UNIVERSITI PUTRA MALAYSIA

SIMULTANEOUS ELECTROCHEMICAL DETECTION OF URIC ACID, DOPAMINE AND ASCORBIC ACID USING POLY (3,4-ETHYLENEDIOXYTHIOPHENE)/REDUCED GRAPHENE OXIDE/MANGANESE DIOXIDE

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FS 2018 57

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By

NURULKHALILAH BINTI TUKIMIN

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirement for the Degree of Master of Science

November 2017

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Master of Science

SIMULTANEOUS ELECTROCHEMICAL DETECTION OF URIC ACID, DOPAMINE AND ASCORBIC ACID USING POLY (3,4-ETHYLENEDIOXYTHIOPHENE)/ REDUCED GRAPHENE OXIDE/MANGANESE DIOXIDE

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November 2017

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The coexistence of uric acid (UA), ascorbic acid (AA) and dopamine (DA) in human body system is difficult to be measured due to their close oxidation potentials. The abnormal level of these analytes in human body would lead to various diseases. In order to solve this problems, poly(3,4-ethylenedioxythiophene)/reduced graphene oxide electrode (PrGO) and manganese dioxide deposited on PrGO (PrGO/MnO_2) composites were prepared using cyclic voltammetry for UA detection in the presence of AA and simultaneous detection of UA, AA and DA, respectively. The PrGO and PrGO/MnO_2 composites showed an improved electrocatalytic activity towards the oxidation of analytes in pH 6.0 (0.1 M PBS). The PrGO/MnO_2 electrode was able to detect UA, AA and DA simultaneously while, PrGO composite was only able to detect UA in the presence of AA, indicating PrGO/MnO_2 composite has better catalytic activity than PrGO composite which lead to the current increased and good peak potential separation (ΔE_p) of each analyte. The limit of detection and sensitivity of PrGO for the detection of UA are 0.19 µM (S/N = 3) and 0.01 µA/µM, respectively in the range of 1-300 µM. The PrGO/MnO_2 electrode has detection limits towards UA, AA and DA with the values of 0.05, 1.00 and 0.02 µM with a linear response of 1-800, 0.03-45 and 0.3-80 µM, respectively. The ΔE_p values of AA-DA, AA-UA and DA-UA were 166, 312 and 146 mV, respectively. Both sensors also showed an excellent reproducibility and repeatability towards the analytes.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains

PENGESANAN ELEKTROKIMIA SERENTAK TERHADAP ASID URIK, DOPAMINA DAN ASID ASKORBIK MENGGUNAKAN POLI (3,4-ETILENADIOKSITIOFENA)/ GRAFIN OKSIDA TERTURUN/MANGAN DIOKSIDA

Oleh

NURULKHALILAH BINTI TUKIMIN

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Pengerusi: Professor Madya Yusran Sulaiman, PhD
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Kehadiran asid urik (UA), asid askorbik (AA) dan dopamina (DA) di dalam sistem tubuh badan manusia agak sukar untuk di kenalpasti kerana keupayaan pengoksidaan mereka adalah lebih kurang sama. Tahap tidak normal kehadiran ketiga-tiga analit ini di dalam tubuh badan manusia boleh menyebabkan pelbagai penyakit. Bagi menyelesaikan masalah ini, poli(3,4etilenadioksitiofena)/grafin oksida terturun (PrGO) dan mangan dioksida yang didepositkan di atas komposit PrGO (PrGO/MnO_2) masing-masing telah dihasilkan menggunakan voltammetri berkitar untuk mengesan UA dengan kehadiran AA dan juga untuk pengesanan serentak terhadap UA, AA dan DA. Komposit PrGO dan PrGO/MnO_2 menunjukkan pencapaian aktiviti elektrokatalitik terhadap pengoksidaan analit di dalam pH 6.0 (0.1 M PBS). Elektrod PrGO/MnO_2 dapat mengesan UA, AA dan DA secara serentak manakala, komposit PrGO hanya dapat mengesan UA dengan kehadiran AA sahaja kerana komposit PrGO/MnO_2 mempunyai aktiviti pemangkin yang lebih baik berbanding komposit PrGO yang membawa kepada peningkatan arus dan pemisahan puncak keupayaan (ΔE_p) yang baik untuk setiap analit. Had pengesanan dan kepekaan PrGO terhadap UA masing-masing adalah 0.19 µM (S/N = 3) dan 0.01 µA/µM dalam julat 1-300 µM. Elektrod PrGO/MnO_2 mempunyai had pengesanan terhadap UA, AA dan DA masing-masing mempunyai nilai 0.05, 1.00 dan 0.02 µM dengan tindak balas linear 1-800, 0.03-45 dan 0.3-80 µM. Nilai ΔE_p AA-DA, AA-UA dan DA-UA adalah 166, 312 dan 146 mV. Kedua-dua alat pengesan mempunyai kebolehasilan dan kebolehulangan yang cemerlang.

ACKNOWLEDGEMENT

Bismillahirrahmaanirrahiim
In the name of Allah, The Most Gracious, The Most Merciful

I am grateful to a number of people who giving me the spirit and courage throughout this research projects especially to Associate Professor Dr.Yusran Sulaiman, my inspired supervisor. He is giving me excellent advice, endlessly supports, wise knowledge and motivates me the way of developing a good research. I also would like to acknowledge my co-supervisor, Dr. Jaafar Abdullah for their support, advice and knowledge. It was really great and unforgettable experience throughout finishing this research under their supervision.

Not to forget, I would like to express my special profound gratitude to my parents, Tukimin Yasir and Rumini Salleh also my siblings for their unconditional supports, pray, understanding and love since I have been born into this world and always be by my side when I is about to lost in motivation which also contributed to the success of this research.

My special note of appreciation also dedicated to all my friends and labmates who assist me to complete this study. Without their constant assistance, moral support and valuable opinions throughout this journey, this research would not be accomplished. Last but not least, I would like to thanks other people who have contributed to this research to be successful either by knowingly or unknowingly. My special thanks also dedicated to myBrain15 programme, Graduate Research Fellowship (GRF) and Universiti Putra Malaysia Research Grant (GP-IPS/2016/9512900) for sponsoring my study fees, giving allowance and research funding, respectively

I certify that a Thesis Examination Committee has met on 28 November 2017 to conduct the final examination of Nurulkhalilah binti Tukimin on her thesis entitled "Simultaneous Electrochemical Detection of Uric Acid, Dopamine And Ascorbic Acid using Poly(3,4- Ethylenedioxythiophene)/ Reduced Graphene Oxide/Manganese Dioxide" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Master of Science.

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This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Master of Science. The members of the Supervisory Committee were as follows:

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LIST OF SYMBOLS

Symbol	Meaning	Usual unit
A	area of electrode	cm^2
C	concentration	mol cm^{-3}
E	electrode potential	V
E_p	peak potential	V
ΔE_p	peak potential separation	V
I	current	A
I_{pa}	anodic peak current	A
R_{ct}	charge transfer resistance	Ω
υ	scan rate	V s^{-1}
t	time	s
n	number of electrons	-
D	diffusion coefficient	cm^2 s^{-1}
Z'	real impedance	Ω
Z''	imaginary impedance	Ω

LIST OF ABBREVIATIONS

A	ampere
µA	microampere
mA	milliampere
AA	ascorbic acid
ac	alternating current
BPPF6	1-butylpyridinium hexafluorophosphate
CNS	central nervous system
CPs	conducting polymers
CSHM	chitosan/silica sol–gel hybrid membranes
CT	catechol
CV	cyclic voltammetry
2D	two-dimensional
DA	dopamine
DHB	3,4-dihydroxybenzaldehyde
DPV	differential pulse voltammetry
EASA	electrochemical active surface area
EG	exfoliated graphite
EIS	electrochemical impedance spectroscopy
FESEM	field emission scanning electron microscopy
FIA	flow injection analysis
FTIR	Fourier transform infrared
FTO	fluorine doped tin oxide
GCE	glassy carbon electrode
GO	graphene oxide

GOx	glucose oxidase
Hz	hertz
kHz	kilohertz
HQ	hydroquinone
IL	carbon ionic liquid
LOD	limit of detection
LSV	linear sweep voltammetry
cm	centimeter
M	molar
µM	micromolar
mM	millimolar
nM	nanomolar
MNC	mesoporous nitrogen rich carbonaceous
MO	metal oxide
MPs	metal nanoparticles
MTNCPE	TiO_2 nanoparticle carbon paste
MWCNT	multi walled carbon nanotube
NP	nanoparticle
OCP	open circuit potentials
PANI	polyaniline
PANI/GO	polyaniline/graphene oxide
PBS	phosphate buffer solution
Pd/CNFs	palladium loaded with carbon nanofibers
PEDOT	poly(3,4-ethylenedioxythiophene)
ppm	parts per million
PPy	polypyrrole

PPy/rGO	polypyrrole/reduced graphene oxide
PrGO	poly (3,4-ethylenedioxythiophene/ reduced graphene oxide
PrGO/MnO_2	poly(3,4-ethylenedioxythiophene)/reduced graphene oxide/manganese dioxide
Pt	platinum
Pt/GE	platinum/graphene
rGO	reduced graphene oxide
RSD	relative standard deviation
S/N	signal of ratio
SnO_2/GN	SnO_2/graphene nanocomposite
SOF	silica optical fibers
UA	uric acid
V	volts
mV	millivolt
XPS	X-ray photoelectron spectroscopy
XRD	X-ray diffraction

CHAPTER 1

INTRODUCTION

1.1 Background of study

Uric acid (UA) exists in bio-fluids in the form of urine and blood in human body. It is a protein metabolism desecrates which presents a large amount in certain foods that may cause some harms because humans do not have any enzyme to break down the uric acid (Oda *et al*., 2002). Thus, uric acid will accumulate and contribute to gout sickness or kidney stones. Gout is one of the diseases where uric acid crystals are formed in the joints which cause an aching inflammatory response (Rock *et al*., 2013). Based on Desideri *et al*., (2014), the normal range of UA in urine is about 2.4 - 6.0 mg/dL (14.3 - 35.7 μM). Therefore, the detection of UA (Figure 1.1) becomes necessary to prevent from abnormal levels of UA occurred in the body which can be related to other kinds of diseases such as hypertension, metabolic syndrome and kidney injury (Soltani *et al*., 2013).

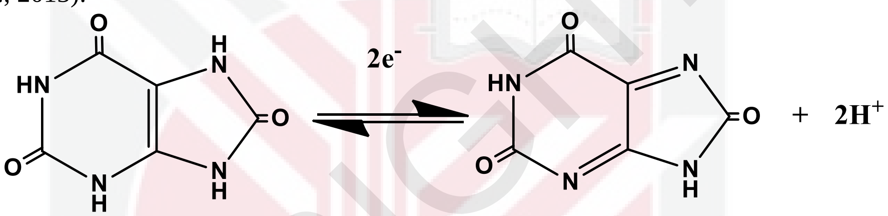

Figure 1.1: Chemical reaction of uric acid (UA)

While, dopamine (DA) as shown in Figure 1.2 presents as an essential neurotransmitter or known as chemical messengers having a crucial function in the central nervous system (CNS) of human which serves as an emotion control and hormonal balance (Thomas, 1997). When the level of DA is decline, it will cause to nervous system diseases, such as Parkinson's disease and schizophrenia (Sansuk *et al*., 2012). Thus, the detection of DA is crucial to control the hormonal balance in the human body and prevent from aforementioned kind of diseases occurred and maintaining the normal level in human body as shown in table 1.1.

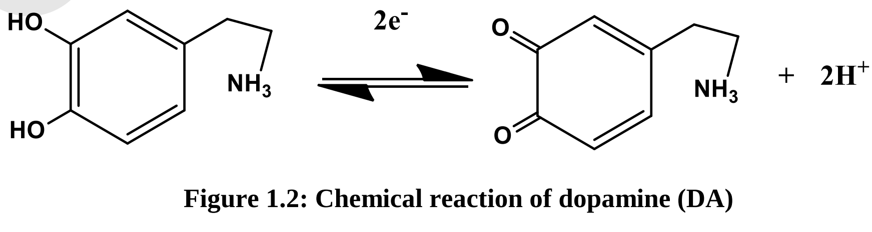

Figure 1.2: Chemical reaction of dopamine (DA)

Table 1.1: The normal range of DA in human body (Gardner and Shoback, 2011)

Ages	Dopamine contain
4-6 years	95-221 µg/day
7-12 years	76-371 µg/day
13-17 years	137-393 µg/day
18-69 years	77-324 µg/day
70 years and older	56-272 µg/day

Furthermore, ascorbic acid (AA) as shown in Figure 1.3 is an influential antioxidant which naturally exists in vegetable products and also presence in citrus fruits like oranges, lemons, grapefruit, and limes. High quantity of oxidative molecules contained in the human body could damage human cells and lead to severe diseases (Jones, 2006) such as cancer, heart disease, muscle degeneration and many other health problems. The normal range of AA in children and adult is about 2 – 400 mg/dL (11 µM – 2.3 mM) and 2-2,000 mg/dL (11 µM – 11 mM), respectively (Joint, 2002, Levine *et al.*, 1999). Moreover, being over exposure under the sun could also cause human skin cell to be oxidized and create the free-radicals. Thus, the antioxidant is needed in the human body in order to stop this cellular oxidation chain reaction phenomenon by neutralizing the free radicals. Antioxidants are commonly used to cure and prevent from infertility, scurvy, hepatic disease, common cold and mental illnesses (Du *et al*., 2014). However, it is important to control the level of AA-contain in the human body from getting other side effects due to over consume for example urinary oxalate arises (Davis *et al*., 1994) and glycosylation of proteins (Davie *et al.*, 1992, Khatami *et al.*, 1988).

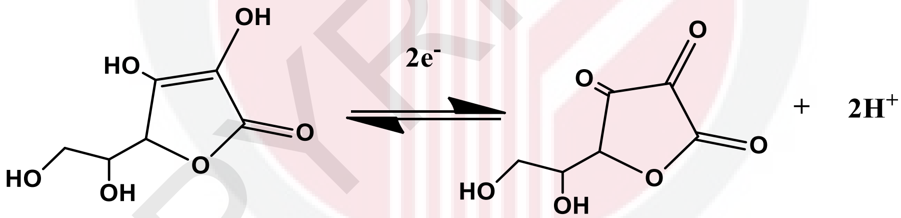

Figure 1.3: Chemical reaction of ascorbic acid (AA)

Recently, many research related in the field of applied science focusing on the electrochemical sensors. The electrochemical sensors have high sensitivity towards electro-active molecules. As different electro-active molecules can be reduced or oxidized at different potential values, electrochemical sensors are able to determine the potential of redox reaction of the molecules and it has high effective towards molecule which is able to be used in biofluids and has good limit of detection for small volume of analyte content (D'Orazio, 2003, Wilson, 2005). An electrochemical sensor is a device with integrated self-contained which is able to provide quantitative information using receptor which is in direct contact with the transduction element (Thévenot *et al*., 2001). Thus, the human interest and the world market demand to have devices that are able to do a simple and effective detection of the concentration of UA, DA and AA in the samples. The technique of detection for an electrochemical sensor is determined by the reaction which produces a potential (potentiometric), measurable current (amperometric), or by the changes of the conductivity of an intermediate (conductometric) among the electrodes (Chaubey and Malhotra, 2002). As an electrochemical sensor which applying three-electrode system, it consists of a working, reference and a counter electrode as shown in Figure 1.4. Commonly, the reference electrode is made of Ag/AgCl and in order to maintain the potential, it is kept in the Cl^- ion by immersing in salt solution either potassium or sodium chloride solution. A connection to the electrolytic solution is provided by the counter electrode while, working electrode act as transduction component in the biological sample. Thus, current is connected to the working electrode or transducer in order to give a signal information towards the detection of electro-active molecules (analytes) such as hydroxylamine (Wu *et al.*, 2014), glucose (Batchelor-McAuley *et al.*, 2008, Hui *et al.*, 2015), nitrite (Nie *et al.*, 2013), DNA (Lim *et al.*, 2010), dopamine (Ensafi *et al.*, 2010a, Si *et al.*, 2011, Wang *et al.*, 2014a, Zhang *et al.*, 2003, Zhou *et al.*, 2014), ascorbic acid (Ensafi *et al.*, 2010a, Wang *et al.*, 2014a) and uric acid (Ensafi *et al.*, 2010a, Wang *et al.*, 2014a, Zhou *et al.*, 2014).

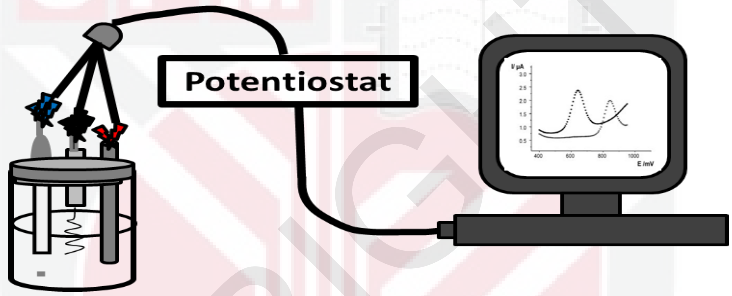

Figure 1.4: Three-electrode system of electrochemical sensor

Many studies concerned on the simultaneous sensing of UA, AA and DA because of these three compounds composed together in human living systems. Their presence in the human body must be controlled in order to keep alarm their abnormal concentration levels which may lead to certain disease (Adams, 1976, Arrigoni and De Tullio, 2002, Wightman *et al.*, 1988). These three compounds have similar electrochemical properties which complicate the identification of their oxidation potential that often overlapped and foul the electrodes besides; these compounds are also easily oxidized (Adams, 1976, Gao and Huang, 1998). Thus, the interest towards modification of electrochemical sensors for simultaneous determination of these three compounds using varieties of materials from conducting polymers (Hui *et al.*, 2015, Manurung *et al.*, 2012, Zhou *et al.*, 2015), graphene-based (Choi *et al.*, 2012, Du *et al.*, 2013) and metal oxide-based (Puangjan *et al.*, 2016, Sriramprabha *et al.*, 2015, Wu *et al.*, 2009) is considered significant in order to have better sensitivity, limit of detection and selectivity.

1.2 Problem statements

The abnormal level of UA, AA and DA in the human body could lead to certain diseases such as kidney injury, scurvy and insomnia, respectively (Arrigoni and De

Tullio, 2002, Rock *et al.*, 2013, Wightman *et al.*, 1988). In order to control and manage the level of these compounds containing in the human body, researchers have developed sensor platforms to determine these three compounds. However, UA, AA and DA are electro-active compounds that have similar electrochemical properties, have more than one isomer which could be formed during the detection, their oxidation potential often overlapped, could foul the electrodes and they are easily oxidized (Adams, 1976, Gao and Huang, 1998). These factors complicate their individual electrochemical identification and lead to the difficulty to measure them accurately.

The detection of DA in the presence of UA has been performed by Wang *et al*. (2014c). Thus, in this work PrGO and PrGO/MnO_2 modified electrodes was fabricated for detection of UA in the presence of AA and simultaneous detection of UA, DA and AA, respectively using electrochemical techniques. The PrGO and PrGO/MnO_2 modified electrodes possesses good properties for electrochemical sensing which increase the peak current and exhibited well-separated oxidation peaks of the analytes.

1.3 Objectives

1. To prepare poly (3,4-ethylenedioxythiophene)/reduced graphene oxide (PrGO) and poly(3,4-ethylenedioxythiophene)/reduced grapheme oxide/manganese dioxide (PrGO/MnO_2) films as sensor platforms using cyclic voltammetry technique.

2. To investigate the sensor performance of PrGO film towards detection of uric acid in the presence of ascorbic acid.

3. To evaluate the sensor performance of PrGO/MnO_2 film towards simultaneous detection of uric acid, ascorbic acid and dopamine.

REFERENCES

Adams, R. N. (1976) Probing brain chemistry with electroanalytical techniques. *Analytical Chemistry*. 48**.** 1126A-1138A.

Arrigoni, O. and De Tullio, M. C. (2002) Ascorbic acid: much more than just an antioxidant. *Biochimica et Biophysica Acta (BBA)-General Subjects.* 1569**.** 1-9.

Bai, H., Xu, Y., Zhao, L., Li, C. and Shi, G. (2009) Non-covalent functionalization of graphene sheets by sulfonated polyaniline. *Chemical Communications.* 1667-1669.

Bao, S.-J., He, B.-L., Liang, Y.-Y., Zhou, W.-J. and Li, H.-L. (2005) Synthesis and electrochemical characterization of amorphous MnO_2 for electrochemical capacitor. *Materials Science and Engineering: A.* 397**.** 305-309.

Bao, Y., Song, J., Mao, Y., Han, D., Yang, F., Niu, L. and Ivaska, A. (2011) Graphene Oxide-Templated Polyaniline Microsheets toward Simultaneous Electrochemical Determination of AA/DA/UA. *Electroanalysis.* 23**.** 878-884.

Bard, A. J. and Faulkner, L. R. (2001) Fundamentals and applications. *Electrochemical Methods.* 2.

Batchelor-Mcauley, C., Wildgoose, G. G., Compton, R. G., Shao, L. and Green, M. L. H. (2008) Copper oxide nanoparticle impurities are responsible for the electroanalytical detection of glucose seen using multiwalled carbon nanotubes. *Sensors and Actuators B: Chemical.* 132**.** 356-360.

Batumalay, M., Harith, Z., Rafaie, H. A., Ahmad, F., Khasanah, M., Harun, S. W., Nor, R. M. and Ahmad, H. (2014) Tapered plastic optical fiber coated with ZnO nanostructures for the measurement of uric acid concentrations and changes in relative humidity. *Sensors and Actuators A: Physical.* 210**.** 190-196.

Bhadra, S., Khastgir, D., Singha, N. K. and Lee, J. H. (2009) Progress in preparation, processing and applications of polyaniline. *Progress in Polymer Science.* 34**.** 783-810.

Bowling, R., Packard, R. T. and Mccreery, R. L. (1989) Mechanism of electrochemical activation of carbon electrodes: role of graphite lattice defects. *Langmuir.* 5**.** 683-688.

Carrera, V., Sabater, E., Vilanova, E. and Sogorb, M. A. (2007) A simple and rapid HPL-MS method for the simultaneous determination of epinephrine, norepinephrine, dopamine and 5-hydroxytryptamine: Application to the secretion of bovine chromaffin cell cultures. *Journal of Chromatography B.* 847**.** 88-94.

Chang, X., Zhai, X., Sun, S., Gu, D., Dong, L., Yin, Y. and Zhu, Y. (2017) MnO_2/g-C_3N_4 nanocomposite with highly enhanced supercapacitor performance. *Nanotechnology.* 28**.** 1-27.

Chaubey, A. and Malhotra, B. D. (2002) Mediated biosensors. *Biosensors and Bioelectronics.* 17**.** 441-456.

Chen, F., Qing, Q., Xia, J. and Tao, N. (2010) Graphene field-effect transistors: electrochemical gating, interfacial capacitance, and biosensing applications. *Chemistry-An Asian Journal.* 5**.** 2144-2153.

Choi, H.-J., Jung, S.-M., Seo, J.-M., Chang, D. W., Dai, L. and Baek, J.-B. (2012) Graphene for energy conversion and storage in fuel cells and supercapacitors. *Nano Energy.* 1**.** 534-551.

Choi, K. S., Liu, F., Choi, J. S. and Seo, T. S. (2010) Fabrication of free-standing multilayered graphene and poly (3, 4-ethylenedioxythiophene) composite films with enhanced conductive and mechanical properties. *Langmuir.* 26**.** 12902-12908.

Clavero, C. (2014) Plasmon-induced hot-electron generation at nanoparticle/metal-oxide interfaces for photovoltaic and photocatalytic devices. *Nature Photonics.* 8**.** 95-103.

Comini, E. (2006) Metal oxide nano-crystals for gas sensing. *Analytica chimica acta.* 568**.** 28-40.

Compton, O. C. and Nguyen, S. T. (2010) Graphene oxide, highly reduced graphene oxide, and graphene: versatile building blocks for carbon-based materials. *Small.* 6**.** 711-723.

Cui, R., Wang, X., Zhang, G. and Wang, C. (2012) Simultaneous determination of dopamine, ascorbic acid, and uric acid using helical carbon nanotubes modified electrode. *Sensors and Actuators B: Chemical.* 161**.** 1139-1143.

D'orazio, P. (2003) Biosensors in clinical chemistry. *Clinica Chimica Acta.* 334**.** 41-69.

Da Silva, L. V., Silva, F. A. S., Kubota, L. T., Lopes, C. B., Lima, P. R., Costa, E. O., Júnior, W. P. and Goulart, M. O. F. (2016) Amperometric sensor based on carbon nanotubes and electropolymerized vanillic acid for simultaneous determination of ascorbic acid, dopamine, and uric acid. *Journal of Solid State Electrochemistry.* 20**.** 2389-2393.

Davie, S. J., Gould, B. J. and Yudkin, J. S. (1992) Effect of vitamin C on glycosylation of proteins. *Diabetes.* 41**.** 167-173.

Davis, P. A., Wandzilak, T. R., D'andre, S. D. and Williams, H. E. (1994) Effect of high dose vitamin C on urinary oxalate levels. *Urolithiasis 2.* Springer.

Deng, K., Li, X. and Huang, H. (2016) A glassy carbon electrode modified with a nickel (II) norcorrole complex and carbon nanotubes for simultaneous or individual determination of ascorbic acid, dopamine, and uric acid. *Microchimica Acta.* 183**.** 2139-2145.

Desideri, G., Castaldo, G., Lombardi, A., Mussap, M., Testa, A., Pontremoli, R., Punzi, L. and Borghi, C. (2014) Is it time to revise the normal range of serum uric acid levels. *Eur Rev Med Pharmacol Sci.* 18**.** 1295-306.

Devaraj, S. and Munichandraiah, N. (2008) Effect of crystallographic structure of MnO_2 on its electrochemical capacitance properties. *The Journal of Physical Chemistry C.* 112**.** 4406-4417.

Doğan, H., Ekinci, D. and Demir, Ã. (2013) Atomic scale imaging and spectroscopic characterization of electrochemically reduced graphene oxide. *Surface Science.* 611**.** 54-59.

Dryhurst, G. (1972) Electrochemical oxidation of uric acid and xanthine at the pyrolytic graphite electrode mechanistic interpretation of electrochemistry. *Journal of the Electrochemical Society.* 119**.** 1659-1664.

Du, J., Yue, R., Ren, F., Yao, Z., Jiang, F., Yang, P. and Du, Y. (2014) Novel graphene flowers modified carbon fibers for simultaneous determination of ascorbic acid, dopamine and uric acid. *Biosensors and Bioelectronics.* 53**.** 220-224.

Du, J., Yue, R., Yao, Z., Jiang, F., Du, Y., Yang, P. and Wang, C. (2013) Nonenzymatic uric acid electrochemical sensor based on graphene-modified carbon fiber electrode. *Colloids and Surfaces A: Physicochemical and Engineering Aspects.* 419**.** 94-99.

Ensafi, A. A., Taei, M. and Khayamian, T. (2010a) Simultaneous determination of ascorbic acid, dopamine, and uric acid by differential pulse voltammetry using tiron modified glassy carbon electrode. *Int. J. Electrochem. Sci.* 5**.** 116-130.

Ensafi, A. A., Taei, M., Khayamian, T. and Arabzadeh, A. (2010b) Highly selective determination of ascorbic acid, dopamine, and uric acid by differential pulse voltammetry using poly (sulfonazo III) modified glassy carbon electrode. *Sensors and Actuators B: Chemical.* 147**.** 213-221.

Fang, Y. and Wang, E. (2013) Electrochemical biosensors on platforms of graphene. *Chemical Communications.* 49**.** 9526-9539.

Ferrari, A. C., Meyer, J. C., Scardaci, V., Casiraghi, C., Lazzeri, M., Mauri, F., Piscanec, S., Jiang, D., Novoselov, K. S. and Roth, S. (2006) The Raman fingerprint of graphene. *arXiv preprint cond-mat/0606284.*

Gao, F., Cai, X., Wang, X., Gao, C., Liu, S., Gao, F. and Wang, Q. (2013) Highly sensitive and selective detection of dopamine in the presence of ascorbic acid at graphene oxide modified electrode. *Sensors and Actuators B: Chemical.* 186**.** 380-387.

Gao, Z. and Huang, H. (1998) Simultaneous determination of dopamine, uric acid and ascorbic acid at an ultrathin film modified gold electrode. *Chemical Communications.* 2107-2108.

Gardner, D. G. and Shoback, D. (2011) Normal hormone reference ranges. *GreenspanTs Basic and Clinical Endocrinology, 9th edn. The McGraw-Hill Companies: China.*

Geim, A. K. and Novoselov, K. S. (2007) The rise of graphene. *Nature materials.* 6**.** 183-191.

George, P. M., Lavan, D. A., Burdick, J. A., Chen, C. Y., Liang, E. and Langer, R. (2006) Electrically controlled drug delivery from biotin-doped conductive polypyrrole. *Advanced materials.* 18**.** 577-581.

Gerard, M., Chaubey, A. and Malhotra, B. D. (2002) Application of conducting polymers to biosensors. *Biosensors and Bioelectronics.* 17**.** 345-359.

Ghadimi, H., Mahmoudian, M. R. and Basirun, W. J. (2015) A sensitive dopamine biosensor based on ultra-thin polypyrrole nanosheets decorated with Pt nanoparticles. *RSC Advances.* 5**.** 39366-39374.

Grimshaw, J. (2000) *Electrochemical reactions and mechanisms in organic chemistry.* Elsevier.

Guo, H.-L., Wang, X.-F., Qian, Q.-Y., Wang, F.-B. and Xia, X.-H. (2009) A green approach to the synthesis of graphene nanosheets. *ACS nano.* 3**.** 2653-2659.

Guo, Z., Luo, X., Li, Y., Li, D., Zhao, Q., Li, M., Ma, C. and Zhao, Y. (2017) Simultaneous electrochemical determination of ascorbic acid, dopamine and uric acid based on reduced graphene oxide-Ag/PANI modified glassy carbon electrode. *Chemical Research in Chinese Universities.* 1-6.

Hadi, M. and Rouhollahi, A. (2012) Simultaneous electrochemical sensing of ascorbic acid, dopamine and uric acid at anodized nanocrystalline graphite-like pyrolytic carbon film electrode. *Analytica chimica acta.* 721**.** 55-60.

Han, D., Han, T., Shan, C., Ivaska, A. and Niu, L. (2010) Simultaneous determination of ascorbic acid, dopamine and uric acid with chitosan-graphene modified electrode. *Electroanalysis.* 22**.** 2001-2008.

Harish, S., Mathiyarasu, J., Phani, K. L. N. and Yegnaraman, V. (2008) PEDOT/palladium composite material: synthesis, characterization and application to simultaneous determination of dopamine and uric acid. *Journal of applied electrochemistry.* 38**.** 1583-1588.

Hathoot, A. A., Hassan, K. M., Essa, W. A. and Abdel-Azzem, M. (2017) Simultaneous determination of ascorbic acid, uric acid and dopamine at modified electrode based on hybrid nickel hexacyanoferrate/poly (1, 5-diaminonaphthalene). *Journal of the Iranian Chemical Society.* 1-11.

He, B., Hong, L., Lu, J., Hu, J., Yang, Y., Yuan, J. and Niu, L. (2013) A novel amperometric glucose sensor based on PtIr nanoparticles uniformly dispersed on carbon nanotubes. *Electrochimica Acta.* 91**.** 353-360.

Hepel, M. (1998) The electrocatalytic oxidation of methanol at finely dispersed platinum nanoparticles in polypyrrole films. *Journal of the Electrochemical Society.* 145**.** 124-134.

Hu, C.-C. and Chu, C.-H. (2001) Electrochemical impedance characterization of polyaniline-coated graphite electrodes for electrochemical capacitors-effects of film coverage/thickness and anions. *Journal of Electroanalytical Chemistry.* 503**.** 105-116.

Hu, L., Hecht, D. S. and Gruner, G. (2009a) Infrared transparent carbon nanotube thin films. *Applied Physics Letters.* 94**.** 81103.

Hu, L., Hecht, D. S. and Gruner, G. (2009b) Infrared transparent carbon nanotube thin films. *Applied Physics Letters.* 94**.** 1-4.

Hu, W., Sun, D. and Ma, W. (2010a) Silver Doped Poly (L-valine) Modified Glassy Carbon Electrode for the Simultaneous Determination of Uric Acid, Ascorbic Acid and Dopamine. *Electroanalysis.* 22**.** 584-589.

Hu, Y., Jin, J., Wu, P., Zhang, H. and Cai, C. (2010b) Graphene-gold nanostructure composites fabricated by electrodeposition and their electrocatalytic activity toward the oxygen reduction and glucose oxidation. *Electrochimica Acta.* 56**.** 491-500.

Huang, J., Liu, Y., Hou, H. and You, T. (2008) Simultaneous electrochemical determination of dopamine, uric acid and ascorbic acid using palladium nanoparticle-loaded carbon nanofibers modified electrode. *Biosensors and Bioelectronics.* 24**.** 632-637.

Hui, N., Wang, W., Xu, G. and Luo, X. (2015) Graphene oxide doped poly (3, 4-ethylenedioxythiophene) modified with copper nanoparticles for high performance nonenzymatic sensing of glucose. *Journal of Materials Chemistry B.* 3**.** 556-561.

Huimin, D. (2015) Design and construction of biosensing platforms for the detection of biomarkers

Janata, J. and Josowicz, M. (2003) Conducting polymers in electronic chemical sensors. *Nature materials.* 2**.** 19-24.

Jeyalakshmi, S. R., Kumar, S. S., Mathiyarasu, J., Phani, K. L. N. and Yegnaraman, V. (2007) Simultaneous determination of ascorbic acid, dopamine and uric acid using PEDOT polymer modified electrodes. *Indian Journal of Chemistry.* 957-961.

Jiang, J. and Du, X. (2014) Sensitive electrochemical sensors for simultaneous determination of ascorbic acid, dopamine, and uric acid based on Au@ Pd-reduced graphene oxide nanocomposites. *Nanoscale.* 6**.** 11303-11309.

Joint, F. A. O. (2002) Human vitamin and mineral requirements.

Jones, D. P. (2006) Redefining oxidative stress. *Antioxidants & redox signaling.* 8**.** 1865-1879.

Joshi, A., Schuhmann, W. and Nagaiah, T. C. (2016) Mesoporous nitrogen containing carbon materials for the simultaneous detection of ascorbic acid, dopamine and uric acid. *Sensors and Actuators B: Chemical.* 230**.** 544-555.

Kamyabi, M. A. and Shafiee, M. A. (2012) Electrocatalytic oxidation of dopamine, ascorbic acid and uric acid at poly2, 6 diaminopyridine on the surface of carbon nanotubes/gc electrodes. *Journal of the Brazilian Chemical Society.* 23**.** 593-601.

Khatami, M., Suldan, Z., David, I., Li, W. and Rockey, J. H. (1988) Inhibitory effects of pyridoxal phosphate, ascorbate and aminoguanidine on nonenzymatic glycosylation. *Life sciences.* 43**.** 1725-1731.

Kim, D.-H., Richardson-Burns, S. M., Hendricks, J. L., Sequera, C. and Martin, D. C. (2007) Effect of immobilized nerve growth factor on conductive polymers: electrical properties and cellular response. *Advanced Functional Materials.* 17**.** 79-86.

Kim, D.-H., Wiler, J. A., Anderson, D. J., Kipke, D. R. and Martin, D. C. (2010a) Conducting polymers on hydrogel-coated neural electrode provide sensitive neural recordings in auditory cortex. *Acta biomaterialia.* 6**.** 57-62.

Kim, T. W., Yoo, H., Kim, I. Y., Ha, H. W., Han, A. R., Chang, J. S., Lee, J. S. and Hwang, S. J. (2011) A composite formation route to well-crystalline manganese oxide nanocrystals: high catalytic activity of manganate-alumina nanocomposites. *Advanced Functional Materials.* 21**.** 2301-2310.

Kim, Y.-R., Bong, S., Kang, Y.-J., Yang, Y., Mahajan, R. K., Kim, J. S. and Kim, H. (2010b) Electrochemical detection of dopamine in the presence of ascorbic acid using graphene modified electrodes. *Biosensors and Bioelectronics.* 25**.** 2366-2369.

Kolmakov, A. and Moskovits, M. (2004) Chemical sensing and catalysis by one-dimensional metal-oxide nanostructures. *Annu. Rev. Mater. Res.* 34**.** 151-180.

Levine, M., Rumsey, S. C., Daruwala, R., Park, J. B. and Wang, Y. (1999) Criteria and recommendations for vitamin C intake. *Jama.* 281**.** 1415-1423.

Li, D. and Kaner, R. B. (2008) Graphene-based materials. *Nat Nanotechnol.* 3**.** 1-2.

Li, F., Chai, J., Yang, H., Han, D. and Niu, L. (2010) Synthesis of Pt/ionic liquid/graphene nanocomposite and its simultaneous determination of ascorbic acid and dopamine. *Talanta.* 81**.** 1063-1068.

Li, J. and Lin, X. (2007) Simultaneous determination of dopamine and serotonin on gold nanocluster/overoxidized-polypyrrole composite modified glassy carbon electrode. *Sensors and Actuators B: Chemical.* 124**.** 486-493.

Li, J. and Zhang, X. (2012) Fabrication of poly (aspartic acid)-nanogold modified electrode and Its application for simultaneous determination of dopamine, ascorbic acid, and uric acid. *American Journal of Analytical Chemistry.* 3**.** 1-9.

Li, W., Liang, C., Zhou, W., Qiu, J., Zhou, Z., Sun, G. and Xin, Q. (2003) Preparation and characterization of multiwalled carbon nanotube-supported platinum for cathode catalysts of direct methanol fuel cells. *The Journal of Physical Chemistry B.* 107**.** 6292-6299.

Li, X.-B., Rahman, M. M., Xu, G.-R. and Lee, J.-J. (2015) Highly sensitive and selective detection of dopamine at poly (chromotrope 2B)-modified glassy carbon electrode in the presence of uric acid and ascorbic acid. *Electrochimica Acta.* 173**.** 440-447.

Li, Y., Lin, H., Peng, H., Qi, R. and Luo, C. (2016) A glassy carbon electrode modified with MoS_2 nanosheets and poly(3,4-ethylenedioxythiophene) for simultaneous electrochemical detection of ascorbic acid, dopamine and uric acid. *Microchimica Acta.* 183**.** 2517-2523.

Li, Y., Ran, G., Yi, W. J., Luo, H. Q. and Li, N. B. (2012) A glassy carbon electrode modified with graphene and poly (acridine red) for sensing uric acid. *Microchimica Acta.* 178**.** 115-121.

Lian, Q., He, Z., He, Q., Luo, A., Yan, K., Zhang, D., Lu, X. and Zhou, X. (2014) Simultaneous determination of ascorbic acid, dopamine and uric acid based on tryptophan functionalized graphene. *Analytica chimica acta.* 823**.** 32-39.

Lim, C. X., Hoh, H. Y., Ang, P. K. and Loh, K. P. (2010) Direct voltammetric detection of DNA and pH sensing on epitaxial graphene: an insight into the role of oxygenated defects. *Analytical Chemistry.* 82**.** 7387-7393.

Liu, A., Jones, R., Liao, L., Samara-Rubio, D., Rubin, D., Cohen, O., Nicolaescu, R. and Paniccia, M. (2004) A high-speed silicon optical modulator based on a metalâ€“oxideâ€“semiconductor capacitor. *Nature.* 427**.** 615-618.

Liu, M., Wen, Y., Li, D., He, H., Xu, J., Liu, C., Yue, R., Lu, B. and Liu, G. (2011) Electrochemical immobilization of ascorbate oxidase in poly (3, 4-ethylenedioxythiophene)/multiwalled carbon nanotubes composite films. *Journal of Applied Polymer Science.* 122**.** 1142-1151.

Liu, X., Xie, L. and Li, H. (2012) Electrochemical biosensor based on reduced graphene oxide and Au nanoparticles entrapped in chitosan/silica sol-gel hybrid membranes for determination of dopamine and uric acid. *Journal of Electroanalytical Chemistry.* 682**.** 158-163.

Lu, L., Zhang, O., Xu, J., Wen, Y., Duan, X., Yu, H., Wu, L. and Nie, T. (2013) A facile one-step redox route for the synthesis of graphene/poly (3, 4-ethylenedioxythiophene) nanocomposite and their applications in biosensing. *Sensors and Actuators B: Chemical.* 181**.** 567-574.

Ma, X., Chao, M. and Wang, Z. (2012) Electrochemical detection of dopamine in the presence of epinephrine, uric acid and ascorbic acid using a graphene-modified electrode. *Analytical Methods.* 4**.** 1687-1692.

Malitesta, C., Palmisano, F., Torsi, L. and Zambonin, P. G. (1990) Glucose fast-response amperometric sensor based on glucose oxidase immobilized in an electropolymerized poly (o-phenylenediamine) film. *Analytical Chemistry.* 62**.** 2735-2740.

Manivel, P., Dhakshnamoorthy, M., Balamurugan, A., Ponpandian, N., Mangalaraj, D. and Viswanathan, C. (2013) Conducting polyaniline-graphene oxide fibrous nanocomposites: preparation, characterization and simultaneous electrochemical detection of ascorbic acid, dopamine and uric acid. *RSC Advances.* 3**.** 14428-14437.

Manurung, R. V., Kurniawan, E. D. and Risdian, C. (2012) The electropolymerization of conductive polymer Ppy-PANi on gold electrodes for uric acid biosensor. 1-4.

Mazloum-Ardakani, M., Talebi, A., Beitollahi, H., Naeimi, H. and Taghavinia, N. (2010) Determination of ascorbic acid in the presence of uric acid and folic acid by a nanostructured electrochemical sensor based on a TiO_2 nanoparticle carbon paste electrode. *Analytical Letters.* 43**.** 2618-2630.

Mecklenburg, M., Schuchardt, A., Mishra, Y. K., Kaps, S., Adelung, R., Lotnyk, A., Kienle, L. and Schulte, K. (2012) Aerographite: ultra lightweight, flexible nanowall, carbon microtube material with outstanding mechanical performance. *Advanced materials.* 24**.** 3486-3490.

Mousavi, Z., Bobacka, J., Lewenstam, A. and Ivaska, A. (2006) Response mechanism of potentiometric Ag^+ sensor based on poly (3, 4-ethylenedioxythiophene) doped with silver hexabromocarborane. *Journal of Electroanalytical Chemistry.* 593**.** 219-226.

Mukdasai, S., Crowley, U., Pravda, M., He, X., Nesterenko, E. P., Nesterenko, P. N., Paull, B., Srijaranai, S., Glennon, J. D. and Moore, E. (2015) Electrodeposition of palladium nanoparticles on porous graphitized carbon monolith modified carbon paste electrode for simultaneous enhanced determination of ascorbic acid and uric acid. *Sensors and Actuators B: Chemical.* 218**.** 280-288.

Naccarato, A., Gionfriddo, E., Sindona, G. and Tagarelli, A. (2014) Development of a simple and rapid solid phase microextraction-gas chromatography-triple quadrupole mass spectrometry method for the analysis of dopamine, serotonin and norepinephrine in human urine. *Analytica chimica acta.* 810**.** 17-24.

Neri, G., Leonardi, S. G., Latino, M., Donato, N., Baek, S., Conte, D. E., Russo, P. A. and Pinna, N. (2013) Sensing behavior of SnO_2/reduced graphene oxide nanocomposites toward NO_2. *Sensors and Actuators B: Chemical.* 179**.** 61-68.

Nie, T., Zhang, O., Lu, L., Xu, J., Wen, Y. and Qiu, X. (2013) Facile synthesis of poly (3, 4-ethylenedioxythiophene)/graphene nanocomposite and its application for determination of nitrite. *Int J Electrochem Sci.* 8**.** 8708-8718.

Nijjer, S., Thonstad, J. and Haarberg, G. M. (2000) Oxidation of manganese (II) and reduction of manganese dioxide in sulphuric acid. *Electrochimica Acta.* 46**.** 395-399.

Noroozifar, M., Khorasani-Motlagh, M., Akbari, R. and Parizi, M. B. (2011) Simultaneous and sensitive determination of a quaternary mixture of AA, DA, UA and Trp using a modified GCE by iron ion-doped natrolite zeolite-multiwall carbon nanotube. *Biosensors and Bioelectronics.* 28**.** 56-63.

Oda, M., Satta, Y., Takenaka, O. and Takahata, N. (2002) Loss of urate oxidase activity in hominoids and its evolutionary implications. *Molecular biology and evolution.* 19**.** 640-653.

Peik-See, T., Pandikumar, A., Nay-Ming, H., Hong-Ngee, L. and Sulaiman, Y. (2014) Simultaneous electrochemical detection of dopamine and ascorbic acid using an iron oxide/reduced graphene oxide modified glassy carbon electrode. *Sensors.* 14**.** 15227-15243.

Penn, S. G., He, L. and Natan, M. J. (2003) Nanoparticles for bioanalysis. *Current opinion in chemical biology.* 7**.** 609-615.

Pérez, L., Briza and Merkoçi , A. (2011) Magnetic nanoparticles modified with carbon nanotubes for electrocatalytic magnetoswitchable biosensing applications. *Advanced Functional Materials.* 21**.** 255-260.

Pernaut, J.-M. and Reynolds, J. R. (2000) Use of conducting electroactive polymers for drug delivery and sensing of bioactive molecules. A redox chemistry approach. *The Journal of Physical Chemistry B.* 104**.** 4080-4090.

Ping, J., Wu, J., Wang, Y. and Ying, Y. (2012) Simultaneous determination of ascorbic acid, dopamine and uric acid using high-performance screen-printed graphene electrode. *Biosensors and Bioelectronics.* 34**.** 70-76.

Priyatharshni, S., Tamilselvan, A., Viswanathan, C. and Ponpandian, N. (2017) LaCoO3 Nanostructures Modified Glassy Carbon Electrode for Simultaneous Electrochemical Detection of Dopamine, Ascorbic Acid and Uric Acid. *Journal of the Electrochemical Society.* 164**.** B152-B158.

Pron, A. and Rannou, P. (2002) Processible conjugated polymers: from organic semiconductors to organic metals and superconductors. *Progress in Polymer Science.* 27**.** 135-190.

Puangjan, A., Chaiyasith, S., Wichitpanya, S., Daengduang, S. and Puttota, S. (2016) Electrochemical sensor based on PANI/MnO_2-Sb_2O_3 nanocomposite for selective simultaneous voltammetric determination of ascorbic acid and acetylsalicylic acid. *Journal of Electroanalytical Chemistry.* 782**.** 192-201.

Qiao, X., Liao, S., You, C. and Chen, R. (2015) Phosphorus and nitrogen dual doped and dimultaneously reduced graphene oxide with high surface area as efficient metal-free electrocatalyst for oxygen reduction. *Catalysts.* 5**.** 1-11.

Ragupathy, P., Vasan, H. N. and Munichandraiah, N. (2008) Synthesis and characterization of nano-MnO2 for electrochemical supercapacitor studies. *Journal of the Electrochemical Society.* 155**.** A34-A40.

Rahman, M. M., Lopa, N. S., Kim, K. and Lee, J.-J. (2015) Selective detection of L-tyrosine in the presence of ascorbic acid, dopamine, and uric acid at poly (thionine)-modified glassy carbon electrode. *Journal of Electroanalytical Chemistry.* 754**.** 87-93.

Ramesh, P. and Sampath, S. (2004) Selective determination of uric acid in presence of ascorbic acid and dopamine at neutral pH using exfoliated graphite electrodes. *Electroanalysis.* 16**.** 866-869.

Richardson-Burns, S. M., Hendricks, J. L., Foster, B., Povlich, L. K., Kim, D.-H. and Martin, D. C. (2007) Polymerization of the conducting polymer poly (3, 4-ethylenedioxythiophene)(PEDOT) around living neural cells. *Biomaterials.* 28**.** 1539-1552.

Rock, K. L., Kataoka, H. and Lai, J.-J. (2013) Uric acid as a danger signal in gout and its comorbidities. *Nature Reviews Rheumatology.* 9**.** 13-23.

Rodrigues, S., Shukla, A. K. and Munichandraiah, N. (1998) A cyclic voltammetric study of the kinetics andmechanism of electrodeposition of manganese dioxide. *Journal of applied electrochemistry.* 28**.** 1235-1241.

Roy, P. R., Okajima, T. and Ohsaka, T. (2003) Simultaneous electroanalysis of dopamine and ascorbic acid using poly (N, N-dimethylaniline)-modified electrodes. *Bioelectrochemistry.* 59**.** 11-19.

Roy, P. R., Okajima, T. and Ohsaka, T. (2004) Simultaneous electrochemical detection of uric acid and ascorbic acid at a poly (N, N-dimethylaniline) film-coated GC electrode. *Journal of Electroanalytical Chemistry.* 561**.** 75-82.

Roy, S. S., Papakonstantinou, P., Okpalugo, T. I. T. and Murphy, H. (2006) Temperature dependent evolution of the local electronic structure of atmospheric plasma treated carbon nanotubes: near edge x-ray absorption fine structure study. *Journal of applied physics.* 100**.** 1-4.

Safavi, A., Maleki, N., Moradlou, O. and Tajabadi, F. (2006) Simultaneous determination of dopamine, ascorbic acid, and uric acid using carbon ionic liquid electrode. *Analytical biochemistry.* 359**.** 224-229.

Sahoo, N. G., Pan, Y., Li, L. and Chan, S. H. (2012) Graphene-based materials for energy conversion. *Advanced materials.* 24**.** 4203-4210.

Samanta, S. K., Subrahmanyam, K. S., Bhattacharya, S. and Rao, C. N. R. (2012) Composites of graphene and other nanocarbons with organogelators assembled through supramolecular interactions. *Chemistry-A European Journal.* 18**.** 2890-2901.

Sansuk, S., Bitziou, E., Joseph, M. B., Covington, J. A., Boutelle, M. G., Unwin, P. R. and Macpherson, J. V. (2012) Ultrasensitive detection of dopamine using a carbon nanotube network microfluidic flow electrode. *Analytical Chemistry.* 85**.** 163-169.

Schaarschmidt, A., Farah, A. A., Aby, A. and Helmy, A. S. (2009) Influence of nonadiabatic annealing on the morphology and molecular structure of PEDOT- PSS films. *The Journal of Physical Chemistry B.* 113**.** 9352-9355.

Schedin, F., Geim, A. K., Morozov, S. V., Hill, E. W., Blake, P., Katsnelson, M. I. and Novoselov, K. S. (2007) Detection of individual gas molecules adsorbed on graphene. *Nature materials.* 6**.** 652-655.

Shahrokhian, S., Ghalkhani, M. and Amini, M. K. (2009) Application of carbon-paste electrode modified with iron phthalocyanine for voltammetric determination of epinephrine in the presence of ascorbic acid and uric acid. *Sensors and Actuators B: Chemical.* 137**.** 669-675.

Shankar, S. S., Swamy, B. E. K., Ch, U., Manjunatha, J. G. and Sherigara, B. S. (2009) Simultaneous determination of dopamine, uric acid and ascorbic acid with CTAB modified carbon paste electrode. *Int. J. Electrochem. Sci.* 1-10.

Shanmugharaj, A. M. and Ryu, S. H. (2012) Excellent electrochemical performance of graphene-silver nanoparticle hybrids prepared using a microwave spark assistance process. *Electrochimica Acta.* 74**.** 207-214.

Sheng, Z.-H., Zheng, X.-Q., Xu, J.-Y., Bao, W.-J., Wang, F.-B. and Xia, X.-H. (2012) Electrochemical sensor based on nitrogen doped graphene: simultaneous determination of ascorbic acid, dopamine and uric acid. *Biosensors and Bioelectronics.* 34**.** 125-131.

Si, P., Chen, H., Kannan, P. and Kim, D.-H. (2011) Selective and sensitive determination of dopamine by composites of polypyrrole and graphene modified electrodes. *Analyst.* 136**.** 5134-5138.

Šljukić, B. and Compton, R. G. (2007) Manganese dioxide graphite composite electrodes formed via a low temperature method: detection of hydrogen peroxide, ascorbic acid and nitrite. *Electroanalysis.* 19**.** 1275-1280.

Soltani, Z., Rasheed, K., Kapusta, D. R. and Reisin, E. (2013) Potential role of uric acid in metabolic syndrome, hypertension, kidney injury, and cardiovascular diseases: is it time for reappraisal? *Current hypertension reports.* 15**.** 175-181.

Sriramprabha, R., Divagar, M., Mangalaraj, D., Ponpandian, N. and Viswanathan, C. (2015) Formulation of SnO_2/graphene nanocomposite modified electrode for synergitic electrochemcial detection of dopamine. 1-6.

Stankovich, S., Dikin, D. A., Dommett, G. H. B., Kohlhaas, K. M., Zimney, E. J., Stach, E. A., Piner, R. D., Nguyen, S. T. and Ruoff, R. S. (2006) Graphene-based composite materials. *Nature.* 442**.** 282-286.

Sun, C.-L., Lee, H.-H., Yang, J.-M. and Wu, C.-C. (2011) The simultaneous electrochemical detection of ascorbic acid, dopamine, and uric acid using graphene/size-selected Pt nanocomposites. *Biosensors and Bioelectronics.* 26**.** 3450-3455.

Sun, Z., Fu, H., Deng, L. and Wang, J. (2013) Redox-active thionine-graphene oxide hybrid nanosheet: One-pot, rapid synthesis, and application as a sensing platform for uric acid. *Analytica chimica acta.* 761**.** 84-91.

Tang, L., Wang, Y., Li, Y., Feng, H., Lu, J. and Li, J. (2009) Preparation, structure, and electrochemical properties of reduced graphene sheet films. *Advanced Functional Materials.* 19**.** 2782-2789.

Temmer, R., Maziz, A., Plesse, C., Aabloo, A., Vidal, F. and Tamm, T. (2013) In search of better electroactive polymer actuator materials: PPy versus PEDOT versus PEDOT-PPy composites. *Smart Materials and Structures.* 22**.** 104006.

Thévenot, D. R., Toth, K., Durst, R. A. and Wilson, G. S. (2001) Electrochemical biosensors: recommended definitions and classification. *Biosensors and Bioelectronics.* 16**.** 121-131.

Thomas, M. D. (1997) Textbook of biochemistry with clinical correlations. Wiley, New York.

Tian, X., Cheng, C., Yuan, H., Du, J., Xiao, D., Xie, S. and Choi, M. M. F. (2012) Simultaneous determination of l-ascorbic acid, dopamine and uric acid with gold nanoparticles-β -cyclodextrin-graphene-modified electrode by square wave voltammetry. *Talanta.* 93**.** 79-85.

Tığ, G. A., Günendi, G. and Pekyardımcı, Ş. (2017) A selective sensor based on Au nanoparticles-graphene oxide-poly (2, 6-pyridinedicarboxylic acid) composite

for simultaneous electrochemical determination of ascorbic acid, dopamine, and uric acid. *Journal of Applied Electrochemistry.* 47**.** 607-618.
Toupin, M., Brousse, T. and Bã©Langer, D. (2004) Charge storage mechanism of MnO_2 electrode used in aqueous electrochemical capacitor. *Chemistry of Materials.* 16**.** 3184-3190.
Ulubay, Ş. and Dursun, Z. (2010) Cu nanoparticles incorporated polypyrrole modified GCE for sensitive simultaneous determination of dopamine and uric acid. *Talanta.* 80**.** 1461-1466.
Vilian, A. T. E., Rajkumar, M., Chen, S.-M., Hu, C.-C. and Piraman, S. (2014) A promising photoelectrochemical sensor based on a ZnO particle decorated N-doped reduced graphene oxide modified electrode for simultaneous determination of catechol and hydroquinone. *RSC Advances.* 4**.** 48522-48534.
Wang, C., Du, J., Wang, H., Zou, C., Jiang, F., Yang, P. and Du, Y. (2014a) A facile electrochemical sensor based on reduced graphene oxide and Au nanoplates modified glassy carbon electrode for simultaneous detection of ascorbic acid, dopamine and uric acid. *Sensors and Actuators, B: Chemical.* 204**.** 302-309.
Wang, C., Yin, L., Zhang, L., Xiang, D. and Gao, R. (2010a) Metal oxide gas sensors: sensitivity and influencing factors. *Sensors.* 10**.** 2088-2106.
Wang, H., Hao, Q., Yang, X., Lu, L. and Wang, X. (2010b) A nanostructured graphene/polyaniline hybrid material for supercapacitors. *Nanoscale.* 2**.** 2164-2170.
Wang, H., Ren, F., Wang, C., Yang, B., Bin, D., Zhang, K. and Du, Y. (2014b) Simultaneous determination of dopamine, uric acid and ascorbic acid using a glassy carbon electrode modified with reduced graphene oxide. *RSC Advances.* 4**.** 26895-26901.
Wang, W., Xu, G., Cui, X. T., Sheng, G. and Luo, X. (2014c) Enhanced catalytic and dopamine sensing properties of electrochemically reduced conducting polymer nanocomposite doped with pure graphene oxide. *Biosensors and Bioelectronics.* 58**.** 153-156.
Wang, Y., Gao, S., Zang, X., Li, J. and Ma, J. (2012a) Graphene-based solid-phase extraction combined with flame atomic absorption spectrometry for a sensitive determination of trace amounts of lead in environmental water and vegetable samples. *Analytica chimica acta.* 716**.** 112-118.
Wang, Y., Li, Y., Tang, L., Lu, J. and Li, J. (2009) Application of graphene-modified electrode for selective detection of dopamine. *Electrochemistry Communications.* 11**.** 889-892.
Wang, Y., Zhang, S., Chen, H., Li, H., Zhang, P., Zhang, Z., Liang, G. and Kong, J. (2012b) One-pot facile decoration of graphene nanosheets with Ag nanoparticles for electrochemical oxidation of methanol in alkaline solution. *Electrochemistry Communications.* 17**.** 63-66.
Westervelt, R. M. (2008) Graphene nanoelectronics. *science.* 320**.** 324-325.
Wightman, R. M., May, L. J. and Michael, A. C. (1988) Detection of dopamine dynamics in the brain. *Analytical Chemistry.* 60**.** 769A-793A.
Wilson, M. S. (2005) Electrochemical immunosensors for the simultaneous detection of two tumor markers. *Analytical Chemistry.* 77**.** 1496-1502.
Wu, L., Feng, L., Ren, J. and Qu, X. (2012) Electrochemical detection of dopamine using porphyrin-functionalized graphene. *Biosensors and Bioelectronics.* 34**.** 57-62.
Wu, S., Cao, H., Yin, S., Liu, X. and Zhang, X. (2009) Amino acid-assisted hydrothermal synthesis and photocatalysis of SnO_2 nanocrystals. *The Journal of Physical Chemistry C.* 113**.** 17893-17898.

Wu, Y., Zhang, K., Xu, J., Zhang, L., Lu, L., Wu, L., Nie, T., Zhu, X., Gao, Y. and Wen, Y. (2014) Sensitive Detection of Hydroxylamine on Poly (3, 4-ethylenedioxythiophene)/graphene Oxide Nanocomposite Electrode. *Int. J. Electrochem. Sci.* 9**.** 6594-6607.

Xu, T.-Q., Zhang, Q.-L., Zheng, J.-N., Lv, Z.-Y., Wei, J., Wang, A.-J. and Feng, J.-J. (2014) Simultaneous determination of dopamine and uric acid in the presence of ascorbic acid using Pt nanoparticles supported on reduced graphene oxide. *Electrochimica Acta.* 115**.** 109-115.

Xu, X., Zhang, H., Shi, H., Ma, C., Cong, B. and Kang, W. (2012) Determination of three major catecholamines in human urine by capillary zone electrophoresis with chemiluminescence detection. *Analytical biochemistry.* 427**.** 10-17.

Yamato, H., Ohwa, M. and Wernet, W. (1995) Stability of polypyrrole and poly (3, 4-ethylenedioxythiophene) for biosensor application. *Journal of Electroanalytical Chemistry.* 397**.** 163-170.

Yan, W., Feng, X., Chen, X., Li, X. and Zhu, J.-J. (2008) A selective dopamine biosensor based on AgCl/ polyaniline core-shell nanocomposites. *Bioelectrochemistry.* 72**.** 21-27.

Yang, Y. J. (2015a) One-pot synthesis of reduced graphene oxide/zinc sulfide nanocomposite at room temperature for simultaneous determination of ascorbic acid, dopamine and uric acid. *Sensors & Actuators: B. Chemical.* 750-759.

Yang, Y. J. (2015b) One-pot synthesis of reduced graphene oxide/zinc sulfide nanocomposite at room temperature for simultaneous determination of ascorbic acid, dopamine and uric acid. *Sensors and Actuators B: Chemical.* 221**.** 750-759.

Yu, L., Zhang, G., Wu, Y., Bai, X. and Guo, D. (2008) Cupric oxide nanoflowers synthesized with a simple solution route and their field emission. *Journal of Crystal Growth.* 310**.** 3125-3130.

Zain, Z. M. and Zakaria, N. (2014) Hydrogen Peroxide Impedimetric Detection on Poly-Ortho-Phenylenediamine Modified Platinum Disk Microelectrode. *Malaysian Journal of Analytical Sciences.* 18**.** 107-115.

Zhang, J. and Zhao, X. S. (2012) Conducting polymers directly coated on reduced graphene oxide sheets as high-performance supercapacitor electrodes. *The Journal of Physical Chemistry C.* 116**.** 5420-5426.

Zhang, X., Zhang, Y. C. and Ma, L. X. (2016) One-pot facile fabrication of graphene-zinc oxide composite and its enhanced sensitivity for simultaneous electrochemical detection of ascorbic acid, dopamine and uric acid. *Sensors and Actuators, B: Chemical.* 227**.** 488-496.

Zhang, Y., Jin, G., Wang, Y. and Yang, Z. (2003) Determination of dopamine in the presence of ascorbic acid using poly (acridine red) modified glassy carbon electrode. *Sensors.* 3**.** 443-450.

Zhang, Y., Kolmakov, A., Chretien, S., Metiu, H. and Moskovits, M. (2004) Control of catalytic reactions at the surface of a metal oxide nanowire by manipulating electron density inside it. *Nano Letters.* 4**.** 403-407.

Zhao, D., Yu, G., Tian, K. and Xu, C. (2016) A highly sensitive and stable electrochemical sensor for simultaneous detection towards ascorbic acid, dopamine, and uric acid based on the hierarchical nanoporous PtTi alloy. *Biosensors and Bioelectronics.* 82**.** 119-126.

Zhao, Q., Jamal, R., Zhang, L., Wang, M. and Abdiryim, T. (2014) The structure and properties of PEDOT synthesized by template-free solution method. *Nanoscale Research Letters.* 1**.** 1-9.

Zhao, Y., Meng, Y., Wu, H., Wang, Y., Wei, Z., Li, X. and Jiang, P. (2015) In situ anchoring uniform MnO_2 nanosheets on three-dimensional macroporous graphene thin-films for supercapacitor electrodes. *RSC Advances.* 5**.** 90307-90312.

Zhou, X., Ma, P., Wang, A., Yu, C., Qian, T., Wu, S. and Shen, J. (2015) Dopamine fluorescent sensors based on polypyrrole/graphene quantum dots core/shell hybrids. *Biosensors and Bioelectronics.* 64**.** 404-410.

Zhou, Y., Tang, W., Wang, J., Zhang, G., Chai, S., Zhang, L. and Liu, T. (2014) Selective determination of dopamine and uric acid using electrochemical sensor based on poly (alizarin yellow R) film-modified electrode. *Analytical Methods.* 6**.** 3474-3481.