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Design of Highly Selective Cu^{2+} Fluorescent Probe Based on Pyrene Derivatives

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Abstract

A new probe P was synthesized and characterized from pyrene formaldehyde. The probe showed good selectivity for Cu^{2+} over other metal ions in ethanol-water solution ($V_{ethanol}$:V_{water}=3.5:1.5, pH 6.5, 0.02 M HEPES). With the increasing of Cu^{2+} concentration (2-10 μM), the P-Cu^{2+} system displayed excellent linear relationship at 464 nm with the detection limit down to 0.66 μM.

Keywords: Fluorescent probe; Pyrene derivatives; Cu^{2+}.

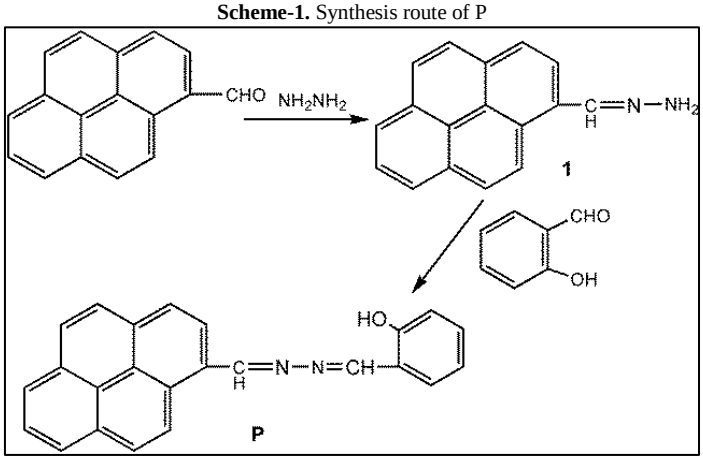
1. Introduction

Metal ions, as indispensable substances in human survival, development and life activities, are essential trace elements for human body. When excessive metal ions enter human body through respiration, diet and other ways, they will cause harm to human body. Meanwhile, their enrichment in the environment will also cause environmental pollution and ecological destruction. Among them, Cu^{2+} is an indispensable trace element ingested by the human body through daily diet [1], Cu^{2+} has an important impact on the growth and development of the human body and normal metabolism. Excessive intake of Cu^{2+} will cause damage to the human nervous system, and then lead to a series of neurological diseases. Therefore, there is a need for efficient and sensitive methods to detect metal ions in the environment and organisms that are easy to operate and can provide fast and accurate results. Among the current scientific detection methods of metal ions, most of them rely on large instruments [2-5]. Fluorescent probe method has excellent characteristics such as wide source, easy modification, high sensitivity, high selectivity, convenient operation, rapid response, etc.[6-8], which has gained a high popularity in the detection of metal ions in the environment and ecology. The development and exploration of fluorescent probes with better performance has gradually become a research focus, so it is of great significance to design and synthesize fluorescent probes with high selectivity and sensitivity.

Pyrene and its derivatives can form excimer, and the fluorescence quantum yield generated by the excited state is high and long, the fluorescence emission spectrum is different from that of monomer, and the changes in the microenvironment are extremely sensitive, so that these derivatives are widely used in the field of microenvironment changes[9-11]. Researchers successfully reported many fluorescent probes based pyrene for the highly selective detection of Fe^{3+}, Hg^{2+}、Cu^{2+}、Zn^{2+}, etc. [12-16].

Most of the reported Cu^{2+} fluorescent probes cause a quenching of the fluorescence emission upon addition of this metal ion due to its paramagnetic nature [17, 18], only a few probes in which the binding of Cu^{2+} leads to an increase in the fluorescence intensity, which are desirable for analytical purposes by the fluorescence enhancement [19, 20]. Based on the above-mentioned reasons and our work [21-24], a fluorescent probe containing a pyrene derivative was synthesized. Research showed that probe P had good selectivity for Cu^{2+} over the measured ions. The synthesis route of P was shown in Scheme 1.

Scheme-1. Synthesis route of P



2. Experimental Section

2.1. Reagents and Instruments

All reagents and solvents were commercially available and used without further treatment.

UV-Vis spectra were obtained on a Hitachic U-2910 spectrophotometer and a 1 cm quartz cell was used. Fluorescence emission spectra were conducted on a Hitachi4600 spectrofluorometer and a 1 cm quartz cell was used.

2.2. Synthesis of Compounds

Synthesis of Compound 1: 0.40 g pyrene formaldehyde was in a 250 mL round-bottomed flask, 16 mL hydrazine hydrate and 50 mL anhydrous ethanol was added. The reaction was heated 4 h and cooled to room temperature. The formed yellow solid was dried.

Synthesis of P: 80 mg of compound 1, 45 μL of salicylaldehyde (slightly excessive) and 50 mL anhydrous ethanol were added in a 250 mL round-bottomed flask. After reflux reaction for 6 h, it was cooled to room temperature. The yellow solid P was obtained by filtration.

2.3. General Spectroscopic Methods

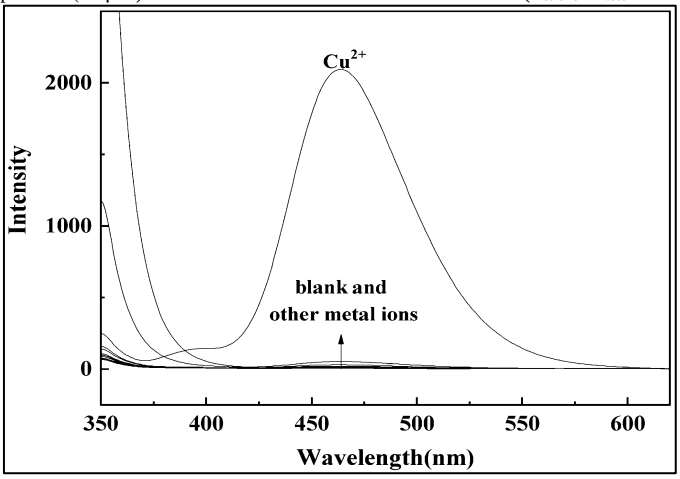
Common metal ions and anions, as well as probe P, were dissolved in deionized water and DMSO to obtain 0.01 M stock solution, respectively. The excitation wavelength for all fluorescence measurements was fixed at 340 nm, and the excitation and emission slit widths were both 10 nm.

3. Results and Discussion

3.1. Fluorescent Selectivity of P

The selectivity of probe P was tested for metal ions under the condition of ethanol-water solution ($V_{ethanol}$:V_{water}=3.5:1.5, pH 6.5, 0.02 M HEPES), as shown in Figure 1. The results showed that under the condition, the free P displayed a very weak fluorescence, while the fluorescence peak at 464 nm was found with the fluorescence intensity even up to 2000 upon additon of Cu^{2+}, which was more conducive to the expression of recognization between P and Cu^{2+}, and other metal ions caused little signal change. At the same time, neutral and weak alkaline environments was also an advantage of the probe in some applications.

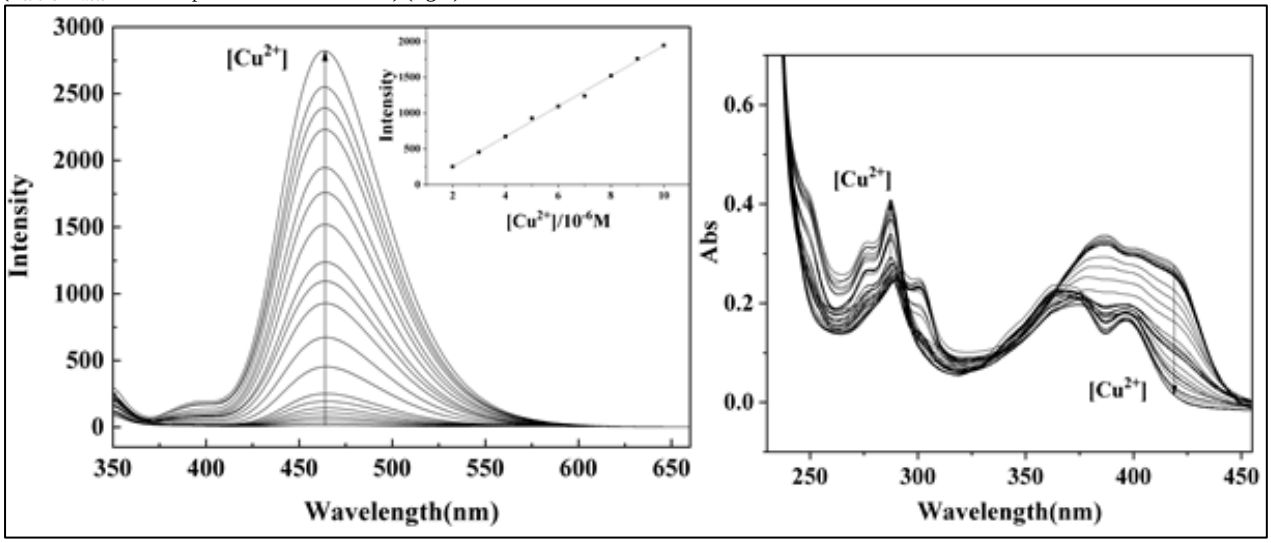
Figure-1. The selectivity of probe P (10 μM) to metals ions under ethanol-water solution ($V_{ethanol}$:V_{water}=3.5:1.5, pH 6.5, 0.02 M HEPES)



3.2. Fluorescent Titration of P with Cu^{2+}

In order to study the reaction between P and Cu^{2+}, fluorescent titration experiment was carried out (Figure 2, left). From the results, it could be included that the fluorescent intensity at 464 nm enhanced accordingly with the increase of Cu^{2+} concentration. In the range of 2-10 μM, the correlation coefficient was 0.997 with linear equation F=211.768c-174.354, the detection limit was 0.66 μ M (based on S/N = 3, inset of Fig. 212). It was proved that the probe was an ideal off-on fluorescent probe for Cu^{2+}. In Figure 2 (right), the influence of different concentrations of Cu^{2+} on the absorption spectra of the probe P was also examined. It was found that isoelectric points appeared at 294 nm and 363 nm with the change of Cu^{2+} concentration. The absorbance at 287 nm increased with the increase of Cu^{2+} concentration, while the absorbance at 418 nm decreased. These results also provided some experimental support and feasibility for the detection of Cu^{2+} in water environment.

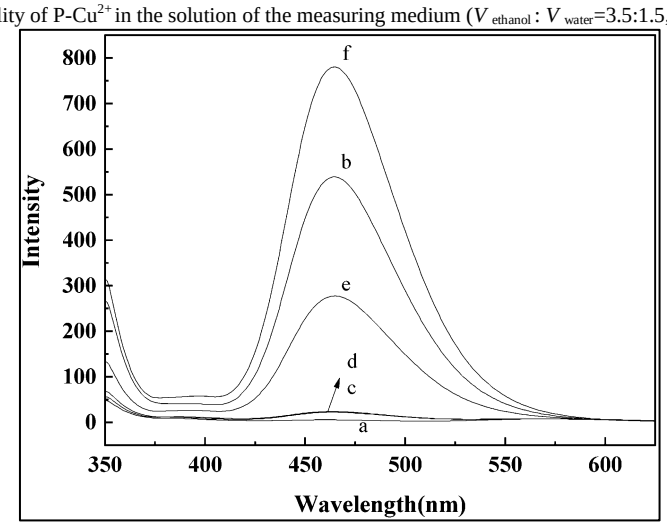
Figure-2. Fluorescence spectra of probe P (10 μM) in the presence of various concentrations of Cu^{2+} [0.1-90 μM] in ethanol-water medium ($V_{ethanol}$:V_{water}=3.5:1.5, pH 6.5, 0.02 M HEPES); (Inset) : Linear fluorescence intensity (F) of P (10 μM) upon addition of Cu^{2+} (2–10 μM) (left); The absorption spectra of probe P (10 μM) in the presence of various concentrations of Cu^{2+} [0.1-90 μM] in ethanol-water medium ($V_{ethanol}$:V_{water}=3.5:1.5, pH 6.5, 0.02 M HEPES) (right)



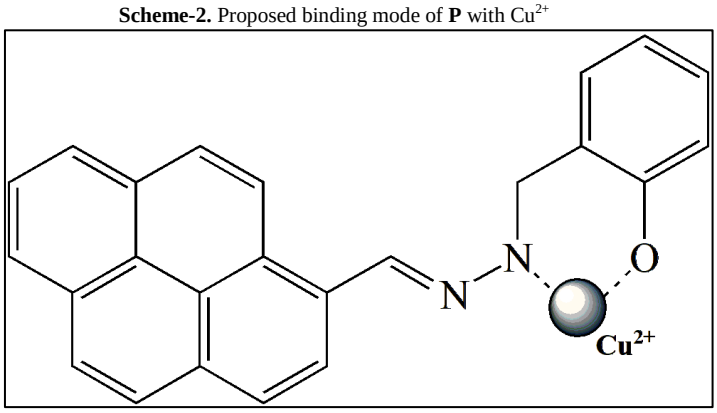
3.3. Binding Mode of P with Cu^{2+}

Figure 3 was used to investigate the reversibility of the P-Cu^{2+} system. Experimental results showed that the fluorescence peak at 464 nm appeared when the addition of Cu^{2+} into the solution and caused the change of its structure as seen in Figure 3(b). As shown in Figure 3(c, d), when EDTA was added into the P-Cu^{2+} solution as a complexing agent, it reacted with Cu^{2+} to form a compound with a greater stability constant in the system, resulting in fluorescence intensity decreased. When excess of Cu^{2+} was added again, it can be seen from Figure 3(e, f) that the fluorescence intensity at 464 nm recovered even enhanced more violently, which proved that the probe had a certain reversibility and can be reused. In order to further explore the combination model, the binding mode of P with Cu^{2+} was proposed as shown in Scheme 2, the N (-C=N) and O (–OH) participated in the coordination process of P-Cu^{2+}.

Figure-3. The reversibility of P-Cu^{2+} in the solution of the measuring medium ($V_{ethanol}$: V_{water}=3.5:1.5, pH 6.5, 0.02 M HEPES)



Scheme-2. Proposed binding mode of **P** with Cu^{2+}



4. Conclusions

In summary, a pyrene derivative was synthesized and characterized which could specifically recognize Cu^{2+} in the aqueous buffer solution by UV/vis and fluorescent responses. Furthermore, it also showed a "off-on" type of absorption and fluorescence response. The quenching effect of water will limit the probes applicability in biological milieu at some extent. However, by simple modifications with hydrophilic groups, we believed that this kind of probe can be used for many practical applications, including biological systems. Therefore, it could be concluded that this study had the potential to promote the development and application of Cu^{2+} selective probes.

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References

[1] Giuffrida, M. L., Sfrazzetto, G. T., and Satriano, C., 2018. "A new ratiometric lysosomal copper(II) fluorescent probe to map a dynamic metallome in live cells [J]." *Inorganic Chemistry*, vol. 57, pp. 2365-2368.

[2] Li, Y., Wang, L., and Zheng, M. G., 2023. "Thin-layer chromatography coupled with HPLC-DAD/UHPLC-HRMS for target and non-target determination of emerging halogenated organic contaminants in animal-derived foods[J]." *Food Chemistry*, vol. 404, p. 134678.

[3] Makarishcheva, D. D., Kolesnikova, O. N., and Tregubova, V. E., 2022. "Development of a quantitative determination method for aluminum ions in adsorbed drugs using atomic absorption spectrometry with electrothermal atomization [J]." *Pharmaceutical Chemistry Journal*, vol. 56, pp. 527-531.

[4] Nugraha, W. C., Nagai, H., and Ohira, S. I., 2020. "Semi-continuous monitoring of Cr(VI) and Cr(III) during a soil extraction process by means of an ion transfer device and graphite furnace atomic absorption spectroscopy [J]." *Analytical Sciences*, vol. 36, pp. 617-620.

[5] Parts, L., Drews, M., and Eha, K., 2021. "Development and validation of a method for selenium determination by flame atomic absorption spectrometry in dietary supplements and food samples[J]." *Toxicology Letters*, vol. 350, p. 148.

[6] Nie, P., Dong, T., He, Y., and Xiao, S., 2018. "Research on the effects of drying temperature on nitrogen detection of different soil types by near infrared sensors [J]." *Sensors*, vol. 18, p. 391.

[7] Sun, N., Ding, Y., and Tao, Z. X., 2018. "Development of an upconversion fluorescence DNA probe for the detection of acetamiprid by magnetic nanoparticles separation [J]." *Food Chemistry*, vol. 257, pp. 289- 294.

[8] Sun, X. H., Guo, F., and Ye, Q. Y., 2023. "Fluorescent sensing of glutathione and related bio-applications [J]." *Biosensors-Basel*, vol. 13, p. 16.

[9] Wang, Y., Huang, C. S., and Jia, N. Q., 2020. "Molecular fluorescent probe for monitoring cellular microenvironment and active molecules[J]." *Progress In Chemistry*, vol. 32, pp. 204-218.

[10] Xia, P. P., Chen, J. T., and Shi, G. F., 2022. "Research progress of naphthalimide derivatives optical probes for monitoring Physical and chemical properties of microenvironment and active sulfur substances [J]." *Chinese Journal of Organic Chemistry*, vol. 42, pp. 3620-3629.

[11] Yuan, Y. R., Yu, L., and Liu, Q. H., 2022. "Multi-dentate chelation induces fluorescence enhancement of pyrene moiety for highly selective detection of Fe(III)[J]." *Analytical Sciences*, vol. 38, pp. 1095-1103.

[12] Chethanakumar, Budri, M., and Gudasi, K. B., 2022. "Luminescent pyrene-based Schiff base receptor for hazardous mercury(II) detection demonstrated by cell imaging and test strip [J]." *Journal of Fluorescence*, vol. 33, pp. 539-551.

[13] Dhivya, R., Gomathi, A., and Viswanathamurthi, P., 2019. "Pyrene based fluorescent turn-on chemosensor for sequential detection of Fe3+ and Fe2+ ions and its application in live cell imaging [J]." *Journal of Fluorescence*, vol. 29, pp. 797-802.

[14] Rangasamy, M. and Palaninathan, K., 2018. "A pyrazoline-based fluorescent chemosensor for Al3+ ion detection and live cell imaging [J]." *New Journal of Chemistry*, vol. 42, p. 10891.

[15] Shellaiah, M., Venkatesan, P., and Sun, K. W., 2023. "Pyrene-based fluorescent probe for "off-on-off" sequential detection of Cu2+ and CN- with hela cells imaging[J]." *Chemosensors*, vol. 11, p. 115.

[16] Yang, Y. S., Cao, J. Q., and Ma, C. M., 2022. "A novel pyrazoline-based fluorescence probe armed by pyrene and naphthol system for the selective detection of Cu2+ and its biological application[J]." *Journal of The Iranian Chemical Society*, vol. 19, pp. 3451-3461.

[17] Gao, L., Xu, J., and Luo, H. "A poly(carbazole-alt-triazole) with thiabendazole side groups as an “on-off-on” fluorescent probe for detection of Cu(II) ion and cysteine[J]." *Journal of Fluorescence*, Available: https://doi.org/10.1007/s10895-023-03164-9

[18] Wang, H., Shi, D. L., and Li, J., 2018. "A facile fluorescent probe with a large Stokes shift for sequentially detecting copper and sulfide in 100% aqueous solution and imaging them in living cells [J]." *Sensors and Actuators B-Chemical*, vol. 256, pp. 6-8.

[19] Jiang, D. D., Zheng, M. G., and Yan, X. Y., 2022. "A “turn-on” ESIPT fluorescence probe of 2-(aminocarbonyl)phenylboronic acid for the selective detection of Cu(II)[J]." *RSC Advances*, vol. 12, pp. 31186-31191.

[20] Jiao, Y., Zhou, L., and He, H., 2018. "A novel rhodamine B-based “off-on” fluorescent sensor for selective recognition of copper (II) ions[J]." *Talanta*, vol. 184, pp. 143-148.

[21] Yu, C. W., Ji, Y. X., and Wen, S. B., 2021. "Synthesis and characterization of a Mg2+-selective probe based on benzoyl hydrazine derivative and its application in cell imaging[J]." *Molecules*, vol. 26, p. 2457.

[22] Yu, C. W., Jian, L., and Ji, Y. X., 2018. "Al(III)-responsive “off-on” chemosensor based on rhodamine derivative and its application in cell imaging[J]." *Rsc. Advances*, vol. 8, pp. 31106-31112.

[23] Yu, C. W., Yang, M., and Cui, S. H., 2022. "A ratiometric selective fluorescent probe derived from pyrene for Cu2+ detection[J]." *Chemosensors*, vol. 10, p. 207.

[24] Zhang, W. T., Yu, C. W., and Yang, M., 2021. "Characterization of a Hg2+-selective fluorescent probe based on rhodamine B and its imaging in living cells[J]." *Molecules*, vol. 26, p. 3385.