

Synthesis and characterization of novel urea and thiourea substitute cyclotriphosphazene compounds as naked-eye sensors for F⁻ and CN⁻ anions

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Abstract: Novel hexakisurea and thiourea cyclotriphosphazene compounds (**3-7**) were synthesized. The structure of all compounds was identified using FT-IR ¹H, ¹³C, and ³¹P NMR spectroscopy; MALDI-TOF MS; and elemental analysis. The optical sensor properties for anions of **3-7** were investigated using UV-Vis spectroscopy. It was determined that compounds **6** and **7** are spectrophotometric and naked eye sensors for F⁻ and CN⁻ anions, respectively. Sensor properties of these compounds for anions were investigated using UV-Vis spectroscopy. The stoichiometry of host-guest complexes was found to be 1:6.

Key words: Cyclotriphosphazene, urea, thiourea, naked-eye sensor

1. Introduction

Phosphazenes that contain -P=N(X₂)- units in their skeleton create a large class of inorganic-organic hybrid compounds.^{1,2} Phosphazene compounds have been a focus of interest for many researchers due to their applications such as forming a core for dendrimeric molecules,^{3,4} multicentered ion sensors,^{5,6} metal carbonyl derivative,⁷ flame retardant agent,^{8,9} biodegradable materials,¹⁰⁻¹² and liquid crystalline materials.¹³

Urea and thiourea derivatives are very interesting compounds due to their biological activities. Recently, numerous urea and thiourea compounds have been reported in the literature as antitumor agents,^{14,15} glucokinase activators,¹⁶ pruvate dehydrogenase inhibitors,¹⁷ and corrosion inhibitors.¹⁸ At the same time, urea and thiourea compounds are good hydrogen binding donors. Thanks to these features, numerous urea and thiourea derivatives have been used as naked-eye anion sensors.¹⁹⁻²⁹ Many of these sensor compounds are monopodal or dipodal compounds. Khandelwal et al. have reported tetrapodal urea derivatives as colorimetric sensors for fluoride and pyrophosphate anions.³⁰

In the present study, we synthesized novel hexapodal urea and thiourea compounds with cyclotriphosphazene cores. Firstly, hexakis(4-aminophenoxy)cyclotriphosphazene **2** was synthesized according to the literature procedure.^{31,32} Afterwards, four urea (**3-6**) and one thiourea derivative (**7**) were synthesized from the reaction of **2** with isocyanate and isothiocyanate compounds. Structures of all synthesized compounds were

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characterized using spectral methods such as FT-IR, NMR, and MALDI TOF-MS. Then the interaction of all compounds with anions in solvent media was investigated. It was determined that 4-nitrophenylurea derivative **6** and 4-nitrophenylthiourea derivative **7** act as naked-eye sensors for fluoride and cyanide anions, respectively. Detailed sensor studies were performed for these two compounds.

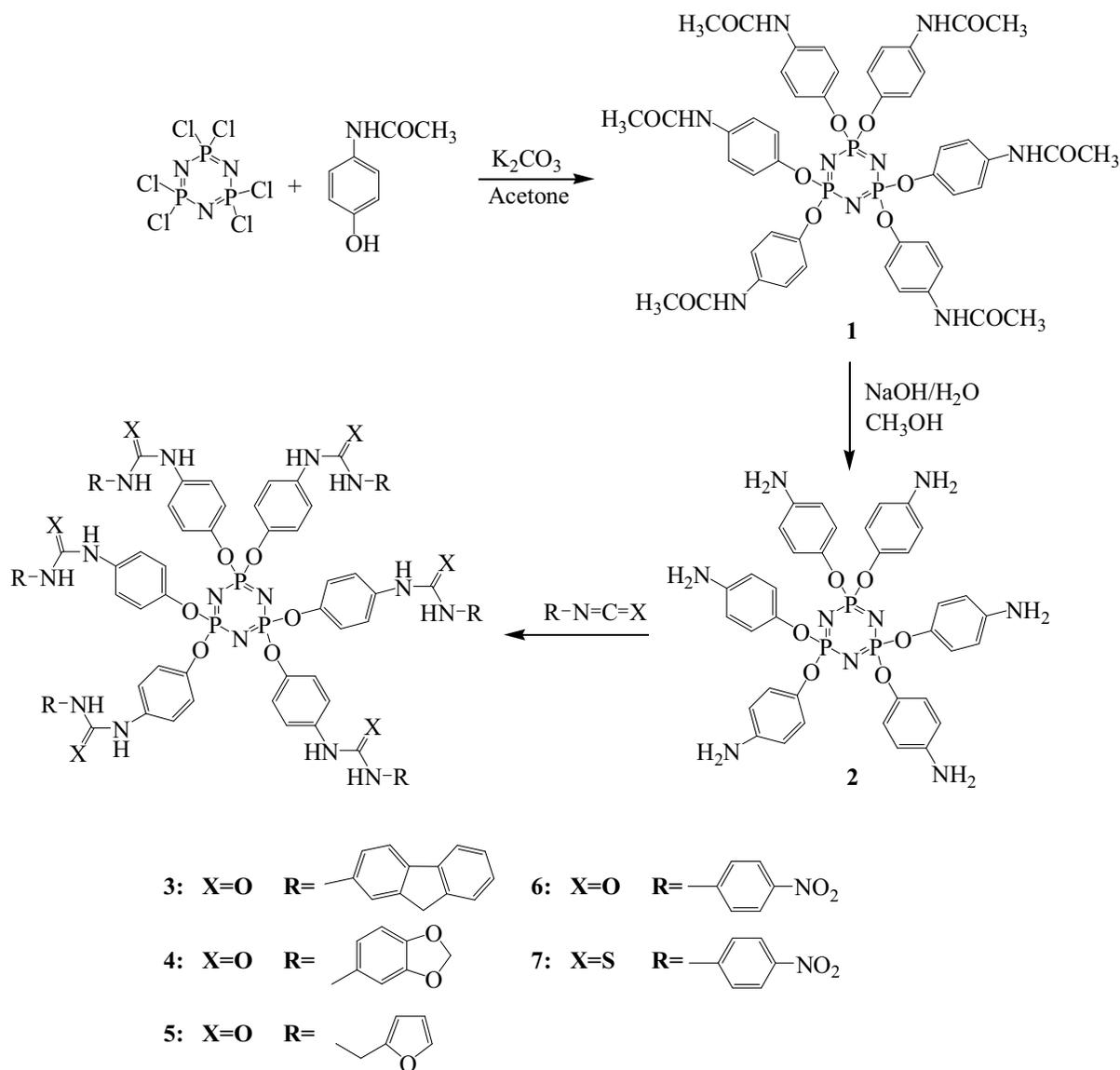
2. Results and discussion

2.1. Synthesis and structural characterization of all compounds

It is well known that hexachlorocyclotriphosphazene can easily react with nucleophiles such as amines, alcohols, and phenols.^{33–35} Therefore, firstly the reaction of hexachlorocyclotriphosphazene with 4-acetamidophenol in the presence of K_2CO_3 as base was carried out in acetone. Compound **1** was obtained from this reaction with good yield (83%). Acetamide groups of compound **1** were converted to amine groups by hydrolysis with aqueous NaOH.^{31,32} Hexapodal urea and thiourea compounds **3–7** were synthesized from the reaction of hexamine substitute cyclotriphosphazene compound **2** and different isocyanate and isothiocyanate compounds under mild reaction conditions with good yield (Scheme 1).

The structures of all compounds were identified using FT-IR, 1H NMR, ^{13}C NMR, ^{31}P NMR, and MALDI TOF-MS spectroscopy, and elemental analysis data. All results are given in the experimental section. In the FT-IR spectrum of compound **1** stretching vibrations of C=O and –P=N– were observed at 1658 and 1162 cm^{-1} , respectively. The peaks related to N–H and –P=N– of compound **2** were observed at 3340–3204 and 1158 cm^{-1} in the FT-IR spectrum. Urea and thiourea compounds **3–7** produced peaks related to –P=N– stretching vibration at 1162, 1177, 1159, 1162, and 1159 cm^{-1} , respectively. As seen in the 1H NMR spectrum, NH protons of urea groups in the structure of compound **3** resonated at $\delta = 8.75$ and 8.70 ppm. The aromatic protons of **3** resonate in the $\delta = 6.86$ –7.69 region. The signal related to methylene protons of the fluorene group was observed at $\delta = 3.74$ ppm as a singlet. Compound **3** has 17 signals in the ^{13}C NMR spectrum. The carbonyl carbon was observed at $\delta = 152.99$ ppm. The chemical shifts for aromatic carbons were at $\delta = 144.31, 142.95, 141.56, 139.19, 137.37, 135.54, 127.06, 126.15, 125.31, 121.35, 120.54, 119.85, 119.55, 117.61,$ and 115.49 ppm. The signal of fluorene –CH₂– was observed at $\delta = 36.87$ ppm. The signals related to NH protons of **4** were observed at $\delta = 8.59$ and 8.45 ppm in the 1H NMR spectrum. Aromatic protons resonate in the region of $\delta = 6.70$ –7.33 ppm. The signal of methylene protons in the structure of **4** was observed at $\delta = 5.92$ ppm as a singlet. According to the ^{13}C NMR spectrum of **4**, the compound has 10 signals. The signal for carbonyl carbon was observed at $\delta = 153.06$ ppm. The signals related to aromatic carbons were observed at $\delta = 147.59, 142.47, 137.34, 134.39, 122.23, 110.72, 111.54, 108.44,$ and 101.48 ppm. The methylene carbon resonated at $\delta = 101.22$ ppm. The signal related to $M^+ + H^+$ for the compound in the MS spectrum was observed at 1763.2150. All spectral results are confirmed for the purposed structure.

The aromatic and aliphatic NH protons of urea groups of compound **5** were observed at $\delta = 8.58$ ppm as a singlet signal and $\delta = 6.55$ ppm as a triplet signal, respectively. The signals related to aromatic protons were observed at $\delta = 7.57$ ppm as a multiplet; $\delta = 7.32, 6.78,$ and 6.27 ppm as doublets; and $\delta = 6.39$ ppm as a multiplet. The chemical shift for aliphatic –CH₂– protons was observed at $\delta = 4.30$ ppm as a doublet signal. Compound **5** has 10 signals related to carbonyl carbon, and 8 aromatic and 1 aliphatic carbons in the ^{13}C NMR spectrum. The signal related to the protonated molecular ion of **5** was observed at 1523.9500 in the MS spectrum. All the spectral results were consistent with the predicted structure of **5**. NH protons of the nitro substituted compound **6** were observed at $\delta = 9.32$ and 8.87 ppm. The signals of aromatic protons in **6** were observed at $\delta = 7.97, 7.57, 7.38,$ and 6.83 ppm as doublet signals. The compound has 10 signals in ^{13}C NMR



Scheme 1. Synthetic route for compounds.

spectrum. The chemical shift related to carbonyl carbon was observed at $\delta = 152.24$ ppm. The molecular ion peak of **6** was observed at 1768.3280 in the MS spectrum. All the spectral results were consistent with the predicted structure of **6**. NH protons of thiourea derivative **7** were observed at $\delta = 10.39$ and 10.23 ppm. The aromatic protons of the compound resonate at $\delta = 8.16$, 7.85, 7.54, and 6.99 ppm as doublet signals. The signal related to the C=S group in **7** was observed at $\delta = 186.55$ ppm in the ^{13}C NMR spectrum. The chemical shifts of aromatic carbons were observed at $\delta = 153.85$, 146.14, 143.20, 137.55, 128.51, 125.30, 123.12, and 120.68 ppm. The signal related to M^+ at 1865.3250 in the MS spectra confirmed the predicted structure. A single peak related to three identical phosphorus atoms was observed in the ^{31}P NMR spectra of all compounds. The identical phosphorus atoms of compound **3-7** resonated at $\delta = 9.65$, 9.34, 9.42, 9.69, and 9.67 ppm.

2.2. The sensor applications of compounds 3–7

The sensor features of **3–7** were investigated with a UV-Vis spectrophotometer in DMSO and DMSO:H₂O solvent mixture in the presence of anions such as AcO⁻, F⁻, NO₂⁻, HSO₄⁻, SCN⁻, CN⁻, Br⁻, Cl⁻, I⁻, H₂PO₄⁻, and NO₃⁻. It was determined that receptors **3–5** did not exhibit naked-eye and spectrophotometric sensor properties for these anions (data not shown). However, receptors **6** and **7** exhibited selective sensor behavior for F⁻ and CN⁻ anions (Figures 1a and 1b).

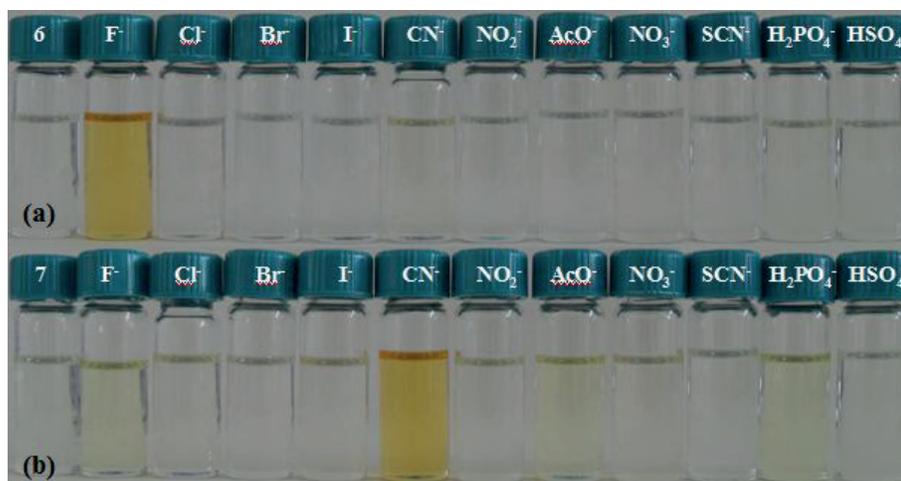


Figure 1. Solution color of **6** and **7** exposed to various types of anions under sunlight. (a) **6** (50 μM) and anion (500 μM) in DMSO, (b) **7** (25 μM) and anion (250 μM) in DMSO:H₂O (9:1).

Urea derivative compounds contain a relatively acidic NH group as center that interacts with the anions. These compounds interact with the F⁻ anion, which is a relatively strong base. This interaction may result in deprotonation of acidic amid NH groups.²⁵ However, a negligible change as a result of interaction of urea compounds with CN⁻ anion has been reported in the literature.^{21,22}

Urea derivative **6** showed an absorption maximum at $\lambda = 390$ nm in DMSO. After the addition of AcO⁻, F⁻, NO₂⁻, HSO₄⁻, SCN⁻, CN⁻, Br⁻, Cl⁻, I⁻, H₂PO₄⁻, and NO₃⁻ anions, a remarkable increase in absorption was observed at $\lambda = 478$ nm only in the presence of fluoride anions (Figures 2a and 2b). Similarly to reports in the literature, negligible change was observed in the presence of CN⁻ anion in the UV-Vis spectrum and in the color of solution of **6**. No changes were observed in the presence of Br⁻, Cl⁻, I⁻, NO₂⁻, HSO₄⁻, AcO⁻, H₂PO₄⁻, NO₃⁻, and SCN⁻ anions. It can be said that compound **6** does not enter into any remarkable interaction with these anions.^{21,22} Additionally, it was observed that the absorption at $\lambda = 478$ nm increased with increasing concentration of fluoride anions (Figures 2c and 2d). A new absorption maximum at $\lambda = 478$ nm indicated intramolecular charge transfer (ICT) between anion–urea and the electron deficient p-nitrophenyl groups.^{25,36}

Stoichiometry for the host–guest complex between compound **6** and F⁻ anions was determined as 1:6 from the Job's plot. The total concentration was kept constant at 500 μM (Figure 3a). As shown in Figure 3b, the apparent stability constant K_{as} was calculated as 1.77×10^8 from UV-Vis titration data ($y = 2.5068x + 8.2469$, $R^2 = 0.9816$) using the Benesi–Hildebrand equation. The K_{as} value of **6** is greater than the values obtained for a large number of similar mono-, di-, and tripodal compounds. According to the literature, higher

binding values for host–guest interactions are obtained because the interaction increases with the number of centers interacting with the anions.^{26,28–30}

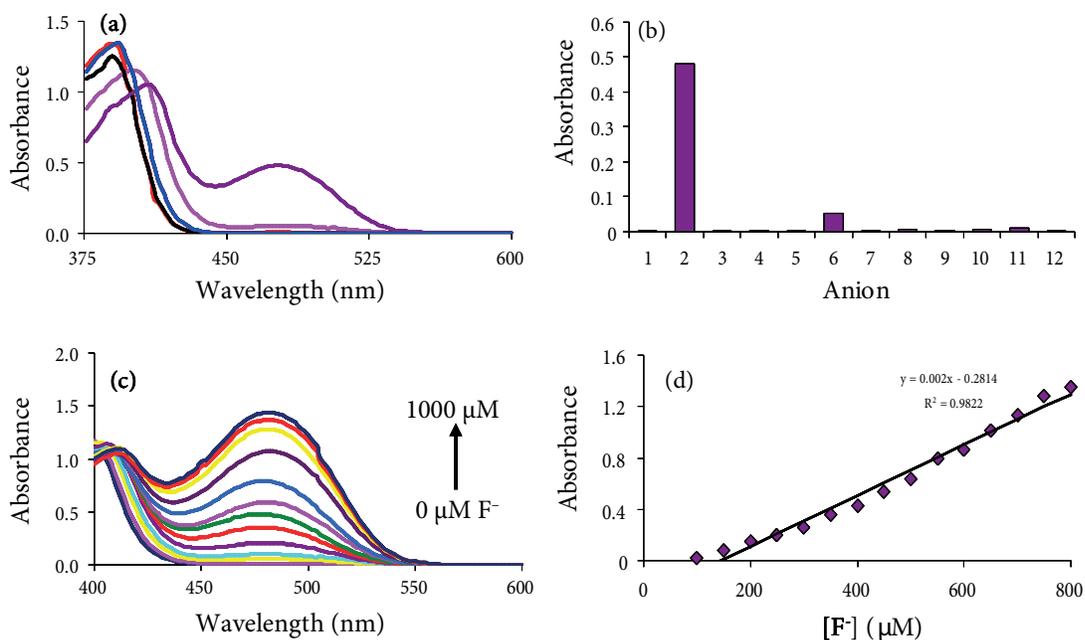


Figure 2. (a) Absorption spectra, (b) Absorption intensity of **6** (50 μM) in the presence of different anions (500 μM) in DMSO, (c) Absorption spectra of **6** (50 μM) upon addition of different amounts of F⁻ in DMSO, (d) Plot of absorbance for **6** (50 μM) and F⁻ (100–800 μM): 1: **6** (Blank), 2: F⁻, 3: Cl⁻, 4: Br⁻, 5: I⁻, 6: CN⁻, 7: NO₂⁻, 8: AcO⁻, 9: NO₃⁻, 10: SCN⁻, 11: H₂PO₄⁻, 12: HSO₄⁻.

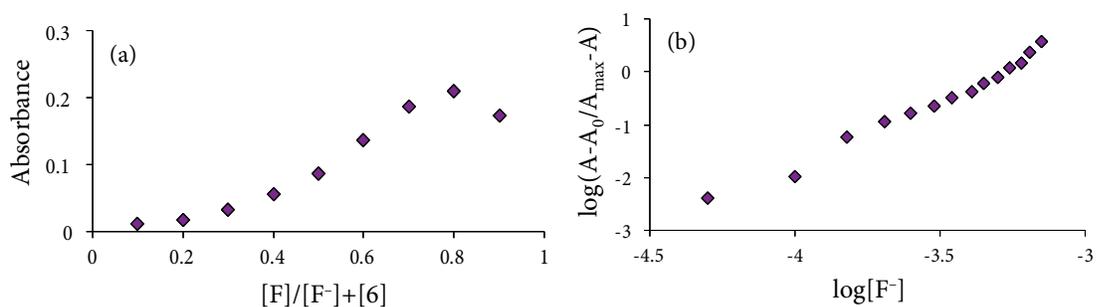


Figure 3. (a) Job's plot of absorbance for the determination of binding stoichiometry of **6**–F⁻ complex, (b) Determination of the apparent stability constant (K_{as}) for **6**–F⁻.

CN⁻ anion is a toxic species for living organisms. Therefore, the determination of this anion in aqueous media is very important. NH groups of thiourea derivatives have higher acidities than urea NH groups because sulfur atoms form weaker intermolecular hydrogen bonds than oxygen atoms.²⁵ This feature makes the thiourea compounds active against CN⁻ anions. For this reason, thiourea compounds with naked-eye sensor features for both F⁻ and CN⁻ anions have been reported in the literature.^{21,22,36,37} Thiourea derivative **7** showed a remarkable response only to the CN⁻ anion in DMSO:H₂O (9:1). The color of the solution of **7** turned from colorless to yellow in the presence of CN⁻ anions (Figure 1b). As shown in UV-Vis spectra of compound **7**,

a new absorption maximum related to the intramolecular charge transfer (ICT) formed at $\lambda = 472$ nm only in the presence of CN^- anions. Negligible changes were observed in the UV-Vis spectra and solution color of **7** in the presence of F^- , AcO^- , and H_2PO_4^- in DMSO:H₂O (9:1) solvent mixture. The reason for the weak signal observation for the F^- anion, which is a strong base, is the decrease in hydrogen binding ability of the F^- anion with thiourea NH protons in the presence of water.²⁷ Absorption intensity at $\lambda = 472$ nm increased during the titration with CN^- anions (Figures 4a–4d).

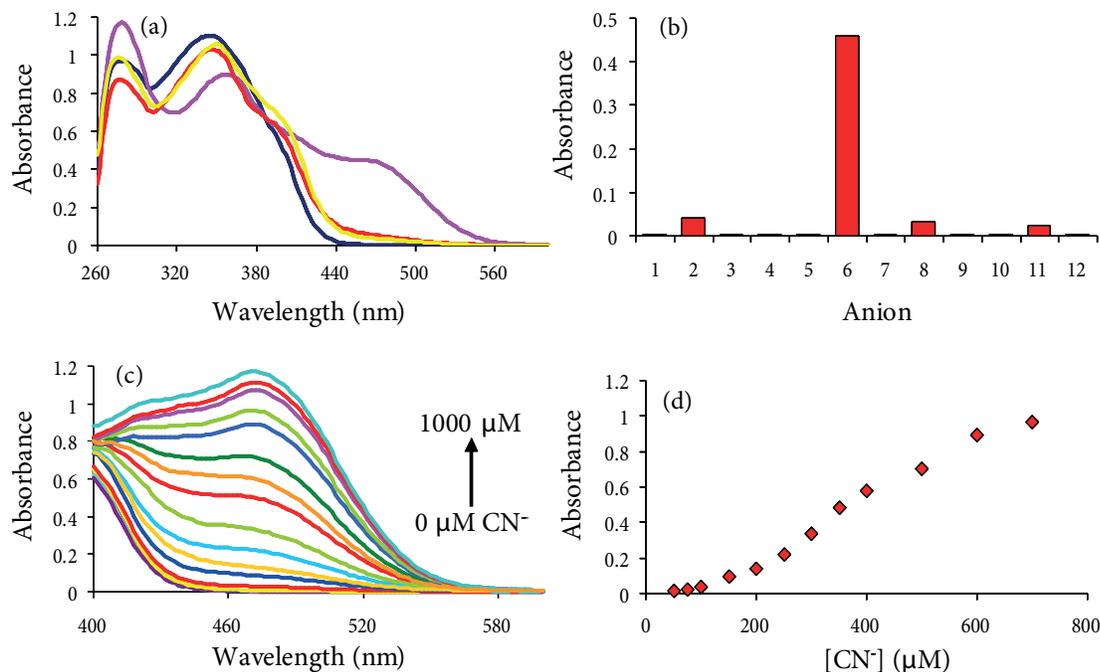


Figure 4. (a) Absorption spectra, (b) Absorption intensity of **7** (25 μM) in the presence of different anions (250 μM) in DMSO:H₂O (9:1), (c) Absorption spectra of **7** (25 μM) upon addition of different amounts of CN^- in DMSO:H₂O, (d) Plot of absorbance for **7** (25 μM) and CN^- (50–700 μM): 1: **7** (Blank), 2: F^- , 3: Cl^- , 4: Br^- , 5: I^- , 6: CN^- , 7: NO_2^- , 8: AcO^- , 9: NO_3^- , 10: SCN^- , 11: H_2PO_4^- , 12: HSO_4^- .

Stoichiometry for the **7**– CN^- complex ion was determined by the Job's plot. The absorption reaches a maximum at approximately 0.85 molar fraction of CN^- , and it was determined that compound **7** formed a 1:6 complex with a CN^- anion (Figure 5a). The binding constant for **7**– CN^- complex was calculated as $K_{as} = 2.25 \times 10^8$ using the Benesi–Hildebrand equation ($y = 2.444x + 8.353$, $R^2 = 0.9533$) (Figure 5b).

The interaction mechanisms of compound **6** and **7** with F^- and CN^- anions were investigated using ^1H NMR titration in DMSO- d_6 . NH protons observed at $\delta = 9.32$ and 8.87 of compound **6** disappeared in the presence of tetrabutylammonium fluoride (Figure 6a). A similar observation of deprotonation of urea protons or strong hydrogen binding with F^- anions has been reported in the literature.^{21,22,26–29}

Similar effects were observed for compound **7**. As shown in Figure 6b, addition of tetrabutylammonium cyanide to the solution of compound **7** resulted in disappearance of signals at $\delta = 10.39$ and 10.23 ppm of NH protons due to the deprotonation process. As a result of all these spectral findings, a binding model for **6** (or **7**)–anion was proposed with the structure in Scheme 2 in accordance with the literature.^{25,27}

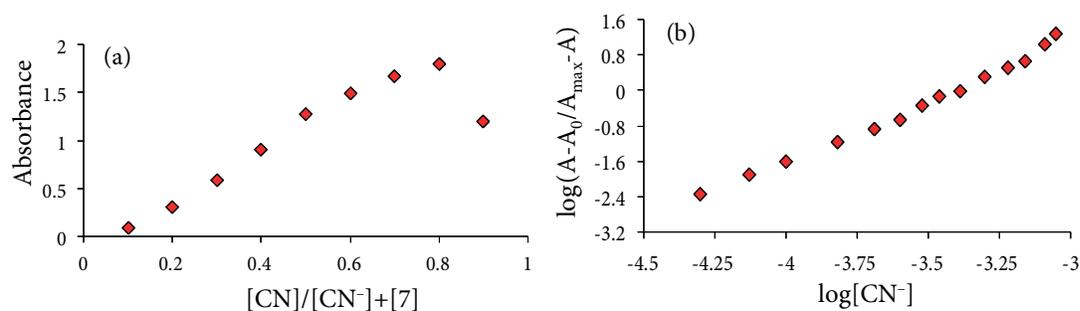


Figure 5. (a) Job's plot of absorbance for the determination of binding stoichiometry of **7**- CN^- complex, (b) determination of the apparent stability constant (K_{as}) for **7**- CN^- .

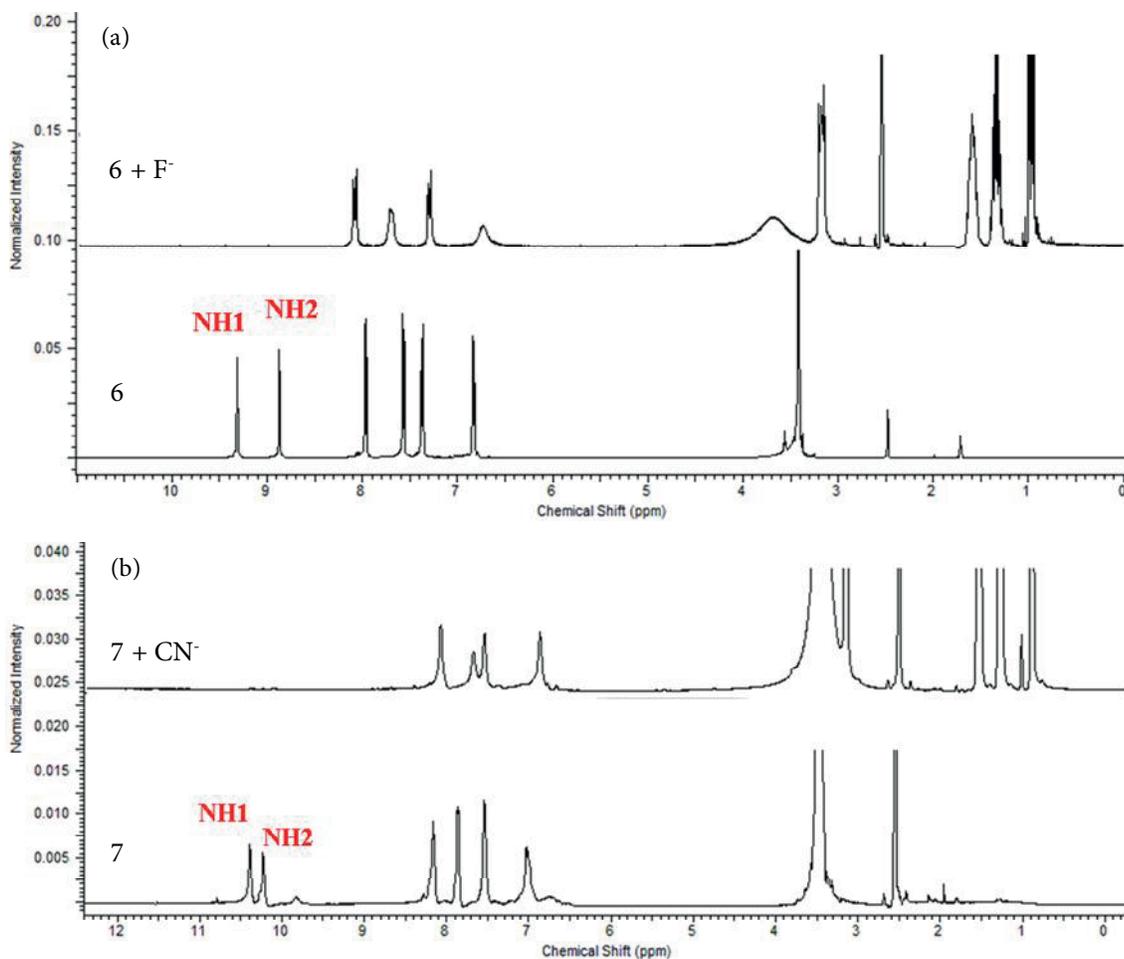
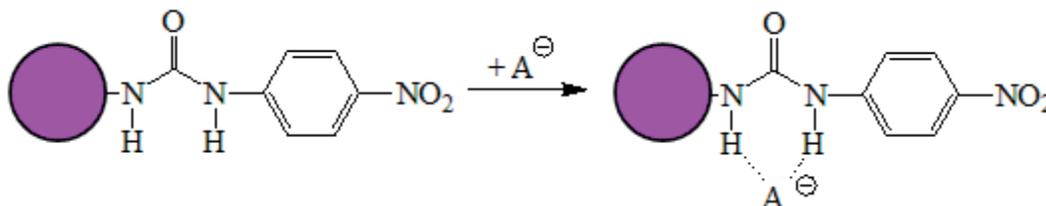


Figure 6. 1H NMR spectra of (a) **6** in the presence of 6 equivalents of TBAF, (b) **7** in the presence of 6 equivalents of TBACN in $DMSO-d_6$ at 25 °C.

Consequently, we synthesized novel fully substituted cyclotriphosphazene compounds (**3–7**) with urea and thiourea functional groups. Thus, a new type of class of compounds was added to the literature. Moreover, we used compounds **6** and **7** as receptors for detection of anions. Compound **6** showed good selectivity for F^- anions in the presence of other anions in DMSO as solvent. Compound **7** showed good selectivity for

CN⁻ anions in the presence of other anions in DMSO:H₂O solvent mixture. Deprotonation or strong hydrogen bonding of compounds in the presence of anions in DMSO was confirmed by ¹H NMR titration.



Scheme 2. The proposed sensing mechanism for host-guest complex.

3. Experimental

3.1. Materials and equipment

Hexachlorocyclotriphosphazene was purified by recrystallization from hexane. THF was dried by sodium/benzophenone system under argon atmosphere. All reagents for synthesis were purchased from a chemical company (Sigma-Aldrich) and were used as received without purification. All reactions were monitored by using TLC (Kieselgel 60F254 silica gel pre-coated plates). In the sensor applications tetrabutylammonium salts of AcO⁻, F⁻, NO₂⁻, HSO₄⁻, SCN⁻, CN⁻, Br⁻, Cl⁻, I⁻, H₂PO₄⁻, and NO₃⁻ were used as anion sources. FT-IR spectra of compounds were recorded using a PerkinElmer FT-IR instrument with ATR apparatus with 4 cm⁻¹ resolution between 4000 and 650 cm⁻¹. All NMR spectra were recorded using Varian Unity INOVA (500 MHz) instrument. Tetramethylsilane as interval reference was used in ¹H and ¹³C NMR measurements and 85% H₃PO₄ as interval reference was used in ³¹P NMR measurements. All NMR measurements were carried out using DMSO-d₆ as solvent. Mass spectra of compounds were recorded on Bruker Microflex LT MALDI-TOF MS spectrometers. All UV-Vis absorption spectra were recorded using a PG Instruments T80+ spectrophotometer in the sensor studies. The melting points of all compounds were measured on an Electrothermal IA 9100 model melting point apparatus using a capillary tube.

3.2. Synthesis of hexakis(4-acetamidophenoxy)cyclotriphosphazene (1)

Compound **1** was synthesized in a similar way to the literature procedure.^{31,32} A solution of hexachlorocyclotriphosphazene (3.48 g, 10.00 mmol) in dry acetone (50 mL) was added dropwise to a solution of 4-acetamidophenol (10.88 g, 72.00 mmol) and anhydrous K₂CO₃ (13.94 g, 0.10 mol) in dry acetone (250 mL). The reaction mixture was refluxed for 72 h under argon atmosphere. At the end of this time, salts were filtered and the solvent was removed by rotary evaporator under reduced pressure. The crude solid was washed with deionized water (200 mL) to remove salts. Afterwards, the solid product was washed with ethanol (2 × 50 mL) and hexane (2 × 25 mL), consecutively. The obtained white solid was dried. Yield 8.57 g (83%). mp 254–255 °C. FTIR-ATR (ν_{\max} , cm⁻¹): 3284 (N–H), 1658 (C=O), 1501 (C=C), 1162 (P=N), 953 (P–O–C). ¹H NMR (500 MHz, DMSO-d₆, 25 °C, ppm): δ 9.94 (s, 6H, NH), 7.42 (d, 12H, *J* = 8.1 Hz, ArH), 6.79 (d, 12H, *J* = 8.1 Hz, ArH), 2.02 (s, 18H, CH₃). ¹³C NMR (125 MHz, DMSO-d₆, 25 °C, ppm): δ 168.69 (C=O), 145.53, 136.87, 121.01, 120.58, 24.33. ³¹P NMR (202 MHz, DMSO-d₆, 25 °C, ppm): δ 9.19. MALDI MS *m/z*: Calcd for C₄₈H₄₈N₉O₁₂P₃ + H⁺ 1036.1761 Found: 1036.2020.

3.3. Synthesis of hexakis(4-aminophenoxy)cyclotriphosphazene (2)

Compound **2** was synthesized according to the literature procedure.^{31,32} To a solution of compound **1** (8.00 g, 7.22 mmol) in methanol (300 mL) was added a solution of NaOH (37.00 g, 0.93 mol) in water (50 mL). The reaction mixture was refluxed for 24 h under argon atmosphere. During this time, a white solid formed in the reaction mixture. At the end of the reaction time, the solid formed was separated by filtration. The pale yellow solid was washed with water until neutral and was dried at room temperature. Yield 3.98 g (66.82%). mp 188–189 °C. FTIR-ATR (ν_{\max} , cm^{-1}): 3340, 3204 (N–H), 1621, 1503 (C=C), 1158 (P=N), 961 (P–O–C).

3.4. Synthesis of hexakis(1-oxyphenyl-3-fluorene urea)cyclotriphosphazene (3)

A solution of compound **2** (0.39 g, 0.50 mmol) in dry THF (50 mL) was added dropwise to a solution of 9H-fluorene-2-yl-isocyanate (0.73 g, 3.25 mmol) in dry THF (50 mL). The reaction mixture was stirred at ambient temperature for 24 h under argon atmosphere. At the end of this time, the white solid matter formed was filtered, washed with THF (25 mL), and dried. Yield 0.95 g (94%). mp 273–274 °C. FTIR-ATR (ν_{\max} , cm^{-1}): 3289 (N–H), 3043 (Ar–H), 1648 (C=O), 1554, 1501 (Aromatic C=C), 1162 (P=N), 963 (P–O–C). ¹H NMR (500 MHz, DMSO- d_6 , 25 °C, ppm): δ 8.75 (s, 6H, ArNH), 8.70 (s, 6H, ArNH), 7.69 (s, 6H), 7.63 (t, 12H, $J = 8.8$ Hz, ArH), 7.41 (m, 24H), 7.26 (t, 6H, $J = 7.4$ Hz, ArH), 7.17 (t, 6H, $J = 7.5$ Hz, ArH), 6.86 (d, 12H, $J = 8.8$ Hz, ArH) 3.74 (s, 12H, –CH₂– Fluorene). ¹³C NMR (125 MHz, DMSO- d_6 , 25 °C, ppm): δ 152.99 (C=O), 144.31, 142.95, 141.56, 139.19, 137.37, 135.54, 127.06, 126.15, 125.31, 121.35, 120.54, 119.85, 119.55, 117.61, 115.49, 36.87. ³¹P NMR (202 MHz, DMSO- d_6 , 25 °C, ppm): δ 9.65. MALDI MS m/z : Calcd for C₁₂₀H₉₀N₁₅O₁₂P₃ – (6H⁺) + (Na⁺), 2044.1170. Found: 2044.1130. Anal. Calcd. for C₁₂₀H₉₀N₁₅O₁₂P₃: C, 71.10; H, 4.48; N, 10.37%. Found: C, 71.04; H, 4.46; N, 10.32%.

3.5. Synthesis of hexakis(1-oxyphenyl-3-((3,4-methylenedioxy)phenyl) urea)cyclotriphosphazene (4)

To a solution of 3,4-(methylenedioxy)phenyl isocyanate (0.68 g, 4.15 mmol) in dry THF (50 mL) was added dropwise a solution of compound **2** (0.50 g, 0.64 mmol). The reaction mixture was stirred at ambient temperature for 24 h under argon atmosphere. Then the white solid formed in the reaction mixture was filtered and washed with THF (25 mL). Compound **4** was obtained as a white solid. Yield 1.05 g (93%). mp 264–265 °C. FTIR-ATR (ν_{\max} , cm^{-1}): 3315 (N–H), 1658 (C=O), 1558 (Aromatic C=C), 1177 (P=N), 948 (P–O–C). ¹H NMR (500 MHz, DMSO- d_6 , 25 °C, ppm): δ 8.59 (s, 6H, ArNH), 8.45 (s, 6H, ArNH), 7.33 (d, 12H, $J = 8.8$, ArH), 7.15 (s, 6H, ArH), 6.81(d, 12H, $J = 8.8$ Hz, ArH), 6.76–6.70 (m, 12H, ArH), 5.92 (s, 12H, CH₂). ¹³C NMR (125 MHz, DMSO- d_6 , 25 °C, ppm): δ 153.06 (C=O), 147.59, 142.47, 137.34, 134.39, 122.23, 110.72, 111.54, 108.44, 101.48, 101.22 (Ar–C). ³¹P NMR (202 MHz, DMSO- d_6 , 25 °C, ppm): δ 9.34. MALDI MS m/z : Calcd for C₈₄H₆₆N₁₅O₂₄P₃ + H⁺, 1763.4310. Found: 1763.2150. Anal. Calcd. for C₈₄H₆₆N₁₅O₂₄P₃: C, 57.24; H, 3.77; N, 11.92%. Found: C, 57.19; H, 3.76; N, 11.89%.

3.6. Synthesis of hexakis(1-oxyphenyl-3-furfuryl urea)cyclotriphosphazene (5)

A solution of compound **2** (0.39 g, 0.50 mmol) in dry THF (40 mL) was added dropwise to a solution of furfuryl isocyanate (0.40 g, 3.25 mmol) in dry THF (10 mL). The reaction mixture was stirred at ambient temperature for 24 h under argon atmosphere, then filtered, and a white solid crude product was obtained. The crude

product was washed with THF (25 mL) and dried at ambient temperature. Yield 0.64 g (92%). mp 230–231 °C. FTIR-ATR (ν_{\max} , cm^{-1}): 3297 (N–H), 1636 (C=O), 1563, 1503 (Aromatic C=C), 1177–1159 (P=N), 952 (P–O–C). ^1H NMR (500 MHz, DMSO- d_6 , 25 °C, ppm): δ 8.58 (s, 6H, ArNH), 7.57 (m, 6H), 7.32 (d, 12H, J = 9.1 Hz, ArH), 6.78 (d, 12H, J = 8.9 Hz, ArH), 6.55 (t, 6H, J = 5.8 Hz, NH-Aliphatic), 6.39 (m, 6H), 6.27 (d, 6H, J = 3.0 Hz, ArH), 4.30 (d, 12H, J = 5.8 Hz, $-\text{CH}_2$). ^{13}C NMR (125 MHz, DMSO- d_6 , 25 °C, ppm): δ 155.44 (C=O), 153.59, 144.63, 142.52, 137.86, 121.17, 119.24, 110.89, 106.93 (Ar–C), 36.64 ($-\text{CH}_2$). ^{31}P NMR (202 MHz, DMSO- d_6 , 25 °C, ppm): δ 9.42. MALDI MS m/z: Calcd for $\text{C}_{72}\text{H}_{66}\text{N}_{15}\text{O}_{18}\text{P}_3 + (\text{H}^+)$, 1523.3100. Found: 1523.950. Anal. Calcd. for $\text{C}_{72}\text{H}_{66}\text{N}_{15}\text{O}_{18}\text{P}_3$: C, 56.81; H, 4.37; N, 13.80%. Found: C, 56.77; H, 4.35; N, 13.76%.

3.7. Synthesis of hexakis(1-oxyphenyl-3-(4-nitrophenyl) urea)cyclotriphosphazene (6)

A solution of compound **2** (0.50 g, 0.64 mmol) in dry THF (50 mL) was added dropwise to a solution of 4-nitrophenyl isocyanate (0.69 g, 4.15 mmol) in dry THF (50 mL). The reaction mixture was stirred at ambient temperature for 24 h under argon atmosphere and then the yellow solid formed was separated by filtration. The yellow crude product was washed with THF (25 mL) and dried at ambient temperature. Yield 1.07 g (95%). mp 290–291 °C. FTIR-ATR (ν_{\max} , cm^{-1}): 3352 (N–H), 3080 (Ar–H), 1679 (C=O), 1558 (Aromatic C=C), 1491 and 1329 ($-\text{NO}_2$), 1162 (P=N), 948 (P–O–C). ^1H NMR (500 MHz, DMSO- d_6 , 25 °C, ppm): δ 9.32 (s, 6H, ArNH), 8.87 (s, 6H, ArNH), 7.97 (d, 12H, J = 9.3 Hz, ArH), 7.57 (d, 12H, J = 9.3 Hz, ArH), 7.38 (d, 12H, J = 8.5 Hz, ArH), 6.83 (d, 12H, J = 8.5 Hz, ArH). ^{13}C NMR (125 MHz, DMSO- d_6 , 25 °C, ppm): δ 152.24 (C=O), 146.70, 145.30, 141.20, 136.64, 125.30, 121.32, 120.23, 117.68. ^{31}P NMR (202 MHz, DMSO- d_6 , 25 °C, ppm): δ 9.69. MALDI MS m/z: Calcd for $\text{C}_{78}\text{H}_{60}\text{N}_{21}\text{O}_{24}\text{P}_3$, 1768.3610. Found: 1768.3280. Anal. Calcd. for $\text{C}_{78}\text{H}_{60}\text{N}_{21}\text{O}_{24}\text{P}_3$: C, 52.98; H, 3.42; N, 16.63%. Found C, 52.95; H, 3.41; N, 16.59%.

3.8. Synthesis of hexakis(1-oxyphenyl-3-(4-nitrophenyl) thiourea) cyclotriphosphazene (7)

To a solution of 4-nitrophenyl isothiocyanate (0.59 g, 3.25 mmol) in dry THF (10 mL) was added dropwise a solution of compound **2** (0.39 g, 0.50 mmol) in dry THF (40 mL). The reaction mixture was stirred at ambient temperature for 24 h under argon atmosphere. At the end of this time, to the yellow reaction mixture was added CHCl_3 (50 mL). The bright yellow solid formed was filtered and washed with CHCl_3 (25 mL). The yellow product was obtained by drying the crude product. Yield 0.78 g (84%). mp 198–199 °C. FTIR-ATR (ν_{\max} , cm^{-1}): 3316 (N–H), 1595 and 1499 (Aromatic C=C), 1255 (N–C=S), 1159 (P=N), 952 (P–O–C). ^1H NMR (500 MHz, DMSO- d_6 , 25 °C, ppm): δ 10.39 (s, 6H, $-\text{NH}$), 10.23 (s, 6H, $-\text{NH}$), 8.16 (d, 12H, J = 8.7 Hz, ArH), 7.85 (d, 12H, J = 6.4 Hz, ArH), 7.54 (m, 12H), 6.99 (m, 2H). ^{13}C NMR (125 MHz, DMSO- d_6 , 25 °C, ppm): δ 186.55 (C=S), 153.85, 146.14, 145.30, 143.20, 137.55, 128.51, 125.30, 123.12, 120.68. ^{31}P NMR (202 MHz, DMSO- d_6 , 25 °C): δ 9.67. MALDI MS m/z: Calcd for $\text{C}_{78}\text{H}_{60}\text{N}_{21}\text{O}_{18}\text{P}_3\text{S}_6 + (\text{H}^+)$, 1865.7500. Found: 1865.3250. Anal. Calcd. for $\text{C}_{78}\text{H}_{60}\text{N}_{21}\text{O}_{18}\text{P}_3\text{S}_6$: C, 50.24; H, 3.24; N, 15.77%. Found C, 50.19; H, 3.22; N, 15.73%.

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