Estimation of Cyclic Voltammetry Data for SrCl₂, CaCl₂ and Their Interaction with Ceftriaxone Sodium Salt in KNO₃ Using Palladium Working Electrode

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ABSTRACT

The cyclic voltammetry data for the redox reaction for strontium chloride and calcium chloride in 0.1M KNO₃ pollution were estimated. New palladium electrode was prepared and used as working electrode. Palladium electrode has already redox waves which used as analytical method for the estimation of calcium and strontium in solutions. Also, interaction of both strontium and calcium ions with drug ceftriaxone sodium salt was studied and the data obtained are used for the analytical evaluation for both calcium and strontium. The different kinetic and thermodynamic data was evaluated for the two kinds of ions alone and in the presence of ceftriaxone sodium salt and their data were discussed.

Keywords: Estimation voltammetry parameters – strontium chloride – calcium chloride – kinetic parameters- thermodynamic parameters.

I. INTRODUCTION

Strontium is a mineral found in seawater, we get mainly from sea food, but also small amounts found in milk wheat bran, meat, poultry and vegetables.

Strontium is similar to calcium. It plays a role in how body makes new bone while it slows the breakdown of old bone. That means affect the strength of the bone. Some research proves that women with osteoporosis not absorb strontium as they need. We can buy different forms like strontium citrate at supermarkets and health stores.

There is no enough research known if strontium fight osteoporosis. In many countries like Australia a form of strontium known as strontium ranelate (Osseor, Protelos) is available as a prescription medication to treat and prevent osteoporosis and bone fractures. The drug containing strontium makes bones stronger and lowers getting fractures [1]. Strontium is the 15th most common element on the plant. It has several applications in medicine; radioactive strontium -89 is given to relieve bone pain. Strontium chloride is added to toothpaste to reduce pain in sensitive teeth [2]. Calcium is nutrient which all living organisms need, including humans. It is the most abundant element in the body and is vital for bone health.

Humans need calcium to build strong bones and most human body contain calcium in bones and teeth. Calcium plays a role in muscle movement and cardiovascular function [3]. Therefore, our aim of the work here is to give many data for strontium and calcium ions which help the biologist for the estimation of the two elements.

II. EXPERIMENTAL

Strontium chloride and calcium chloride are provided from Adwic Co. KNO₃ is provided from El gomheria Pharmaceutical Co.

Palladium electrode was prepared by cutting small pies from 99.99% BDH pure palladium sheet, jointed with copper wire and isolated by heat shrink polymer to avoid contact with the solutions. The electrochemical DY 2000 potentiostat in cell containing 30 ml of 0.1M KNO₃ at 19°C. The three used electrodes are palladium working electrode, platinum wire counter electrode and Ag/AgCl/put in saturated KCl as reference electrode. The cell used has the symbol:

Ag/AgCl(s), KCl(aqueous) KNO₃ 0.1M /Pd E palladium electrode

It is important to clean the working electrode with fine emery paper then washed well with bidistilled water.
III. RESULTS AND DISCUSSION

A. The electrochemical behavior of SrCl₂ alone in 0.1M KNO₃

The electrochemical behavior of SrCl₂ alone in 0.1M KNO₃ using Palladium electrode PdE show three different wave two for reduction and one for oxidation. Actually, SrCl₂ form and CaCl₂ form peaks very far in the volt scale above 2.5V. But the waves we saw in Fig. 1 are the peaks for palladium. Then we study the effect of SrCl₂ on the redox waves for palladium in absence and presence of Ceftriaxone sodium salt drug.

Fig. 1. Cyclic voltammograms of different SrCl₂ concentrations in 0.1 M KNO₃.

The reduction peaks show in Fig. 1 are due to the following reactions.

\[ \text{Pd(OH)}_2 + 2e^- \rightarrow [\text{PdCl}_4]^{2-} + 2OH^- \text{ at } \approx 0.3V \] \hspace{1cm} (1)

and

\[ [\text{PdCl}_2]^2+2e^- \rightarrow \text{Pd}^{2+} + 2\text{Cl}^- \] \hspace{1cm} (2)

This mechanism for the reduction processes. The oxidation mechanism is the oxidation of the second process as:

\[ \text{Pd}^{2+} + 2\text{Cl}^- = [\text{PdCl}_2]^2+2e^- \text{ at } \approx 0.2V \] \hspace{1cm} (3)

We took in consideration the reversible waves the second reduction one and the oxidation peak. The redox reaction is here reversible one because \( \Delta E \) is less than 0.59V.

The selecting reversible reduction and oxidation precede consuming two electrons. We noticed that all the three used waves are sharp and good defined.

Estimation of the cyclic voltammetry data:

The different equations used for the estimation of the analytical redox parameters are [4]-[10]:

\[ I_p = 0.4463 \times 10^{0.12} F^{0.02} D^{0.12} \frac{AC}{(RT)^{0.12}} \] \hspace{1cm} (4)

\[ D^{1/2} = (\text{slope, } I_p vs. \nu^{1/2}) \times (RT)^{1/2}/0.4465n^{1/2}F^{3/2}AC \] \hspace{1cm} (5)

\[ \Delta E = E_p - E_0 = 2.303(RT/nF) \] \hspace{1cm} (6)

\[ \psi = \alpha k_1 \sqrt{\pi n F/(RT\nu D_o)} \] \hspace{1cm} (7)

\[ \gamma = \sqrt{D_n a/D_c} \] \hspace{1cm} (8)

Where \( \psi \) is the charge transfer parameters taken as one foe better approximation [11]-[16], \( \alpha \) is the charge transfer coefficient, \( k_1 \) is the standard rate constant for electron transfer, \( \nu \) is the scan rate , \( D_o \) is the anodic diffusion coefficient, \( D_c \) is the cathode diffusion coefficient, \( F \) is faradays constant, \( T \) is the absolute temperature, \( n \) is the number of electrons and \( \alpha = 0.5 \) for reversible processes. \( A \) is the surface area of the working electrode.

The \( k_1 \), which is the heterogeneous electron rate constant was evaluated by applying equation (9) [16]-[20].

\[ k_1 = 2.18 \times [D n a F \nu/(RT)^{1/2}] \exp[a^2 n F(E_p - E_o)/RT] \] \hspace{1cm} (9)

The electrode surface coverage was estimated for both the selected reduction and oxidation processes by using equation (10) [21]-[23].

\[ \Gamma = \frac{i_p}{4 \pi R T} \frac{T}{n^2 F^2} \frac{1}{\nu} \] \hspace{1cm} (10)

The quantity of electricity used for the redox reactions was estimated on applying equation (11) [24].

\[ Q = n \Gamma A F \] \hspace{1cm} (11)

All the above parameters following equations (4-11) for the selected couple of peaks were calculated for SrCl₂ alone and tabulated in Table (1).

It was shown from Table 1 the increase in most of the estimated analytical parameters like \( k_1 \), \( I_p \), \( Q_e \) and \( Q_a \) parameters with the increase in SrCl₂ concentration favoring diffusion control reaction.

| [M] \times 10^3 mol L⁻¹ | Ep,a Volt | Ep,c Volt | AEp Volt | I_p,a x10² Amp | I_p,c x10² Amp | I_p,a/I_p,c | E' Volt | D_na x10⁵ cm² s⁻¹ | D_c x10⁵ cm² s⁻¹ | Γ e x10⁸ mol cm⁻² | Γ a x10⁸ mol cm⁻² | (+)Qc x10⁸ mol cm⁻² | (+)Qa x10⁸ mol cm⁻² |
|------------------------|-----------|-----------|----------|----------------|----------------|-------------|---------|------------------|------------------|-----------------|------------------|------------------|------------------|
| 3.32                   | -0.2272   | -0.3807   | 0.1535   | 1.13           | 1.32           | -0.8606     | -0.3039 | 0.0159           | 2.15             | 0.7127          | 2.49             | 4.3602           | -1.32            | -3.7528          |
| 6.62                   | -0.2317   | -0.3746   | 0.1429   | 1.12           | 1.36           | -0.8190     | -0.3031 | 0.0039           | 5.82             | 0.6168          | 1.08             | 4.5179           | 1.37             | 3.7003           |
| 1.32                   | -0.1223   | -0.2838   | 0.1615   | 1.44           | 0.5136        | -0.2031     | 0.0004  | 1.0532           | 2.43             | 2.495           | 2.39             | 2.495            | 8.96             | 3.7413           |
| 1.64                   | -0.0905   | -0.2965   | 0.2060   | -7.40          | 1.78          | -0.4156     | -0.1935 | 0.0002           | 1.60             | 0.7684          | 1.30             | 5.8995           | 1.82             | 2.4524           |
| 1.64                   | -0.0905   | -0.2965   | 0.2060   | -7.40          | 1.78          | -0.4156     | -0.1935 | 0.0002           | 1.60             | 0.7684          | 1.30             | 5.8995           | 1.82             | 2.4524           |

**TABLE 1: EFFECT OF DIFFERENT CONCENTRATIONS OF SRCl₂ BY USING PALLADIUM ELECTRODE AT 292.15 K AND SCAN RATE 0.1 V.S⁻¹**

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B. Effect of different scan rates on the cyclic voltammograms of SrCl₂

The effect of different scan rates 0.1, 0.05 and 0.02 V Sec⁻¹ was studied on SrCl₂ in 0.1M KNO₃. The data given in Fig. 2 for the relation between peaks currents and square root of scan rate is given in Fig. 2 showing approximate straight line indicating the diffusion process.

![Graph showing the relation between peak currents and square root of the scan rate.]

Fig. 2. The relation between peak current square root of the scan rates.

C. Effect of Ceftriaxone sodium salt drug on the electrochemical behavior of SrCl₂

Effect of Ceftriaxone sodium salt drug on the electrochemical behavior of SrCl₂ in 0.1M KNO₃ using palladium electrode at 19 °C was experimentally studied (see Fig. 3).

![Cyclic voltammogram of 0.5 ml SrCl₂: 0.01M in Ceftriaxone (Pd electrode).]

Fig 3. Cyclic voltammogram of 0.5 ml SrCl₂: 0.01M in Ceftriaxone (Pd electrode).

Different concentrations of the ligand Ceftriaxone were studied by adding to the SrCl₂ solution in 0.1M KNO₃ supporting electrolyte and the data are given in Table 2 and Fig. 3. Fig. 4 shows the relation between ip for the reduction and oxidation peaks versus SrCl₂ concentration which gave and approximate straight lines. The medium 0.1 M KNO₃ was illustrated in Fig. 3 with specific Pd Peaks, but on adding Ceftriaxone to SrCl₂ specific strontium peaks were observed which here used four the evaluation of solvation parameters. Also, more negative shift in reduction peak potential and positive shift in oxidation peak potentials on adding Ceftriaxone to SrCl₂ solution.

Decrease in all the limiting currents for the redox waves was observed and shift towards negative potentials for the reduction processes and more positive potential for the oxidation peak is given indicating complexation behavior. All the estimated kinetic and cyclic voltammetry data estimated for the effect of the drug on SrCl₂ redox peaks show decrease in all values indicating complex reaction happened. The complexionation stability constant (β) for SrCl₂- Ceftriaxone sodium salt complexes in 0.1M KNO₃ was calculated by the application of equation (12) [25]-[30].

\[ (E_p)_{c} - (E_p)_{M} = 2.303 \frac{RT}{nF} \log \beta \text{c} + 2.303\frac{RT}{nF} \log C \]  

(12)

where \( \beta_c \) is the stability constant, \((E_p)_{M}\) is the peak potential for\( \text{SrCl}_2 \) in absence of the drug, \((E_p)_{C}\) is the peak potential for the complex, \(C\) is the ligand concentration (drug) and other symbols are explained before.

The Gibbs free energy of interaction between \( \text{SrCl}_2 \) and the drug were calculated using equation (13) [22]-[30].

\[ \Delta G = -2.303RT \log \beta \text{c} \]  

(13)

From the data given in Table 2 we conclude that the interaction between \( \text{SrCl}_2 \) and ceftriaxone sodium salt antibiotic forming strong complex.

| [M] x 10⁻⁵ mol·L⁻¹ | [L] x 10⁻⁷ mol·L⁻¹ | (Eₚ, 1/2)M | (Eₚ, 1/2)C | AE v | J (l/l) | Log β | ΔG (kJ/mol) |
|----------------------|----------------------|-------------|-------------|--------|--------|-------|----------|
| 3.32                 | 3.27                 | 0.1547      | 0.2109      | 0.0561 | 0.9836 | 8.3335| -46.4670 |
| 6.62                 | 6.51                 | 0.1828      | 0.2129      | 0.0301 | 0.9837 | 7.5901| -42.3129 |
| 9.90                 | 9.74                 | 0.1974      | 0.1580      | -0.0393| 0.9837 | 6.2168| -34.6570 |
| 1.64                 | 3.23                 | 0.2006      | 0.1777      | -0.0229| 1.9677 | 12.3764| -68.9951 |

From the data given in Table 2 we conclude that the interaction between \( \text{SrCl}_2 \) and ceftriaxone sodium salt antibiotic forming strong complex.
D. Electrochemical behavior of CaCl₂ alone in 0.1M KNO₃ at 19°C

The same medium was used for evaluating the analytical parameters for CaCl₂ alone in 0.1M KNO₃. Same effect as in the case of SrCl₂ was used and the evaluated cyclic voltammograms and analytical data are discussed.

Fig. 5. Cyclic voltammogram of CaCl₂ 0.01M in 30 ml KNO₃ 0.01 M (Pd electrode).

![Cyclic voltammogram of CaCl₂](image)

Fig. 6. Effect of Ceftriaxone sodium salt on CaCl₂

All the data given in Table 3 are greater than that on using SrCl₂ indicating more ionization and more diffusion for the calcium salt.

| [M] x10⁻² mol.L⁻¹ | Ep.a Volt | Ep.c Volt | ΔEp Volt | (+) Ip,a x10⁻¹ Amp | Ip.c x10⁻¹ Amp | Ip.a/Ip.c | E' Volt | Da x10⁸ cm².s⁻¹ | Dc x10⁸ cm².s⁻¹ | Φmol | ksc | Γc x10⁴ mol.cm⁻² | (+) Qc x10⁴ C | Γa x10⁴ mol.cm⁻² | (+) Qa x10⁴ C |
|-------------------|----------|----------|----------|-----------------|---------------|-----------|---------|----------------|----------------|------|-----|----------------|--------------|----------------|--------------|
| 1.32              | -0.2986  | -0.3665  | 0.0678   | -1.25           | 1.27          | -0.9836   | -0.3326 | 0.0012         | 1.28           | 0.6100 | 2.40 | 4.2153         | 1.28         | -4.1464        | -1.26        |
| 1.64              | -0.2346  | -0.3199  | 0.0853   | -1.47           | 2.11          | -0.6988   | -0.2773 | 0.0011         | 2.27           | 0.7415 | 4.18 | 6.9902         | 2.12         | -4.8853        | -1.48        |
| 3.23              | -0.2662  | -0.3393  | 0.0731   | -1.03           | 4.70          | -2.1927   | -0.3028 | 0.0001         | 2.92           | 1.0805 | 5.06 | 1.5581         | 4.72         | -3.4166        | -1.04        |
| 4.76              | -0.2497  | -0.5339  | 0.2841   | -1.86           | 6.49          | -2.8694   | -0.3918 | 0.0002         | 2.55           | 0.7827 | 3.30 | 2.1499         | 6.51         | -6.1692        | -1.87        |

E. Different drug

Ceftriaxone concentrations were added to CaCl₂ solution we observe the formation of complex between CaCl₂ and the drug.

The stability constant and Gibbs free energy of calculation were estimated and with smaller complexation values than that for SrCl₂. This means that the electrostatic complexation between the drug and SrCl₂ is greater than that between CaCl₂ and the drug. All the data given in Tables 4 are greater than that on using SrCl₂ indicating more ionization and more diffusion for the calcium salt whereas the data in Table 5 is smaller than SrCl₂ data.

| [M] x10⁻² mol.L⁻¹ | Ep.a Volt | Ep.c Volt | ΔEp Volt | (+) Ip,a x10⁻¹ Amp | Ip.c x10⁻¹ Amp | Ip.a/Ip.c | E' Volt | Da x10⁸ cm².s⁻¹ | Dc x10⁸ cm².s⁻¹ | Φmol | ksc | Γc x10⁴ mol.cm⁻² | (+) Qc x10⁴ C | Γa x10⁴ mol.cm⁻² | (+) Qa x10⁴ C |
|-------------------|----------|----------|----------|-----------------|---------------|-----------|---------|----------------|----------------|------|-----|----------------|--------------|----------------|--------------|
| 1.32              | -0.2986  | -0.3665  | 0.0678   | -1.25           | 1.27          | -0.9836   | -0.3326 | 0.0012         | 1.28           | 0.6100 | 2.40 | 4.2153         | 1.28         | -4.1464        | -1.26        |
| 1.64              | -0.2346  | -0.3199  | 0.0853   | -1.47           | 2.11          | -0.6988   | -0.2773 | 0.0011         | 2.27           | 0.7415 | 4.18 | 6.9902         | 2.12         | -4.8853        | -1.48        |
| 3.23              | -0.2662  | -0.3393  | 0.0731   | -1.03           | 4.70          | -2.1927   | -0.3028 | 0.0001         | 2.92           | 1.0805 | 5.06 | 1.5581         | 4.72         | -3.4166        | -1.04        |
| 4.76              | -0.2497  | -0.5339  | 0.2841   | -1.86           | 6.49          | -2.8694   | -0.3918 | 0.0002         | 2.55           | 0.7827 | 3.30 | 2.1499         | 6.51         | -6.1692        | -1.87        |

**Table 5: Stability constant for (CaCl₂—ligand) complex**

| [L] x10⁻³ mol.L⁻¹ | (Ep,1/2) M Volt | (Ep,1/2) C Volt | θE Volt | J (L/M) | Log βj | ΔG (kJ mol⁻¹) |
|-------------------|----------------|----------------|---------|---------|--------|---------------|
| 3.27              | -0.3918        | -0.3076        | 0.0841  | 0.2     | 2.354  | -13.124       |
| 6.51              | -0.3918        | -0.2694        | 0.1224  | 0.4     | 3.792  | -21.144       |
| 9.74              | -0.3918        | -0.2546        | 0.1372  | 0.6     | 4.781  | -26.655       |
| 1.29              | -0.3918        | -0.2657        | 0.1261  | 0.8     | 5.292  | -29.506       |
| 1.61              | -0.3918        | -0.2562        | 0.1356  | 1       | 6.139  | -34.227       |

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F. Life Cyclic voltammograms

Here are some cyclic voltammograms like from the used instrument which explain the peaks for both calcium and strontium ions.

Fig. 7. Life cyclic voltammograms of medium 0.1 M KNO₃, red, plus 0.5 ml CaCl₂ blue, plus 0.5 ml SrCl₂ green at 18 °C using Pd Electrode.

Fig. 8. Open circuit voltammetry of the medium 0.1 M KNO₃, red, plus 0.5 ml CaCl₂(0.1M) blue, plus 0.3 ml drug.

Fig. 9. Open circuit voltammetry life for 0.2 ml ceftriaxone with 0.5 ml CaCl₂ (0.1M).

On comparing the open circuit voltammetry of the two Fig. 8, 9 we observe that the number of cycles decrease on using CaCl₂+Ceftriaxone in period 30 second than that of the medium 0.1 M KNO₃ alone indicating the decrease in diffusion processes due to complexation.

Linear sweep voltammetry: The specific reduction wave for calcium ion is appeared at -0.6 V and became clearer on adding the drug ceftriaxone sodium salt antibiotic.

G. Aqueous free energies of the proton in SrCl₂ and CaCl₂ solutions by adding Ceftriaxone antibiotic

Estimation of real solvation free energy of the proton from our cyclic voltammetry data is available by using Truhlar cycle [30]-[32].

We can estimate from this cycle the solution free energy of the proton. Also, the ΔG°rxn (atomization free energy) and the ion solvation free energy, ΔG°ion together can be detected as interaction free energies ΔG°rxn and their values can be estimated [33].

When we study the cycle given above, we can estimate the ESHE the standard hydrogen electrode potential under our conditions applying equation (14) and the ΔG°rxn under the complex reaction between SrCl₂, CaCl₂ and Ceftriaxone sodium salt.

ESHE = - ΔG/F

-ΔG°rxn = ΔG°ion + ΔG°atm + ΔG°S (H⁺) = Δ f G° (H⁺) + ΔG°S (H⁺)

ΔG°ion + ΔG°atm = Δ f G° (H⁺)

The corresponding Δ f G° (H⁺) based on Fermi-Dirack statistics is 1095 k.J/mole [34].

The data given in Table 6 show SrCl₂ solutions gave bigger, ΔG°rxn, ΔG°S (H⁺) results indicating that it is more active in solvation than CaCl₂ solutions. The increase in negativity for Δ G°S (H⁺) in both solutions of SrCl₂+Ceftriaxone and CaCl₂+Ceftriaxone indicate the complexation reaction and replacing proton by ligand molecules.

| [Ceftriaxone] | SrCl₂ | SrCl₂ | CaCl₂ | CaCl₂ |
|---------------|-------|-------|-------|-------|
| x10⁻³         | ΔG°rxn| ΔG°S (H⁺) | ΔG°rxn| ΔG°S (H⁺) |
| 3.27          | -46.4670| -1141.467 | -13.124 | -1108.124 |
| 6.51          | -42.3129| -1137.313 | -21.144 | -1116.144 |
| 9.74          | -34.6370| -1129.957 | -26.655 | -1121.655 |
| 1.29          | -68.9951| -1163.985 | -29.506 | -1124.506 |
IV. CONCLUSIONS

We explained the redox behavior for SrCl₂ and CaCl₂ from cyclic voltammetry in 0.1 M KNO₃ at 19 °C.

The estimation of different cyclic voltammetry parameters was carried out for SrCl₂, CaCl₂ and their interaction with ceftriaxone sodium salt antibiotic. The stability constant, Gibbs free energies of complexion were obtained, and their values were discussed.

REFERENCES

[1] www.webmed.com ,osteoporosis, guide.
[2] www.verywell/health.com.
[3] www.med.calahnewstody.com.
[4] F. A. Cotton, G. Wilkinson, "Advanced Inorganic Chemistry",4th Edn. John Wiley & Sons, New York, 1980.
[5] P. L. Timmanagoounder, G. A. A. Hiremath, S. T. Nandibewoor, Trans. Met. Chem., 1997, 22, 193-196.
[6] Y. Wang, R. M. Hernandez, D. J. Bartlett, J. M. Bingham, T. R. Kline, A. Sen & T. E. Mallouk, Langmuir; 2006; 22(25), 10451-10456.
[7] A. E. El-Askalany & A. M. Abo El-Magd, Chemical and Pharmaceutical Bulletin, 1995, 43(10), 1791-1792.
[8] E. A. Gomaa, R.M. Abu-Qun, Journal of Molecular Liquids, 2017, 232, 319-324.
[9] E. A. Gomaa, M. A. Tahoon, A. Negm, Journal of Molecular Liquids, 2017, 241, 595-602.
[10] E. A. Gomaa, R. R., Zaky, A. Shokr, Journal of Molecular Liquids, 2017, 232, 319-324.
[11] E. A. Gomaa, R. R. Zaky, A. Shokr, Chemical Data Collections, 2017, 11, 67-76.
[12] E. A. Gomaa, A. Negm, M. A. Tahoon, Journal of Taibah University for Science, 2017, 11(5), 741-748.
[13] S. E. El-Sherefy, E. A. Gomaa, A. M., Yousif, A. S., El-Yazeyed, Iranian Journal of Materials Science & Engineering, 2017, 14(4); 48-57.
[14] J. I. Kim, A. Cecal, H. J. Born, E. A. Gomaa, Z. Phys. Chem., NeueFolge, 1978, 110-209.
[15] J. I. Kim, E. A. Gomaa; Bull Soc. Chim. Belg., 1981, 90 391.
[16] M. A. Ghandour, R. A. Abo-Doma, E. A. Gomaa, Electrochim. Acta,1982, 27, 159.
[17] E. A. Gomaa, Thermochim. Acta, 1984, 80 ; 355.
[18] A. K. Abd-Elkader, E. A., Gomaa, A. H. El-Askalany, 1985; Acta Chimica Hung., 1985, 118, 197.
[19] M. N. A. El-Hady, E. A. Gomaa, A. G. Al-Harazie AG, Journal of Molecular Liquids, 2019, 276-970-985.
[20] R. S. Nicholson, L. Shain, Analytical Chemistry, 1965, 37(2), 178-190.
[21] G. A. Mahtedi, Journal of Chemical Education, 1983, 60(9), 697-702.
[22] D. A. C. Brownson, C. E. Banks, The Handbook of Graphene Electrochemistry,.; 2014; Springer.
[23] E. A. Gomaa, M. A. Tahoon, M. A. Journal of Molecular Liquids; 2016; 214, 19-23.
[24] J. Wang, Analytical Electrochemistry- 3rd ed., John Wiley & Sons, Inc.; London, 2006.
[25] E. A. Gomaa, M. A. Tahoon, A. Shokr; Chemical Data Collections, 2016, 3-4, 58-67.
[26] E. A. Gomaa, M. H., Mahmoud, M. G. Mousa, E. M. El-Dahshah, Chemical Methodologies, 2018, 3, 1-11.
[27] E. A. Gomaa and G. Begheit, Asian J. of Chem., 2 (1990) 444.
[28] Esam A. Gomaa, Monatshefte für Chemie, 119 (1988) 287.
[29] M. A. Ghandour, E. A. Gomaa and R. A. Abo Doma, Monatshefte für Chemie, 116 (1985).
[30] M. N. Abd El-Hady, E. A. Gomaa, R. R. Zaky, A. I. Gomaa, J. Molecular Liquids, 2020, 305,112794.
[31] Esam A., Gomaa, Radwa T. Rashad, Biomedical Journal of Scientific & technical Research, 2019, 232,17345-17349.
[32] Casey P. Kelly, Christopher J. Cramer, Donald G. Truhlar, J. Phys. Chem. B., 2006,110, 16066-16081.
[33] Casey P. Kelly, Christopher J. Cramer, Donald G. Truhlar, J. Phys. Chem. B., 2006, 1-40.
[34] Paul Winget, Christopher J. Cramer, Donald G. Truhlar, Theor. Chem. Acc. 2004, 1122, 217-227.