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Sensitive detection of acetaminophen based on Fe_3O_4 nanoparticles-coated poly(diallyldimethylammonium chloride)-functionalized graphene nanocomposite film

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ABSTRACT

An electrochemical sensor based on Fe_3O_4 nanoparticles (NPs)-coated poly(diallyldimethylammonium chloride) (PDDA)-functionalized graphene (Fe_3O_4-PDDA-G) nanocomposite was fabricated for sensitive detection of acetaminophen. The nanocomposite was characterized by X-ray diffraction (XRD), transmission electron microscopy (TEM) and vibrating sample magnetometer (VSM). The electrochemical behaviors of acetaminophen on Fe_3O_4-PDDA-G composite film modified glassy carbon electrode (GCE) were investigated by cyclic voltammetry (CV) and differential pulse voltammetry (DPV). The experimental results indicated that the incorporation of Fe_3O_4 NPs with PDDA-G greatly enhanced the electrochemical response of acetaminophen. This fabricated sensor displayed excellent analytical performance for acetaminophen detection over a range from 0.1 to 100 $\mu mol\,L^{-1}$ with a detection limit of $3.7 \times 10^{-8}\,mol\,L^{-1}$ ($S/N = 3$). The redox peaks of acetaminophen, dopamine (DA) and ascorbic acid (AA) can be well separated on the Fe_3O_4-PDDA-G/GCE. Moreover, the proposed electrochemical sensor also exhibited good reproducibility and stability, and has been used to detect acetaminophen in tablets with satisfactory results.

1. Introduction

Acetaminophen (N-acetyl-p-aminophenol or paracetamol), an analgesic and antipyretic drug, is an effective and safe agent used widely for the relief of mild to moderate pain associated with headache, backache, arthritis and postoperative pain [1]. However, overdoses of acetaminophen can lead to the accumulation of toxic metabolites, causing severe and sometimes fatal hepatotoxicity and nephrotoxicity [2,3]. Thus, it is necessary to develop efficient, sensitive, simple and accurate analytical techniques for the determination of acetaminophen. Some analytical methods, such as spectrophotometry [4], liquid chromatography [5], titrimetry [6], capillary electrophoresis [7], chemiluminescence [8] and electrochemical techniques [9–15], have been used in the determination of acetaminophen. In contrast to these methods, electrochemical technique is a less time-consuming, simple, and inexpensive technique with high sensitivity. Therefore, a number of modified electrodes were fabricated and applied to the electrochemical determination of acetaminophen, for example, carbon ionic liquid electrode [10], nanogold-modified indium tin oxide electrodes [11], glassy carbon electrode (GCE) modified with single-wall carbon nanotube-dicetyl phosphate film [12], graphite oxide film [13], carbon-coated nickel magnetic nanoparticles [14] and nano-TiO_2/polymer [15]. Better modified materials with unique electronic and catalytic properties can lead to excellent sensitivity, selectivity and stability of electrodes. While, to the best of our knowledge, there is no report based on using Fe_3O_4 nanoparticles (NPs)-coated functionalized graphene modified electrodes for the determination of acetaminophen. In addition, highly dispersed NPs on support with larger surface areas have advantages in catalytic activity and sensor sensitivity [16]. Therefore, Fe_3O_4 NPs-coated functionalized graphene nanocomposite may be good material to modified electrodes.

Recently, graphene has attracted enormous attention in constructing electrochemical sensors due to its novel properties such as good mechanical strength, large specific surface area and high conductivity [17–20]. However, graphene is hydrophobic and tends to agglomerate in water, which may limit their further applications in designing sensors [21]. Therefore, great efforts have been made to improve their solubility through covalent or non-covalent functionalization, such as using polymers or DNA as the functionalization agent [22,23]. Among them, poly(diallyldimethylammonium chloride) (PDDA), a linear positively charged polyelectrolyte, has been found to be an effective material for the functionalization of graphene. Moreover, the positive PDDA-functionalized graphene (PDDA-G) reported in our

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previous work [24] exhibited good conductivity, solubility and biocompatibility. Thus PDDA-G can be modified by the negative NPs for the formation of NPs-PDDA-G hybrid architecture. Therefore, graphene-based sensors should be an appropriate platform for electrochemical sensing and biosensing. Meanwhile, Fe_3O_4 NPs have attracted an increasing interest in biotechnology and medicine. Due to their good biocompatibility, strong superparamagnetic property, low toxicity, easy preparation and high adsorption ability, nano-Fe_3O_4 has been widely investigated as electrode modified material in sensors and biosensors [25,26]. Therefore, the combination of PDDA-G with Fe_3O_4 NPs should be beneficial to develop highly sensitive sensors.

In this work, a sensor based on the Fe_3O_4 NPs-coated PDDA-G nanocomposite film modified GCE was fabricated for sensitive detection of acetaminophen in 0.1 mol L^{-1} Britton–Robinson (BR) buffer solution (pH 7.0). Cyclic voltammetry (CV) was used to investigate the electrocatalytic ability of acetaminophen on the Fe_3O_4-PDDA-G/GCE, and differential pulse voltammetry (DPV) was used for the quantification of acetaminophen. The fabricated electrode showed excellent electrocatalytic activity towards acetaminophen, and could be used for the detection of acetaminophen in real samples with satisfactory results.

2. Experiments

2.1. Reagents and apparatus

Graphite flake (nature, −325 mesh) was from Alfa Aesar. PDDA and acetaminophen were purchased from Sigma. Ferric chloride ($FeCl_3{\cdot}6H_2O$), anhydrous sodium acetate, 1,6-hexanediamine and ethylene glycol were obtained from Beijing Chemical Factory. BR buffer solution was prepared by mixing definite weights of boric acid, acetic acid and phosphoric acid and the desired pH was adjusted using 0.20 mol L^{-1} sodium hydroxide. All other reagents and solvents were of analytical grade and used without further purification. All chemicals were prepared with deionized water purified via Milli-Q unit.

Electrochemical measurements were performed on a CHI 1210A electrochemical workstation (CH Instrument, China) with a three-electrode system consisting of an Ag/AgCl as the reference electrode, a platinum wire electrode as the auxiliary electrode and a bare or modified GCE (Φ = 3 mm) as the working electrode. Characterization of morphology and crystalline structure was performed on transmission electron microscopy (TEM, JEOL-2100 EX) and X-ray powder diffraction (XRD, Rigaku D/max-2400). The magnetic properties were measured using a vibrating sample magnetometer (VSM, Lake Shore, USA).

2.2. Synthesis of Fe_3O_4 NPs-coated PDDA-G nanocomposite

Firstly, the amine-functionalized Fe_3O_4 NPs were prepared by a facile one-pot method according to the literature [27]. A mixture of $FeCl_3{\cdot}6H_2O$ (0.5 g), 1,6-hexanediamine (3.5 g) and anhydrous sodium acetate (1.0 g) was dissolved in 15 mL ethylene glycol and stirred vigorously at 50 °C to get a transparent solution. The as-prepared solution was transferred into a Teflon-lined autoclave and reacted at 200 °C for 6 h. The NPs were collected by applying an external magnetic field and rinsed with water and ethanol to remove the solvent and unbound 1,6-hexanediamine.

Graphite oxide (GO) was prepared from graphite powder by a modified Hummers method [28]. 50 mg GO was dispersed in 100 mL deionized water to yield a yellow–brown dispersion by ultrasonication for 2 h, followed by centrifugation at 3000 rpm to remove any unexfoliated GO. Subsequently, the homogeneous GO dispersion was mixed with 2.5 mL PDDA solution and stirred for 30 min. Then, the PDDA wrapped GO solution was mixed with 5 mL Fe_3O_4 (5 mg/mL) hydrosol prepared above (the pH value of Fe_3O_4 hydrosol was adjusted to about 11–12 with NaOH solution) and stirred for 1 h. The resulting mixture was further treated with 2.5 mL hydrazine hydrate and allowed to react for 24 h at 90 °C. Finally, the obtained Fe_3O_4 NPs-coated PDDA-G nanocomposite was separated by centrifugation and further washed with water.

2.3. Preparation of Fe_3O_4-PDDA-G/GCE sensor

Before modification, the bare GCE was polished to obtain a mirror-like surface with 0.3 and 0.05 μm γ-alumina, then cleaned ultrasonically in deionized water for 2 min and finally cleaned in turn in an ultrasonic cleaner with 1:1 nitric acid solution, alcohol and doubly deionized water. 1.0 mg Fe_3O_4-PDDA-G nanocomposite was added into 1 mL deionized water, followed by ultrasonication for 2 h to form a homogenous mixture. Then, 5 μL of the mixture was dropped on the pretreated GCE and dried in a desiccator. For comparison, the Fe_3O_4/GCE and PDDA-G/GCE were prepared with the similar procedure.

2.4. Electrochemical measurements

About 10 mL of the BR buffer solution containing an appropriate amount of acetaminophen standard solution or sample was added into the electrochemical cell and then the three-electrode system was installed on it. The CVs were recorded in the potential range from 0.20 to 0.80 V after 200 s (supplementary content) accumulation under stirring with a scan rate of 50 mV s^{-1}. The DPV was carried out with the parameters of increment potential, 0.004 V; pulse amplitude, 0.05 V; pulse width, 0.05 s; sample width, 0.0167 s; pulse period, 0.2 s; and quiet time, 2 s.

2.5. Preparation of real samples

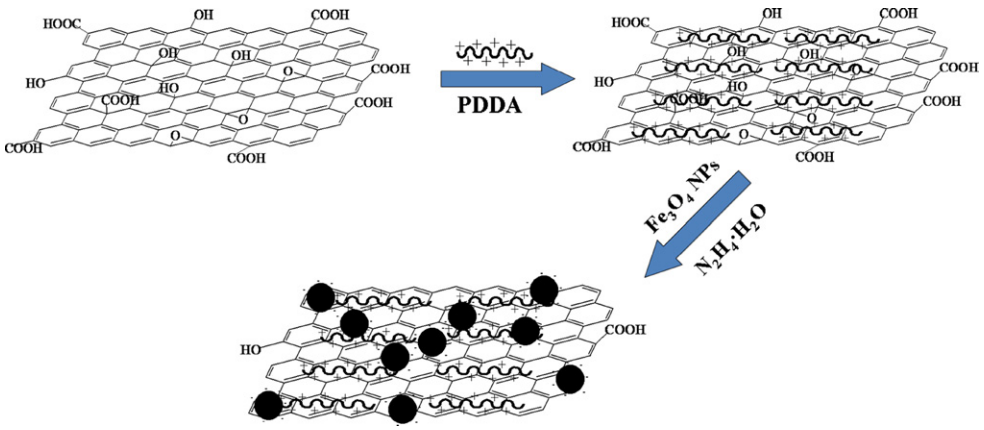
The acetaminophen tablet was purchased from a local pharmacy. Four tablets (equivalent to 0.500 g of acetaminophen in each tablet) of acetaminophen pharmaceutical formulation were accurately weighed and finely powdered in a mortar. Then, the obtained powder was dispersed in 50 mL of ethanol with ultrasonic agitation for 30 min and the mixture was filtrated. After filtration, the filter cake was extracted five times using 10 mL of ethanol each, and all filtrates were transferred into a 250 mL calibrated flask and diluted to volume with ethanol for further analysis.

The urine and blood serum samples were collected from healthy volunteers undergoing treatment with acetaminophen tablet. Urine samples were centrifuged for 10 min at 10,000 rpm and stored under refrigeration. The supernatant was diluted with BR buffer solution (pH 7.0). Then, a portion volume of the resultant solution was taken out and spiked with appropriate amounts of acetaminophen for recovery experiments. In addition, human serum samples used for measurements were centrifuged before the experiment. The samples were analyzed directly after diluted with BR buffer solution (pH 7.0) without any further treatment. The diluted serum sample was spiked with different amounts of acetaminophen. The acetaminophen concentrations were determined according to the recommended procedure.

3. Results and discussion

3.1. Fe_3O_4 NPs-coated PDDA-G nanocomposite

Fe_3O_4 NPs-coated PDDA-G nanocomposite was prepared by a simple procedure for assembly of the Fe_3O_4 NPs on the surface of PDDA-G. The main steps were summarized in Scheme 1. First



Scheme 1. Illustration of the synthesis procedure of Fe_3O_4-PDDA-G nanocomposite.

step was the functionalization of GO by PDDA. Owing to the non-covalent adsorption of PDDA, the PDDA-GO was positively charged. The Fe_3O_4 NPs dissolved in basic aqueous solution were negatively charged and therefore electrostatically attracted to the positively charged PDDA-G.

Fig. 1 shows the XRD patterns of GO, PDDA-G and Fe_3O_4-PDDA-G. In Fig. 1a, a strong peak centered at 10.6° corresponding to the (0 0 2) plane of GO [29]. The diffraction peak at around 43° is associated with the (1 0 0) plane of the hexagonal structure of carbon [30]. For PDDA-G (Fig. 1b), a broad diffraction peak (0 0 2) shifts to higher angle (21.2°), meaning that partial oxygen-containing functional groups have been removed and GO has been reduced to graphene. From Fig. 1c, it can be seen that all the diffraction peaks of the Fe_3O_4-PDDA-G sample can be indexed to Fe_3O_4 NPs (JCPDS: 87-2334). Furthermore, except the peaks assigned to Fe_3O_4, no any diffraction peaks resulted from GO or PDDA-G can be found, suggesting that GO was effectively reduced into graphene and the stacking of graphene sheets in the Fe_3O_4-PDDA-G nanocomposite is disordered [31].

The morphology of the Fe_3O_4-PDDA-G composite was characterized by TEM. It is clearly seen from Fig. 2A that Fe_3O_4 NPs with a size of about 15 nm were uniformly distributed on transparent graphene and almost no Fe_3O_4 NPs were found outside of the graphene sheets, indicating a strong interaction between graphene substrate and the NPs. Some NPs were slightly aggregated due to the loading degree close to saturation. Furthermore, these graphene nanosheets are composed of crumpled silk waves-like carbon sheets and possess large surface areas, and NPs can be deposited on both sides of these sheets [32]. So highly dispersed Fe_3O_4 NPs on support with larger surface areas have advantages in sensor sensitivity. Therefore, the Fe_3O_4-PDDA-G nanocomposite should be a potential material for use in future sensors. The selected-area electron diffraction (SAED) pattern (inset of Fig. 2A) clearly shows the ring pattern arising from the Fe_3O_4 NPs, further confirming the polycrystalline nature. The magnetic property of the obtained samples was investigated using a vibrating sample magnetometer. Fig. 2B shows the room-temperature magnetization hysteresis loops of the Fe_3O_4-PDDA-G composites and pure Fe_3O_4 nanocrystals. The saturation magnetization of the Fe_3O_4-PDDA-G composites is 34.9 emu/g, which is lower than that of pure Fe_3O_4 nanocrystals (55.2 emu/g), mainly attributing to the presence of graphene. The inset of Fig. 2B demonstrates that the composites can be easily manipulated by an external magnetic field, which is important for the promising applications ranging from electromagnetic devices to biomedicine.

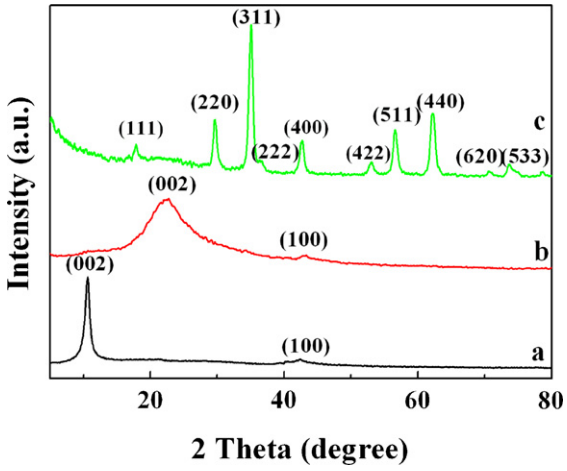


Fig. 1. XRD patterns of (a) GO, (b) PDDA-G, and (c) Fe_3O_4-PDDA-G.

3.2. Electrochemical behaviors of acetaminophen

CVs were used to investigate the electrochemical behavior of 0.1 mmol L^{-1} acetaminophen in 0.1 mol L^{-1} BR buffer solution (pH 7.0) at a scan rate of 50 mV s^{-1}. At the bare GCE (Fig. 3a), acetaminophen shows an irreversible behavior with relatively weak redox current peaks at E_{pa} = 0.558 V and E_{pc} = 0.477 V. In contrast, on the Fe_3O_4/GCE (Fig. 3b) and PDDA-G/GCE (Fig. 3c), the redox peak currents are significantly increased respectively. However, in the case of Fe_3O_4-PDDA-G/GCE (Fig. 3d), a pair of well-defined and quasi-reversible redox peaks of acetaminophen was obtained, with E_{pa} = 0.540 V and E_{pc} = 0.496 V. Since smaller potential difference between the anodic and cathodic peaks responds to larger electron transfer rate. The Fe_3O_4-PDDA-G/GCE shows the largest redox peak currents compare to other electrodes, which are about 19 times higher than those at the bare GCE and almost twice as large as the summation of PDDA-G/GCE and Fe_3O_4/GCE. The remarkably enhanced voltammetric response of acetaminophen can be reasonably ascribed to the large specific surface area and electrocatalytic activity of graphene and the conductivity of Fe_3O_4 NPs [9,33], which improves the absorption efficiency and electrochemical reactivity of acetaminophen. The above results suggest that, owing to its high adsorptivity and good biocompatibility, Fe_3O_4 NPs effectively modify the surface chemistry of graphene sheets, which provides an efficient interface and microenvironment for the electrochemical reaction of acetaminophen and accelerates the electron transfer between the electrode and acetaminophen.

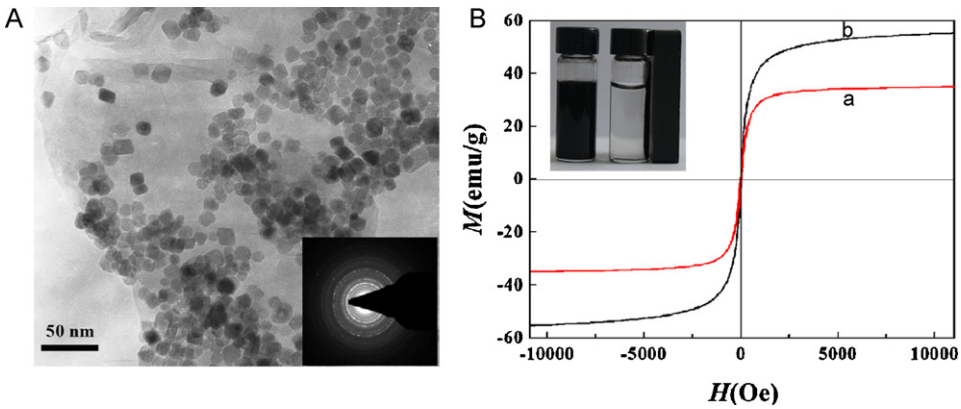


Fig. 2. (A) TEM image of Fe_3O_4-PDDA-G. Inset: SAED pattern of Fe_3O_4. (B) Room-temperature magnetization hysteresis loops of (a) Fe_3O_4-PDDA-G and (b) Fe_3O_4. Inset: the behavior of the composites under an external magnetic field.

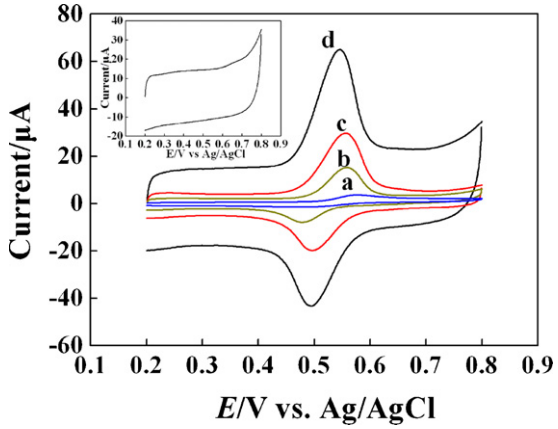


Fig. 3. CVs on the (a) bare GCE, (b) Fe_3O_4/GCE, (c) PDDA-G/GCE, and (d) Fe_3O_4-PDDA-G/GCE in 0.1 mol L^{-1} BR buffer solution (pH 7.0) with 0.1 mmol L^{-1} acetaminophen at scan rate of 50 mV s^{-1}. Inset: the CV on the Fe_3O_4-PDDA-G/GCE in 0.1 M BR buffer solution (pH 7.0) without acetaminophen.

3.3. Effect of scan rate

The effect of scan rates on the redox reaction of acetaminophen on the Fe_3O_4-PDDA-G/GCE was investigated by CV. The CVs for 0.1 mmol L^{-1} acetaminophen in 0.1 mol L^{-1} BR buffer solution (pH 7.0) on the Fe_3O_4-PDDA-G/GCE with scan rates ranging from 20 to 500 mV s^{-1} are shown in Fig. 4. Both the anodic and cathodic peak currents were linearly related with the scan rates (inset of Fig. 4)

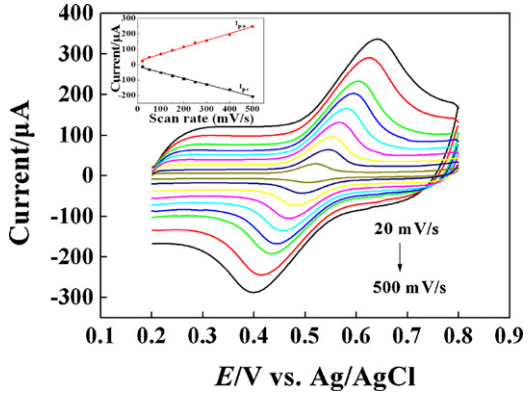


Fig. 4. CVs of 0.1 mM acetaminophen on the Fe_3O_4-PDDA-G/GCE at different scan rates (20, 50, 100, 150, 200, 250, 300, 400, and 500 mV s^{-1}) in 0.1 mol L^{-1} BR buffer solution (pH 7.0). Inset: the plot of the redox peak current versus scan rate.

with the linear regression equation as: I_{pa} (μA) = 23.31 + 0.4446ν (mV s^{-1}, R = 0.9982) and I_{pc} (μA) = −11.40 − 0.3900ν (mV s^{-1}, R = 0.9975), respectively. The results indicated that the process was predominantly surface-controlled process. In the scan rates ranging from 100 to 500 mV s^{-1}, the liner regression equations of the E_{pa} and E_{pc} versus the logarithm of the scan rates are expressed as E_{pa} = 0.6248 + 0.07251logν (V s^{-1}, R = 0.9980) and E_{pc} = 0.4235 − 0.05913logν (V s^{-1}, R = 0.9987), respectively. Based on the slopes of the lines $2.303RT/(1-\alpha)nF$ and $-2.303RT/\alpha nF$, the value of the electron-transfer coefficient (α) and the electron-transfer number (n) were calculated as 0.55 and 1.8, respectively.

3.4. Effect of pH value

The redox system should be affected by changing in pH values because of the involvement of protons in the overall electrode reaction. The influence of solution pH values on the redox reaction of acetaminophen on the Fe_3O_4-PDDA-G/GCE was studied in the pH range from 4.0 to 9.0. CVs of 0.1 mmol L^{-1} acetaminophen in 0.1 mol L^{-1} BR buffer solution on the Fe_3O_4-PDDA-G/GCE with different pH values are shown in Fig. 5. As can be seen in Fig. 5, the pH value obviously influenced the redox peak current and the maximum current response was obtained at pH 7.0. Thus this pH was chosen for the subsequent analytical experiments. The pH value also influenced the redox peak potential of acetaminophen. The redox peak shifted negatively with increasing solution pH,

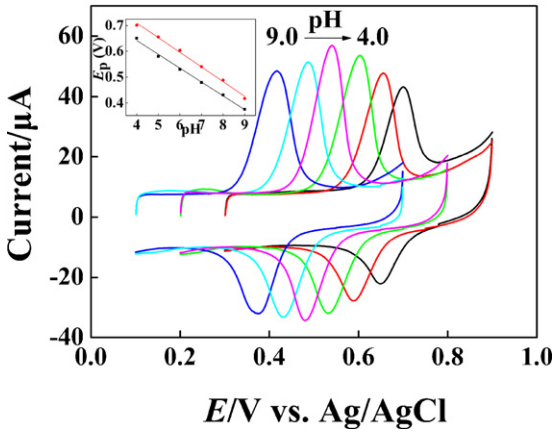


Fig. 5. CVs obtained on the Fe_3O_4-PDDA-G/GCE in 0.1 mol L^{-1} BR buffer solution in different pH values (4.0, 5.0, 6.0, 7.0, 8.0, and 9.0) containing 0.1 mmol L^{-1} acetaminophen at scan rate of 50 mV s^{-1}. Inset: the plot of anodic peak potential (E_{pa}) of acetaminophen versus pH values.

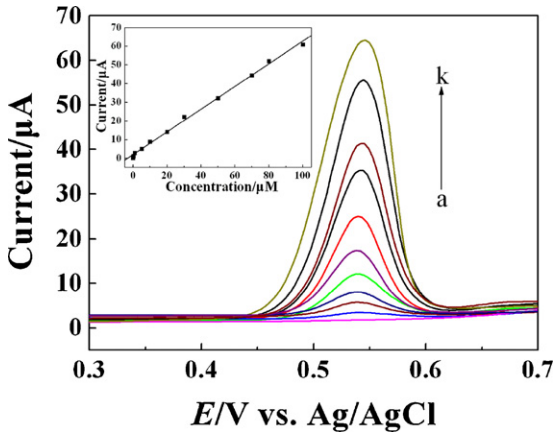


Fig. 6. DPVs of (a–k) 0, 0.1, 1.0, 5.0, 10, 20, 30, 50, 70, 80 and 100 μmol L^{-1} acetaminophen on Fe_3O_4-PDDA-G/GCE in 0.1 mol L^{-1} BR buffer solution (pH 7.0). Inset: the plot of peak current versus acetaminophen concentration.

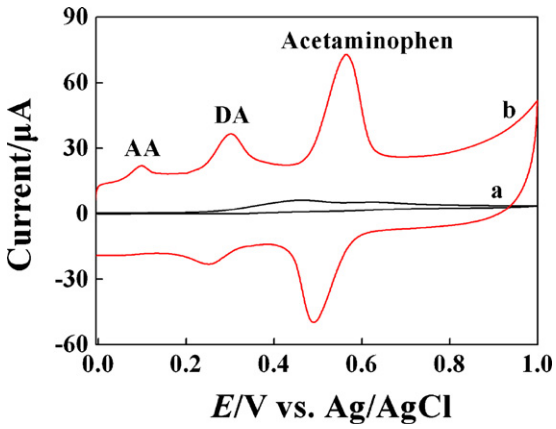


Fig. 7. CVs recorded on the (a) bare GCE and (b) Fe_3O_4-PDDA-G/GCE with AA (0.1 mmol L^{-1}), DA (0.1 mmol L^{-1}) and acetaminophen (0.1 mmol L^{-1}) in 0.1 M BR buffer solution (pH 7.0) at scan rate of 50 mV s^{-1}.

indicating that proton is involved in the redox reaction of acetaminophen. A good linear relationship can be established between E_p and the solution pH. The regression equation can be expressed as E_{pa} (V) = −0.05667pH + 0.9357 (R = 0.9979, oxidation process) and E_{pc} = −0.05351pH + 0.8553 (R = 0.9983, reduction process). Based on the formula [34]: $dE_p/dpH = 2.303mRT/nF$, where m is the number of proton, n is the number of electron, m/n is calculated to be 0.96 and 0.91 for the oxidation and reduction processes, respectively. It indicates that the number of proton and electron involved in the electrochemical reaction of acetaminophen is equal. Therefore, the electrochemical reaction of acetaminophen on the Fe_3O_4-PDDA-G/GCE is a two-electron and two-proton process.

3.5. Determination of acetaminophen

Under the optimal conditions, DPV was performed to investigate the relationship between the peak current and concentration of acetaminophen due to its higher sensitivity than CV. As can be seen in Fig. 6, the oxidation peak current was proportional to acetaminophen concentration in the range from 0.1 to 100 μmol L^{-1} with the regression equation of I_{pa} (μA) = 0.6067C (μmol L^{-1}) + 2.016 (R = 0.9986). The detection limit was 3.7×10^{-8} mol L^{-1} (S/N = 3), which is lower than those obtained on GCE modified with nano-TiO_2/polymer (2.0×10^{-6} mol L^{-1}) [15], Nafion/TiO_2–graphene (2.1×10^{-7} mol L^{-1}) [35]. This lower detection limit could be attributed to the combination of Fe_3O_4 NPs and PDDA-G, in which the Fe_3O_4 NPs can increase the electrochemically adsorptive site and the PDDA-G could also provide the large specific surface area to increase the loading of acetaminophen. Meanwhile, the electron transfer on the electrode surface could be accelerated and the electrochemical signal was amplified due to the outstanding electric conductivity of Fe_3O_4 NPs and PDDA-G. Therefore, sensitive detection of acetaminophen was achieved.

Furthermore, to estimate the fabrication repeatability of the modified electrode, the proposed electrochemical sensor was evaluated by repeating the determination of 50 μmol L^{-1} acetaminophen solution. The relative standard deviation (RSD) for ten measurements was 3.75%, which suggests acceptable repeatability and precision. And the response of the modified electrode to 50 μmol L^{-1} acetaminophen only decreased 5.47% of its initial response after stored at 4 °C for 2 weeks, indicating the good stability.

Acetaminophen generally suffers from the interferences of ascorbic acid (AA) and dopamine (DA) in biological samples [35]. Thus, experiment with interferences of AA and DA on both bare GCE and Fe_3O_4-PDDA-G/GCE were studied using CVs. As shown in Fig. 7, acetaminophen exhibits well-defined wave with good separations from AA and DA on Fe_3O_4-PDDA-G/GCE, while that cannot be separated on the bare GCE. Therefore, excellent selectivity of acetaminophen on Fe_3O_4-PDDA-G/GCE was achieved. In addition, other influences from common co-existing substances were also investigated. The inorganic species K^+, Na^+, NH_4^+, Ca^{2+}, Mn^{2+}, Cd^{2+}, Zn^{2+}, Cu^{2+}, Al^{3+}, Cl^-, Ac^-, SO_4^{2-}, and PO_4^{3-} in a 100-fold concentrations and 50-fold concentrations of p-aminophenol, glucose, vitamin C, caffeine, xanthine, N-acetylcysteine and tyrosine, almost have no influence on the detection of 10 μmol L^{-1} acetaminophen when the peak current change is below 5%. Interference could be observed for the uric acid when its concentration was up to a 20-fold excess over acetaminophen.

3.6. Detection of acetaminophen in real samples

In order to test the practical application of the proposed method, the Fe_3O_4-PDDA-G/GCE was applied to the analysis of a kind of acetaminophen (0.500 g/tablet) tablet. All the samples were determined in triplicate under the same conditions, and the results are shown in Table 1. As seen in Table 1, the content of acetaminophen in the tablet was calculated to be 495.8 mg per tablet on average, which is in good agreement with the label amount. In addition, the recovery of four independent experiments varied from 98.5% to 100.3%. These results indicate that the Fe_3O_4-PDDA-G/GCE was very reliable and sensitive enough for the determination of acetaminophen in real pharmaceutical samples.

In addition, the applicability of the proposed method was also tested by measuring the concentrations of acetaminophen in urine and human serum samples. The standard addition method was used for calculating the acetaminophen concentrations. These analyses were performed in triplicate, and the results obtained are shown in Table 2. The results show the relative standard derivations (RSDs) and the recovery rates are acceptable. Thus, the modified electrode can be successfully used for the determination of acetaminophen in both urine and human serum samples.

Table 1
Determination of acetaminophen in tablets.

Sample	Declared (mg/tablet)	Average (mg/tablet)	RSD (%)	Recovery (%)
1	500	493.5	1.17	98.70
2	500	492.7	0.86	98.54
3	500	501.3	0.98	100.3
4	500	495.6	1.04	99.12
Average	500	495.8		99.16

Table 2
Determination of acetaminophen in urine and human serum samples.

Sample	Added (μmol L^{-1})	Found (μmol L^{-1})	RSD (%)	Recovery (%)
Urine	10.0	10.2 ± 0.29	3.68	102.0
	20.0	20.9 ± 0.28	1.92	104.4
	30.0	29.8 ± 0.19	0.85	99.4
Human serum	10.0	10.1 ± 0.17	2.26	101.0
	20.0	19.7 ± 0.34	2.48	98.6
	30.0	30.3 ± 0.33	1.43	101.0

4. Conclusions

In this paper, a novel acetaminophen electrochemical sensor based on Fe_3O_4 NPs-coated PDDA-G nanocomposite was introduced, and the sensor exhibited an excellent electrochemical activity of acetaminophen. Under the optimized conditions, the nanocomposite film modified GCE was successfully employed for the voltammetric determination of acetaminophen with low detection limit, a wide linear range and good selectivity, and has been applied to the determination of acetaminophen in commercial tablets. The proposed method provides a way to NPs coated functionalized graphene nanocomposite with good compatibility and dispersibility, thus providing promising application in drug analysis.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.talanta.2011.10.029.

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