J Fluoresc (2011) 21:803–811
DOI 10.1007/s10895-010-0774-2

ORIGINAL PAPER

Study of Enhanced Chemiluminescence of Diperiodatocuprate (III) on 1,10-Phenanthroline/Hydrogen Peroxide/Cetyltrimethylammonium Bromide System

Jing Kang · Jieli Tang · Lu Han · Yihua Zhang

Received: 24 August 2010 / Accepted: 16 November 2010 / Published online: 3 December 2010

Abstract In the paper, a chemiluminescence (CL) system was developed based on the catalytical effect of diperiodatocuprate (III) (DPC) on the 1,10-phenanthroline (phen)/hydrogen peroxide (H_2O_2) in the presence of cetyltrimethylammonium bromide (CTAB). The effects of experimental conditions were investigated. Meanwhile the increase of CL intensity of the DPC/phen/H_2O_2/CTAB system is proportional to the concentration of phen in the range of low concentration. The linear range of the calibration curve is 5.0×10^{-9}–1.0×10^{-6} mol L^{-1}, and the corresponding detection limit is 1.9×10^{-9} mol L^{-1}. The effects of phenolic compounds (PCs) on the system were investigated. Hydroquinone was used as an example to investigate the application of the CL system to the determination of PCs. The quenched CL intensity is linearly related to the logarithm of concentration of hydroquinone. The linear range of the calibration curve is 2.5×10^{-9}–1.0×10^{-5} g mL^{-1}, and the corresponding detection limit is 1.8×10^{-9} g mL^{-1}. This phen and hydroquinone can be synchronously determined. The method was applied to the determination of hydroquinone in water samples and the recoveries were from 92% to 106%.

Keywords Chemiluminescence · Diperiodatocuprate (III) · 1, 10-phenanthroline · Hydroquinone

J. Kang · J. Tang · L. Han · Y. Zhang (✉)
Department of Analytical Chemistry, College of Chemistry,
Jilin University,
Changchun 130012, People's Republic of China
e-mail: yihuazh47@yahoo.com.cn

Introduction

In the recent past, interest in transition metals in highest oxidation state has increased significantly because of their characters of strong oxidation and supernormal catalysis. Transition metals in higher oxidation state can be stabilized by chelation with suitable polydentate ligands. The known transition metals in highest oxidation state include diperiodatocuprate (III) (DPC) [1–3], ditelluratocuprate (III) (DTC) [4], diperiodatoargentate (III) (DPA) [5, 6], diperiodatonickelate (IV) (DPN) [7, 8] and potassium ferrate (VI) [9]. Hitherto, a considerable amount of researches focused on the field of the reaction rate of transition metals in highest oxidation state and the existent form of reaction active center etc. [10–14]. Periodate and tellurate complexes of copper in its trivalent state were used in the analysis of several organic compounds [15, 16]. The kinetics of self-decomposition of these complexes was studied in some detail [17, 18]. The use of DPC as an oxidant in alkaline medium is new and restricted to a few cases due to its limited solubility and stability in aqueous medium. DPC has recently received considerable attention in the polymerization reaction. DPC is used as oxidant and polymer is used as reductant for the redox system, which initiates the radical graft copolymerization or block copolymerization [19–21]. DPC is a versatile one-electron oxidant for the oxidation of various organic compounds in alkaline medium and its use as an analytical reagent is now well recognized [22]. The chemiluminescence (CL) reactions based on their strong oxidation and supernormal catalysis effect have been reported [23–26].

The CL has attracted a great deal of attention as an interesting and useful detection method in analytical chemistry [27–30]. The CL detection has a number of advantages: (1) high detection sensitivity, (2) wide linear range of signal response, (3) inexpensive reagent and apparatus, (4) easy and rapid measurement. In the paper, the metal chelate DPC was prepared based on the complexation of trivalent copper and periodate in strong alkaline medium. The effect of DPC on the CL of the reaction of 1,10-phenanthroline (phen) and hydrogen peroxide (H_2O_2) in the presence of a cationic surfactant cetyltrimethylammonium bromide (CTAB) was studied. It was found that the addition of DPC into the phen/H_2O_2/CTAB system could induce significant enhancement on CL signal. Under the optimal conditions, the effects of phenolic compounds (PCs) on the DPC/phen/H_2O_2/CTAB CL system were investigated. PCs were observed to inhibit the CL signal of the system. This system can synchronously detect phen and hydroquinone. The CL mechanism was also discussed briefly based on the photoluminescence (PL) and CL spectra. To evaluate practical application for the proposed method, the water samples were analyzed and the results obtained were satisfactory.

Experimental

Reagents and Chemicals

$K_2S_2O_8$, $CuSO_4{\cdot}5H_2O$, KOH, NaOH, H_2O_2 (30%), phen, and CTAB were purchased from Beijing Chemical Plant in China. Phenol, catechol, hydroquinone, resorcinol were purchased from Tianjin Guangfu Fine Chemical Research Institute in China. Chlorogenic acid, catechin and kaempferol were purchased from National Institute for the Control of Pharmaceutical and Biological Products (Beijing China). All the reagents were of analytical reagent grade and all solutions were prepared with ultra-pure water.

Synthesis of DPC

The 0.01 mol L^{-1} DPC stock solution was prepared by oxidizing Cu (II) in the alkaline medium according to the reported method [22]. In briefly, KIO_4 (0.23 g), $CuSO_4{\cdot}5H_2O$ (0.125 g), $K_2S_2O_8$ (0.159 g), KOH (0.8 g) were dissolved in 30 mL water. The mixture was heated to boiling for about 20 min on a hot plate with constant stirring. The boiling mixture turned intensely red and was heated for another 20 min for the completion of the reaction. The mixture was then cooled and diluted to 50 mL with ultra-pure water. The obtained stock solution was stored in refrigeration at 0–4 °C. Under such storage condition, it was found fairly stable for several months and DPC solutions were freshly prepared before use. The complex was characterized by UV/visible spectrum, which exhibits a brood band at 415 nm, and the result is shown in Fig. 1.

Apparatus

The CL analysis was conducted on a laboratory-built steady injection CL system. The schematic diagram of the system is shown in Fig. 2. The steady injection Analysis Processor FIA-3100 (Beijing Wantuo Instruments Co. Ltd.) consists of two peristaltic pumps, a 16-hole eight-way valve and a digital-system to control the time and pump pressure. PTFE tube (0.8 mm i.d.) was used as connection material in the steady system. The CL emission was detected by an ultra-weak luminescence analyzer (type BPCL manufactured at the Institute of Biophysics, Chinese Academy of Sciences, Beijing, China). The acquisition and treatment of data were performed with BPCL software running under Windows XP.

Fluorescence spectra were recorded on a RF-5301 spectrofluorimeter (Shimadzu, Japan). The absorption spectra were recorded on an Australian GBC Cintra 10e UV–vis Spectrometer within the wavelength range from 200 to 800 nm.

Procedure

Experimental results were obtained using the following operation parameters: pump rate, 60 r/min; sample

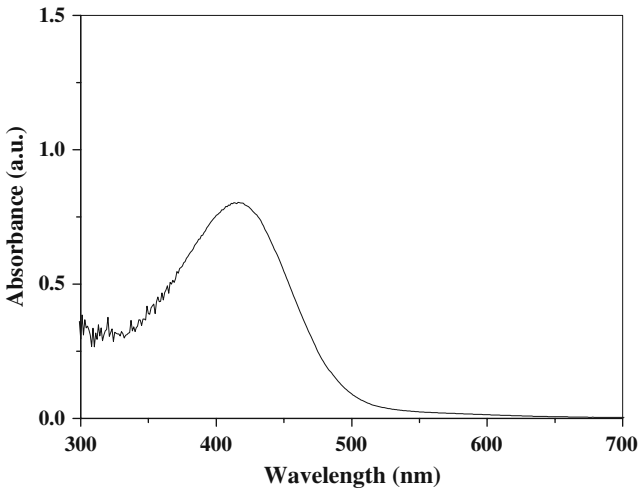


Fig. 1 The absorption spectrum of DPC

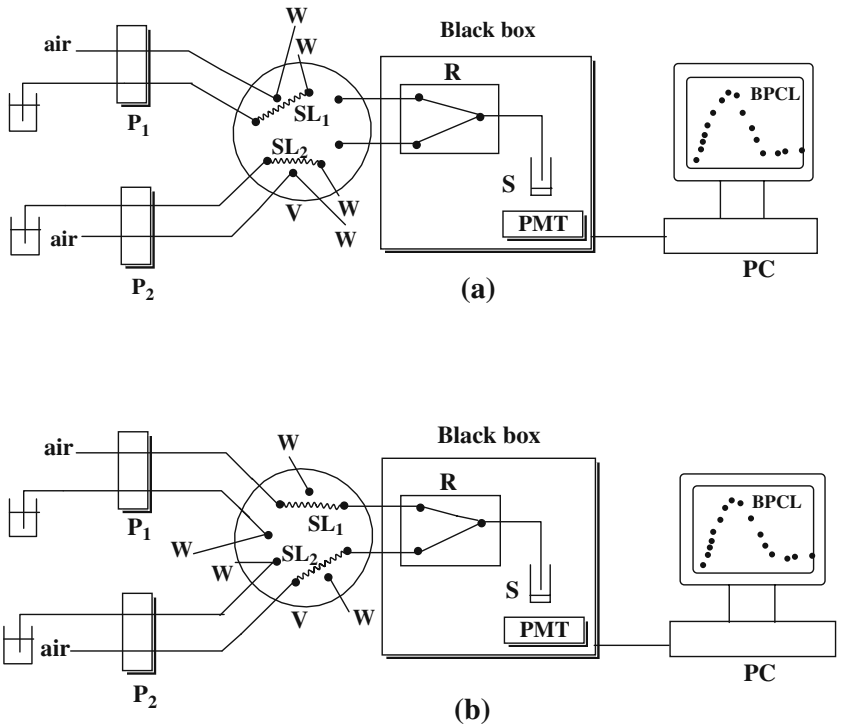


Fig. 2 Schematic diagram of the steady-injection CL system. A: H_2O_2 solution; B: phen solution; P_1, P_2: peristaltic pump; SL: sample loop; V: eight-way valve; R: chemifold; S: sample cell; PMT: photomultiplier tube; PC: computer; W: waste. **a** Loading position. **b** Injection position

loop volume, 300 μL; sampling time, 12 s; sample injection time, 20 s; the PMT negative voltage, −700 V; the integral time of the CL signal, 60 s. 200 μL of DPC solution (or solution containing DPC and PCs) and 200 μL of CTAB solution were first added into the sample cell (1 cm i.d. of colorless glass tube), and then H_2O_2 and phen solution were synchronously injected into the sample cell using the steady injection system.

In sequence 1 (Fig. 2a), pumps P_1 and P_2 were activated, and valve V was in the loading position. The pump P_1 was used to deliver H_2O_2 solution into the sample $loop_1$ (SL_1) and the pump P_2 was used to introduce phen solution into the sample $loop_2$ (SL_2). In sequence 2 (Fig. 2b), pumps P_1 and P_2 were activated, and valve V was in the injection position. The pumps P_1 and P_2 were used to deliver the air current. The H_2O_2 solution and phen solution were simultaneously pumped at the same rate separately into chemifold R where they were mixed. The mixed solution was carried into sample cell S and mixed with DPC (or solution containing DPC and PCs) and CTAB solution in the sample cell S. CL signal was measured and recorded. After determination, the mixed solution in the sample cell S was emptied. The sample cell S was washed and dried. All experiments were performed in triplicate.

The concentration of analyte was quantified by measuring the change of CL intensity. $\Delta I = I_s - I_0$ is for the determination of phen, and $\Delta I = I_0 - I_s$ is for the determination of hydroquinone, where I_0 and I_s are CL

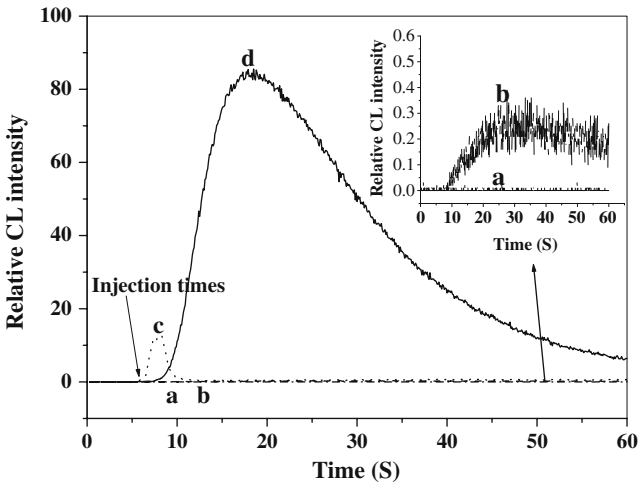


Fig. 3 Dynamic CL intensity–time profiles of phen/DPC/CTAB (*a*), DPC/phen/H_2O_2 (*b*), phen/H_2O_2/CTAB (*c*) and DPC/phen/H_2O_2/CTAB (*d*) CL reactions. Conditions: phen, 1.0×10^{-3} mol L^{-1}; H_2O_2, 1.0 mol L^{-1}; DPC, 1.0×10^{-4} mol L^{-1}; NaOH, 0.1 mol L^{-1}; CTAB, 2.0×10^{-3} mol L^{-1}

signals in the absence and presence of the analyte, respectively.

Preparation of Sample

The sample solution was filtered into the beaker, and 100 mL of the resulting solution was added to 250 mL distillation flask. The solution was heated and distilled. The hydroquinone was slowly volatilized with steam. When there was about 90 mL distilled solution left, the residual liquid was cooled and 10 mL of ultra-pure water was added into the distillation flask. The mixture was continuous heated and distilled until the distilled solution was at 100 mL.

Results and Discussion

CL of DPC/phen/H_2O_2/CTAB System

The dynamic CL intensity–time profiles are shown in Fig. 3. The results indicate that the CL signals of phen/DPC/CTAB, DPC/phen/H_2O_2 and phen/H_2O_2/CTAB system are very low (Fig. 3a, b and c), but the CL signal of

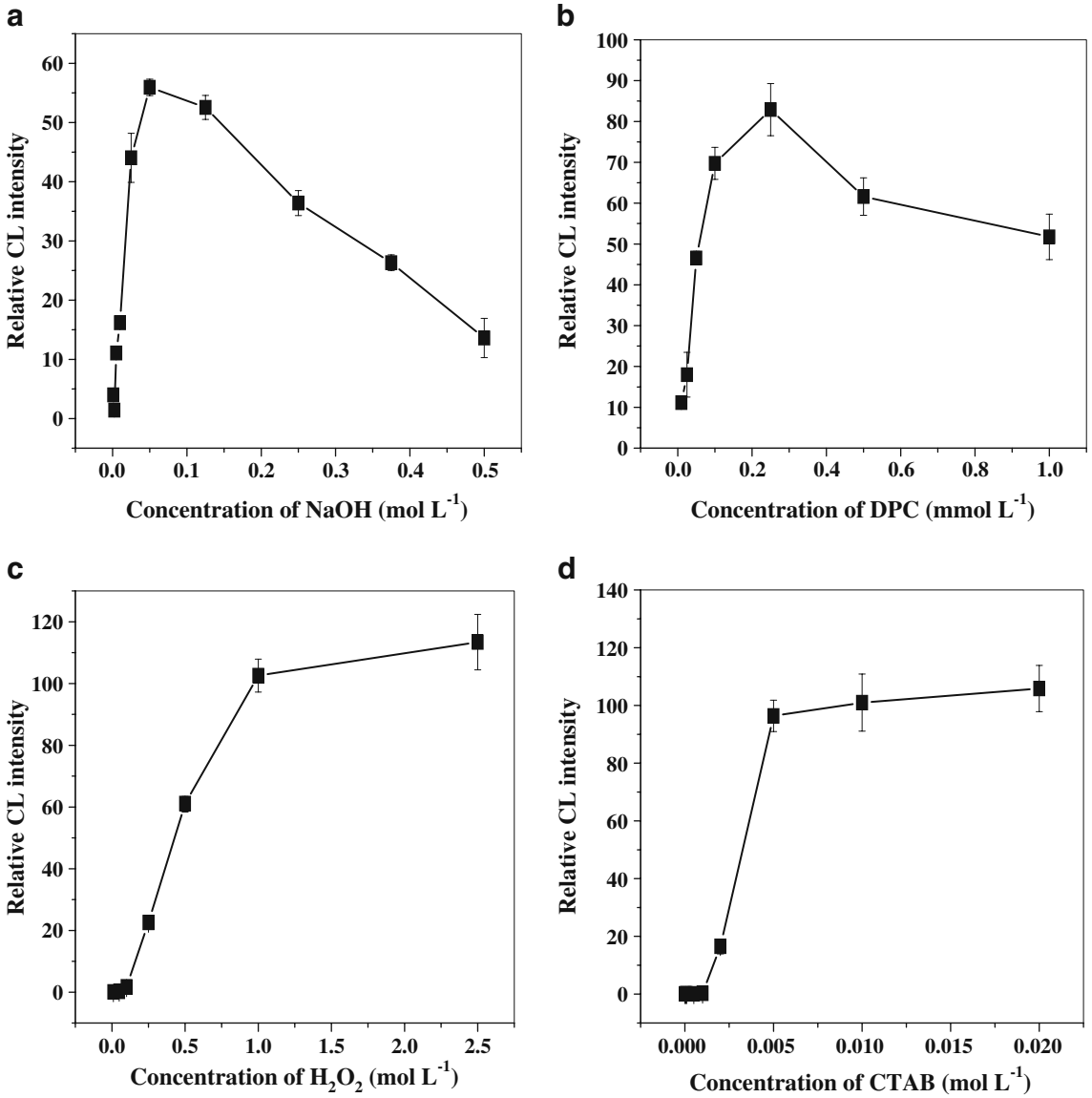


Fig. 4 Optimization of the reaction conditions. Concentration: (**a**) phen, 1.0×10^{-3} mol L^{-1}; H_2O_2, 1.0 mol L^{-1}; DPC, 1.0×10^{-4} mol L^{-1}; CTAB, 2.0×10^{-3} mol L^{-1}. (**b**) phen, 1.0×10^{-3} mol L^{-1}; H_2O_2, 1.0 mol L^{-1}; NaOH, 0.05 mol L^{-1}; CTAB, 2.0×10^{-3} mol L^{-1}. (**c**) phen, 1.0×10^{-3} mol L^{-1}; DPC, 2.5×10^{-4} mol L^{-1}; NaOH, 0.05 mol L^{-1}; CTAB, 2.0×10^{-3} mol L^{-1}. (**d**) phen, 1.0×10^{-3} mol L^{-1}; H_2O_2, 1.0 mol L^{-1}; DPC, 2.5×10^{-4} mol L^{-1}; NaOH, 0.05 mol L^{-1}

phen/H_2O_2/CTAB system could be remarkably enhanced in the presence of DPC (Fig. 3d). Moreover, the CL intensity–time profiles (Fig. 3) confirmed that the CL reactions were slow and the maximum emission intensity was attained within 2.8 s for phen/H_2O_2/CTAB system and 13 s for DPC/phen/H_2O_2/CTAB system after initiating the reactions.

Effect of the Concentration of NaOH

The proposed CL reaction under the acidic or neutral medium cannot produce CL signals. When the CL reaction was conducted in alkaline medium, surprisingly, the CL emission can be enhanced drastically. The NaOH solution was employed as the reaction medium and the DPC was diluted with NaOH solution. The influence of NaOH concentration on the CL intensity was tested, as shown in Fig. 4a. The most suitable NaOH concentration for DPC/phen/H_2O_2/CTAB CL system was 0.05 mol L^{-1}. When the NaOH concentration exceeded 0.05 mol L^{-1}, a simultaneous decrease of CL intensity was observed.

Effect of the Concentration of DPC

The effect of the concentration of DPC on the CL intensity was examined in the range of 1.0×10^{-5}–1.0×10^{-3} mol L^{-1}, and the results are shown in Fig. 4b. The CL intensity increases when the DPC concentration increases from 1.0×10^{-5} to 2.5×10^{-4} mol L^{-1}, and the intensity started to decrease when the concentration is higher than 2.5×10^{-4} mol L^{-1}. Therefore, the optimum DPC concentration was chosen to be 2.5×10^{-4} mol L^{-1}.

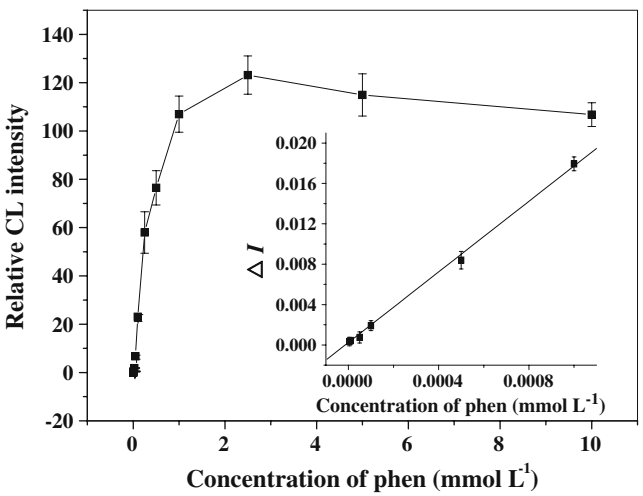


Fig. 5 Influence of phen concentration on the CL intensity. Concentration: H_2O_2, 1.0 mol L^{-1}; DPC, 2.5×10^{-4} mol L^{-1}; NaOH, 0.05 mol L^{-1}; CTAB, 5.0×10^{-3} mol L^{-1}

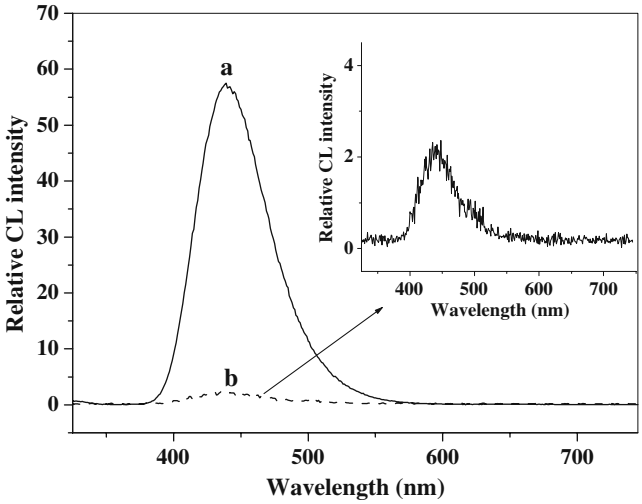


Fig. 6 The CL spectra of DPC/phen/H_2O_2/CTAB (*a*) and phen/H_2O_2/CTAB (*b*) system. Concentration: phen, 2.5×10^{-3} mol L^{-1}; H_2O_2, 1.0 mol L^{-1}; DPC, 2.5×10^{-4} mol L^{-1}; CTAB, 5.0×10^{-3} mol L^{-1}; NaOH, 0.05 mol L^{-1}

Effect of the Concentration of H_2O_2

The influence of H_2O_2 concentration on the CL intensity was studied in the range of 0.010–2.5 mol L^{-1}. The experimental results are shown in Fig. 4c. The CL intensity increases with increasing H_2O_2 concentration. The CL intensity significantly increases with increasing H_2O_2 concentration up to 1.0 mol L^{-1}. When the H_2O_2 concentration is higher than 1.0 mol L^{-1}, the CL intensity is slowly increased. The H_2O_2 concentration of 1.0 mol L^{-1} was chosen for further research.

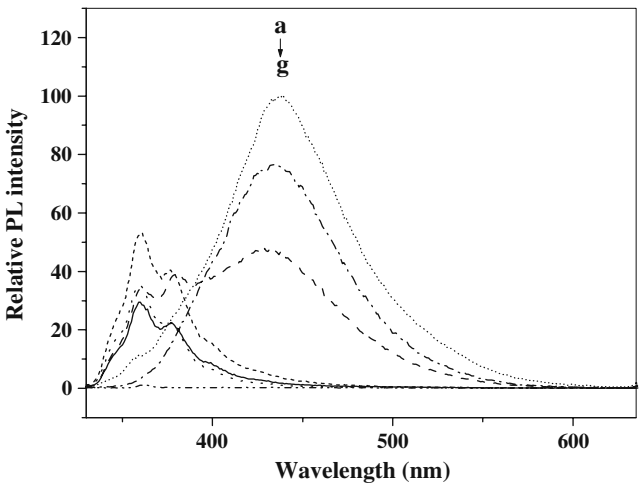
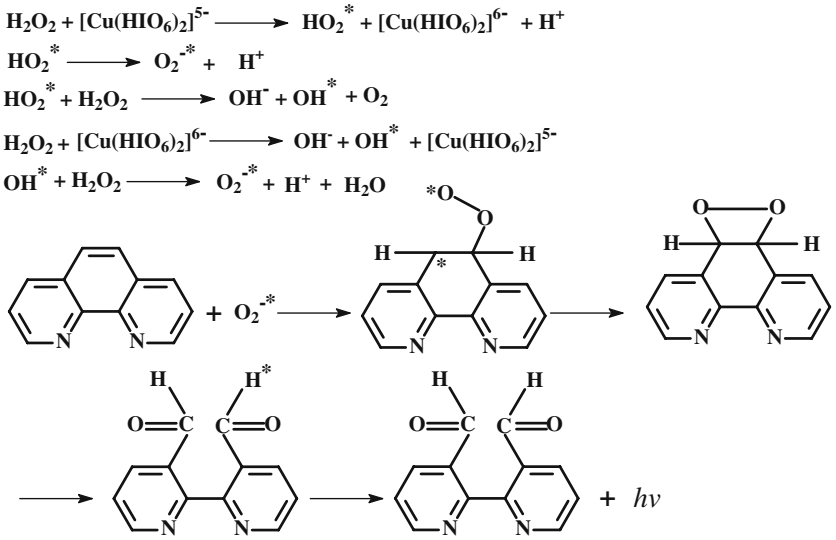


Fig. 7 The PL spectra of DPC/phen/H_2O_2/CTAB (*a*), DPC/phen/H_2O_2 (*b*), phen/H_2O_2 (*c*), phen/CTAB (*d*), phen (*e*), phen/DPC (*f*) and DPC/H_2O_2 (*g*) system. Concentration: phen, 2.5×10^{-3} mol L^{-1}; H_2O_2, 1.0 mol L^{-1}; DPC, 2.5×10^{-4} mol L^{-1}; CTAB, 5.0×10^{-3} mol L^{-1}; NaOH, 0.05 mol L^{-1}

Scheme 1 The mechanism of the CL



Effect of the Concentration of CTAB

The effect of CTAB concentration on the CL signals was studied in the range of 1×10^{-6}–2×10^{-2} mol L^{-1}, and the experimental results are shown in Fig. 4d. It can be seen from Fig. 4d that the CL intensity increases with increasing CTAB concentration up to 5.0×10^{-3} mol L^{-1}. When the CTAB concentration is higher than 5.0×10^{-3} mol L^{-1}, the CL intensity is essentially constant. Hence, 5.0×10^{-3} mol L^{-1} CTAB was chosen as the optimum concentration. The CTAB has not significant influence on the CL intensity when the concentration of CTAB is lower than the critical micelle concentration (CMC, 9×10^{-4} mol L^{-1} for CTAB [31]). When the concentration of CTAB is higher than the CMC, CTAB molecules tend to form a micell. The local microenvironment of micell leads to a significant increase in CL quantum yield [32]. When the concentration of CTAB is higher than CMC, the compartmentalization due to the formation of the micell prevents oxygen-based quenching and leads to CL increase. When the concentration of micell is high enough to completely prevent oxygen-based quenching, the CL intensity of the system does not increase with the increase of the CTAB concentration. So the CL signal is constant when concentration of CTAB is higher than 5.0×10^{-3} mol L^{-1}.

Effect of the Concentration of Phen

The effect of phen concentration on the CL intensity was tested, as shown in Fig. 5. The CL intensity increases with increasing phen concentration up to 2.5×10^{-3} mol L^{-1}. When the phen concentration is higher than 2.5×10^{-3} mol L^{-1}, the CL intensity of the system decreases with the increasing concentration of phen. Hence, the phen solution of 2.5×10^{-3} mol L^{-1} was chosen for subsequent studies.

There is a good linear relationship between the enhanced CL intensity and the concentration of phen in the range of

Table 1 Inhibition effects of phenolic compounds on phen/H_2O_2/CTAB system

Compounds	Concentration (μg/mL)	Quenching (%)	Concentration (μg/mL)	Quenching (%)	Concentration (μg/mL)	Quenching (%)
Phenol	10	31.0	5	14.4	1	6.0
Catechol	10	51.3	5	35.1	1	16.1
Hydroquinone	10	58.1	5	31.0	1	22.8
Resorcinol	10	45.3	5	22.3	1	18.3
Chlorogenic acid	10	77.0	5	65.7	2.5	30.2
Catechin	10	96.8	5	81.6	2.5	41.1
Kaempferol	10	72.1	5	50.5	2.5	27.1

Table 2 Inhibition effects of phenolic compounds on DPC/phen/H_2O_2/CTAB system

Compounds	Concentration (μg/mL)	Quenching (%)	Concentration (μg/mL)	Quenching (%)	Concentration (μg/mL)	Quenching (%)
Phenol	1	40.4	0.1	25.3	0.01	12.5
Catechol	1	54.4	0.1	41.4	0.01	23.4
Hydroquinone	1	56.2	0.1	43.3	0.01	23.7
Resorcinol	1	46.9	0.1	34.9	0.01	18.7
Chlorogenic acid	1	60.7	0.1	50.1	0.01	18.2
Catechin	1	70.1	0.1	59.8	0.01	20.7
Kaempferol	1	60.5	0.1	42.6	0.01	13.4

low concentration (Fig. 5 inset). The linear range is 5.0×10^{-9}–1.0×10^{-6} mol L^{-1}, linear regression equation is $\Delta I = 17.58C + 0.0002440$ (C, mmol L^{-1}; $r = 0.9993$) and the detection limit is 1.9×10^{-9} mol L^{-1}. The relative standard deviation for determining 1.0×10^{-7} mol L^{-1} phen is 3.0% (n=11). The results demonstrate that the proposed CL system may be used to detect phen.

Mechanism

The CL spectrum of the reaction was examined and the results are shown in Fig. 6. The CL emission peaks of phen/H_2O_2/CTAB and DPC/phen/H_2O_2/CTAB system are at about 440 nm. When the DPC was added into the phen/H_2O_2/CTAB system, the shape of the CL emission peak was not significantly affected, but the CL intensity significantly was enhanced. In order to understand the mechanism of the CL reaction, the PL spectrum of the reaction was examined. Figure 7 shows significant difference in the PL spectra of different systems. From Fig. 7e it can be seen that the characteristic emission peak of phen in alkaline medium appears at 360 nm. When the CTAB (Fig. 7d) and DPC (Fig. 7f) were added into the alkaline solution containing phen, they had not significant influence on the shape of the PL emission peak, but the PL intensity of phen/CTAB system (Fig. 7d) was enhanced. When the H_2O_2 was added into the alkaline solution containing phen, a new PL emission peak which was a broad peak appears at 436 nm (Fig. 7c). Simultaneously, the characteristic emission peak of phen decreases. The PL emission peaks of phen/DPC/H_2O_2 (Fig. 7b) and CTAB/phen/DPC/H_2O_2 (Fig. 7a) system are also at about 436 nm, and the characteristic emission peak of phen disappears. The PL spectrum shows peak at 436 nm coinciding with the CL spectrum. Therefore it is proposed that the phen can be oxidized to new substance by oxidant. The relaxation of this excited state of the substance induces the transitions, which produces CL signal. The addition of DPC into the phen/H_2O_2/CTAB system could induce significant enhancement on CL signal.

The possible mechanism of CL emission is shown in Scheme 1. In this reaction, DPC catalyzes the decomposition of H_2O_2 and production of superoxide ion (O_2^{-*}). The O_2^{-*} reacts with phen to form an intermediate product, which emits light by fragmenting the intermediate product [33]. Enhancement of CL by adding cationic micellular solutions

Table 3 Tolerance of foreign substances

Substance	Concentration (μmol/L)	Relative error (%)	Substance	Concentration (μmol/L)	Relative error (%)
K^+, Cl^-	1,000	−2.6	Cd^{2+}, Cl^-	25	−0.9
Na^+, Cl^-	1,000	−1.0	Mn^{2+}, SO_4^{2-}	10	2.2
Mg^{2+}, Cl^-	500	−4.7	Cr^{3+}, NO_3^-	25	0.2
Ca^{2+}, Cl^-	500	1.9	Pb^{2+}, NO_3^-	50	2.0
Zn^{2+}, Cl^-	250	−1.3	Fe^{2+}, Cl^-	10	−3.8
Al^{3+}, SO_4^{2-}	250	−2.8	tetrachloromethane	1,000	−1.8
Ba^{2+}, Cl^-	250	−2.2	methanol	1,000	−1.8
Ag^+, NO_3^-	1,000	4.0	ethanol	1,000	4.1

Concentration of hydroquinone is 1.0×10^{-7} g/mL

is thought to involve more efficient reaction of phen with O_2^{-*} in the Stern region of the micelles [34].

Influence of PCs

Tables 1 and 2 show the effects of PCs on the phen/H_2O_2/CTAB and DPC/phen/H_2O_2/CTAB CL system, respectively. All the tested PCs inhibited the CL signals of phen/H_2O_2/CTAB and DPC/phen/H_2O_2/CTAB system. It can be seen form Tables 1 and 2 that the inhibition effects of PCs on the DPC/phen/H_2O_2/CTAB system were strong. Based on the quenching of CL for DPC/phen/H_2O_2/CTAB system by PCs, a sensitive CL quenching method has been developed for the determination of PCs. By comparison with the determination of PCs using the phen/H_2O_2/CTAB system, the determination of PCs using the DPC/phen/H_2O_2/CTAB system has higher sensitivity.

The hydroquinone was used as an example, and the analytical potential of the inhibition effects of PCs on the proposed DPC/phen/H_2O_2/CTAB system was explored. There is a good linear relationship between the ΔI and the logarithm of concentration of hydroquinone. The linear range is 2.5×10^{-9}–1.0×10^{-5} g mL^{-1}, linear regression equation is $\Delta I = 3.460lgC + 5.611$ (*C, ng* mL^{-1}; $r = 0.9950$) and the detection limit is 1.8×10^{-9} g mL^{-1}. The relative standard deviation for determination of 1.0×10^{-7} g mL^{-1} hydroquinone is 2.3% (n=11). By comparison with some existing methods [35–38], the proposed method has advantages of instrumental simplicity, low cost, high sensitivity and wide linear response range.

Interfering Substance

The interferences of foreign substances were tested when the concentration of hydroquinone was 1.0×10^{-7} mol L^{-1}. The results are listed in Table 3. It can be seen from Table 3 that most of the coexisting substances do not interfere with the determination of hydroquinone. A good selectivity exists in the method.

Analytical Applications

In order to test the feasibility of the method, it was applied to the determination of hydroquinone in water samples, such as tap water, rain water and lake water samples. The water samples were analysed and the results indicated that the hydroquinone in the samples was not detectable. The standard solutions of hydroquinone were added into water and the spiked samples were analyzed. The obtained results are shown in Table 4. The recoveries of hydroquinone at the different concentration levels range from 92% to 106%. These results indicate that the proposed method can be applied for the determination of PCs in water, although sensitivity varies with the compounds.

Conclusion

In the work, an effective catalyzer DPC has been used for its excellent catalytical effect on the phen/H_2O_2 CL reaction in the presence of CTAB. The possible enhancement mechanism of DPC on phen/H_2O_2/CTAB CL was further investigated based on the PL and CL spectra. Based on the studies, a new CL system of DPC/phen/H_2O_2/CTAB was developed. The effects of experimental conditions were investigated. The proposed method could be successfully applied to the simultaneous determination of phen and hydroquinone. The proposed method has the advantages, such as simple instrument, low cost, high sensitivity and wide linear response range for determination of hydroquinone. The method was successfully applied to the determination of hydroquinone in the water samples, such as tap water, rain water and lake water samples. This work is important for the investigation of new and efficient catalysts for chemiluminescent reactions. Moreover, there is more potential application of DPC to CL analysis.

Table 4 Determination of hydroquinone in water samples

Sample	Added (g/mL)	Found (g/mL) (n=5)	Recovery (%)	RSD (%)
Tap water	5.0×10^{-8}	5.2×10^{-8}	104	2.3
	1.0×10^{-7}	9.5×10^{-8}	95	2.4
	5.0×10^{-7}	4.7×10^{-7}	94	1.8
Rain water	5.0×10^{-8}	5.3×10^{-8}	106	2.2
	1.0×10^{-7}	9.7×10^{-8}	97	3.6
	5.0×10^{-7}	4.6×10^{-7}	92	2.3
Lake water	5.0×10^{-8}	5.1×10^{-8}	102	1.4
	1.0×10^{-7}	9.9×10^{-8}	99	2.1
	5.0×10^{-7}	5.2×10^{-7}	104	1.6

References

1. Movius WG (1973) Oxidation of alcohols by diperiodatocuprate (III). Inorg Chem 12:31–33
2. Shan JH, Wang LP, Shen SG, Sun HW (2002) Kinetics and mechanism of oxidation of ethylene glycol monobutyl ether by diperiodatocuprate (III) in alkaline medium. Chin J Inorg Chem 18:887–891
3. Jose TP, Tuwar SM (2007) Oxidation of threonine by the analytical reagent diperiodatocuprate (III)—an autocatalysed reaction. J Mol Struct 827:137–144
4. Shan JH, Wang LP, Shen SG, Sun HW (2003) Kinetics and mechanism of oxidation of some hydroxy butyric acid salts by ditelluratocuprate (III) in alkaline medium. Turk J Chem 27:265–272
5. Kumar A, Kumar P, Ramamurthy P (1999) Kinetics of oxidation of glycine and related substrates by diperiodatoargentate (III). Polyhedron 18:773–780
6. Veeresh TM, Nandibewoor ST (2008) Thermodynamic quantities for the different steps involved in the mechanism of osmium (VIII) catalysed oxidation of L-lysine by a new oxidant, diperiodatoargentate (III) (stopped flow technique). J Chem Thermodyn 40:284–291
7. Shan JH, Qian J, Gao MZ, Shen SG, Sun HW (2004) Kinetics and mechanism of oxidation of n-propanolamine by dihydroxydiperiodatonickelate (IV) in alkaline medium. Turk J Chem 28:9–15
8. Shettar RS, Nandibewoor ST (2005) Kinetic, mechanistic and spectral investigations of ruthenium (III)-catalysed oxidation of 4-hydroxycoumarin by alkaline diperiodatonickelate (IV) (stopped flow technique). J Mol Catal A Chem 234:137–143
9. Delaude L, Laszlo P, Lehance P (1995) Oxidation of organic substrates with potassium ferrate (VI) in the presence of the K10 montmorillonite. Terrahedron lett 36:8505–8508
10. Veeresh TM, Patil RK, Nandibewoor ST (2008) Thermodynamic quantities for the oxidation of ranitidine by diperiodatocuprate (III) in aqueous alkaline medium. Transit Met Chem 33:981–988
11. Chimatadar SA, Basavaraj T, Thabaj KA, Nandibewoor ST (2007) Ruthenium (III) catalysed oxidation of gabapentin (neurontin) by diperiodatocuprate (III) in aqueous alkaline medium—a kinetic and mechanistic study. J Mol Catal A Chem 267:65–71
12. Kumar A, Kumar P (1999) Kinetics and mechanism of oxidation of nitrilotriacetic acid by diperiodatoargentate (III). J Phys Org Chem 12:79–85
13. Hosamani RR, Nandibewoor ST (2009) Mechanistic study of ruthenium (III) catalysed oxidation of L-lysine by diperiodatoargentate (III) in aqueous alkaline medium. J Chem Sci 121:275–281
14. Sharma VK, Anquandah GAK, Nesnas N (2009) Kinetics of the oxidation of endocrine disruptor nonylphenol by ferrate (VI). Environ Chem Lett 7:115–119
15. Niu WJ, Zhu Y, Hu KC, Tong CL, Yang HS (1996) Kinetics of oxidation of SCN- by diperiodato cuprate (III) (DPC) in alkaline medium. Int J Chem Kinet 28:899–904
16. Hiremath DC, Sirsalmath KT, Nandibewoor ST (2008) Osmium (VIII)/ruthenium (III) catalysed oxidation of L-lysine by diperiodatocuprate (III) in aqueous alkaline medium: a comparative mechanistic approach by stopped flow technique. Catal Lett 122:144–154
17. Rozovoskii GI, Misyavichyus AK, Prokopchik AY (1975) Reduction of copper (III) in alkaline ditelluratocuprate (III) solutions. Kinet Catal 16:337
18. Kulkarni SD, Nandibewoor ST (2006) A kinetic and mechanistic study on oxidation of Isoniazid drug by alkaline diperiodatocuprate (III)—a free radical intervention. Transit Met Chem 31:1034–1039
19. Liu YH, Liu ZH, Zhang YZ, Deng KL (2003) Graft copolymerizaztion of methyl acrylate onto chitosan initiated by potassium diperiodatocuprate (III). J Appl Polym Sci 89:2283–2289
20. Savina IN, Mattiasson B, Galaev IY (2006) Graft polymerization of vinyl monomers inside macroporous polyacrylamide gel, cryogel, in aqueous and aqueous-organic media initiated by diperiodatocuprate (III) complexes. J Polym Sci A Polym Chem 44:1952–1963
21. Liu YH, Bai LB, Zhang RY, Li YX, Liu YW, Deng KL (2005) Block copolymerization of poly(ethylene glycol) and methyl acrylate using potassium diperiodatocuprate (III). J Appl Polym Sci 96:2139–2145
22. Jose TP, Tuwar SM (2007) Oxidation of threonine by the analytical reagent diperiodatocuprate (III)—an autocatalysed reaction. J Mol Struct 827:137–144
23. Li BX, Zhang ZJ, Liu W (2001) Flow-injection chemiluminescence determination of chlortetracycline using on-line electrogenerated $[Cu(HIO_6)_2]^{5-}$ as the oxidant. Talanta 55:1097–1102
24. Zhang YT, Zhang ZJ, Sun YH, Wei Y (2007) Development of an analytical method for the determination of β2-agonist residues in animal tissues by high-performance liquid chromatography with on-line electrogenerated [Cu(HIO6)2]5–luminol chemiluminescence detection. J Agric Food Chem 55:4949–4956
25. Hu YF, Zhang ZJ (2008) Determination of free cholesterol based on a novel flow-injection chemiluminescence method by immobilizing enzyme. Luminescence 23:338–343
26. Hu YF, Zhang ZJ, Yang CY (2007) The determination of hydrogen peroxide generated from cigarette smoke with an ultrasensitive and highly selective chemiluminescence method. Anal Chim Acta 60:95–100
27. Marquette CA, Blum LJ (2006) Applications of the luminol chemiluminescent reaction in analytical chemistry. Anal Bioanal Chem 385:546–554
28. Tsukagoshi K, Nakahama K, Nakajima R (2004) Direct detection of biomolecules in a capillary electrophoresis-chemiluminescence detection system. Anal Chem 76:4410–4415
29. Gámiz-Gracia L, García-Campaña AM, Soto-Chinchilla JJ, Huertas-Pérez JF, González-Casado A (2005) Analysis of pesticides by chemiluminescence detection in the liquid phase. Trends Anal Chem 24:927–942
30. Fletcher KA, Fakayode SO, Lowry M, Tucker SA, Neal SL, Kimaru IW, McCarroll ME, Patonay G, Oldham PB, Rusin O, Strongin RM, Warner IM (2006) Molecular fluorescence, phosphorescence, and chemiluminescence spectrometry. Anal Chem 78:4047–4068
31. Chauhan S, Chauhan MS, Kaushal D, Syal VK, Jyoti J (2010) Study of micellar behavior of SDS and CTAB in aqueous media containing furosemide—a cardiovascular drug. J Solution Chem 39:622–638
32. Paleos CM, Vassilopoulos G, Nikokavouras J (1982) Chemiluminescence in oriented systems: chemiluminescence of 10, 10'-dimethyl-9, 9'-biacridinium nitrate in micellar media. J Photochem 18:327–334
33. Xiao CB, Palmer DA, Wesolowski DJ, Lovitz SB, King DW (2002) Carbon dioxide effects on luminol and 1, 10-phenanthroline chemiluminescence. Anal Chem 74:2210–2216
34. Yamada M, Suzuki S (1984) Micellar enhanced chemi-luminescence of 1, 10-phenanthroline for the determination of ultratraces of copper (II) by flow-injection method. Anal Lett 17:251–263
35. Marrubini G, Calleri E, Coccini T, Castoldi AF, Manzo L (2005) Direct analysis of phenol, catechol and hydroquinone in human urine by coupled-column HPLC with fluorimetric detection. Chromatographla 62:25–31
36. Kang J, Li J, Tang JL, Li MJ, Li XZ, Zhang YH (2010) Sensitized chemiluminescence of Tween 20 on CdTe/H_2O2 and its analytical applications for determination of phenolic compounds. Colloid Surf B 76:259–264
37. Cui H, He CX, Zhao GW (1999) Determination of polyphenols by high-performance liquid chromatography with inhibited chemiluminescence detection. J Chromatogr A 855:171–179
38. Ding YP, Liu WL, Wu QS, Wang XG (2005) Direct simultaneous determination of dihydroxybenzene isomers at C-nanotube-modified electrodes by derivative voltammetry. J Electroanal Chem 575:275–280