Rapid determination of cysteine and chiral discrimination of D-/L-cysteine via the aggregation-induced emission enhancement of gold nanoclusters by Ag⁺

Shengli Ruan¹ · Yan Zhou² · Min Zhang² · Hongyang Zhang¹ · Yuerong Wang¹ · Ping Hu¹

Received: 8 July 2021 / Accepted: 14 October 2021
© The Author(s), under exclusive licence to The Japan Society for Analytical Chemistry 2022

Abstract
Cysteine (Cys) plays vital roles in various physiological and pathological functions. Either a deficiency or excess of Cys could lead to severe ailments in human. The identification and determination of Cys are the key issues for the early diagnosis of relevant diseases. This contribution has presented a promising potential of fluorescent gold nanoclusters (AuNCs) for Cys determination and D-/L-Cys enantiomer discrimination. Cys determination and discrimination are involved three steps. First, as a reducing and capping ligand, glutathione was applied to fabricate weak fluorescent AuNCs. Second, Ag⁺ was introduced to lead the aggregation-induced emission (AIE) to form well-dispersed aggregates. The fluorescence intensity of AuNCs was monitored at excitation/emission wavelengths of 396/620 nm. Third, Cys was found to quickly bind with Ag⁺ to form a grid network to light up the system via aggregation-induced emission enhancement (AIEE). A novel sensor for a sensitive and a visually selective detection of Cys was established on the basis of the AIEE mechanism. Rapid quantitative determination of Cys was achieved in 2 min via AIEE within the range of 0.5–100 μmol L⁻¹ and a detection limit of 0.365 μmol L⁻¹. Moreover, due to the specific interactions of D-/L-Cys with mandelic acid and tartaric acid, the visual discrimination of D-/L-Cys enantiomers with naked eyes was realized by replacing the organic acid buffer.

Keywords Cysteine · Gold nanoclusters · Silver ion · Aggregation-induced emission enhancement · Chiral recognition

Introduction
Cysteine (Cys) is a thio-containing amino acid that widely exists in different organisms and controls the three-dimensional structure of proteins through the formation of disulfide bonds. Cys plays vital roles in various physiological and pathological functions, such as detoxification [1] and metabolism [2, 3]. A deficiency of Cys could lead to decreased hematopoietic function [4], edema [5], psoriasis [6], growth retardation [7, 8], while liver damage [9], and excessive Cys resulted in neurodegenerative diseases [10], amyotrophic lateral sclerosis, and Huntington’s disease [11]. Therefore, accurate identification and determination of Cys are key issues for the early diagnosis of relevant diseases.

The enantiomers of Cys also have different contrasting effects on the physical function of humans. Previous studies have shown that L-Cys at a low level acted as a neuroprotective antioxidant in neuronal activity, while a high level of L-Cys could cause neuronal damage [12]. In contrast, D-Cys caused no excitotoxic damage to the brain and protected cerebellar neurons more effectively than L-Cys. The result relied on the higher transport activity of D-Cys than that of L-Cys at the same concentration [13, 14]. Therefore, the selective recognition of Cys enantiomers has been under focus within biochemistry and chiral drug regimes.
this scenario, developing a more efficient sensor for a stereoselective analysis of Cys enantiomer is urgently needed. Various analytical techniques, including mass spectrometry, high-performance liquid chromatography, capillary electrophoresis, and other electrochemistry techniques, have been applied to determine Cys. However, these methods require expensive equipment. Using fluorescent sensors, in contrast, is a quite simple method to perform Cys determination.

Gold nanoclusters (AuNCs) have drawn much attention owing to their fundamental properties and practical applications [15]. As a new type of fluorescent nanomaterial, AuNCs have expressed remarkable potentials in sensing because of their distinctive features of superior biocompatibility and tunable fluorescence emission within the visible to near-infrared range. The preparation of AuNCs usually starts from the reduction of Au(III) and ends with the formation of atomic Au(0) [16]. The growth mechanism has been fully elucidated by Xie et al. [17] The intermediate Au(I) has also shown potential advantages in the sensing and recognition of specific targets attributed to the fluorescence tuning of Au(I) complexes [18]. These complexes were prepared with the addition of a reducing agent and a stabilizing agent. Water-soluble biothiols were popularized in fabricating AuNCs for the formation of the Au-S bond, because of gold-thiol interactions [19]. Glutathione (GSH) is the most common candidate as a reducing and capping ligand to obtain AuNCs. [20].

Aggregation-induced emission (AIE), which was discovered by Tang et al., was first reported in the organic molecules regime [21]. Fluorophores has generally shown bright fluorescence in dilute solutions, but weak fluorescence in concentrated solutions or agglomerations with an aggregation-caused quenching (ACQ) effect. The ACQ effect results in drawbacks of weak resistance to photobleaching, high background, and poor photosensitivity.

The AIE and AIE enhancement (AIEE) characteristics of various types of fluorophores have been found to have completely opposite effects on ACQ. These AIE luminescence agents (AIEgens) usually show negligible fluorescence in dilute solutions, but emit strong fluorescence when forming aggregates. The properties of the AIEgens were attractive in fields of biological detection and solid-state optical materials or devices fabrication. In recent reports, novel metal nanoclusters also expressed AIE properties. Beneficial luminescent nanoclusters, such as Au [22–24], Cu [25], and Ag [26], have been extensively focused on, of which AuNCs have been the frontrunner due to their high stabilities [27]. AIE has played a major role in the luminescence properties of nanoclusters, where the aggregation degree acts as a focal point for emission wavelength and the intensity. The AIE in NCs occurs through self-assembled routes (non-electrostatic and electrostatic), which usually causes considerable blueshifts in emission accompanied by the transformation from a disordered to an ordered morphology.

In this contribution, the AIEE properties of AuNCs were applied to sensitively and rapidly determine Cys. The sensing strategy is described in Scheme 1. In the presence of Ag⁺, the coordination of the carboxyl group of AuNCs at the GSH terminal and Ag⁺ shortened the distance between AuNCs, and improved the fluorescence emission of AuNCs. As a bridge, Ag⁺ interacting with GSH-AuNCs through coordination connected with Cys to form an aggregated network. The aggregation state resulting in AIEE occurrence greatly enhanced the fluorescence emission of AuNCs. The level of Cys could also be quantitatively determined depending on the increase in the fluorescence intensity. As AIEE occurred very rapidly, the detection process could be completed within two minutes. Moreover, due to the specific interactions of D-/L-Cys with mandelic acid and tartaric
acid, the chiral discrimination of D-/L-Cys with the naked eyes was realized by replacing the organic acid buffer.

**Experimental**

**Reagents and chemicals**

Silver nitrate (AgNO₃), glutathione (GSH), hydrogen tetrachloroaurate (III) trihydrate (HAuCl₄·3H₂O) and amino acids were purchased from Adamas-Beta Co., Ltd. Other inorganic reagents were obtained from Shanghai Lingfeng Chemical Reagent Co., Ltd. without further purification. The water applied in all experiments was deionized (resistivity > 18 MΩ cm − 1).

**Preparation of GSH-AuNCs**

Typically, a freshly prepared aqueous solution of HAuCl₄ (20 mM, 5 mL) and GSH (100 mM, 2.5 mL) was mixed with 43.5 mL of deionized water under gentle stirring at 25 °C for 5 min. The precipitate was observed, and then an aqueous solution of NaOH (1.0 M) was added to the mixture to adjust the pH to ∼7.0. After the precipitate was dissolved, the reaction mixture was heated to 90 °C under gentle stirring for 24 h. Eventually the obtained light-yellow aqueous solution was dialyzed using a dialysis bag (MWCO: 2000 Da) against deionized water for 24 h. The AuNCs were stored at 4 °C before use.

**Transitional metal ions-induced AIEE**

AIEE of GSH-AuNCs was induced by transition-metal ions including Ag⁺, Cr³⁺, Cd²⁺, Ce³⁺, Co²⁺, Cu²⁺, Pb²⁺, Zn²⁺, Fe²⁺, and Fe³⁺. The concentration of metal ions was kept at 10 mM. The variation of the fluorescence intensity was recorded to investigate the coordination between metal ions and GSH-AuNCs. The fluorescence spectrum was measured by a spectrometer.

**Determination of L-Cys based on Ag⁺ induced AIEE**

A volume of 500 μL of freshly prepared citrate buffer (0.1 M, pH 4.0) containing 0–10 mM Ag⁺ was mixed with the AuNCs complex (1:1, v/v). The fluorescence emission spectra were recorded in the range of 500–800 nm with an excitation wavelength of 396 nm. A volume of 500 μL of freshly prepared citrate buffer (0.1 M, pH 4.0) containing 0–100 μM L-Cys was mixed with the AuNCs-Ag⁺ complex (1:1, v/v). The fluorescence emission spectra measurement was recorded in the range of 500–800 nm with an excitation wavelength of 396 nm.

**Determination of L-Cys in human serum samples**

Human serum samples were from healthy individual at Jiangxi Provincial People’s Hospital. The L-Cys solutions at different concentrations of 1.0 μM, 10 μM, and 50 μM were then spiked into diluted samples and further added into the GSH-AuNCs-Ag⁺ sensing system. The measurements were carried out after intensive blending for 0.5 min. The concentration of Cys in serum was determined by the method established in this work.

**Determination of L-Cys in human serum samples**

A volume of 500 μL of freshly prepared tartaric acid/mandelic acid (0.1 M) containing D/L-Cys was mixed with the AuNCs and Ag⁺ complex (1:1, v/v). Photos of samples under sunlight and ultraviolet light (365 nm) were recorded and the UV spectrum was collected. The fluorescence emission spectra were recorded in the range of 500–800 nm with an excitation wavelength of 396 nm.

**Apparatus**

Fluorescence spectra were recorded on an F-4600 spectrofluorophotometer (HITACHI Co., Ltd., Japan). UV–vis absorption spectra were monitored on a UV-2550 UV–Vis spectrometer (Shimadzu Co., Ltd.). Transmission electron microscopy (TEM) was measured on a JEM-2100 high-resolution transmission electron microscope (HITACHI Co., Ltd., Japan). Dynamic light scattering (DLS) measurements were conducted by a Malvern Zetasizer Nano ZSE (Malvern Panalytical Ltd).

**Results and discussion**

**Characterization of GSH-AuNCs**

The optical behavior of GSH-AuNCs was measured using a UV–Vis absorption spectrometer and fluorescence spectrometer. Figure 1 shows the UV–Vis spectrum of the AuNCs prepared under neutral conditions. In this work, the GSH molecules acted as a reducing agent and a template. As shown in Fig. 1, the fluorescence emission peak of AuNCs, prepared at neutral condition, was at 620 nm, with excitation at 396 nm. The morphologies of GSH-AuNCs were characterized by TEM. As shown in Fig. 2A, the GSH-AuNCs prepared in this work were spherical and in uniform size, having a distinct lattice structure. The results of characterization and the optical properties of GSH-AuNCs are consistent with the previous synthesis.
protocols, indicating that AuNCs were successfully prepared [28].

Coordination between GSH-AuNCs and transitional metal ions

The GSH molecule, rich in the sulphydryl moiety (-SH) and coordinative atoms, is able to interact with metal ions. As GSH coordinated with positive-charged metal ions, coordination bonds were formed between the lone-pair electrons of GSH and the unoccupied orbit of metal ions [29]. In the present work, the interaction between transitional metal ions and GSH-AuNCs was probed by investigating the fluorescence intensity variation. Figure 3C shows the fluorescence intensity variation of GSH-AuNCs upon the addition of various transition metal ions. The fluorescence spectrometry results showed that all of the selected transitional metal ions (Ag+, Cr3+, Cd2+, Ce3+, Co2+, Cu2+, Pb2+, Zn2+, Fe2+, and Fe3+) could coordinate with GSH-AuNCs. The process realized charge transfer between the ligand molecules and the metal ions and aroused fluorescence changes in GSH-AuNCs. As shown in Fig. 3B, the metal ions of Ag+, Cd2+, Ce3+, Pb2+, and Zn2+ noticeably formed visible coordination with GSH-AuNCs, and a significant fluorescence enhancement was observed. Similar visible complexes also formed between Cu2+ and GSH-AuNCs, while the fluorescence of the complex was quenched. This phenomenon possibly was attributed to the relatively less charge transfer of the ions (Ag+, Cd2+, Ce3+, Pb2+, and Zn2+) with a d10 valence electron structure, and the charge easily transferred to the higher s-orbital. Compared with these ions, the charge transfer between Cu2+ and GSH was sufficient to increase the tendency of oxidizing GSH, and Cu2+ was found to be already reduced to Cu+ [30]. The metal ions of Co2+, Fe2+, Fe3+, and Cr3+ could also coordinate with GSH-AuNCs, but the complex had a higher solubility in water, leading to fluorescence quenching.

Since the pH could affect the stability of GSH, citrate buffer (pH 4.0) was then added to form an association with GSH to prevent its decomposition [31]. The effect of the buffer solution on the coordination between GSH-AuNCs and ions was further investigated. As shown in Fig. 4A and B, the addition of Ag+, Cu2+, Fe2+, and Fe3+ into AuNCs with the addition of citrate, resulted in no obvious visual change, while the fluorescence intensities of AuNCs varied differently. The fluorescence intensity of AuNCs induced by Ag+ reached to over 6.5-fold of its original level with the addition of citrate, while those by Cd2+, Ce3+, Pb2+, and Zn2+ were decreased to almost the same levels as the blank control, indicating that a reversible coordination occurred between the ions and GSH-AuNCs at pH = 4.0. The equilibrium was reached within a few seconds. This rapid enhancement of fluorescence under mild conditions revealed that the complex was formed. The coordination of the carboxyl group of AuNCs at the GSH terminal and Ag+ shortened the distance between AuNCs, and improved the fluorescence emission of the AuNCs. Therefore, citrate was introduced to induce the aggregation of AuNCs by Ag+.

Determination of L-Cys by Ag+ triggered AIEE of GSH-AuNCs

As shown in Fig. 5, the fluorescence intensity of GSH-AuNCs was increased 5.37-fold with the addition of Ag+. The photo insets displayed more visualized evidence. The red fluorescence of the GSH-AuNCs/Ag+ solution was significantly stronger than that of GSH-AuNCs. Figure 2C shows the TEM images of the GSH-AuNCs/Ag+ complex. After Cys was added, the fluorescence intensity of the AuNCs/Ag+ system increased 6.44-fold, whereas that of GSH-AuNCs had no obvious variation. This result illustrated that the Ag+-triggered “light-up” GSH-AuNC sensing system was competent for the detection of Cys. The DLS data in Fig. 2F shows that the addition of Cys further increased the aggregation degree of the GSH-AuNCs/Ag+ system. Moreover, a grid network (Fig. 2E) that was formed after the addition of Cys resulted in a fluorescence enhancement, as Cys exhibited a strong binding ability for metal ions and formed C-metal ion-C base pairs [32]. As a bridge, Ag+ could interact with GSH-AuNCs through coordination, and connect with Cys to form a grid network which could strengthen the AIEE effect. Therefore, the fluorescence intensity of the

Figure 1: UV–Vis spectrum (blue trace) and fluorescence emission spectrum (red trace) of GSH-AuNCs
system could be greatly enhanced. Thus, the concentration of Ag⁺ had an influence on the enhanced performance of the Ag⁺-modulated “light-up” method.

The fluorescence intensity of the GSH-AuNCs system mixed with various concentrations of Ag⁺ in the presence and absence of Cys is shown in Figure S1. The optimized value of the fluorescence enhancement ratio between the GSH-AuNCs/Ag⁺/Cys system and the GSH-AuNCs/Ag⁺ system was obtained when the concentration of Ag⁺ reached 7.5 mM. Therefore, 7.5 mM of Ag⁺ was chosen to realize the detection of Cys. We then investigated the effect of the mixed time. Figure S2A and Figure S2B show the fluorescence intensities of GSH-AuNCs/Ag⁺ system in the presence and absence of Cys in different mixed duration, respectively. The fluorescence intensity of the GSH-AuNCs/Ag⁺ system reached the peak within 1 min with or without the addition
Thus, the whole determination process of Cys could be completed in 2 min.

The effect of the pH on the fluorescence intensity of the GSH-AuNCs/Ag+/Cys system was further explored. GSH has four ionizable functional groups with pKa 2.12, 3.53, 8.66, and 9.12, respectively [33]. The ionization equilibrium of GSH in solution affected the coordination between the Ag+ and GSH. Meanwhile, the GSH has O, N, and S electronegative atoms to bind with metal ions. As shown in Fig. 6, the solutions displayed a low fluorescence intensity at a strong acidic pH (2–3). In the strong acidic environment, the amino groups of GSH-AuNCs were protonated to generate a low interaction with Ag+. At pH = 4, the coordination between GSH and Ag+ resulted in the strongest fluorescence emission. The fluorescence was quenched by the increase in the pH until pH = 6. As the pH of the solution increased, the sulphydryl group in GSH became more electronegative, and
the enhanced coordination with Ag⁺ caused the fluorescence of the solution to be enhanced at pH = 7. We speculate that the reason for the above trend of the pH effect on the fluorescence enhancement was that the interaction between Cys and GSH-AuNCs/Ag⁺ was dominated by electronegative atoms and the pH environment of the solution. We chose the pH = 4 as the detection condition of Cys.

Under the optimal conditions, various concentrations of Cys were mixed with the GSH-AuNC/Ag⁺ system. Meanwhile, the spectra were recorded in Fig. 7A. With the increase of the Cys concentration from 0.5 μM to 100 μM, the fluorescence intensity of the GSH-AuNC/Ag⁺ sensing system gradually increased. As shown in Fig. 7B, it was found that there was a linear relationship between the fluorescence intensity ratio (F-F₀)/F₀ and the concentration of Cys, where F₀ and F are the fluorescence intensity of the GSH-AuNCs/Ag⁺ system in the absence and presence of Cys, respectively. The linear equation was y = 0.0659x + 0.0207, with R² = 0.993. The detection limit was calculated to be 0.365 μM.

**Specificity study**

The selectivity of the AuNCs-based method for Cys determination was investigated. The fluorescence responses of Ag⁺-modulated GSH-AuNCs with the addition of Cys, homocysteine (Hcy), aspartic acid (Asp), histidine (His), isoleucine (Ile), alanine (Ala), glutamic acid (Glu), and lysine (Lys) were recorded. Figure 8 shows that only D-/L-Cys and Hcy resulted in a significant fluorescence enhancement, while other interfering amino acids had no obvious increase. The discrimination of Cys from Hcy could not be achieved by this method. In the case of GSH, the addition could not result in the fluorescence variation of GSH-AuNCs, thus improving the specificity of detection. The possible reason could be attributed to the steric hindrance of the GSH molecule, which could not cause a visible aggregation of GSH-AuNCs. Hence, the above results exposed that the method based on Ag⁺-modulated GSH-AuNCs expressed high specificity for Cys recognition from interfering amino acids.

**Determination of L-Cys in human serum**

L-Cys in diluted human serum samples was investigated to further evaluate the GSH-AuNCs application in samples. The standard addition method was applied to measure the recoveries of Cys in serum samples. Different concentrations of Cys were spiked to the samples. As shown in Table 1, the GSH-AuNC sensor showed reasonable recoveries in the...
range of 106.7–111.3% and exhibited good reproducibility, with RSD values of less than 7.7%. The obtained recoveries of Cys detection were satisfactory, indicating that this proposed fluorescence AIEE method has good feasibility for measuring Cys in human serum matrices.

**Comparison of different analytical methods**

The developed method in this study is for the rapid determination of Cys. Various probes have already been reported for the analysis of Cys in different samples. Table 2 shows comparative results for different methods. The method used in this work has the advantage of the detection time. This advantage has prospects in the rapid determination of Cys.

**Discrimination of D-/L-Cys**

This study was conducted based on the interactions between different organic acids and different chiral Cys, and realized the selective recognition of D-/L-Cys. According to previous reports, mandelic acid had an interaction with D-Cys [41], while tartaric acid had an interaction with L-Cys [42]. In the present work, mandelic acid and tartaric acid were added into the GSH-AuNCs solution separately to realize the selective discrimination of D-/L-Cys. Photos under sunlight and UV light were recorded and UV and FL spectrum data were collected for further analysis. As shown in Fig. 9, when mandelic acid was added, only L-Cys caused a significant aggregation of GSH-AuNCs due to the stronger interaction between mandelic acid and D-Cys, and this change was visible under sunlight and UV light. The UV spectrum showed that the absorbance wavelength at 300–400 nm of the solution with L-Cys increased significantly; while adding D-Cys, the absorbance of the solution did not change much, and the UV spectrum was almost monodispersed. The fluorescence spectra of the samples were collected at an excitation wavelength of 398 nm as shown in Fig. 9D. The fluorescence emission intensity of adding D-/L-Cys increased by 1.2/2.4 times, respectively.

As expected, when tartaric acid, which tended to coordinate with L-Cys, was added, aggregation caused only by D-Cys was observed. This change could be distinguished by the naked eyes under sunlight and UV light. Similarly, the UV spectra illustrated that the absorbance of the solution with D-Cys at 300–400 nm was significantly enhanced, while the UV spectrum of the solution with L-Cys was almost monodispersed and slightly changed. Using 398 nm as the excitation wavelength, fluorescence spectra were collected, as shown in Fig. 10, and the fluorescence emission intensity of adding D-/L-Cys increased by 1.5 times/1.1 times. Based on the above results, D-/L-Cys were

---

**Table 1** Results of determination of L-Cys in human serum

| Sample       | Added/μM (μM) | Found/μM (μM) | Recovery, % (n = 6) | RSD, % (n = 6) |
|--------------|--------------|--------------|---------------------|---------------|
| Human serum  | 1.0          | 1.11±0.09    | 111.3               | 7.7           |
|              | 10.0         | 10.30±0.27   | 103.0               | 2.6           |
|              | 50.0         | 53.35±2.13   | 106.7               | 0.4           |

**Table 2** Comparison of various fluorescent probes applications for the determination of Cys

| Method                  | System                        | Linear range/μM | Detection limit/μM | Detection time/min |
|-------------------------|-------------------------------|-----------------|--------------------|-------------------|
| Method in this paper     | GSH-AuNCs-Ag⁺                  | 0.5–100         | 0.365              | 2                 |
| Method A [27]            | GSH-AuNCs-Ce³⁺                 | 0.4–120         | 0.15               | 30                |
| Method B [34]            | Chemical probe (CR1)           | 0–20            | 0.029              | 60                |
| Method C [35]            | Chemical probe (Cy.7-PT)       | 0–100           | 0.39               | –                 |
| Method D [36]            | Chemical probe (Cys-AN)        | –               | 0.96               | –                 |
| Method E [37]            | Xylan-AuNPs                    | 0–1000          | 0.57               | –                 |
| Method F [38]            | GSH-AuNCs                      | 2.49–800        | 0.42               | –                 |
| Method G [39]            | Chemical probe (BODIPY-coumarin fuorophores) | 0–100          | 0.366              | –                 |
| Method H [40]            | Chemical probe (ACA)           | 0–40            | 0.657              | 20                |

“–” Donates no clear record in the reference.
distinguished by naked eyes. Thus, the method had a promising application in chiral discrimination and resolution.

**Conclusions**

In summary, a method for the rapid determination of Cys using GSH-AuNCs was established. Selective analysis of the enantiomer of Cys was also achieved by this method. The mechanism behind the determination was driven by coordination between transition metal ions and GSH-AuNCs. Since Ag⁺ has a coordination effect with GSH-AuNCs, Cys could coordinate with Ag⁺ to form the complex and then bridge GSH-AuNCs. A regular network structure of the complex indicated that Cys connects GSH-AuNCs with Ag⁺ as a bridging agent. The network structure restricted intramolecular vibration and rotation, and reduced intermolecular collisions. Accordingly, the energy loss caused by the non-radiative transition decreased and the AIEE process occurred. Therefore, the concentration of Cys could be quantitatively determined, depending on the variation of the fluorescence intensity. More importantly, due to the large steric hindrance of GSH, fluorescence enhancement was hardly produced at the same concentration, thus improving the specificity of detection. Since the AIEE effect occurred rapidly, the detection process could be completed within 2 min. Moreover, due to the specific interactions of D-/L-Cys with mandelic acid and tartaric acid, the chiral discrimination of D-/L-Cys with naked eyes was realized by replacing the organic acid buffer. The results showed that AIEE has a potential of being applied to chiral discrimination.

![Digital photographs of GSH-AuNCs/Ag⁺ system responding to D-/L-Cys in the mandelic acid (100 mM) under A visible light and B UV light. C The UV spectra of the above solutions. D Fluorescence spectra at 620 nm of D/L-Cys in mandelic acid buffer.](image)
Fig. 10 Digital photographs of GSH-AuNCS/Ag⁺ system responding to D-/L-Cys in tartaric acid (100 mM) under A visible light and B UV light. C UV spectra of the above solutions. D Fluorescence spectra at 620 nm of D/L-Cys in tartaric acid buffer

Supplementary Information The online version contains supplementary material available at https://doi.org/10.2116/analsci.21P207.

Acknowledgements This research was financially supported by the National Natural Science Foundation of China (Nos. 81973285 and 81573397) and Shanghai Natural Science Foundation (15ZR1409400).

References

1. K. Axelsson, B. Mannervik, FEBS Lett. 152, 114 (1983)
2. Z.A. Wood, E.S. der Schröder, J.R. Harris, L.B. Poole, Trends Biochem. Sci. 28, 32 (2003)
3. E. Weerapana, C. Wang, G.M. Simon, F. Richter, S. Khare, M.B.D. Dillon, D.A. Bachovchin, K. Mowen, D. Baker, B.F. Cravatt, Nature 468, 790 (2010)
4. C.L. Jones, B.M. Stevens, A. D’Alessandro, R. Culp-Hill, J.A. Reisz, S. Pei, A. Gustafson, N. Khan, J. DeGregori, D.A. Polleyea, C.T. Jordan, Blood 134, 389 (2019)
5. A. Badalo, J.W. Hsu, C. Taylor-Bryan, C. Green, M. Reid, T. Forrester, F. Jahoor, Am. J. Clin. Nutr. 95, 84 (2012)
6. M.D. Kornberg, P. Bharagava, P.M. Kim, V. Putluri, A.M. Snowman, N. Putluri, P.A. Calabresi, S.H. Snyder, Science 360, 449 (2018)
7. M.W. Lieberman, A.L. Wiseman, Z.Z. Shi, B.Z. Carter, R. Barrios, C.N. Ou, P. Chevez-Barrios, Y. Wang, G.M. Habib, J.C. Goodman, S.L. Huang, R.M. Lebovitz, M.M. Matzuk, Proc. Natl. Acad. Sci. USA 93, 7923 (1996)
8. L. Huang, H. Ying, Z. Chen, Y.Gu. Yi Zhu, L. Hu, D. Chen, N. Zhong, Placenta 80, 27 (2019)
9. S. Chu, Z. Niu, Q. Guo, H. Bi, X. Li, F. Li, Z. Zhang, W. He, P. Cao, N. Chen, X. Sun, Eur. J. Pharmacol. 882, 173258 (2020)
10. M.F. McCarty, J.H. O’Keefe, J.J. Di Nicolantonio, Med. Hypotheses 132, 109356 (2019)
11. Y. KoSUGE, Exp. Ther. Med. 19, 1565 (2020)
12. A. Slivka, G. Cohen, Brain Res. 608, 33 (1993)
13. N. Shibuya, S. Koike, M. Tanaka, M. Ishigami-Yuasa, Y. Kimura, Y. Ogasawara, K. Fukui, N. Nagahara, H. Kimura, Nat. Commun. 4, S26 (2013)
14. C.H. Misra, Neurochem. Res. 14, 253 (1989)
15. H. Peng, Z. Huang, H. Deng, W. Wu, K. Huang, Z. Li, W. Chen, J. Liu, Angew. Chem. Int. Ed. Engl. 59, 9982 (2020)
16. Z.T. Luo, X. Yuan, Y. Yu, Q.B. Zhang, D.T. Leong, J.Y. Lee, J.P. Xie, J. Am. Chem. Soc. 134, 16662 (2012)
17. Z.T. Luo, V. Nachamnai, B. Zhang, N. Yan, D.T. Leong, D.E. Jiang, J.P. Xie, J. Am. Chem. Soc. 136, 10577 (2014)
18. T. Shu, L. Su, J. Wang, X. Lu, F. Liang, C. Li, X. Zhang, Anal. Chem. 88, 6071 (2016)
19. Y. Guo, X. Tong, L. Ji, Z. Wang, H. Wang, J. Hu, R. Pei, Chem. Commun. 51, 396 (2015)
20. N. Murshid, D.S. Smith, V. Kitaev, Part. Part. Syst. Charact. 35, 1800285 (2018)
21. J. Luo, Z. Xie, J.W.Y. Lam, L. Cheng, H. Chen, C. Qiu, H.S. Kwok, X. Zhan, Y. Liu, D. Zhu, B.Z. Tang, Chem. Commun. 18, 1740 (2001)
Rapid determination of cysteine and chiral discrimination of D-/L-cysteine via the…

22. Y. Yu, J. Li, T. Chen, Y.N. Tan, J. Xie, J. Phys. Chem. C 119, 10910 (2015)
23. Z. Gan, Y. Lin, L. Luo, G. Han, W. Liu, Z. Liu, C. Yao, L. Weng, L. Liao, J. Chen, X. Liu, Y. Luo, C. Wang, S. Wei, Z. Wu, Angew. Chem. Int. Ed. Engl. 55, 11567 (2016)
24. Y. Wei, W. Luan, F. Gao, X. Hou, Part. Part. Syst. Charact. 36, 1900314 (2019)
25. Z. Wu, H. Liu, T. Li, J. Liu, J. Yin, O.F. Mohammed, O.M. Bakr, Y. Liu, B. Yang, H. Zhang, J. Am. Chem. Soc. 139, 4318 (2017)
26. W.X. Wang, Y. Wu, H.W. Li, J. Colloid Interface Sci. 505, 577 (2017)
27. Q. Lai, Q. Liu, K. Zhao, X. Duan, G. Wang, X. Su, Microchem. Acta 186, 327 (2019)
28. M. Wu, J. Zhao, D.M. Chevrier, P. Zhang, L. Liu, J. Phys. Chem. C 123, 6010 (2019)
29. X. Lai, L. Tan, X. Deng, J. Liu, A. Li, J. Liu, J. Hu, ACS. Appl. Mater. Interfaces 9, 5118 (2017)
30. J. Liu, H. Liu, Y. Li, H. Wang, J. Biol. Phys. 40, 313 (2014)
31. W. Ding, Y. Liu, Y. Li, Q. Shi, H. Li, H. Xia, D. Wang, X. Tao, RSC Adv. 4, 22651 (2014)
32. X. Jiang, J. Huang, T. Chen, Q. Zhao, F. Xu, X. Zhang, Int. J. Biol. Macromol. 153, 412 (2020)
33. N.W. Pirie, K.G. Pinhey, J. Biol. Inorg. Chem. 84, 321 (1929)
34. S. Chen, Y. Luo, N. Wang, X. Chen, Y. Guo, H. Deng, J. Xu, S.W. Chen, J. Wang, Talanta 208, 119934 (2020)
35. X. Yang, Y. Wang, M.X. Zhao, W. Yang, Spectrochim. Acta Part A 212, 10 (2019)
36. S. Zhang, D. Wu, J. Wu, Q. Xia, X. Jia, X. Song, L. Zeng, Y. Yuan, Talanta 204, 747 (2019)
37. Y. Luo, Z. Shen, P. Liu, L. Zhao, X. Wang, Carbohydr. Polym. 140, 122 (2016)
38. Y. Zhang, H. Xu, Y. Chen, X. You, Y. Pu, W. Xu, X. Liao, J. Fluoresc. 30, 1491 (2020)
39. X.L. Liu, L.Y. Niu, Y.Z. Chen, Y. Yang, Q.Z. Yang, Biosens. Bioelectron. 90, 403 (2017)
40. X. Dai, Q.H. Wu, P.C. Wang, J. Tian, Y. Xu, S.Q. Wang, J.Y. Miao, B.X. Zhao, Biosens. Bioelectron. 59, 35 (2014)
41. H. Huang, L. Hu, Y. Sun, Y. Liu, Z. Kang, D.R. MacFarlane, Microchim. Acta 186, 298 (2019)
42. G. Song, C. Xu, B. Li, Sens. Actuators B 215, 504 (2015)