phenol 19	THF	-8.880	1
Complex 31	THF	-9.019	2
Phenol 20	THF	-8.898	1
Complex 32	THF	-9.052	2
Phenol 21	THF	-8.911	1
Complex 33	THF	-9.059	2
Phenol 22	Benzene	-9.098	1
Complex 34	Benzene	-9.340	2
Complex 35	Benzene	-9.378	2
Phenol 23	Benzene	-9.106	1
Complex 37	Benzene	-9.288	2
Complex 38	Benzene	-9.329	2
Complex 39	Benzene	-9.319	2
Phenol 24	Benzene	-9.180	1
Complex 39	Benzene	-9.367	2

### Thermal Stability of Metal-Complexes

The thermal stability of the phenols and phenolates was measured by 5 thermogravimetric analysis (TGA). The instrument used was the Q500 model made by TA Instruments. The procedure was to heat a dried sample at 10°C/min under Nitrogen to a temperature of 450°C. The starting temperature was around 35°C and a typical sample

size was 5 mg. The temperatures for 5%, 10%, and 20% weight loss are reported in Table 4. In some cases it was necessary to drive off absorbed solvent or water in order to report accurate weight losses. This was achieved by heating the sample to a temperature no greater than 180°C, cooling the sample back to room temperature, and then reheating to a 5 temperature of 450°C

Table 4: Temperatures in Celsius for 5, 10, and 20 percent weight loss as measured by TGA.

Molecule	5% Weight Loss	10% Weight Loss	20% Weight Loss
Phenol-1	180	195	211
Complex 1	285	288	308
Complex 2	340	377	425
Phenol 2	195	209	226
Complex 3	251	257	282
Phenol 3	95	195	212
Complex 4	240	251	269
Phenol 4	208	222	238
Complex 5	386	403	442
Phenol 5	230	249	269
Complex 6	376	387	397
Phenol 7	231	247	264
Complex 8	337	345	354
Phenol 8	250	270	289
Complex 9	268	297	336
Phenol 9	264	283	302
Complex 10	418	431	444
Phenol 10	264	280	295
Complex 12	258	290	328
Phenol 11	304	323	343
Complex 13	319	350	394
Phenol 12	335	352	371
Complex 14	341	377	425
Complex 15	321	360	414
Complex 17	325	359	399
Complex 19	257	300	322
Complex 20	413	444	465
Phenol 13	348	373	394
Complex 22	384	407	432
Complex 23	417	426	436
Phenol 14	321	350	377
Complex 24	333	371	403
Complex 25	384	412	428
Phenol 15	243	291	353
Complex 26	414	424	441
Complex 27	381	394	400
Phenol 16	260	275	293

Complex 28	265	283	299
Phenol 17	247	261	278
Complex 29	334	346	356 5
Phenol 18	256	275	295
Complex 30	267	304	331
Phenol 19	271	289	308
Complex 31	357	375	386
Phenol 20	183	256	267
Complex 32	389	389	390
Phenol 21	264	305	329
Complex 33	400	406	408
Phenol 22	242	263	294
Complex 34	387	409	440
Complex 35	361	370	409
Phenol 23	210	330	361
Complex 36	356	394	421
Complex 37	211	359	385
Complex 38	359	386	416
Phenol 24	296	343	365
Complex 39	277	321	354

## Fluorescence Observations

### Step A: Preparation of samples

A spatula-tip of either phenol or metal complex was added with 2 mL of THF to a clean vial. The vial was sealed and the vial sat until the chemical completely dissolved.

### 5 Step B: Fluorescence determination

The vials were and exposed to 365 nm wavelength UV light source in a darkened room and visual observations were recorded. The data are shown in Table 5 below.

Table 5. Fluorescence observations.

Molecule	Fluorescent	Molecule	Fluorescent
Phenol 1	No	Phenol 14	No
Complex 1	Strong	Complex 24	Moderate-Strong
Complex 2	Moderate-Strong	Complex 25	Moderate-Strong (orange)
Phenol 2	Weak	Phenol 15	No
Complex 3	Moderate-Strong	Complex 26	Strong (green)
Phenol 4	No	Complex 27	Strong
Complex 5	Moderate (red)	Phenol 16	No
Phenol 5	No	Complex 28	No
Complex 6	Strong	Phenol 17	No
Phenol 7	No	Complex 29	Weak
Complex 8	Moderate-Strong	Complex 30	No
Phenol 8	Weak	Phenol 19	No
Complex 9	Moderate-Strong	Complex 31	Moderate-Strong (orange)
Phenol 9	No	Phenol 20	No
Complex 10	Strong	Complex 32	Strong (green)
Phenol 10	No	Phenol 21	Weak
Complex 11	Moderate-Strong	Complex 33	Strong (green)
Complex 12	Moderate-Strong	Phenol 22	No
Phenol 11	Weak	Complex 34	Strong (green)
Complex 13	Moderate-Strong	Complex 35	Strong
Phenol 12	No	Phenol 23	No
Complex 14	Strong	Complex 36	Strong (blue)
Complex 15	Moderate-Strong	Complex 37	Strong (blue)
Complex 16	Strong	Complex 38	Strong
Complex 17	Moderate-Strong	Phenol 24	No
Complex 18	Moderate-Strong	Complex 39	Moderate-Strong (orange)

10

## Anti-oxidant Studies

### Step A - Preparation of Compounded Additives

To prepare the samples, one of the additives was dry blended into polypropylene. The concentration is specified in Table 6 below. The materials were compounded in a conical twin-screw extruder. The extrusion temperature ranged from about 250°C to 15 300°C. The extrusion speeds ranged from 5 to 7 lbs / hr. The resins used were either MF-650X (PP-1) or MF-650W (PP-2), where both resins were purchased from LyondellBasell.

### Step B – Determination of Anti-Oxidant Ability

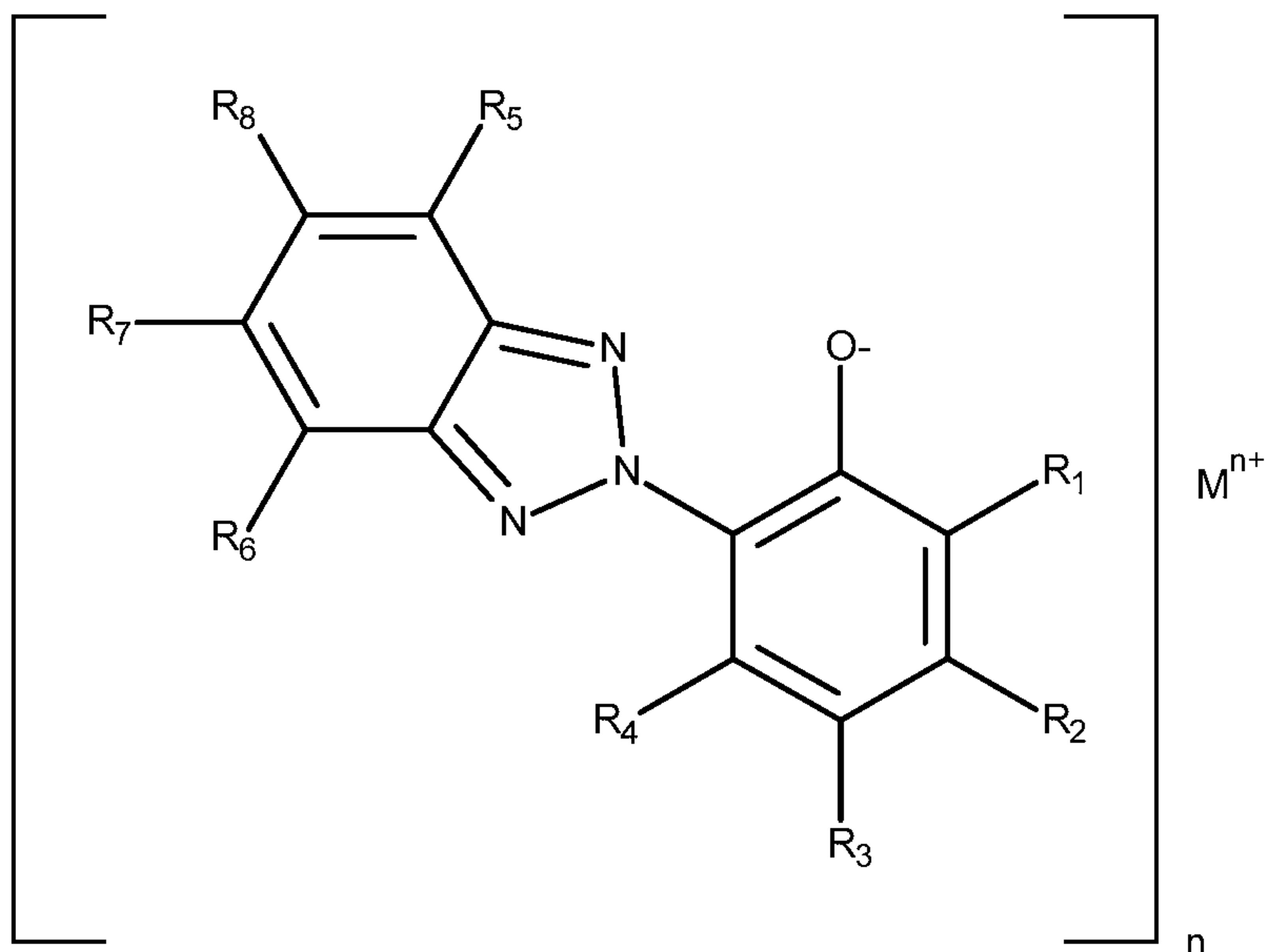
A modified oxidative-induction time (OIT) test that is similar to ASTM D3895 was performed. In the modified test, 2 – 6 mg of sample were placed in an aluminum pan and heated to 190°C under nitrogen in a differential scanning calorimeter (DSC). The atmosphere was then switched to an atmosphere of 21% oxygen and 78% nitrogen and the temperature at between was held at 180°C and 200°C until an abrupt increase in evolved heat was displayed on the recorded thermogram. The induction time was then defined as the time between exposure to the oxygen-containing environment and onset of heat evolution. The data presented in Table 6 are an average of 3 samples.

Table 6: OIT data for metal complexes.

Resin	Additive	Additive Concentration	Temperature (°C)	OIT (min)
PP-1			180	45.0
PP-2			180	26.5
PP-1			190	18.1
PP-1			200	6.5
PP-1	Phenol 11	0.2%	200	291.1
PP-1	Complex 13	0.2%	200	342.7
PP-1	Complex 9		190	32.8
PP-2	Phenol 12	0.2%	180	27.7
PP-1	Complex 21		180	53.4
PP-2	Complex 17		180	81.6
PP-2	Complex 17		180	107.7
PP-1	Complex 24	0.6%	190	151.2
PP-1	Phenol 13	0.2%	190	29.9
PP-1	Complex 22	0.2%	190	187.6
PP-1	Phenol 14	0.2%	190	5.05
PP-1	Complex 24	0.2%	190	62.7

What is claimed is:

1. An antioxidant composition comprising one or more macromolecular salt compositions, the macromolecular salt composition comprising an assembly of metal salts comprising repeat units of a substituted benzotriazole phenolate anion and a metal cation with the structure:



wherein each R<sup>1</sup>, R<sup>2</sup>, R<sup>3</sup>, R<sup>4</sup>, R<sup>5</sup>, R<sup>6</sup>, R<sup>7</sup>, and R<sup>8</sup>, independently comprises a hydrogen atom, an alkyl group, an alkenyl group, an aryl group, a halogen atom, or a substituted heteroatom group comprising a -B(OR<sup>18</sup>)(OR<sup>19</sup>), a -SiR<sup>20</sup><sub>3</sub>, a -CH<sub>2</sub>-R<sup>9</sup>, an -O-R<sup>9</sup>, a -N-

10 R<sup>9</sup>R<sup>10</sup>, a -S-R<sup>9</sup>,

a -S(O)-R<sup>9</sup>, or a -S(O)<sub>2</sub>-R<sup>9</sup> group, wherein R<sup>9</sup> comprises a hydrogen atom, an alkyl group, an alkenyl group, an aryl group, or a heteroatom-containing group comprising one or more oxygen, nitrogen, sulfur, or phosphorous atoms, wherein the -B(OR<sup>18</sup>)(OR<sup>19</sup>), -SiR<sup>20</sup><sub>3</sub>,

-CH<sub>2</sub>-R<sup>9</sup>, -O-R<sup>9</sup>, -N-R<sup>9</sup>R<sup>10</sup>, -S-R<sup>9</sup>, -S(O)-R<sup>9</sup>, or -S(O)<sub>2</sub>-R<sup>9</sup> group may be neutral or anionic,

15 and R<sup>10</sup> comprises a hydrogen atom, an alkyl group, an alkenyl group, an aryl group, or a heteroatom-containing group comprising one or more oxygen, nitrogen, sulfur, or phosphorous atoms, or R<sup>9</sup> and R<sup>10</sup> together with the atoms connecting form a heterocyclic ring structure, R<sup>18</sup> and R<sup>19</sup> are independently hydrogen atoms, alkyl groups or R<sup>18</sup> and R<sup>19</sup> together with the atoms connecting form a heterocyclic ring structure, each R<sup>20</sup>

20 independently comprises an alkyl group;

n is an integer of 1-4; and

M comprises a metal atom with a valency of n; and  
the macromolecular assembly comprises 2-4 repeat units.

2. The antioxidant composition of claim 1, wherein n = 1 and M comprises lithium,  
5 sodium, or potassium.

3. The antioxidant composition of claim 1, wherein R<sup>1</sup> comprises an -O-R<sup>9</sup> group wherein  
R<sup>9</sup> comprises:

an alkyl group with 1-20 carbon atoms; or

10 an aryl group; and

R<sup>3</sup> is an alkyl group with 1-20 carbon atoms.

4. The antioxidant composition of claim 3, wherein R<sup>9</sup> comprises:

an alkyl group with 1-6 carbon atoms; or

15 an aryl group comprising a 3-methyl phenyl group, or a 4-methyl phenyl group.

5. The antioxidant composition of claim 1, wherein R<sup>1</sup> comprises an -N-R<sup>9</sup>R<sup>10</sup> group  
wherein R<sup>9</sup> comprises:

an alkyl group with 1-20 carbon atoms; or

20 an aryl group;

R<sup>10</sup> comprises a hydrogen atom or alkyl group with 1-6 carbon atoms; and

R<sup>3</sup> is an alkyl group with 1-20 carbon atoms.

6. The antioxidant composition of claim 5, wherein R<sup>9</sup> comprises:

25 an alkyl group with 1-6 carbon atoms; or

an aryl group comprising a 4-alkyl substituted phenyl group, wherein the alkyl  
substituted group has 1-6 carbon atoms;

R<sup>10</sup> comprises a hydrogen atom.

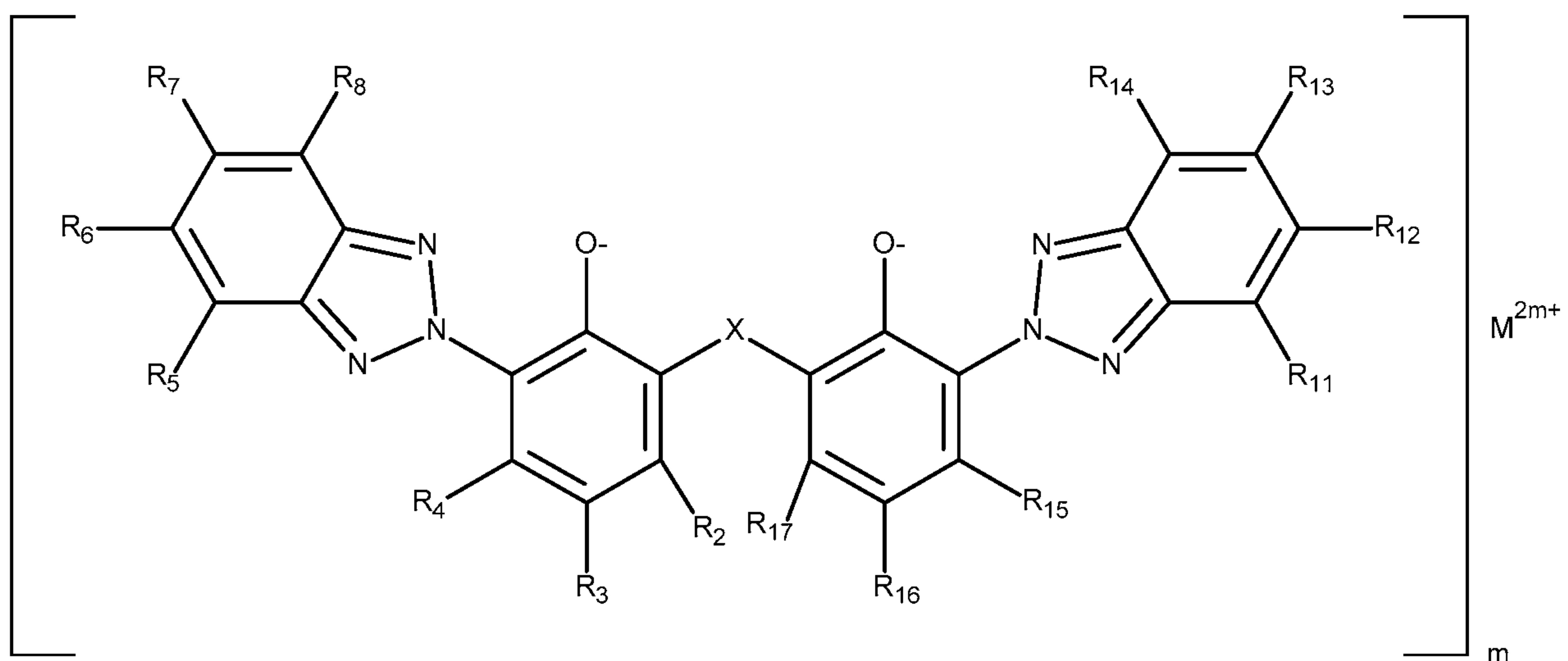
30 7. The antioxidant composition of claim 1, wherein R<sup>1</sup> comprises a hydrogen atom, an  
alkyl, alkylene, an aryl group, or an aralkylene group; and

R<sup>3</sup> is an alkyl group with 1-20 carbon atoms, or an alkoxy group with 1-6 carbon atoms.

8. The antioxidant composition of claim 1, wherein  $R^1$  comprises a halogen atom or a  $-SiR^{20}_3$  group wherein each  $R^{20}$  comprises an alkyl group with 1-4 carbon atoms; and  $R^3$  is an alkyl group with 1-20 carbon atoms.

5

9. The antioxidant composition of claim 1, wherein the repeat unit of the macromolecular salt has the structure:



10 wherein X comprises a -CH<sub>2</sub>-, -O-, -S-, -S(O)<sub>2</sub>-, or -NR<sup>10</sup>- linking group where R<sup>10</sup> comprises a hydrogen atom, an alkyl group, or an aryl group; each R<sup>2</sup>, R<sup>3</sup>, R<sup>4</sup>, R<sup>5</sup>, R<sup>6</sup>, R<sup>7</sup>, R<sup>8</sup>, R<sup>11</sup>, R<sup>12</sup>, R<sup>13</sup>, R<sup>14</sup>, R<sup>15</sup>, R<sup>16</sup>, and R<sup>17</sup>, independently, comprises a hydrogen atom, an alkyl group, an alkenyl group, an aryl group, or a halogen atom;

15 m = 0.5, 1, or 2;

M is a metal ion with a valency of  $2m$  such that M is lithium, sodium, or potassium when  $m = 0.5$ ; M is calcium, magnesium, or cobalt, when  $m = 1$ ; and M is vanadium or titanium when  $m = 2$ .

10. The antioxidant composition of claim 9, wherein X comprises a -CH<sub>2</sub>- linking group, and R<sup>3</sup> and R<sup>16</sup> each comprises an alkyl group with 8 carbon atoms.

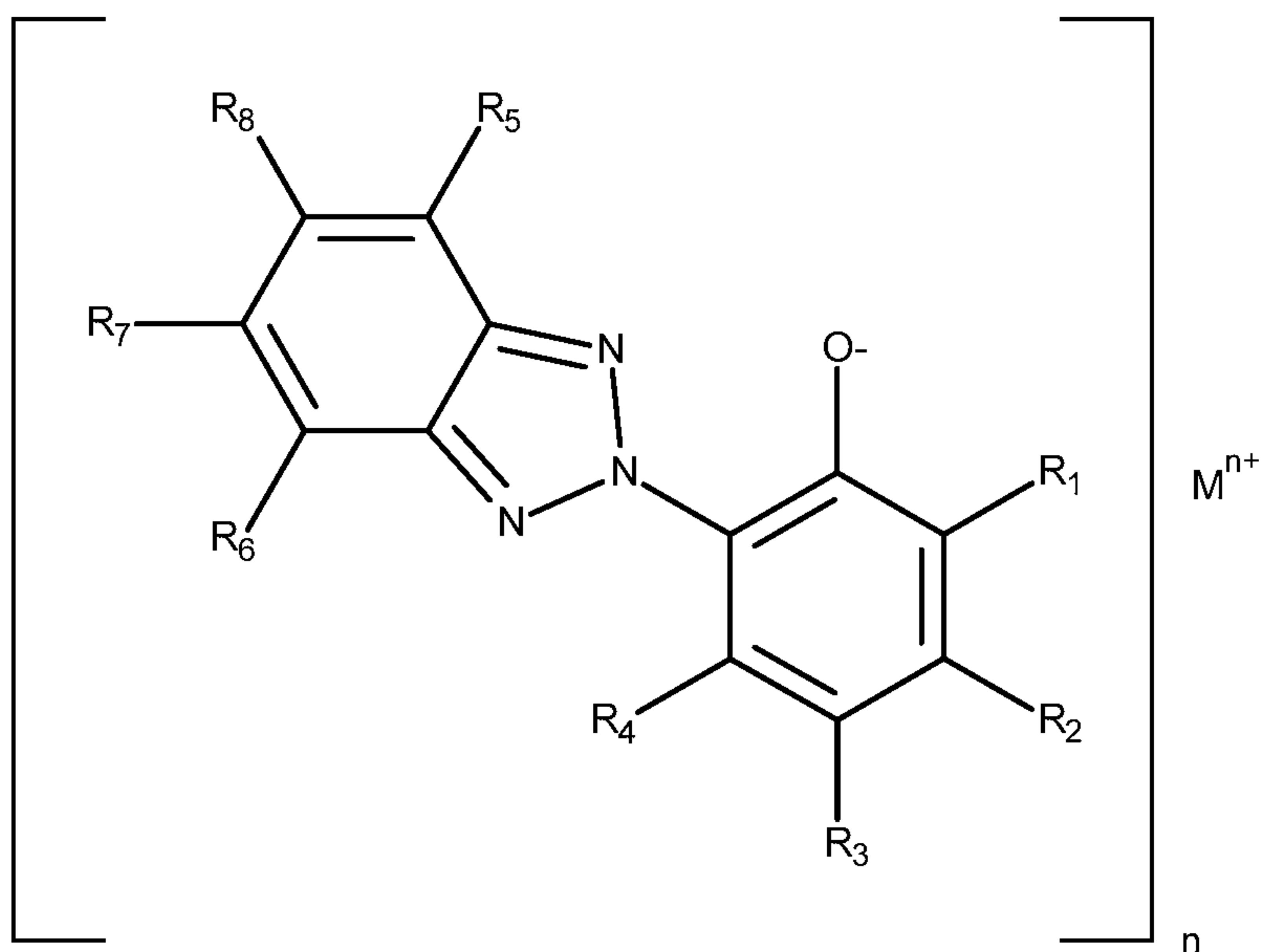
11. The antioxidant composition of claim 9, wherein X comprises a -NR<sup>10</sup>- linking group, where R<sup>10</sup> comprises a hydrogen atom or a methyl group, and R<sup>3</sup> and R<sup>16</sup> each comprises an alkyl group with 8 carbon atoms.

5 12. The antioxidant composition of claim 9, wherein X comprises a -S- linking group, and R<sup>3</sup> and R<sup>16</sup> each comprises an alkyl group with 8 carbon atoms.

13. The antioxidant composition of claim 1, wherein the antioxidant composition comprises a mixture of macromolecular salts.

10

14. A macromolecular salt composition comprising an assembly of metal salts comprising repeat units of a substituted benzotriazole phenolate anion and a metal cation with the structure:



15 wherein each R<sup>1</sup>, R<sup>2</sup>, R<sup>3</sup>, R<sup>4</sup>, R<sup>5</sup>, R<sup>6</sup>, R<sup>7</sup>, and R<sup>8</sup>, independently comprises a hydrogen atom, an alkyl group, an alkenyl group, an aryl group, a halogen atom, or a substituted heteroatom group comprising a -B(OR<sup>18</sup>)(OR<sup>19</sup>), a -SiR<sup>20</sup><sub>3</sub>, a -CH<sub>2</sub>-R<sup>9</sup>, an -O-R<sup>9</sup>, a -N-R<sup>9</sup>R<sup>10</sup>, a -S-R<sup>9</sup>, a -S(O)-R<sup>9</sup>, or a -S(O)<sub>2</sub>-R<sup>9</sup> group, wherein R<sup>9</sup> comprises a hydrogen atom, an alkyl group, an alkenyl group, an aryl group, or a heteroatom-containing group comprising one or more oxygen, nitrogen, sulfur, or phosphorous atoms, wherein the -B(OR<sup>18</sup>)(OR<sup>19</sup>), -SiR<sup>20</sup><sub>3</sub>,

20

-CH<sub>2</sub>-R<sup>9</sup>, -O-R<sup>9</sup>, -N-R<sup>9</sup>R<sup>10</sup>, -S-R<sup>9</sup>, -S(O)-R<sup>9</sup>, or -S(O)<sub>2</sub>-R<sup>9</sup> group may be neutral or anionic, and R<sup>10</sup> comprises a hydrogen atom, an alkyl group, an alkenyl group, an aryl group, or a heteroatom-containing group comprising one or more oxygen, nitrogen, sulfur, or phosphorous atoms, or R<sup>9</sup> and R<sup>10</sup> together with the atoms connecting form a heterocyclic ring structure, R<sup>18</sup> and R<sup>19</sup> are independently hydrogen atoms, alkyl groups or R<sup>18</sup> and R<sup>19</sup> together with the atoms connecting form a heterocyclic ring structure, each R<sup>20</sup> independently comprises an alkyl group;

5 n is an integer of 1-4; and

M comprises a metal atom with a valency of n; and

10 the macromolecular assembly comprises 2-4 repeat units.

15. The salt composition of claim 14, wherein n = 1 and M comprises lithium, sodium, or potassium.

15 16. The salt composition of claim 14, wherein n = 2 and M comprises calcium, or cobalt.

17. The salt composition of claim 14, wherein R<sup>1</sup> comprises an -O-R<sup>9</sup> group wherein R<sup>9</sup> comprises:

an alkyl group with 1-6 carbon atoms; or

20 an aryl group comprising a 3-methyl phenyl group, or a 4-methyl phenyl group; and

R<sup>3</sup> is an alkyl group with 1-20 carbon atoms.

18. The salt composition of claim 14, wherein R<sup>1</sup> comprises an -N-R<sup>9</sup>R<sup>10</sup> group wherein 25 R<sup>9</sup> comprises:

an alkyl group with 1-6 carbon atoms; or

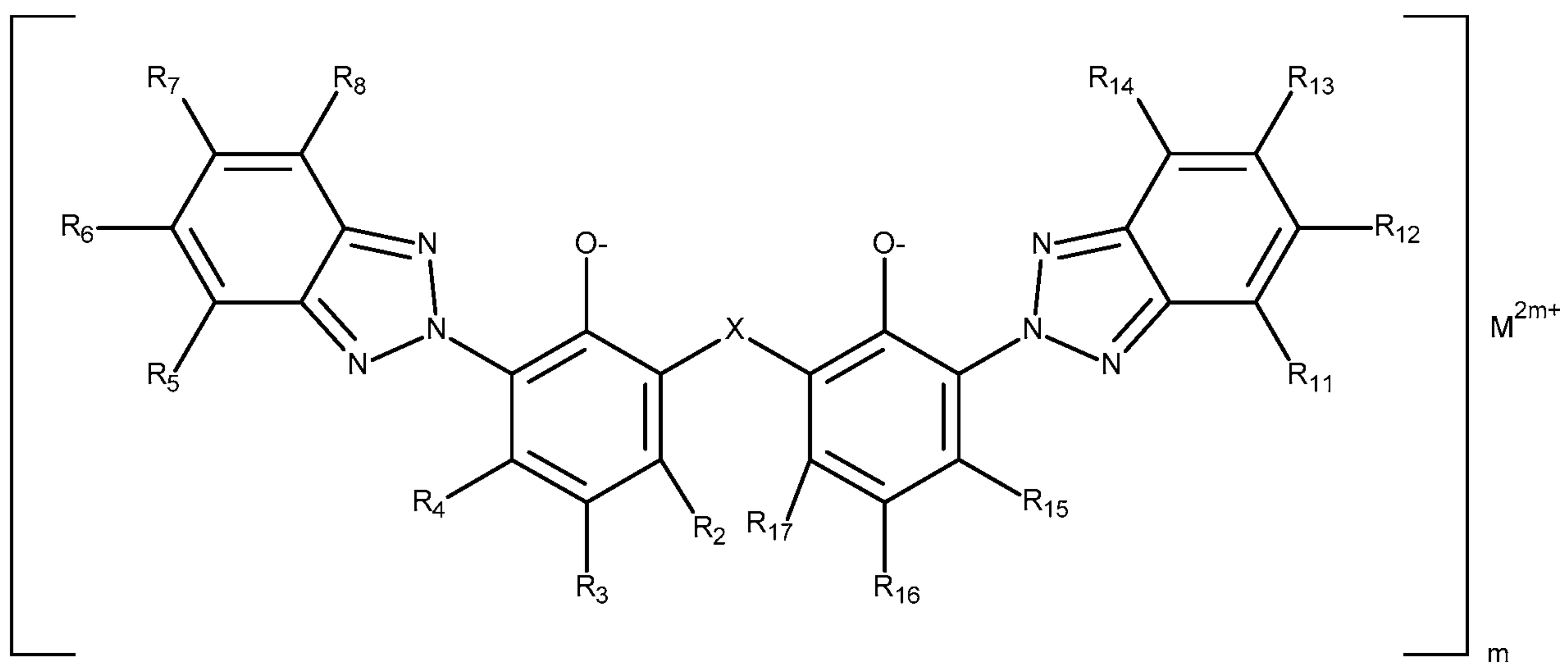
an aryl group comprising a 4-alkyl substituted phenyl group, wherein the alkyl substituted group has 1-6 carbon atoms;

30 R<sup>10</sup> comprises a hydrogen atom or alkyl group with 1-6 carbon atoms; and R<sup>3</sup> is an alkyl group with 1-20 carbon atoms.

19. The salt composition of claim 14, wherein  $R^1$  comprises a hydrogen atom, an alkyl, alkylene, an aryl group, or an aralkylene group; and  $R^3$  is an alkyl group with 1-20 carbon atoms, or an alkoxy group with 1-6 carbon atoms.

5 20. The salt composition of claim 14, wherein  $R^1$  comprises a halogen atom or a  $-SiR^{20}3$  group wherein each  $R^{20}$  comprises an alkyl group with 1-4 carbon atoms; and  $R^3$  is an alkyl group with 1-20 carbon atoms.

10 21. The salt composition of claim 14, wherein the repeat unit of the macromolecular salt has the structure:



wherein X comprises a  $-CH_2-$ ,  $-O-$ ,  $-S-$ ,  $-S(O)-$ ,  $-S(O)_2-$ , or  $-NR^{10}-$  linking group where  $R^{10}$  comprises a hydrogen atom, an alkyl group, or an aryl group;

15 each  $R^2$ ,  $R^3$ ,  $R^4$ ,  $R^5$ ,  $R^6$ ,  $R^7$ ,  $R^8$ ,  $R^{11}$ ,  $R^{12}$ ,  $R^{13}$ ,  $R^{14}$ ,  $R^{15}$ ,  $R^{16}$ , and  $R^{17}$ , independently comprises a hydrogen atom, an alkyl group, an alkenyl group, an aryl group, or a halogen atom;

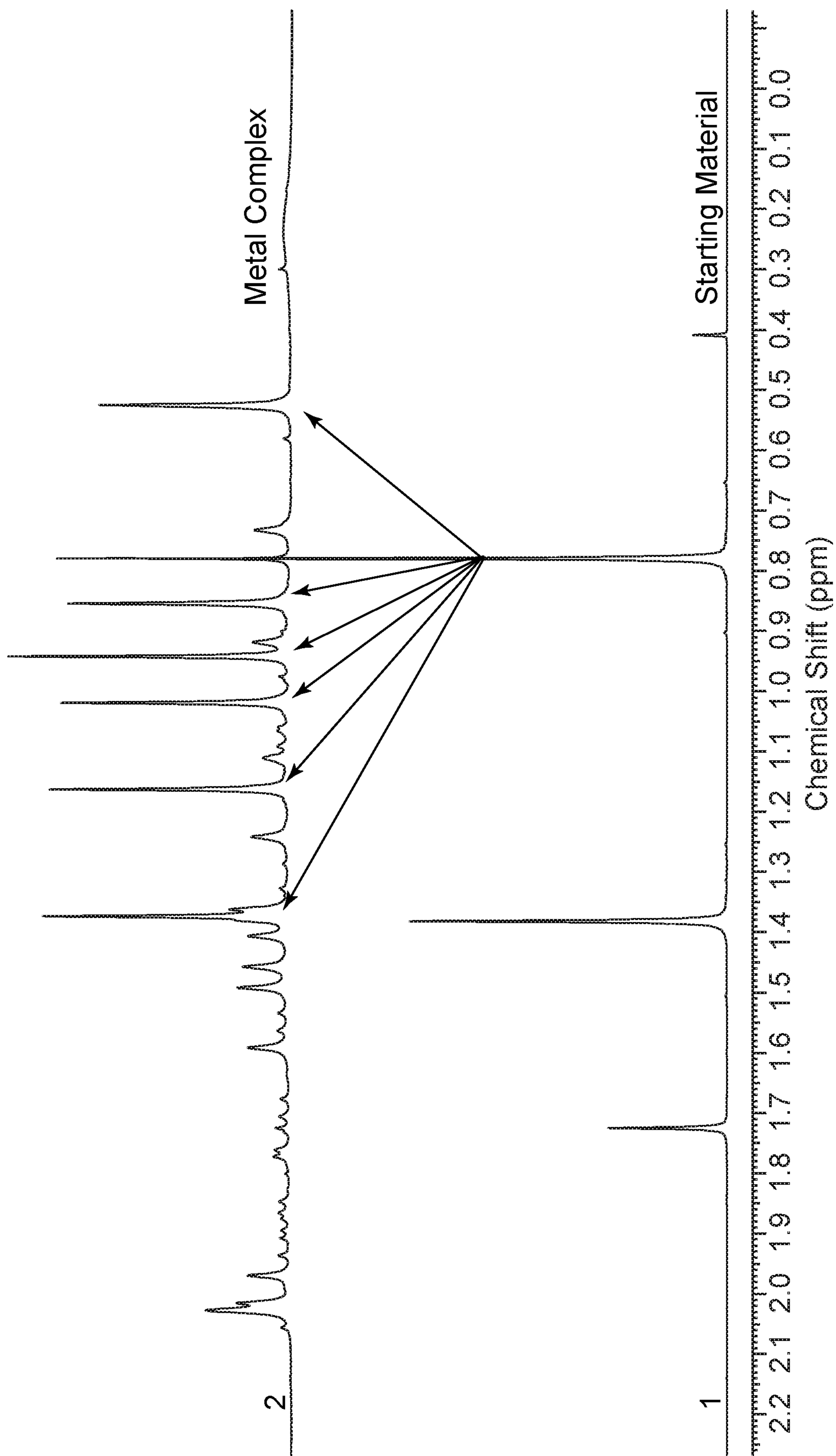
$m = 0.5, 1, \text{ or } 2$ ;

20  $M$  is a metal ion with a valency of  $2m$  such that  $M$  is lithium sodium or potassium when  $m = 0.5$ ;  $M$  is calcium, magnesium, or cobalt, when  $m = 1$ ; and  $M$  is vanadium or titanium when  $m = 2$ .

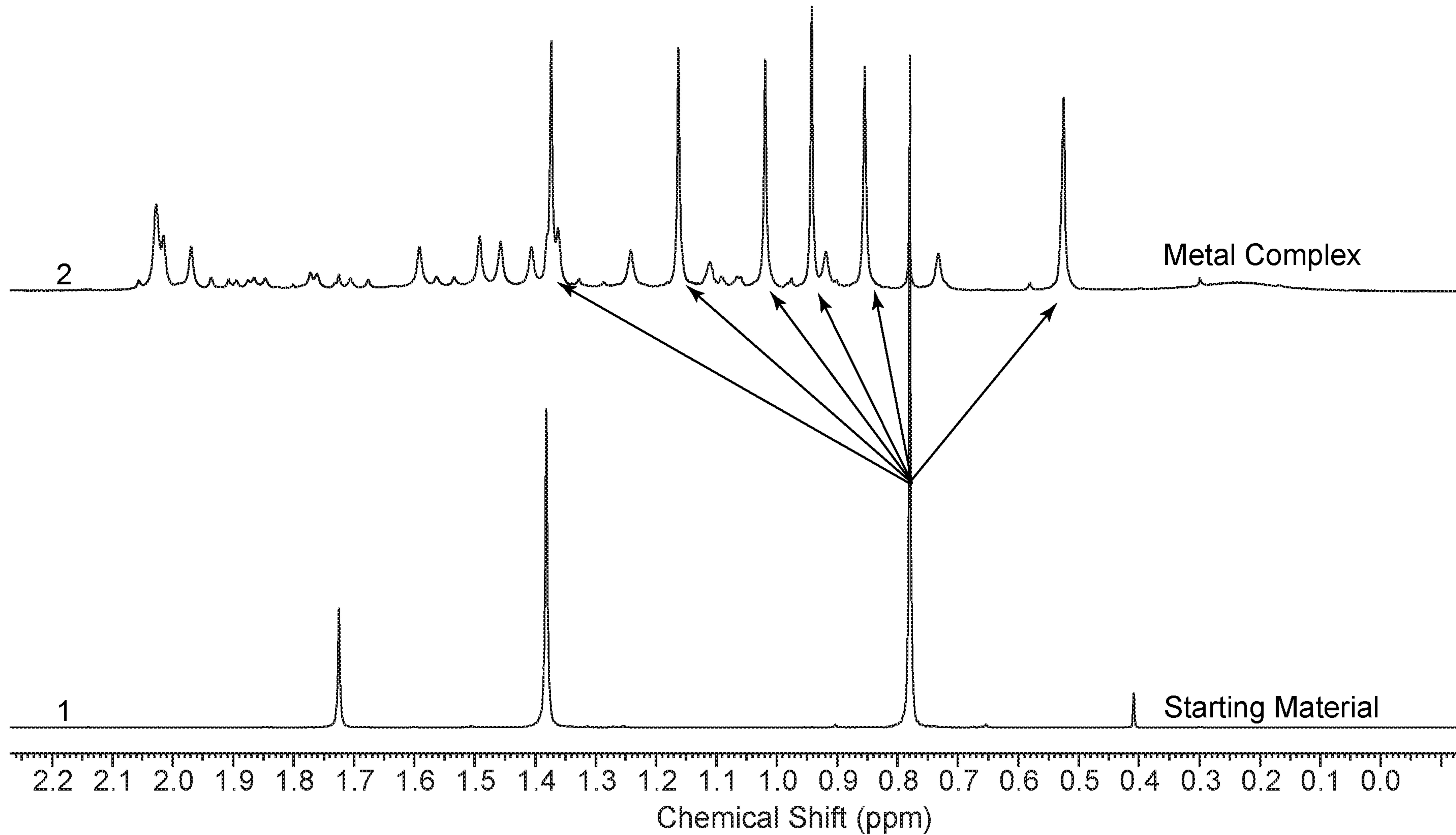
22. The salt composition of claim 21, wherein X comprises a -CH<sub>2</sub>- linking group, and R<sup>3</sup> and R<sup>16</sup> each comprises an alkyl group with 8 carbon atoms.

23. The salt composition of claim 21, wherein X comprises a -NR<sup>10</sup>- linking group, where R<sup>10</sup> comprises a hydrogen atom or a methyl group, and R<sup>3</sup> and R<sup>16</sup> each comprises an alkyl group with 8 carbon atoms.

24. The antioxidant composition of claim 21, wherein X comprises a -S- linking group, and R<sup>3</sup> and R<sup>16</sup> each comprises an alkyl group with 8 carbon atoms.



**Fig. 1**



*Fig. 1*