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DETERMINATION OF DOPAMINE WITH TWO-DIMENSIONAL MoS_2 MODIFIED GLASSY CARBON ELECTRODE

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ABSTRACT

Dopamine (DA) is a hormone secreted in the brain and it provides communication between nerve cells and ensures that body movements are carried out in a balanced way. Since dopamine is an electroactive compound, its determination by electrochemical techniques can be done with high sensitivity, easy processing and low cost. Molybdenum Sulfide (MoS_2) is one of the important two-dimensional (2D) transition metal dialcogenes from graphene analogues. Transition metal dicalcogenes (TMD) are denoted by the general formula MX_2 (M = Mo, W, V, Nb, Ta, Ti, Zr, Hf and X = S, Se, Te). With their unique electronic, optical, thermal, mechanical and electrical properties and structures similar to graphene, they have found a wide range of applications by forming an interesting group of materials. In recent years, the most studied of the transition metal dicalcogenes are MoS_2 and WS_2. In the study, glassy carbon electrode (GCE) was modified with MoS_2. In experimental studies, two different methods were used for the preparation of modified electrodes. The first of these methods is the drip coating (DC) method. The electrode prepared by modifying the GCE with this method is called MoS2 (1)/GCE electrode. The second method applied is the electrochemical coating method. The electrode prepared by modifying the GCE with this method is called MoS2(2)/GCE electrode. In this study, electrode modification was made for dopamine and dopamine was detected electrochemically with these two electrodes. In order to see the efficiency in DA determination, DA determination in a commercial drug called Dopmin was successfully performed with MoS2(1)/GCE and MoS2(2)/GCE with a relative error of 4.9 % and -1.0 %, respectively.

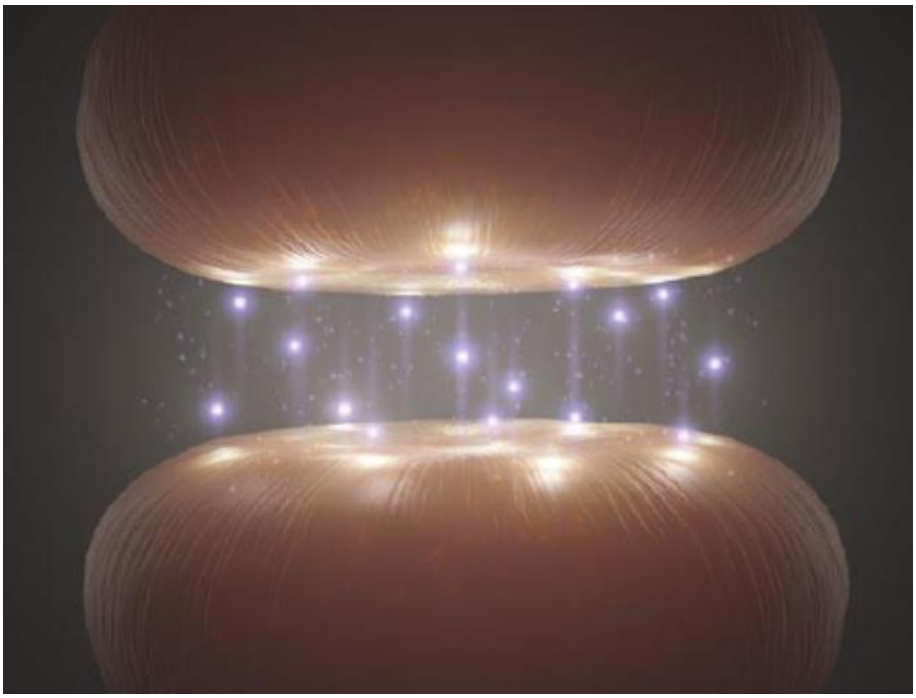
KEYWORDS: Two-Dimensional, Molibdendisülfür, Dopamine, Electrochemical Determination

1. INTRODUCTION

Today, with the increase in the income level, an increase has been observed in people's orientation to a quality and healthy life. While different theories are being put forward every day for a healthy life, the importance of protecting health and early diagnosis has emerged rather than treating the disease. Therefore, new methods are being developed for the determination of molecules of biological importance. Chromatographic (De Benedetto et al., 2014; Kanďár, Drábková, & Hampl, 2011; Li & Franke, 2009) and spectrophotometric (Güçlü, Sözgen, Tütem, Özyürek, & Apak, 2005; Nevado, Gallego, & Laguna, 1996; M. Zhu, Huang, Li, & Shen, 1997) methods are mostly used in the determination of these molecules. These methods have advantages such as being reproducible and being able to detect more than one

substance at the same time. However, they have disadvantages such as requiring pre-treatment (separation, purification, concentration, etc.), chemical costs spent for these processes, loss of time, and the necessity of using expensive devices. However, it is possible to determine molecules of biological importance with simple and inexpensive devices with high sensitivity, short times, without the need for preprocessing by electrochemical methods (Balamurugan, Senthil Kumar, Thangamuthu, & Pandurangan, 2013; Cao, Luo, Ding, Zou, & Bian, 2008; Wu et al., 2014).

Dopamine (DA) is a hormone naturally produced in the body and secreted in the brain. By acting as a neurotransmitter, DA provides communication between nerve cells and ensures proper body movements and balance function. Dopamine is often referred to as the "happiness hormone," like serotonin. In addition to giving a feeling of happiness, dopamine is involved in many different functions in humans and animals such as movement, memory, comprehension, concentration, mood, pleasure, sleep and learning. An excess or deficiency of dopamine causes some serious health problems. In the absence of dopamine, disruptions in the nervous system may occur and lead to Parkinson's disease. The increase in the amount of dopamine as a result of drug or cigarette use leads to addiction. This chemical works in the brain by transmitting millions of signals within seconds. Thanks to these signals, body systems work, movement is provided and cognitive activities occur. These electrical signals, which are transmitted very quickly through the nerve cells, are carried by certain chemicals at the junction points of the nerve cells. These chemicals are called neurotransmitters, and without them there can be no transmission. The bright spots between nerve cells in Picture 1 represent neurotransmitters. "Dopamine" is one of the most important of the more than 100 neurotransmitters discovered by science. Picture 1 shows the function of neurotransmitters between nerve cells.



Picture 1. Neurotransmitters between nerve cells
(https://www.istockphoto.com/tr/foto%C4%9Fraflar/n%C3%B6rofilament)

Dopamine determination is very important. Some of the suggested methods for DA are chemiluminescence (Duan et al., 2015; Q. Zhu et al., 2015), spectrophotometric (Mamiński, Olejniczak, Chudy, Dybko, & Brzózka, 2005; Moghadam, Dadfarnia, Shabani, & Shahbazikhah, 2011) and chromatographic (Baranyi, Milusheva, Vizi, & Sperlágh, 2006; Virag & Whittington, 2002) techniques. Electrochemical determination of DA has a very large place in the literature. The reason for this is that it can be determined electrochemically in a short time, cheaply, easily and reliably. Figure 1 shows the electrochemical oxidation of DA at pH=7 (Oko et al., 2015; Ping, Wu, Wang, & Ying, 2012; Wang et al., 2012; Zhao, Zhang, & Yuan, 2001).

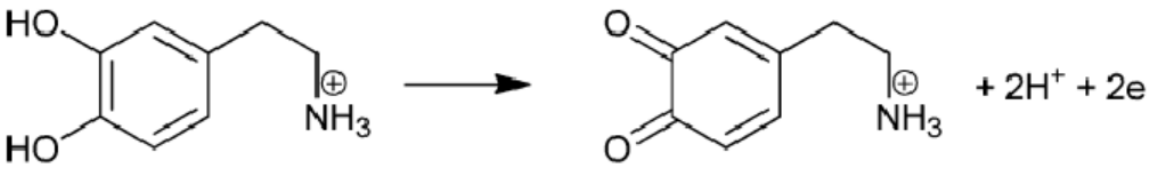


Figure 1. Electrochemical oxidation of Dopamine (at pH=7)

The glassy carbon electrode (GCE) is modified with MoS_2. Molybdenum Sulfide (MoS_2) is one of the important two-dimensional (2D) transition metal dichalcogenides from graphene analogues. MoS_2 is the most interesting material of this group with its graphite-like structure (Zhou, Liu, Wen, Hu, & Gui, 2014). MoS_2 has a hexagonal layer configuration. The atoms in the layer are connected by strong covalent bonds, the layers are connected to each other by weak forces, as in graphite, and each Mo layer is sandwiched between 2 sulfur layers (Huang et al., 2013).

In this study, it was planned to detect dopamine electrochemically by modifying GCE MoS_2 for dopamine and to analyze real samples with the prepared electrode modification.

2. MATERIALS AND METHODS

A three-electrode system was used in electrochemical studies. Measurements were made with a computer-controlled CHI 660E potentiostat. Also C3 cell stand, glassy carbon electrode (GCE) as working electrode and modified glassy carbon electrodes (MoS2(1)/GCE electrode and MoS2(2)/GCE electrode), platinum wire as counter electrode and saturated calomel as reference electrode electrode (SCE) was used. MoS_2 in powder form was obtained from Özdogu Madencilik Ltd.Şti. and dopamine was obtained from Sigma Aldrich. Standard solutions of dopamine were prepared in phosphate buffer pH=7.

Again, pH=7 phosphate buffer solution was used as the supporting electrolyte used in the electrochemical measurements. For the preparation of MoS2(1)/GCE electrode and MoS2(2)/GCE electrode, drip coating method and electrochemical coating method were applied. The preparation of the MoS2(1)/GCE electrode prepared by the drip coating method is not described here again, since it was given in detail in our previously published publication (ASAN & Çelikkan, 2017). Electrochemical coating method was used for the preparation of the MoS2(2)/GCE electrode. Coating Suspension; 100 mg of MoS_2 was kept in 100 mL of

isoamyl alcohol in an ultrasonic bath for 8 hours. It was then centrifuged at 6000 rpm for 10 minutes. After the isoamyl alcohol in the filtrate was separated, MoS_2 was washed twice with deionized water, and a homogeneous suspension was obtained by taking it into 100 mL of water and keeping it in an ultrasonic bath for 1 hour. The cleaned surface of the GCE electrodes was coated in three different times and the optimum time was determined as 3600 seconds. The coating was carried out by keeping the GCE in 0.5 M NaOH containing the coating suspension (10%, v/v) at constant potential (1.0 V) for 60 minutes. For the detailed preparation of this electrode (Asan, 2015) can be looked at.

3. RESULTS AND DISCUSSIONS

3.1. Dopamine Determination with MoS2(1)/GCE

Electrochemical analysis studies against dopamine were performed with MoS2(1)/GCE electrode prepared with 5 µL coating from the coating suspension. An attempt was made to determine DA at ambient temperature with MoS2(1)/GCE. Since the ambient temperature was around 35°C during the study, dopamine deteriorated rapidly. Therefore, the operation could not be carried out at ambient temperature. In order to prevent the degradation of dopamine, the dopamine solution added during the experiment was taken freshly from the refrigerator each time, and voltammograms were taken by placing the cell in a cold water bath and keeping the temperature constant at 11 °C. During the study, temperature control was carried out using a thermometer. The experimental setup is given in Picture 2.

Picture 2. The image of the cell in a cold water bath in the determination of dopamine with MoS2(1)/GCE

DP voltammograms against increasing DA concentrations at 11 °C with the MoS2(1)/GCE numbered electrode (in pH=7 phosphate buffer) are given in Figure 2 and the peak currents read from these voltammograms are plotted against the concentration and given in Figure 3.

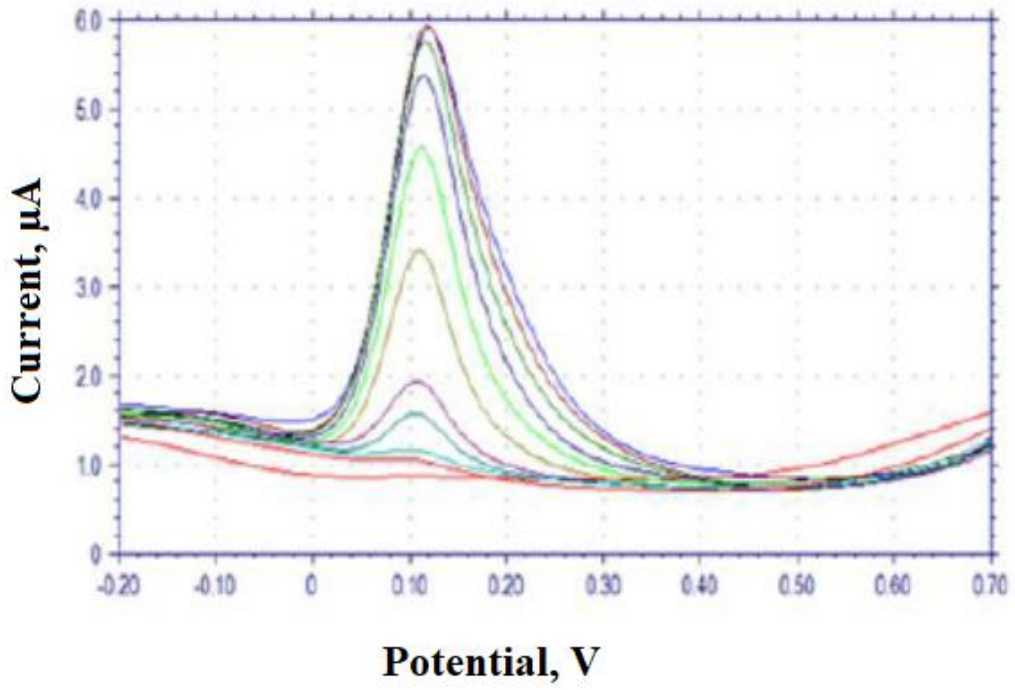


Figure 2. DPVs taken at different concentrations for DA determination with MoS2(1)/GCE (in pH=7 buffer, 11°C)

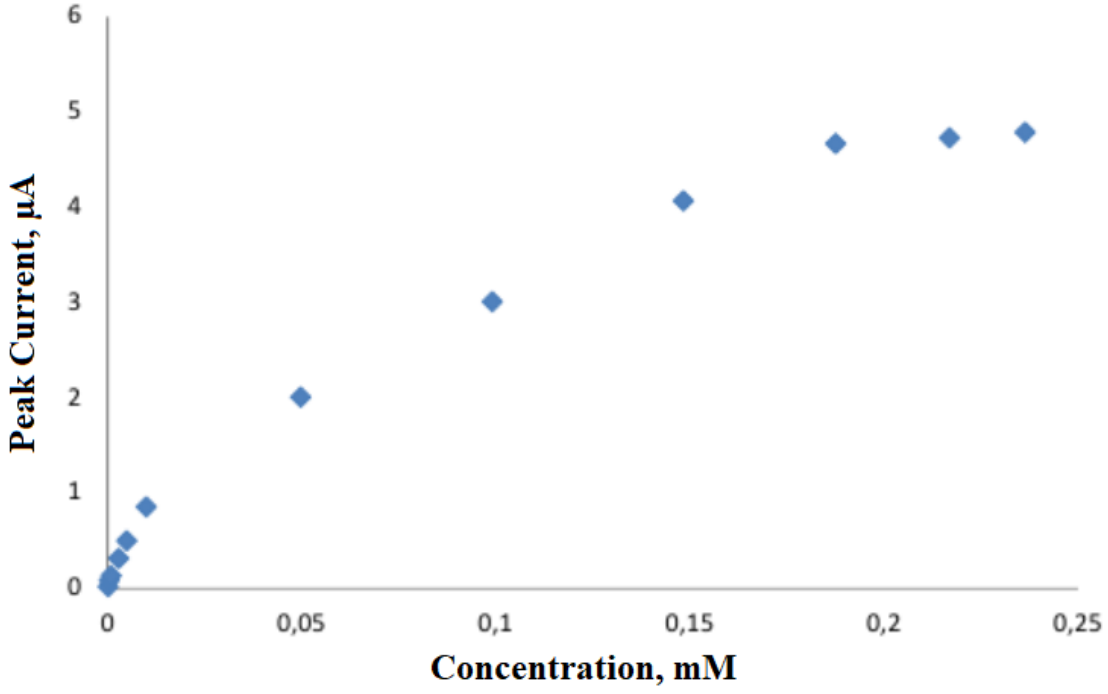


Figure 3. Graph of DA concentration versus peak currents with MoS2(1)/GCE (at 11°C)

If Figure 3 is examined, first, a higher sensitivity was observed with the addition of DA, and then a decrease in the slope began. For this reason, the graph has been evaluated as having two working ranges. It is given as the 1st linear operating range in Figure 4 and the 2nd linear operating range in Figure 5.

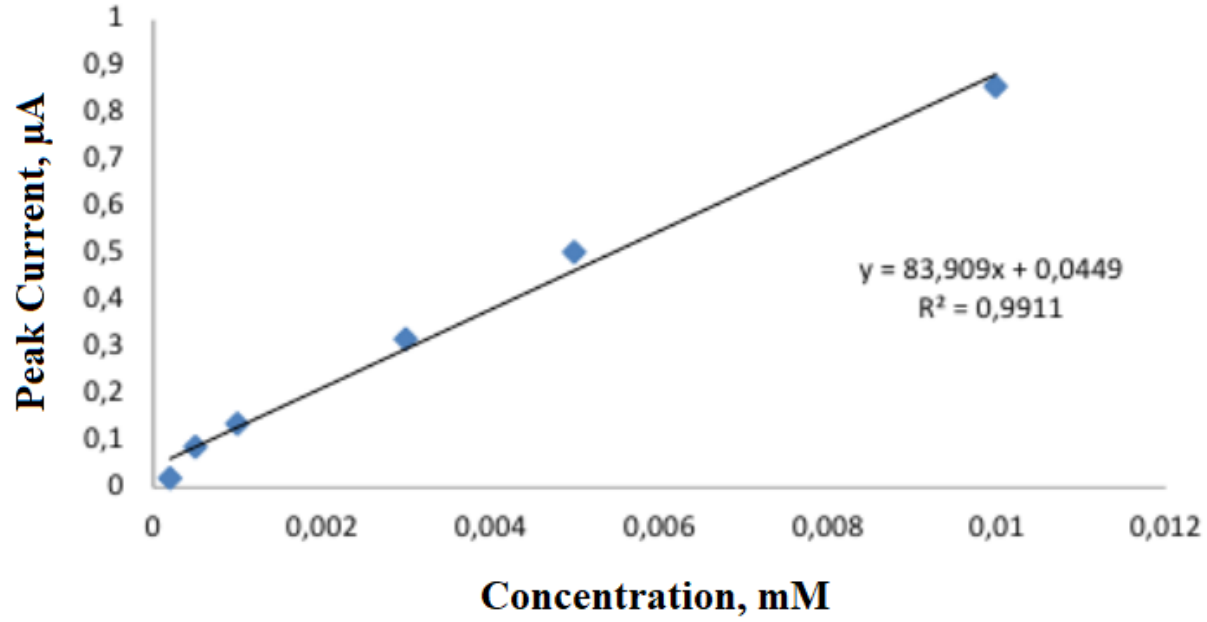


Figure 4. Graph of DA concentration versus peak currents with MoS2(1)/GCE 1st linear operating range (at 11°C)

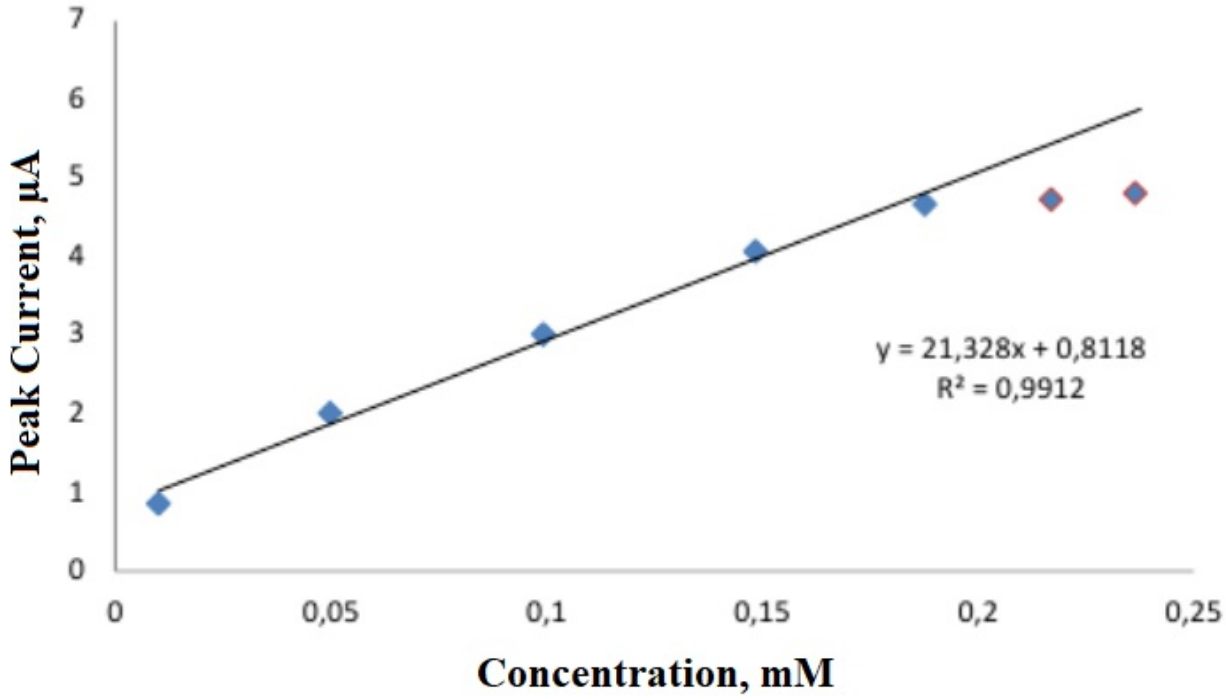


Figure 5. Graph of DA concentration versus peak currents with MoS2(1)/GCE 2nd linear operating range (at 11°C)

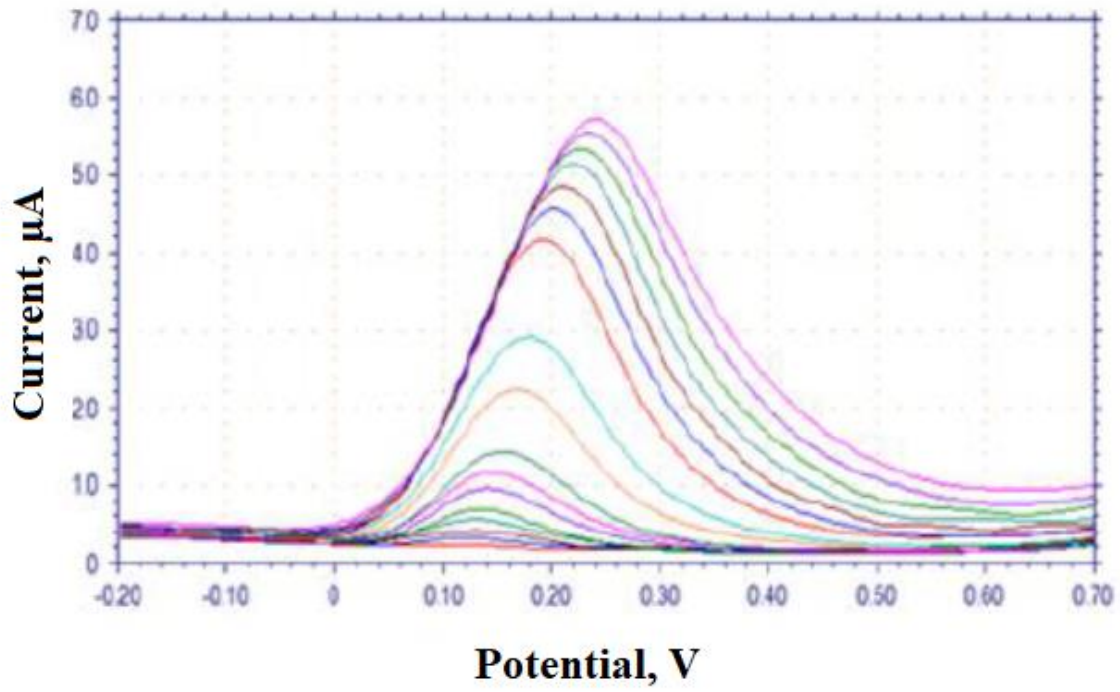


Figure 6. DPVs taken at different concentrations for Dopamine determination by GCE (in pH=7 buffer, 11°C)

DPVs against DA concentrations at 11°C in pH=7 phosphate buffer with GCE are overlapped in Figure 6 and the peak currents read against concentration are given in Figure 7 by plotting.

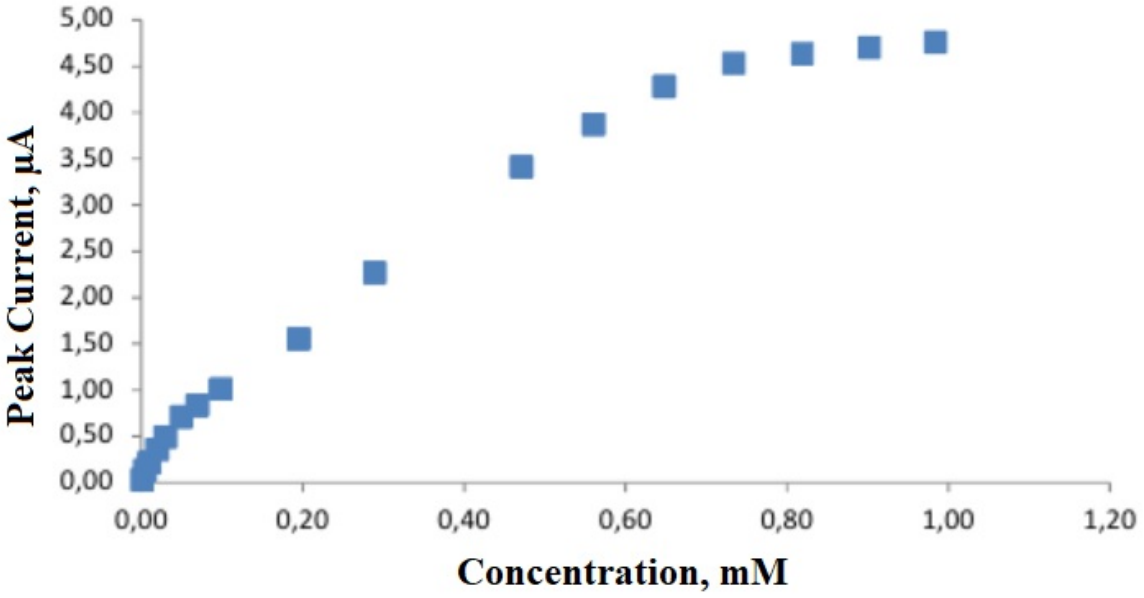


Figure 7. Plot of DA concentration versus peak currents for GCE (at 11°C)

The experimental data obtained in the dopamine environment for the comparison of MoS2(1)/GCE with GCE are given in Table 1 collectively.

Table 1. Comparison of MoS2(1)/GCE and the values obtained in DA environment with GCE

	Electrode Name		
	GCE	MoS2(1)/GCE	
Linear Operating Range (µM)	1 – 650	0.2 -10	10 – 190
Line Equation (µA/ mM)	y=6.4808x+0.254	y=83.909x+0.0449	y=21.328x+0.8118
R^2	0.9926	0.9911	0.9912
Sensitivity (µA/ mM)	6.48	83.91	21.33

If Table 1 is examined, MoS2(1)/GCE was found to be 12.9 times more sensitive in the 1st linear operating range and 3.3 times more sensitive in the 2nd linear operating range for DA compared to GCE. As a result, the electroanalytical sensitivity of the MoS_2 modified electrode for dopamine was better than that of the GCE. Analytical performance values for MoS2(1)/GCE and DA are given in Table 2.

Table 2. Analytical performance values for DA with MoS2(1)/GCE

1.Linear Working Range(LWR) (µM)	0.2 - 10
(1. LWR) Sensitivity ($\mu A.mM^{-1}$)	83.9
2.Linear Working Range(LWR) (mM)	10 – 190
(2. LWR) Sensitivity ($\mu A.mM^{-1}$)	21.3
LOD (nM)	52.2
LOQ (nM)	174

3.2. Determination of Dopamine with MoS2(2)/GCE

Differential pulse voltammograms at varying DA amounts with MoS2(2)/GCE were taken and superimposed, and the resulting graph is given in Figure 8, and the peak currents against concentration are plotted in Figure 9.

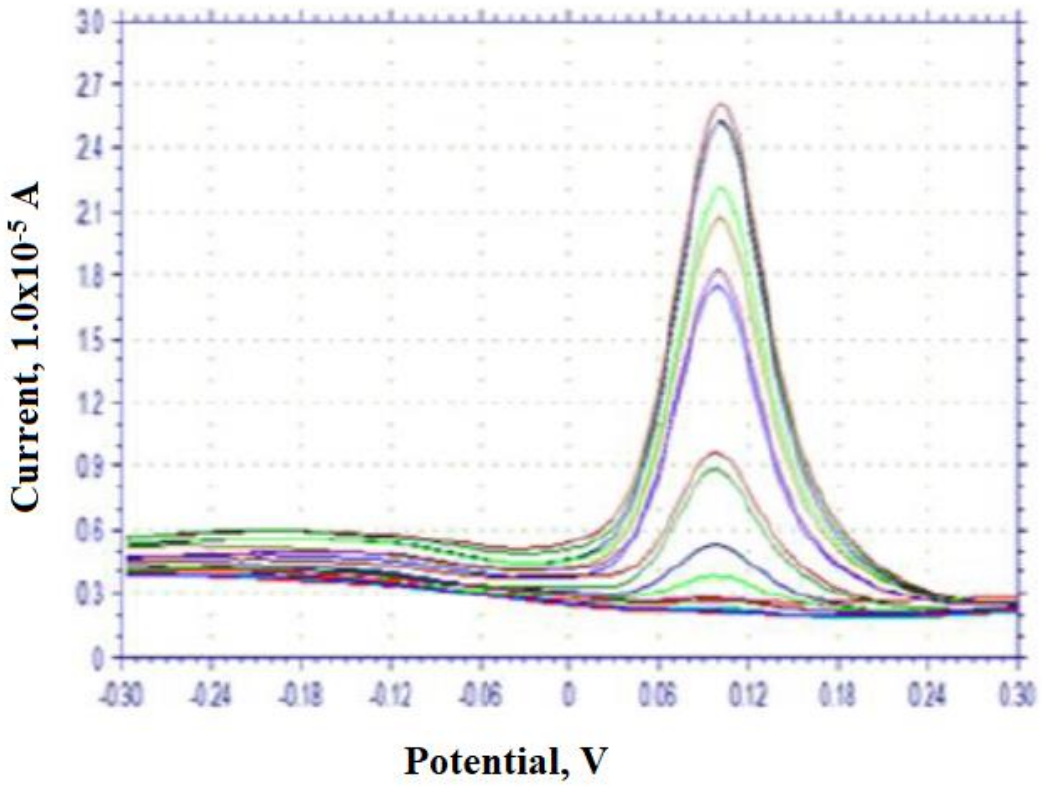


Figure 8. DPVs taken at different concentrations for DA determination with MoS2(2)/GCE (in pH=7 buffer)

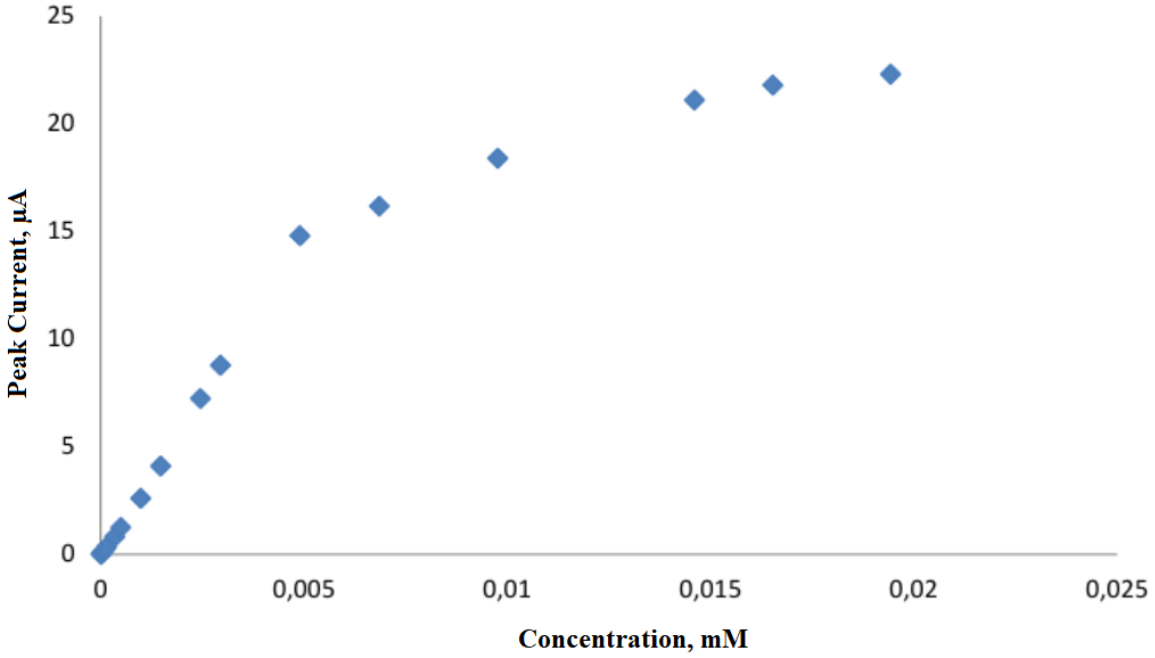


Figure 9. Graph of peak currents versus DA concentration in pH=7 buffer with MoS2(2)/GCE

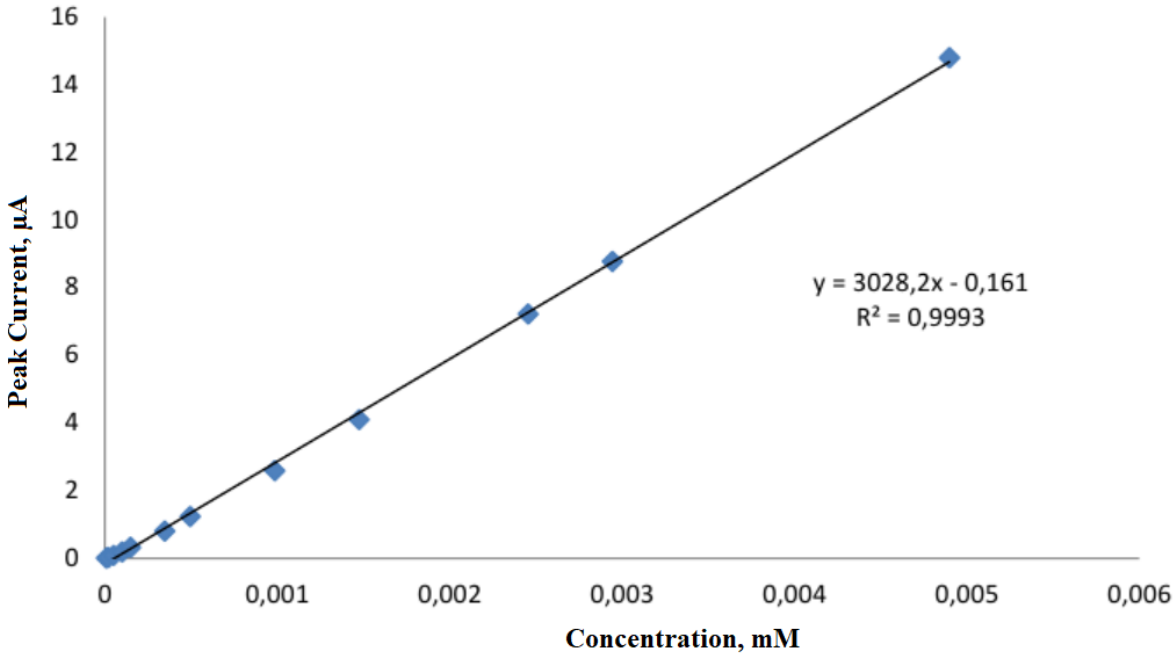


Figure 10. 1st linear operating range for DA determination with MoS2(2)/GCE

As can be seen from the graph, the sensitivity of the first operating range is quite high. The 1st linear operating range is presented in Figure 10, and the 2nd linear operating range is presented in Figure 11.

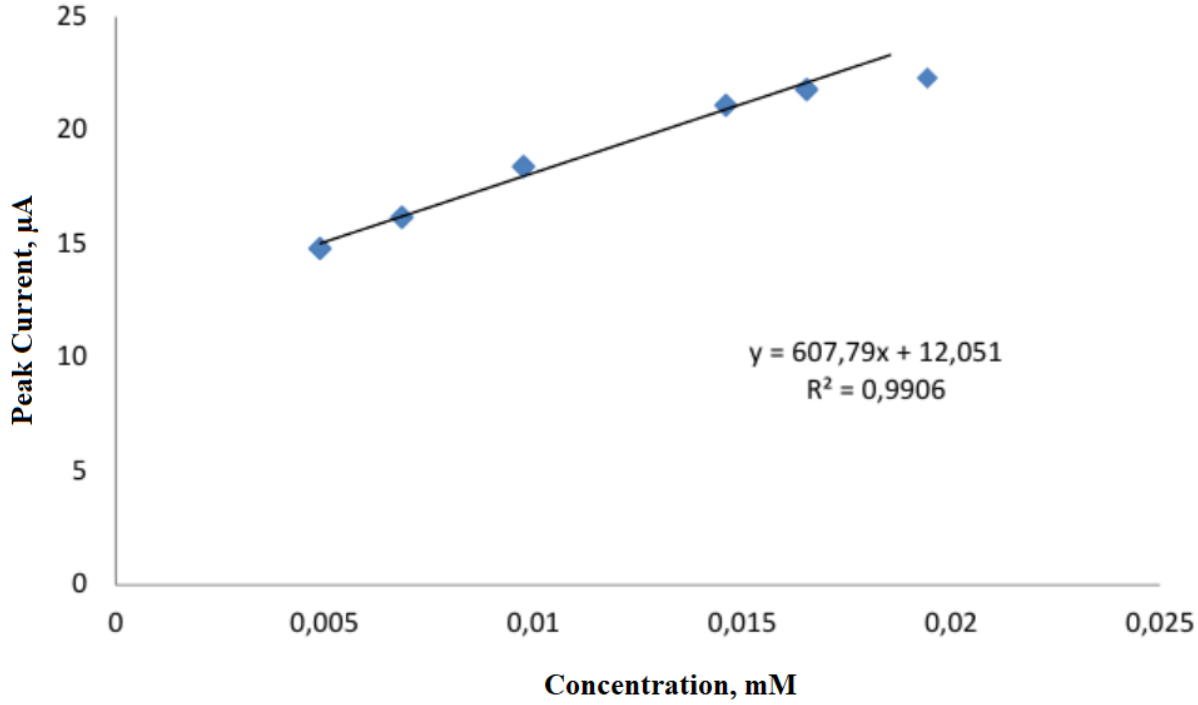


Figure 11. 2nd linear operating range for DA determination with MoS2(2)/GCE

Table 3 has been prepared to compare the electrode sensitivity of MoS2(2)/GCE with GCE and MoS2(1)/GCE.

Table 3. Comparison of MoS2(2)/GCE values obtained in DA environment with GCE and MoS2(1)/GCE

	Electrode Name				
	GCE	MoS2(1)/GCE		MoS2(2)/GCE	
LinearOperatingRange,µM	1 - 650	0.2 – 10	10 - 190	0.01 – 5	5 – 16.5
Line Equation (µA/mM)	y=6.4808 x+0.254	y=83.909x + 0.0449	y=21.328x + 0.8118	y=3028.2x – 0.161	y=607.79x + 12.051
R^2	0.9926	0.9911	0.9912	0.9993	0.9906
Sensitivity (µA/ mM)	6.5	83.9	21.3	3028	607.8

When Table 3 is examined, it is seen that the sensitivity in the determination of DA with MoS2(2)/GCE increases 466 times compared to GCE and 36 times compared to the electrode numbered MoS2(1)/GCE in the 1st linear operating range. In addition, it was found that the sensitivity value in the 2nd linear operating range with MoS2(2)/GCE increased 94 times compared to GCE and 28.5 times compared to the electrode numbered MoS2(1)/GCE. Analytical performance values for MoS2(2)/GCE and DA are presented in Table 4.

Table 4. Analytical performance values for DA with MoS2(2)/GCE

1.Linear Working Range(LWR) (µM)	0.01 – 5
(1. LWR) Sensitivity (µA.mM^{-1})	3028
2.Linear Working Range(LWR) (mM)	5 – 16.5
(2. LWR) Sensitivity (µA.mM^{-1})	607.8
LOD (nM)	12.8
LOQ (nM)	42.6

3.3. Determination of DA in a Commercial Drug named Dopmin with MoS2(1)/GCE

For the determination of DA in a commercial drug called Dopmin with MoS2(1)/GCE, a sample solution of 4.22 µM was prepared by adding 2 µL of drug solution to 100 mL pH=7 phosphate buffer. DPV was taken from three sample solutions. Then, DA solutions were prepared at known concentrations in pH=7 buffer solution and the concentrations were calculated for three samples by the calibration line method. The calibration line is given in Figure 12.

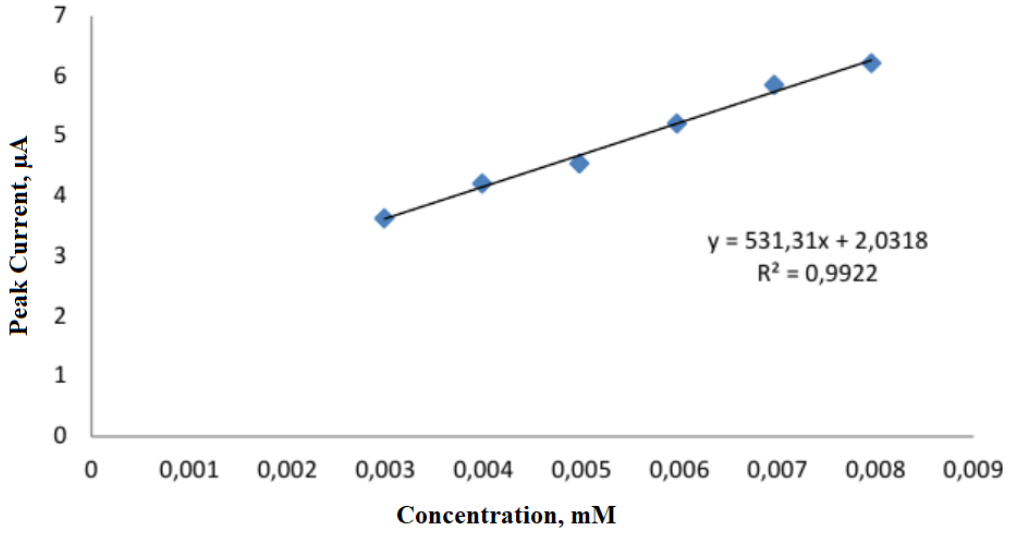


Figure 12. Determination of DA by the calibration line method in a drug called Dopmin with MoS2(1)/GCE

In Table 5, DA values obtained from real samples are presented with their relative errors.

Table 5. DA concentrations obtained from real samples with MoS2(1)/GCE, with their relative errors

Sample	Peak Current for X (µA)	Value Found for X (µM)	Actual Value (µM)	% Relative Error
1	4.346	4,36	4.22	3,21
2	4.510	4,67	4.22	10.6
3	4.301	4.26	4.22	1.03

$(X)_{average}$ = 4,43 µM, t = 4,30 (at 95% Confidence Level)

% 95 CL = 4,43 ± 0,53 µM

At 95 % CL (3.90 µM to 4.96 µM). The actual value is 4.22 µM between this range.

The results are within the 95 % confidence interval.

3.4. Determination of DA in a Commercial Drug named Dopmin with MoS2(2)/GCE

For the determination of dopamine in a commercial drug called Dopmin with MoS2(2)/GCE, a sample solution of 4.22 µM was prepared by adding 2 µL of drug solution to 100 mL pH=7 phosphate buffer. DPV was taken from three samples taken from the solution. Then, DA solutions were prepared at known concentrations in pH=7 buffer solution and the concentrations were calculated for three samples by the calibration line method. The calibration line is given in Figure 13.

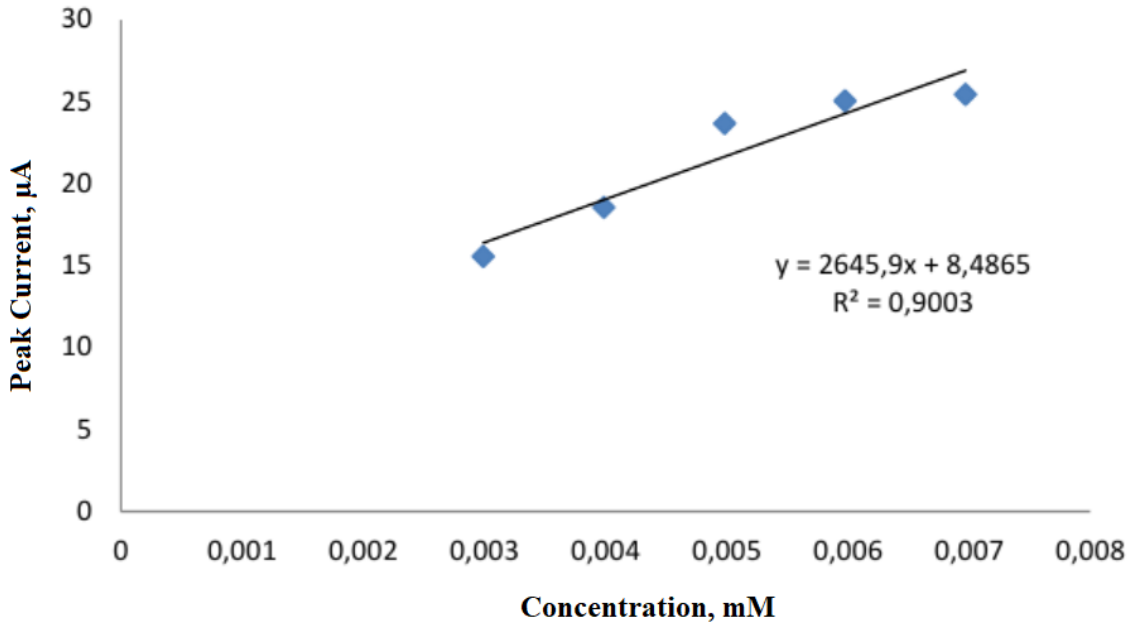


Figure 13. Determination of DA with MoS2(2)/GCE in a drug called Dopmin by calibration line method

In Table 6, Dopamine values obtained from real samples are presented with their relative errors.

Table 6. DA concentrations obtained from real samples with MoS2(2)/GCE, with their relative errors

Sample	Peak Current for X (µA)	Value Found for X (µM)	Actual Value (µM)	% Relative Error
1	1.851	3.79	4.22	-10.2
2	1.980	4.28	4.22	1.50
3	2.030	4.46	4.22	5.80

$(X)_{average}$ = 4,18 µM, t = 4,30 (at 95% Confidence Level)

% 95 CL = 4,18 ± 0,86 µM

At 95 % CL (3.32 µM to 5.04 µM). The actual value is 4.22 µM between this range.

The results are within the 95 % confidence interval.

4. CONCLUSIONS

MoS2(1)/GCE was found to be 12.9 times more sensitive in the 1st linear operating range and 3.3 times more sensitive in the 2nd linear operating range for DA compared to GCE. With MoS2(1)/GCE, the sensitivity for dopamine was increased up to 12.9 times. The 1st linear

working range for dopamine was found to be 0.2 µM – 10 µM, the sensitivity 83.9 µA mM-1 and the limit of detection 5.2x10-8 M. 2. linear operating range 10 µM - 190 µM, sensitivity 21.3 µA mM-1 was determined. The 1st linear working range for dopamine with MoS2(2)/GCE was 0.01 µM – 5 µM, the sensitivity was 3028 µA.mM-1 and the detection limit was 1.3x10-8 M. 2. linear operating range 5 µM – 16.5 µM, sensitivity 608 µA.mM-1 was determined. MoS2(2)/GCE was found to be 466 times more sensitive in the 1st linear operating range and 93.5 times more sensitive in the 2nd linear operating range compared to GCE. Thus, it was achieved to increase the sensitivity for dopamine up to 466 times with MoS2(2)/GCE. Determination of DA in a commercial drug called Dopmin to see the efficiency in determination of DA with MoS2(1)/GCE and MoS2(2)/GCE, relative to 4.9% and -1.0% with MoS2(1)/GCE and MoS2(2)/GCE, respectively. executed successfully with no error.

5. REFERENCES

Asan, G. (2015). *MoS2 İLE MODİFİYE EDİLMİŞ CAMSI KARBON ELEKTROT KULLANILARAK ASKORBİK ASİT, DOPAMİN VE ÜRİK ASİT ' İN ELEKTROKİMYASAL YÖNTEMLERLE TAYİNİ*. Gazi Üniversitesi. Retrieved from https://tez.yok.gov.tr/UlusalTezMerkezi/tezSorguSonucYeni.jsp

ASAN, G., & Çelikkan, H. (2017). ASKORBİK ASİTİN MoS2 ESASLI ELEKTROTLA ELEKTROKİMYASAL TAYİNİ. *Gazi Üniversitesi Mühendislik-Mimarlık Fakültesi Dergisi*, 32(3), 617–625. Retrieved from https://doi.org/10.17341/gazimmfd.337608

Balamurugan, J., Senthil Kumar, S. M., Thangamuthu, R., & Pandurangan, A. (2013). Facile and controlled growth of SWCNT on well-dispersed Ni-SBA-15 for an efficient electro-catalytic oxidation of ascorbic acid, dopamine and uric acid. *Journal of Molecular Catalysis A: Chemical*, 372, 13–22. Retrieved from https://doi.org/10.1016/j.molcata.2013.02.001

Baranyi, M., Milusheva, E., Vizi, E. S., & Sperlágh, B. (2006). Chromatographic analysis of dopamine metabolism in a Parkinsonian model. *Journal of Chromatography A*, 1120(1–2), 13–20. Retrieved from https://doi.org/10.1016/j.chroma.2006.03.018

Cao, X., Luo, L., Ding, Y., Zou, X., & Bian, R. (2008). Electrochemical methods for simultaneous determination of dopamine and ascorbic acid using cetylpyridine bromide/chitosan composite film-modified glassy carbon electrode. *Sensors and Actuators, B: Chemical*, 129(2), 941–946. Retrieved from https://doi.org/10.1016/j.snb.2007.10.008

De Benedetto, G. E., Fico, D., Pennetta, A., Malitesta, C., Nicolardi, G., Lofrumento, D. D., … La Pesa, V. (2014). A rapid and simple method for the determination of 3,4-dihydroxyphenylacetic acid, norepinephrine, dopamine, and serotonin in mouse brain homogenate by HPLC with fluorimetric detection. *Journal of Pharmaceutical and Biomedical Analysis*, 98, 266–270. Retrieved from https://doi.org/10.1016/j.jpba.2014.05.039

Duan, H., Li, L., Wang, X., Wang, Y., Li, J., & Luo, C. (2015). A sensitive and selective chemiluminescence sensor for the determination of dopamine based on silanized magnetic graphene oxide-molecularly imprinted polymer. *Spectrochimica Acta - Part A: Molecular and Biomolecular Spectroscopy*, 139, 374–379. Retrieved from

https://doi.org/10.1016/j.saa.2014.12.051

Güçlü, K., Sözgen, K., Tütem, E., Özyürek, M., & Apak, R. (2005). Spectrophotometric determination of ascorbic acid using copper(II)-neocuproine reagent in beverages and pharmaceuticals. *Talanta*, 65(5), 1226–1232. Retrieved from https://doi.org/10.1016/j.talanta.2004.08.048

Huang, K. J., Wang, L., Liu, Y. J., Gan, T., Liu, Y. M., Wang, L. L., & Fan, Y. (2013). Synthesis and electrochemical performances of Layered tungsten sulfide-graphene nanocomposite as a sensing platform for catechol, resorcinol and hydroquinone. *Electrochimica Acta*, 107, 379–387. Retrieved from https://doi.org/10.1016/j.electacta.2013.06.060

Kanďár, R., Drábková, P., & Hampl, R. (2011). The determination of ascorbic acid and uric acid in human seminal plasma using an HPLC with UV detection. *Journal of Chromatography B: Analytical Technologies in the Biomedical and Life Sciences*, 879(26), 2834–2839. Retrieved from https://doi.org/10.1016/j.jchromb.2011.08.007

Li, X., & Franke, A. A. (2009). Fast HPLC-ECD analysis of ascorbic acid, dehydroascorbic acid and uric acid. *Journal of Chromatography B: Analytical Technologies in the Biomedical and Life Sciences*, 877(10), 853–856. Retrieved from https://doi.org/10.1016/j.jchromb.2009.02.008

Mamiński, M., Olejniczak, M., Chudy, M., Dybko, A., & Brzózka, Z. (2005). Spectrophotometric determination of dopamine in microliter scale using microfluidic system based on polymeric technology. *Analytica Chimica Acta*, 540(1), 153–157. Retrieved from https://doi.org/10.1016/j.aca.2004.09.011

Moghadam, M. R., Dadfarnia, S., Shabani, A. M. H., & Shahbazikhah, P. (2011). Chemometric-assisted kinetic-spectrophotometric method for simultaneous determination of ascorbic acid, uric acid, and dopamine. *Analytical Biochemistry*, 410(2), 289–295. Retrieved from https://doi.org/10.1016/j.ab.2010.11.007

Nevado, J. J. B., Gallego, J. M. L., & Laguna, P. B. (1996). Flow-injection spectrophotometric determination of adrenaline and dopamine with sodium hydroxide. *Journal of Pharmaceutical and Biomedical Analysis*, 14(5), 571–577. Retrieved from https://doi.org/10.1016/0731-7085(95)01663-5

Oko, D. N., Garbarino, S., Zhang, J., Xu, Z., Chaker, M., Ma, D., … Tavares, A. C. (2015). Dopamine and ascorbic acid electro-oxidation on Au, AuPt and Pt nanoparticles prepared by pulse laser ablation in water. *Electrochimica Acta*, 159, 174–183. Retrieved from https://doi.org/10.1016/j.electacta.2015.01.192

Ping, J., Wu, J., Wang, Y., & Ying, Y. (2012). Simultaneous determination of ascorbic acid, dopamine and uric acid using high-performance screen-printed graphene electrode. *Biosensors and Bioelectronics*, 34(1), 70–76. Retrieved from https://doi.org/10.1016/j.bios.2012.01.016

Virag, L., & Whittington, R. A. (2002). Highly sensitive chromatographic assay for dopamine determination during in vivo cerebral microdialysis in the rat. *Journal of Chromatography B: Analytical Technologies in the Biomedical and Life Sciences*, 772(2), 267–272. Retrieved from https://doi.org/10.1016/S1570-0232(02)00106-X

Wang, C., Yuan, R., Chai, Y., Chen, S., Hu, F., & Zhang, M. (2012). Simultaneous determination of ascorbic acid, dopamine, uric acid and tryptophan on gold

nanoparticles/overoxidized-polyimidazole composite modified glassy carbon electrode. *Analytica Chimica Acta*, 741, 15–20. Retrieved from https://doi.org/10.1016/j.aca.2012.06.045

Wu, D., Li, Y., Zhang, Y., Wang, P., Wei, Q., & Du, B. (2014). Sensitive electrochemical sensor for simultaneous determination of dopamine, ascorbic acid, and uric acid enhanced by amino-group functionalized mesoporous Fe3O4@Graphene sheets. *Electrochimica Acta*, 116, 244–249. Retrieved from https://doi.org/10.1016/j.electacta.2013.11.033

Zhao, H., Zhang, Y., & Yuan, Z. (2001). Study on the electrochemical behavior of dopamine with poly(sulfosalicylic acid) modified glassy carbon electrode. *Analytica Chimica Acta*, 441(1), 117–122. Retrieved from https://doi.org/10.1016/S0003-2670(01)01086-8

Zhou, K., Liu, J., Wen, P., Hu, Y., & Gui, Z. (2014). A noncovalent functionalization approach to improve the dispersibility and properties of polymer/MoS 2 composites. *Applied Surface Science*, 316(1), 237–244. Retrieved from https://doi.org/10.1016/j.apsusc.2014.07.136

Zhu, M., Huang, X., Li, J., & Shen, H. (1997). Peroxidase-based spectrophotometric methods for the determination of ascorbic acid, norepinephrine, epinephrine, dopamine and levodopa. *Analytica Chimica Acta*, 357(3), 261–267. Retrieved from https://doi.org/10.1016/S0003-2670(97)00561-8

Zhu, Q., Chen, Y., Wang, W., Zhang, H., Ren, C., Chen, H., & Chen, X. (2015). A sensitive biosensor for dopamine determination based on the unique catalytic chemiluminescence of metal-organic framework HKUST-1. *Sensors and Actuators, B: Chemical*, 210, 500–507. Retrieved from https://doi.org/10.1016/j.snb.2015.01.012