



Synthesis of cinacalcet containing acrylamide hydrogels by photopolymerization and studying their sensing properties

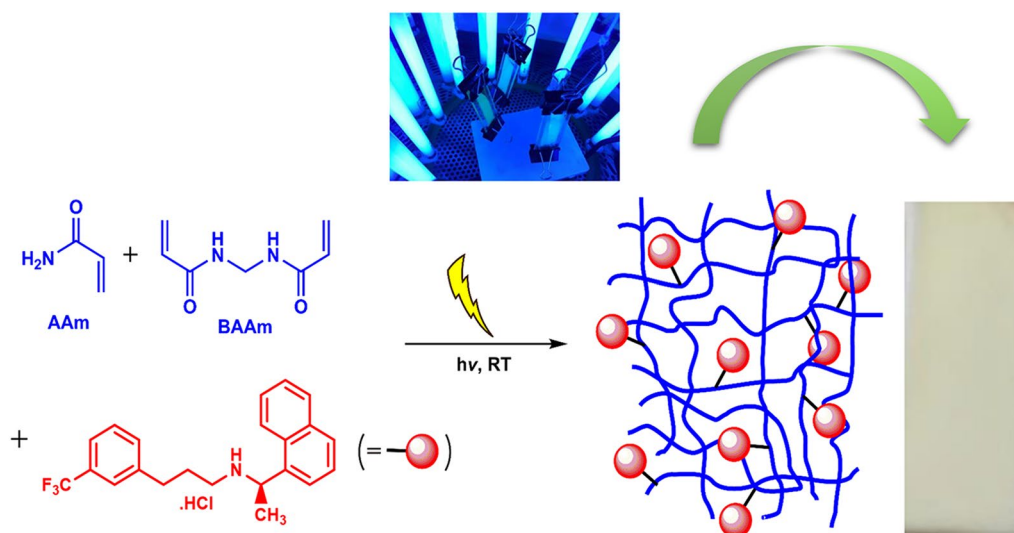
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Abstract

Novel cinacalcet containing acrylamide hydrogel (CIN-gel) was fabricated by free radical photopolymerization of acrylamide/*N,N'*-methylenebisacrylamide with cinacalcet hydrochloride as a photoinitiator. This hydrogel prepared by a one-pot photo-induced polymerization system was characterized with respect to its morphological and fluorescence features by means of SEM, UV–vis, and fluorescence spectroscopy. The CIN-gel displayed dual fluorescence emission when excited at 250 nm in water:acetonitrile (1:1, w/w) solution system owing to twisted intramolecular charge transfer between naphthalene and dimethylamino units in the cinacalcet moiety. The prepared fluorophore containing CIN-gel was employed as a fluorescent probe towards certain specific heavy metal ions (HMIs) such as Pb^{2+} , Sn^{2+} , Zn^{2+} and nitroaromatic compounds (NACs) such as 2-nitrotoluene, 2,4-dinitrophenol, 1,2-dinitrobenzene, 2,4,6-trinitrotoluene, 2,4,6-trinitrophenol, 4-nitrophenol, and 2,4-dinitrophenol. The use of cinacalcet hydrochloride as a photoinitiator and analyte for measuring HMIs and NACs during the production of the hydrogel is being reported for the first time. Fluorescence intensity of CIN-gel was gradually reduced upon the addition of NACs and HMIs. For all compounds, the highest quenching efficiencies were attained in the presence of Zn^{2+} (35.93%), 2,4,6-trinitrotoluene (95.67%), and 2,4-dinitrophenol (94.96%). Because of its simplicity and sensitivity, the proposed CIN-gel can be considered as potential chemical probe to detect the HMIs ions and NACs compounds.

Graphical abstract



Keywords Cinacalcet hydrochloride · Photoinitiation · Heavy metal ion-sensing · Nitroaromatic compound · Hydrogel

Introduction

For the last few decades, detection of heavy metal ions (HMIs) such as mercury, cadmium lead, stannous and zinc, and nitroaromatic compounds (NACs) like 2,4,6-trinitrotoluene, 2,4,6-trinitrophenol and 2,4-dinitrotoluene have attracted significant attention due to their serious negative effects on human health, living organisms and environment [1–4]. Great efforts have been made to find cheap, reliable and simple ways to detect these species. Owing to sensitivity, selectivity and response time advantages, fluorescence spectroscopy has been employed and the construction of selective sensor materials containing fluorophore groups has gained great importance [5–7].

Over the last decade, hydrogel sensors have gained considerable recognition as a valuable tool for sensing applications [8–10]. Due to their three-dimensional network structures and capability of swelling and retaining a significant amount of water, these materials enable the detection of toxic or environmentally harmful compounds with high selectivity, sensitivity, stability and reproducibility [11–13]. The hydrogel sensors are designed by characterizing the analyte-stimulated change in physical properties of light emission, light diffraction and refraction, resonance frequency, color and light absorbance. Two main synthetic routes have been followed for the preparation of hydrogel networks containing fluorophore sites. First route is a one-pot synthesis of hydrogel sensors by polymerization of suitable monomers and fluorophores [14, 15]. Second route is initially the synthesis of the hydrogel matrix and functionalization of the previously formed matrix with fluorophore groups [16]. Generally, hydrogel sensors are prepared via photo [17–19] or redox [20–22] polymerization of water-soluble acrylamide monomers. Among them, the photoinduced process is one of the effective and environmentally friendly methods for the preparation of hydrogels [16, 23]. Different chromophore groups like coumarin [24, 25], dansyl [26, 27], pyrene [16, 28], fluorescein [29, 30], 2-vinylnaphthalene [31], 9-vinyl anthracene [32], quinoline groups [33], 1,8-naphthalimide derivative [34] and rhodamine [35, 36] are covalently or physically bonded to hydrogels to construct sensor materials. Recently the calcimimetic drug, as cinacalcet hydrochloride, was utilized to bond calcium-sensing receptor of the parathyroid and to lower the sensitivity for receptor activation by extracellular calcium, thus decreasing the parathyroid hormone [37–39].

In this research, one-pot preparation of hydrogels containing cinacalcet fluorophore was described by photopolymerization of acrylamide and *N,N'*-methylenebisacrylamide initiated upon UV irradiation of cinacalcet hydrochloride without any photoinitiator. This is the first

report cinacalcet hydrochloride used in the synthesis of the hydrogel as a photoinitiator and an analyte for sensing HMIs and NACs. In this approach, photolysis of a cinacalcet hydrochloride forms free radicals, which can initiate the polymerization of acrylamide monomers. The performance of the obtained hydrogel has been studied by detecting HMIs and NACs in fluorescence spectroscopy. Scanning electron microscopy (SEM) was also utilized to prove the porous structures of the gels.

Experimental

Materials

Acrylamide (AAm, 99%, Alfa Aesar, Germany), cinacalcet hydrochloride (CIN, Lupin, $\geq 99\%$, USA), *N,N'*-methylenebisacrylamide (BAAm, 99.0%, AppliChem, USA), manganese (II) chloride dihydrate (Merck, $\geq 99\%$, Germany), mercury (II) chloride (Alfa Aesar, $\geq 98\%$, Germany), cobalt (II) chloride hexahydrate (Sigma-Aldrich, $\geq 97\%$, Germany), lead (II) acetate trihydrate (Sigma-Aldrich, $\geq 99.5\%$, Germany), zinc acetate (Aldrich, 99.99%, Germany), nickel (II) chloride (Aldrich, 98%, Germany) and, acetonitrile (Merck Millipore, 99.9 $\geq \%$, Germany) were used as received. 1,2-Dinitrobenzene (1,2-DNB, $\geq 99\%$), 2,4,6-trinitrophenol (picric acid, PA, $\geq 98\%$), 2,4,6-trinitrotoluene (1 mg/mL TNT solution), 4-nitrophenol (4-NP, $\geq 99\%$), 2,4-dinitrotoluene (2,4-DNT, 97%), 4-nitrotoluene (4-NT, 99%), 2,4-dinitrophenol (2,4-DNP, $\geq 98\%$) were used as received from Sigma-Aldrich (Germany).

Instrumentation

Ultraviolet–visible (UV–vis) spectrophotometry measurements of the hydrogels were performed at ambient conditions on a Shimadzu UV-2101 spectroscopy device and fluorescence emission spectra of the gels were recorded on a Varian Eclipse spectrofluorometer. Both spectra were measured using quartz within the cavity of a 1 cm path-length cuvette. The morphology of the CIN hydrogels has been examined by utilizing a scanning electron microscope (FEI-Quanta FEG 200-Field Emission Scanning Electron Microscope (FE-SEM) and energy dispersive X-ray spectrometer (EDX)). Fourier-transform infrared spectroscopy (FTIR) was taken on Perkin–Elmer Paragon 1000 spectrometer using the attenuated total reflectance (ATR) method at frequencies ranging from 650 to 4000 cm^{-1} .

Synthesis of linear CIN-PMMA polymer

Linear cinacalcet-poly(methyl methacrylate) (CIN-PMMA) was synthesized through free radical photopolymerization of

methyl methacrylate (MMA) (30 mmol) monomer by utilizing cinacalcet hydrochloride (0.03 mmol) as a photoinitiator in 3 mL chloroform. The samples are placed in quartz tubes and the system is being flushed with nitrogen, sealed, and then surrounded using 12 lamps having an emission maximum at 295 nm in a photoreactor to photocured at ambient temperature for 1 h.

Synthesis of CIN-gel

The cinacalcet hydrogels (CIN-gels) were produced by free radical photopolymerization of BAAM/AAM (0.09/7.0 mmol) using cinacalcet chloride (0.08 mmol) in 1:1 water:acetonitrile (ACN) solution system (1.5 g). To accomplish this aim, deaerated samples were prepared and injected between two glass slides separated by a thick gasket (1.5 mm) and were externally irradiated for 1 h at ambient conditions in a photoreactor equipped with 12 lamps having an emission maximum of 295 nm. A Delta Ohm model HD-9021 radiometer (10.0 mW/cm^2) was utilized to gauge light intensities at the sample locations. After the fabrication of CIN-gels, the gels were washed in solvent mixture [ACN/water, (1:1, w/w)] three times. Lastly, hydrogels were stored at room temperature for 24 h in a highly aqueous solution at room conditions to eliminate residual reagents from the CIN-gels. The efficiency was calculated by measuring the weights of the dried CIN-gels (> 96%).

Fluorescence sensing applications of CIN-gel against NACs and HIMs

A certain weight quantity of CIN-gel was placed into a quartz cell containing solvent mixture to supply the molarity of the CIN group at 1.25×10^{-5} . Afterwards, CIN-gel was treated with a defined amount of HMIs (Cd^{2+} , Co^{2+} , Hg^{2+} , Pb^{2+} , Mn^{2+} , Ni^{2+} , and Zn^{2+}) and NACs (TNT, 2-NT, 2,4-DNT, 3-NT, PA, 2,6-DNT, 2,4-DNP, 4-NP, and 1,2-DNB). The performance of CIN-gel against different analytes was determined using fluorescence spectroscopy at ambient conditions.

Results and discussion

Cinacalcet hydrochloride is a key intermediate for calcimimetic drug that mimics the action of calcium in the body [40–43]. It is a secondary amino compound containing a naphthalene chromophore and a 3-[3-(trifluoromethyl)phenyl]propyl group. The UV–vis spectrum of CIN displays a strong absorption at 295 nm, the shoulder peaks at 282 nm and 305 nm peculiar to naphthalene analogs [44, 45], in acetonitrile/water, (1:1, w/w). The emission spectrum of CIN shows a wide band having a primary peak at 351 nm, which

was ascribed to the interaction between the naphthalene group and the amino group (Fig. 1) [44]

Recently, our group reported a one-pot synthesis of fluorescent hydrogels via acrylamide, *N,N'*-methylenebisacrylamide and dansyl chloride as a monomer, a cross-linker and a photoinitiator, respectively. In the previous study, the dansyl chloride was directly used as a photoinitiator in the polymerization without any additional due to its photosensitive chemical structure containing dimethylamino, naphthalene and sulfonyl chloride group [15]. Since, the chemical structure of dansyl chloride and cinacalcet hydrochloride are very similar, perhaps, the cinacalcet hydrochloride is a potential photoinitiator for the one-pot synthesis of fluorescent hydrogels. Cinacalcet hydrochloride includes an electron acceptor unit consisting of a naphthalene chromophore, and an electron donor unit consisting of a secondary amine. Upon UV irradiation, the inter- or intra-electron-transfer reaction between these units was responsible for the free radical generation [44, 46, 47]. Furthermore, the photodegradation of cinacalcet hydrochloride in solution was studied in various photolytic conditions (sunlight, UV-light and dark light irradiation) and found that it degraded by 65%, 18.2% and 11.2% for 24 h, respectively [48]. In accordance with our previous study, the cinacalcet functional gels were prepared via photopolymerization and sensing properties were examined in fluorescence spectroscopy. The presence of CIN groups in the CIN-gel network was further demonstrated by a model study synthesizing linear poly(methyl-methacrylate) under identical experimental conditions. By comparing UV spectra of PMMA with linear CIN-PMMA, the significant CIN band between 235 and 320 nm is distinctly evident in Fig. 2.

The morphology of fluorescent hydrogels was also crucial to determine their sensor capacity to work in physiological conditions. For this purpose, the CIN-gel sample was frozen in liquid nitrogen and finally freeze-dried and coated

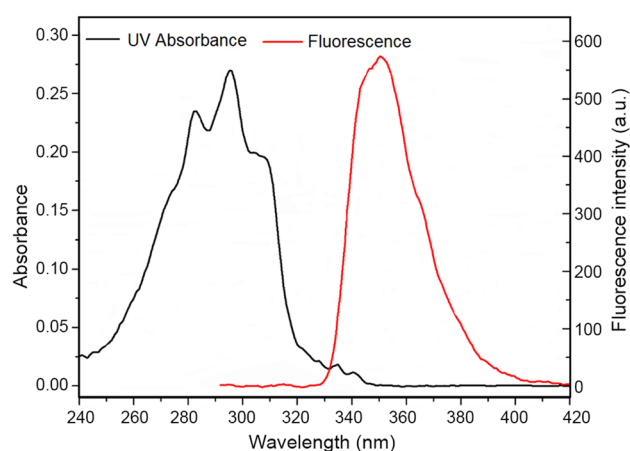


Fig. 1 UV–Visible (black) and fluorescence (red) spectra of cinacalcet HCl in acetonitrile/water (1:1, w/w)

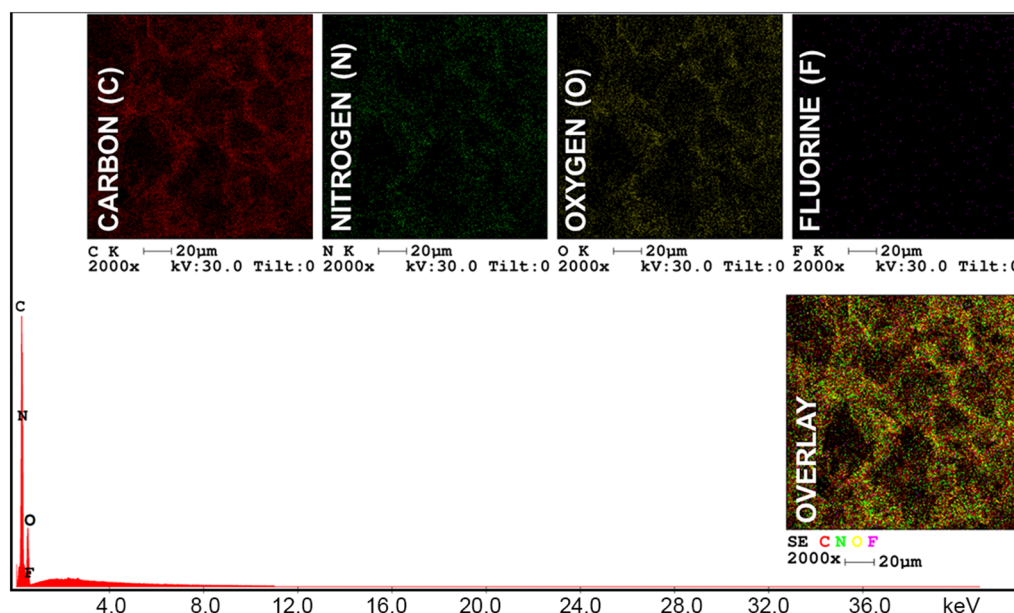


Fig. 4 The EDX spectra and EDX maps of CIN-gel

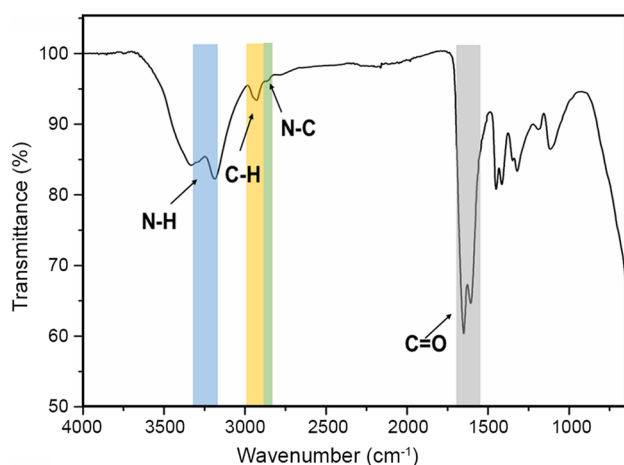


Fig. 5 FTIR spectrum of CIN-gel

electron transfer from the excited CIN to nearby NACs and HMIs (which is a typical process in naphthalene derivatives) [6, 53] or to exciplex formation [41, 54]. The fluorescence quenching efficiency (FQE) of NACs and HMIs can be calculated in accordance with the following equation:

$$QE = \frac{(I_0 - I)}{I_0} \times 100. \quad (1)$$

The obtained results for quenching efficiency ratios (QERs) of all compounds are shown in Fig. 7. The strongest QERs among the studied NACs and HMIs were detected

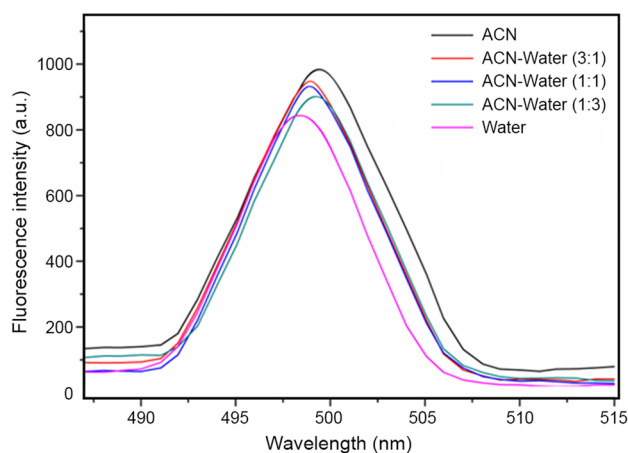


Fig. 6 Fluorescence spectral response of CIN-gel (containing 1.25×10^{-5} M CIN) in ACN, water, ACN:water mixtures with different ratios w/w (3:1), (1:1) and (1:3), respectively

for TNT (95.67%), 2,4-DNP (94.96%) and Zn^{2+} (35.93%), respectively.

Among the NACs, the CIN-gel displayed the strongest quenching capacity for TNT. Therefore, the influence of TNT amounts on the fluorescence emission of the CIN-gel was evaluated by adding 0.06 to 4.55 equivalent ratios of TNT. At different concentrations of TNT, the fluorescence emission intensity of the CIN-gel was essentially linearly proportional to the concentration (Fig. 8). Besides, the correlation coefficient was calculated as $R^2 = 0.999$, and the fluorescence emission of CIN-gel completely disappeared by the addition of TNT up to 4.55 eq.

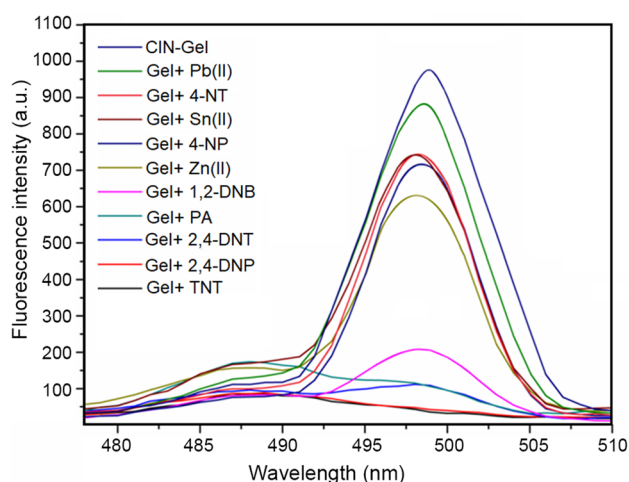


Fig. 7 Fluorescence spectral response of CIN-gel (containing 1.25×10^{-5} M CIN) in ACN:water (1:1, w/w) upon addition of 4.55 eq. of NACs and HMIs

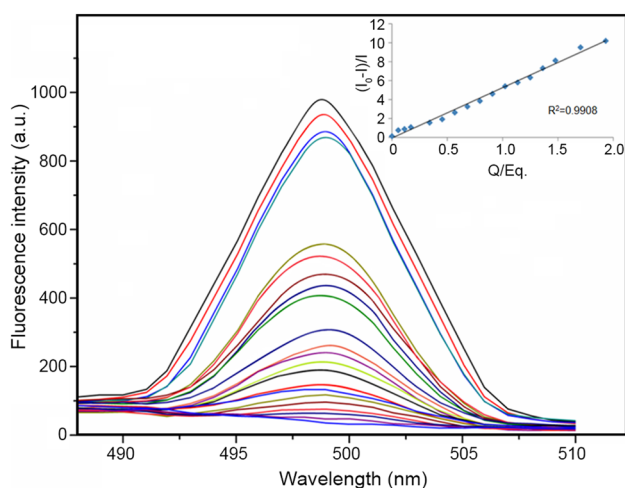


Fig. 8 Fluorescence emission spectra of CIN-gel (1.25×10^{-5} M) in ACN:water (1:1, w/w) in the presence of TNT at 0.06, 0.11, 0.17, 0.34, 0.45, 0.57, 0.68, 0.80, 0.91, 1.02, 1.14, 1.25, 1.36, 1.48, 1.70, 1.93, 2.05, 2.27, 2.50, 3.07 and 4.55 equivalent ratios

Among all heavy metal cations, Zn^{2+} was detected as the highest value for quenching efficiency (35.93%). As shown in Fig. 9, since other background HMIs (except for Sn^{2+} and Pb^{2+}) had small interferences for fluorogenic detection, the CIN-gel offered that could be utilized as a potential chemical probe for Zn^{2+} ion. According to these results as well as its high sensitivity, the prepared CIN-gel can be utilized as a fluorescence chemical probe for TNT, 2,4-DNP and Zn^{2+} ion.

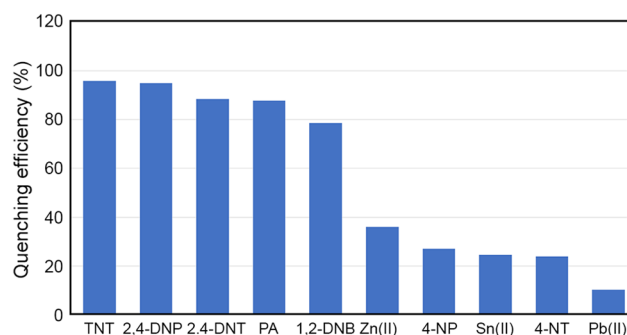


Fig. 9 Quenching efficiency ratios of the cinacalcet-modified CIN-gel upon the addition of 4.5 eq. targeted NACs and HMIs

Conclusion

The cinacalcet functional was synthesized via one-pot photopolymerization of acrylamide/*N,N'*-methylenebisacrylamide, utilizing cinacalcet chloride as a photoinitiator. The SEM, UV-vis, and fluorescence spectroscopy data verified the accomplished synthesis of the gel. Then, CIN-gel was used as a fluorescence sensor probe for different NACs and HMIs. Fluorescence emissions of CIN-gel were markedly quenched upon titration of NACs and HMIs. The strongest QERs for HMIs and NACs were observed for Zn^{2+} (35.93%), TNT (95.67%) and 2,4-DNP (94.96%), respectively. In addition, the CIN-gel showed a highly linear plot to the titration of TNT by 4.55 equivalent. Therefore, CIN-gel as a potentially chemical probe could be utilized as a fluorescent sensor for the determination of Zn^{2+} cation for HMIs and TNT and 2,4-DNP for NACs.

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Data availability The data that support the findings of this study are presented in the paper.

References

- De Vries W, Schütze G, Lofts S, Meili M, Römkens P, Farret R, De Temmerman L, Jakubowski M (2002) Proceedings of the Expert Meeting on Critical Limits for Heavy Metals and Methods for Their Application, Berlin, Germany, pp 29–78
- Desvergne JP, Czarnik AW (eds) (2012) Chemosensors of ion and molecule recognition. In: NATO Sci Ser C, Springer Science & Business Media, p 492
- Theyagarajan K, Thenmozhi K, Senthilkumar S (2021) Metal oxides in nanocomposite-based electrochemical sensors for toxic chemicals, 1st edn. Elsevier
- Shamim MA, Zia H, Zeeshan M, Khan MY, Shahid M (2022) Metal organic frameworks (MOFs) as a cutting-edge tool for the

- selective detection and rapid removal of heavy metal ions from water: Recent progress. *J Environ Chem Eng* 10:106991
5. Harris HH, Pickering IJ, George GN (2003) The chemical form of mercury in fish. *Science* 301:1203
 6. Järup L (2003) Hazards of heavy metal contamination. *Br Med Bull* 68:167–182
 7. Cheng J, Li Z, Lin W (2021) Development of a one-step synthesized red emission fluorescent probe for sensitive detection of viscosity in vitro and in vivo. *Spectrochim Acta Part A* 258:119808
 8. Buenger D, Topuz F, Groll J (2012) Hydrogels in sensing applications. *Prog Polym Sci* 37:1678–1719
 9. Tavakoli J, Tang Y (2017) Hydrogel based sensors for biomedical applications: an updated review. *Polymers* 9:364
 10. Pinelli F, Magagnin L, Rossi F (2020) Progress in hydrogels for sensing applications: A review. *Mater Today Chem* 17:100317
 11. Soto-Quintero A, Meneses-Acosta A, Romo-Urbe A (2015) Tailoring the viscoelastic, swelling kinetics and antibacterial behavior of poly(ethylene glycol)-based hydrogels with polycaprolactone. *Eur Polym J* 70:1–17
 12. Güler MA, Gök MK, Figen AK, Özgümüş S (2015) Swelling, mechanical and mucoadhesion properties of Mt/starch-g-PMAA nanocomposite hydrogels. *Appl Clay Sci* 112:44–52
 13. Baek K, Clay NE, Qin EC, Sullivan KM, Kim DH, Kong H (2015) In situ assembly of the collagen–polyacrylamide interpenetrating network hydrogel: Enabling decoupled control of stiffness and degree of swelling. *Eur Polym J* 72:413–422
 14. Chen Q, Zhu L, Zhao C, Wang Q, Zheng J (2013) A robust, one-pot synthesis of highly mechanical and recoverable double network hydrogels using thermoreversible sol-gel polysaccharide. *Adv Mater* 25:4171–4176
 15. Uygun M, Doganci E, Tasdelen M, Gurek A (2019) One-pot photoinduced synthesis of dansyl containing acrylamide hydrogels and their chemosensing properties. *J Appl Polym Sci* 136:47096
 16. Yilmaz G, Kahveci MU, Yagci Y (2011) A one pot, one step method for the preparation of clickable hydrogels by photoinitiated polymerization. *Macromol Rapid Commun* 32:1906–1909
 17. Nguyen KT, West JL (2002) Photopolymerizable hydrogels for tissue engineering applications. *Biomaterials* 23:4307–4314
 18. Wang H, Zhang B, Zhang J, He X, Liu F, Cui J, Lu Z, Hu G, Yang J, Zhou Z (2021) General one-pot method for preparing highly water-soluble and biocompatible photoinitiators for digital light processing-based 3D printing of hydrogels. *ACS Appl Mater Interf* 13:55507–55516
 19. Pamplona R, González-Lana S, Romero P, Ochoa I, Martín-Rapún R, Sánchez-Somolinos C (2023) Tuning of mechanical properties in photopolymerizable gelatin-based hydrogels for in vitro cell culture systems. *ACS Appl Polym Mater* 5:1487–1498
 20. Biswal D, Hilt JZ (2006) Microscale analysis of patterning reactions via FTIR imaging: application to intelligent hydrogel systems. *Polymer* 47:7355–7360
 21. Xue J, Zhang Z, Nie J, Du B (2017) Formation of microgels by utilizing the reactivity of catechols with radicals. *Macromolecules* 50:5285–5292
 22. Li K, Liu Y, Ge Y, Cao H, Zhuang S, Yang X, Zhao Y, Gu X (2023) An ultrasound-induced MXene doped PAM–SA super-tough hydrogel. *J Mater Chem C* 11:1908–1918
 23. Nelson BR, Kirkpatrick BE, Miksch CE, Davidson MD, Skillin NP, Hach GK, Khang A, Hummel SN, Fairbanks BD, Burdick JA, Bowman CN, Anseth KS (2023) Photoinduced dithiolane crosslinking for multiresponsive dynamic hydrogels. *Adv Mater*, p 2211209. <https://doi.org/10.1002/adma.202211209>
 24. Han J, Burgess K (2009) Fluorescent indicators for intracellular pH. *Chem Rev* 110:2709–2728
 25. Xiong S, Duan L, Cheng X (2020) A novel coumarin-chitosan fluorescent hydrogel for the selective identification of Fe²⁺ in aqueous systems. *Polym Chem* 11:6066–6072
 26. Gorur M, Doganci E, Yilmaz F, Isci U (2015) Synthesis, characterization, and Pb²⁺ ion sensing application of hexa-armed dansyl end-capped poly(ϵ -caprolactone) star polymer with phosphazene core. *J Appl Polym Sci* 132:42380
 27. Huy BT, Thangadurai DT, Sharipov M, Nghia NN, Van Cuong N, Lee Y-I (2022) Recent advances in turn off-on fluorescence sensing strategies for sensitive biochemical analysis—a mechanistic approach. *Microchem J* 179:107511
 28. He X, Jia H, Sun N, Hou M, Tan Z, Lu X (2022) Fluorescent hydrogels based on oxidized carboxymethyl cellulose with excellent adsorption and sensing abilities for Ag⁺. *Int J Biol Macromol* 213:955–966
 29. Grabchev I, Bosch P, Staneva D (2011) A new detector for metal cations based on the combined effect of photoinduced electron transfer and a light harvesting system. *J Photochem Photobiol A* 222:288–292
 30. Qu Z, Zhang D, Wang C, Tian S, Deng Y, Qin D, Duan H (2022) Fluorescein derivative immobilized optical hydrogels: fabrication and its application for detection of H₂O₂. *Polymers* 14:3005
 31. Xiao W, Dong Q (2022) The recent advances in bulk and microfluidic-based pH sensing and its applications. *Catalysts* 12:1124
 32. Dong M, Wang Y-W, Peng Y (2010) Highly selective ratiometric fluorescent sensing for Hg²⁺ and Au³⁺, respectively, in aqueous media. *Org Lett* 12:5310–5313
 33. Kim H, Kang J, Kim KB, Song EJ, Kim C (2014) A highly selective quinoline-based fluorescent sensor for Zn (II). *Spectrochim Acta Part A* 118:883–887
 34. Dong H-Q, Wei T-B, Ma X-Q, Yang Q-Y, Zhang Y-F, Sun Y-J, Shi B-B, Yao H, Zhang Y-M, Lin Q (2020) 1,8-Naphthalimide-based fluorescent chemosensors: recent advances and perspectives. *J Mater Chem C* 8:13501–13529
 35. Ozay H, Ozay O (2013) Rhodamine based reusable and colorimetric naked-eye hydrogel sensors for Fe³⁺ ion. *Chem Eng J* 232:364–371
 36. Qu Z, Meng X, Duan H, Qin D, Wang L (2020) Rhodamine-immobilized optical hydrogels with shape deformation and Hg²⁺-sensitive fluorescence behaviors. *Sci Rep* 10:1–10
 37. Thiel OR, Bernard C, Tormos W, Brewin A, Hirotani S, Murakami K, Saito K, Larsen RD, Martinelli MJ, Reider PJ (2008) Practical synthesis of the calcimimetic agent, cinacalcet. *Tetrahedron Lett* 49:13–15
 38. Franceschini N, Joy MS, Kshirsagar A (2003) Cinacalcet HCl: a calcimimetic agent for the management of primary and secondary hyperparathyroidism. *Expert Opin Invest Drugs* 12:1413–1421
 39. Xiong Y, Liu S, Zheng J, Chen J, Wen Z, Deng X, Bai B, Li D, Yu Z, Han S, Liu X, Li P (2023) Cinacalcet exhibits rapid bactericidal and efficient anti-biofilm activities against multidrug-resistant Gram-positive pathogens. *iScience* 26:106378
 40. Mostafa GA, Al-Badr AA (2017) Profiles of drug substances, excipients and related methodology. Elsevier
 41. Sorbera L, Castaner R, Bayes M (2002) Cinacalcet hydrochloride. *Drug Future* 27:831–836
 42. Verheyen N, Pilz S, Eller K, Kienreich K, Fahrleitner-Pammer A, Pieske B, Ritz E, Tomaschitz A (2013) Cinacalcet hydrochloride for the treatment of hyperparathyroidism. *Expert Opin Pharmacother* 14:793–806
 43. Harrington PE, Fotsch C (2007) Calcium sensing receptor activators: calcimimetics. *Curr Med Chem* 14:3027–3034
 44. Nuin E, Andreu I, Torres MJ, Jiménez MC, Miranda MA (2011) Enhanced photosafety of cinacalcet upon complexation with serum albumin. *J Phys Chem B* 115:1158–1164
 45. Oliverio F, Nuin E, Andreu I, Ragno G, Miranda MA (2014) Assessment of drug entrapment within liposomes using photo-physical probes. *Eur J Pharm Biopharm* 88:551–555

46. Pina F, Lima J, Lodeiro C, Seixas de Melo J, Díaz P, Albelda MT, García-España E (2002) Long range electron transfer quenching in polyamine chains bearing a terminal naphthalene unit. *J Phys Chem A* 106:8207–8212
47. Nuin E, Jiménez MC, Gn S, Andreu I, Miranda MA (2013) Drug–drug interactions within protein cavities probed by triplet–triplet energy transfer. *J Phys Chem Lett* 4:1603–1607
48. Krishnan M, Karunanidhi SL, Sola G, Akshitha Y (2013) Stability indicating HPLC method for the estimation of cinacalcet hydrochloride API. *Indian J Res Pharm Biotechnol* 1:346
49. Kaşgöz H, Özgümüş S, Orbay M (2003) Modified polyacrylamide hydrogels and their application in removal of heavy metal ions. *Polymer* 44:1785–1793
50. Güngör N, Karaoğlu S (2001) Interactions of polyacrylamide polymer with bentonite in aqueous systems. *Mater Lett* 48:168–175
51. Dumitrescu A, Lisa G, Iordan A, Tudorache F, Petrila I, Borhan A, Palamaru M, Mihailescu C, Leontie L, Munteanu C (2015) Ni ferrite highly organized as humidity sensors. *Mater Chem Phys* 156:170–179
52. Ma N, Li X, Ding Z, Tao J, Xu G, Wang Y, Huang Y, Liu J (2023) A polyacrylic acid/polyacrylamide-based hydrogel electrolyte containing gelatin for efficient electrochromic device with outstanding cycling stability and flexible compatibility. *Eur Polym J* 190:112024
53. Cai Z, Zhang J-T, Xue F, Hong Z, Punihaole D, Asher SA (2014) 2D photonic crystal protein hydrogel coulometer for sensing serum albumin ligand binding. *Anal Chem* 86:4840–4847
54. Chen M, Zhou L, Guan Y, Zhang Y (2013) Polymerized microgel colloidal crystals: photonic hydrogels with tunable band gaps and fast response rates. *Angew Chem Int Ed* 52:9961–9965

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