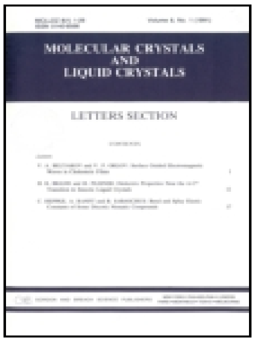
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Synthesis of Isophorone based D-π-A Type Chemosensor for the Response of Hg^{2+}

YOUNG-A SON[1],* AND SUNG-HOON KIM[2],*

[1]Department of Advanced Organic Materials Engineering, Chungnam National University, Daejeon, South Korea
[2]Department of Advanced Organic Materials and Science Engineering, Kyungpook National University, Daegu, South Korea

A new bifunctional probe based on indole-isophorone conjugate for the distinct response of Hg^{2+} and F^- ion was demonstrated for the first time. The sensing property of 3 with F^- ion is due to the formation of H-bonds between F^- ion and NH moiety which has been enhanced ICT between NH and isoporone unit. Sensing mechanism of Hg^{2+} has also been confirmed by competitive experiment. The association constant were found to be 5.89×10^4 and 1.15×10^4 M^{-1} for the 3-Hg^{2+} and 3-F^-, respectively. Theoretical calculation was performed to explain the optical sensing property of 3 with Hg^{2+} and F^- ion.

Keywords Isophorone; Indole; Intramolecular charge transfer (ICT); Push; Pull; π conjugation; Computational calculation

1. Introduction

The development of optical-chemo sensors is promising field due to their simplicity, high sensitivity and instantaneous response [1]. Many chemosensors were developed for cation or anionic species [2–5]. Among these sensors, bi-functional probes, which has been act as a single host that can independently recognize two guest species with distinct visual and optical responses via the same or different mechanism, have already emerged and have gradually become a new research focus [6]. This type of chemosensor has used to overcome many difficulties such as cross-talk, a larger invasive effect, etc. encountered with the combination of several probes [7]. So for, some interesting dual-sensor have been successfully constructed and recognized three types of combinations including metal ion/metal ion, anion/metal ion, and anion/anion either simultaneously or consecutively [8, 9]. The design of other dual sensor for miscellaneous combinations of analytes is still in high demand.

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*Address correspondence to Prof. Young-A Son, Department of Advanced Organic Materials Engineering, Chungnam National University, 220 Gung-dong, Daejeon 305-764, South Korea, E-mail: yason@cnu.ac.kr and Prof. Sung-Hoon Kim, Department of Advanced Organic Materials Science and Engineering, Kyungpook National University, Daegu, 702-701 South Korea, E-mail: shokim@knu.ac.kr.

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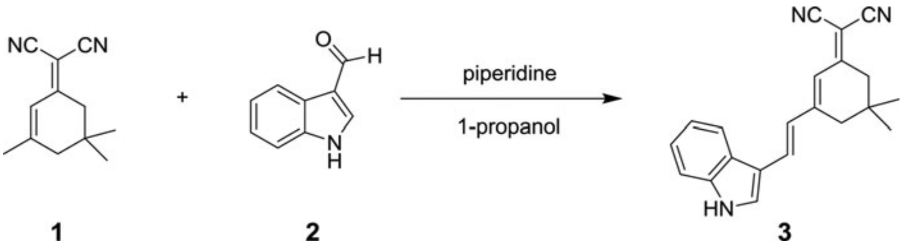
Hg^{2+} is one of the most toxic and dangerous metal ion [10]. Hg^{2+} pollution occurs in environment by various activities such as volcanic emissions, mining, solid waste incineration and the combustion of fossil fuels [11]. Noticeably, that mercury-containing chemicals have been linked with a number of human health problems, including minamata, myocardial infarction, and some kinds of autism, and can lead to damage of the brain, kidneys, central nervous system, immune system and endocrine system [12, 13].

The smallest anion, fluoride, with high charge density is of particular importance because of its roles in dental care and clinical treatment for osteoporosis [14, 15]. And also, NaF functions as a potent G protein activator and Ser/Thr phosphatase inhibitor that affect many essential cell signaling transductions [16–18]. However, excessive use may create fluorosis resulting in the discoloration of teeth and skeletal fluorosis [19, 20]. As the smallest and the most electronegative atom, fluorine has unique chemical properties and can form the strongest hydrogen bond interaction with hydrogen bond donors. Consequently, selective detection of these two toxic ions becomes essential either visually or spectroscopically. The visual detection of analytes has shown huge advantage over sensing methods due to its quick response and simplicity as it does not require any equipment for analyte detection [21–23]. Thus, much attention has been focused on developing new methods to monitor Hg^{2+}/F^- in biological and environmental samples Scheme 1.



Scheme 1. Synthesis routes for dye sensor (3).

Until now, there are different kinds of signaling mechanisms such as intramolecular charge transfer (ICT) [24], photoinduced electron transfer (PET) [25], fluorescence resonance energy transfer (FRET), metal-to-ligand charge transfer (MLCT) [26], excimer/exciplex formation [27] and excited-state intramolecular proton transfer (ESIPT) [28]. In general, isophorone moiety is a well-known example for push-pull type of ICT dye [29–31]. Recently, we have prepared bifunctional isophorone (3) optical probes for selective detection of F^- ion in CH_3CN medium by using ICT phenomenon [32]. As we know that, the intramolecular CT phenomenon is highly solvent dependent [33], leading to altering the absorbance maximum of chromophore. This solvent environment has been widely used for fine tuning of sensing property of such ICT based sensor. In this line of our research, herein we also have been developing a dual chemosensor for both Hg^{2+} and F^- ion with distinct color changes. In connection with our continuing research of chemosensors for biologically and environmentally important F^- [32], herein we report a highly selective optical chemosensor probe for F^- in DMSO. Switch of selectivity to Hg^{2+} was also observed after the tuning ICT by using DMSO. Hence, this Indole-isophorone based receptor were prepared, characterized and employed as colorimetric sensors.

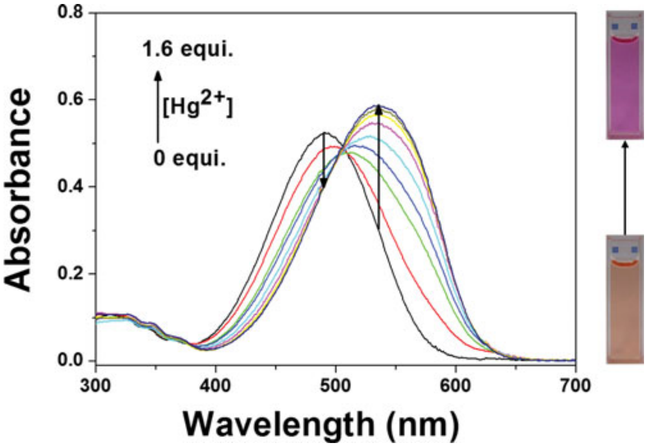


Figure 1. Effect of Mercury cation concentration on the absorbance of a 1 × 10^{-5}M solution of 3 in DMSO.

2. Experimental

All reagent and chemicals were purchased from Aldrich Chemical Co. and TCI. Solvents were purified by standard procedures and used under moisture free atmosphere. The other materials were commercial products and were used without further purification. Elemental analyses were recorded on a Carlo Elba Model 1106 analyzer. UV-visible absorption spectra were measured on an Agilent 8453 spectrophotometer whilst fluorescence spectra were measured on a Shimadzu RF-5301 PC fluorescence spectrophotometer. Mass spectra were recorded on a Shimadzu QP-1000 spectrometer using electron energy of 70 eV and the direct probe EI method. ^{1}H NMR spectra were recorded using a Varian Inova 400 MHz FT-NMR spectrometer with TMS as internal standard. Melting point was determined using an Electrothermal IA900.

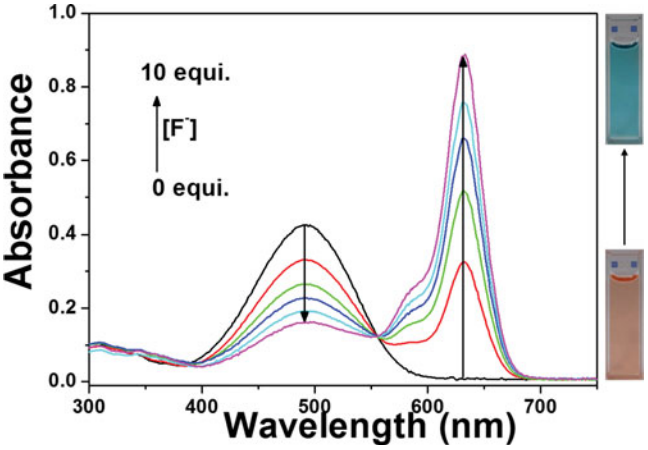


Figure 2. Effect of fluoride anion concentration on the absorbance of a 1 × 10^{-5} M solution of 3 in DMSO.

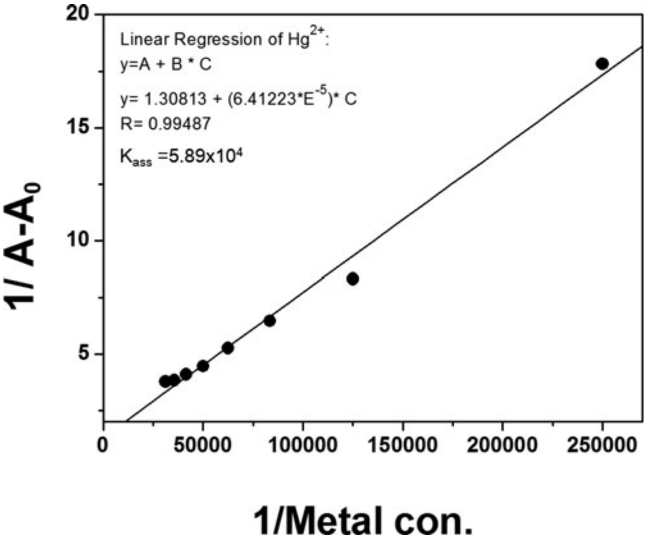


Figure 3. Benesi-Hildebrand plot of absorption titration data of 3 (1×10^{-5}M) with Hg^{2+}.

2.1. *Synthesis of Propanedinitrile, 2-[3-[(1E)-2-(1H-indol-3-yl)ethenyl]-5,5-dimethyl-2-cyclohexen-1-ylidene] (3)*

2-(3,5,5-Trimethylcyclohex-2-enylidene)-malononitrile 1 (0.5 g, 2.7mmol) and indole-3-carboxaldehyde 2 (0.4 g, 2.7mmol) were dissolved in 25 ml of 1-propanol. Piperidine was added dropwise and the ensuing mixture was refluxed for 10 h, after which time, the desired solid compound was removed by filtration and washed with 1-propanol and hexane (60% yield) [32, 34].

^{1}H NMR(400 MHz) DMSO-d_6: δ (ppm) 1.03 (s, 6H, -$(CH_3)_2$), 2.57 (br s, 4H), 6.85 (s, 1H), 7.15 (m, 3H), 7.45 (d, J = 7.44, 1H), 7.58 (d, J = 16.04, 1H), 7.93 (s, 1H), 8.12 (d,

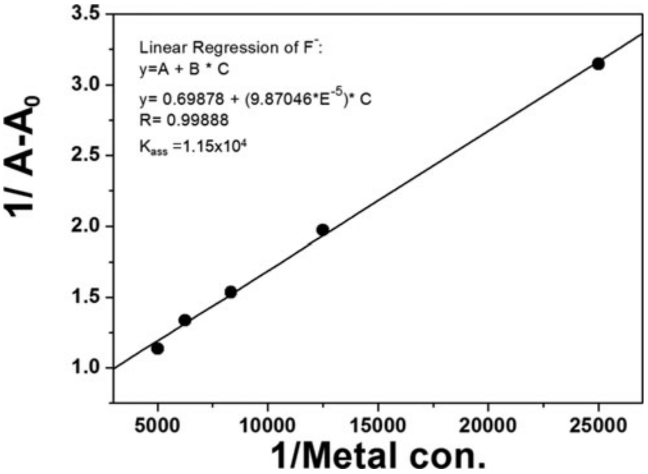


Figure 4. Benesi-Hildebrand plot of absorption titration data of 3 (1×10^{-5} M) with F^-.

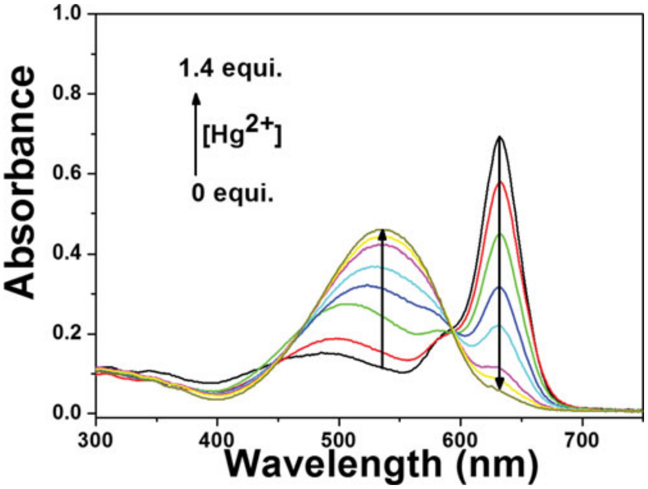


Figure 5. Effect of Mercury cation concentration on the absorbance of 3 (1×10^{-5}M) with fluoride anion (1×10^{-4}M) solution in DMSO.

J = 7.4, 1H), 11.81 (s, 1H, -NH); EA: anal. calcd. $C_{21}H_{19}N_3$: C; 80.45, H; 6.11, N; 13.41. Found C; 79.74, H; 6.30, N; 13.16 %; EI-MS: $[M]^+$, 313; mp: 250 °C.

3. Results and Discussion

3.1. Solvatochromism and Visual Detection of 3 in DMSO

To evaluate the solvatochromic behaviour of 3, we carried out colorimetric sensing study in two different solvents such as CH_3CN and DMSO. The colour of the chemosensor 3 in CH_3CN and DMSO is yellow and brown, respectively. Likewise, the electronic absorption spectrum of 3 in CH_3CN and DMSO exhibits at 460 and 480 nm, respectively. This is indicating the exhibit intramolecular CT bands are highly solvent dependent. To keep this point in our mind, we check the sensing property of 3 in both CH_3CN [32] and DMSO, in the case of CH_3CN the chemosensor 3 is colorimetrical sense the F^- ion alone. While in the case of DMSO it has been sense both Hg^{2+} and F^- ion. As depicted in Figure 1, solution of 3 in DMSO turns brown to intense pink color after the addition of Hg^{2+}. Whereas, the solution of 3 was attain the green colour in the presence of F^-. Hence, the distinct colour change of 3 with Hg^{2+} and F^- ion is containing the advantages over the other chemosensor.

3.2. Binding Studies Using UV-Vis Spectrophotometry

To ascertain the sensing properties of 3 towards Hg^{2+} and F^- ions, we have carried out the UV-Vis absorption spectroscopy studies. The electronic spectra of 3 at a concentration of 1×10^{-5} M in DMSO upon addition of F^- and Hg^{2+} ions are shown in Figure 1 and 2, respectively. The receptor 3 had an absorption maximum at 480 nm which corresponds to the intramolecular charge transfer (ICT) transition from indole N-atom to the malononitrile (n-π^*) [32]. As shown in Figure 2, incremental addition of fluoride ion to 3 solutions, the absorption peak at 480 nm diminished gradually accompanying the formation of a new band at 640 nm. This new band is due to ICT between the receptor (>NH… F-) and

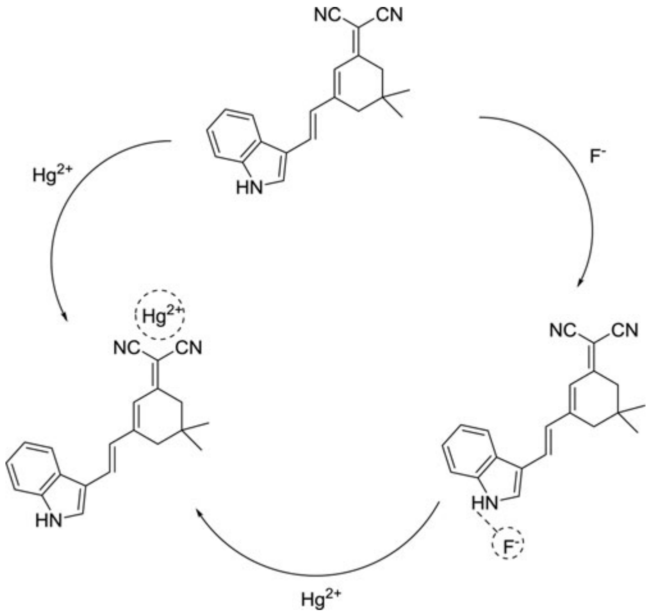


Figure 6. Proposed binding mechanism of 3 with Hg^{2+} and F^- ions.

acceptor (malononitrile) units [32]. Likewise, upon the addition of Hg^{2+} (up to 1.6 equiv.) to solution of 3 in DMSO, the intensity of the original absorption band at 480 nm decreased gradually with accompanying of new peak at 520 nm. This bathochromic shift of ICT peak was mainly due to the enhancement of ICT between the indole -NH and malonitrile. In both the cases, shown the single isosbestic point it is indicating that there exists only one

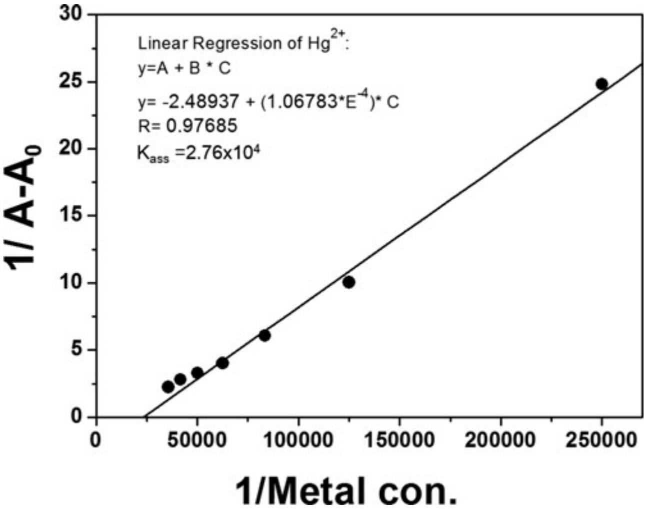


Figure 7. Benesi-Hildebrand plot of absorption titration data of 3 (1×10^{-5}M)-F^- (1×10^{-4}M) complex with Hg^{2+}.

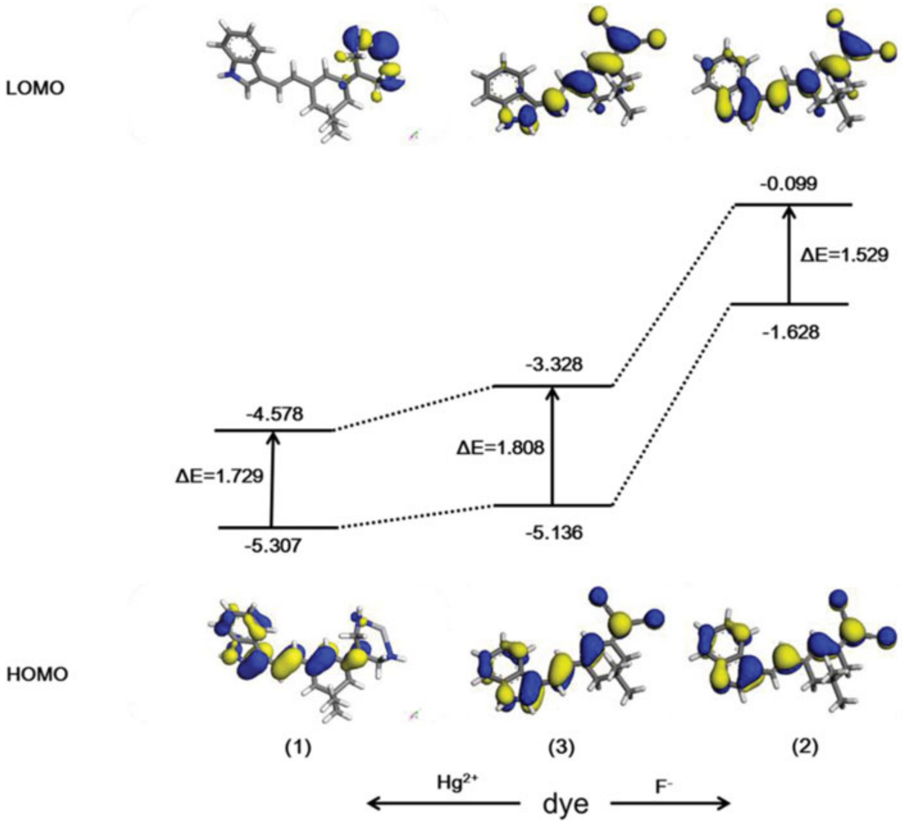


Figure 8. Electron distribution of HOMO and LUMO energy levels for the complex formation of (1) 3-Hg^{2+}, (2) 3-F^{-}, (3) 3.

type of 3-F^{-}/ 3-Hg^{2+} ion complex formation. The $\Delta\lambda_{ICT}$ of 3-F^{-} is greater than that of the 3-Hg^{2+}, this can be further explained in the theoretical studies.

The association constant of 3 with Hg^{2+} and F^{-} ion complexes, has been estimated using the Benesi-Hildebrand equation (equation 1) [35].

$$\frac{1}{A - A_0} = \frac{1}{\{Ka \times (Amax - A_0) \times [Guest]\}} \tag{1}$$

In both the cases the Benesi-Hildebrand plot is linear (Figure 3 and 4) and the association constants of 3 with Hg^{2+} and F^{-} were founded to be 5.89×10^{4} M^{-1} and 1.15×10^{4} M^{-1}, respectively. The relatively higher values for the receptor-Hg^{2+} is indicating Hg^{2+} form the strong bond with chemosensor than that of the F^{-} ion.

3.3. *Competitive studies between F^{-} and Hg^{2+} ions*

With an aim to shed some light on the sensing property of 3 with Hg^{2+}, we employed competitive experiment between F^{-} and Hg^{2+} on 3. It is well established that the sensing behaviour of 3 towards fluoride ion is mainly due to the presence of H bonding between NH and F^{-} [32]. Therefore to find out the binding mechanism of Hg^{2+} with 3, we prepared the adduct 3 (1×10^{-5}M) with F^- ion (1×10^{-4}M), thus the 3-F^- adduct solution was used for the further photo physical study with Hg^{2+} ion (Figure 5). In the case of 3-F^- adduct the strong peak was appear at 640 nm, this is corresponded to the 3-F^- species. Whilst the addition of incremental amount of Hg^{2+} ion to the adduct solution, the peak at 640 nm was sharply decreased, consequently the 3-Hg^{2+} ion peak was intensely growing at 520 nm, This results indicated that the incoming Hg^{2+} ion replace the F^- ion and it form the linkage with NH group. (Figure 6). From this UV-Vis titration, the association constant was calculated for 3-Hg in the presence of F^- ion, the association constant was found to be 2.76×10^4 M^{-1} (Figure 7). This is indicating the F^- ion was reduced the sensing property of 3 with Hg^{2+} ion.

3.4. *Computational Study*

To insight the recognition abilities of 3 towards Hg^{2+} and F^- ions, the theoretical calculations were performed using $DMol_3$ program of *Materials Studio* 4.3 package calculations. The HOMO and LUMO of simple 3 and their complexes with Hg^{2+} and F^- ions are shown in figure 8. The HOMO to LUMO excitation is responsible for ICT transition at 480 nm in the electronic spectrum of 3. The energy gap between HOMO and LUMO (DE) of simple 3 is 1.808 eV, while in the case of 3-Hg^{2+} and 3-F^- complexes, the ΔE values are 1.729 eV and 1.529 eV, respectively. This results are clearly indicating the ICT transition in 3-F^- is very easier than that of the 3-Hg^{2+} complexes.

4. Conclusion

In summary, isophorone bifunctional derivative has been synthesised and characterized as a new dual-function colorimetric probe for Hg^{2+} and F^- in DMSO. The probe displays high selectivity and extremely high sensitivity for Hg^{2+} and F^- with distinct color changes in DMSO. The salvatochromic character of chemosensor 3 has been confirmed by spectral techniques. The Hg^{2+} and F^- recognition could be easily monitored by UV-Vis absorption spectra and naked eye. It has been demonstrated that the receptors can bind Hg^{2+} and F^- ions by H-bonding with indole N-H proton. The order of the strength of chemosensor-Hg^{2+}/F^- interaction was found to 3-Hg^{2+} > 3-F^-. The distinct color changes of 3 with Hg^{2+} and F^- has been used to detect these two toxic ions in environment.

Acknowledgments

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References

[1] Janzen, M. C., Ponder, J. B., Bailey, D. P., Ingison, C. K., & Suslick, K. S. (2006). *Anal. Chem.*, *78*, 3591.

[2] Chetia, B., & Parameswar, K. (2008). *Tetradedron Letters*, *49*, 94.

[3] Wang, S., & Kim, S. H. (2009). *Current Applied Physics*, *9*, 783.

[4] Bianchi, A., Bowman, J. K., & Garcia-Espana, E. (1997). *Supramolecular Chemistry of Anions*, Wiley-VCH, New York.

[5] Wang, L., Li, H., & Cao, D. (2013). *Sens Actuators B Chem*, *181*, 749.

[6] Lavigne, J. J., Anslyn, E. V. (2001). *Angew. Chem., Int. Ed. 40*, 3118.

[7] Komatsu, H., Miki, T., Citterio, D., Kubota, T., Shindo, Y., Kitamura, Y., Oka, K., & Suzuki, K. (2005). *J. Am. Chem. Soc.*, *127*, 10798.

[8] Maity, D., & Govindaraju, T. (2012). *Chem. Commun.*, *48*, 1039.

[9] He, X., & Yam, V. W. W. (2011). *Org. Lett.*, *13*, 2172.

[10] Wolfe, M. F., Schwarzbach, S., & Sulaiman, R. A. (1998). *Environ. Toxicol. Chem.*, *17*, 146.

[11] Renzoni, A., Zino, F., & Franchi, E. (1998). *Environ. Res.*, *77*, 68.

[12] Von Burg, R. (1995). *J. Appl. Toxicol.*, *15*, 483.

[13] Clarkson, T.W., Magos, L., & Myers, G.J. (1731). *N. Engl. J. Med.*, *349*, 1731.

[14] Krik, K. L. (1991). *Biochemistry of the halogens and inorganic halides*. New York: Plenum Press; p. 58.

[15] Kleerkoper, M. (1998). *Endocrinol Metab Clin North Am*, *27*, 441.

[16] Anuradha, C. D., Kanno, S., & Hirano, S. (2000). *Arch. Toxicol.*, *74*, 226.

[17] Refsnes, M., Schwarze, P. E., Holme, J. A., & Lag, M. (2003). *Hum. Exp. Toxicol.*, *22*, 111.

[18] Chen, T. J., Chen, T. M., Chen, C. H., Lai, Y. K., & Cell, J. (1998). *Biochem.*, *69*, 221.

[19] Geddes, C. D. (2001). *Meas. Sci. Technol.*, *12*, R53.

[20] Kissa, E. (1987). *Clin. Chem.*, *33*, 253.

[21] Gunnalaugasson, T., Kruger, P. E., Jensen, P., Tierney, J., Li H. D. P., Hussery, G. M. (2005). *J. Org. Chem.*, *70*, 10875.

[22] Satheshkumar, A., & Elango, K. P. (2013). *Dyes Pigment.*, *96*, 364.

[23] Liu, Y., Lv, X., Zhao, Y., Chen, M., Liu, J., Wang, P., & Guo, W. (2012). *Dyes Pigment.*, *92*, 909.

[24] Wu, F. Y., Li, Z., Guo, L., Wang, X., Lin, M. H., Zhao, Y. F., & Jiang, Y. B. (2006). *Org. Biomol. Chem.*, *4*, 624.

[25] Thiagarajan, V., Ramamurthy, P., Thirumalai, D., & Ramakrishnan, V. T. (2005). *Org. Lett.*, *7*, 657.

[26] Sun, S. S., Anspach, J. A., Lees, A. J., & Zavalij, P. Y. (2002). *Organometallics*, *21*, 685.

[27] Wu, J. S., Zhou, J. H., Wang, P. F., Zhang, X. H., & Wu, S. K. (2005). *Org. Lett.*, *7*, 2133.

[28] Wu, Y., Peng, X., Fan, J., Gao, S., Tian, M., Zhao, J., & Sun, S. (2007). *J. Org. Chem.*, *72*, 62.

[29] Meyer, M., Mialocq, J. C., & Perly, B. (1990). *J. Phys. Chem.*, *94*, 98.

[30] Pal, S. K., Sukul, D., Mandal, D., & Bhattacharyya, K. (2000). *J. Phys. Chem. B*, *104*, 4529.

[31] Boldrini, B., Cavalli, E., Painelli, A., & Terenziani, F. (2002). *J. Phys. Chem. A*, *106*, 6286.

[32] Kim, S. H., Gwon, S. Y., Bae, J. S., & Son, Y. A. (2011). *Spectroc. Acta Pt. A-Molec. Biomolec. Spectr.*, *78*, 234.

[33] Satheshkumar, A., & Elango, K. P. (2013). *RSC Advances*, *3*, 1502.

[34] Lemke, R. (1970). *Chem. Ber. 103*, 1894.

[35] Benesi, H. A., & Hildebrand, J. H. (1949). *J. Am. Chem. Soc.*, *71*, 2703.