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# A new chemiluminescence method for the determination of nickel ion

Li Na Li, Nian Bing Li, Hong Qun Luo\*

School of Chemistry and Chemical Engineering, Southwest China Normal University, Beibei, Chongqing 400715, China

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# Abstract

A new chemiluminescence (CL) phenomenon described as the second-chemiluminescence (SCL) was observed and a strong CL signal was detected, when Ni(II) ion was injected into the mixture after the end of the reaction of potassium permanganate with alkaline luminol. The possible CL mechanism is proposed based on the kinetic curve of the CL reaction, CL spectra, UV–vis spectra and some other experiments. A flow-injection analysis for the determination of nickle(II) ion has been developed, based on the catalysis of nickel(II) ion on the CL reaction between potassium manganate produced on-line and luminol under alkaline condition. Under the optimum conditions, the SCL intensity is linear with the concentration of nickel(II) ion in the range of 8.0–200.0  $\mu$ g l<sup>-1</sup> and 0.2–2.0 mg l<sup>-1</sup>. The R.S.D. was 4.5% for 11 determinations of 250  $\mu$ g l<sup>-1</sup> nickel(II) ion and the detection limit (3 $\sigma$ ) for nickel(II) ion was 0.33  $\mu$ g l<sup>-1</sup>. The method was applied to determine nickel(II) ion in synthetic samples with satisfactory results.

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Keywords: Nickel(II) ion; Second-chemiluminescence reaction; Flow-injection analysis

# 1. Introduction

Nickel is one of the essential elements in the organism and can strengthen the secretion of the insulin, lower the blood sugar level, stimulate the hemutopoiesis function, promote the regeneration of the red corpuscles, and treat the anaemia and cirrhosis. Nickel still has buffer action to lung worry, asthma and heart-lungs function in disfigurement [1]. Though nickel has such important function on people, the amount of nickel needed is very little in human metabolism. However, the source of nickel is very extensive in the surrounding environment, and the phenomenon of lacking nickel is very seldom. On the contrary, excessive nickel can cause nose cancer, lung cancer and leukaemia in the rich nickel environment [2,3]. In addition, it can also produce the diseases such as heart attack, apoplexy, chronic hepatitis, uremia and gall stone, etc. Therefore, people pay more and more attention to their own health with the improvement of the living standard, and the question about the pollution of nickel has been paid close attention to. Therefore, the importance

of the determination of nickel in environmental samples can hardly be overemphasized because they have undoubtedly a serious potential hazard to the human organism. The main sources of nickel in aquatic systems are from dissolution of rocks and soils, biological cycles, atmospheric fallout, and especially industrial processes and water disposal [4]. The development of reliable, yet affordable, analytical approaches for the determination of Ni(II) ion in low concentration levels seems worthwhile.

At present, the determination of nickel could be carried out directly by X-ray fluorescence in electroplating solution [5], flame atomic adsorption spectrometry (FAAS) in water samples [6] and gasoline [7], graphite furnace atomic absorption spectrometry (GFAAS) in fingernails and forearm skin [8], gasoline [9] and residual fuel oil [10], electrothermal atomic absorption spectrometry (ETAAS) in aluminium-base alloys [11] and marine sediments [12], inductively-coupled plasma atomic emission spectrometry (ICP-AES) in plant samples [13], square-wave adsorptive stripping voltammetry (SWASV) in duraluminium, iron ore and a reference river water sample [14] and flow-injection solid-phase spectrophotometry (FI-SPS) in copper-based alloys [15]. Each of these proposed methods often offer their own set of

<sup>\*</sup> Corresponding author. Tel.: +86 23 68252360; fax: +86 23 68254000. *E-mail address:* linb@swnu.edu.cn (H.Q. Luo).

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advantages and disadvantages. However, some disadvantages, such as several time-consuming manipulation steps, sophisticated instruments and special training, or low sensitivity, made these methods not simple, rapid and sensitive for the determination of nickel. The chemiluminescence (CL) analysis is attractive because very low detection limits and wide linear response ranges can be achieved for certain species by using simple instrumentation. When coupled with flow-injection analysis (FIA), CL-based FIA methods provide a rapid, cheap, simple and reproducible means of detection.

Over the last few decades, the CL analysis has become one of most powerful technique for the determination of trace metal ions, such as Co(II), Cu(II), Fe(II), Fe(III), Cr(VI), Cr(III) and alkaline earth metal ions [16–20]. However, up to now, there is no report about the use of this method to determine nickel. Recently, we surprisingly observed that when nickel ion was injected into a reaction mixture of luminol and potassium permanganate, which has just finished the CL reaction, a new CL phenomenon was observed and a strong CL signal was detected. We describe this new CL phenomenon as second-chemiluminescence (SCL) reaction. Our experiment discovered that the SCL intensity was a linear function of the concentration of nickel. Based on this phenomenon, a new method for the determination of nickel by SCL has been established.

## 2. Experimental

# 2.1. Reagents

Nickel(II) ion stock solution  $(10.0 \text{ g} \text{ l}^{-1})$  was prepared by dissolving appropriate amounts of nickel sulfate in water. The working solution was freshly prepared by appropriate dilution of the stock solution with water. Luminol stocking solution  $(1.0 \times 10^{-2} \text{ mol } l^{-1})$  was prepared by dissolving 0.1771 g luminol (Sigma) with  $0.1 \text{ mol } l^{-1}$  sodium hydroxide and diluting with  $0.1 \text{ mol } 1^{-1}$  sodium hydroxide to 11. The luminol working solution was prepared in a suitable concentration of sodium hydroxide. Potassium permanganate stock solution  $(4.0 \times 10^{-2} \text{ mol } l^{-1})$  was prepared by dissolving 1.5790 g of potassium permanganate in water and diluting to 250 ml with water. More diluting solution of potassium permanganate was prepared freshly by diluting the stock solution of potassium permanganate with water. All of the other reagents were of analytical-reagent grade and doubly distilled water was used throughout.

#### 2.2. Apparatus

An IFFL-D multifunction CL analyser (Xi'an Remax Electronic Science-Tech Co. Ltd., China) was used for measuring the CL signals. A personal computer employing an IFFL-D multifunction data processing system (Xi'an Remax Electronic Science-Tech Co. Ltd., China) was used for acquir-



Fig. 1. Schematic diagram of the flow-injection SCL system: (a) luminol solution, (b) potassium permanganate solution, (c) nickel ion solution,  $(P_1)$  auxiliary pump,  $(P_2)$  main pump, (MT) mixing tube, (L) cell-valve distance, (V) injection valve, (CE) CL reaction cell, (W) waste, (HV) high voltage source, (PMT) photomultiplier tube, (AMP) amplifier, (R) recorder.

ing and treating the CL data. A series of interference filters (Biophysics Institute of China, Beijing, China) were used for obtaining the CL spectra. A UV–vis 8500 spectrophotometer (Tianmei Co., Shanghai, China) was used for recording the absorption spectra.

#### 2.3. General procedure

The FIA system used for the detection of nickel ion is shown in Fig. 1. Channels a and b was used for carrying luminol and permanganate solutions and channel c was used for carrying the nickel(II) solution. The permanganate stream was initially merged with the luminol stream using a Y-piece to make the two solutions mix thoroughly and interact with each other until the CL signal became very weak and a stable baseline was given. Subsequently, 50 µl of working solution of nickel(II) ion was injected into the merged steam of permanganate and luminol solutions through a six-way injection valve. The change of SCL intensity,  $\Delta I (\Delta I = I_n - I_o)$ , where  $I_n$  and  $I_o$  were the SCL signals in the presence and absence of Ni(II) ion, respectively), was measured. The relative SCL intensities,  $\Delta I$ , versus the concentrations of nickel(II) were used for the calibration.

### 3. Results and discussion

#### 3.1. CL kinetic characteristics of the reactions

The CL kinetic characteristics of the reactions were studied in detail using the static injection method. The CL kinetic curves are shown in Fig. 2. Curve 1 is the CL kinetic curve obtained when 1.0 ml of  $2.0 \times 10^{-6} \text{ mol } 1^{-1}$  permanganate solution was injected into 1.0 ml of  $2.0 \times 10^{-5} \text{ mol } 1^{-1}$  luminol solution. About 18 s later, the CL reaction terminated and the CL signal declined to baseline. When the CL signal returned to zero, 1.0 ml of  $2.5 \times 10^{-4} \text{ g } 1^{-1}$  nickel solution was then injected into the reaction mixture solution, and a new CL kinetic curve (curve 2) was appeared, which was the SCL signal. The rate of the SCL reaction in solution was



Fig. 2. Kinetic curves of chemiluminescence: curve 1: the CL signal of luminol and potassium permanganate, curve 2: the CL signal of Ni(II) and the mixture of luminol and potassium permanganate.

shown to be very fast. The SCL signal took approximately 0.8 s to reach the maximum value and then less than about 12 s to decline to baseline again.

# 3.2. Possible reaction mechanism

The absorption spectra of potassium permanganate solution and the mixed solution of luminol and potassium permanganate with different molar ratios were obtained and are shown in Fig. 3. Examination of this figure shows that the characteristic absorption peaks of potassium permanganate at 504, 525 and 544 nm disappeared and a new absorption peak at 605 nm emerged on the absorption spectra of the mixtures of luminol and potassium permanganate with different molar ratios. The new absorption peak matches well with that obtained for potassium manganate solution prepared by reduction of potassium permanganate with sodium sulfite. From the above experimental facts, it can be con-



Fig. 3. Absorption spectra of the different solutions: (1)  $1.0 \times 10^{-4} \text{ mol } 1^{-1}$  luminol, (2)  $5.0 \times 10^{-4} \text{ mol } 1^{-1}$  KMnO<sub>4</sub>, (3) mixed solution of  $5.0 \times 10^{-4} \text{ mol } 1^{-1}$  KMnO<sub>4</sub> and  $1.0 \times 10^{-3} \text{ mol } 1^{-1}$  luminol, (4) mixed solution of  $5.0 \times 10^{-4} \text{ mol } 1^{-1}$  KMnO<sub>4</sub> and  $5.0 \times 10^{-4} \text{ mol } 1^{-1}$  luminol, (5) mixed solution of  $5.0 \times 10^{-4} \text{ mol } 1^{-1}$  KMnO<sub>4</sub> and  $1.0 \times 10^{-4} \text{ mol } 1^{-1}$  luminol.

cluded that potassium manganate is produced during the reaction of potassium permanganate with luminol in alkaline solution.

Keeping permanganate concentration at  $2.0 \times 10^{-6}$  $mol 1^{-1}$ , a series of the mixtures of permanganate and luminol with different molar ratios were prepared. They were classified into two groups: in group A, the concentrations of luminol are higher than that of potassium permanganate, and in group B, the concentrations of luminol are lower than that of potassium permanganate. According to the procedure described above, when  $2.5 \times 10^{-4} \text{ mol } 1^{-1}$  nickel ion solution was injected into the reaction mixture of groups A and B, respectively, it was founded that a strong CL signal was obtained for the mixtures in group A; however, no CL signal was detected for the mixed solution in group B. These results indicate that the CL signal was obtained only when the concentration of luminol exceeded that of potassium permanganate in the luminol-potassium permanganate CL system. That is, the SCL phenomenon originates from the reaction of luminol with potassium manganate. The study of the effect of length of mixing tube on the SCL intensity illuminated that potassium manganate, one of the SCL reagents, came from the resultant of the reaction of luminol with potassium permanganate on-line (see Section 3.3.1).

After setting the mixtures of groups A and B aside for some time, the green color of the mixtures in group A was observed to turn gradually to yellow and finally to produce the granule brown-grey manganese dioxide precipitate. However, the color of the mixtures in group B was bottle green. When nickel ion was added into the freshly prepared solutions of group A, the color of solutions faded to colorless sharply and small powder manganese dioxide precipitate generated instantly. These experimental results indicate that potassium manganate can react with luminol in alkaline condition. However, the rate of this reaction is too small to produce a detectable CL signal. When nickel ion was added into the above reaction system, the rate of reaction between luminol and potassium manganate was accelerated and a strong CL signal was produced. That is, nickel ion acts as a catalyst in the reaction of luminol with potassium manganate. The difference in the reaction rate is also reflected by the difference in shape and color of precipitate.

It is well known that 3-aminophthalate is the luminophor of the system of luminol-potassium permanganate, and the maximum emission of the CL reaction is at 425 nm [21]. The emission spectrum of the luminol-potassium manganate SCL reaction system in the presence of nickel ion is shown in Fig. 4. The maximum emission also appeared at 425 nm. It is easily seen that the luminophor for the SCL reaction of luminol-potassium manganate-nickel ion is still 3aminophthalate.

According to the above discussion, the possible CL mechanism of the SCL reaction is suggested as follows: potassium permanganate is firstly reduced by luminol to potassium manganate in alkaline medium, while luminol was oxidized to the excited species, 3-aminophtalate<sup>\*</sup> ion. When the



Fig. 4. CL spectra of different reactions. Luminol,  $1.0 \times 10^{-4} \text{ mol } 1^{-1}$ ; KMnO<sub>4</sub>,  $5.0 \times 10^{-5} \text{ mol } 1^{-1}$ ; Ni(II),  $5.0 \times 10^{-3} \text{ g } 1^{-1}$ .

excited species returned to ground state and loss its energy by the emission of electromagnetic radiation, the CL signal occurred. This is the common CL phenomenon observed (We call this phenomenon as the first CL process, FCL.). The further reaction of potassium manganate with excessive luminol is too slow to observe the CL signal. However, at this time, when nickel ion was added to the system, the reaction that potassium manganate was reduced to  $MnO_2$  and that luminol was oxidized to 3-aminophtalate<sup>\*</sup> ion was accelerated because of the catalysis of nickel ion, resulting in the strong CL signal appear (This is the SCL phenomenon we call.). The processes described above can be expressed by the following reactions:

The FCL process:



The SCL process:





Fig. 5. Effect of the length of mixing tube on the CL intensity.

#### 3.3. Optimization of reaction conditions

#### 3.3.1. Effect of the length of mixing tube

The effect of the length of mixing tube on the SCL intensity was very important, since nickel ion should be injected to the mixture at that time when the CL reaction of permanganate with luminol has been completed sufficiently, whereas the reaction of manganate with excessive luminol did not obviously occur. Therefore, in order to obtain the maximum SCL intensity, the effect of the length of mixing tube on the CL intensity of the FCL process was tested and the result is shown in Fig. 5, when the flow rate of pump 2 was fixed at 1.0 ml min<sup>-1</sup>. It can be seen that the FCL intensity



Fig. 6. Effect of the cell-valve distance. Luminol,  $2.0 \times 10^{-5} \text{ mol } l^{-1}$ ; KMnO<sub>4</sub>,  $2.0 \times 10^{-6} \text{ mol } l^{-1}$ .

decreased with increasing the length of mixing tube. When the length of mixing tube exceeded 120 cm, the FCL intensity decreased to the minimum value, and almost did not change with increasing the length of mixing tube. In addition, the effect of the length of mixing tube on the CL intensity of the SCL process was examined as the length of mixing tube exceeded 120 cm at the same flow rate of each channel. The plot of the change of SCL intensity,  $\Delta I$ , versus the length of mixing tube is also shown in Fig. 5. It can be seen that the SCL intensity decreased with the length of mixing tube increase. The degree of decrease in the SCL intensity was small in the length of mixing tube range from 125 to 175 cm. However, when the length of mixing tube exceeded 175 cm, the SCL intensity decreased obviously at the flow rate of pump 2 of  $1.0 \,\mathrm{ml}\,\mathrm{min}\,\mathrm{min}^{-1}$ . From our experimental results described above, it was known that when the length of mixing tube was too short, potassium permanganate could not effectively react with luminol, and the first CL signal would affect the measure of SCL signal. However, when the length of mixing tube was too long, excessive luminol would reacted gradually with potassium manganate, which was just produced, resulting in the SCL signal decrease. Therefore, in order to obtain the maximum SCL signal, it was important to choose the optimum length of mixing tube. According to the experimental results, the mixing tube of 150 cm was selected for further studies when the flow rate was  $1.0 \text{ ml min}^{-1}$  for pump 2.

#### 3.3.2. Effect of the cell-valve distance

The cell-valve distance is an important parameter in the CL flow-injection system because it determines the time interval from the final mixing point of the reagents to the point detected by the photomultiplier tube. The cell-valve distance (*L*) was adjusted to yield the maximum light emission in the cell. Fig. 6 demonstrates the effect of *L* on the SCL intensity. It can be seen that the SCL signal almost did not change in the range of 4.5 to 7.5 cm, then it decreased rapidly when *L* exceeded 7.5 cm at a constant flow rate of 1.0 ml min<sup>-1</sup>. Therefore, *L* of 6.5 cm was selected.

#### 3.3.3. Effect of the voltage of PMT

The voltage of PMT influenced not only on the accuracy of the experiment, but also on the sensitivity. The CL intensity of the reaction rose with increasing the voltage of PMT, at the same time, the noise increased, and the accuracy reduced. We have investigated the influence of the voltage of PMT on the SCL intensity in the voltage range from 500 to 850 V and the experimental results showed that the reaction has maximum signal noise ratio at 600 V.

# 3.3.4. Effect of the NaOH concentration

Both the FCL reaction (potassium permanganate–luminol system) and the SCL reaction (potassium manganate–luminol–Ni(II) system) occurred in alkaline solution. In the experiments, the alkalinity of the reaction medium was adjusted by preparing luminol with a suitable concentration of sodium hydroxide. The effect of sodium hydroxide concentration in the range of  $0.01-0.18 \text{ mol } 1^{-1}$  was examined. When  $0.1 \text{ mol } 1^{-1}$  sodium hydroxide was used, the SCL reaction has the maximum CL intensity.

#### 3.3.5. Effect of Ni(II) solution acidity

Considering that the concentration of NaOH solution has influence on the CL intensity, the acidity of nickel ion has been investigated. The acidity of nickel ion solution was adjusted with sulfuric acid and the effect of pH of the Ni(II) solution on the SCL intensity was studied at different pH values. The results showed that the optimum pH value was 5.10.

# *3.3.6. Effects of the concentrations of luminol and permanganate*

Under the experimental conditions described above, the concentrations of luminol and potassium permanganate can be changed in small concentration range. The effects of luminol and potassium permanganate concentrations on the SCL intensities were investigated and the results showed that the SCL intensity reached to the maximum value when the concentrations of luminol and potassium permanganate are  $2.0 \times 10^{-5}$  and  $2.0 \times 10^{-6}$  mol l<sup>-1</sup>, respectively.

# 3.4. Analytical parameters

Under the optimum conditions given above and using the flow-injection system described in Fig. 1, the calibration curve was obtained for the nickel ion determination by plotting the graph of  $\Delta I$  versus the nickel ion concentration, which gave linear ranges with different slopes from 8.0 to 200.0 µg l<sup>-1</sup> and from 200.0 to 2000.0 µg l<sup>-1</sup>. The linear regression equations for these two ranges were  $\Delta I = 0.4082 C (µg l^{-1}) + 4.940 (r = 0.9988)$  and  $\Delta I = 3.118 C$ (µg l<sup>-1</sup>) – 662.3 (r = 0.9957), respectively. The detection limit (3 $\sigma$ ) for nickel ion was 0.33 µg l<sup>-1</sup> and the R.S.D. were 4.5% for 250 µg l<sup>-1</sup> nickel ion in 11 replicated measurements. A typical recording output of the proposed SCL



Fig. 7. Typical recorder outputs for a series of nickel(II) ion standard solutions under the proposed conditions by the flow-injection SCL system. (A): Nickel(II) ion concentrations from (a) to (g) are 10.0, 20.0, 40.0, 60.0, 80.0, 100.0 and 200.0  $\mu$ g l<sup>-1</sup>, respectively. (B): Nickel(II) ion concentrations from (1) to (7) are 0.2, 0.25, 0.4, 0.5, 0.6, 1.0 and 2.0 mg l<sup>-1</sup>, respectively. Luminol,  $2.0 \times 10^{-5}$  mol l<sup>-1</sup>; KMnO<sub>4</sub>,  $2.0 \times 10^{-6}$  mol l<sup>-1</sup>; flow rate, 1.0 ml min<sup>-1</sup>; high voltage, -600 V.

system for the determination of different concentrations of nickel ion is shown in Fig. 7.

#### 3.5. Tolerance of foreign substances

The influence of various foreign species on the determination of 250  $\mu$ g l<sup>-1</sup> nickel ion was investigated. The tolerance limit was taken as the maximum concentration of the foreign substances which caused an approximately  $\pm$ 5% relative error in the determination. The tolerated ratio of foreign substances to 250  $\mu$ g l<sup>-1</sup> nickel ion was 4000 for Na<sup>+</sup>; 500 for NH<sub>4</sub><sup>+</sup>, Cl<sup>-</sup>; 40 for Cr(III); 10 for Zn(II); 5 for Al(III) and 4 for NO<sub>3</sub><sup>-</sup>; respectively. Equal concentration of Ba(II), Ca(II), Mg(II), Fe(III), Cu(II), Pb(II), Re(II) and EDTA interfered with the determination of nickel ion.

# *3.6. Determination of nickel ion in synthetic water samples*

The synthetic water samples were acquired by adding various ions, including  $0.125 \text{ g} \text{ l}^{-1} \text{ Na}^+$ ,  $1.0 \times 10^{-2} \text{ g} \text{ l}^{-1} \text{ NH}_4^+$ ,  $2.0 \times 10^{-2} \text{ g} \text{ l}^{-1} \text{ Cl}^-$ ,  $2.5 \times 10^{-3} \text{ g} \text{ l}^{-1} \text{ SiO}_3^{2-}$ ,  $0.125 \text{ g} \text{ l}^{-1} \text{ SO}_4^{2-}$  and nickel ions of different concentrations. The determination results are shown in Table 1. The R.S.D. are between 0.98 and 4.25%, and the recoveries are between 96.0 and 108.0%.

Table 1

Results for the determination of Ni(II) in the synthetic water samples

Samples	Ni(II) added $(g l^{-1})$	$Ni(II)$ found $(g l^{-1})$	Recovery	R.S.D.% ( <i>n</i> =6)
1	$1.25  imes 10^{-4}$	$1.35  imes 10^{-4}$	108.0	3.47
2	$2.50 \times 10^{-4}$	$2.66 \times 10^{-4}$	106.4	1.53
3	$6.25 \times 10^{-4}$	$6.01 \times 10^{-4}$	96.16	4.25
4	$8.25 \times 10^{-4}$	$8.43 \times 10^{-4}$	102.2	3.21
5	$1.00 \times 10^{-3}$	$9.60 \times 10^{-4}$	96.0	2.75
6	$2.00  imes 10^{-3}$	$2.08  imes 10^{-3}$	104.0	0.98

#### 4. Conclusion

Nickel(II) ion can catalyze the CL reaction between potassium manganate produced on-line and luminol under alkaline condition, which brings the SCL phenomenon. Based on this, a flow-injection SCL method for the determination of nickel(II) ion has been developed. The results demonstrate that the proposed method offers the advantages of simplicity, rapidity, wide linear range as well as high sensitivity for the determination of nickel(II) ion. Further research work on this subject is in progress along with new application, such as combining with ion chromatography or capillary electrophoresis.

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#### References

- S. Hernburg, J. Kikkane, G. Mellin, H. Lilivs, Arch. Environ. Health 21 (1970) 140.
- [2] P. Grandjean, O. Audersen, G.D. Niellsen, Am. J. Ind. Med. 13 (1988) 193.
- [3] F.W. Sanderman, L.G. Morgan, A. Andersen, Ann. Clin. Lab. Sci. 19 (1989) 44.
- [4] E. Merian, Metals and their Compounds in the Environment, vol. 22 (part II), VCH, New York, 1991, p. 1101.
- [5] J. Gao, G.F. Wan, Spectrosc. Spect. Anal. 20 (2000) 550.
- [6] A.R. Khorrami, H. Naeimi, A.R. Fakhari, Talanta 64 (2004) 13.
- [7] P.S. Roldan, I.L. Alcantara, C.C.F. Padilha, P.M. Padilha, Fuel 84 (2005) 305.
- [8] J. Kristiansen, J.M. Christensen, T. Henriksen, N.H. Nielsen, T. Menné, Anal. Chim. Acta 403 (2000) 265.
- [9] R.C. Campos, H.R. Santos, P. Grinberg, Spectrochim. Acta Part B 57 (2002) 15.
- [10] M.G.R. Vale, I.C.F. Damin, A. Klassen, M.M. Silva, B. Welz, A.F. Silvi, F.G. Lepri, D.L.G. Borges, U. Heitmann, Microchem. J. 77 (2004) 131.
- [11] N. Carrión, A.M. Itriago, M.A. Alvarez, E. Eljuri, Talanta 61 (2003) 621.
- [12] M.C. Barciela-Alonso, M.C. Tubio-Franco, R. Prego, Mar. Pollut. Bull. 46 (2003) 1504.
- [13] O. Mestek, I. Tresl, R. Koplík, H. Pavelková, M. Suchánek, B. Vaňas, Talanta 55 (2001) 595.
- [14] M. Morfobos, A. Economou, A. Voulgaropoulos, Anal. Chim. Acta 519 (2004) 57.
- [15] L.S.G. Teixeira, F.R.P. Rocha, M. Korn, B.F. Reis, S.L.C. Ferreira, A.C.S. Costa, Talanta 51 (2000) 1027.
- [16] A. Waseem, M. Yaqoob, A. Nabi, Luminescence 19 (2004) 333.
- [17] M. Susana, C. Pilar, A.T. Luis, B. Francisco, Int. J. Environ. Anal. Chem. 83 (2003) 405.
- [18] S.C. Zhang, Y.Y. Wu, H. Li, Talanta 53 (2000) 609.
- [19] Y.M. Liu, J.K. Cheng, Electrophoresis 556 (2002) 556.
- [20] J.X. Du, W.X. Liu, J.R. Lu, Acta Chim. Sinica 62 (2004) 1323.
- [21] G.N. Chen, F. Zhang, Chemiluminescence and Bioluminescence, Theory and Application, Fujian Science and Technology Press, Fuzhou, China, 1998, p. 83.