# *VOLTAMMETRY-Basic Principles and voltammetry of common RADIOISOTOPES*

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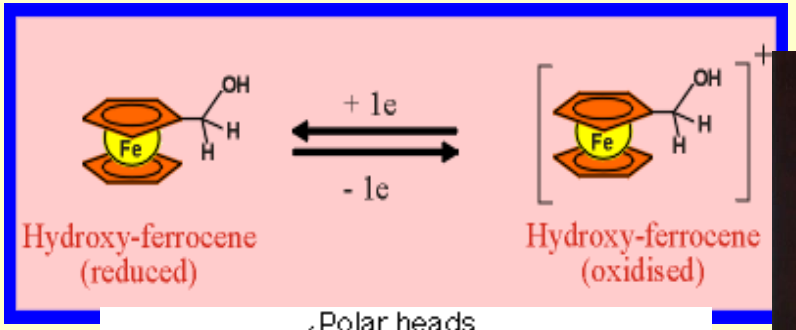
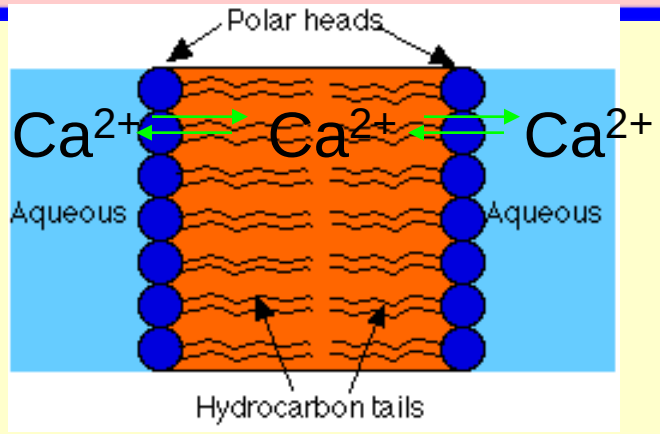
**GOCE DELCEV UNIVERSITY Stip,**
**Radiopharmacy Symposium 2017**

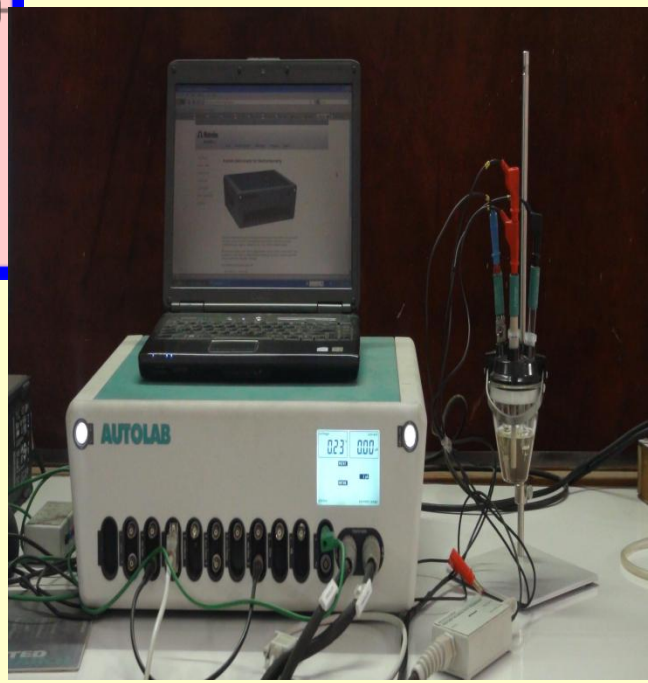
**VOLTAMMETRY is a branch of *ELECTROCHEMISTRY***

***-deals wity the processes of CHARGE transfer between two systems***

***-FLOW of electric charge=CURRENT***

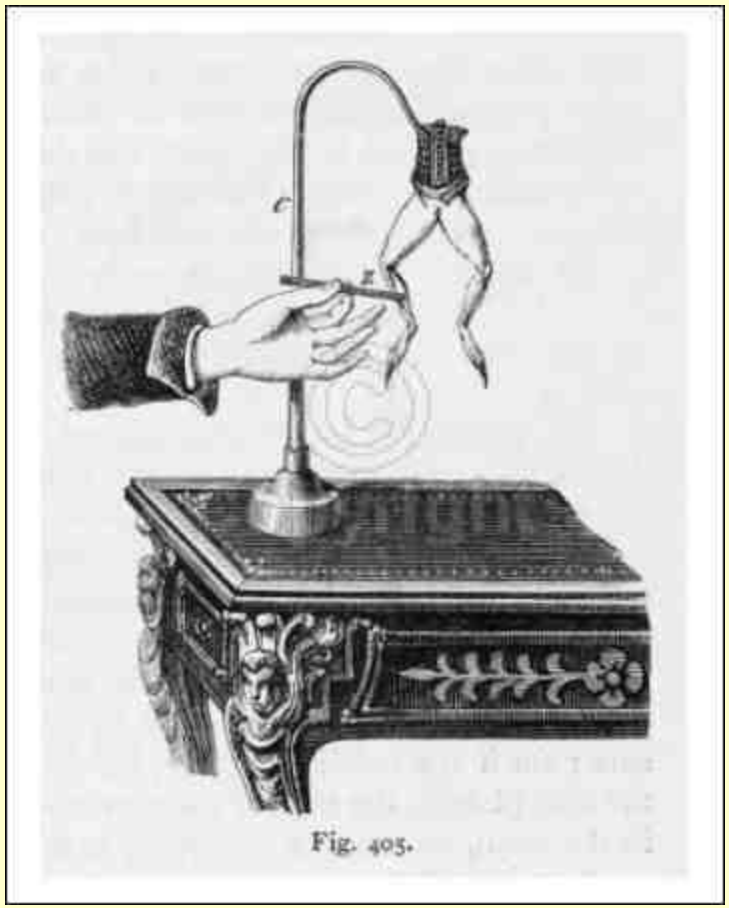


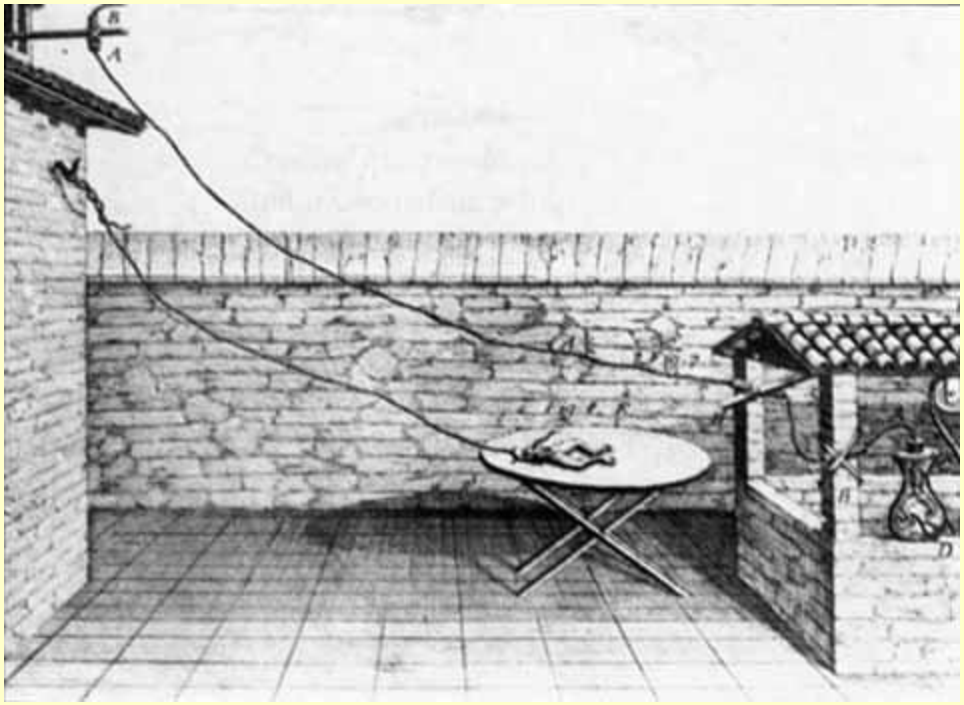



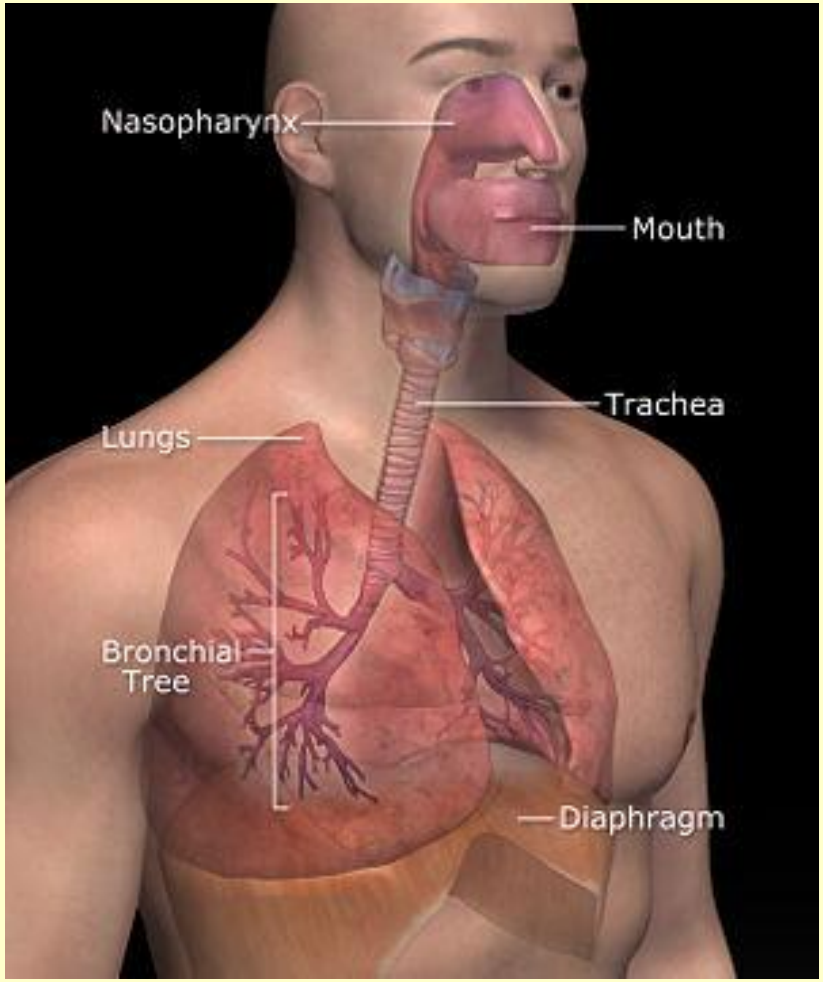




***We can say-voltammetry deals MAINLY with Processes of oxidation and reduction***

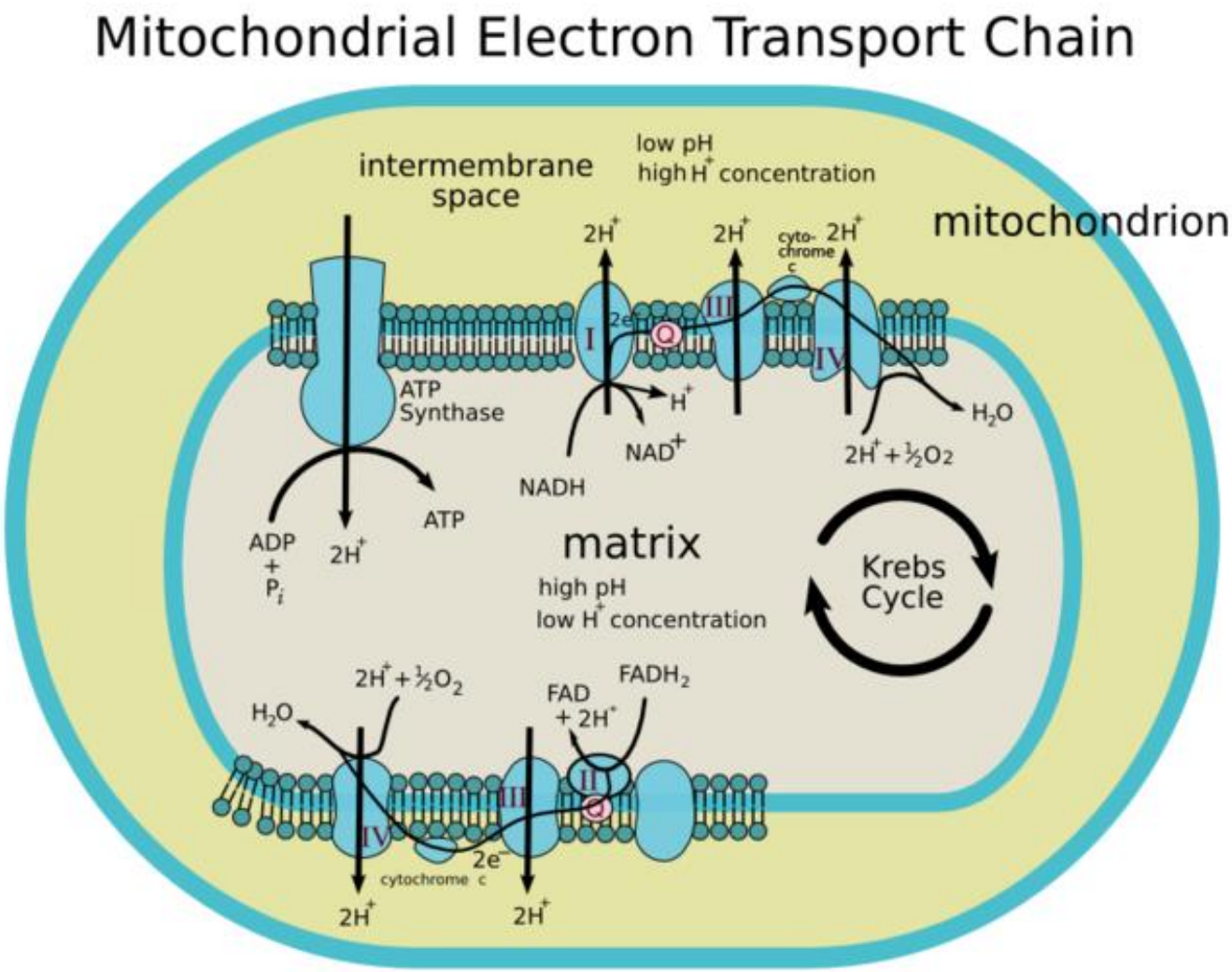
# Galvani experiment on frog legs



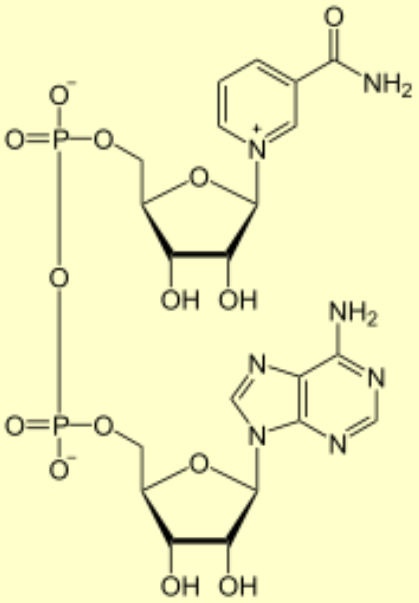



$$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O + 2880\ kJ/mol$$

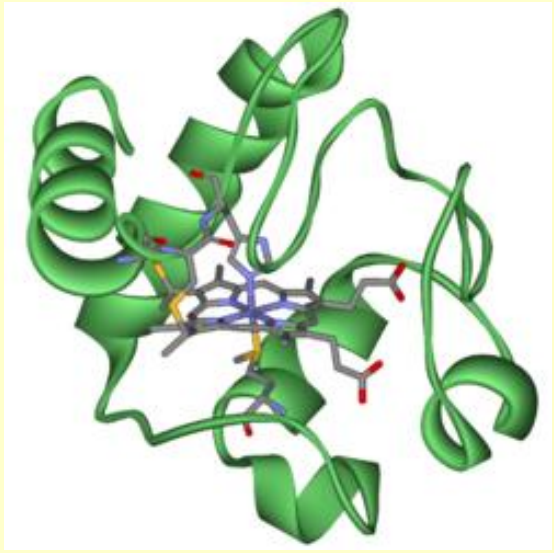



The Electron Transport Chain

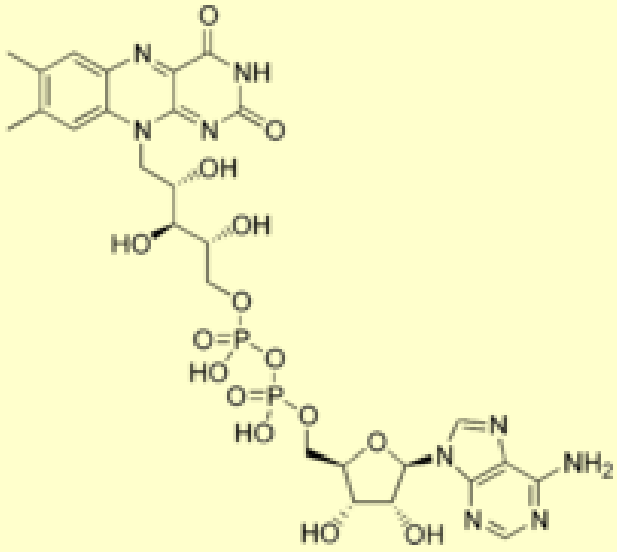
# Most important compounds involved in the Mitochondrial Electron Transport Chain



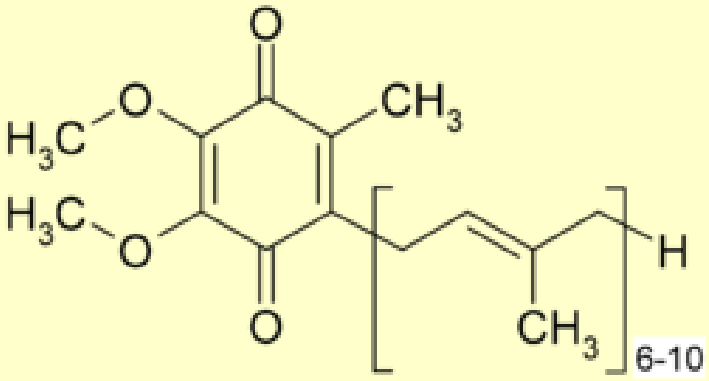
Nicotinamide adenine dinucleotide-
$NAD^+$ (redox enzyme)



Cytochrome C (with Hem)



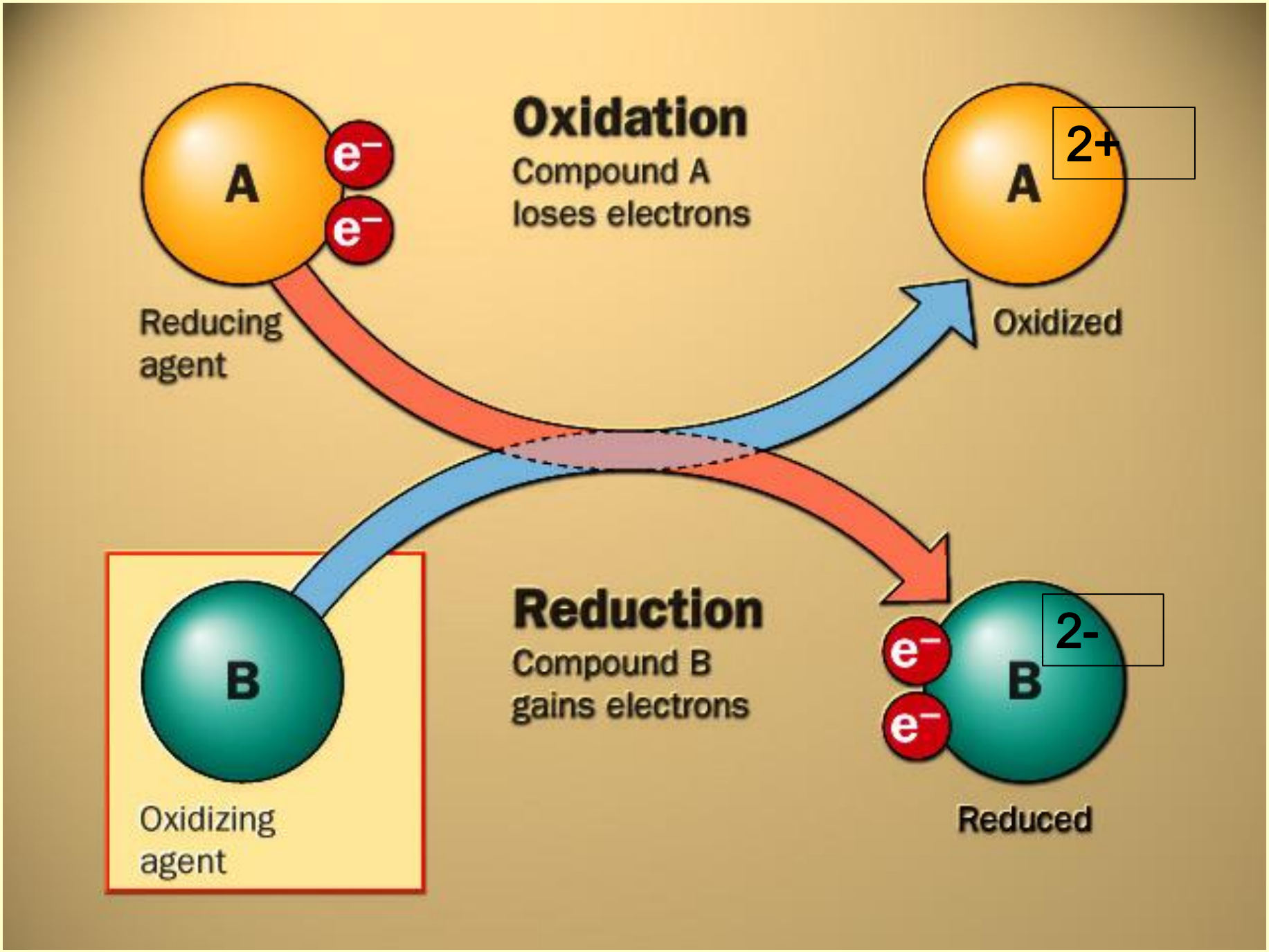
Flavin Adenine dinucleotide-
FAD

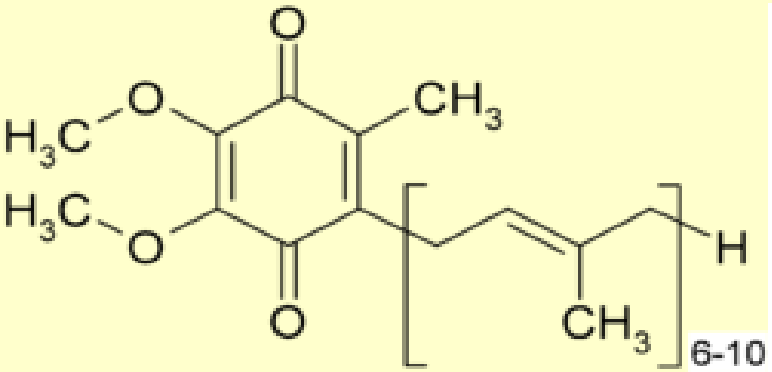


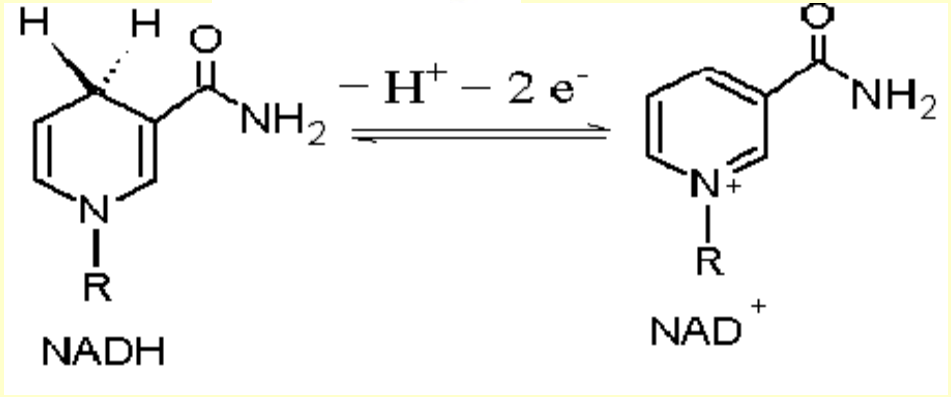
Coenzyme Q

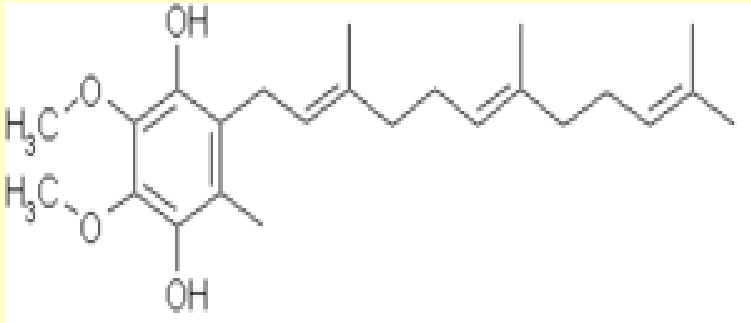
# DEFINITIONS

- **Oxidation**: **Loss of electrons**.
- **Reduction**: **Gain of electro**ns.
- **Reductant**: Species that loses electrons.
- **Oxidant**: Species that gains electrons.
- **Valence**: the electrical charge an atom would acquire if it formed ions in aqueous solution.

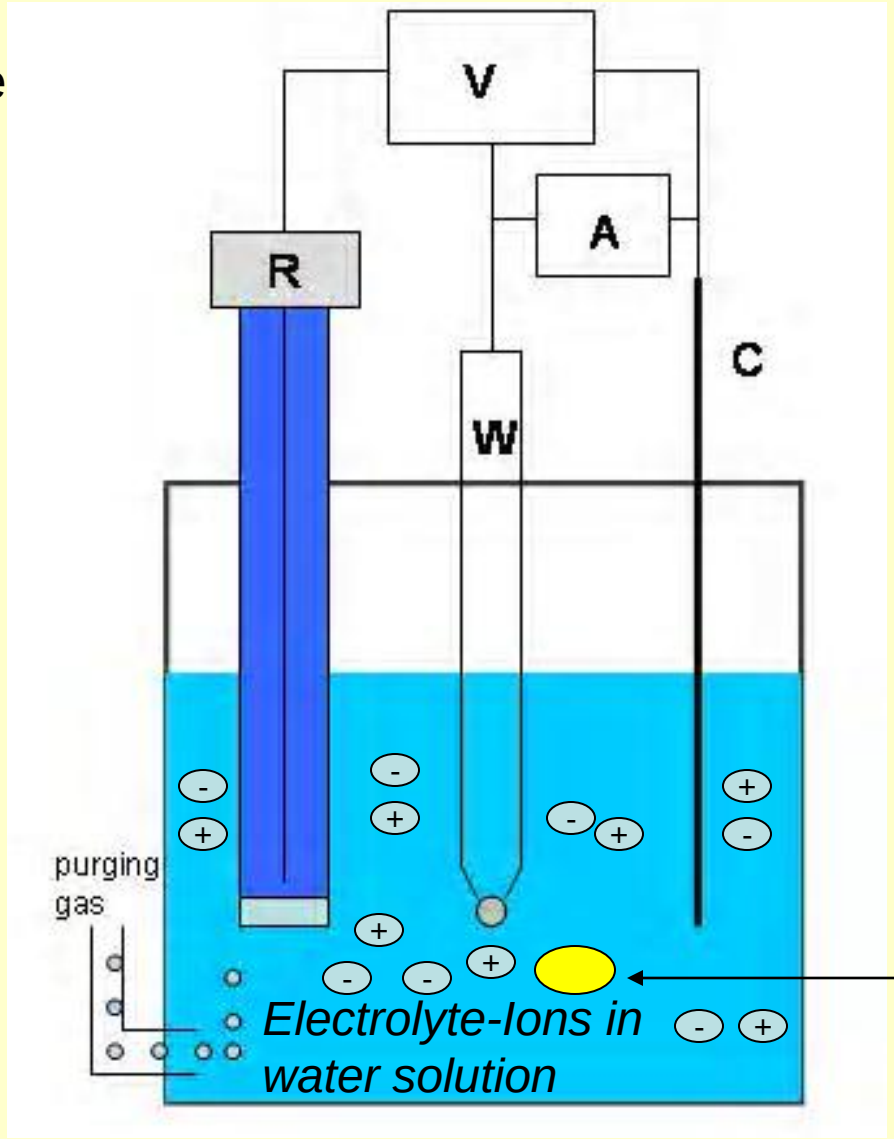

Oxidation
Compound A
loses electrons
A
e⁻
e⁻
Reducing
agent
A
2+
Oxidized
Reduction
Compound B
gains electrons
B
Oxidizing
agent
e⁻
e⁻
B
2-
Reduced


O
H3C
O
CH3
H3C
O
O
CH3
H
6-10


H
H
O
NH2
N
R
NADH
– H+ – 2 e-
O
NH2
N+
R
NAD+

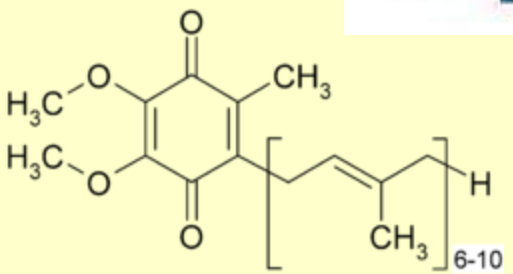

OH
O
H3C
H3C
O
OH

W-working electrode

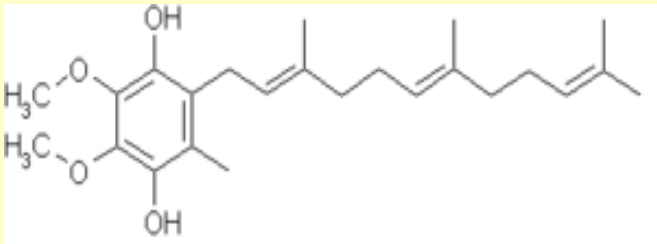


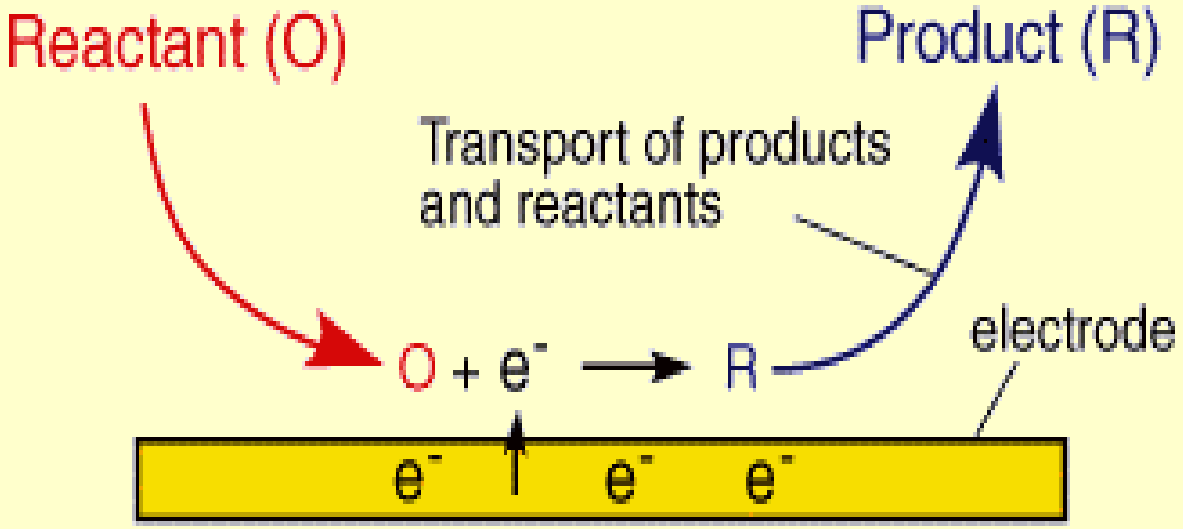

R-reference electrode

**Redox probe**

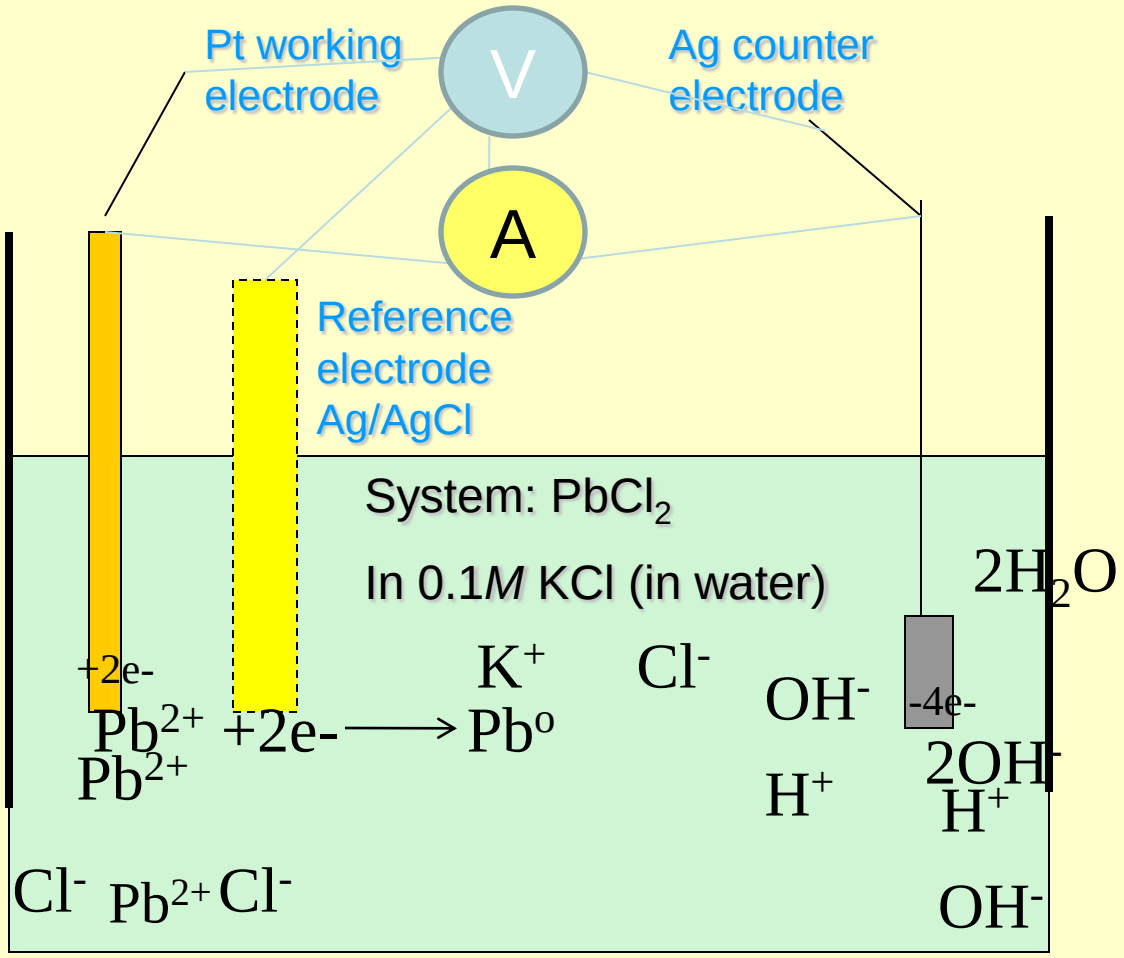


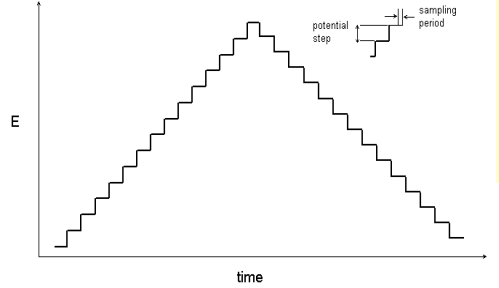

+2 H+ + 2e- ⇌



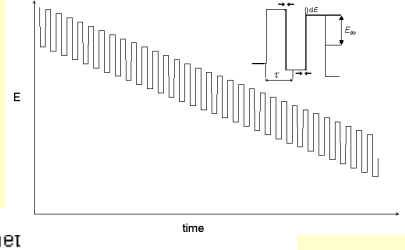

Reactant (O)
Product (R)
Transport of products
and reactants
O + e⁻
R
electrode
e⁻
e⁻
e⁻

# System: PbCl2 in KCl

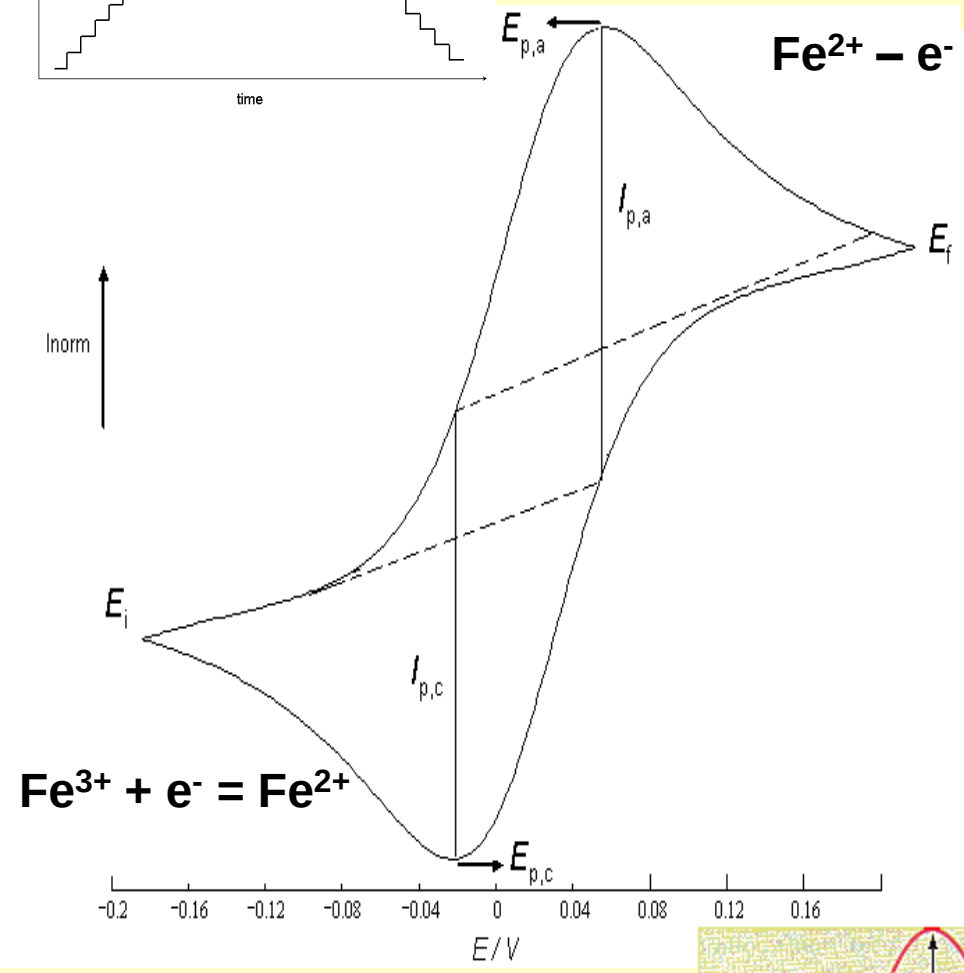




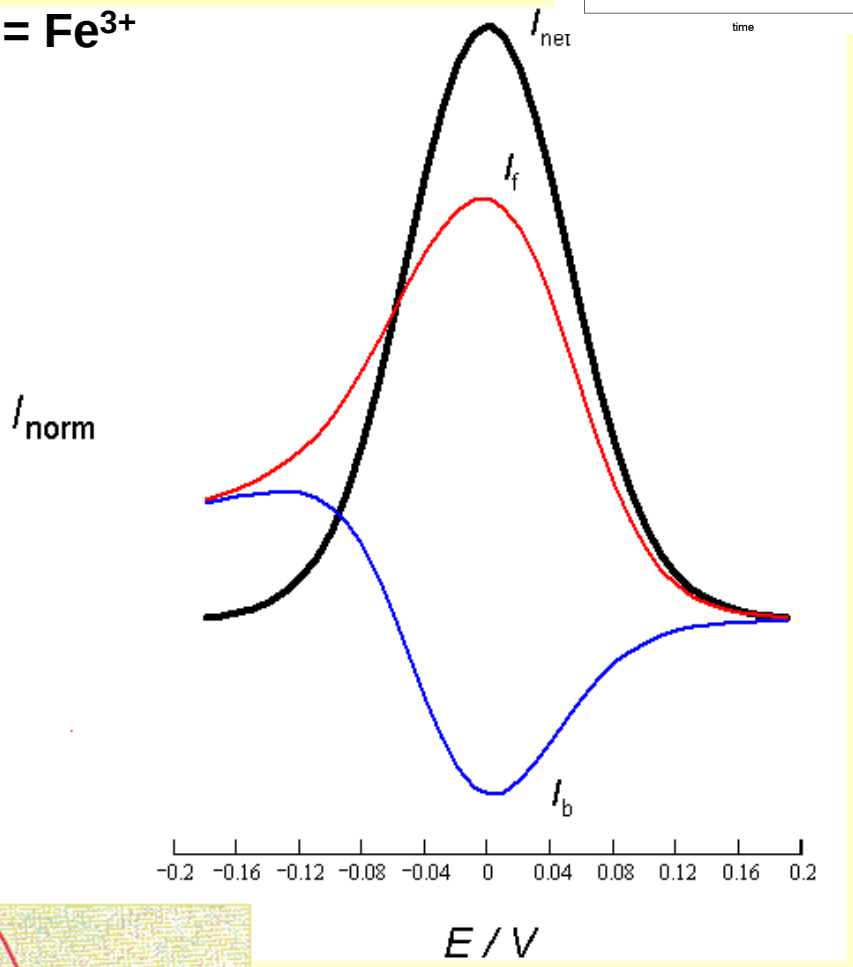

$$Fe^{3+} + e^- \rightleftharpoons Fe^{2+}$$



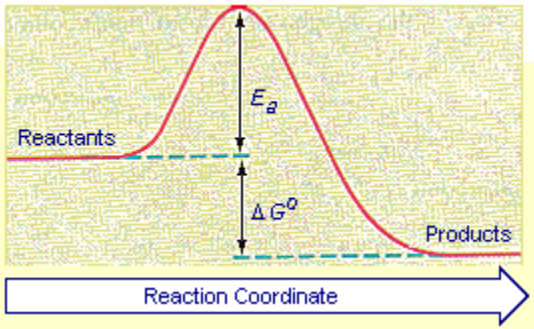

**$Fe^{2+} - e^- = Fe^{3+}$**




**$Fe^{3+} + e^- = Fe^{2+}$**



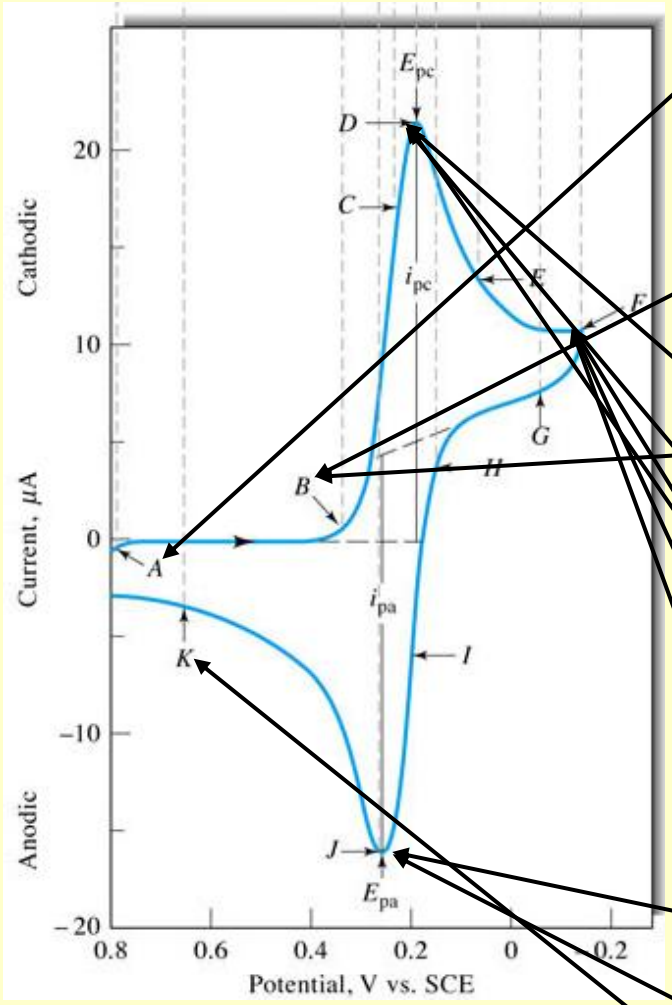

Cyclic voltammogram




Square-Wave Voltammogram

Работна електрода е Pt & референтна електрода е SCE

6 mM $K_3Fe(CN)_6$ & 1 M $KNO_3$




На почеток тече негативна струја поради оксидацијата на $H_2O$ до $O_2$

Не тече струја помеѓу A & B (+0.7 до +0.4V) бидејќи во растворот нема честички што можат да бидат оксидирани или редуцирани во овој регион на потенцијали

B. При 0.4V, струјата почнува да расте како резултат на одвивање на следната рекација на катодата (т.е. На работната електрода):

$$Fe(CN)_6^{3-} + e^- \rightleftharpoons Fe(CN)_6^{4-}$$

B.-D. Нагло зголемување на струјата како резултат на намалување на површинската концентрација на $Fe(CN)_6^{3-}$

D. Катоден пик потенцијал ($E_{pc}$) и катодна пик струја ($i_{pc}$)

D.-F. Струјата почнува нагло да се намалува како што дифузониот слој се проширува кон внатрешноста на растворот

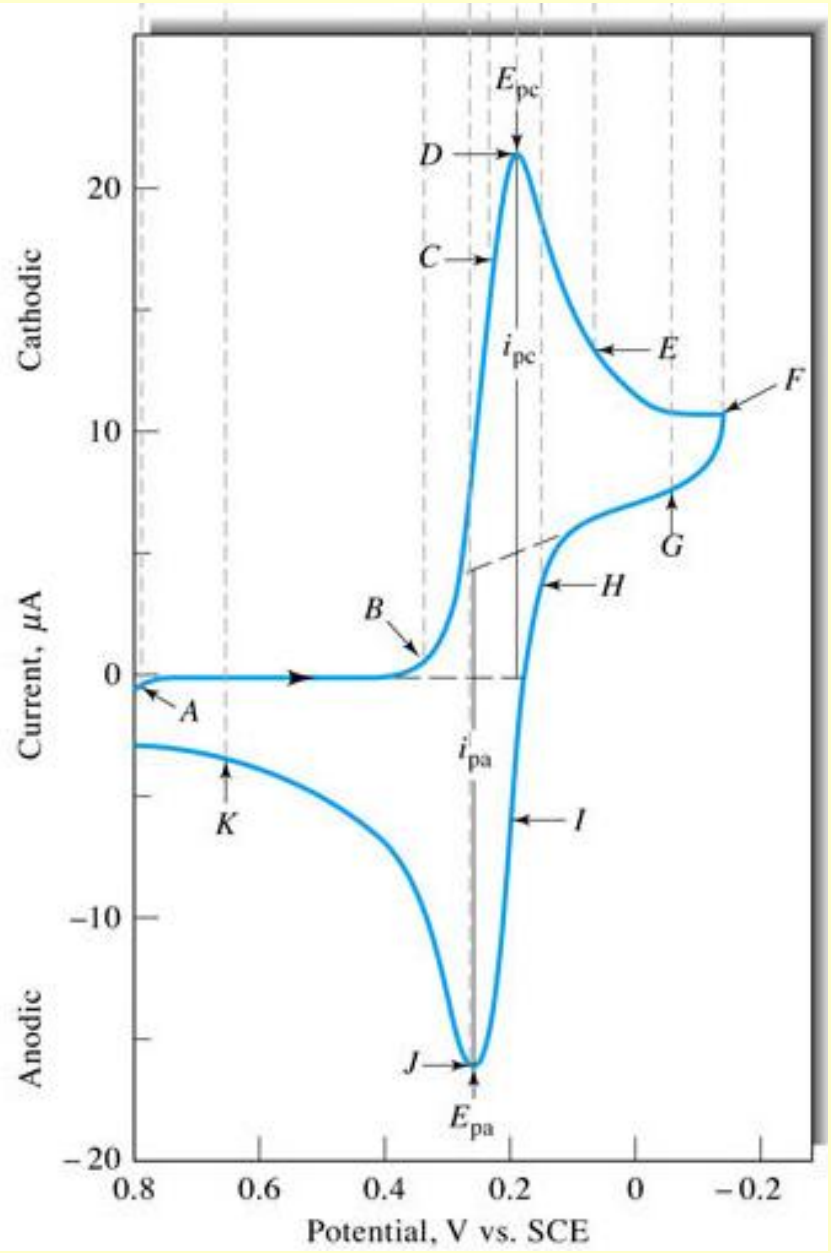
F. Се свртува потенцијалот (-0.15V), потенцијалот е се уште негативе за да овозможи редукција на електроактивните $Fe(CN)_6^{3-}$

F.-J. При овој момент нема повеќе да се случува редукција на $Fe(CN)_6^{3-}$ и ќе почне да тече анодна струја како резултат на реоксидацијата на $Fe(CN)_6^{4-}$

J. Аноден пик потенцијал ($E_{pa}$) и анодна пик струја ($i_{pa}$)

K. Анодната струја се намалува како што акумулираниот $Fe(CN)_6^{4-}$ е употребен во реакцијата на оксидација

# What do we get from cyclic voltammograms




- $i_{pc}$ $i_{pa}$
- $\Delta E_p = (E_{pa} - E_{pc}) = 0.0592/n$, n = number of electrones exchanges
- $E^0$ = mid-peak potential $E_{pa}$ → $E_{pc}$
- $I_p = 2.686 \times 10^5 n^{3/2} A c D^{1/2} v^{1/2}$

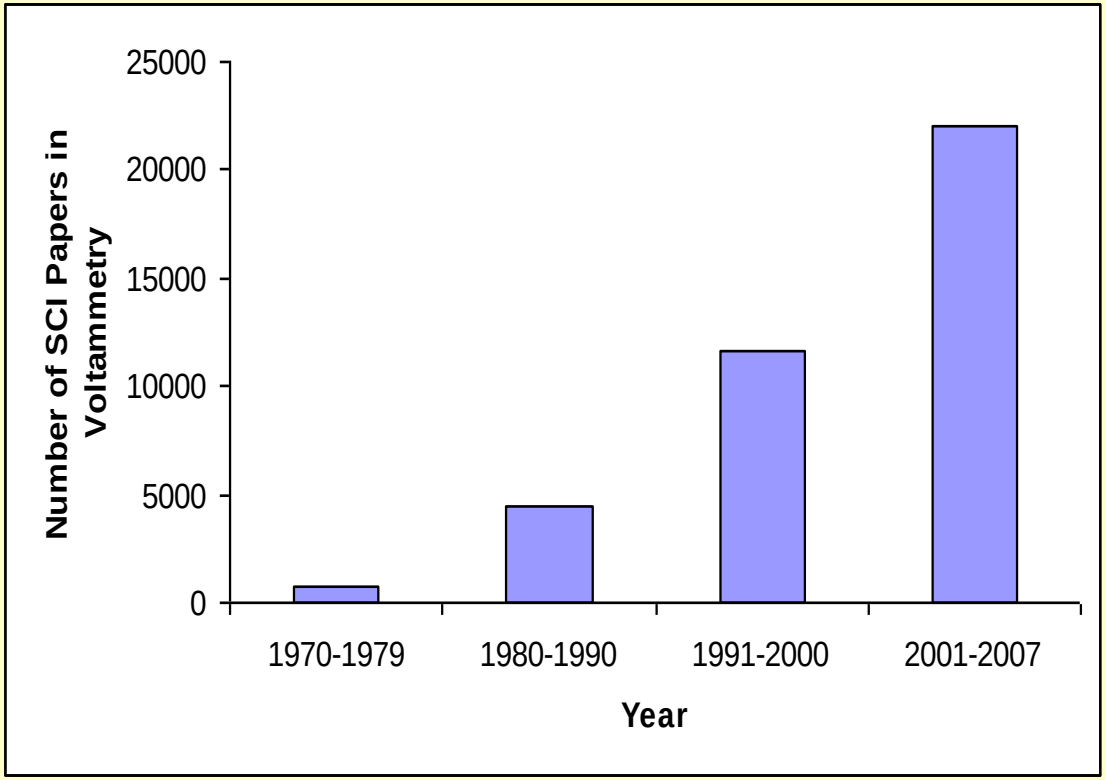
  **- *A*: electrode surface**
  **- *c*: electroactive compound concentration**
  **- v: scan rate**
  **- *D*: diffusion coefficient**

# Application of the Voltammetry

-In Chemistry, Physics and Engineering

-In Biology and Biochemistry (biosensors)

-In Pharmacy



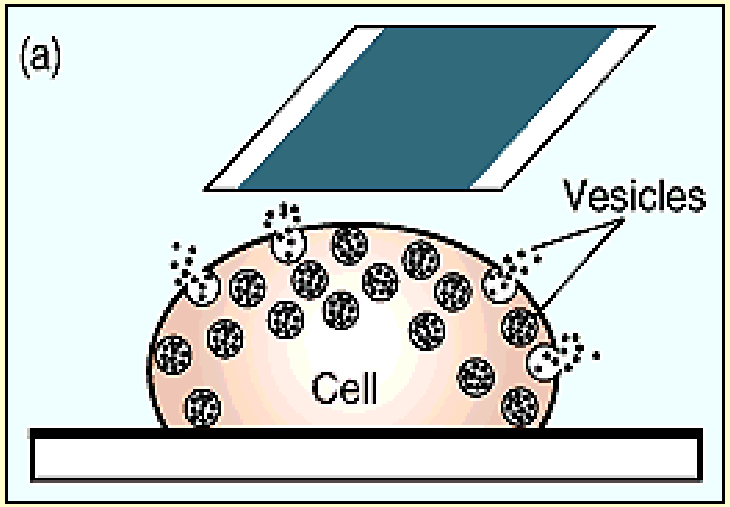

***-In Medicine***

-detection of reactive radicals nitroxides, superoxides,...

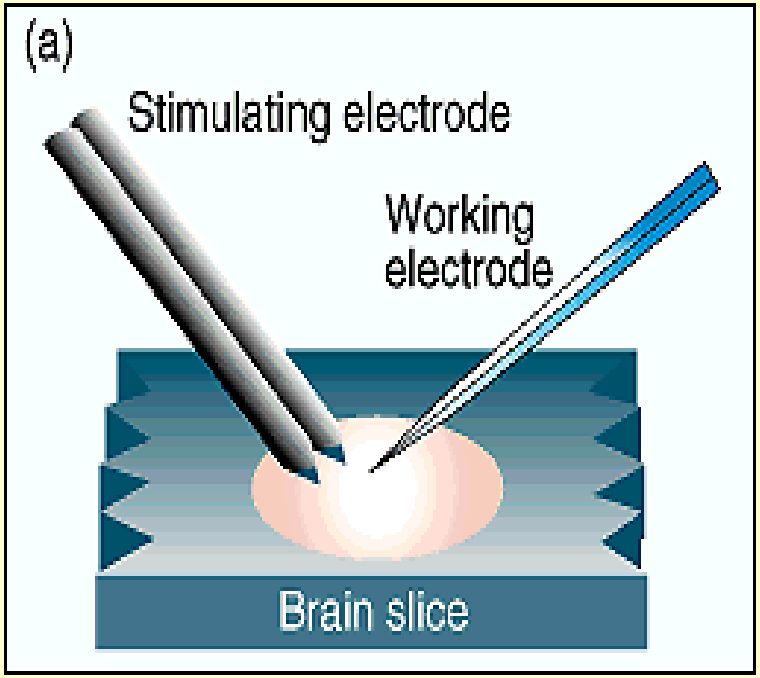
-determination of various active compounds

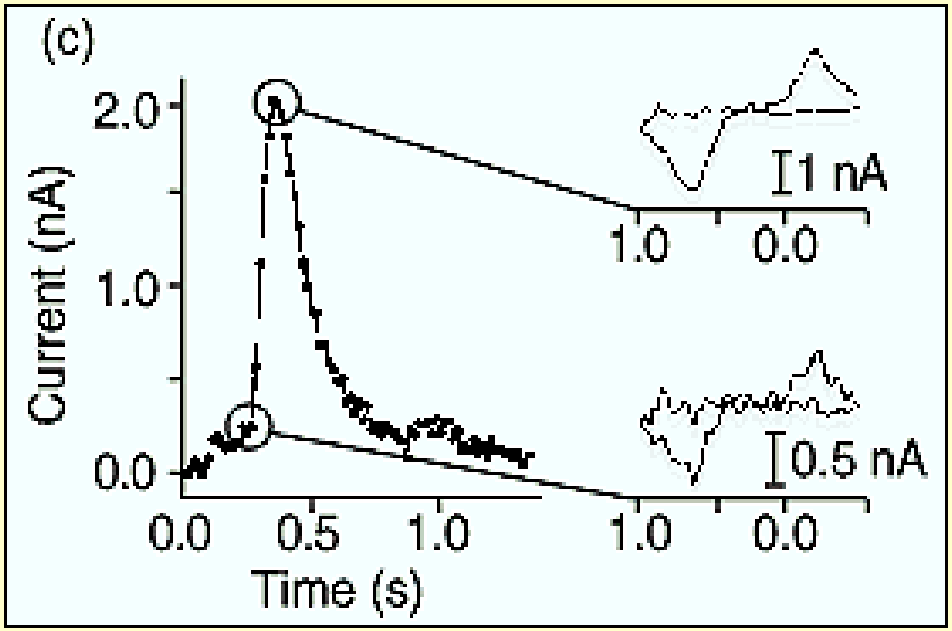
-following of protein-protein interactions

-medical sensors for various electron cariers and neurotransmiters



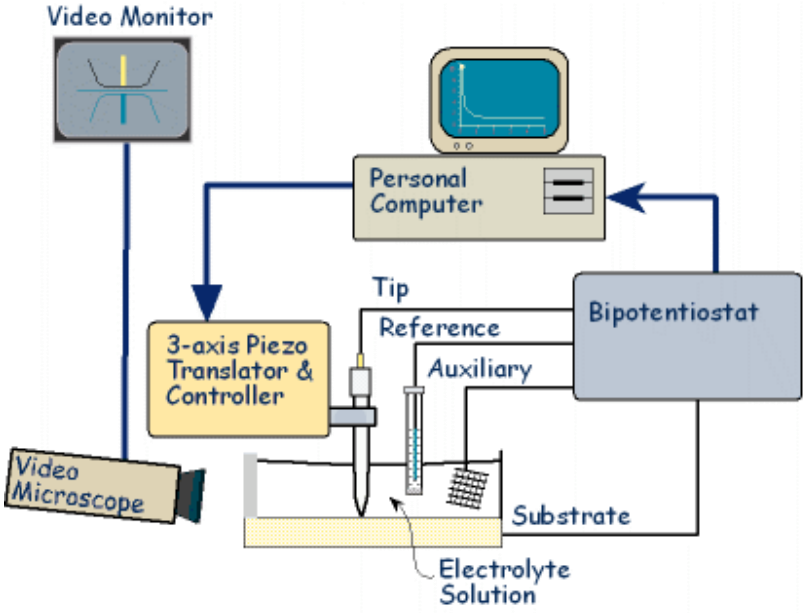

**IN-VIVO** voltammetric determination of catecholamine

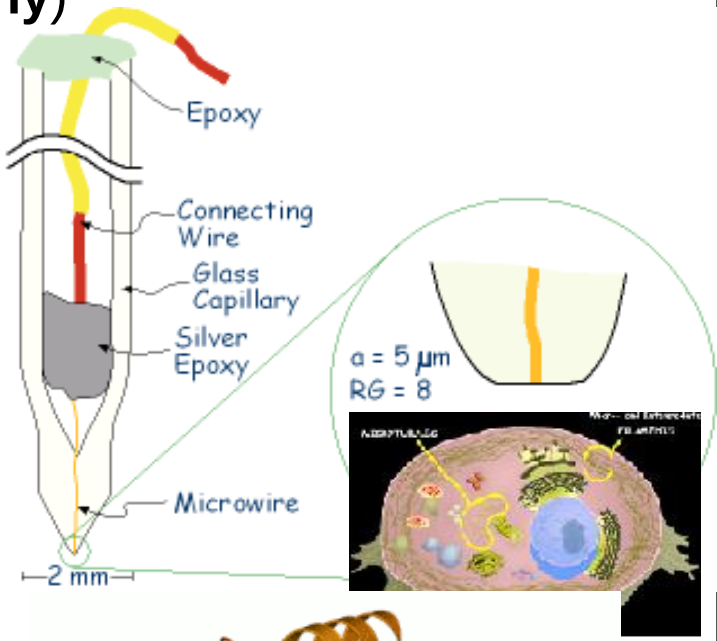


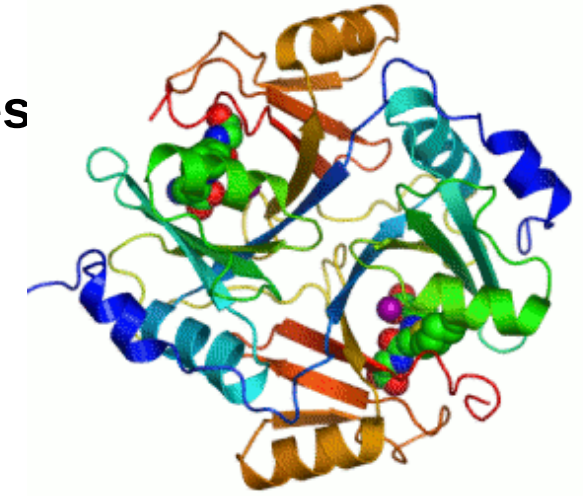
# Voltammetry in service of the Scanning Electrochemical Microscopy

-Powerfull tool for probing the electrochemical activity of single living cells at different spots (**cell topography**)

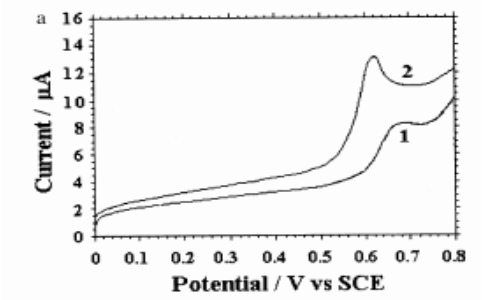



-Detection of **active sites of Enzymes**



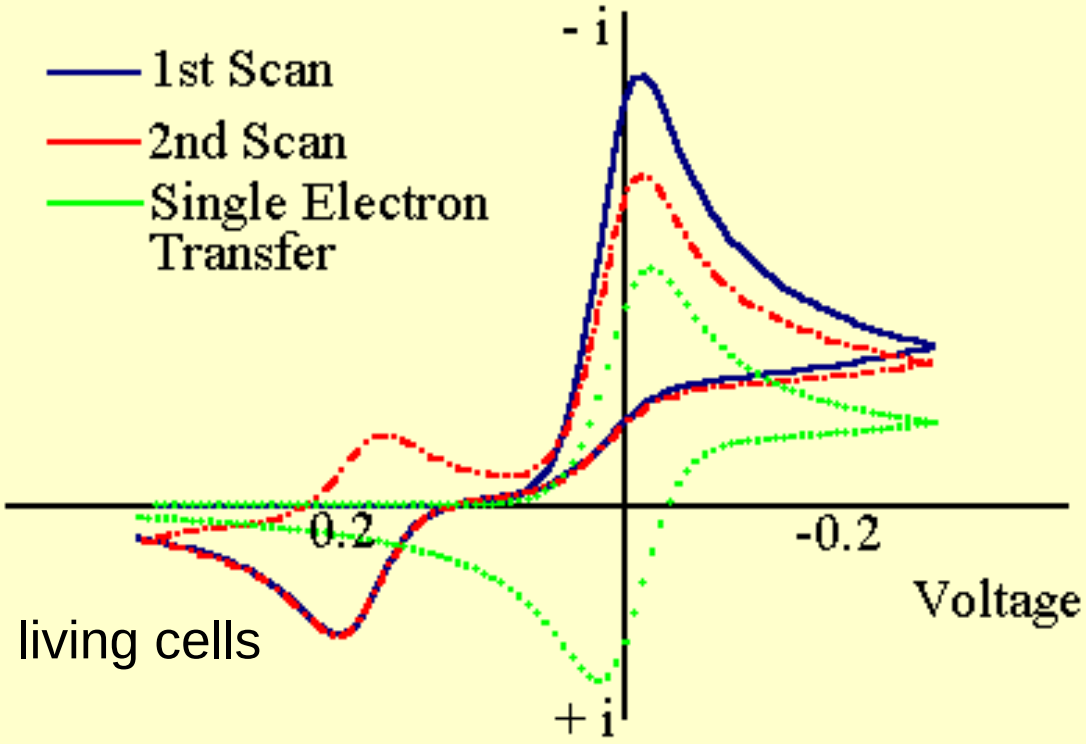
-Detection of **human breast cancer cells**



# What kind of information can provide Voltammetry?

**-Mechanism pathway**

-detection of the **intermediates** and final products of the redox reactions




Peroxyde nitrite oxidation in living cells

$ONO_2^-$ - e- = $ONO_2^{\cdot}$...$NO_2^-$

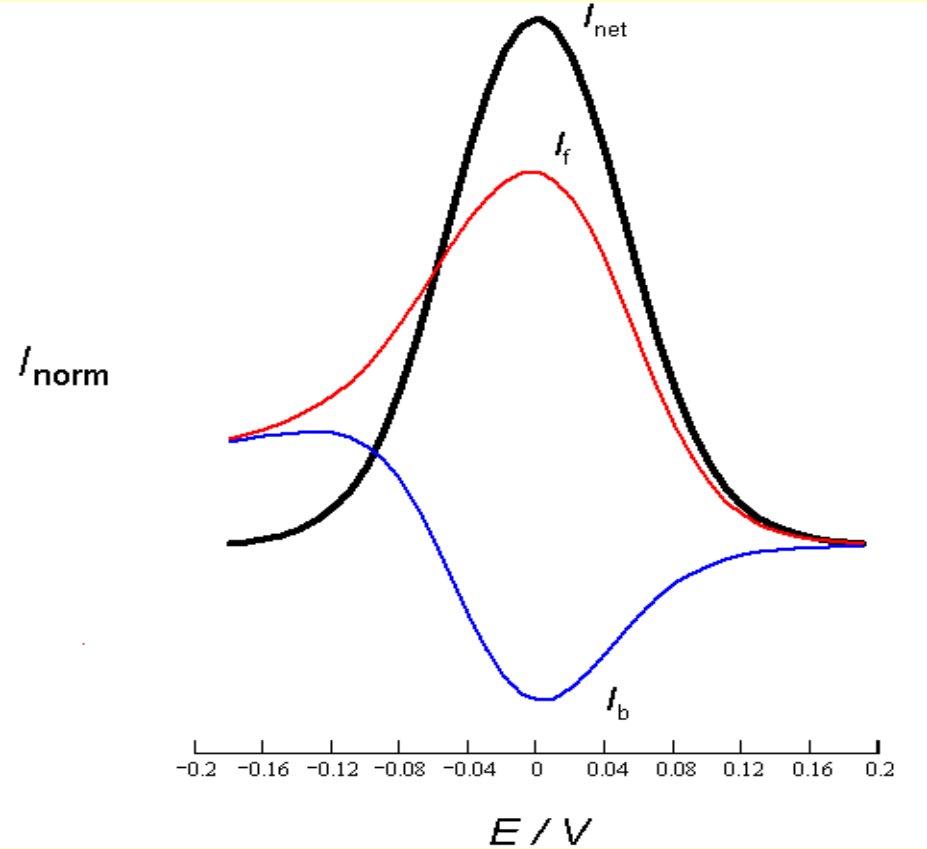
$NO_2^-$ + 2OH- -2e- = $NO_3^-$ + $H_2O$

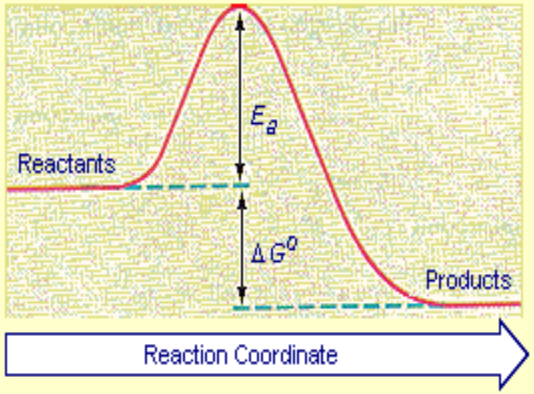
***-Thermodynamic Parameters of Redox Reactions***

***Standard Redox Potential****-Energy of Activation*., Enthalpy, **Complexation Constants**...

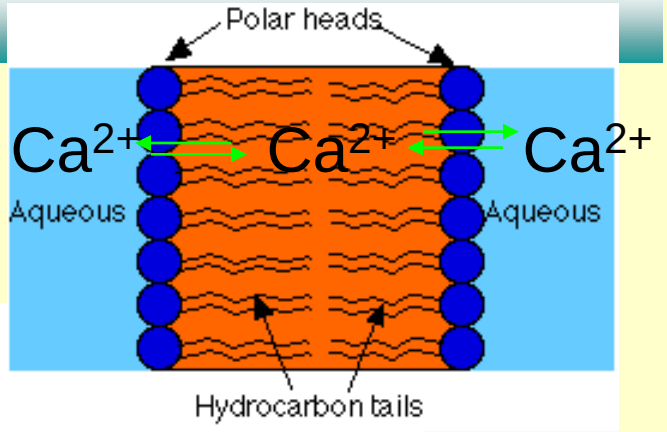
***-Kinetic Parameters***

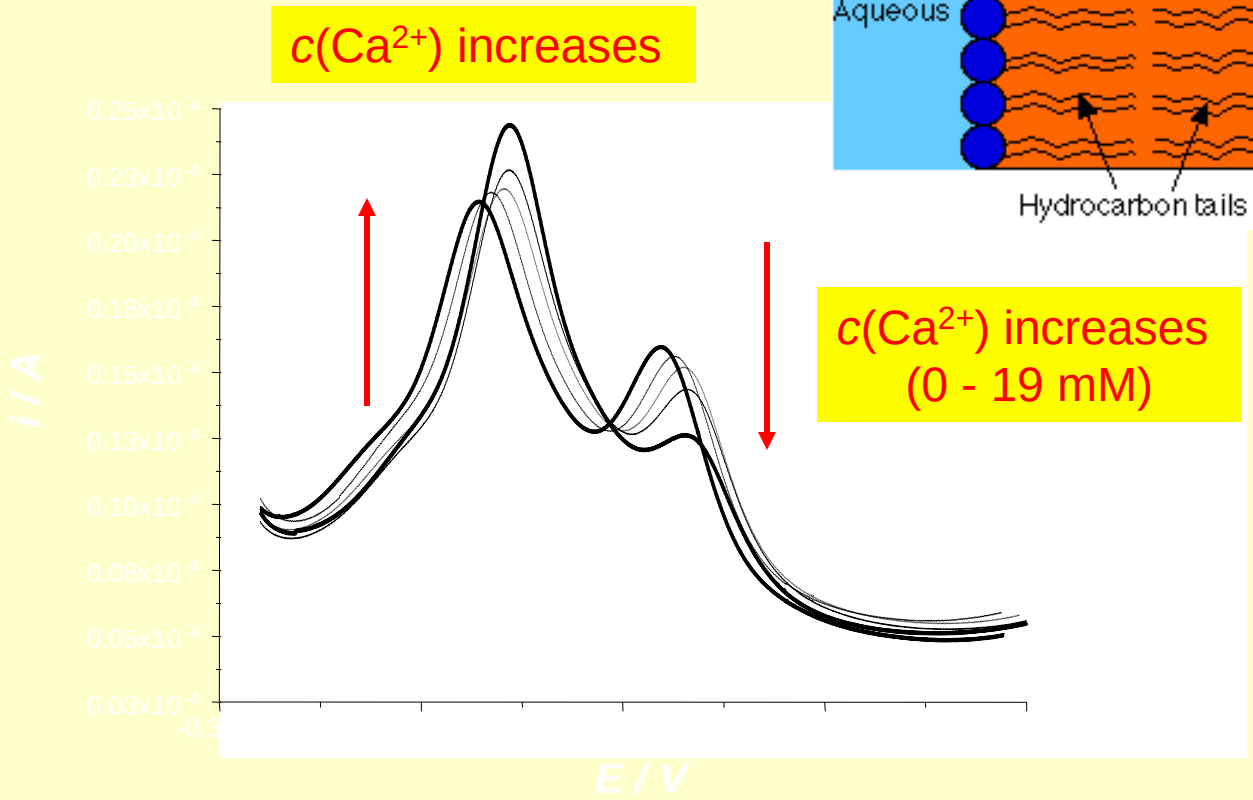
-standar rate constants of electron/ion transfers; kinetics of enzymatic reactions; kinetics of chemical reactions; ***pharmakokinetic parameters...***



# Complexation of Quinone-like compounds and $Ca^{2+}$ ions

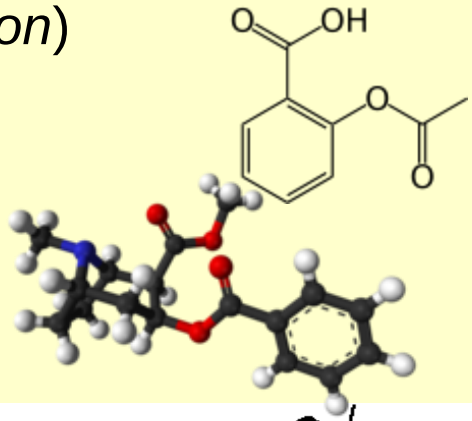


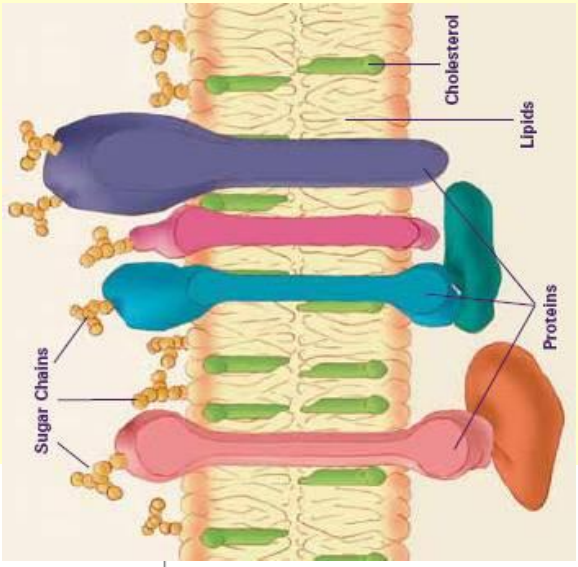



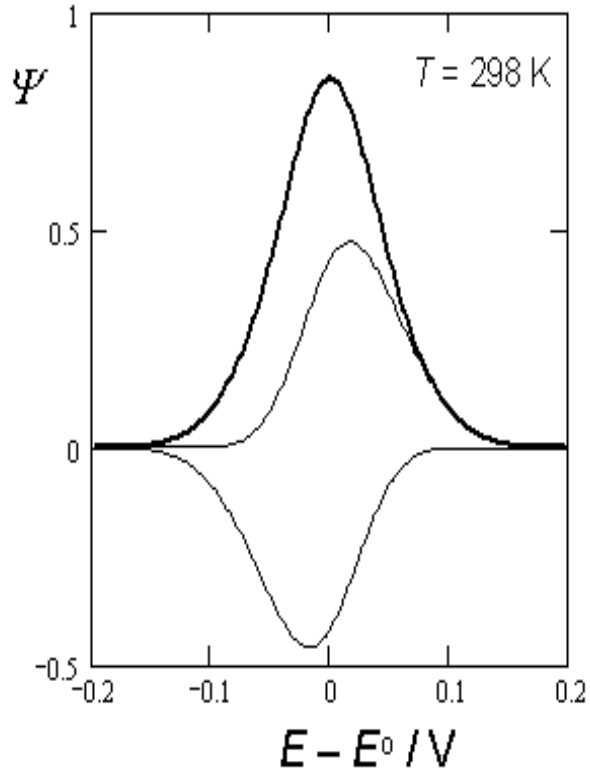

Cyclic voltammograms showing complexation of PalmytoilQuinone with $Ca^{2+}$

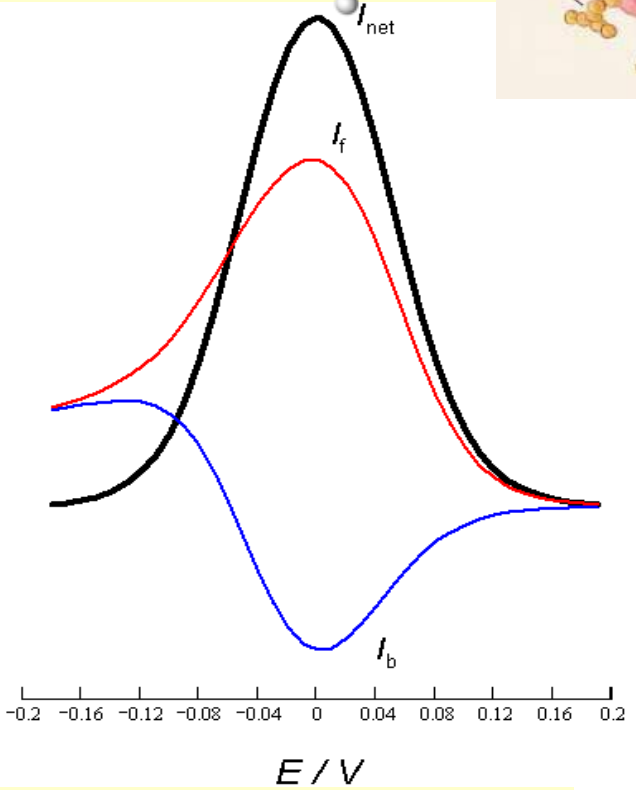
-***physical phenomena taking place in the system***
(*absorption, phase transformation*)

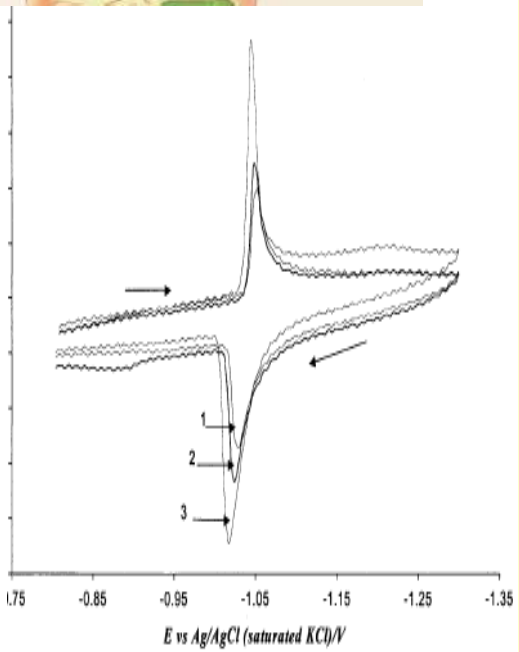
-way of mass transfer




absorption

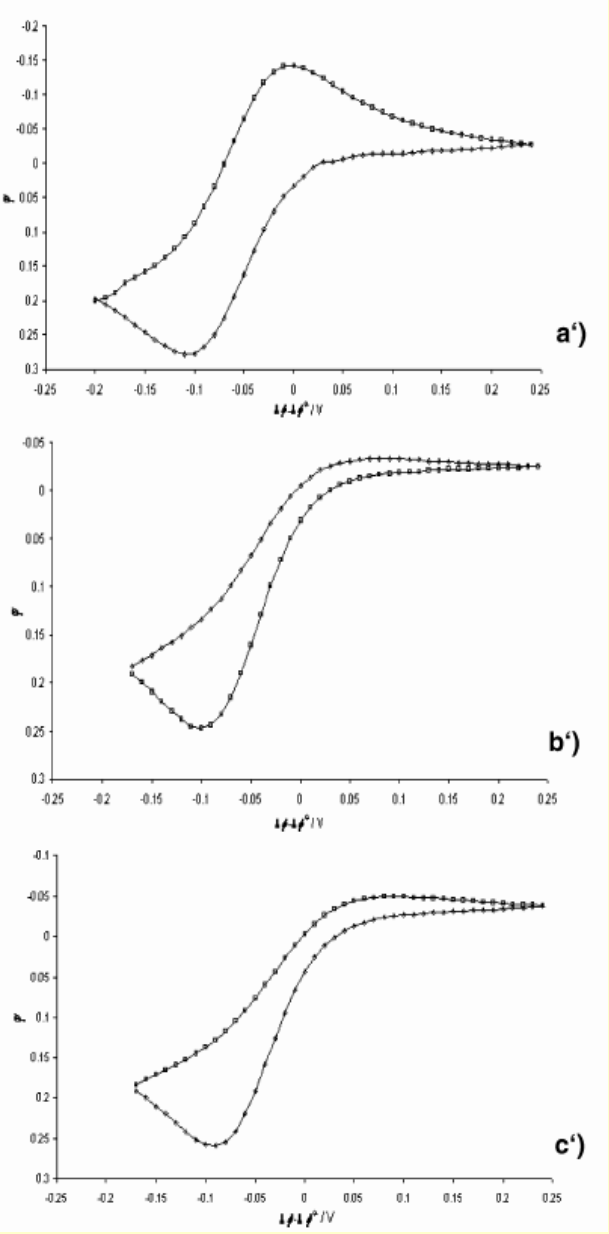
diffusion

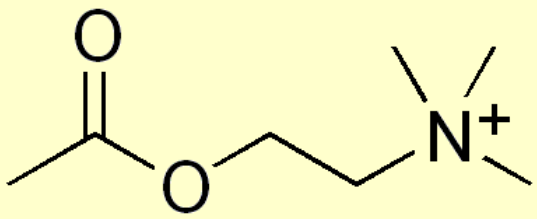
Phase-transformation



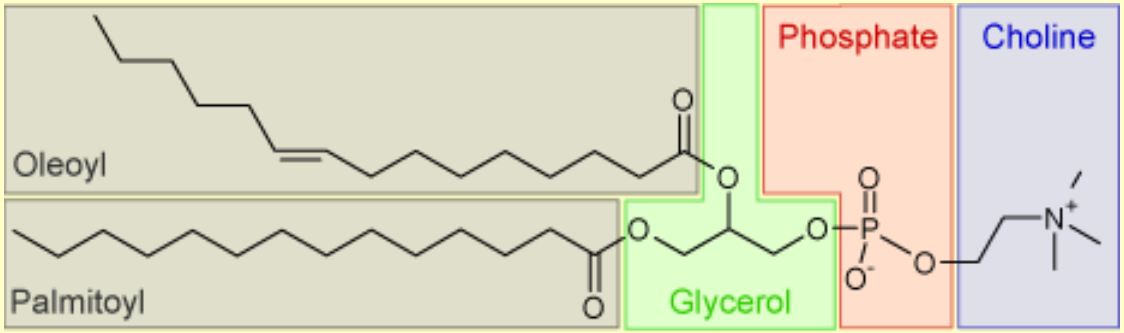
-thermodynamic and kinetic parameters related to the physical phenomena

# -type and strenghts of interactions between various compounds



Acetylcholine




Phospholipids

**TABLE 1: Determined Kinetic Parameters of the Ion Transfer of $AcH^+$ from Water to DCE ($k_s$ and $\alpha$) and for the Interactions between $AcH^+$ and DOPC ($K$, $\epsilon$, $k_f$, and $k_b$)**

| measuring technique | $k_s$/cm $s^{-1}$ | $\alpha$ | $K$ | $\epsilon$/$s^{-1}$ | $k_f$/$s^{-1}$ | $k_b$/$s^{-1}$ |
|---|---|---|---|---|---|---|
| SWV | 0.0030 | 0.50 | 0.44 | 13.10 | 4.00 | 9.10 |
| EIS | 0.0033 | 0.53 | 0.80 | 13.30 | 5.90 | 7.40 |

# Which compounds can be investigated by Voltammetry?

Inorganic compounds, metals, alloys,

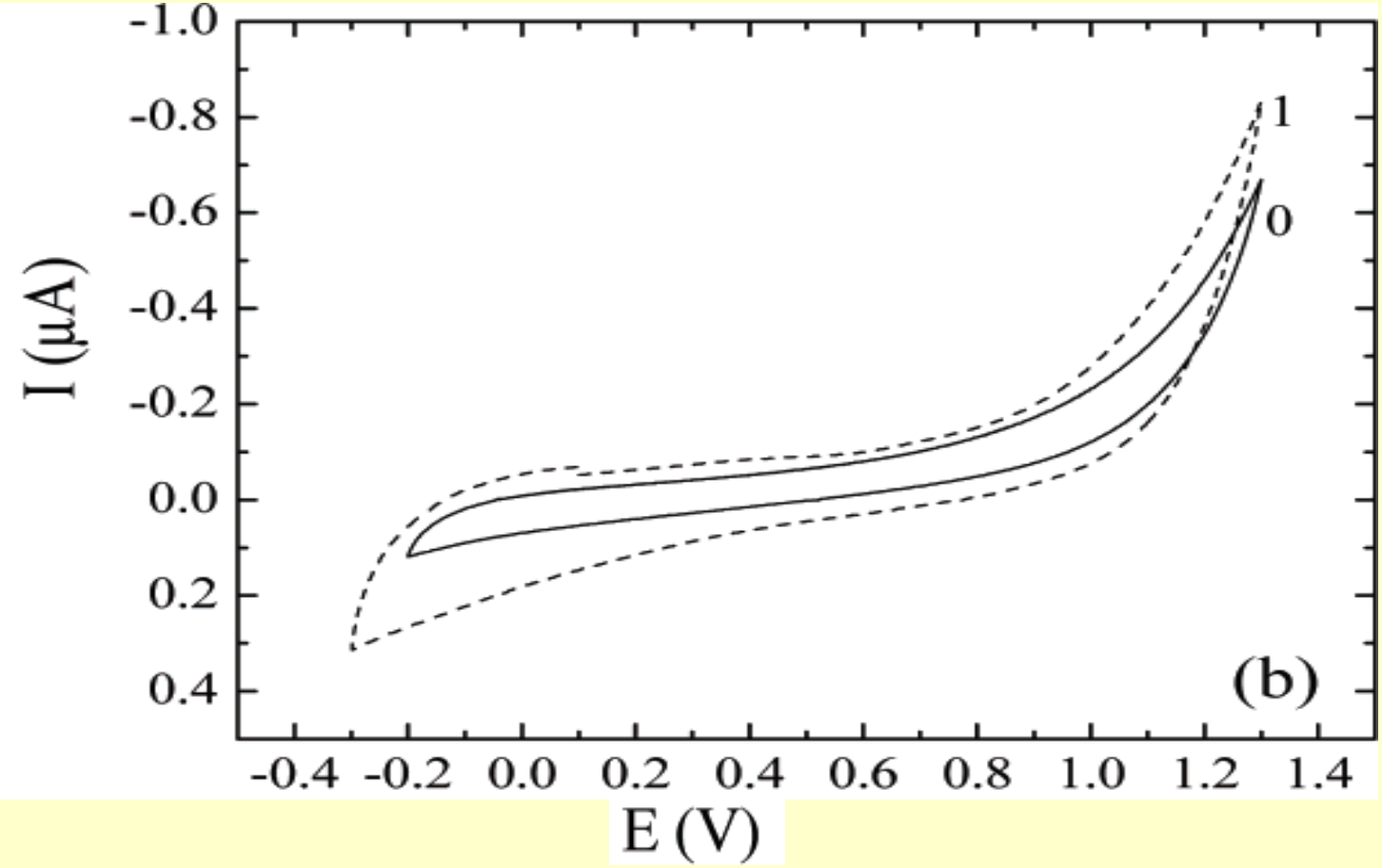
**Organic compounds containing redox active groups**:
C=O;Ar=O; N-R; “=“; N=N; S-H; Ar-OH: Ar-$NO_2$

Organic compounds containing incorporated metal ions (various **redox enzymes**

All medicaments and drugs containing “redox active” sites.

neurotransmitters dopamine, noradrenaline, adrenaline, serotonin…

# Are there some limitations?

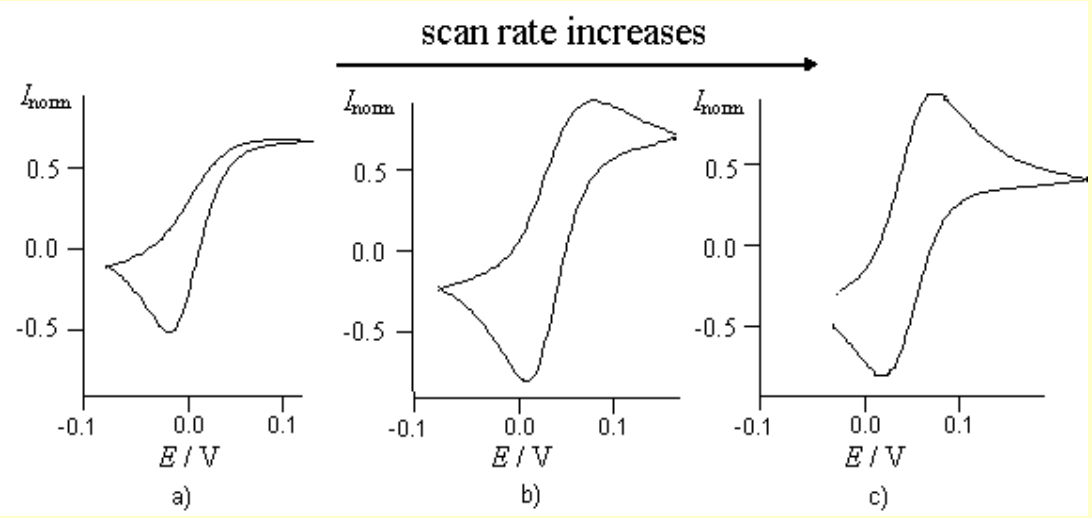


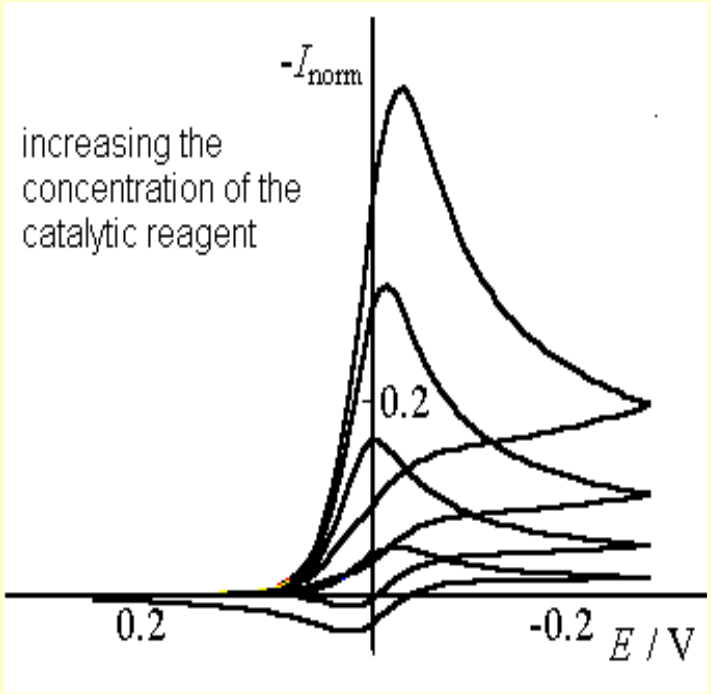

*BLANK Cyclic voltammogram*

## -What can we make in the case if our compound does not show “electrochemical activity”?

transmitters such as GABA, glycine and glutamate are NOT electroactive

-to make coupled CHEMICAL reactions with redox active compounds

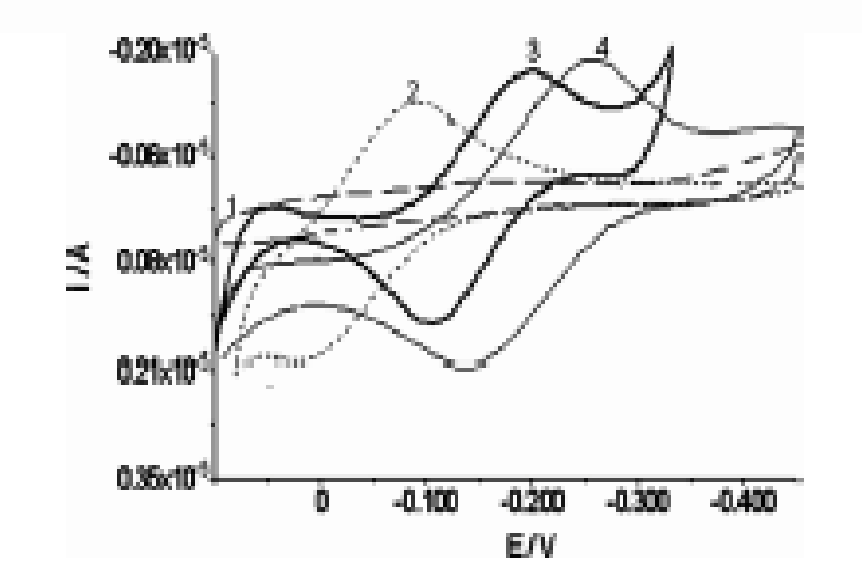


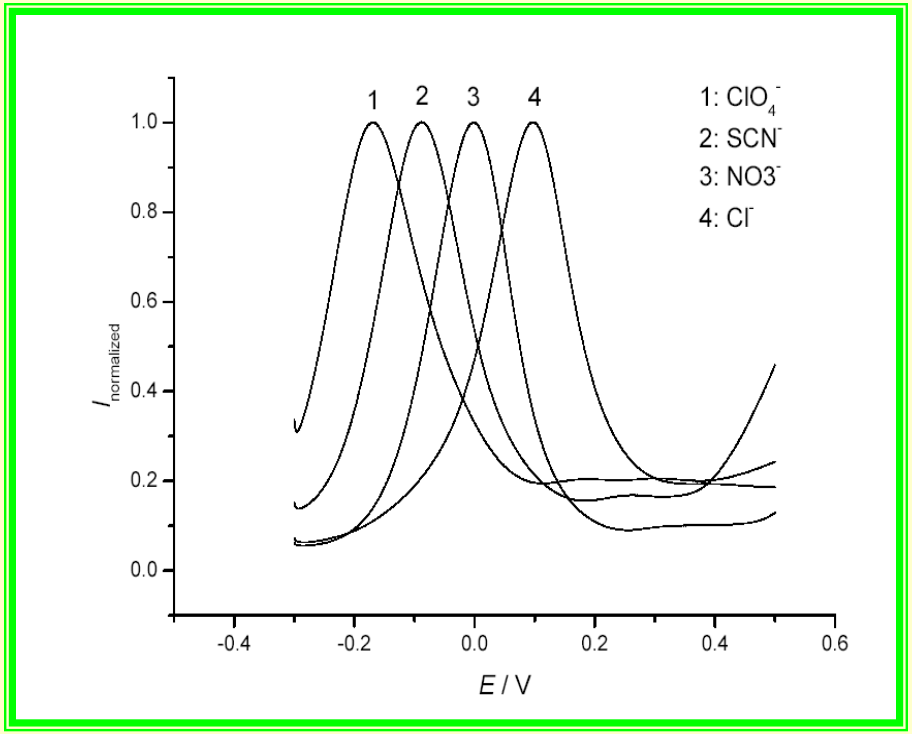




-to probe whether our compound can react with the material of the electrode

***Is it possible to investigate only the "electron" transfer reactions with Voltammetry?***

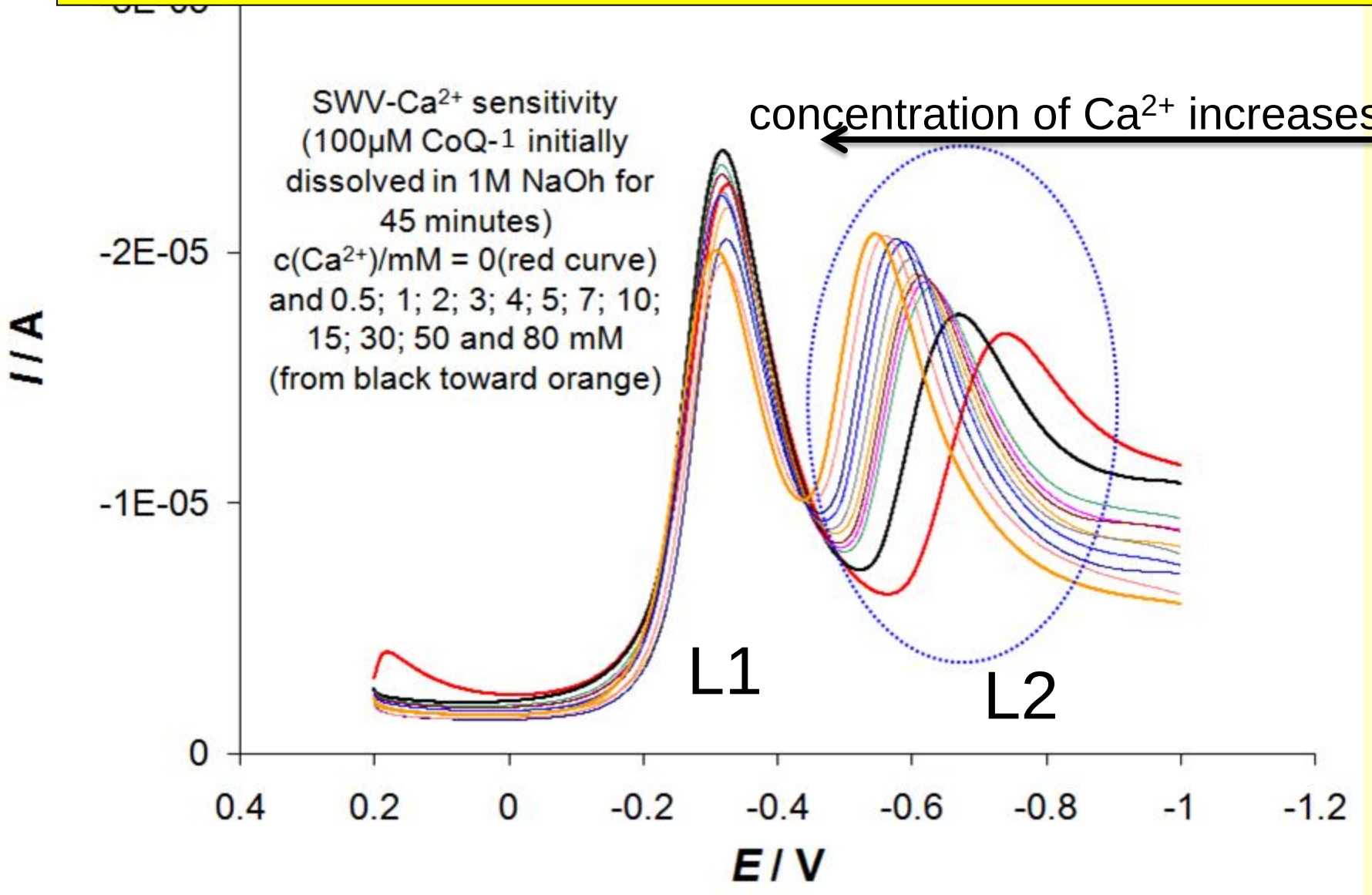
NO, it is possible to follow voltammetrically also reactions comprising only ION transfer, or COUPLED ELECTRON-ION transfer

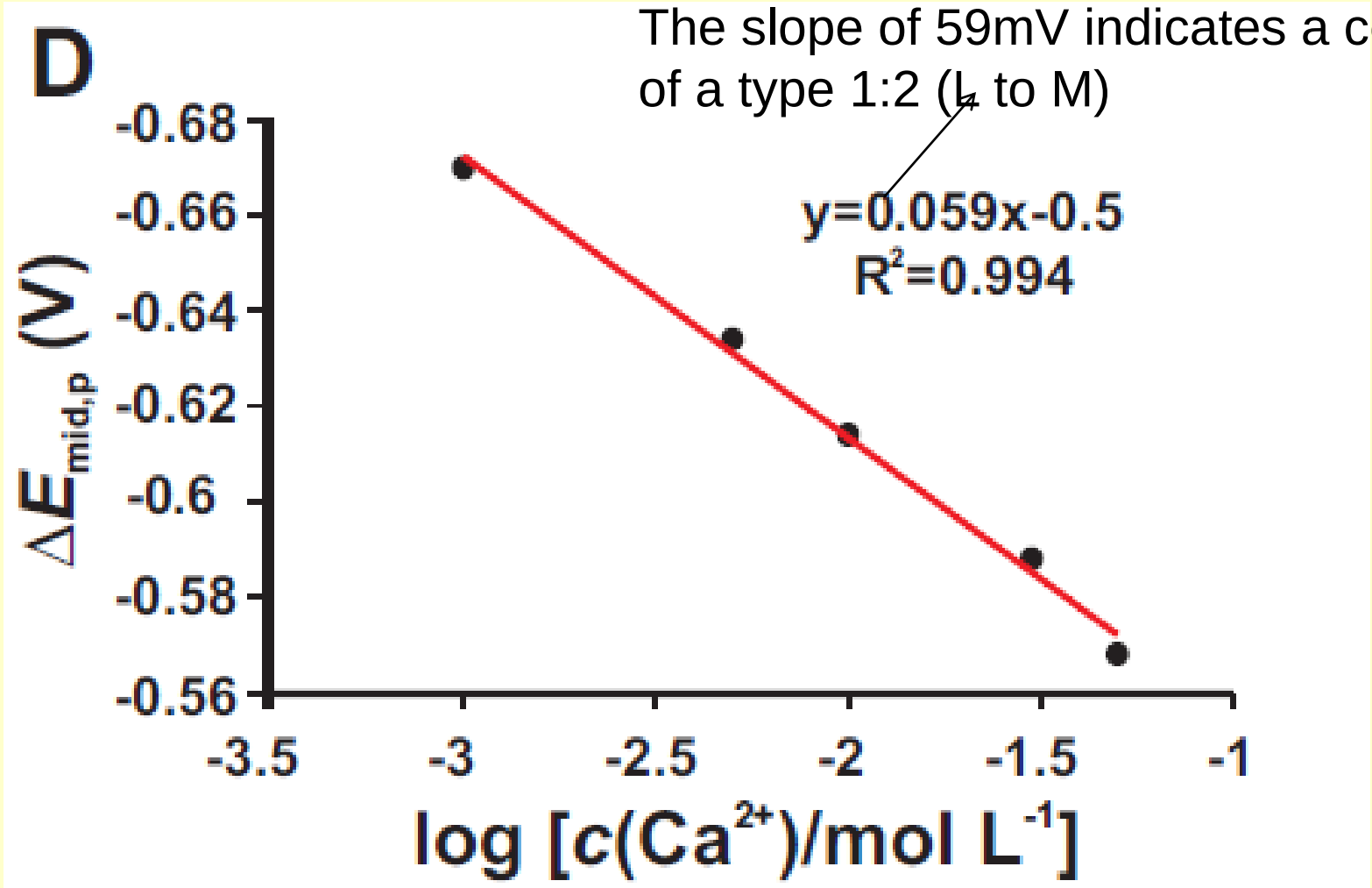



Transfer of Ionized Drugs-
***heroin, cocaine and codeine***
across biomimetic membranes

# TWO LIGANDS L1 and L2-One (L2) is able to bind $Ca^{2+}$ ions in stochiometric ratio 1:2 ($L:M^{2+}$), while the other (L1) NOT





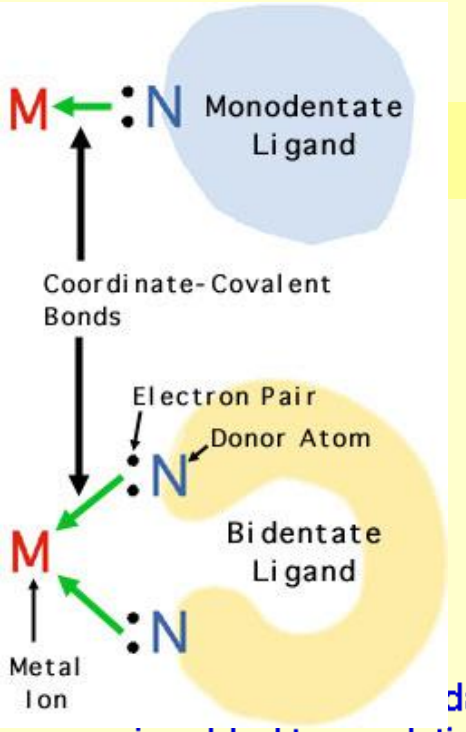

Dependence of the mid-peak potential of the cyclic voltammograms of the Ligands
on the logarithm of $Ca^{2+}$ concentration

# What can we evaluate from voltammetric Experiments?

Kst → Stability constant value

$$M^{X+} + yL = [MLy]^{X+}$$

→ Stochiometry of the complexes




dark blue tetraammine copper(II) ion when ammonia is added to a solution of copper(II) sulfate.

$$Cu^{2+}(aq) + 4NH_3 \rightleftharpoons Cu(NH_3)_4^{2+}(aq)$$

$$K_f = \frac{[Cu(NH_3)_4^{2+}(aq)]}{[Cu^{2+}(aq)][NH_3]^4}$$

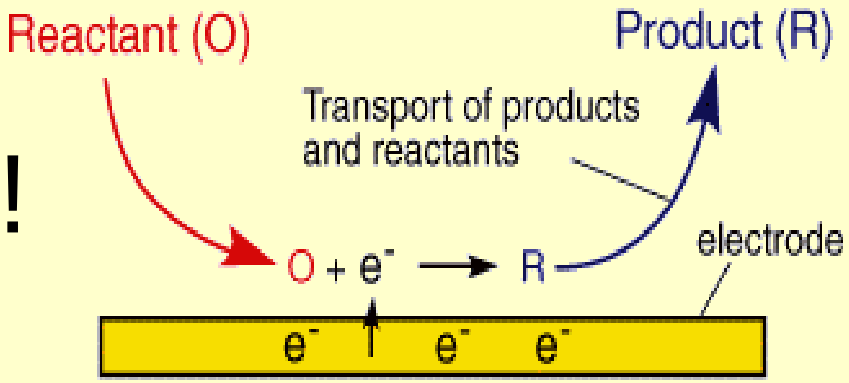
## Stability constant / Formation constant

- According to Bjerrum formation of a complex in aqueous solution proceeds through a stepwise fashion with corresponding equilibrium constants

| | | |
|---|---|---|
| $M + L \overset{K_1}{\rightleftharpoons} ML$ | $ML$ | $K1 = [ML] / [M] [L]$ |
| $ML + L \overset{K_2}{\rightleftharpoons} ML_2$ | $ML_2$ | $K_2 = [ML_2] / [ML] [L]$ |
| $ML_2 + L \overset{K_3}{\rightleftharpoons} ML_3$ | $ML_3$ | $K_3 = [ML_2] / [ML2] [L]$ |
| ..... | | |
| ..... | | |
| $ML_{n-1} + L \overset{K_n}{\rightleftharpoons} ML_n$ | $ML_n$ | $K_n = [ML_n] / [ML_{n-1}] [L]$ |

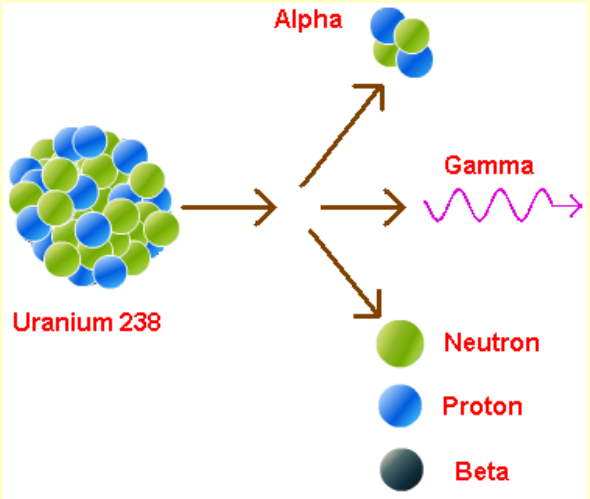
These $K_1, K_2, K_3 \ldots K_n$ are called stepwise formation constants

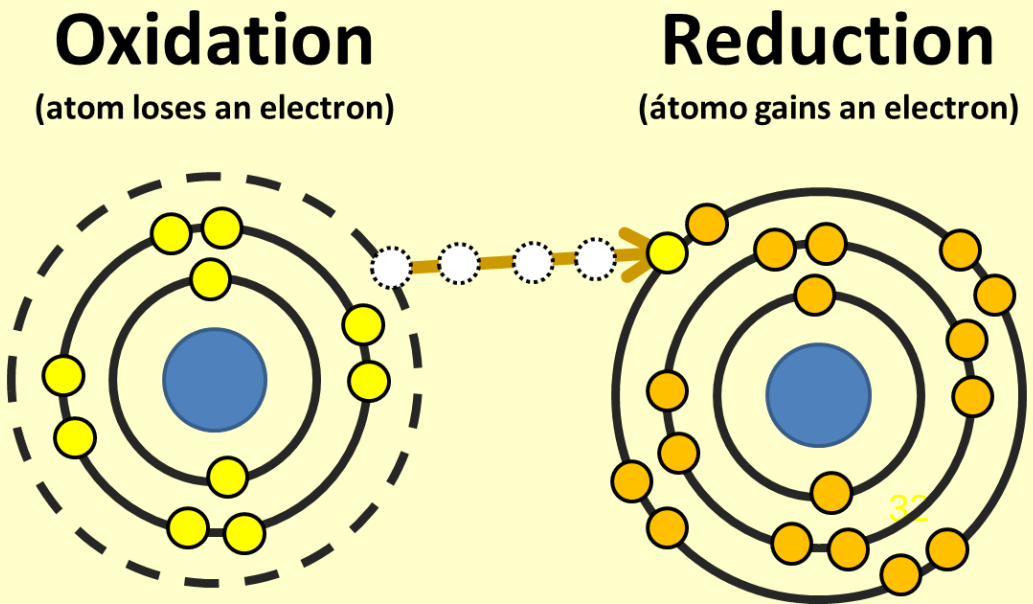
# VERY IMPORTANT!!!




Electrochemistry deals with the electrons, NOT with the CORE particles of the atom!!!

***So, whether we use RADIOACTIVE or „NORMAL“ non -radioactive isotopes, we should have (almost) the Same results!***



**Final Conclusions**:

Voltammetry is a SIMPLE, CHEAP and powerful tool for:

-Quantitative determination (sensing) of various biologically active compounds

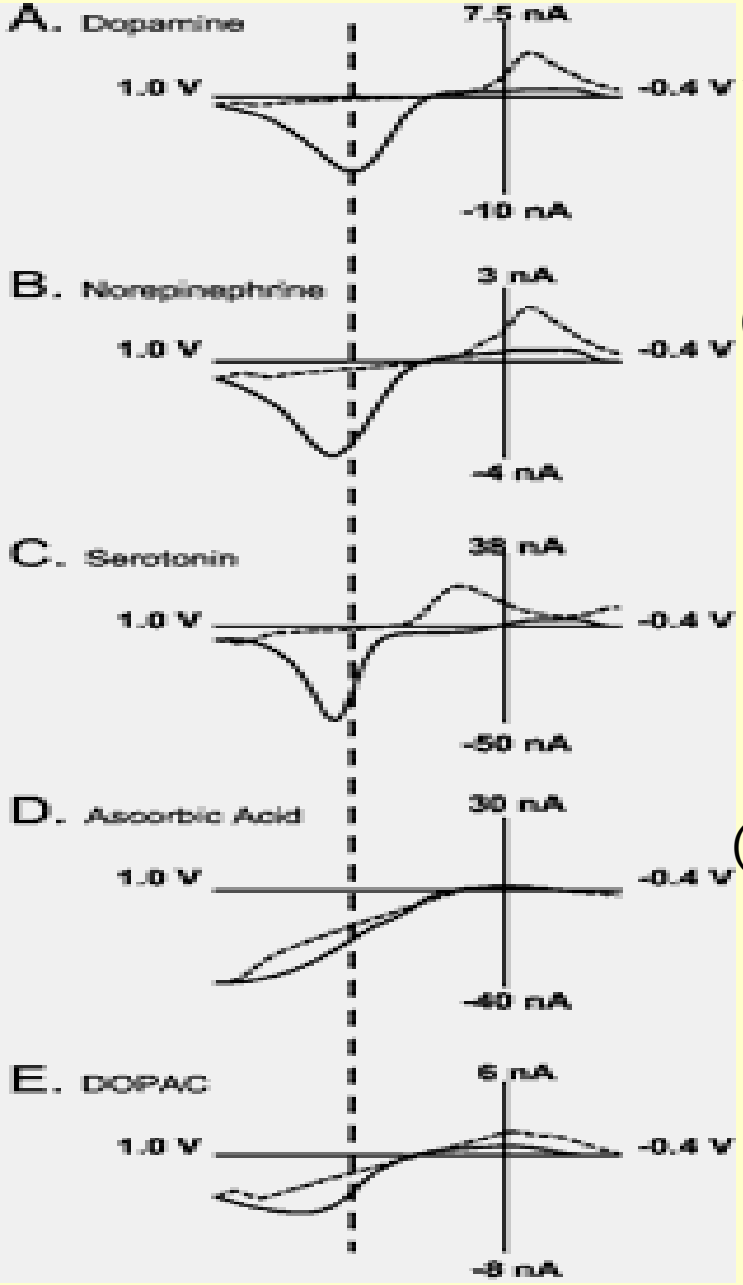
-simple technique for revealing the mechanistic pathways

-effective tool for thermodynamic and kinetic measurements

-Inevitable technique in almost ALL research laboratories

**In GENERAL**: FOR EVERY SYSTEM (Compound) ONE CAN GET ELECTROCHEMICAL INFORMATION REGARDLESS OF ITS STRUCTURE

# Cyclic Voltammograms of some NUEORTRANSMITTERS



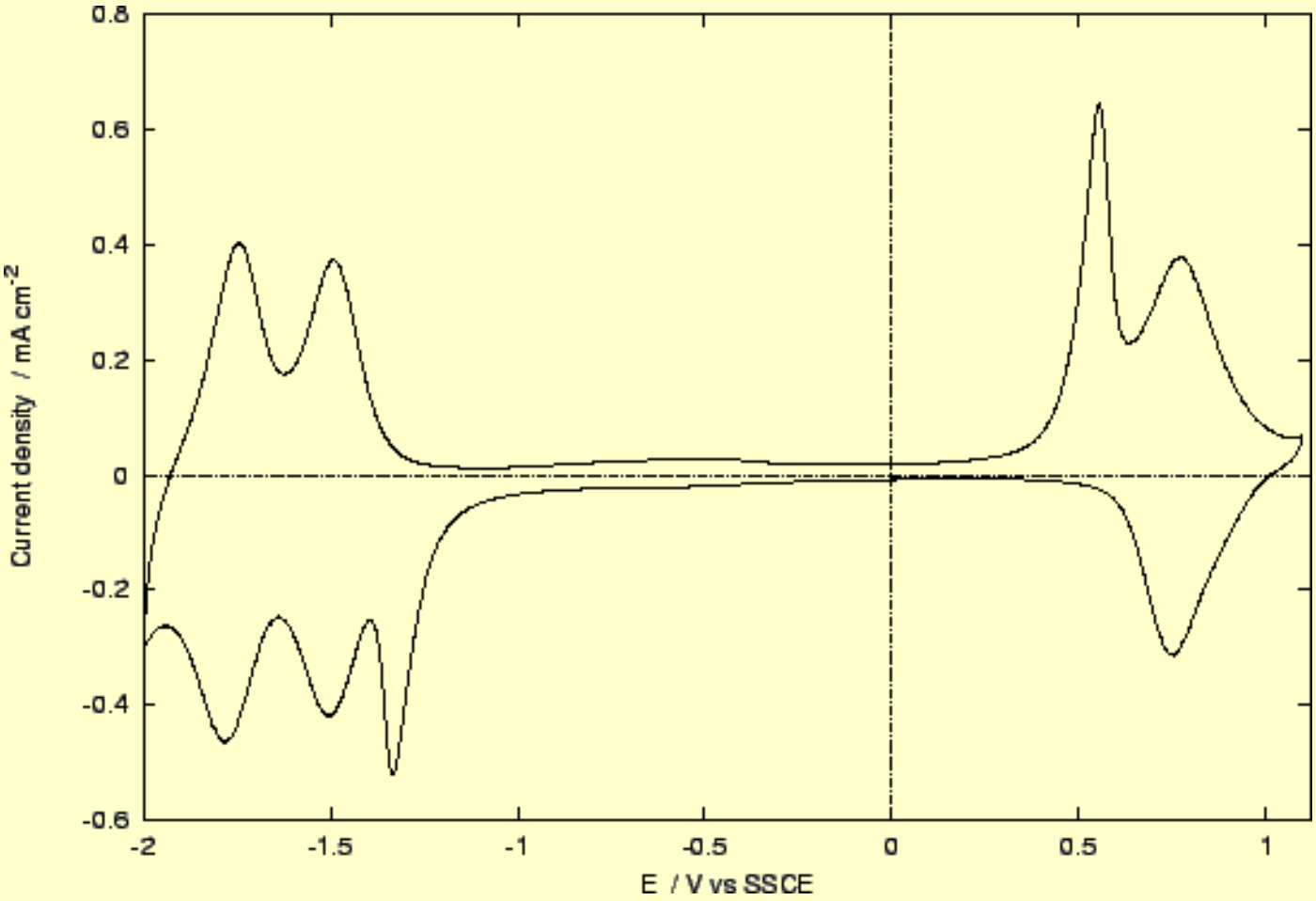

(*A*), cyclic voltammogram for 2 µmol/L **dopamine**.

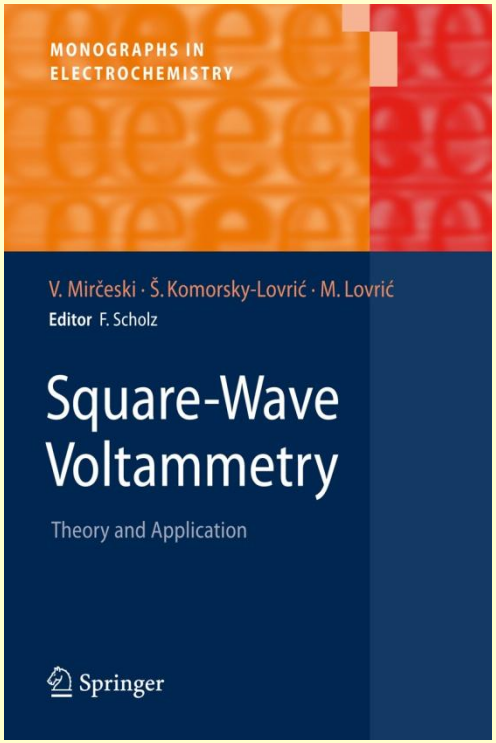
(*B*), cyclic voltammogram for 2 µmol/L **norepinephrine**

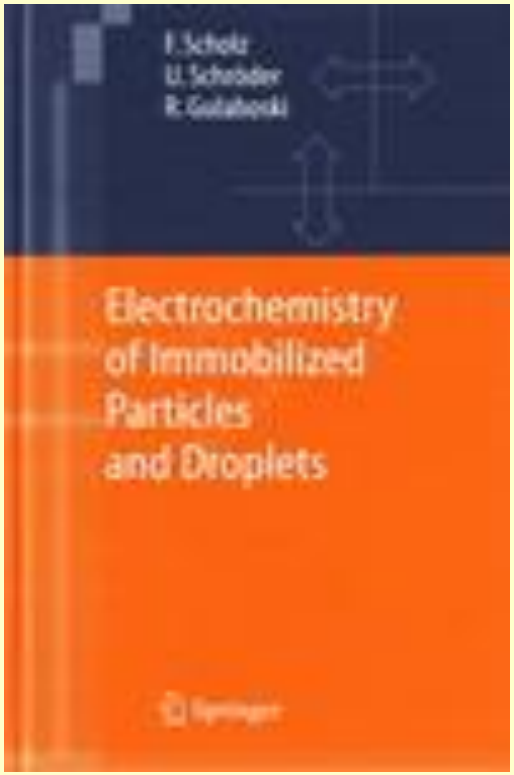
(*C*), cyclic voltammogram for 2 µmol/L **serotonin**

(*D*), cyclic voltammogram for 200 µmol/L **ascorbic acid**

(*E*), cyclic voltammogram for 20 µmol/L **DOPAC**


0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-2
-1.5
-1
-0.5
0
0.5
1
Current density / mA cm-2
E / V vs SSCE


**Rubin Gulaboski**, in
**ELECTROCHEMICAL DICTIONARY** (2008)
A. J. Bard, G. Inzelt, F. Scholz (editors)

F. Scholz, U. Schroeder, **R. Gulaboski**

**R. Gulaboski**, C. M. Pereira in
**Handbook of Food Analysis Instruments** (2008)
Semih Otles (Ed.)

# Acknowledgments

A. v. Humboldt Foundation
Prof. Markus Hoth
Dr Ivan Bogeski

Prof. Fritz Scholz
Greifswald University

Prof. Valentin Mirceski
Macedonia University

Prof. Milivoj and Sebojka Lovric
Croatia


**The speaker's attendance at this conference was sponsored by the Alexander von Humboldt Foundation.**

- http://www.humboldt-foundation.de