

Flourescence Sensing Mechanism and Hydrazide Moiety

Chandana Sen

Department of Chemistry, Behala College, Kolkata 700060, West Bengal, India

Corresponding Author's Email: chandanasen2016@gmail.com

Abstract

Hydrazide-based fluorescent chemosensors have emerged as a versatile and highly efficient class of molecular probes for the selective and sensitive detection of biologically and environmentally important cations and anions. The growing concern over the toxicity of toxic metal ions, such as Hg^{2+} , Pb^{2+} , Cd^{2+} , and Cu^{2+} , as well as hazardous anions including F^- , CN^- , and H_2PO_4^- , has intensified the need for rapid, cost-effective, and reliable sensing strategies. Hydrazide moieties possess unique structural features, including nitrogen and oxygen donor atoms, facile hydrogen-bonding capability, and tunable electronic properties, making them excellent recognition units for ion sensing. Upon interaction with target ions, hydrazide-based sensors exhibit significant fluorescence responses through mechanisms such as photoinduced electron transfer (PET), intramolecular charge transfer (ICT), chelation-enhanced fluorescence (CHEF), and excited-state intramolecular proton transfer (ESIPT). This review highlights recent advances in hydrazide-based fluorescent chemosensors, emphasizing their design strategies, sensing mechanisms, selectivity toward cations and anions, and practical applications in environmental monitoring, biological imaging, and food safety. Furthermore, the review discusses current challenges and future perspectives in developing highly selective, sensitive, and multifunctional hydrazide-derived fluorescent sensors for real-world analytical applications.

Keywords: Biological; Environmental; Fluorescent Chemosensor; Hydrazide; Toxicity

Introduction

With expanded population and degradation of Mother Nature are very closely associated with each other. The modern habitat is now in major demanding situation due to uncontrolled urbanization and industrialization and different agricultural impurifications. Large amount of artificial and man-made chemical compounds is ejected every moment to the environment and increases day to day; about 700 new synthetic materials are inaugurated into the market every year in the US only (U.S. Environmental Protection Agency, 2014; Pye & Patrick, 1983). Synthetic components are of particular worry is that those may collectively developing severe damage to individual wellness. Some components are directly associated with endocrine disrupting effects, some artificial components are suspected of being promote cancer or directly stored and biomagnified through the food chain (Kantiani *et al.*, 2010). Not only individual deed but also natural calamities like Earthquakes, Volcanoes, Floods, changes of the river pathways, uncontrolled development of different fungi and microbes etc. are responsible of ecological catastrophe and thread to human being.

Around 2 million tonnes of refuse products manufactured by different subjects are being deposited daily into the ocean, sea, river, lakes etc. (Fan *et al.*, 2012; Rijith *et al.*, 2012) in whole world. Around 70% of crude hazards are ejected into the running water bodies in different up growing nations. Every living entity suffered from wastewater contamination from running water body (Li *et al.*, 2013). Developing countries are more liable to those dangerous effects of different contaminants concerning wellbeing and environmental suffering. Villagers are more affected by different diseases because difficulty in establishment, functing and up-keep of trash matter treatment plants and the restricted alternative sources of water supply (Kansal & Kumari, 2014; Shafiquzzaman *et al.*, 2009).

High toxic consequences of chemical contaminants to individuals and the surroundings, communal concerns over chemical wastes in the environment and in diet have been up growing immoderately

Chemical Elements and the Human Health



Toxicity of Anions

Different natural weathering, natural chemical changes materialize within aerosphere, earth's crust and water bodies (geochemical reactions), various anthropogenic activities, biological activity, volcanic degradations influence mobility of arsenic (Moriarty *et al.*, 2013; Sullivan *et al.*, 2010).

Excessive consumption of fluoride ($>1.5 \text{ mg L}^{-1}$) may cause fluorosis (Ayooob & Gupta, 2006) and urolithiasis (Upadhyay *et al.*, 2010), has been reported in various countries, including India, China. Increasing bone density and cancer may cause by fluoride toxicity (Kleerekoper, 1998).

Hypophosphatemia, musculoskeletal and cardiovascular systems, tissue damage highly affected by phosphate toxicity (Razzaque, 2011). Eutrophication has become a global issue in immobile water bodies such as reservoirs, lakes and estuaries (Mak *et al.*, 2003). Excessive soluble phosphates usually conduct to unusual algal growth along with depletion in dissolved oxygen, decomposition, eutrophication and finally reduction in water standard (Warwick *et al.*, 2013).

Chloride and nitrate levels have been executed to trace pollution from different agriculture field, fish farms from waste accumulation. Highly toxic cyanide can lead to severe problems to animals (Dale & Rebek, 2006). Gold mining, electroplating, and the production of various organic chemicals and polymers, including nitriles, nylon and acrylic plastics, increase the likelihood of unintended cyanide release (Westley *et al.*, 1981).

Cations and their Toxicity

Most of the enzyme contains different transition metals at their active site. Free forms of transition metal ions are highly toxic in nature. Histidines, cysteines, aspartates and glutamates (small) are attracted by free Zn^{2+} ions, allows Zn^{2+} to bind to various proteins even at Nano molar concentrations. As a result, induction of protein–protein interactions and enzyme inhibition are common issues. Redox active iron and copper are influential catalysts to generate free radical species (Hessels & Merckx, 2015).

Abnormal deposition of aluminium in body tissues in humans and animals can cause Alzheimer's disease, Parkinson's disease, colic and gastrointestinal problems, rickets, lung cancer etc., it can also damage the brain, liver and kidneys (Becaria *et al.*, 2002).

Inadequate amount of chromium can increase the threats associated with diabetes, cardiovascular diseases and central nervous system disorders (Arakawa *et al.*, 2000) and also higher levels Cr^{3+} may even lead to cancer (Vincent, 2000).

Above discussion clearly shows that ions are essential for healthy life, but they are toxic after a limit. For the healthy living, different internationally accreditation organizations like American Public Health Association (APHA), United States Environmental Protection Agency (USEPA), World Health Organization (WHO), Indian Standard Institution (ISI), Indian Council of Medical Research (ICMR) and Central Pollution Control Board (CPCB) directed the safe limits of various ions in drinking water (Kumar & Puri, 2012).

From the above discussion it is recognized that ions are vital for environmental safety and healthy life. The measurement of ions' concentration is necessary for Growing public interest and increasingly stringent legal requirements for environmental, food, and water monitoring. One of the important aspects is to couple various methodologies, physical process to develop analytical techniques those are highly sensitive, specific, cheap, environmentally benign, easy to handle and versatile. Thus, market demanding research in chemistry is adopting its space.

Instrumental Techniques of Detection

Different techniques have been used for elemental analysis like flame or graphite furnace atomic absorption spectroscopy (AAS) (Cerchiaro *et al.*, 2013), inductively coupled plasma-atomic emission spectrometry (ICP-AES) (Pomazal *et al.*, 1999), voltammetry (van den Berg, 2006), inductively coupled plasma mass spectrometry (ICPMS) (Pröfrock & Prange, 2012), CE (capillary electrophoresis) (Timerbaev *et al.*, 1999), FAAS (flame atomic absorption spectroscopy) (Shamspur *et al.*, 2005), thin chitosan films (McIlwee *et al.*, 2008), functionalized metal nanoparticles (Mehta *et al.*, 2014), flow injection (Ussher *et al.*, 2009), carbon dots (Zhao *et al.*, 2014), graphene quantum dots (Ananthanarayanan *et al.*, 2014), fiber-optic redox

methods (Chudyk *et al.*, 2014) and cyclodextrin supramolecular complex (Xu *et al.*, 2010). However, these techniques are costly, sophisticated; quite inconvenient for its complexity. Furthermore, UV-visible and fluorescence spectroscopy are the most regularly used modes as well as the most favourable methods for the detection of physiologically and environmentally important analyte, due to their low detection limit and imaging of analyte in biological system. Among various sensing techniques UV-visible and fluorescence spectroscopy grabs the most attention of sensor laboratories due to its low cost, simple in operation method, highly selective and sensitive in nature.

Chemical Sensor

Optical absorption, redox potential, luminescence etc. are mostly used techniques. However, sensors based on other spectroscopic techniques, as well as those utilizing optical parameters such as reflectivity and refractive index, have also been extensively developed (McDonagh *et al.*, 2008). Fluorescence spectroscopic technique can provide excellent sensitivity and fluorescent sensors are 105 times more sensitive than any other absorption spectroscopic technique (Valeur, 2002). Excitation and emission spectra, fluorescence intensity, anisotropy, Stokes shift and fluorescence lifetime can provide qualitative recognition and quantitative measurement of various cat ions, anions and particles (Parker, 2000) in case of fluorescence technique.

Basis of Designing Fluorescent Probe

A fluorescent chemosensor is a molecular system that exhibits a change in its fluorescence spectra when an interconnection take place with a chemical species. Two different chemical specieses produced a new species called a fluorescent chemosensor. Where fluorophore is a signalling unit and guest receptor has identification power, spacer is the connecting unit of them (Figure 3), the newly formed species is so-called fluorophore–spacer–receptor scaffold (Lodeiro *et al.*, 2010). When the receptor unit bind with the guest molecule, automatically different fluorophoric property changes, for instances emission wavelength, fluorescence intensity and fluorescence lifetime. They follow different mechanism too. It is a mandatory task to develop and improve various sophisticated fluorescence chemosensor. It uses in different disciplines such as process control, environmental monitoring, food product etc (Bell & Hext, 2004).

The signaling moiety is a signal transducer, i.e. it transfers the information into an optical signal presented as changes in the various photophysical characteristics of the fluorophore. The sensing mechanism basically controlled by different concepts, such as soft-hard acid base principle is the fundamental concept of selection, the principle of coordination theory, size of chelate ring, size of space in chelate cavity etc.

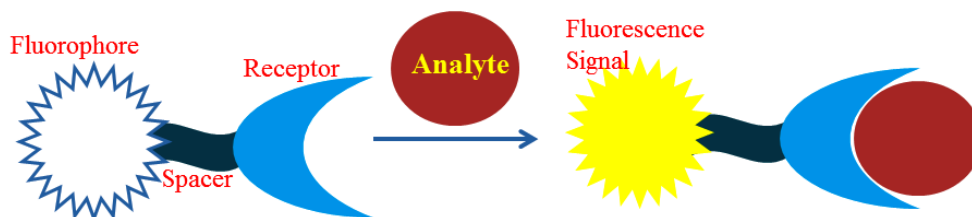


Figure 3: Schematic Diagram Depicting the Binding of an Analyte (Guest) to a Chemosensor (Host), Resulting in the Formation of a Host–Guest Complex with Altered Optical Properties

Most conventional sensing mechanisms are photoinduced electron transfer (PET) (Martinez-Manez *et al.*, 2003), intramolecular charge transfer (ICT) (Kim & Quang, 2007), metal–ligand charge transfer (MLCT) (Zhao & Huang, 2010), twisted intramolecular charge transfer (TICT), electronic energy transfer (EET) (De Silva *et al.*, 1997; Martinez-Manez *et al.*, 2003), and fluorescence resonance energy transfer (FRET) (Carlson & Campbell, 2009) and excimer/exciplex formation (Martinez-Manez *et al.*, 2003). Based on

conformational restriction, two mechanisms are also available, that are Aggregation-induced emission (AIE) (Hong *et al.*, 2009), and CQN isomerisation. ESIPT is another sensing mechanism (Berezin & Achilefu, 2010) but not been well reviewed. Non radiative decay and radiative decay generally encourage by a flexible structure and a rigid fluorophoric structure; Isomerization of the double bond requires energy and promotes nonradiative decay (Toyota, 2010); the rate of electron transfer in the excited state is significantly slower than that of proton transfer (Hsieh *et al.*, 2008). Molecular rotation reduces fluorescence intensity.

Different Functional Motifs to Chemosensor

Hydrazides contain a nitrogen-to-nitrogen covalent bond and at least one acyl group, again 3 substituents also; the derivatives belong to the organic compounds (McNaught *et al.*, 1997). Hydrazides generally have the structure E (=O)-NR-NR₂, with the R substituents most commonly being hydrogen atoms. There is another classification depending on atom attached to the oxygen in hydrazide moiety: sulfonylhydrazides (R-S(=O)₂-NH-NH₂), carbohydrazides (R-C(=O)-NH-NH₂) and phosphonic dihydrazides (R-P(=O)(-NH-NH₂)₂). Various bioactive heterocyclic compounds contain hydrazides and hydrazones moiety; they have wide clinical and biological applications (Narang *et al.*, 2012). Hydrazide derivatives have various biological applications i.e. anthelmintic, anti-inflammatory, anticancer, antimicrobial, anti-HIV, antimycobacterial, antidiabetic, trypanocidal as well antimalarial activities.

Hydrazide derivatives have strong binding ability with different metal ions through stable chelate formation (Das *et al.*, 2015) and due to presence of hydrazides-NH, it may bind with anions via H-bond formation (Samanta *et al.*, 2015). Presence of free -NH₂ creates a wide range of simple condensation probability with carbonyl to generate new and new Schiff bases.

Hydrazide Appended Fluorescence Probes as Analyte Sensors

Here are some pioneering works related to hydrazide moieties sensitive for selective fluorescence sensors are discussing below.

(a) ((2-hydroxy-5-methyl-1,3-phenylene)bis(methanylylidene))bis(quinoline-2-carbohydrazide)

Quinaldic hydrazide (2 mmol) was added to an ethanolic solution of 2,6-diformyl-4-methylphenol (1 mmol), resulting in the formation of a yellow precipitate of the probe (Figure 4). The probe shows multi-analyte sensitivity by displaying distinct emission spectra characteristic of Al³⁺, Zn²⁺, and F⁻ ions. On excitation at 450 nm, the probe showed a remarkable enhancement in emission spectra exclusively in the presence of Al³⁺ and Zn²⁺, with two distinct emission maxima observed at 500 nm and 550 nm, respectively.

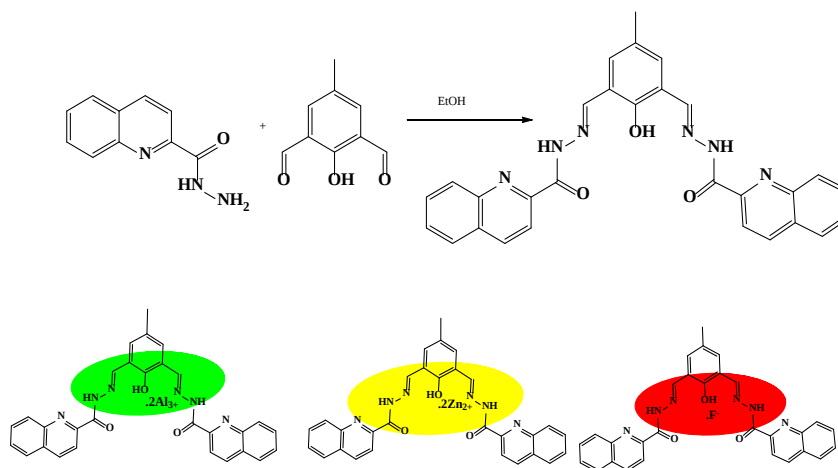


Figure 4: Synthesis of Probe and Schematic Representation of Sensing of Al³⁺, Zn²⁺ and F⁻ by Probe

This response was evaluated in a buffered solution containing various competing metal ions, including Na^+ , K^+ , Mg^{2+} , Ca^{2+} , Cr^{3+} , Fe^{3+} , Co^{2+} , Ni^{2+} , Cu^{2+} , Zn^{2+} , Cd^{2+} , Hg^{2+} , Ag^+ , Pb^{2+} , and Al^{3+} . Also, fluorescence sensitivity of the probe was checked with various anions (F^- , Cl^- , Br^- , I^- , OH^- , NO_3^- , S^{2-} , SO_4^{2-} , HSO_3^- , ClO_4^- , ClO_3^- , CN^- , H_2PO_4^- , and PO_4^{3-}), only F^- conveyed an alteration in the emission spectra of the probe by enhancing emission intensity at 575 nm in an acetonitrile solvent medium with 0.33% DMSO as a co-solvent. The detection limit of probe for Zn^{2+} , Al^{3+} and F^- is 35 ppb, 32 ppb and 40 ppb respectively. Interaction between probe and analyses follow the chelation enhanced fluorescence (CHEF) mechanism. In general, deprotonation initiates the ICT process, resulting in the activation ("turn-on") of the receptor's fluorescence (Datta *et al.*, 2015).

(b) (E)-N'-((E)-3-(4-(dimethylamino)phenyl)allylidene)quinoline-2-carbohydrazide

To a methanolic solution of quinaldic hydrazide, 4-(dimethylamino)cinnamaldehyde was added, followed by the addition of approximately two drops of acetic acid. The reaction mixture was then stirred at room temperature for 12 hours, resulting in the formation of an orange solid probe. The probe can identify Zn^{2+} , Cd^{2+} and Pb^{2+} are environmentally and biologically significant metal ions, in the presence of various metal ions (Na^+ , K^+ , Ca^{2+} , Mg^{2+} , Al^{3+} , Cr^{3+} , Fe^{3+} , Ni^{2+} , Co^{2+} , Cu^{2+} , Zn^{2+} , Hg^{2+} , Pb^{2+} , Cd^{2+} , and Ag^+) via selective turn-on fluorescence responses under physiological pH conditions. In the presence of excess (20 equivalents) Pb^{2+} , probe showed a ~20 fold increase in its fluorescence intensity with a well-defined emission maximum at 582 nm. Similarly, addition of excess (20 equivalents) Zn^{2+} and Cd^{2+} to probe led to approximately a 10-fold and 9-fold increase in fluorescence intensity of the probe, along with the appearance of new emission maxima at 573 nm and 608 nm, respectively (Figure 5). The detection limits for Zn^{2+} , Cd^{2+} , and Pb^{2+} were determined to be 21.27 ppb, 72.81 ppb and 0.68 ppm, respectively. The selective turn-on emission of the probe in the presence of Pb^{2+} , Zn^{2+} , and Cd^{2+} can be attributed to the chelation-enhanced fluorescence (CHEF) mechanism (Samanta *et al.*, 2016).

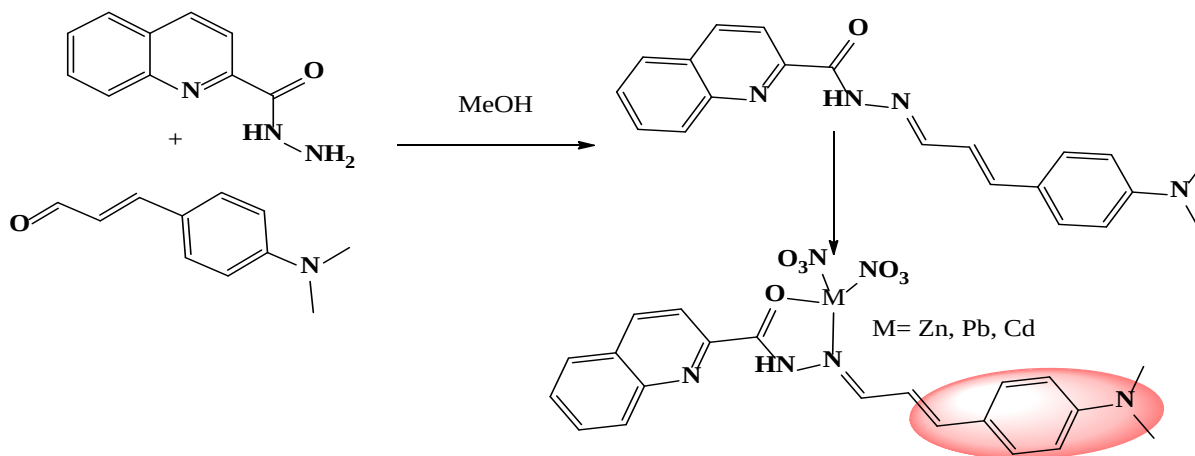


Figure 5: Synthesis of Probe and Schematic Representation of Sensing of Zn^{2+} , Pb^{2+} and Cd^{2+} by Probe

(c) (3,5-dichloro-2- hydroxybenzylidene) quinoline-2-carbohydrazide

A methanolic solution of quinoline-4-carboxylic hydrazide was added to a methanolic solution of 3,5-dichlorosalicylaldehyde, and the resulting reaction mixture was refluxed for 5 hours under a nitrogen (N_2) atmosphere. The mixture was separated by removing solvent under reduced pressure and kept into refrigerator 24 hours. By filtration probe was collected as yellow mass. The probe selectively identifies Al^{3+} in $\text{EtOH-H}_2\text{O}$ and Complexed with Al^{3+} in a 1:1 molar ratio. The detection limit was very low as 0.012 μM (Fig 6). But probe- Al^{3+} was destroyed by F^- in the solution, the complex could be used to identify F^- in solution phase future. The enhancement fluorescence of the probe was explained by CHEF mechanism

induced by Al^{3+} . The probe was successfully employed for the sensitive detection of trace Al^{3+} in human blood serum and tap water samples. Furthermore, it was utilized for fluorescence imaging of Al^{3+} in HeLa cells, demonstrating its potential for both environmental and biological applications (Zhou *et al.*, 2018).

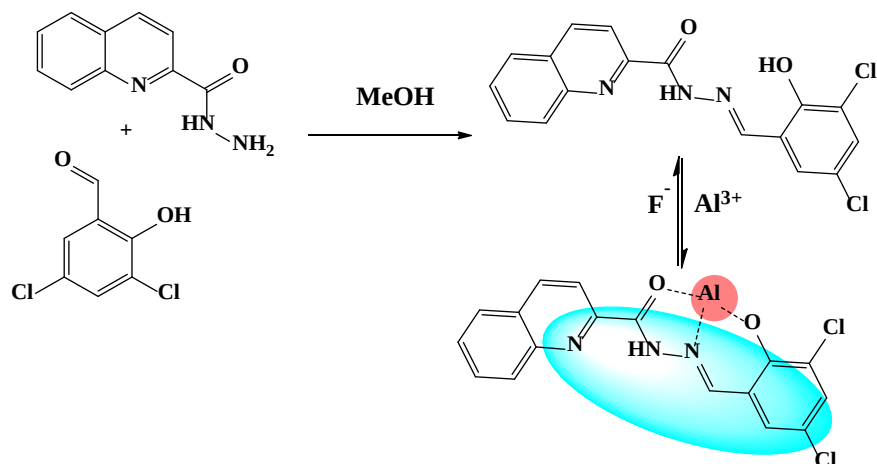


Figure 6: Synthesis of Probe and Schematic Representation of Sensing of Al^{3+} and F^- by Probe

(d) 2-((2-Hydroxynaphthalen-1-yl)methylene)hydrazine carbothioamide

Condensation of simple hydrazide, Thiosemicarbazide and 2-hydroxy-1-naphthaldehyde synthesised 2-((2-hydroxynaphthalen-1-yl)methylene)hydrazine carbothioamide (Fig 7), which recognize AsO_2^- and CN^- ions. At an excitation wavelength of 363 nm, arsenite and cyanide ions are selectively exhibited a 'turn-on' fluorescence emission at 495 nm in the presence of the target analyte, while showing negligible response toward the other anions investigated (F^- , Cl^- , Br^- , I^- , SO_4^{2-} , SCN^- , SO_3^{2-} , H_2PO_4^- , HPO_4^{2-} , CH_3COO^- , NO_3^- , N_3^- , PO_4^{3-} and IO_3^-) in DMF: H_2O medium. The limits of detection (LODs) for cyanide and arsenite ions were 77 nM and 66 nM, respectively. Extensive hydrogen bonding accompanied by deprotonation between the probe and two anions was the driving force for enhancement in the intensity of emission spectra (Yadav *et al.*, 2016).

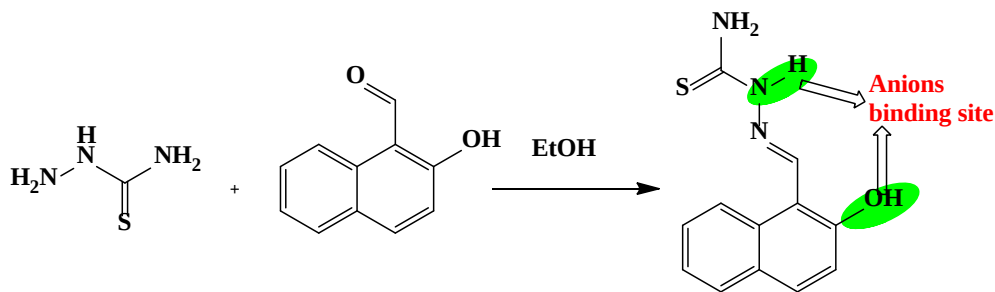


Figure 7: The Synthesis of Dual AsO_2^- , CN^- Sensor Probe with Assignment of Anions Binding Unit

(e) 2,2'-((2-hydroxy-5-methyl-1,3-phenylene)bis(methanylylidene))bis(hydrazinecarbo thioamide)

The probe was synthesized by condensation of thiosemicarbazide with 2-hydroxy-5-methylbenzene-1,3-dialdehyde in 2:1 molar ratio in ethanolic solution and a yellow mass was obtained with good yield (Fig 8). The probe was selectively identifying acetate ion in DMSO medium by reflecting tricolour emission (Lohar *et al.*, 2016). At the initial stage, the emission peak at 562 nm (orange) gradually decreases in intensity while exhibiting a blue shift to 548 nm (yellow) over the first 1 h. Between 1 and 1.5 h, the emission intensity increases at the same wavelength (548 nm) without any further shift. From 1.5 to 2 h, the emission intensity decreases again, accompanied by an additional blue shift. The emission intensity at 515 nm (green)

increased continuously over the time interval from 30 s to 2 h. The association constant (K_a) of the probe toward AcO^- , determined using the Benesi–Hildebrand method, was $6.6 \times 10^4 \text{ M}^{-1}$, while the detection limit for AcO^- was calculated to be $1.06 \times 10^{-7} \text{ M}$.

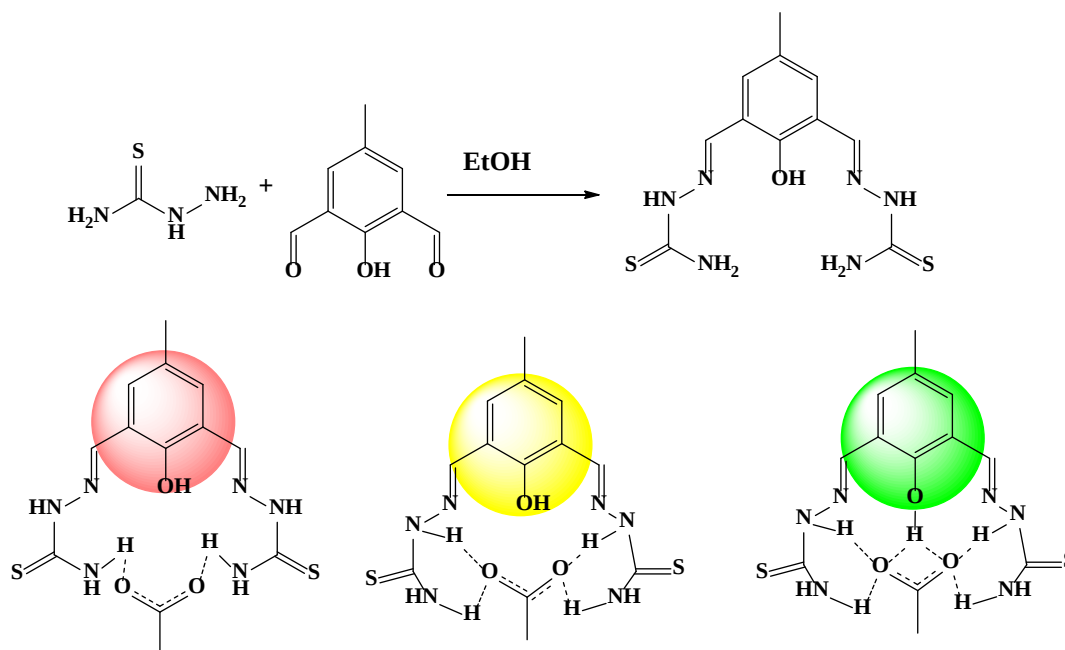


Figure 8: Synthesis of Probe and Schematic Representation of Sensing of AcO^- by Probe

Tang *et al.* (2017a) reported the same fluorescence probe selectively identifies Zn^{2+} and Hg^{2+} in the aqueous HEPES buffer through turn-on fluorescence pathway. On excitation at 390 nm wavelength the probe shows Strong fluorescent emission was observed at 478 nm and 580 nm in the presence of Zn^{2+} and Hg^{2+} , respectively. The limit of detection (LOD) was determined to be $1.46 \times 10^{-7} \text{ M}$ for Zn^{2+} and $2.50 \times 10^{-7} \text{ M}$ for Hg^{2+} . Furthermore, the probe was successfully employed for the fluorescence imaging and detection of Zn^{2+} and Hg^{2+} in living cells, demonstrating its potential for biological applications.

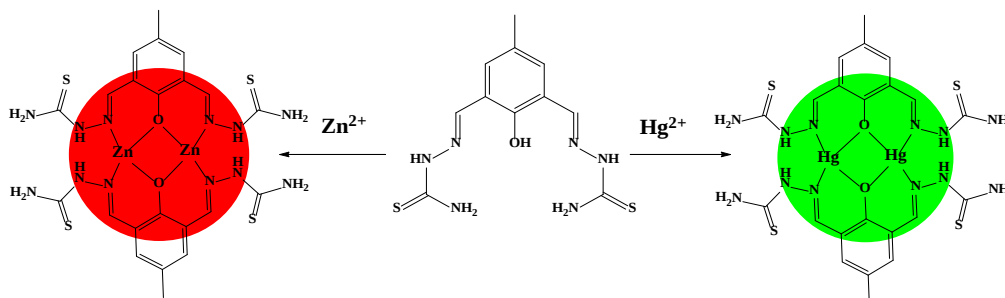


Figure 9: Schematic Representation of Sensing of Zn^{2+} and Hg^{2+} by Probe

(f) (E)-N'-(2-hydroxy-5-methyl-3-(4-oxo-3,4-dihydroquinazolin-2-yl)benzylidene) picolinohydrazide

Picolinohydrazide was mixture with 2-Hydroxy-5-methyl-3-(4-oxo-3,4-dihydro-quinazolin-2-yl)-benzaldehyde in DMSO medium and refluxed for 3 hours at 70°C . The reaction mixture was slowly poured into ice-cold water under continuous stirring. The resulting precipitate was collected by filtration and thoroughly washed with distilled water. A orange yellow solid was obtained (Fig 10). In Tris- HCl buffer solution, probe selectively identify Al^{3+} ion over other metal ions, exhibiting a significant blue shift and

enhanced emission at 473 nm. The probe binds with Al^{3+} in a 1:2 stoichiometric ratio and exhibits a detection limit of 4.79×10^{-8} M. For real-world application, its performance was evaluated through proof-of-concept studies using tap water and lake water samples (Tang *et al.*, 2017b).

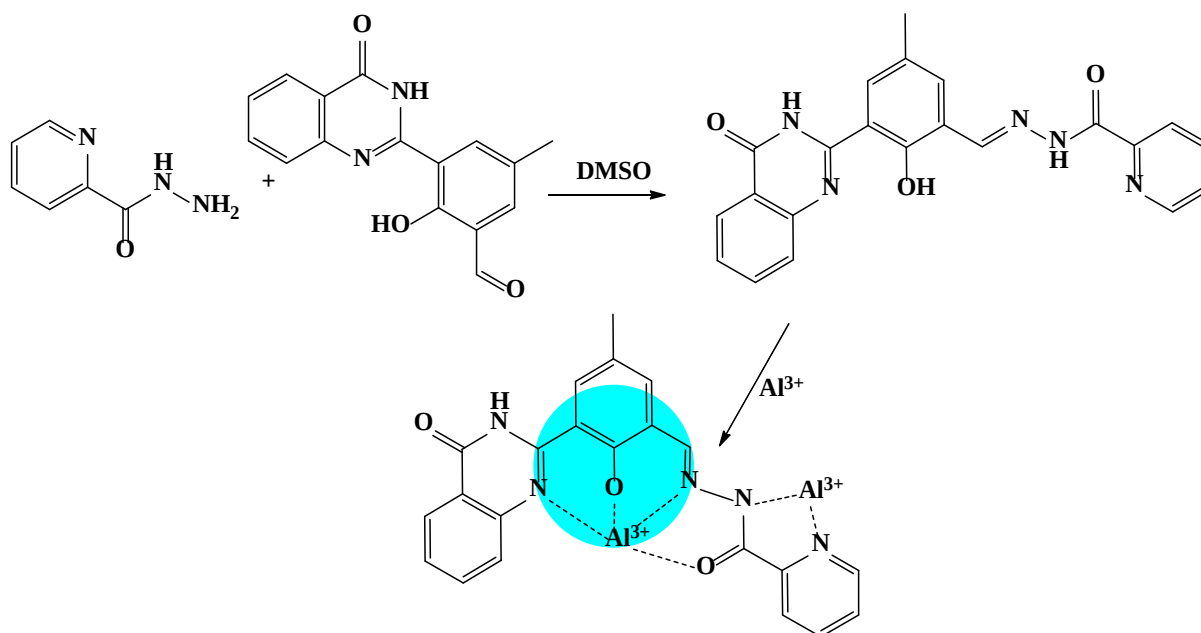


Figure 10: Synthesis of Probe and Schematic Representation of Sensing of Al^{3+} by Probe

(g) (E)-N'-((7-(diethylamino)-2-oxo-2H-chromen-3-yl)methylene)picolinohydrazide

2-picolinyl hydrazide and 7-diethylaminocoumarin-3-aldehyde was mixed in ethanolic solution and by condensation the probe was synthesized. The Probe exhibits a strong green fluorescence at 509 nm. Fluorescence intensity of the probe was enhanced by adding 1.4 equiv. of Cu^{2+} (Fig 11). The probe acts as a “turn off” fluorescence chemosensors for Cu^{2+} . Intramolecular photoinduced electron transfer (PET) from the excited fluorophore to Cu^{2+} upon complex formation can lead to fluorescence quenching. Again, research indicates that copper-probe complex is a “turn-on” Fluorescent chemosensors for cyanide ions (CN^-). The detection limits for CN^- is $0.019 \mu\text{M}$ in acetonitrile medium (Wang *et al.*, 2016).

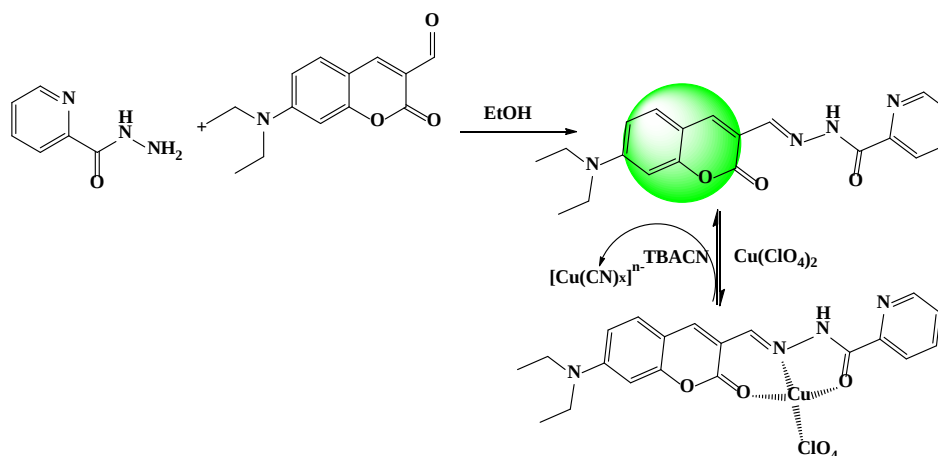


Figure 11: Synthesis of Probe and Schematic Representation of Sensing of Cu^{2+} by Probe

(h) (N',N'''E,N',N'''E)-N',N'''-((2-hydroxy-5-methyl-1,3-phenylene)bis(methanylylidene))di(picolinohydrazide)

Picolinic hydrazide (2 mmol) was added to an ethanolic solution of 2,6-diformyl-4-methylphenol (1 mmol), and the mixture was refluxed for 4 hours. A yellow crystalline crude product was obtained, which was used as the probe (Fig 12). The probe selectively identifies Zn^{2+} is preferentially utilized over other metal ions under physiological conditions. The fluorescence emission intensity was significantly enhanced upon addition of Zn^{2+} , accompanied by a red shift of approximately 25 nm. The experiment was performed under fully physiological conditions (99.7% HEPES buffer) and exhibited visible-light excitation capability. The association constant between probe and Zn^{2+} was found to be $5.58 \times 10^5 \text{ M}^{-1}$. The probe could detect as low as (LOD) 69 ppb Zn^{2+} . The sensing mechanism was explained by chelation enhanced fluorescence (CHEF) processes and intramolecular charge transfer (ICT). The probe was completely non-toxic and enabled intracellular Zn^{2+} detection in HeLa cells, as demonstrated by fluorescence imaging studies (Datta *et al.*, 2014).

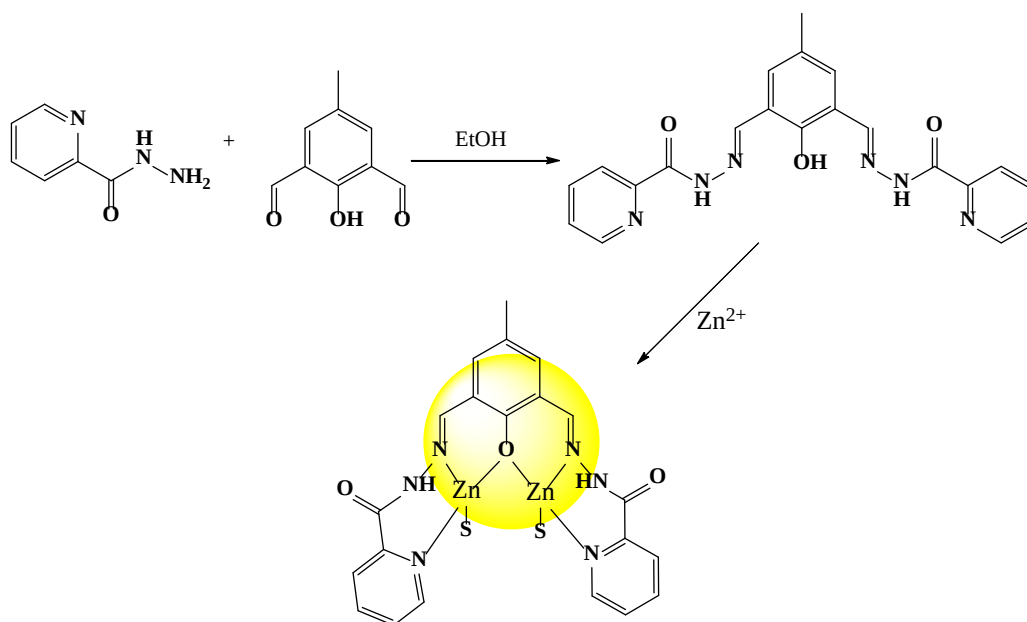


Figure 12: Synthesis of Probe and Schematic Representation of Sensing of Zn^{2+} by Probe

Conclusion

The multitude references reported in the articles emphasize the synthesis of different hydrazide appended fluorometric chemosensors which are able to detect different metal ions in solution phase and in physiological conditions. This research field is prosperous and still flourishing with great dedication.

Acknowledgement

The author gratefully acknowledges Dr. Rakesh Purkait, Jadavpur University, India, for his valuable support, guidance, and insightful contributions throughout the course of this work.

References

Ananthanarayanan, A., Wang, X., Routh, P., Sana, B., Lim, S., Kim, D. H., & Chen, P. (2014). Facile synthesis of graphene quantum dots from 3D graphene and their application for Fe^{3+} sensing. *Advanced Functional Materials*, 24(20), 3021-3026. <https://doi.org/10.1002/adfm.201303441>

- Arakawa, H., Ahmad, R., Naoui, M., & Tajmir-Riahi, H. A. (2000). A Comparative Study of Calf Thymus DNA Binding to Cr (III) and Cr (VI) Ions: evidence for the guanine N-7-chromium-phosphate chelate formation. *Journal of Biological Chemistry*, 275(14), 10150-10153. <https://doi.org/10.1074/jbc.275.14.10150>
- Ayoob, S., & Gupta, A. K. (2006). Fluoride in drinking water: a review on the status and stress effects. *Critical Reviews in Environmental Science and Technology*, 36(6), 433-487. <https://doi.org/10.1080/10643380600678112>
- Becaria, A., Campbell, A., & Bondy, S. C. (2002). Aluminum as a toxicant. *Toxicology and Industrial Health*, 18(7), 309-320. <https://doi.org/10.1191/0748233702th157oa>
- Bell, T. W., & Hext, N. M. (2004). Supramolecular optical chemosensors for organic analytes. *Chemical Society Reviews*, 33(9), 589-598. <https://doi.org/10.1039/B207182G>
- Berezin, M. Y., & Achilefu, S. (2010). Fluorescence lifetime measurements and biological imaging. *Chemical Reviews*, 110(5), 2641-2684. <https://doi.org/10.1021/cr900343z>
- Carlson, H. J., & Campbell, R. E. (2009). Genetically encoded FRET-based biosensors for multiparameter fluorescence imaging. *Current Opinion in Biotechnology*, 20(1), 19-27. <https://doi.org/10.1016/j.copbio.2009.01.003>
- Cerchiaro, G., Manieri, T. M., & Bertuchi, F. R. (2013). Analytical methods for copper, zinc and iron quantification in mammalian cells. *Metallomics*, 5(10), 1336-1345. <https://doi.org/10.1039/c3mt00136a>
- Chudyk, W., Sotolongo, C., & Mueller, E. (2014). A fiber-optic redox sensor for the iron (III)–iron (II) transition. *Environmental Monitoring and Assessment*, 186(1), 415-420. <https://doi.org/10.1007/s10661-013-3386-x>
- Dale, T. J., & Rebek, J. (2006). Fluorescent sensors for organophosphorus nerve agent mimics. *Journal of the American Chemical Society*, 128(14), 4500-4501. <https://doi.org/10.1021/ja057449i>
- Das, K., Panda, U., Datta, A., Roy, S., Mondal, S., Massera, C., ... & Kobayashi, K. (2015). An enolato-bridged dinuclear Cu (II) complex with a coumarin-assisted precursor: a spectral, magnetic and biological study. *New Journal of Chemistry*, 39(9), 7309-7321. <https://doi.org/10.1039/c5nj00789e>
- Datta, B. K., Thiagarajan, D., Ramesh, A., & Das, G. (2015). A sole multi-analyte receptor responds with three distinct fluorescence signals: traffic signal like sensing of Al³⁺, Zn²⁺ and F[−]. *Dalton Transactions*, 44(29), 13093-13099. <https://doi.org/10.1039/C5DT01468A>
- Datta, B. K., Thiagarajan, D., Samanta, S., Ramesh, A., & Das, G. (2014). A novel chemosensor with visible light excitability for sensing Zn²⁺ in physiological medium and in HeLa cells. *Organic & Biomolecular Chemistry*, 12(27), 4975-4982. <https://doi.org/10.1039/C4OB00653D>
- De Silva, A. P., Gunaratne, H. N., Gunnlaugsson, T., Huxley, A. J., McCoy, C. P., Rademacher, J. T., & Rice, T. E. (1997). Signaling recognition events with fluorescent sensors and switches. *Chemical reviews*, 97(5), 1515-1566. <https://doi.org/10.1021/cr960386p>
- Dhillon, A., Nair, M., & Kumar, D. (2015). Analytical methods for sensing of health-hazardous arsenic from biotic and abiotic natural resources. *Analytical Methods*, 7(24), 10088-10108. <https://doi.org/10.1039/C5AY02430G>
- Fan, H. T., Fan, X., Li, J., Guo, M., Zhang, D., Yan, F., & Sun, T. (2012). Selective removal of arsenic (V) from aqueous solution using a surface-ion-imprinted amine-functionalized silica gel sorbent. *Industrial & Engineering Chemistry Research*, 51(14), 5216-5223. <https://doi.org/10.1021/ie202655x>
- Govindhan, M., Adhikari, B. R., & Chen, A. (2014). Nanomaterials-based electrochemical detection of chemical contaminants. *RSC Advances*, 4(109), 63741-63760. <https://doi.org/10.1039/C4RA10399H>
- Hessels, A. M., & Merkx, M. (2015). Genetically-encoded FRET-based sensors for monitoring Zn²⁺ in living cells. *Metallomics*, 7(2), 258-266. <https://doi.org/10.1039/c4mt00179f>
- Hong, Y., Lam, J. W., & Tang, B. Z. (2009). Aggregation-induced emission: phenomenon, mechanism and applications. *Chemical Communications*, 45(29), 4332-4353. <https://doi.org/10.1039/b904665h>
- Hsieh, C. C., Cheng, Y. M., Hsu, C. J., Chen, K. Y., & Chou, P. T. (2008). Spectroscopy and femtosecond dynamics of excited-state proton transfer induced charge transfer reaction. *The Journal of Physical Chemistry A*, 112(36), 8323-8332. <https://doi.org/10.1021/jp804216u>

Flourescence Sensing Mechanism and Hydrazide Moiety

- Kansal, S. K., & Kumari, A. (2014). Potential of *M. oleifera* for the treatment of water and wastewater. *Chemical Reviews*, 114(9), 4993-5010. <https://doi.org/10.1021/cr400093w>
- Kantiani, L., Llorca, M., Sanchís, J., Farré, M., & Barceló, D. (2010). Emerging food contaminants: a review. *Analytical and Bioanalytical Chemistry*, 398(6), 2413-2427. <https://doi.org/10.1007/s00216-010-3944-9>
- Kim, J. S., & Quang, D. T. (2007). Calixarene-derived fluorescent probes. *Chemical Reviews*, 107(9), 3780-3799. <https://doi.org/10.1021/cr068046j>
- Kleerekoper, M. (1998). The role of fluoride in the prevention of osteoporosis. *Endocrinology and Metabolism Clinics*, 27(2), 441-452. [https://doi.org/10.1016/S0889-8529\(05\)70015-3](https://doi.org/10.1016/S0889-8529(05)70015-3)
- Kumar, M., & Puri, A. (2012). A review of permissible limits of drinking water. *Indian Journal of Occupational and Environmental Medicine*, 16(1), 40-44. <https://doi.org/10.4103/0019-5278.99696>
- Li, C., Xu, W., Jia, D., & Liu, X. (2013). Removal of arsenic from drinking water by using the Zr-loaded resin. *Journal of Chemical & Engineering Data*, 58(2), 427-435. <https://doi.org/10.1021/je301148t>
- Lodeiro, C., Capelo, J. L., Mejuto, J. C., Oliveira, E., Santos, H. M., Pedras, B., & Nunez, C. (2010). Light and colour as analytical detection tools: a journey into the periodic table using polyamines to bio-inspired systems as chemosensors. *Chemical Society Reviews*, 39(8), 2948-2976. <https://doi.org/10.1039/b819787n>
- Lohar, S., Sinha, S., Ghosh, S., & Das, D. (2016). Tri-color emission and colorimetric recognition of acetate using semicarbazide and thio-semicarbazide derivatives: Experimental and computational studies. *Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy*, 155, 75-80. <https://doi.org/10.1016/j.saa.2015.10.018>
- Mak, W. C., Chan, C., Barford, J., & Renneberg, R. (2003). Biosensor for rapid phosphate monitoring in a sequencing batch reactor (SBR) system. *Biosensors and bioelectronics*, 19(3), 233-237. [https://doi.org/10.1016/S0956-5663\(03\)00209-4](https://doi.org/10.1016/S0956-5663(03)00209-4)
- Martinez-Manez, R., & Sancenón, F. (2003). Fluorogenic and chromogenic chemosensors and reagents for anions. *Chemical Reviews*, 103(11), 4419-4476. <https://doi.org/10.1021/cr010421e>
- McDonagh, C., Burke, C. S., & MacCraith, B. D. (2008). Optical chemical sensors. *Chemical Reviews*, 108(2), 400-422. <https://doi.org/10.1021/cr068102g>
- McIlwee, H. A., Schauer, C. L., Praig, V. G., Boukherroub, R., & Szunerits, S. (2008). Thin chitosan films as a platform for SPR sensing of ferric ions. *Analyst*, 133(5), 673-677. <https://doi.org/10.1039/b717736d>
- McNaught, A. D., Wilkinson, A., & Jenkins, A. D. (1997). International union of pure and applied chemistry. Compendium of chemical terminology: IUPAC recommendations, 2.
- Mehta, V. N., Kailasa, S. K., & Wu, H. F. (2014). Sensitive and selective colorimetric sensing of Fe³⁺ ion by using p-amino salicylic acid dithiocarbamate functionalized gold nanoparticles. *New Journal of Chemistry*, 38(4), 1503-1511. <https://doi.org/10.1039/c3nj01468a>
- Moriarty, M. M., Koch, I., & Reimer, K. J. (2013). Arsenic species and uptake in amphibians (*Rana clamitans* and *Bufo americanus*). *Environmental Science: Processes & Impacts*, 15(8), 1520-1528. <https://doi.org/10.1039/c3em00223c>
- Narang, R., Narasimhan, B., & Sharma, S. (2012). A review on biological activities and chemical synthesis of hydrazide derivatives. *Current Medicinal Chemistry*, 19(4), 569-612.
- Parker, D. (2000). Luminescent lanthanide sensors for pH, pO₂ and selected anions. *Coordination Chemistry Reviews*, 205(1), 109-130. [https://doi.org/10.1016/S0010-8545\(00\)00241-1](https://doi.org/10.1016/S0010-8545(00)00241-1)
- Pomazal, K., Prohaska, C., Steffan, I., Reich, G., & FK Huber, J. (1999). Determination of Cu, Fe, Mn, and Zn in blood fractions by SEC-HPLC-ICP-AES coupling. *Analyst*, 124(5), 657-663. <https://doi.org/10.1039/a809688k>
- Pröfrock, D., & Prange, A. (2012). Inductively coupled plasma-mass spectrometry (ICP-MS) for quantitative analysis in environmental and life sciences: a review of challenges, solutions, and trends. *Applied spectroscopy*, 66(8), 843-868. <https://doi.org/10.1366/12-06681>

- Pye, V. I., & Patrick, R. (1983). Ground water contamination in the United States. *Science*, 221(4612), 713-718. <https://doi.org/10.1126/science.6879171>
- Razzaque, M. S. (2011). Phosphate toxicity: new insights into an old problem. *Clinical science*, 120(3), 91-97. <https://doi.org/10.1042/CS20100377>
- Rijith, S., Anirudhan, T. S., & Shripathi, T. (2012). Evaluation of iron (III) chelated polymer grafted lignocellulosics for arsenic (V) adsorption in a batch reactor system. *Industrial & Engineering Chemistry Research*, 51(32), 10682-10694. <https://doi.org/10.1021/ie300732t>
- Samanta, S., Datta, B. K., Boral, M., Nandan, A., & Das, G. (2016). A multi-responsive turn-on fluorescent probe to sense Zn²⁺, Cd²⁺ and Pb²⁺: left-right-center emission signal swing. *Analyst*, 141(14), 4388-4393. <https://doi.org/10.1039/C6AN00657D>
- Samanta, S., Manna, U., Ray, T., & Das, G. (2015). Aggregation-induced emission (AIE) active probe for multiple targets: Fluorescent sensor for Zn²⁺ and Al³⁺ and colorimetric sensor for Cu²⁺ and F⁻. *Dalton Transactions*, 44, 18902–18910. <https://doi.org/10.1039/c5dt03186a>
- Shafiquzzaman, M., Azam, M. S., Mishima, I., & Nakajima, J. (2009). Technical and social evaluation of arsenic mitigation in rural Bangladesh. *Journal of Health, Population, and Nutrition*, 27(5), 674–683. <https://doi.org/10.3329/jhpn.v27i5.3779>
- Shamspur, T., Sheikhshoae, I., & Mashhadizadeh, M. H. (2005). Flame atomic absorption spectroscopy (FAAS) determination of iron (III) after preconcentration on to modified analcime zeolite with 5-((4-nitrophenylazo)-N-(2', 4'-dimethoxyphenyl)) salicylaldehyde by column method. *Journal of Analytical Atomic Spectrometry*, 20(5), 476-478. <https://doi.org/10.1039/b416097e>
- Shen, S., Li, X. F., Cullen, W. R., Weinfeld, M., & Le, X. C. (2013). Arsenic binding to proteins. *Chemical Reviews*, 113(10), 7769-7792. <https://doi.org/10.1021/cr300015c>
- Sullivan, C., Tyrer, M., Cheeseman, C. R., & Graham, N. J. (2010). Disposal of water treatment wastes containing arsenic—a review. *Science of the Total Environment*, 408(8), 1770-1778. <https://doi.org/10.1016/j.scitotenv.2010.01.010>
- Tang, X., Han, J., Wang, Y., Bao, X., Ni, L., Wang, L., & Li, L. (2017a). A highly sensitive turn-on fluorescent chemosensor for recognition of Zn²⁺ and Hg²⁺ and applications. *Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy*, 184, 177–183. <https://doi.org/10.1016/j.saa.2017.05.011>
- Tang, L., Ding, S., Zhong, K., Hou, S., Bian, Y., & Yan, X. (2017b). A new 2-(2'-hydroxyphenyl) quinazolin-4 (3H)-one derived acylhydrazone for fluorescence recognition of Al³⁺. *Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy*, 174, 70-74. <https://doi.org/10.1016/j.saa.2016.11.026>
- Timerbaev, A. R., Dabek-Zlotorzynska, E., & Hoop, M. A. V. D. (1999). Inorganic environmental analysis by capillary electrophoresis. *The Analyst*, 124(6), 811-826. <http://lib3.dss.go.th/fulltext/Journal/analyst/Analyst1999/no.6/1999v124n6p811-826.pdf>
- Toyota, S. (2010). Rotational isomerism involving acetylene carbon. *Chemical Reviews*, 110(9), 5398-5424. <https://doi.org/10.1021/cr1000628>
- U.S. Environmental Protection Agency. (2014). TSCA Chemical Substance Inventory. <https://www.epa.gov/tsca-inventory>
- Upadhyay, K. K., Mishra, R. K., Kumar, V., & Chowdhury, P. R. (2010). A coumarin based ICT probe for fluoride in aqueous medium with its real application. *Talanta*, 82(1), 312-318. <https://doi.org/10.1016/j.talanta.2010.04.041>
- Ussher, S. J., Milne, A., Landing, W. M., Attiq-ur-Rehman, K., Séguret, M. J., Holland, T., ... & Worsfold, P. J. (2009). Investigation of iron (III) reduction and trace metal interferences in the determination of dissolved iron in seawater using flow injection with luminol chemiluminescence detection. *Analytica Chimica Acta*, 652(1-2), 259-265. <https://doi.org/10.1016/j.aca.2009.06.011>
- Valeur, B. (2002). Molecular fluorescence: Principles and applications. Wiley-VCH Verlag GmbH.

Flourescence Sensing Mechanism and Hydrazide Moiety

- van den Berg, C. M. (2006). Chemical speciation of iron in seawater by cathodic stripping voltammetry with dihydroxynaphthalene. *Analytical Chemistry*, 78(1), 156-163. <https://doi.org/10.1021/ac051441+>
- Vincent, J. B. (2000). Quest for the molecular mechanism of chromium action and its relationship to diabetes. *Nutrition Reviews*, 58(3), 67-72. <https://doi.org/10.1111/j.1753-4887.2000.tb01841.x>
- Wang, K., Ma, L., Liu, G., Cao, D., Guan, R., & Liu, Z. (2016). Two fluorescence turn-on coumarin Schiff's base chemosensors for cyanide anions. *Dyes and Pigments*, 126, 104-109. <https://doi.org/10.1016/j.dyepig.2015.11.019>
- Warwick, C., Guerreiro, A., & Soares, A. (2013). Sensing and analysis of soluble phosphates in environmental samples: a review. *Biosensors and Bioelectronics*, 41, 1-11. <https://doi.org/10.1016/j.bios.2012.07.012>
- Westley, J., Vannessland, B., Conn, E. E., Knowles, C. J., & Wissing, F. (1981). Cyanide in biology. Academic Press, New York, 61.
- Xu, M., Wu, S., Zeng, F., & Yu, C. (2010). Cyclodextrin supramolecular complex as a water-soluble ratiometric sensor for ferric ion sensing. *Langmuir*, 26(6), 4529-4534. <https://doi.org/10.1021/la9033244>
- Yadav, N., & Singh, A. K. (2016). Dual anion colorimetric and fluorometric sensing of arsenite and cyanide ions. *RSC Advances*, 6(102), 100136-100144. <https://doi.org/10.1039/c6ra19781g>
- Zhao, A., Zhao, C., Li, M., Ren, J., & Qu, X. (2014). Ionic liquids as precursors for highly luminescent, surface-different nitrogen-doped carbon dots used for label-free detection of Cu²⁺/Fe³⁺ and cell imaging. *Analytica Chimica Acta*, 809, 128-133. <https://doi.org/10.1016/j.aca.2013.10.046>
- Zhao, Q., Li, F., & Huang, C. (2010). Phosphorescent chemosensors based on heavy-metal complexes. *Chemical Society Reviews*, 39(8), 3007-3030. <https://doi.org/10.1039/b915340c>
- Zhou, F., Wang, H., Liu, P., Hu, Q., Wang, Y., Liu, C., & Hu, J. (2018). A highly selective and sensitive turn-on probe for aluminum (III) based on quinoline Schiff's base and its cell imaging. *Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy*, 190, 104-110. <https://doi.org/10.1016/j.saa.2017.09.007>