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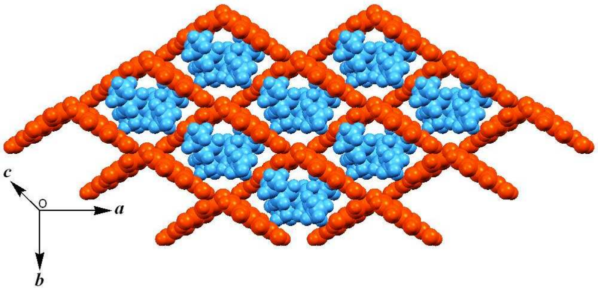

Encapsulation of tetrabutylammonium cations

Different assemblies formed by interactions of tetrabutylammonium fluoride with hydroxy-aromatic oximes show characteristic optical properties

A. Tarai and J. B. Baruah

Study on fluoride detection and assembling of hydroxyaromatic aldoximes caused by tetrabutylammonium fluoride

Arup Tarai, Jubaraj B. Baruah*
Department of Chemistry, Indian Institute of Technology Guwahati, Guwahati -781 039,
Assam, India. Fax: +91-361-2690762; Ph. +91-361-2582311;
email: juba@iitg.ernet.in http://www.iitg.ernet.in/juba

Abstract:

Tetrabutylammonium fluoride (TBAF) forms cocrystal H_2NAP.TBAF with 2-hydroxynaphthaldoxime (H_2NAP) or cocrystal 2(H_3OHPA).TBAF with 2,3-dihydroxyphenylaldoxime (H_3OHPA). Whereas similar reaction of 2,4-dihydroxyphenylaldoxime (H_3PHPA) forms tetrabutylammonium (TBA) salt TBA($H_{2.5}$PHPA)$_2$. Formation of these cocrystals or salt accompanies color change which enables detection of fluoride ions. Cocrystal H_2NAP.TBAF has layered structure formed by hydrogen bonds of fluoride ions with parent oxime molecules; tetrabutylammonium

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cations are held in between layers formed by anionic assemblies. On the other hand, cocrystal 2(H_3OHPA).TBAF has a grid-like architecture constructed by hydrogen bonds between parent oxime molecules and fluoride ions. TBA cations are encapsulated within the grids. It is shown that salt TBA($H_{2.5}$PHPA)$_2$ forms anionic assemblies to encapsulate tetrabutylammonium cation which is devoid of fluoride ion. By interactions of tetrabutylammonium fluoride ions with H_3PHPA molecules, an anionic assembly is formed by sharing of protons, which possesses grid-like structure. Formation of such assembly causes color change which enables one to detect fluoride ion by visual means.

Keywords:

Hydroxyaromatic aldoxime; Self-assembly; Fluoride ions; Deprotonation.

Introduction:

Oximes constitute an important class of organic compounds which are used to protect carbonyl groups[1] and also used as ligands.[2] From crystal engineering point of view, oximes have attracted attention; they form various cocrystals whose structures are guided by substituent atoms and other functional groups.[3] Different catemers are formed by self-assemblies of heterocyclic aromatic oximes.[3a] Possibility to prepare oximes through green methodologies have enhanced future course of chemistry with oximes.[4] Hierarchical effect of weak interactions help to generate specific assemblies of oximes.[5] Despite of having a good amount literature data on structural motifs of oximes, there are limited concerted affords to unearth their utilities.[6] On the other hand, quaternary

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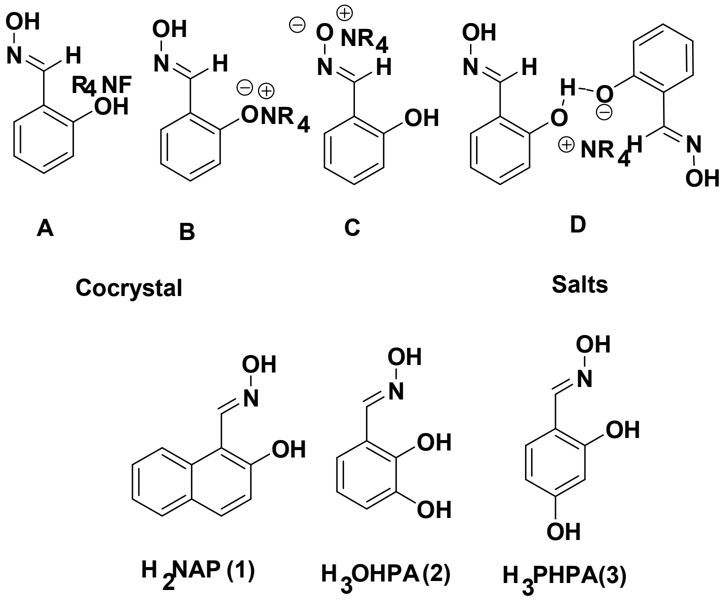

Figure 1: Structures of oximes **1-3.** A-D are some possible cocrystals and salts of quaternary ammonium fluoride with 2-hydroxyphenylaldoxime.

ammonium fluorides form adducts with oximes causing visual color change.[7] It is also a well known fact that fluoride ions deprotonate hydroxy groups to cause colour change of chromophoric substances.[8] Thus, combination of these two facts would help to design sensor for fluoride. Varieties in packing patterns of self-assemblies of hydroxy-aromatic oximes would depend on the components. As an illustration 2-hydroxybenzaldoxime on interaction with a quaternary ammonium fluoride would lead to different compositions of co-crystals or salt such as A-D shown in figure 1. Due to ability of HF_2^- or F^- ions to stabilize different hydrogen bonded assemblies[9] many possibilities in packing pattern can be anticipated. Thus, understanding of assemblies of cocrystals or deprotonated supramolecular assemblies of hydroxyaromatic oximes with/by fluoride ions may emerge as a lead to prepare assemblies with potential applications. With such anticipations structures and optical properties associated with different supramolecular assemblies generated by oximes **1-3** on interaction with tetrabutylammonium fluoride are studied.

Results and discussion

*Fluoride assisted assemblies of oximes **1-3**:*

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Tetrabutylammonium fluoride (TBAF) and 2-hydroxynaphthaldoxime (H_2NAP, **1**), forms cocrystal H_2NAP.TBAF (**4**), on the other hand 2,3-dihydroxyphenylaldoxime (H_3OHPA**,** **2**) forms cocrystal 2(H_3OHPA).TBAF (**5**) with TBAF. 2,4-dihydroxyphenylaldoxime (H_3PHPA, **3**) reacts with tetrabutylammonium fluoride to cause deprotonation of a phenolic hydroxy group to form assembly of a tetrabutylammonium (TBA) salt TBA($H_{2.5}PHPA$)$_2$ (**6**). Constituents of the cocrystals (**4** and **5**) and salt (**6**) are shown in figure 2.

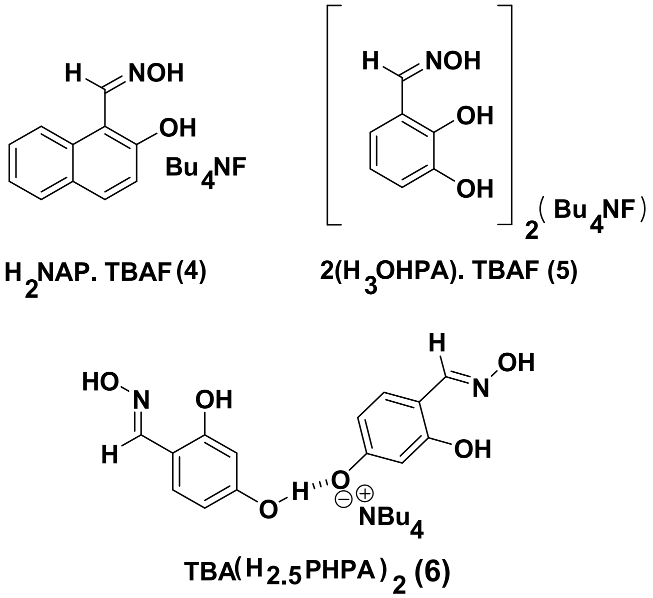

Figure 2: Cocrystals and salt from aldoximes

Structures of **4**, **5** and **6** are determined by single crystal X-ray diffraction and they are also characterized by spectroscopic techniques. Cocrystal **4** is formed by **1** and TBAF in 1:1 molar ratio. Crystal packing of **4** has oxime molecules forming chain-like structures. Such chain-like structures extending along *c*-crystallographic axis are formed by bridging hydrogen bonds between oxime molecules and fluoride ions. Each fluoride ion is connected to two oxime molecules from two opposite directions. One side of fluoride ion is connected through O-H···F interaction involving OH group of oxime functionality. Other side has an O-H···F interaction with phenolic hydroxy group and a C-H···F interaction of a hydrogen atom at *ortho*-position to the hydroxy group to form a chelate-

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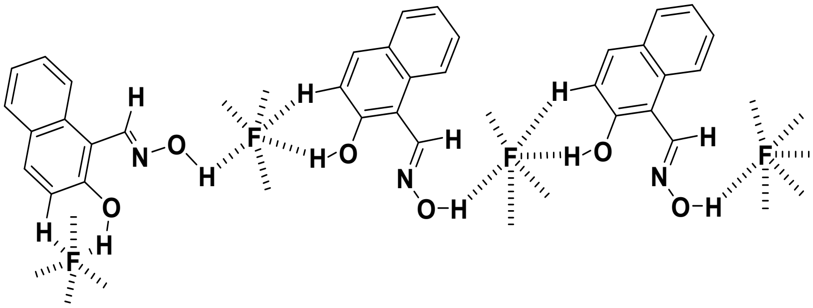
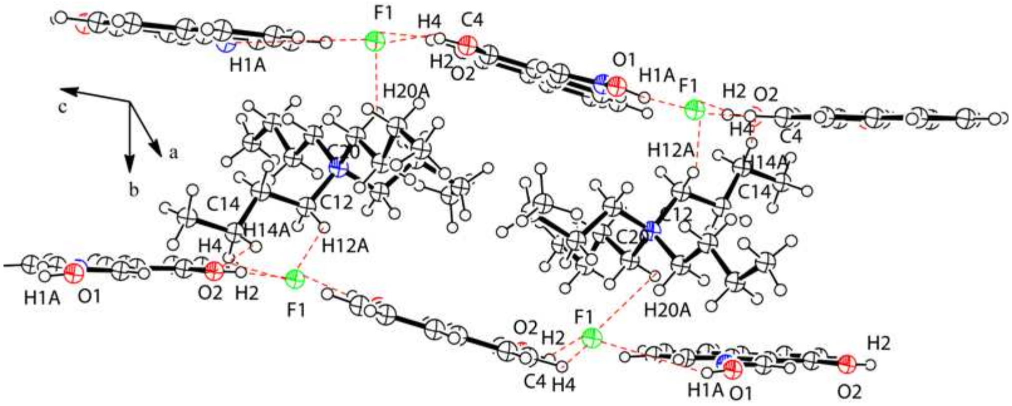
like motif. Such interactions inhibit the *ortho*-hydroxy group to form conventional intramolecular hydrogen bond. Carbon-fluorine bonds have role in oximes to form different cocrystals,[3] in the present case we observed that priority to form O-H···F interactions along with a weak C-H···F interaction to form cyclic motif, is more favorable than formation of an intramolecular cyclic hydrogen bonded motif. A schematic drawing showing these interactions in **4** are shown in figure 3a. Although oximes can self-assemble to form various catemers, strong participation of fluoride ions in hydrogen bond do not allow formation of any of the conventional catemers.[6a] In crystal lattice of cocrystal **4**, tetrabutylammonium ions are held between two such chains, which are stabilized by C-H···O and C-H···F interactions. Some of the important hydrogen bond parameters are listed in table 1. Fluoride ion of cocrystal **4** (figure 3b) also interacts with two tetrabutylammonium cations through C-H···F interactions. Thus, fluoride ions act as a bridging ions for two different types of hydroxy groups at two ends of oxime molecules.



(a)



(b)

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Figure 3: (a) Representation of chain formed through fluoride ions interacting with O-H and C-H bond at one end and through OH of oxime at other end. (b) Packing of cocrystal **4** to show chain-like arrangement of oxime molecules in structure holding terabutylamminium cations in between layers.

Table 1: Hydrogen bond parameters of **4, 5** and **6**

Compound No.	D-H···A	$d_{D\text{-}H}$(Å)	$d_{H\cdots A}$ (Å)	$d_{D\cdots A}$(Å)	∠ D−H···A (°)
4	O(1)-H(1A)···F(1) [-x, 1/2+y, 1/2-z]	0.82	1.74	2.555(3)	173
	C(8) –H(8)···F(1) [1-x, 1/2 +y,1/2 -z]	0.93	2.58	3.468	158
	C(20) –H(20A) ···F(1) [x, 1/2 -y,1/2 +z]	0.97	2.45	3.276(4)	142
5	O(3)-H(3A) ···F(1) [x, -1+y, -1+z]	0.82	1.79	2.579(3)	161
	O(1)-H(1) ···F(1) [x, y, -1+z]	0.82	1.74	2.556(2)	171
	O(6)-H(6) ···F(1) [1+x, y, z]	0.82	1.77	2.576(3)	165
6	O(3)-H(3A) ···O(1) [1/2+x, 1/2+ y, z]	0.82	1.90	2.679(1)	158

Co-crystal **5** is formed between oxime **2** and TBAF in 2 : 1 molar ratio. Composition of this cocrystal is also established from integration of proton signals in ^{1}H-NMR spectra. The ^{1}H-NMR spectra of cocrystal **5**, shows clearly discernable signals from tetrabutylammonium cations in aliphatic region; integration of this set of signals correspond to one molecule TBAF with respect to two molecules of oxime **2**. Assembling process in this case is also guided by strong O-H···F interactions, which results 4 + 4 cyclic units between four molecules of oximes with four fluoride ions (figure 4a). Fluoride ions act as central point to grow such cyclic structures to make grid-like arrangements. Each cyclic unit holds tetrabutylammonium cations within them. Two hydroxy groups and two oxime from four independent 2,3-dihydroxyphenylaldoxime molecules are involved in O-H···F interactions to contribute to coordination environment of fluoride ions in cocrystal **5** (figure 4b). Thus, fluoride ions adopt tetraherdral hydrogen bonds environment around them. Fluoride ions while acting as connect to form two dimensional grid-like structures, they assist in encapsulation of tetrabutylammonium cations within the grids through weak C-H···F interactions. Thus, this structure provides an example of a fluoride assisted assembly to encapsulate TBA cations. Each 2,3-dihydroxyphenylaldoxime molecule possesses intramolecular hydrogen bond between

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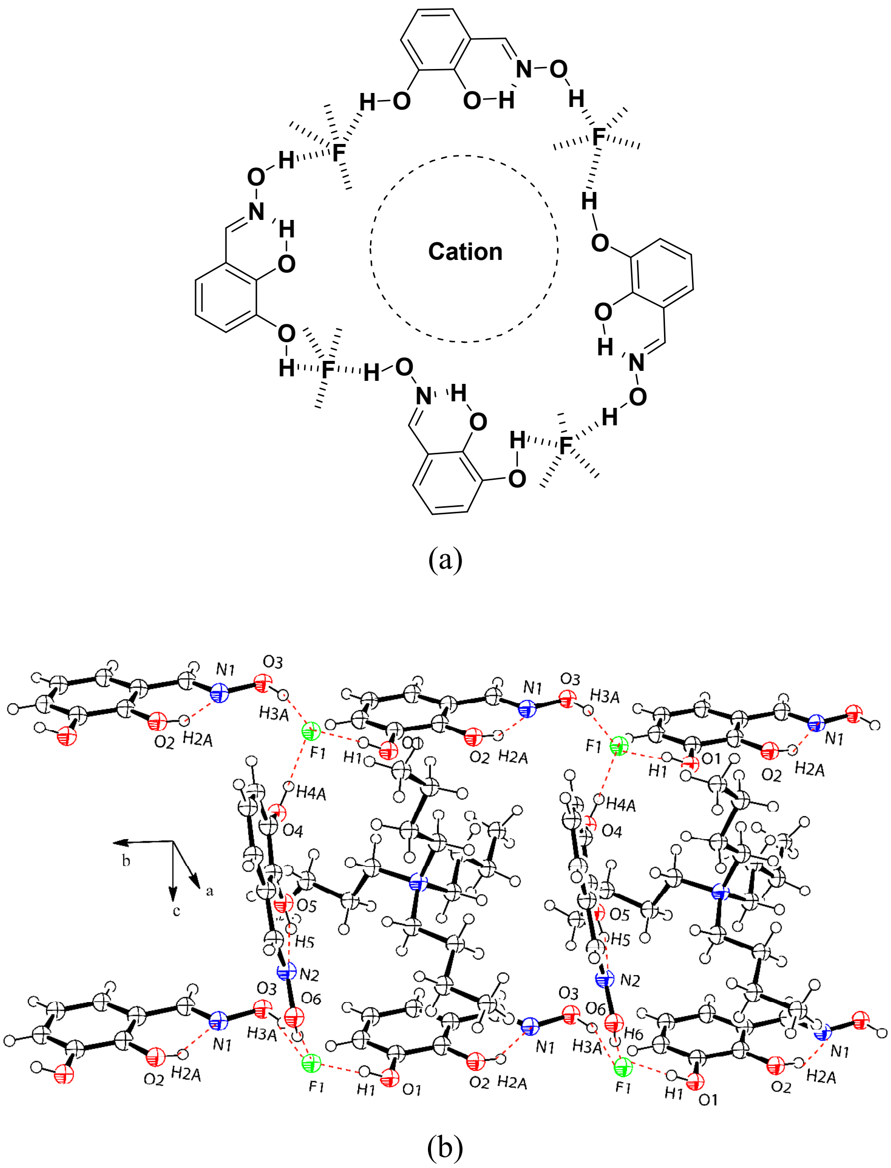

Figure 4: (a) Representation of fluoride assisted cyclic motif observed in the packing of cocrystal **5**. (b) Packing pattern of fluoride assisted assembly of **5** showing encapsulation of tetrabutylammonium cations.

nitrogen atom of oxime and hydroxy-group present at *ortho*-position. Thus, presence and absence of intramolecular hydrogen bond between hydroxy group and oxime nitrogen is a prime difference in structures of cocrystals **4** and **5**. It may be noted that hydroxy group of oxime interacts with fluoride ions[7a] but we have dealt with hydroxy-aromatic oximes, of which phenolic hydroxy groups play important roles to guide their packing patterns.

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Hence such a factor makes much different packing from a packing present in simple oximes. In both cocrystals **4** and **5** participations of hydroxy group of phenolic part in construction hydrogen bond bridges with fluoride ions are observed.

Reaction of oxime **3** with tetrabutylammonium fluoride resulted in abstraction of a proton from a hydroxy group at *para*-position of the ring with respect to oxime group to form a salt **6**; which crystallized as a cocrystal of **3.** Structure of the salt **6** determined by single crystal X-ray diffraction is comprised of self-assemblies of V-shaped dimeric assemblies of oxime molecules formed through sharing of proton. Such dimeric motifs form chain-like structures and chains interact among themselves to make voids which encapsulate tetrabutylammonium cations as illustrated in figure 5a. In case of **6,** hydroxy group present at *para*-position of phenyl ring with respect to oxime group, shows strong intermolecular hydrogen bond interactions which significantly contribute to the formation of assemblies. There is also intramolecular hydrogen bond between hydroxy group present at *ortho*-position with nitrogen atom of oxime. As a result of these interactions rectangular grid-like structure having TBA cations within grids are formed which is shown in figure 5b. There are strong hydrogen bonds between phenolic units through O1-H1···O1′ bonds having electrostatic property (Figure 5b). Due to this a short donor-acceptor bond distance between O1-H1···O1′ (symmetry of ′ = 2-x, y, ½-z) of 2.47 Å is observed. The hydrogen atom bonded to O1 lies on a twofold axis, whereas the nitrogen atom (N2) of tetrabutylammonium cation serves as pivot of a twofold axis. Once such assemblies are connected to each other through hydrogen bonds (O3-H3A···O1) of oxime group of another molecule, rectangular grid-like structures are formed. Alternatively structures of such grids can be explained as combination of linear chains in two different directions to form self-assemblies of anions and neutral molecules. Each chain when hydrogen bonded to another chain in perpendicular direction they form a grid like structure. Tetrabutylammonium cations held within the grids of **6** by C-H···π interactions as depicted in figure 5b. There is difference between grid-like structure in cocrystal **5** and in salt **6**; in former case electrostatic interactions of fluoride ions are involved which is absent in the latter case. Mass spectra of **6** show a mass peak at 547.7 (m/e) which corresponds to anticipated m/e value for an assembly between an anion of **3** and a neutral molecule of **3**. Fluoride ions are special due to their small size and ability to

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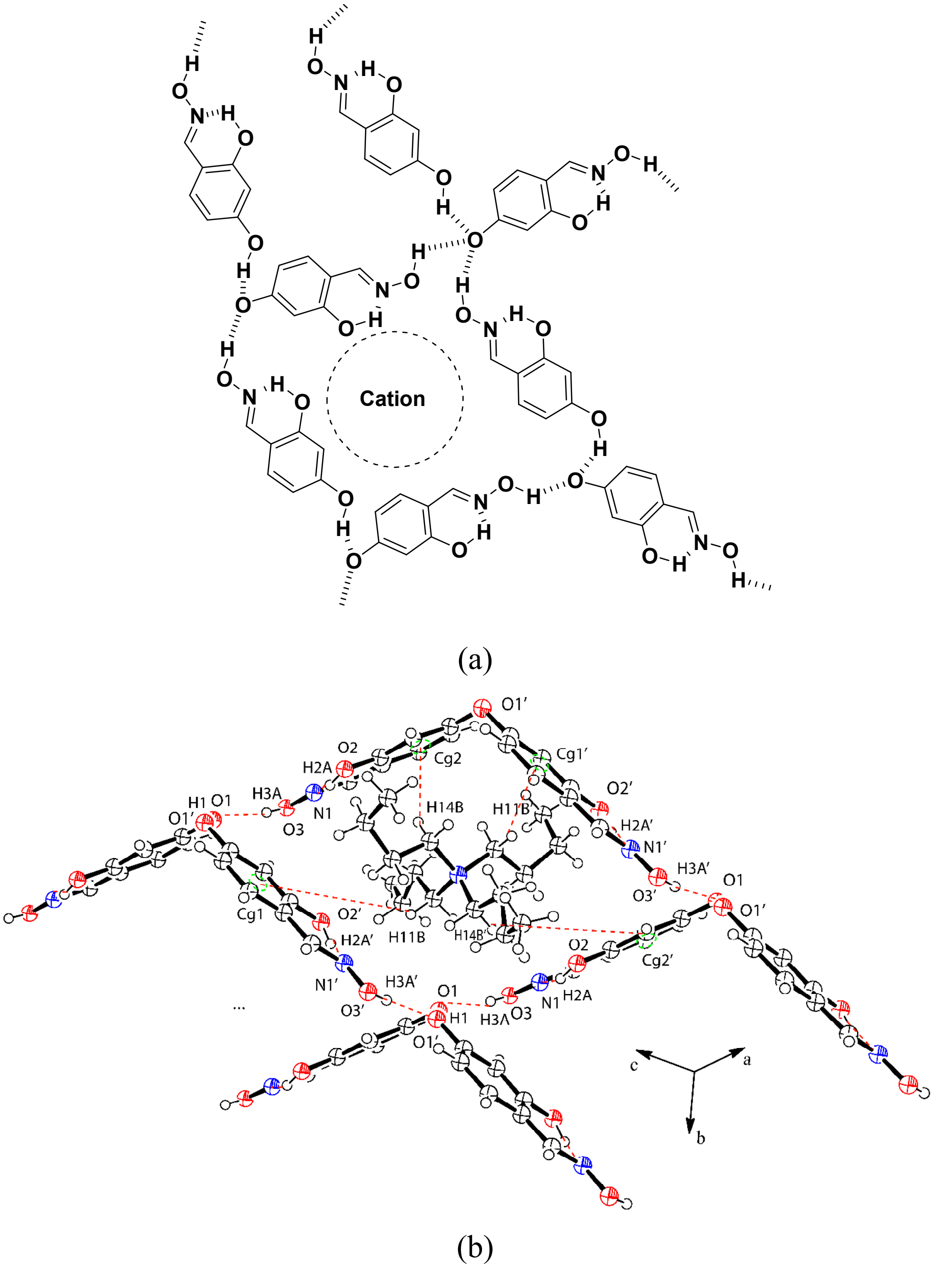
act as base.[10] Deprotonation of hydroxy compounds by fluoride ions were reported earlier;[10a] but anionic self-assemblies generated by fluoride ions in which fluoride ions are not a part of such an assembly has not been not reported yet. Self-assembly of cocrystal of a salt formed by assembly of mono-deprotonated **3** with a neutral molecule of **3** generated by fluoride ion without being a part of the assembly is exceptional.



(a)

(b)

Figure 5: (a) Representative diagram to show assemblies of dimeric motif of monoanion and neutral oxime **3**. (b) Encapsulation of tetrabutylammonium cation in anionic

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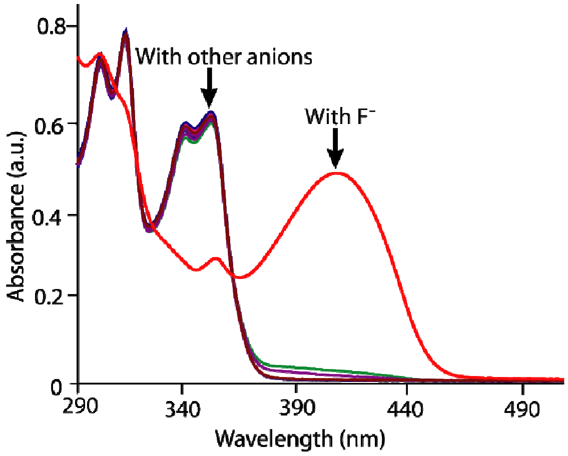
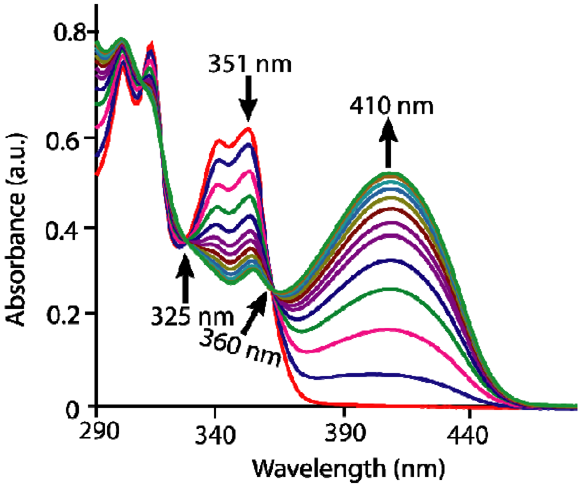
assembly of oximes in salt **6** showing the prominent hydrogen bonds (symmetry of ′ = 2-x, y, ½-z) and C-H···π interactions (Cg1 and Cg2 are the center of gravity of phenoxy and phenolic rings respectively).

*Utility of oximes **1-3** in detection of fluoride ions:*

In the present study, we find that interactions of oximes **1-3** with tetrabutylammonium fluoride selectively changes color. Independent experiments carried out by adding tetrabutylammonium fluoride to compounds **1**-**3** show new absorption peak at 410 nm for **1**, 371 nm for **2** and 336 nm for **3**, respectively (Figures 6d-6e).



(a)



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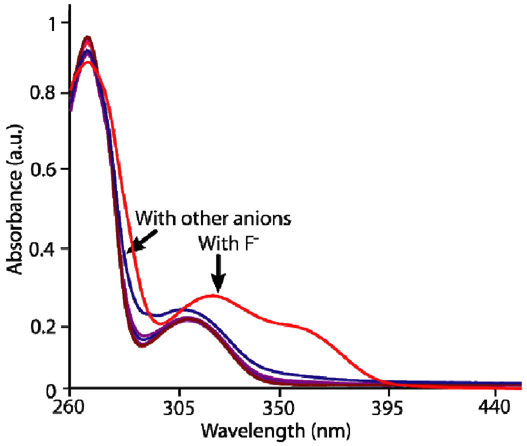

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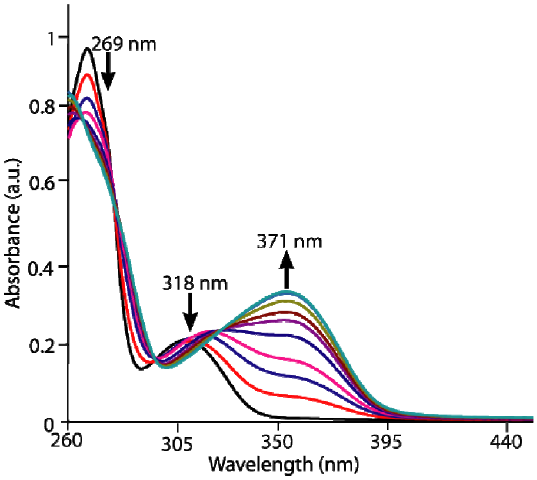

(e)

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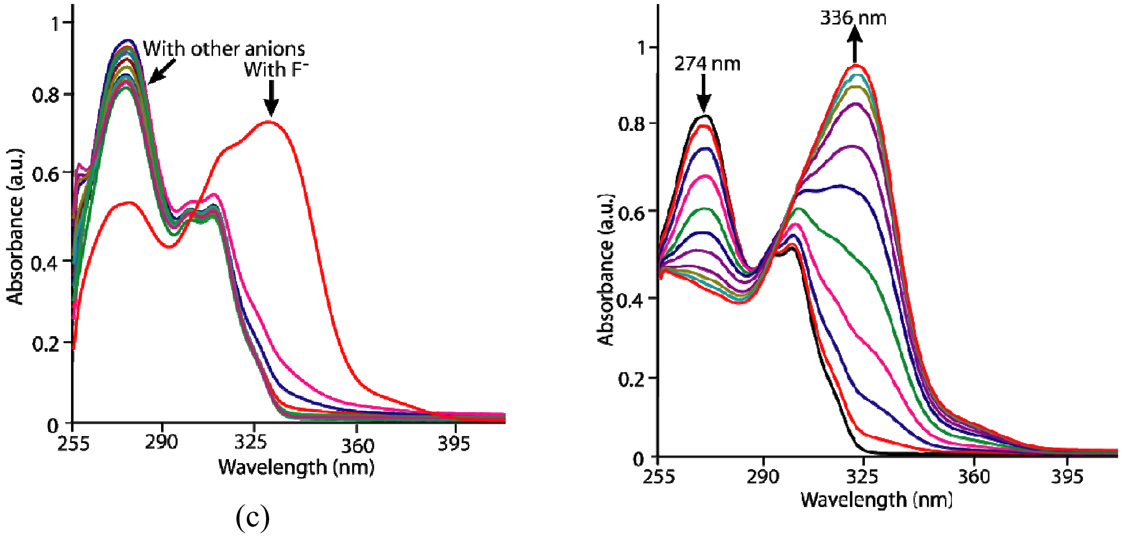

(c)

(f)

Figure 6: UV-visible spectra of (a) **1,** (b) **2,** (c) **3** (10^{-5}M) in dimethylsuphoxide (DMSO) with different tetrabutylammonium salts (100 µl of 10^{-5}M solution) showing fluoride salt only can cause changes in absorptions. UV-visible spectroscopic titration of TBAF (0µl-100µl of 10^{-5}M solution) with (d) **1**; (e) **2** and (f) **3** (10^{-5}M solution in DMSO).

However, other tetrabutylammoinum salts such as chloride, bromide, iodide, acetate, nitrate, bisulphate, biphosphate do not change absorption spectra of compounds **1-3**. Changes in UV-visible absorption of compounds **1, 2** and **3** are observed in corresponding titration carried out with each compound by adding solution of tetrabutylammonium fluoride. Increase in concentration of tetrabutylammonium fluoride reduces intensity of absorption peak at shorter wavelength while intensity of new absorption at longer wavelength increases which are shown in figures 6a-6c. Shifts in absorbance to longer wavelength show change in color. Thus, compounds **1-3** are suitable to sense fluoride ions. Deprotonation of phenols[11] and related compounds[12] by fluoride ions are useful to detect them. On the other hand, there are also examples of hydroxy-naphthalenes[13a] and hydroxy-anthraquinones[13b] which show color change on interactions with fluoride ions without getting deprotonated. Specific deprotonation by fluoride ions of intramolecular hydrogen bonded naphthol derivative was demonstrated earlier.[14] Metal complex of receptors containing several hydroxy groups show O-H···F interactions[15] and selective color changes takes place while cocrystals of naphthylaldoxime with fluoride salt are formed.[7a] It was earlier suggested[16] adduct formation of a fluoride salt versus

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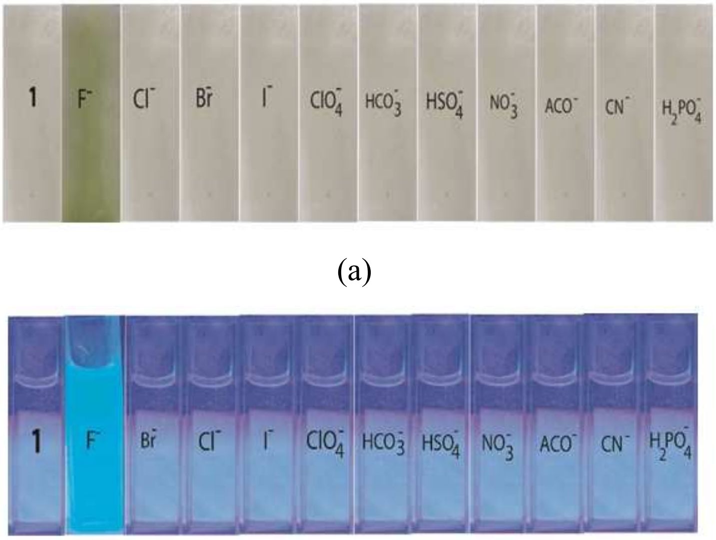
deprotonation of acidic compound by fluoride ions are to be carefully distinguished. In fact, this is true in the present cases and differences in shift of wavelengths in these cases stems from different types of assemblies. An assembly containing no fluoride ion and the neutral assembly containing fluoride ions makes a wide difference. Accordingly, absorption peak of **3** on interaction of fluoride ions appear at 336 nm which is much lower than absorptions shown by **1** and **2** at 410 nm and 371 nm respectively.



(a)

(b)

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Figure 7: (a) Color of filter papers pre-soaked with oxime **1** followed by soaking in solutions of different tetrabutylammonium salts. (b) Fluorescence of oxime **1** in DMSO in presence of different tetrabutylammonium salts on exposure to UV-light at 254 nm (For each tetrabutylammonium salt, respective anions are shown in figures).

Furthermore the peak observed at 336 nm is identical to absorption maximum shown by a solution of the salt **6**, hence it can be easily suggested that the peak has similarity to phenoxide ion. The forgoing examples of assemblies **4-6**, suggest that fluoride ions can act as base to generate new phenolic assemblies with or without being a counterpart of such an assembly. However, tetrabutylammonium hydroxide shows similar change (Supporting figure 7S) as that of fluoride ions in the case of **1** and **2** but with a lower intensity at 410 nm and 371 nm respectively at comparable concentrations. But no change

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in UV-visible spectra of compound **3** was caused by tetrabutylammonium hydroxide. These points suggest that compound **3** is suitable to sense fluoride in a more specific manner. Color shown by such an assembly in case of **6**, formed due to facilitation of proton sharing is useful in sensing fluoride ions; which is an exceptional case.[17]

Selective color change caused by fluoride ions allows their easy detection by dipping a filter paper pre-soaked with solution of any of these oximes (**1, 2** or **3**) in to a solution of fluoride ions in water-DMSO mixture. A series of experiments by dipping filter paper independently in different solutions is depicted in figure 7a. It is clear that aqueous solution containing fluoride ions only develops yellow color on these papers. Thus, these compounds can have practical utility to test for presence of fluoride ions in water. When a solution of TBAF is added to a solution of compound **1** in DMSO, it shows fluorescence emission at 468 nm on excitation at 320 nm, similar peaks are not observed from solution of **1** containing other tetrabutylammonium salts. On the basis of this observation, we have developed a technique to visually detect fluoride ions by exposing solutions containing different anions with **1** by exposing them to UV-light. Solution containing fluoride ions with **1**, exclusively shows a blue fluorescence as illustrated in figure 7b. Thus, compound **1** could be used as a fluorescence sensor for fluoride ions. Despite compounds **2** and **3** are useful in detection of fluoride ions by UV-visible spectroscopy, these two compounds are non-fluorescent hence are not suitable to detect fluoride ions by fluorescence technique.

Conclusions:

In conclusion, we have shown varieties of self-assemblies generated by fluoride ions on interactions with hydroxyaromatic oximes. These assemblies carry specific optical properties and able to provide information to sense fluoride ions visually. Assembly devoid of fluoride ions as well as assemblies having constituent fluoride ions may adopt grid like structures to encapsulate cations.

Experimental:

Physical measurements: Infrared spectra of the solid samples were recorded on a Perkin-Elmer Spectrum-One FT-IR spectrophotometer in the region 4000-400 cm^{-1} by making KBr pellets. UV-visible spectra were recorded on a Perkin-Elmer-Lambda 750 UV-vis spectrometer at room temperature. Mass spectra were recorded on a micro mass Q-TOF

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(waters) mass spectrometer by using an acetonitrile-formic acid matrix. Fluorescence emissions were measured in a Perkin-Elmer LS-55 spectrofluorimeter by taking definite amount of solutions of samples and exciting at required wavelengths.

Synthesis and characterization of oximes and fluoride assisted assemblies:

Oximes **1-3** were prepared from respective hydroxy-aromatic aldehyde by reacting them with hydroxylamine hydrochloride in presence of pyridine. Typical procedure for synthesis of 2-hydroxynapthaldoxime (**1**) is as follows: Pyridine (1 mL) was added drop wise to a solution of hydroxylamine hydrochloride (0.138 g, 2 mmol) dissolved in ethanol (20 mL). Resulting solution was stirred at room temperature for 15 mins followed by which 2-hydroxy-1-naphthaldehyde (0.344 g, 2 mmol) was added and continued stirring at room temperature for 1 hr. Yellow precipitate of compound **1** was obtained from the reaction mixture. This was extracted by ethylacetate and water mixture. Removal of ethylacetate in a rotavapor yielded compound **1**. Yield: 82 %. ^{1}H-NMR (400 MHz, DMSO-d$_6$): 11.53 (s, 1H), 9.04 (s, 1H), 8.48 (d, J = 8.4 Hz, 1H), 7.86 (d, J = 6.4 Hz, 1H), 7.84 (d, J = 6.4 Hz , 1H), 7.55 (t, J = 7.2 Hz, 1H), 7.41(t, J = 6.8 Hz, 1H), 7.34 (d, 1H). IR (KBr, cm^{-1}): 3331 (br, m), 3013 (w), 2924 (w), 2766 (w), 1947 (w), 1758 (w), 1632 (s), 1591 (s), 1526 (w), 1464 (w), 1463(m), 1414 (m), 1369 (w), 1310 (m), 1268 (s), 1239 (s), 1182 (s), 1163 (w), 1143 (w), 1079 (w), 1034 (w), 1014 (s) 938 (s), 878 (w), 854 (w), 814 (s), 776 (s), 744 (m), 718 (w), 649 (w), 541(w). Mass (ESI) m/z: 188.0698 (m+1); (Calculated exact mass 187.0633 for $C_{11}H_9NO_2$).

*2,3-Dihydroxypenylaldoxime (**2**):*

Isolated yield: 83%. ^{1}H-NMR (400MHz, DMSO-d$_6$): 11.30 (s, 1H), 9.58 (s, 1H), 9.27 (s, 1H), 8.31 (s, 1H), 6.91 (d, J = 7.2 Hz, 1H), 6.66 (d, J = 7.6 Hz, 1H), 6.59 (t, J = 8 Hz, 1H). IR (KBr, cm^{-1}): 3454 (bm), 1620 (s), 1592 (w), 1478 (s), 1444 (m), 1412 (w), 1347 (m), 1308 (m), 1285 (m), 1251 (m), 1165 (s), 1075 (m), 1030 (s), 967(s), 850 (s), 782(s), 744 (m), 727 (m), 626 (s), 566 (w). Mass (ESI) m/z: 154.1049. (Calculated exact mass 153.0426 for $C_7H_7NO_3$).

*2,4-Diydroxyphenylaloxime (**3**):*

Isolated yield: 84%. ^{1}H-NMR (400MHz, DMSO-d$_6$): 10.98 (s, 1H), 10.12 (s, 1H), 9.77 (s, 1H), 8.22 (s, 1H), 7.28 (d, J = 8.8 Hz, 1H), 6.32 (m, 2H). IR (KBr, cm^{-1}): 3363 (br, m), 1643 (m), 1623 (m), 1598 (w), 1524 (s), 1488 (m), 1446 (w), 1365 (w), 1344 (w),

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1304 (s), 1255 (s), 1208 (s), 1170 (m), 1117 (m), 1003 (s), 973 (s), 957 (m), 933 (w), 857 (w), 830 (s), 801 (m), 733 (w), 712 (w), 631 (w), 594 (m), 573 (w). Mass (ESI) m/z: 154.1049; (Calculated exact mass 153.0426 for $C_7H_7NO_3$).

Crystals of **4-6** were obtained by slow evaporation of solution of respective aldoxime (0.1 mmol) and tetrabutylammonium fluoride (0.1 mmol) in methanol.

Cocrystal ***4*** *:* ^{1}H-NMR (400 MHz, $CDCl_3$): 9.10 (s, 1H, H-C=), 8.03 (d, J = 8.4 Hz, 1H, H_{ar}), 7.74 (d, J = 6.4 Hz, 1H, H_{ar}), 7.67 (d, J = 6.4 Hz, 1H, H_{ar}), 7.45 (t, J = 7.2 Hz, 1H, H_{ar}), 7.29 (t, J = 6.8 Hz, 1H, H_{ar}), 7.17 (d, 1H, H_{ar}), 3.26 (m, 8H, N-CH_2), 1.61 (m, 8H, -CH_2-), 1.39 (m, 8H, -CH_2-), 0.97 (m, 12H, -CH_2-). There are deuterium exchangeable signals at 2.62 (s, OH) and 1.5 (s, OH). IR (KBr, cm^{-1}): 2959 (s), 2872 (s), 2851 (w), 1783 (w), 1621 (s), 1594 (m), 1571 (s), 1569 (s), 1431 (s), 1373 (m), 1344 (s), 1306 (m), 1274 (w), 1246 (w), 1211(w), 1167 (m), 1108 (w) 1074 (w), 1035 (w), 1002 (w), 937 (s), 880 (m), 828 (s), 783 (w), 760 (m), 668 (w), 582 (w).

Cocrystal ***5****:* ^{1}H-NMR (400MHz, DMSO-d_6): 8.31 (s, 2H, H-C=), 6.91 (d, J = 7.2 Hz, 2H, H_{ar}), 6.66 (d, J = 7.6 Hz, 2H, H_{ar}), 6.56 (t, J = 8.0 Hz, 2H, H_{ar}), 3.17 (t, J = 7.6 Hz , 8H, N-CH_2-), 1.56 (m, 8H, -CH_2-), 1.29 (m, 8H, -CH_2-), 0.97 (m, 12H, -CH_3). IR (KBr, cm^{-1}): 2961 (w), 2874 (w), 2723 (w), 1624 (m), 1577 (m), 1515 (w), 1473 (m), 1379 (s), 1321 (s), 1269 (s), 1243 (w), 1209 (w), 1166 (w), 1108 (w), 1077 (w), 1011 (s), 941 (w), 882 (w), 846 (s), 780(s), 735(s), 622 (s), 587 (m).

Salt ***6*** *:* ^{1}H-NMR (400MHz, DMSO-d_6): 8.16 (s, 2H , H-C=), 7.16 (s, 2H, H_{ar}), 6.25. (s, 2H, H_{ar}), 6.19 (s, 2H, H_{ar}), 3.14 (m, 8H, N-CH_2-), 1.55 (m, 8H, -CH_2-), 1.30 (m, 8H, -CH_2-), 0.93 (m, 12H, –CH_3) and (deuterium exchangeable proton signals at 7.10, 6.85 6.25, 6.19 ppm due to hydroxy protons). IR (KBr, cm^{-1}): 2965 (m), 2876 (w), 1614 (s), 1515 (m), 1477 (w), 1381 (w), 1328 (w), 1311 (m), 1267 (w), 1208 (s), 1117 (m), 994 (m), 969 (m), 887 (w), 757 (w), 733 (w), 651 (w), 576 (m), 506 (m).

Structure determination:

Single crystal X-ray diffraction data were collected on an Oxford SuperNova diffractometer. *SMART* software was used for data collection, indexing the reflections and determination of unit cell parameters. Data refinement and cell reductions were carried out by CrysAlisPro[18a]. Structures were solved by direct methods and refined by full-matrix least-square calculations using *SHELXTL* software[18b]. All non-hydrogen

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atoms were refined in anisotropic approximation against F^2 of all reflections. Hydrogen-atoms, except those attached to oxygen and some carbon atoms of tetrabutylammonium ions were placed at their calculated positions and refined with isotropic approximation; hydrogen atoms attached to oxygen atoms were located in difference Fourier maps and refined with isotopic displacement coefficients. Crystallographic parameters are summarized in Table 2.

Table 2: Crystallographic parameters of **4**, **5** and **6**

Compound No.	**Cocrystal 4**	**Cocrystal 5**	**Salt 6**
Formulae	$C_{27}H_{45}F\,N_2\,O_2$	$C_{30}H_{50}\,F\,N_3O_6$	$C_{30}H_{49}\,N_3O_6$
CCDC No.	1003333	1012763	1012762
Mol. wt.	448.65	567.73	547.72
Space group	$P2_1/c$	Pc	$C2/c$
a /Å	10.1130 (6)	9.5189 (7)	16.2317(7)
b /Å	17.5762 (10)	9.4321 (7)	9.6547 (4)
c /Å	15.6751 (10)	18.7965 (14)	20.2299 (8)
α/°	90.00	90.00	90.00
β/°	102.831 (6)	101.203 (4)	99.931 (3)
γ/°	90.00	90.00	90.00
V/ $Å^3$	2716.7 (3)	1655.5(2)	3122.8 (2)
Density/$g.cm^{-3}$	1.097	1.139	1.165
Abs. Coeff. /mm^{-1}	0.073	0.082	0.081
F(000)	984	616	1192
Total No. of reflections	4901	2989	2711
Reflections, $I > 2\sigma(I)$	2959	1766	1431
Max. θ/°	25.25	25.24	24.99
Ranges (h, k, l)	$-12 \le h \le 12$ $-16 \le k \le 21$ $-18 \le l \le 18$	$-9 \le h \le 10$ $-11 \le k \le 10$ $-22 \le l \le 22$	$-19 \le h \le 18$ $-11 \le k \le 11$ $-23 \le l \le 23$
Complete to 2θ (%)	99.80	99.00	98.50
Data/ Restraints/Parameters	4901/ 0/ 319	5031/3/374	2711/ 8/ 189
Goof (F^2)	1.051	1.029	1.048
R indices [$I > 2\sigma(I)$]	0.0686	0.0383	0.0736
wR_2 [$I > 2\sigma(I)$]	0.1729	0.0919	0.1531
R indices (all data)	0.1120	0.0560	0.1135
wR_2 (all data)	0.2015	0.1024	0.1636

Supporting information: Crystallographic information files of **4**, **5** and **6** are deposited to Cambridge Crystallograpic Center have CCDC Nos. 1003333, 1012763, 1012762. ^{1}H-NMR spectra of the all the compounds and UV-visible titrations of **1**, **2** and **3** with tetrabutylammoinuum hydroxide are supplied as supporting information.

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