Electrochemistry – Bioelectrochemistry and Biosensors

- https://www.zimmerpeacocktech.com/2020/02/05/usn-introduction-to-biosensors/

Content

- Introduction to ZP and I ☺
- Introduction to Electrochemistry
- Introduction to Electroanalytical chemistry
  - Introduction to Biosensors
- Introduction to electroanalytical techniques applied to biosensors
  - Cyclic voltammetry
  - Amperometry
  - Potentiometry

Quick resume

- Martin Peacock
- First degree chemistry
- Second degree electrochemistry
- Industrial roles:
  - GSK – Medicinal Chemist
  - Abbot Diabetes – Electrochemist
- Companies founded in the last 4-years:
  - Zimmer and Peacock Ltd
  - Zimmer and Peacock AS
  - Zimmer and Peacock Inc
  - CeeLab
  - Aliksir

https://www.linkedin.com/in/martinpeacock/

martinpeacock@zimmerpeacock.com

Universitetet i Sørøst-Norge

Swansea University Prifysgol Abertawe

UNIVERSITY OF OXFORD

Zimmer & Peacock

ZP Background – who are we?

- Formed in 2014.
- Locations: USA, UK, Norway and Indonesia
- Products: Standard Products for Sensor Developers
- Services:
  - Contract Development
  - Contract Troubleshooting
  - Contract Manufacturing
  - Contract Commercialization: Packaging, Logistics, Sales Channels Etc.
  - IP development

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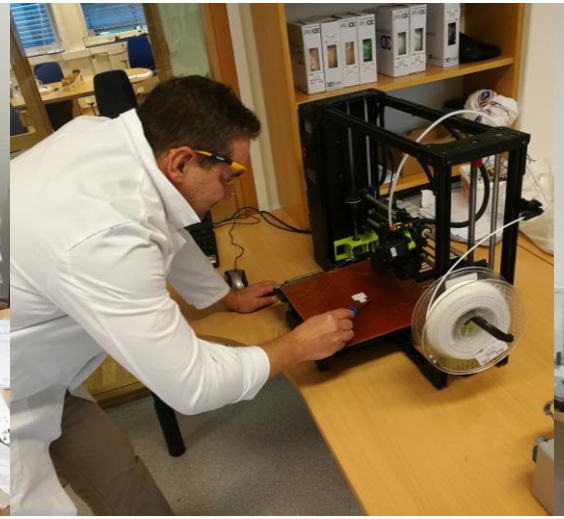
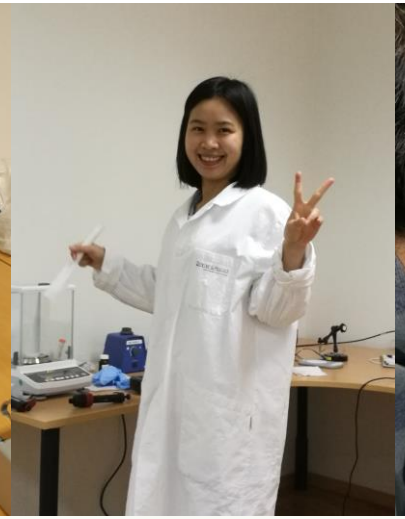
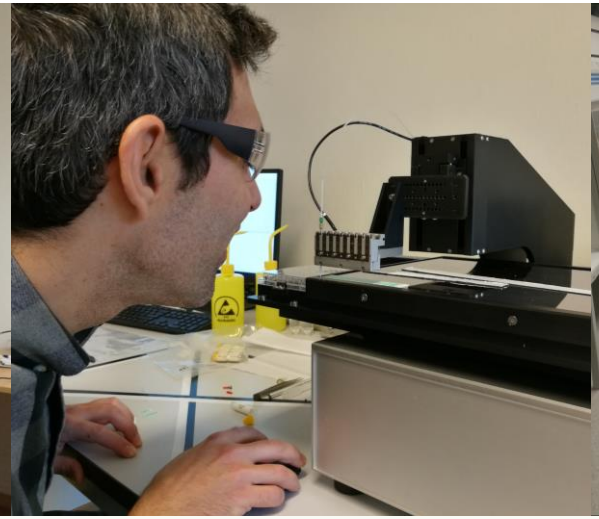
Zimmer and Peacock

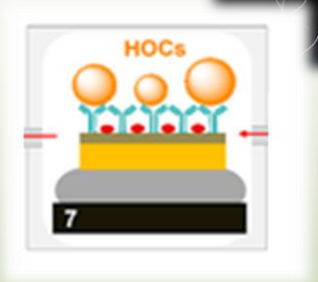






Capabilities

- BioMEMS
- Screen Printing
- Digital printing
- Electronics
- Mechanical Engineering
- iOS Development
- Cloud databases
- Biosensor Manufacturing
- Microfluidics
- Rapid Prototyping/minimum viable product
- Seamstress
- IP Development - Patents

What do sensors mean for ZP

- We like measuring things and sensing things?



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What is electrochemistry?

- **Definition One** - Electrochemistry is a subject studied by electrochemists, who all think it is very important
- **Definition Two** – Electrochemistry is one of the sciences best suited for integrating chemistry/biology with electronics, AI,The Cloud and Big Data
- **Definition Four** – Electrochemistry is a commercially important science, but not commonly taught at University
- **Definition Five -** Electrochemistry is the study of the relationship between electricity, and an identifiable chemical/biology change, with either electricity considered an outcome of a particular chemical change or vice versa.
  - Definition of 5 A – The conversion of chemistry or biology quickly to data to information

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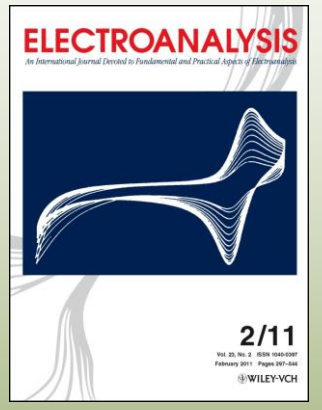
Applications of electrochemistry

Study of corrosion

Power and Energy: capacitors, fuel cells and batteries, solar cells

Electroanalysis – sensors and biosensors



Electrolysis/ Electrochemical Synthesis

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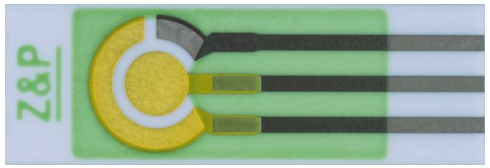
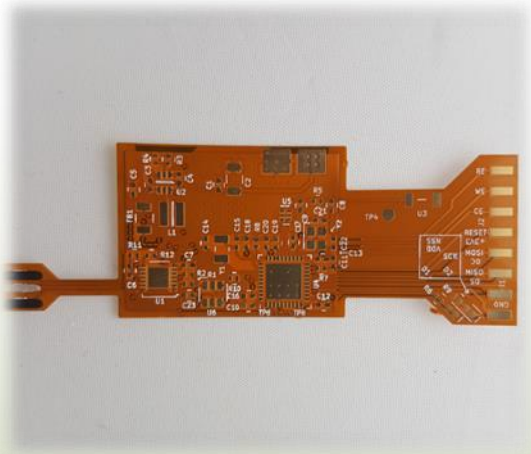
What can electrochemistry do for you?





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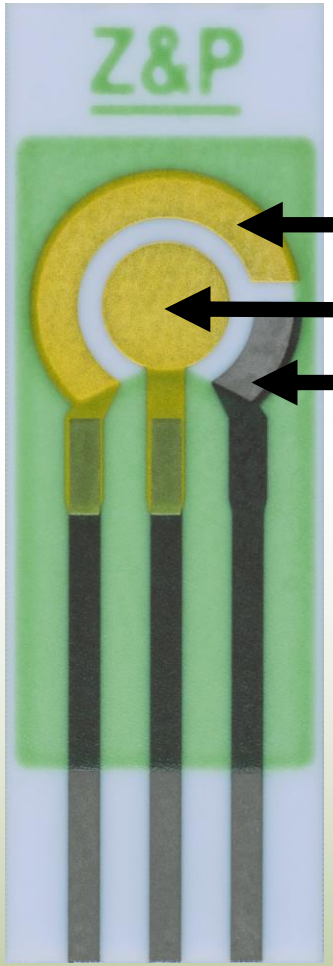
Hardware

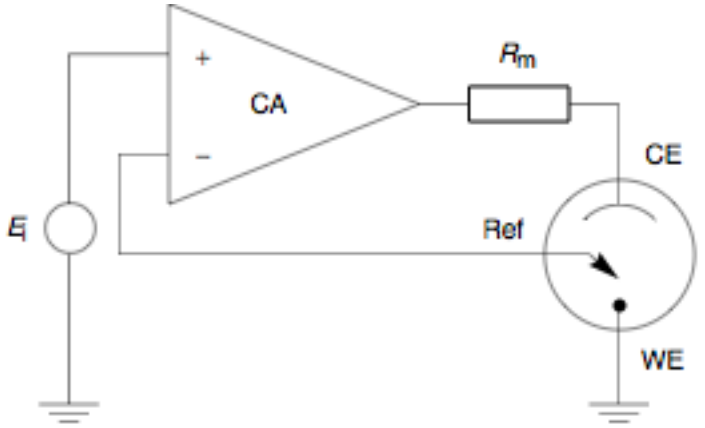
Old fashioned

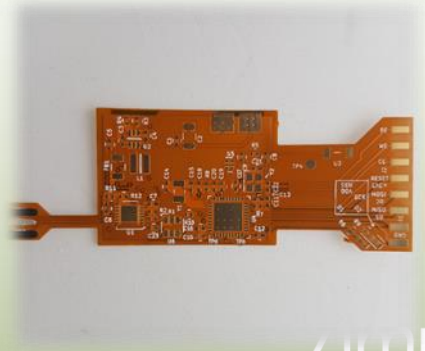


Counter electrode

Working electrode

Reference electrode





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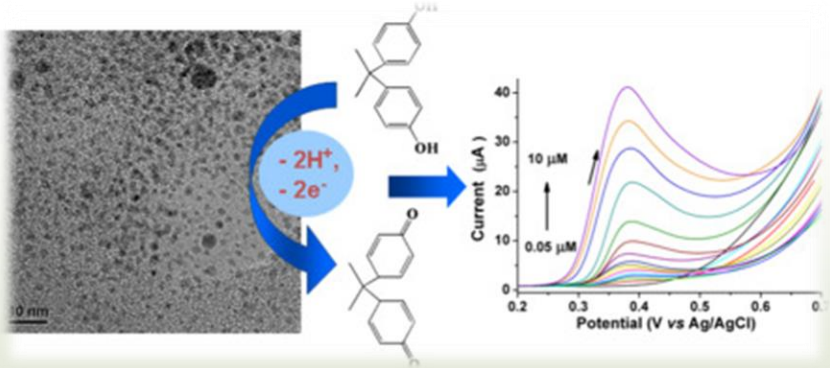
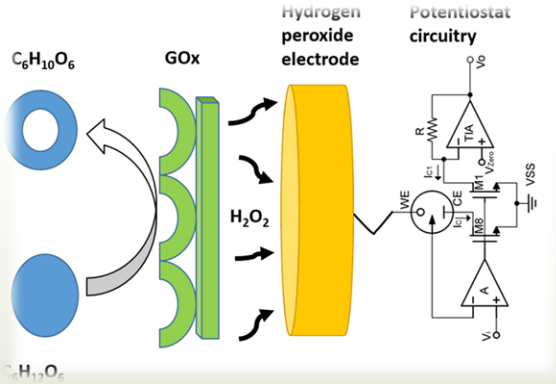
Electroanalytical chemistry - How does our science work?

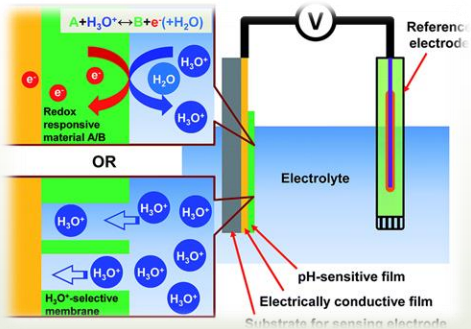
Voltammetric



Amperometric



Potentiometric



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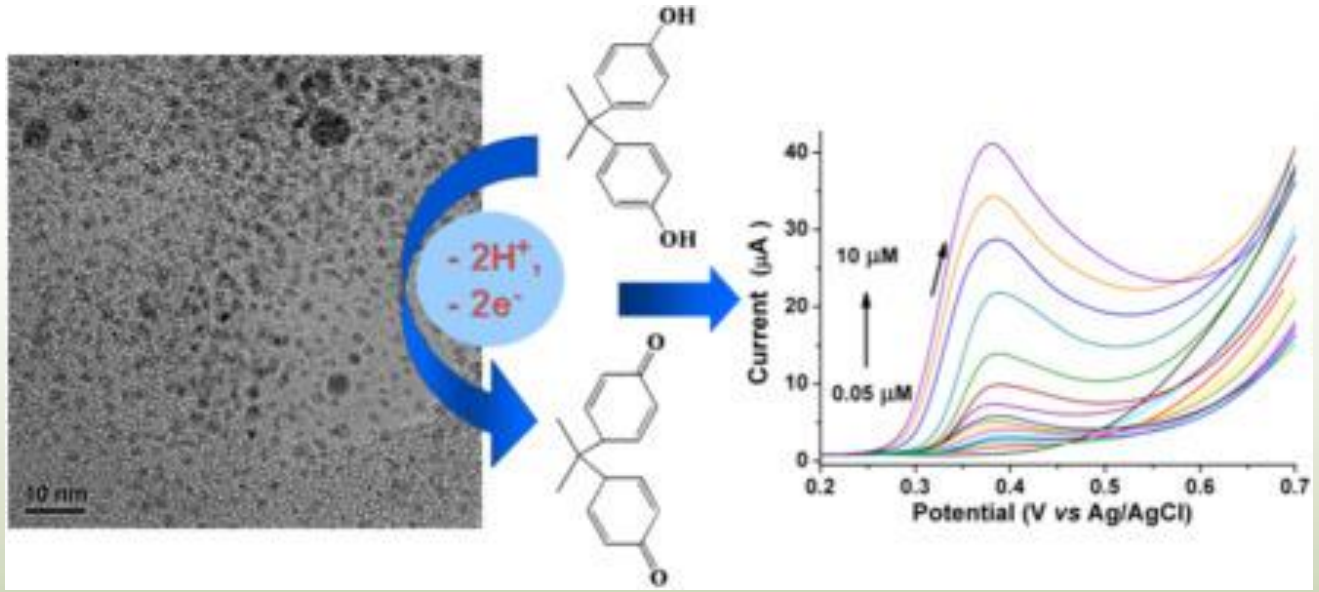
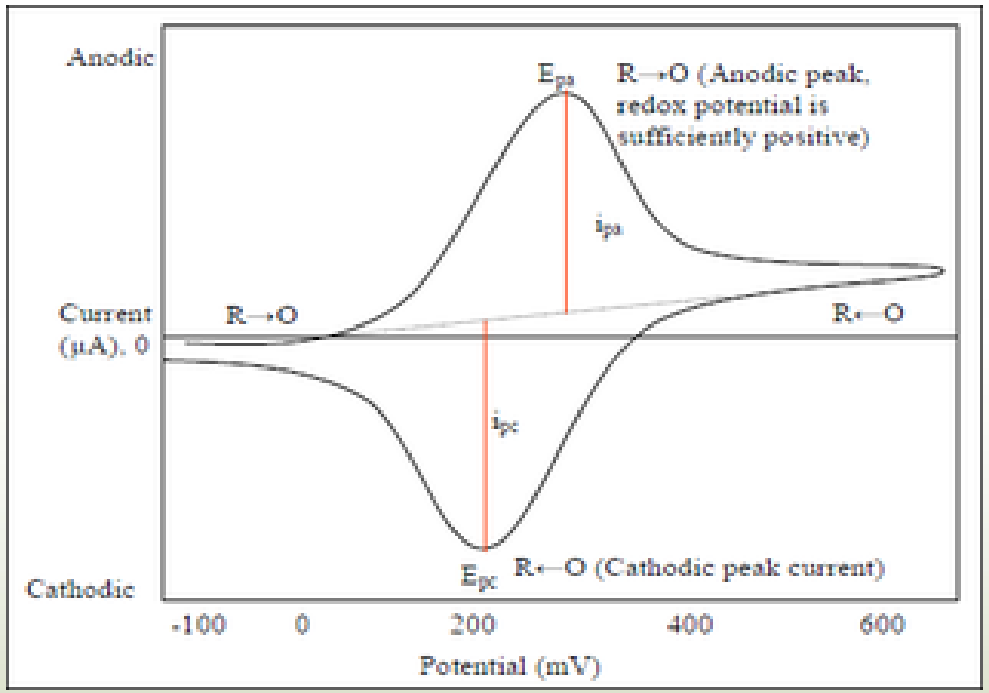
Introduction

Voltammetric



Cyclic voltammetry versus absorption spectroscopy

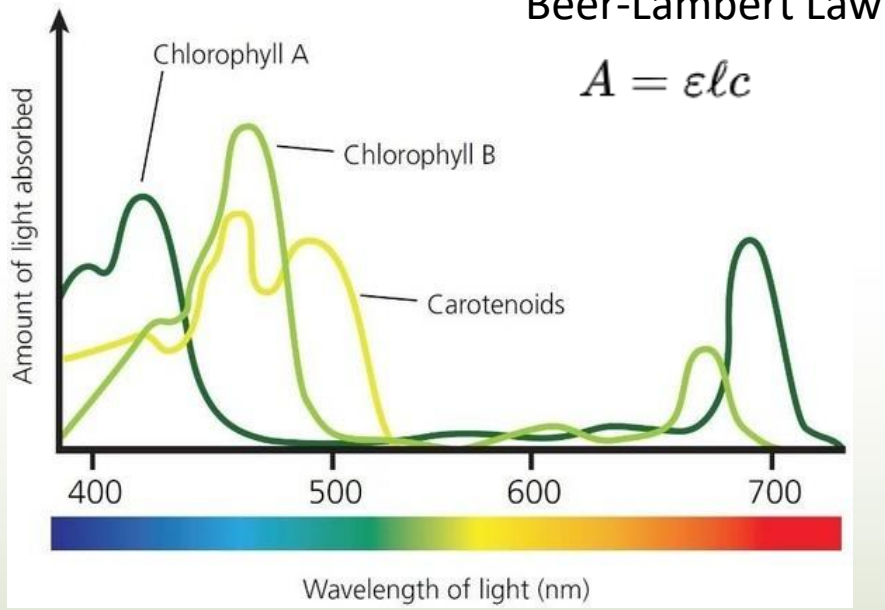
Randles–Sevcik equation



Cyclic voltammetry

Beer-Lambert Law

$$A = \varepsilon \ell c$$



Absorption spectroscopy

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Cuvettes and chips

Cuvette

Chip

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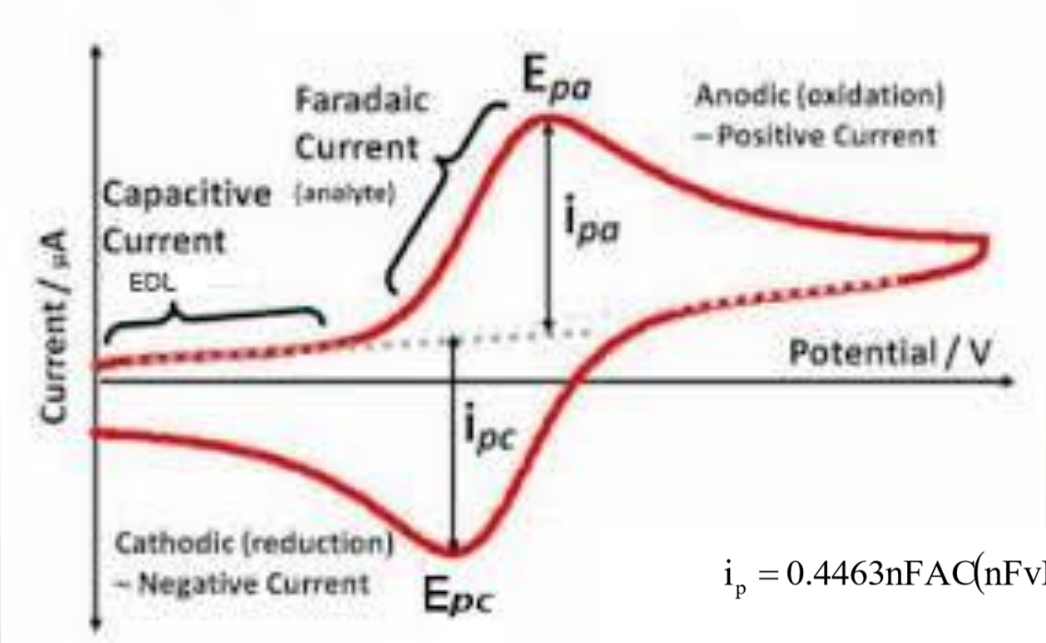
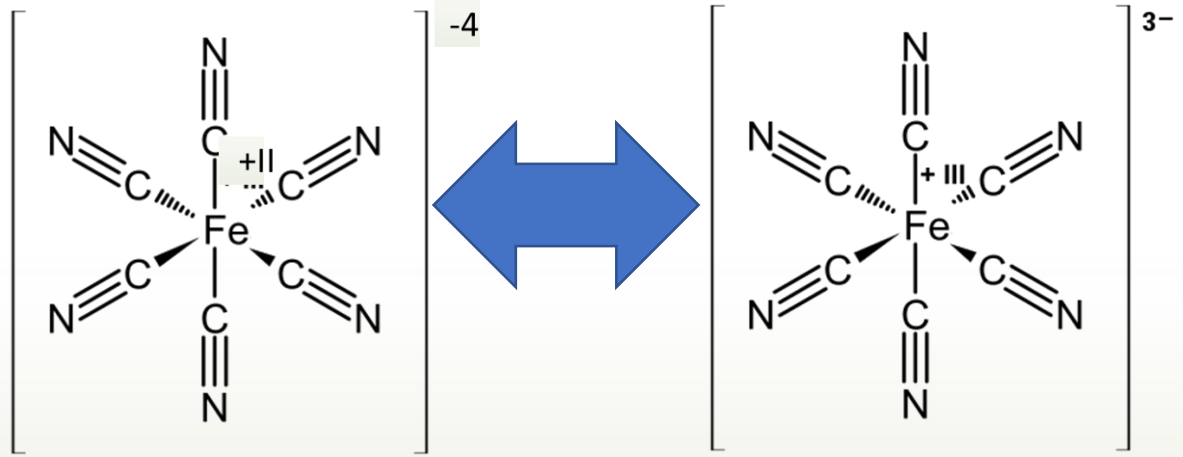
Cyclic voltammetry





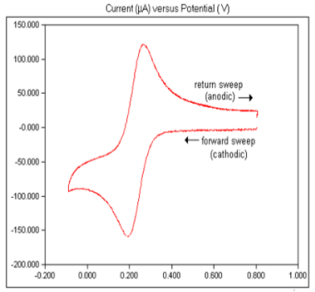
$$i_p = 0.4463nFAC(nFvD/RT)^{1/2}$$

n = Number of electrons

F = Faraday's Constant 96,485 C/mole

A = Electrode Area cm^2

D = Analyte Diffusion Coefficient $cm^2\ s^{-1}$



Ratio of i_{pa} to i_{pc} should be close to one, but vary with chemical reactions coupled to electrode process.

1 mM potassium ferrocyanide and 1 mM ferricyanide in 1 M NaCl

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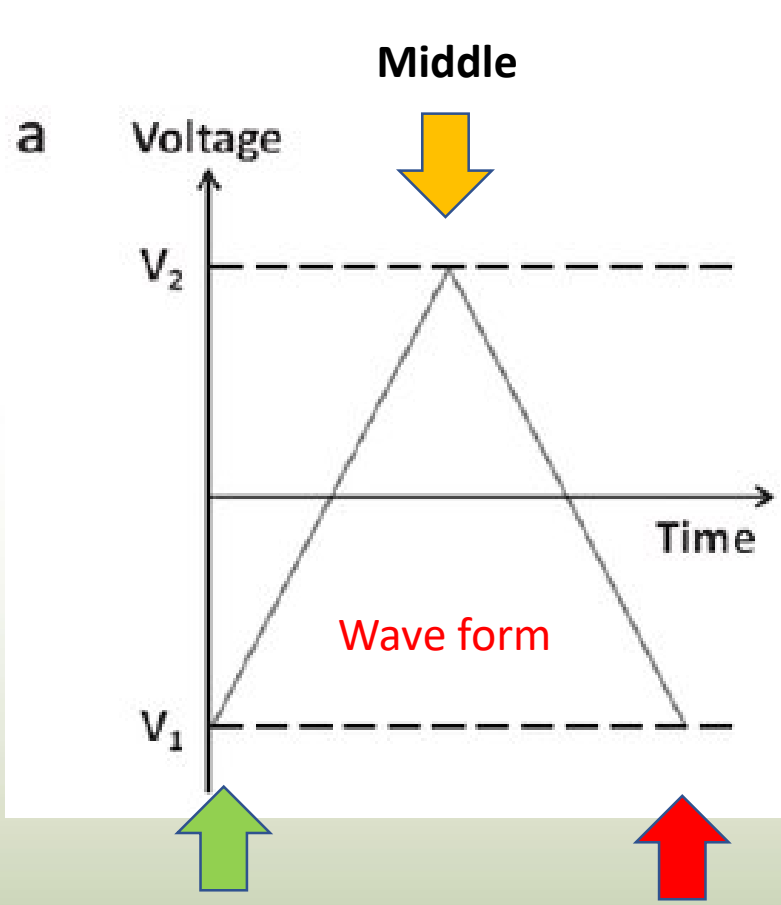
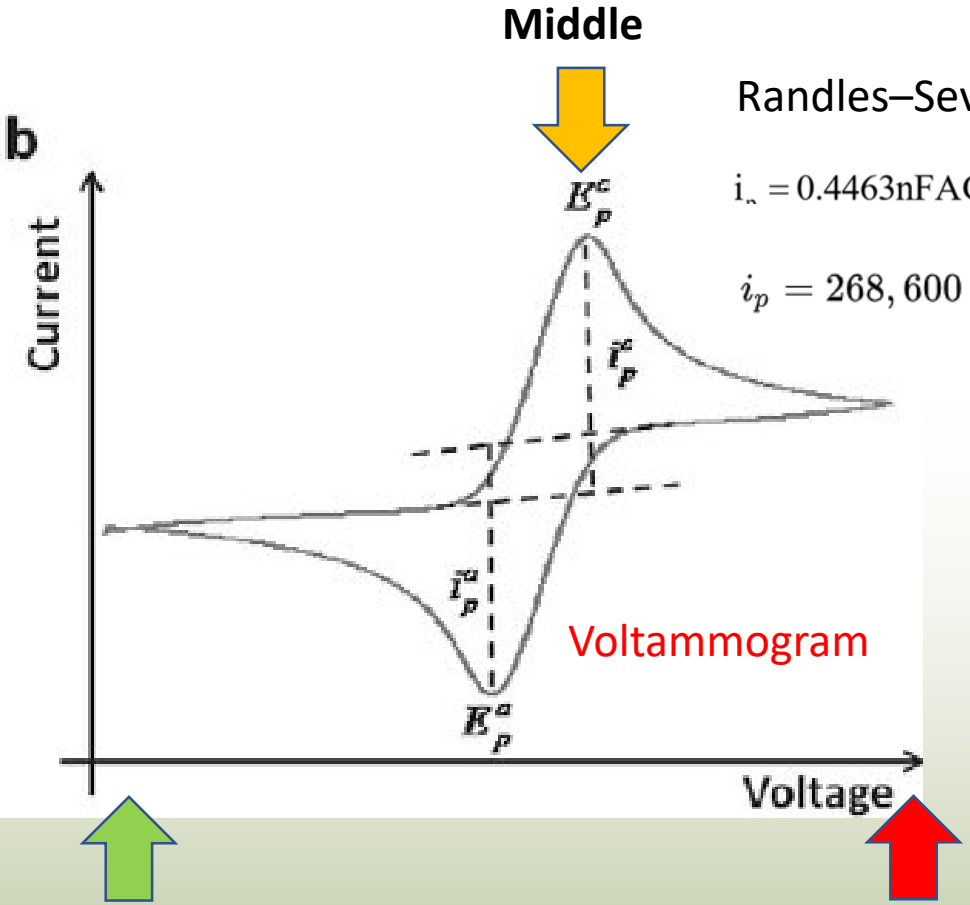
Waveform/Excitation – Cyclic Voltammetry





Randles–Sevcik equation

$$i_p = 0.4463nFAC(nFvD/RT)^{1/2}$$

$$i_p = 268,600\, n^{\frac{3}{2}} AD^{\frac{1}{2}} Cv^{\frac{1}{2}}$$

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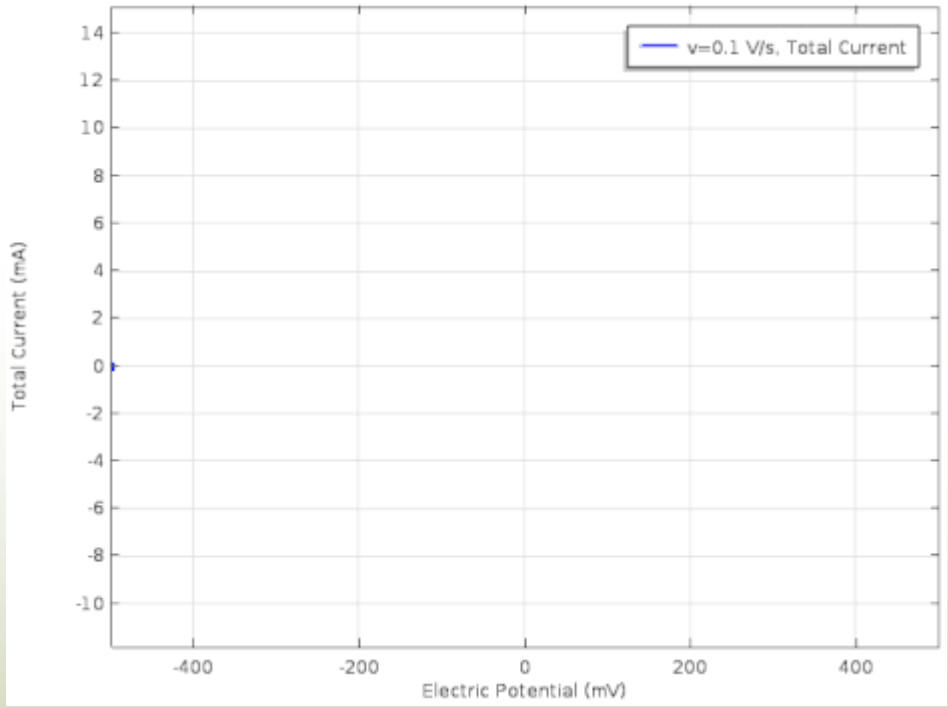
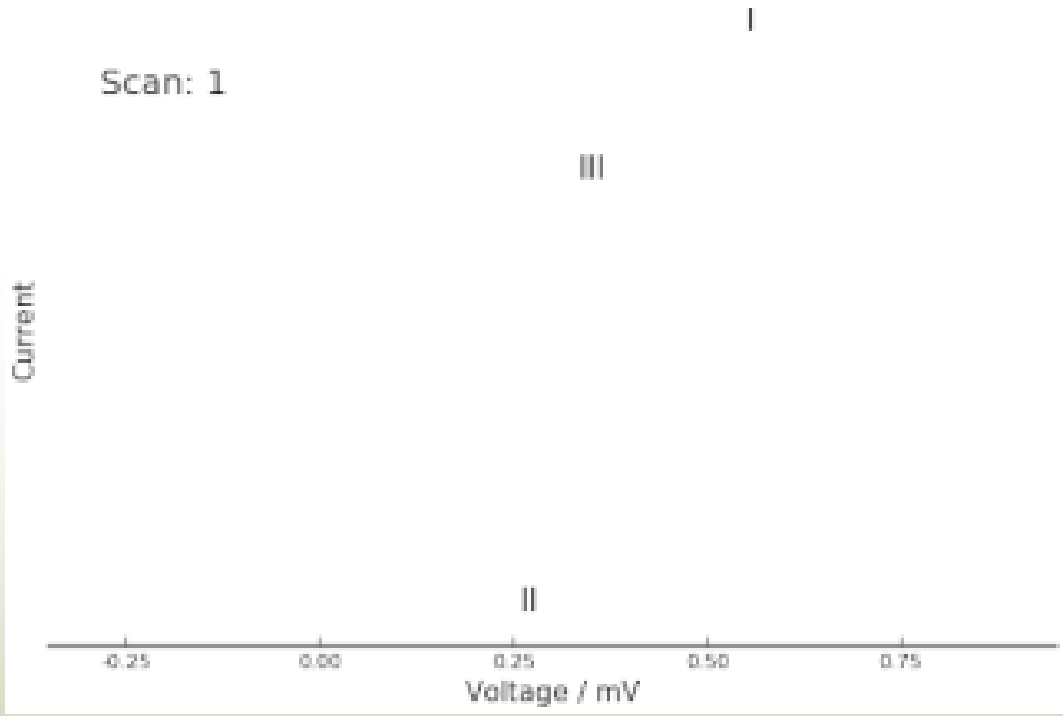
CV simulations



Ferro/ferricyanide



Capsaicin

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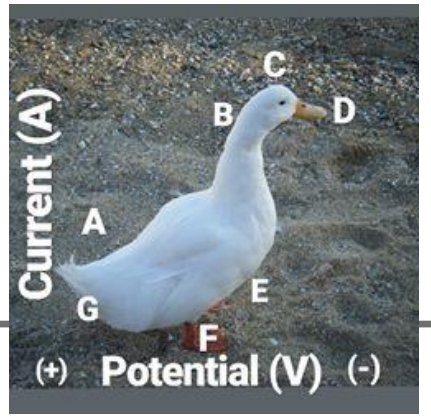
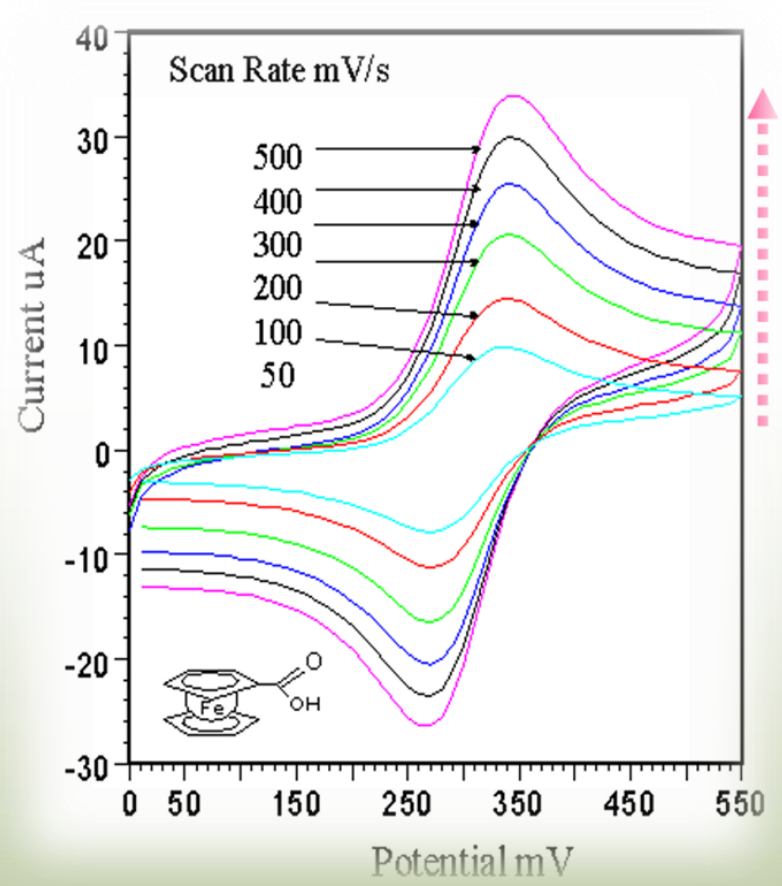
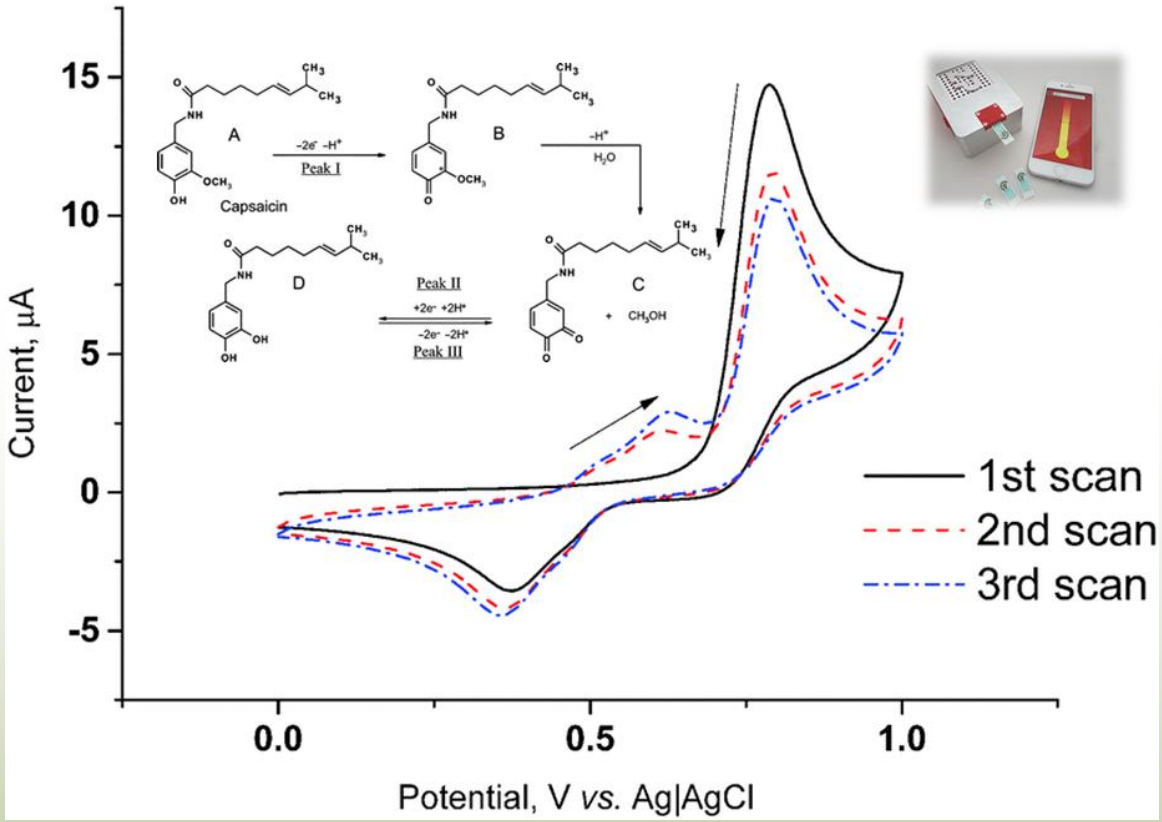
Cyclic voltammetry







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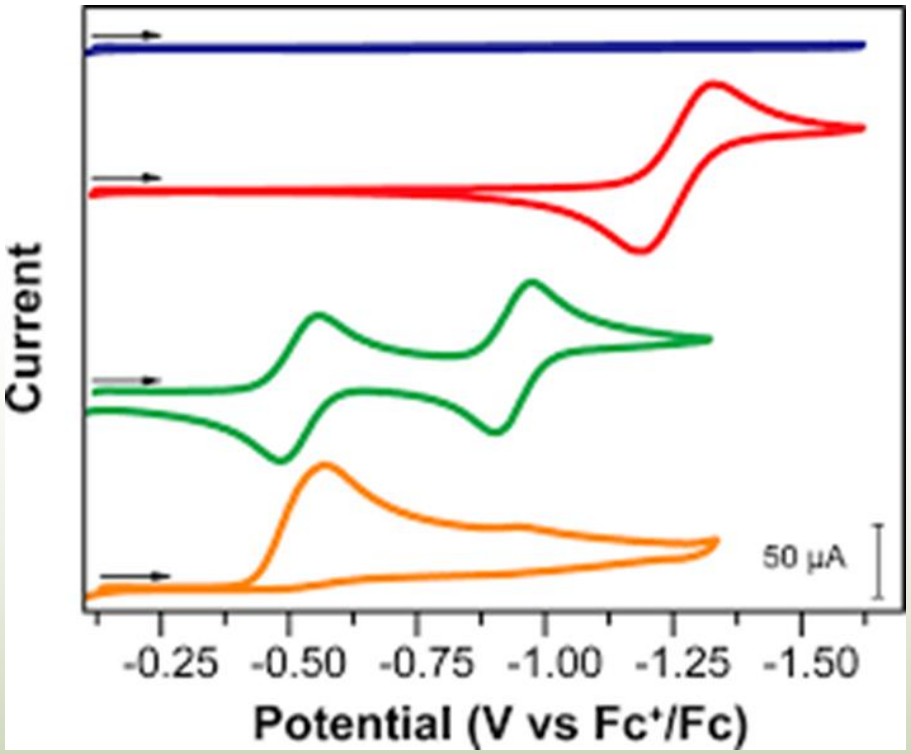
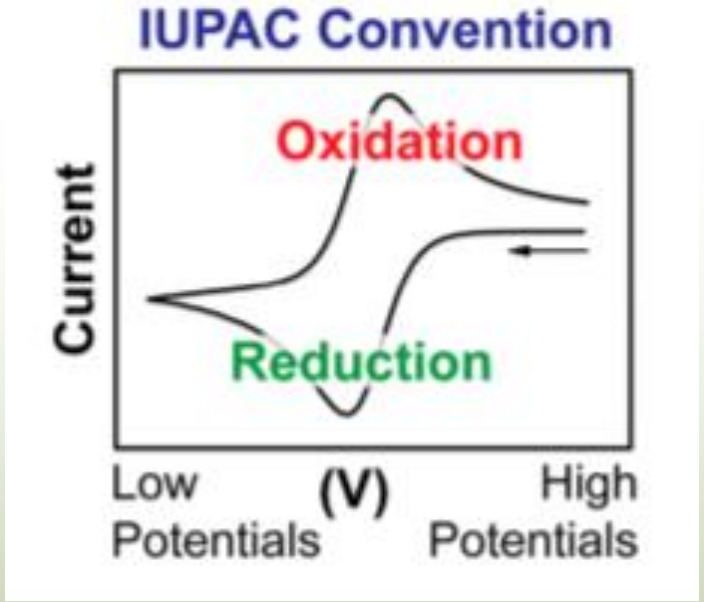
Cyclic voltammetry

$$i_p = 0.446nFAC^0\left(\frac{nF\upsilon D_o}{RT}\right)^{1/2}$$

ip α concentration





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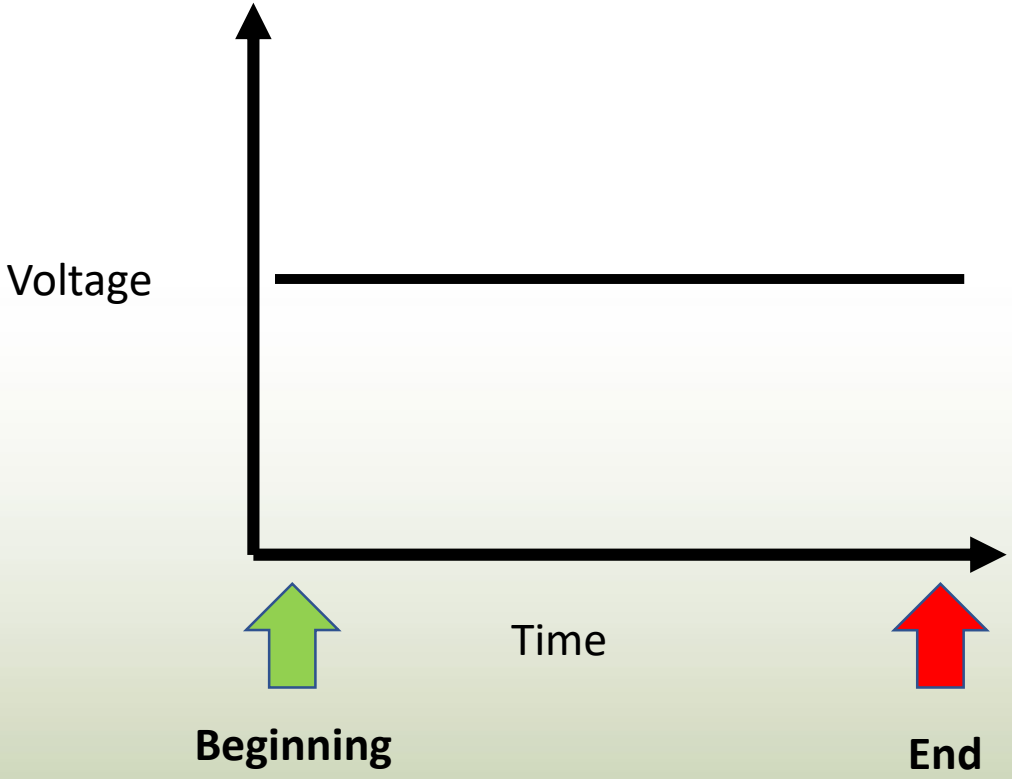
CV demo

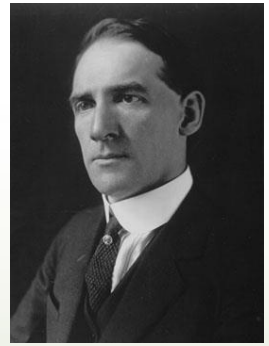
Amperometric wave form

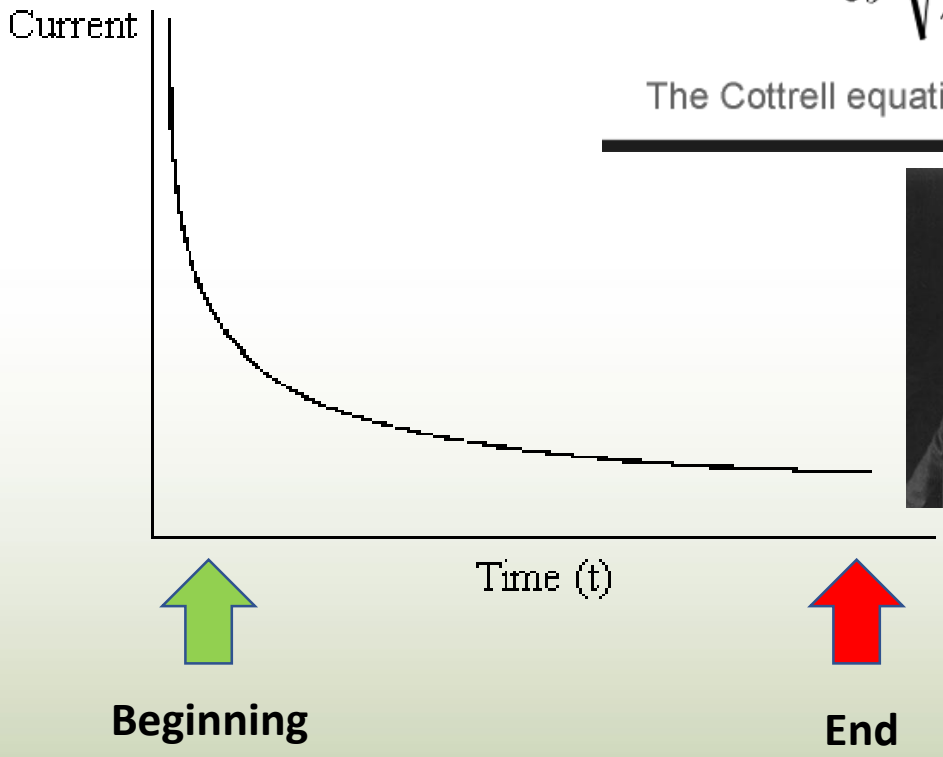


Ficks 2nd Law of diffusion

$$I = n F A c_o \sqrt{\frac{D}{\pi t}}$$

The Cottrell equation





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Potentiometric sensors

$$E = E_0^{'} + 0.0591\ pH_{outside}$$

pH equation derived from the Nernst equation

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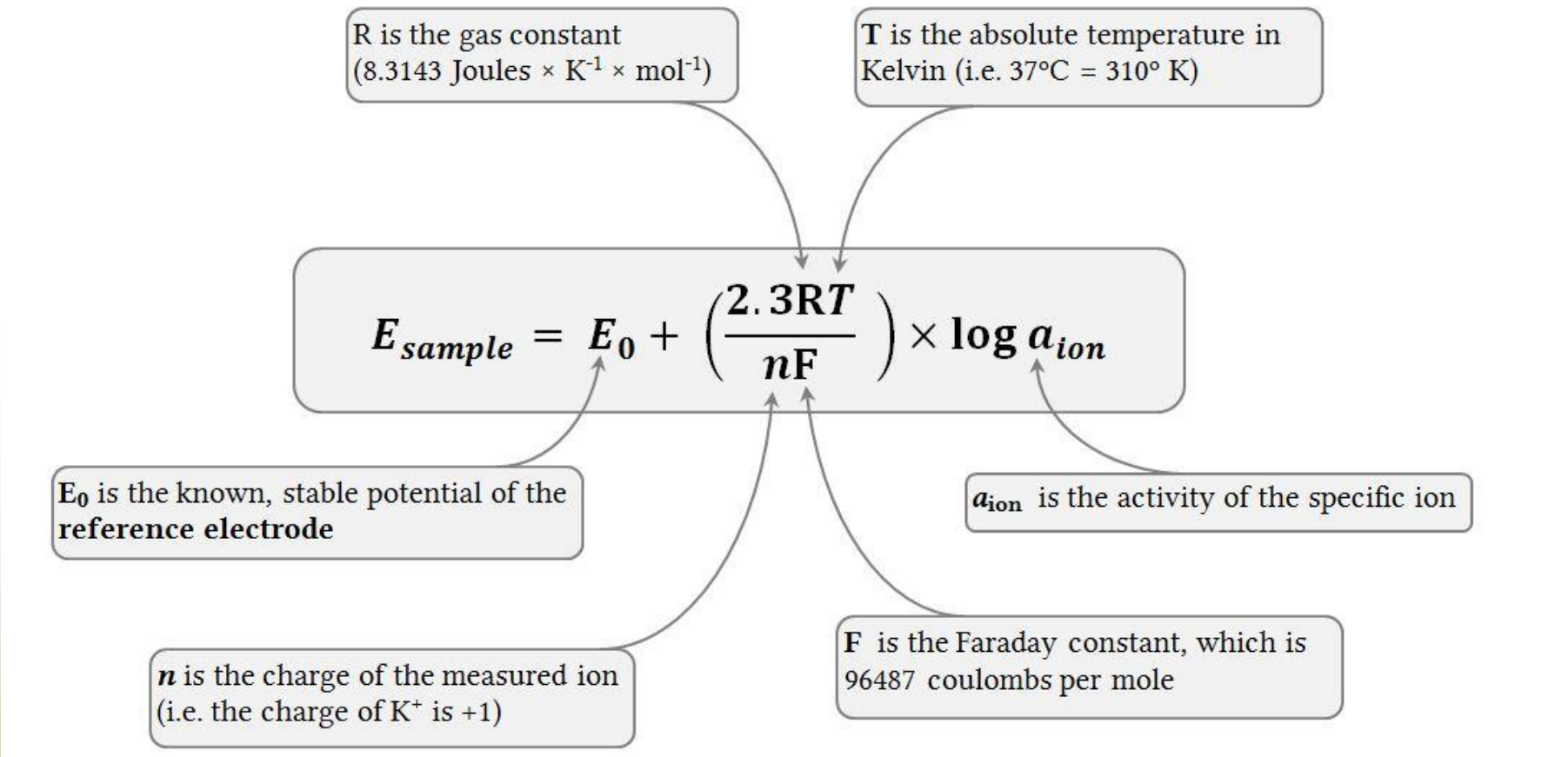
Potentiometric Equation



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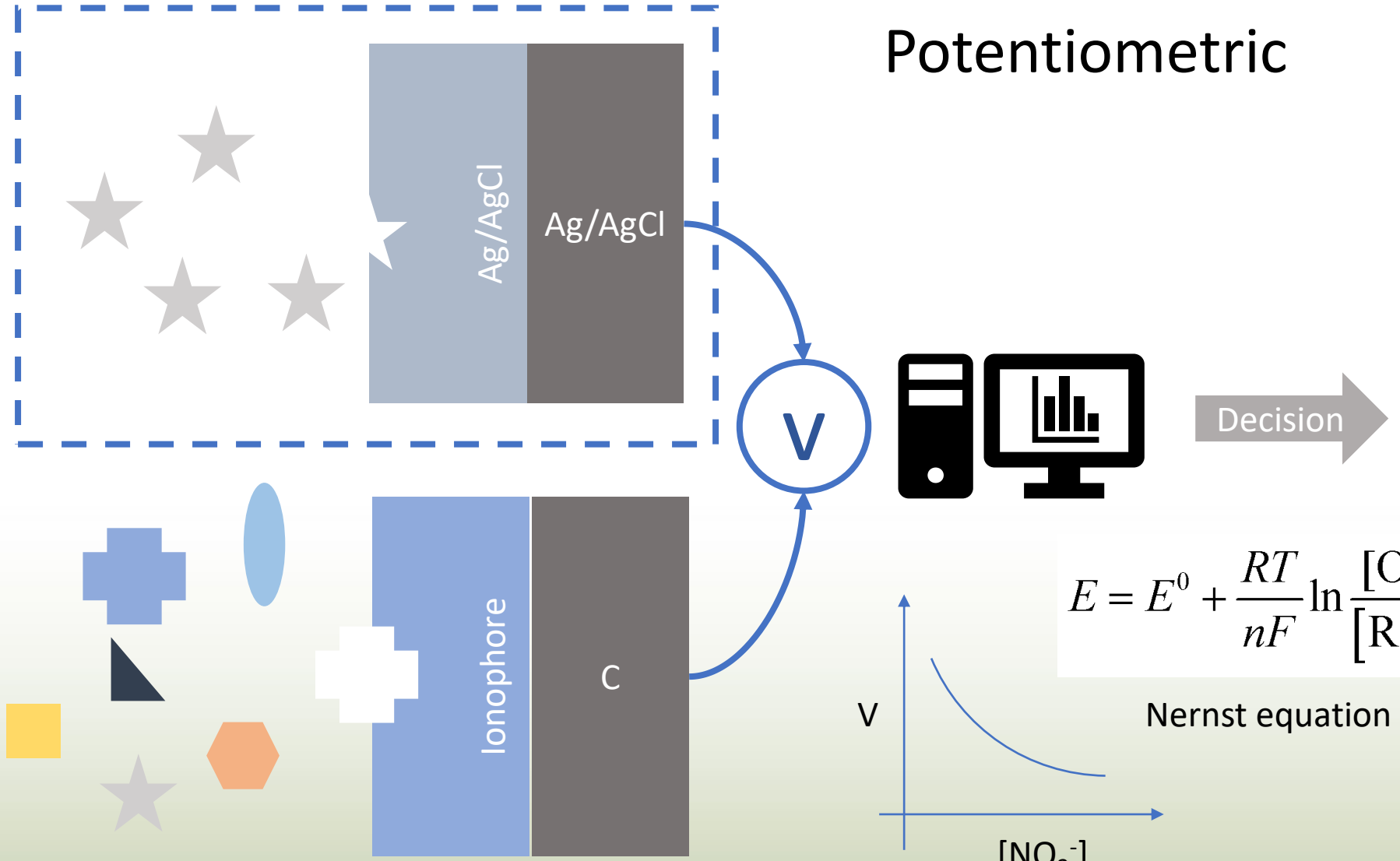
Potentiometric



$$E = E^0 + \frac{RT}{nF} \ln \frac{[\mathrm{Ox}]}{[\mathrm{Red}]}$$

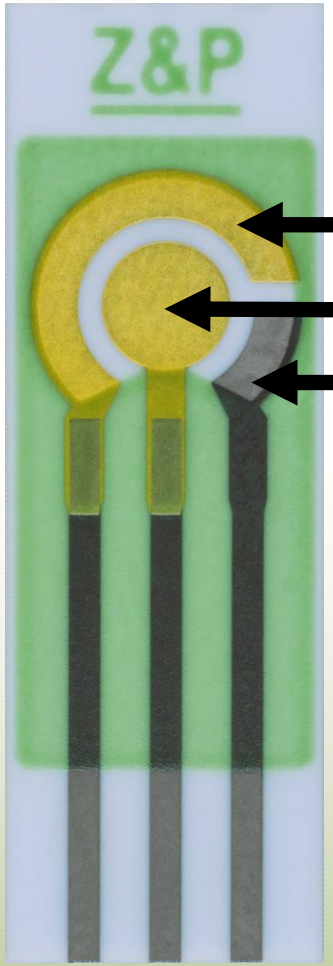
Nernst equation

R. Shaw, A. P. Williams, A. Miller, and D. L. Jones (2013), *Agric.*, vol. 3, no. 3, pp. 327–341, 2013.

Potentiometry demo

Biosensors

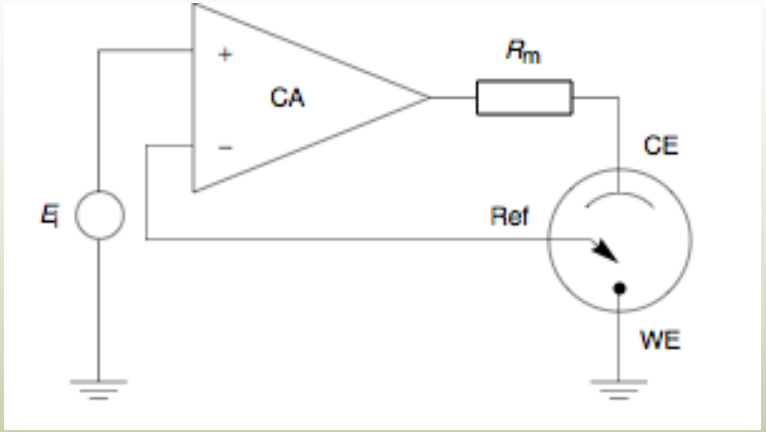
An anatomy lesson

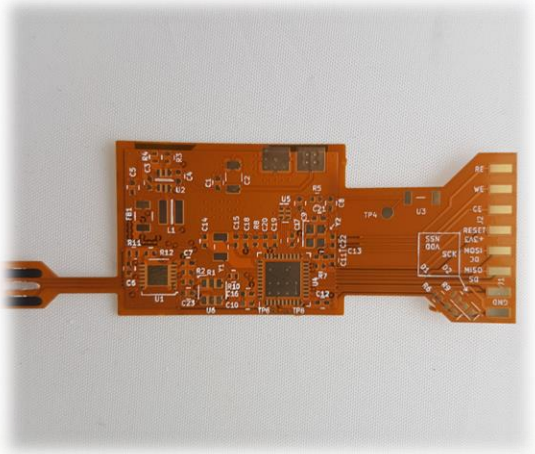


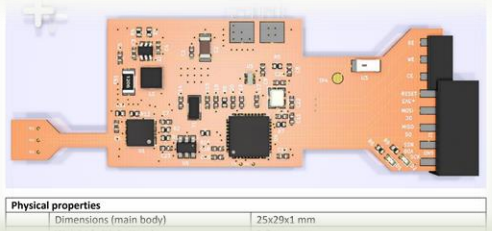
Counter electrode

Working electrode

Reference electrode







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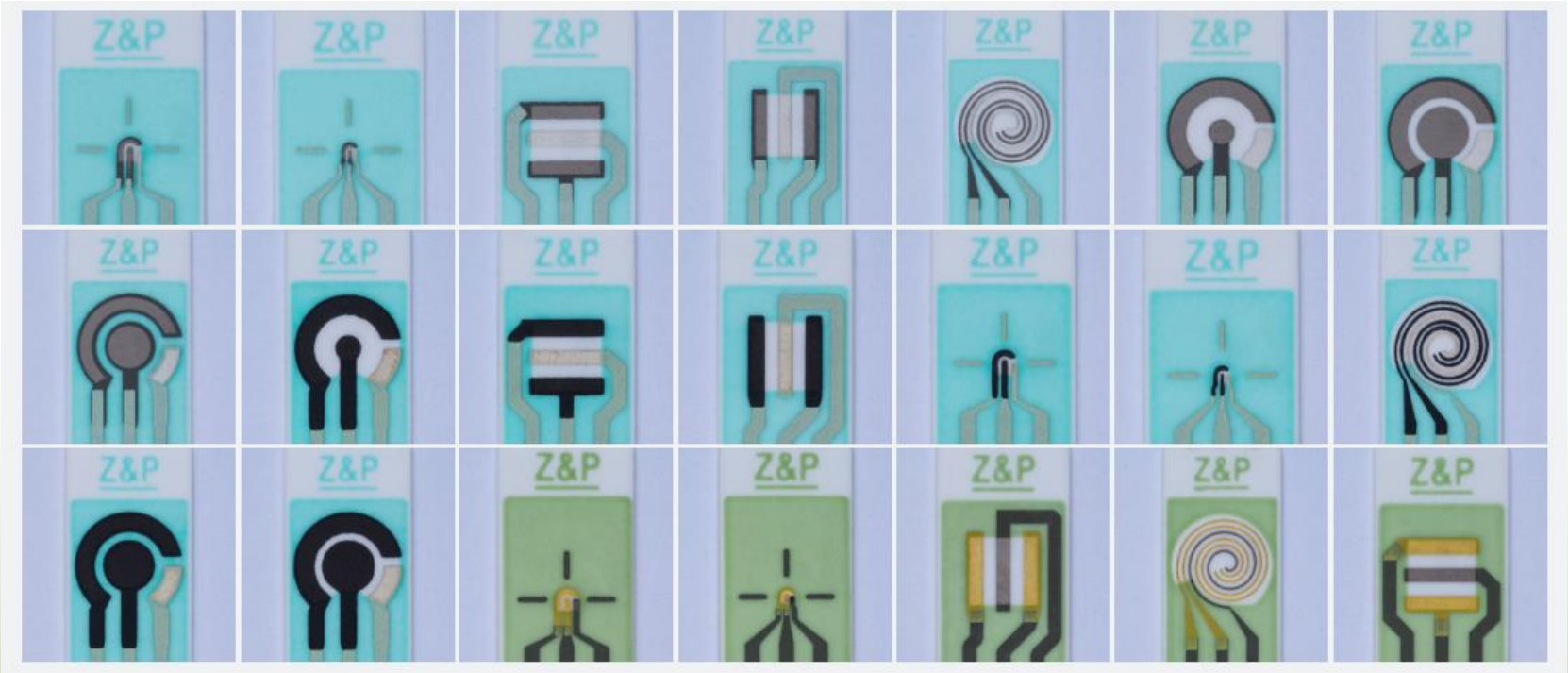
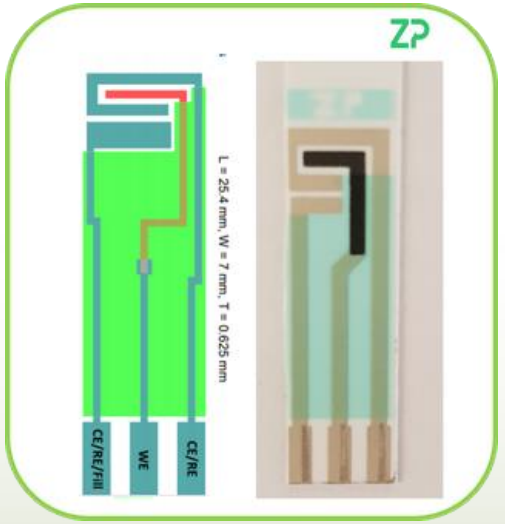
Screen printed electrodes





99 cents

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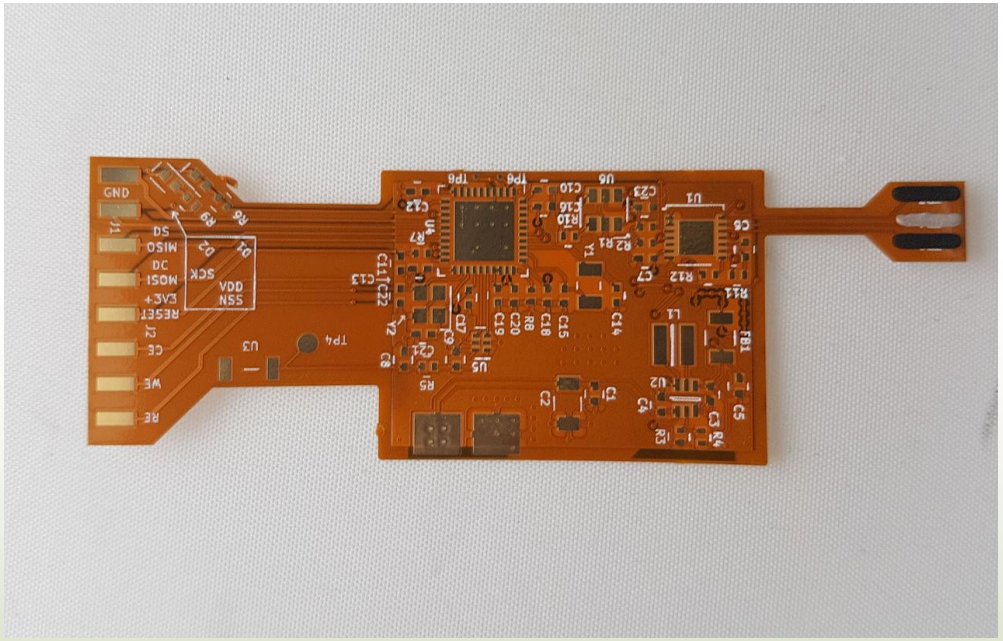
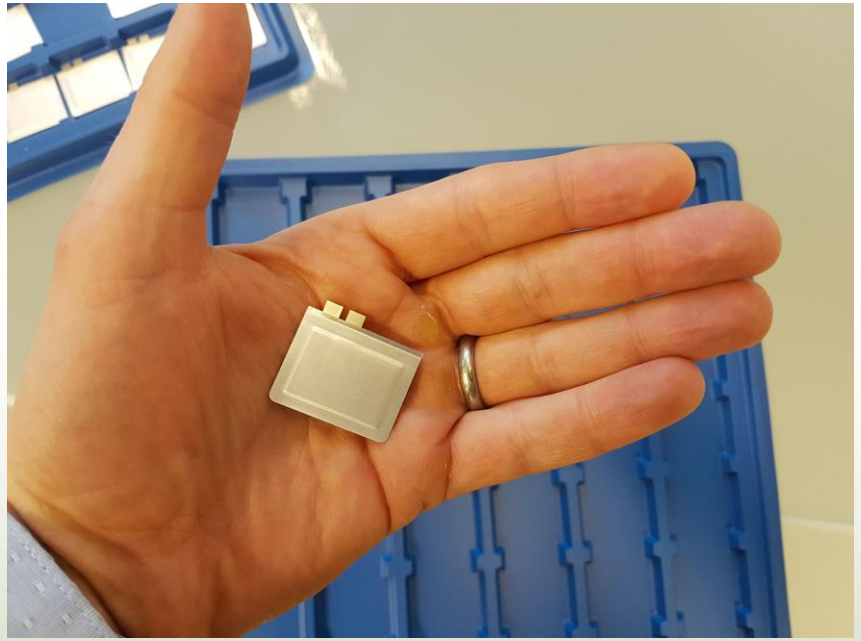
Wearables





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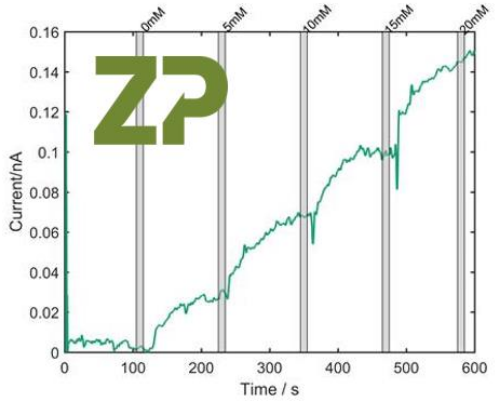
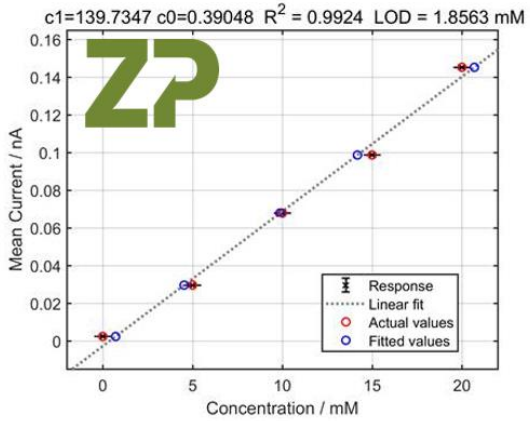
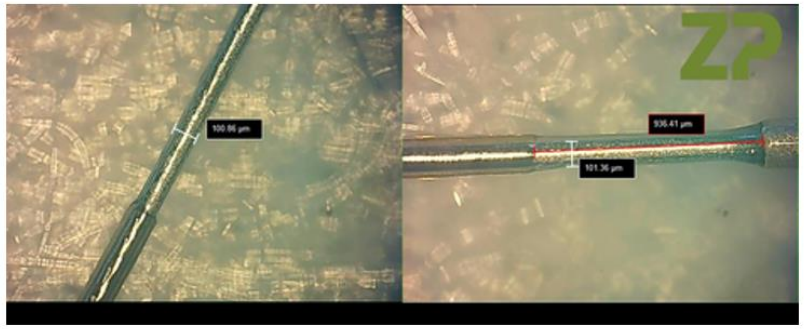
What does a signal look like?

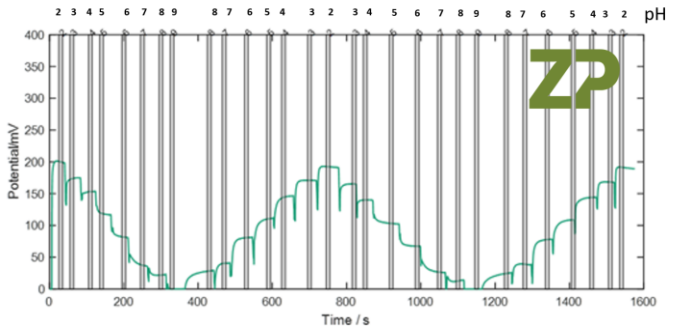
Amperometric Glucose Sensor

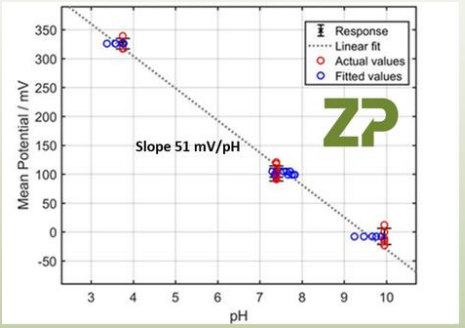






Potentiometric pH Sensor





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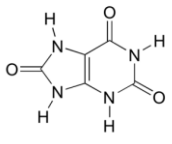
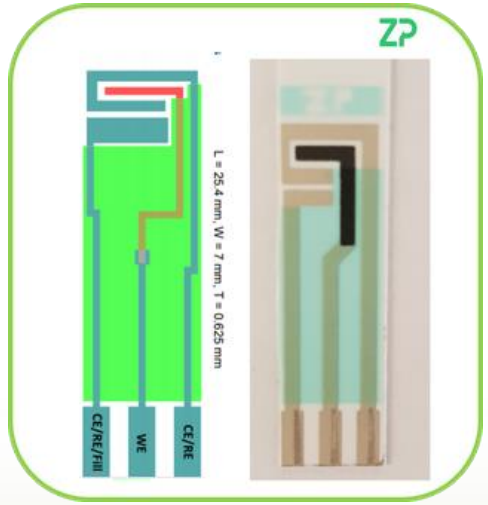
Applications Sensors

O_2	K^+	Lac	NH_4^+	NO	pH	H_2O_2
Glu	Chilli	Ca^{2+}	S/m	Na^+	NO_3^-	HPO_4^{2-}
	SO_3^{2-}	 Uric acid	Cl^-	ORP	TAS	FRAP



Ferric Reducing Ability of Plasma – Total Antioxidant Status

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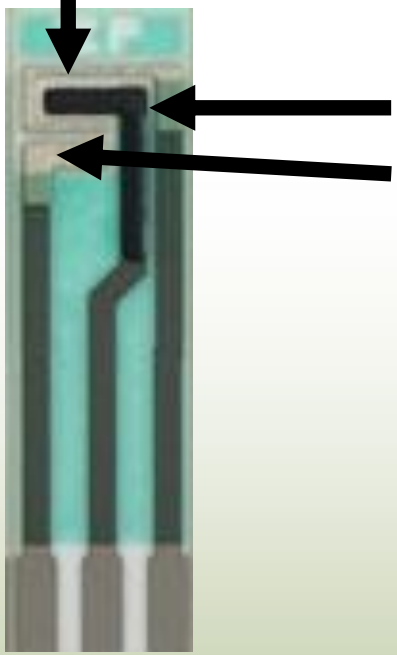
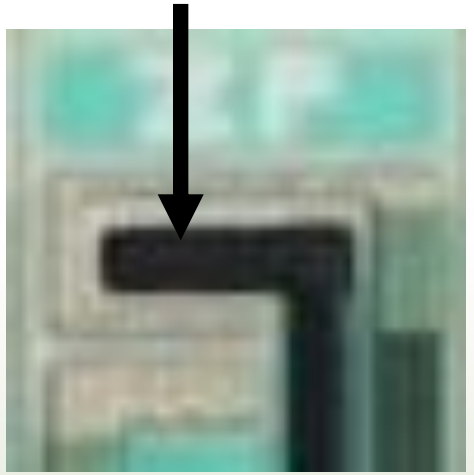
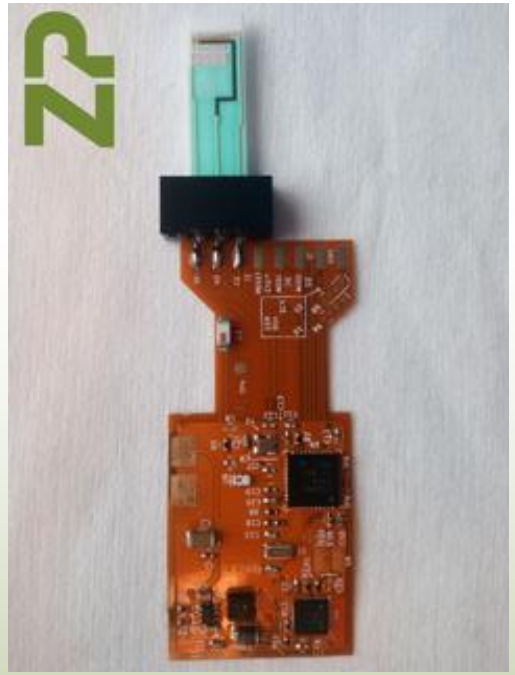
Turning a conductive surface into a biosensor

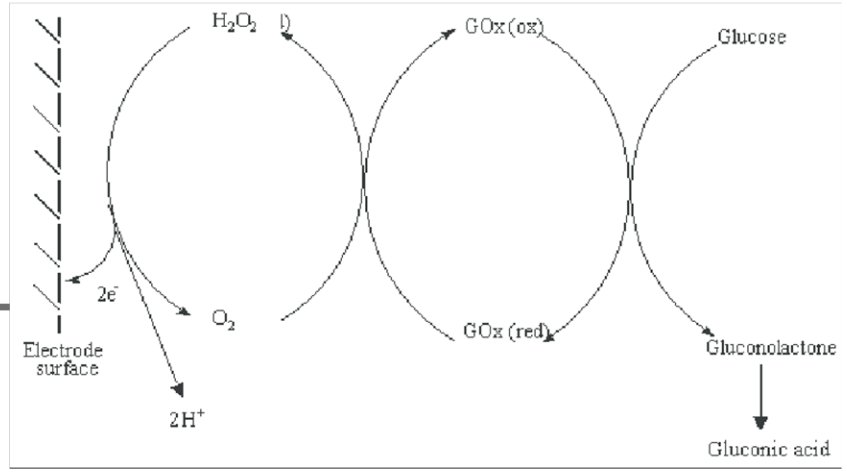


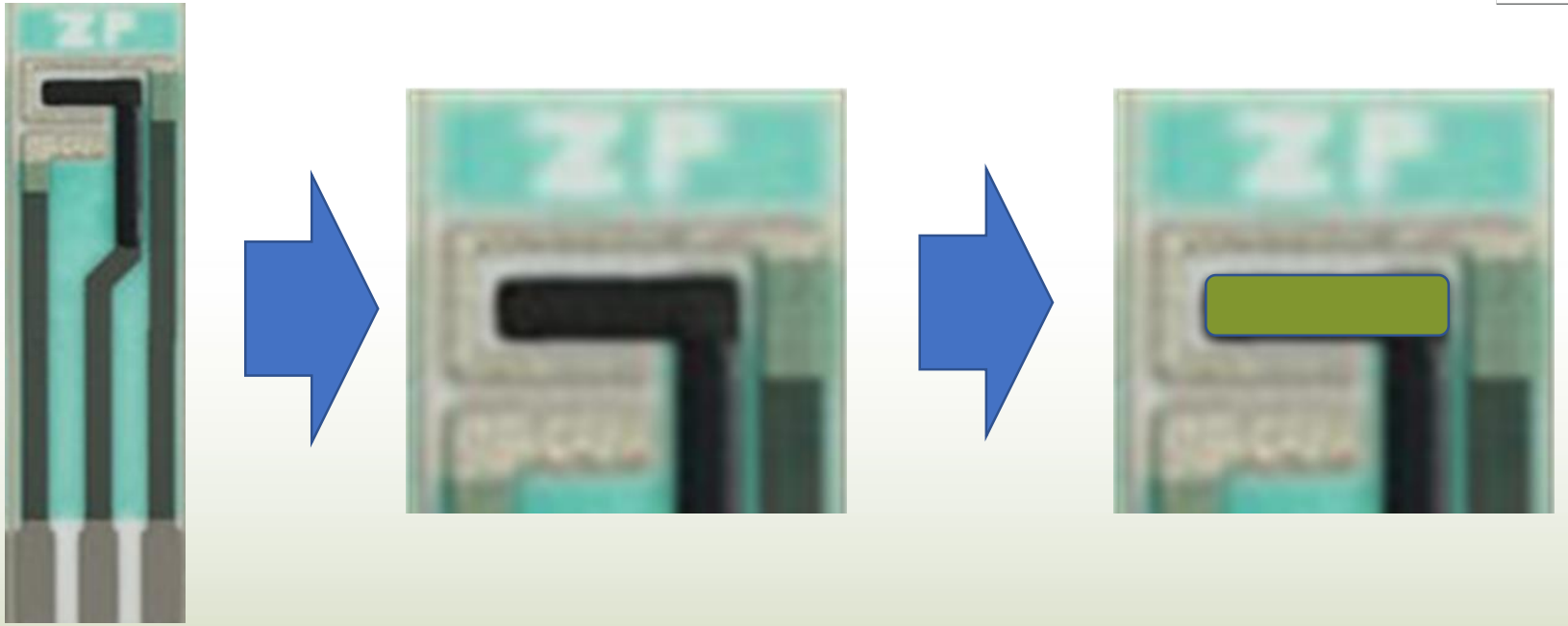




Zimmer & Peacock

Turning an electrode into a sensor





Barrier layer

Enzyme layer

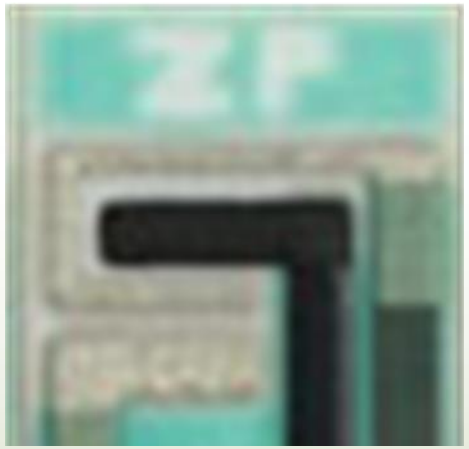
Electrode

Zimmer & Peacock

Functionalization

- Metal oxide – pH
- Ionophores – potassium, sodium, ammonium (0.13 nM)
- Enzymes – glucose, lactate
- Antibodies – Proteins and bacteria (1 µm)

Electrodes are very versatile



Glucose oxidase

Lactate oxidase

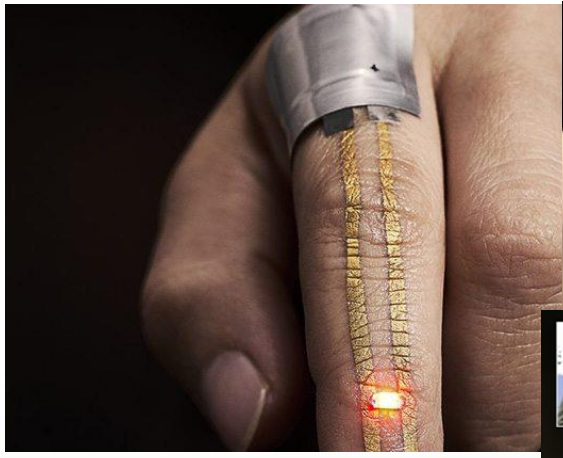
Valinomycin

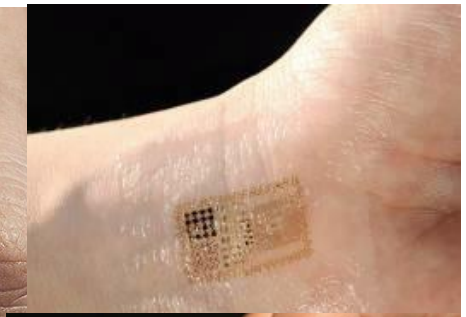
Iridium Oxide

Technology trends in the sensor world IVD

LAB

POC





WEARABLE

ELECTRONIC SKIN/Second Skin

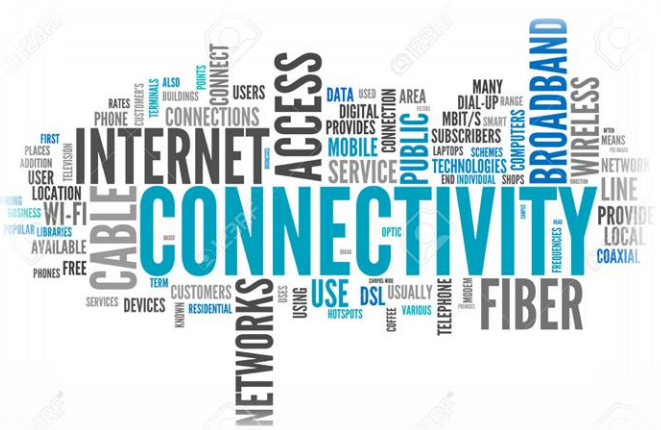
Invasive and Minimally Invasive

Not just medical

Not just the sick

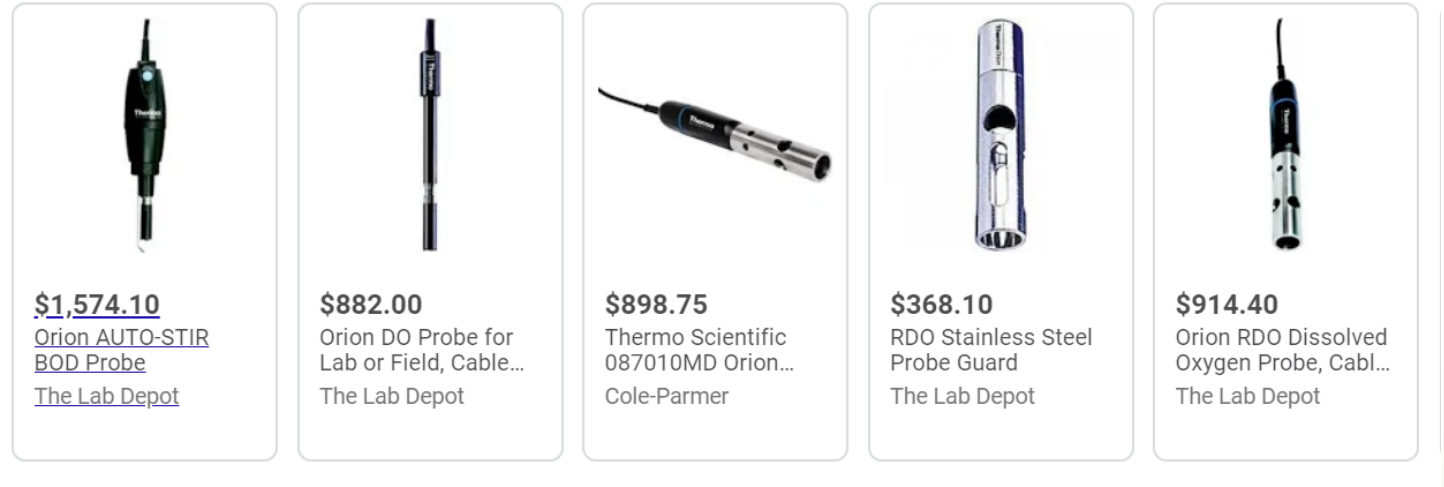
Zimmer & Peacock

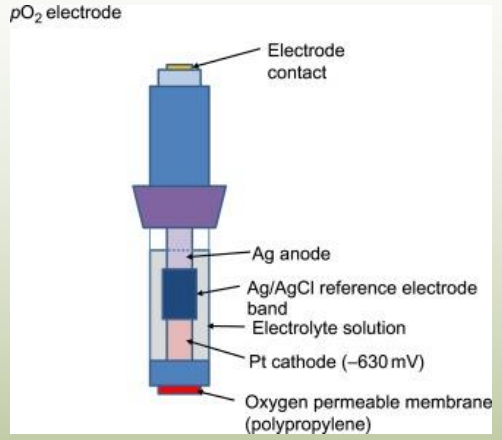
What's hot right now?



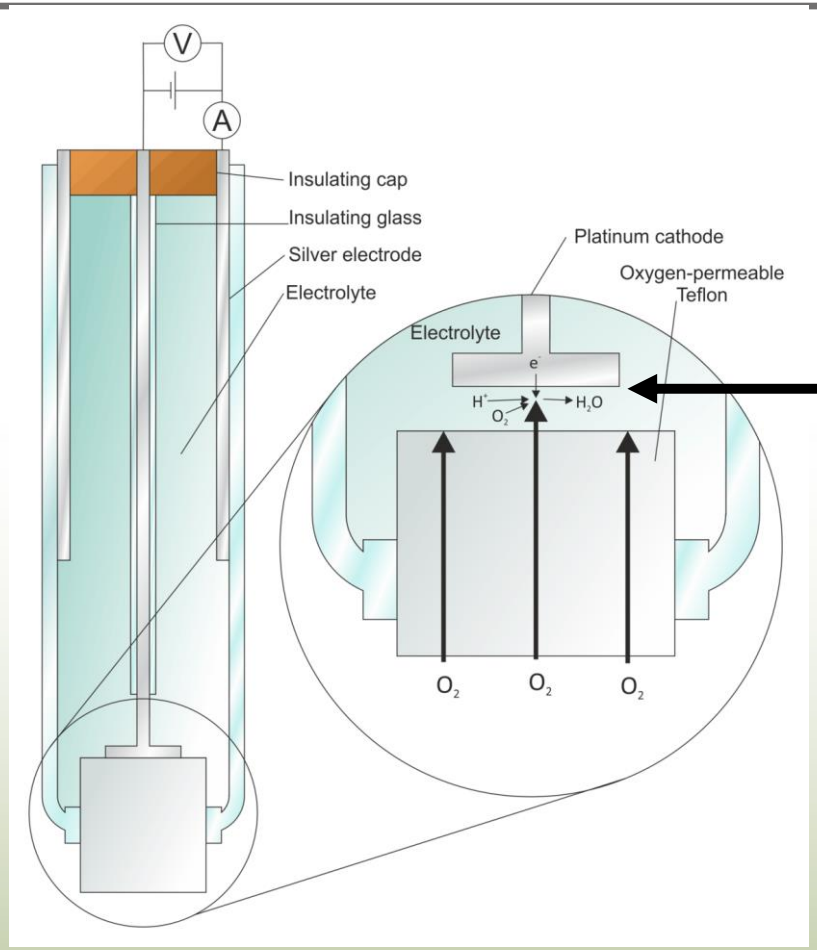
Zimmer & Peacock

Clark electrode – oxygen sensor – first biosensor





Zimmer & Peacock

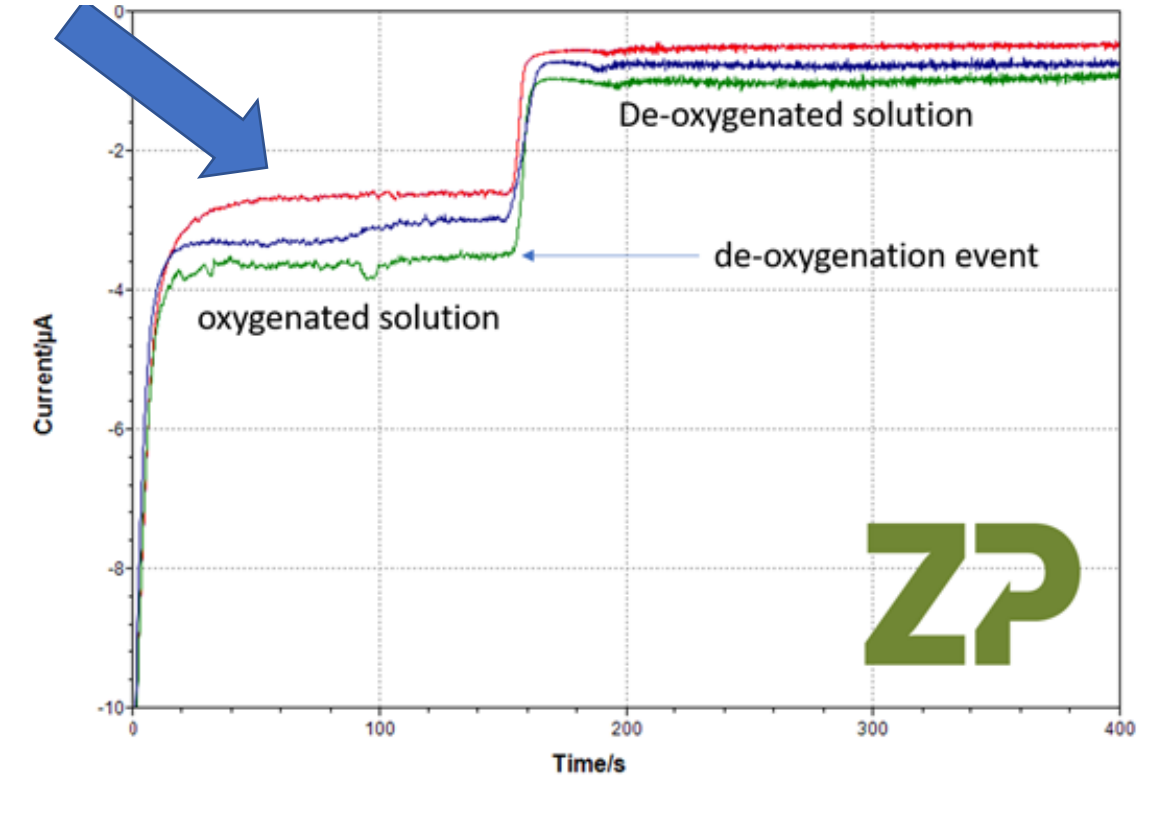


$$O_2 + 4H^- + 4e^- \rightarrow 2H_2O$$

ZP Sensor Data

$$O_2 + 4H^- + 4e^- \rightarrow 2H_2O$$

$$2Na_2SO_3 + O_2 = 2Na_2SO_4$$



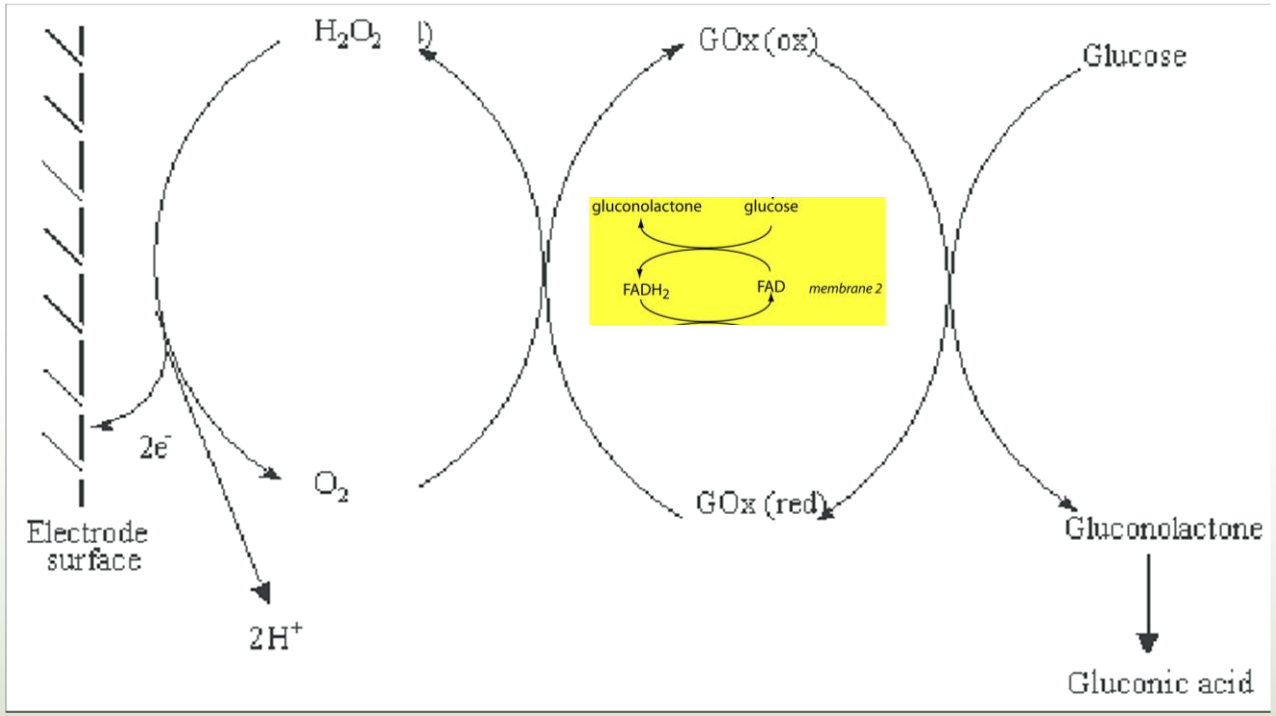
Zimmer & Peacock

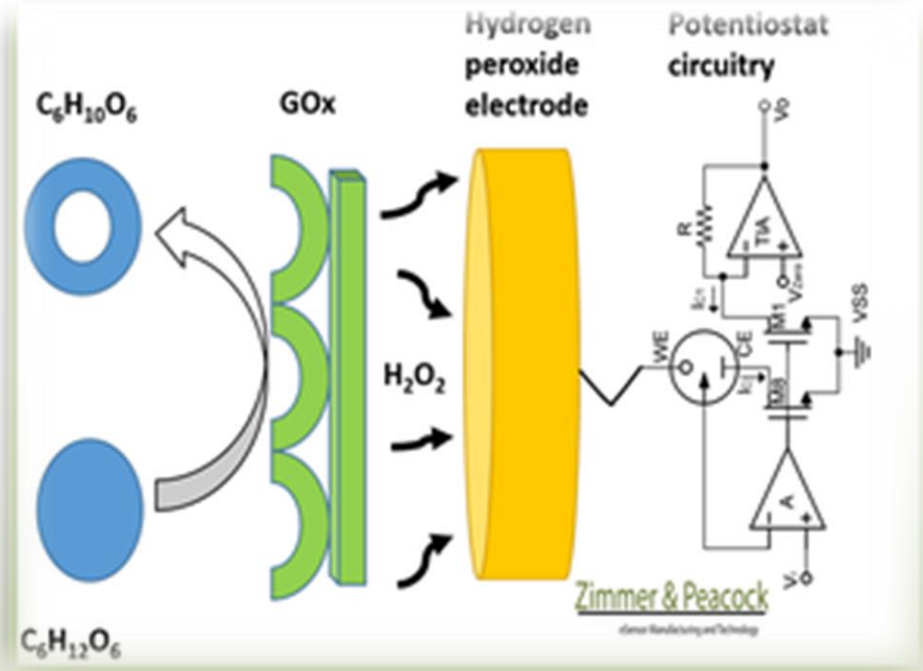
Amperometry - Glucose

Bioelectroanalytical chemistry is the science/technology behind BGM

- Why electrochemistry
  - Easy to manufacture
  - Low cost
  - Runs really well under ambient conditions
  - Limited sample preparation
  - One of the most direct ways of turning chemical/biochemical events into electrical signal

How is the type one glucose sensor working- Gen 1





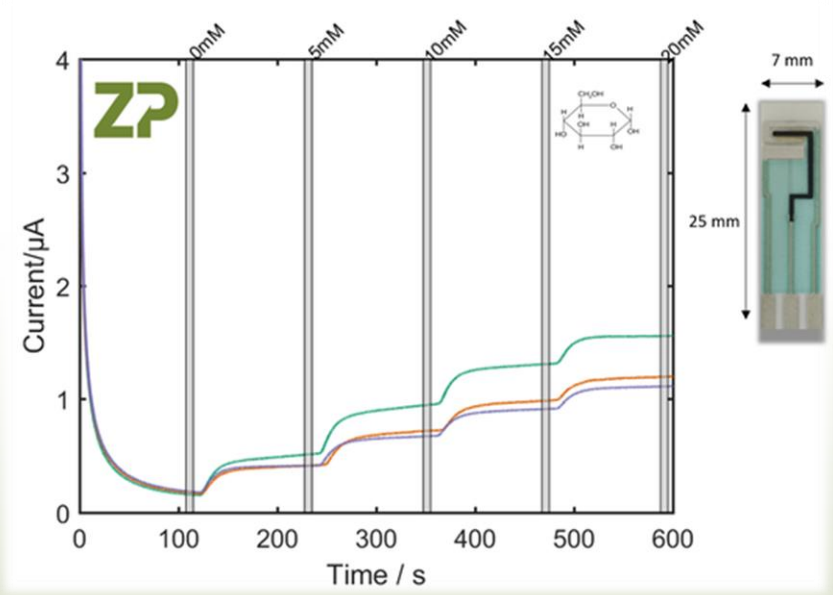
Direction of electron flow

Zimmer & Peacock

Electrochemical detection of glucose

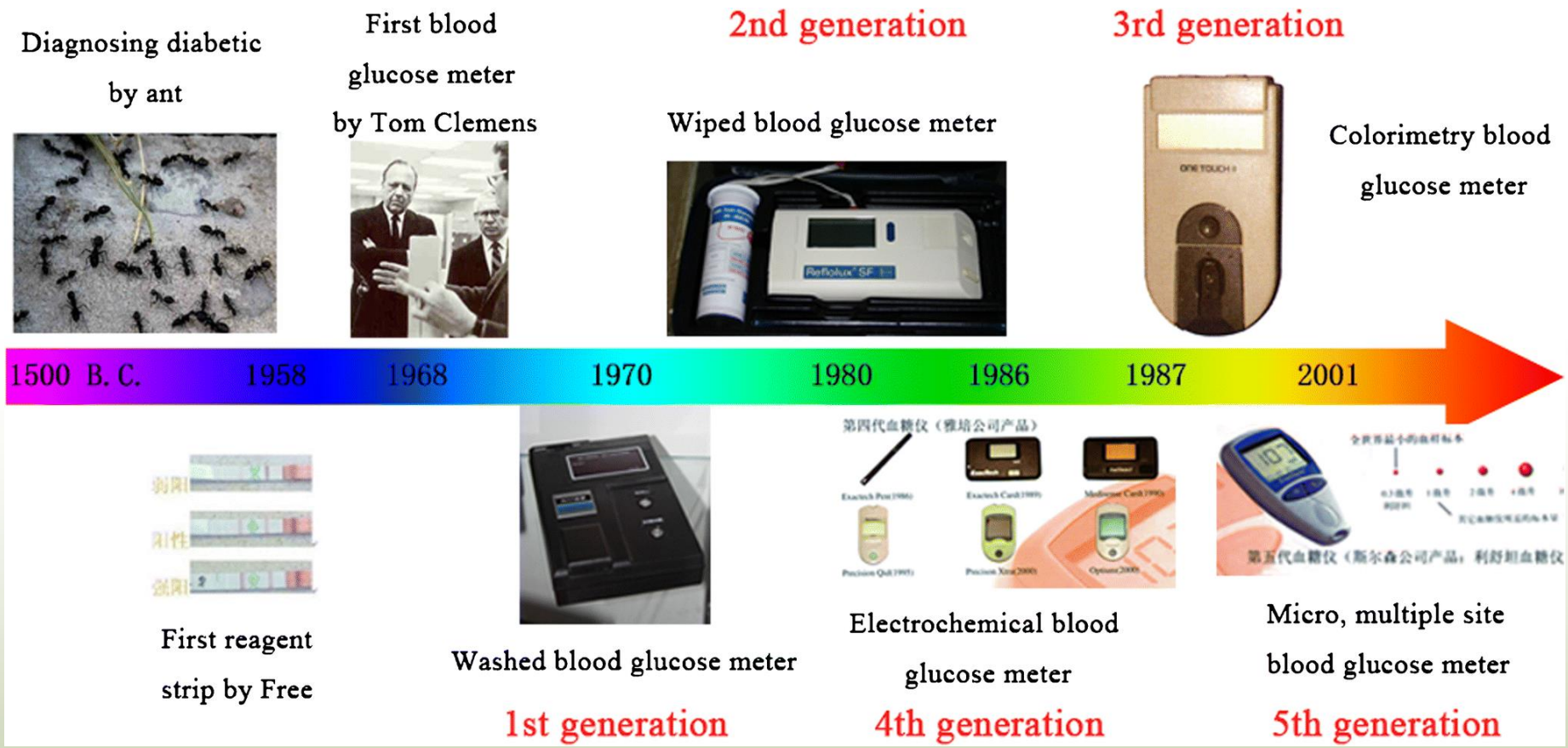
Glu

- Description



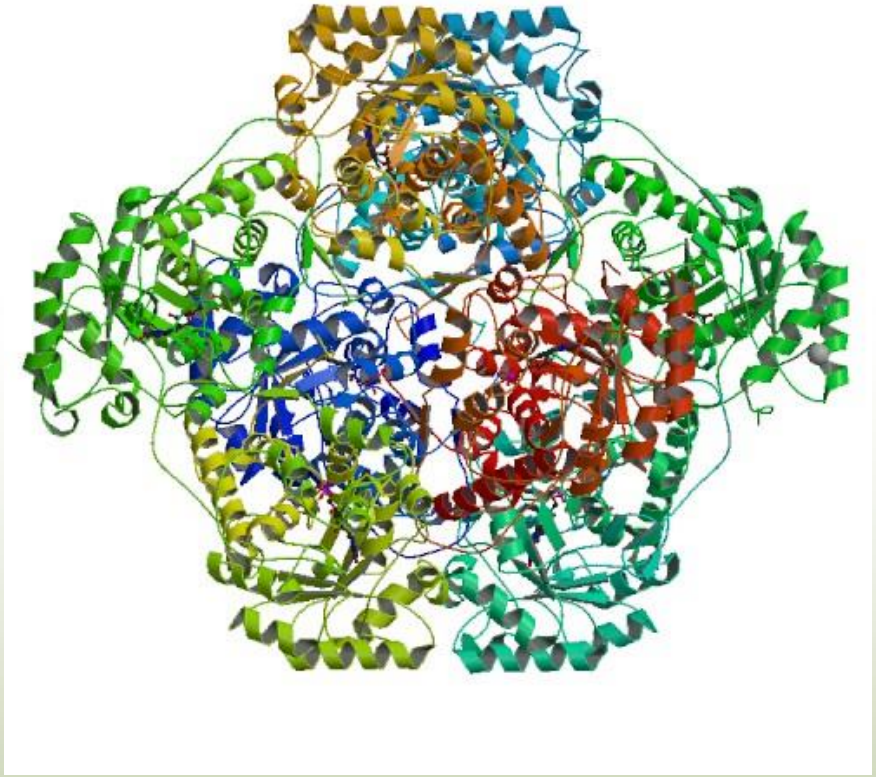
Zimmer & Peacock

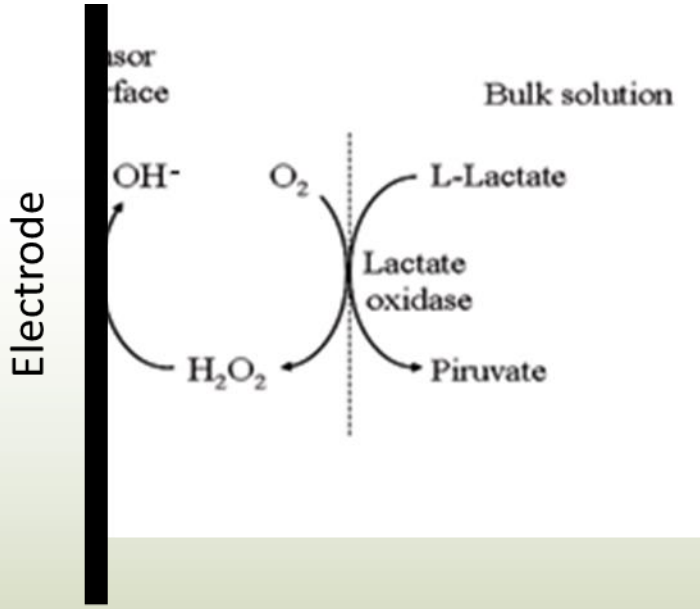
Electrochemistry wasn't the first choice



Lactate

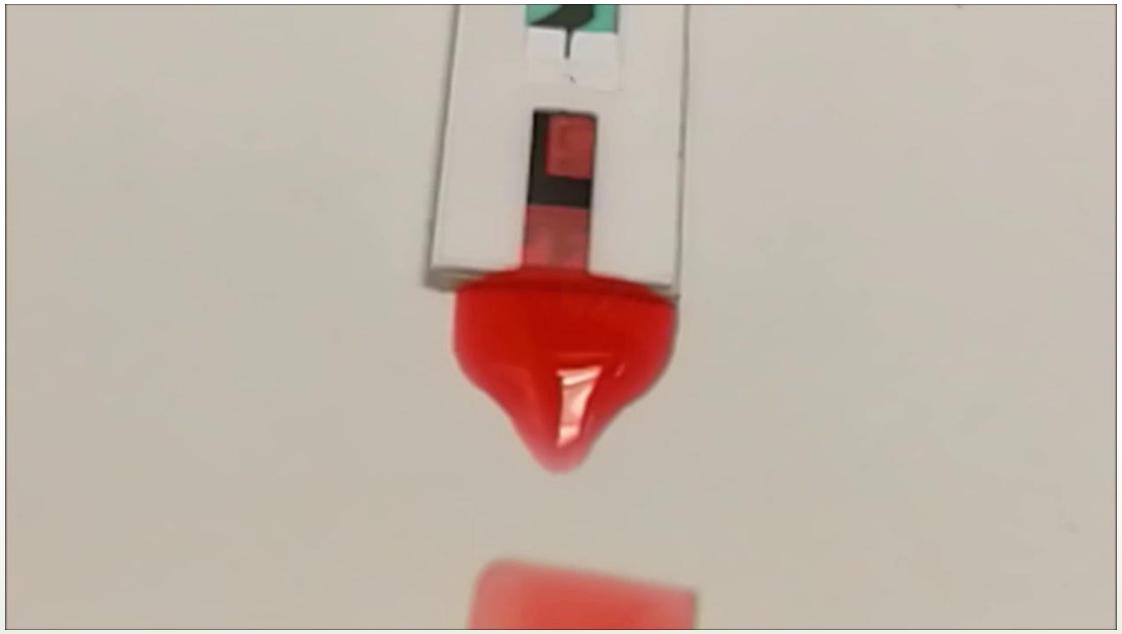
Lactate Oxidase





Microfluidics

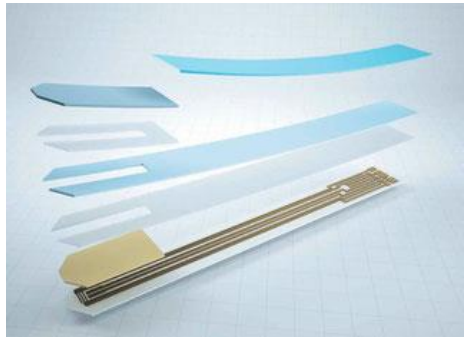
Microfluidics and sensors

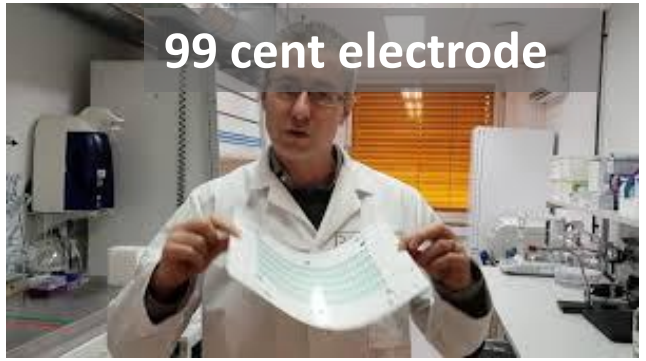


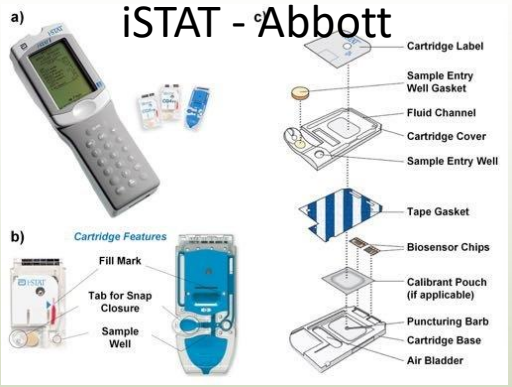
https://www.youtube.com/watch?v=962sjUQLJQE&feature=emb_logo

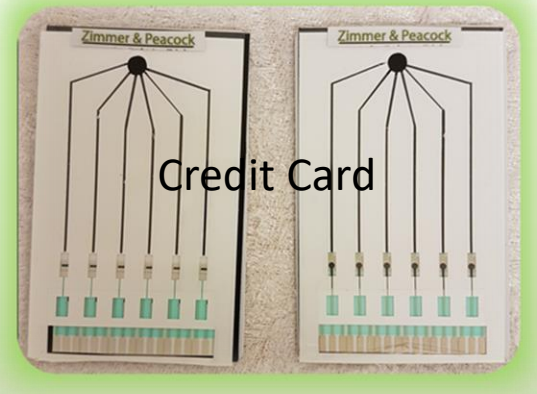
https://www.youtube.com/watch?v=IYdeRfqn92s&feature=emb_logo

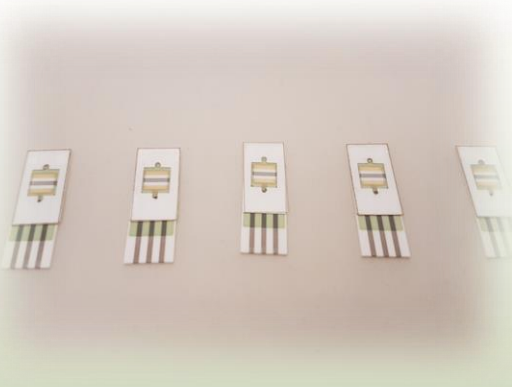
Classic sensors – a quick look at the history of the market









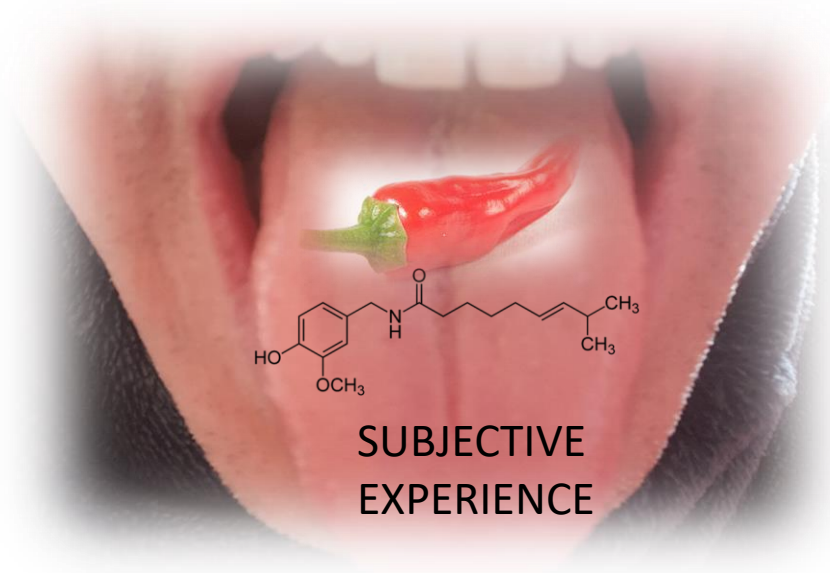


EPOC - Siemens

Case Study - measuring the hotness of chillies

What is ‘hotness’

Heat you feel is a subjective experience ≈
Objective measurement x personal sensitivity



Subjective experience ≈ objective measurement x personal sensitivity

Every person in every culture has a different sensitivity

In my opinion this tastes hot

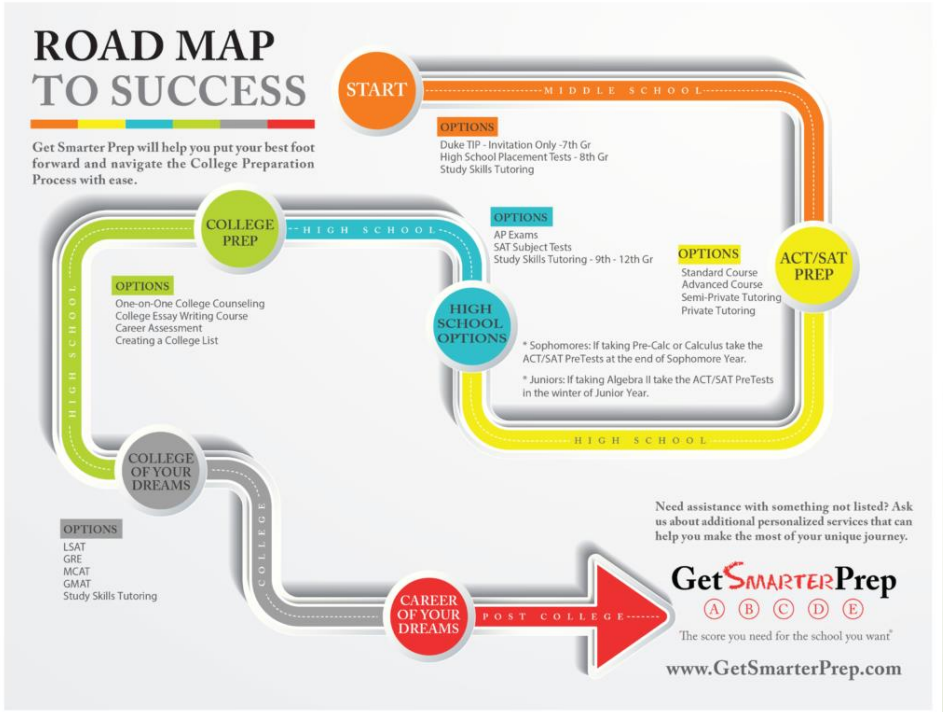
The competition

Analytical Testing

Panel Testing

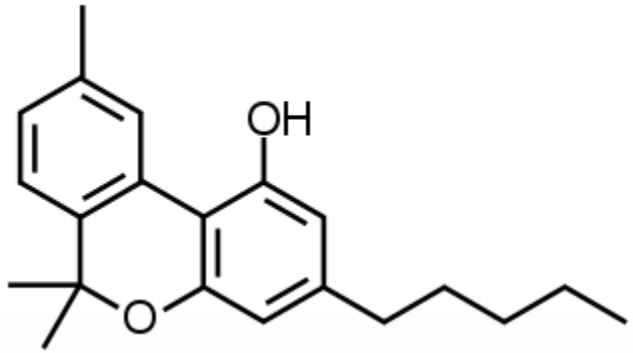
Zimmer & Peacock

Roadmap

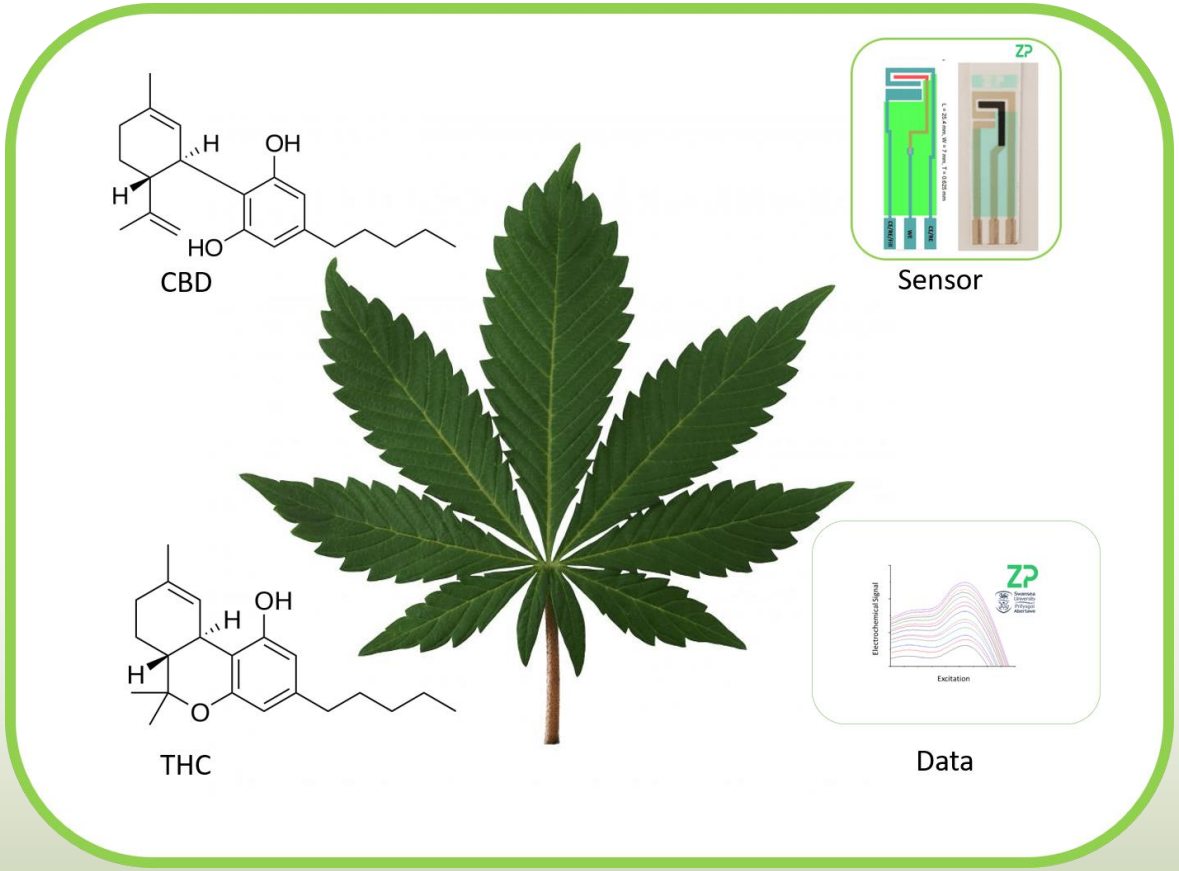


Analyte	Application	Sample matrix	Sample comment	Technology comment	Status
Capsaicin	Food quality	Chillies and chillies products	The hotness of chillies and chillies based products		On the market
Diallyl-disulfide	Food quality	Garlic and garlic products	The pungency of garlic and garlic products		On the market
Sulphite	Food quality and legislative necessity	Wine	The amount of sulphite in the wine		On the market
pH	Food quality	Multiple applications	Has multiple applications across the industry	This is not the traditional glass parallel pH probe which has to be cleaned every time and requires a large amount of sample, and can pose a contamination risk. Rather this is a fully disposable one use pH sensor.	On the market
E. Coli.	Food safety	Multiple applications	The amount of E.coli in the food or beverage	The current way of doing this test is 3 days, this is currently 30 minutes, we can expand this out to all/most gram positive bacteria	Development done but not released
CBD/THC (Cannabidiol)/(Tetrahydrocannabinol)	Product quality and legislative necessity	Multiple applications	Raw materials and derived products	This is a rapid in field test, the alternative is expensive testing in an analytical lab with a fairly slow turnaround	Development done but not released
Gingerol	Food quality	Ginger and ginger products	The gingerness of ginger and ginger products		On the market
Curcumin	Food quality	Turmeric	Measuring the amount of curcumin in turmeric		Development done but not released
Vanillin	Food quality	Vanilla	The amount of vanillin in vanilla		Development done but not released
Piperine	Food quality	Pepper	The amount of piperine in pepper		Development done but not released
Sodium/salt	Food quality	Multiple applications	The amount of salt in a food sample		Development done but not released
Total Anti-oxidant Status	Food quality	Multiple applications	The amount of anti-oxidants in a product linked to freshness, storage, shelf-life, quality and health benefits		Development done but not released
Phosphate	Soil quality	Soil	The amount of phosphate in the soil		Development done but not released
Nitrate	Soil quality	Soil	The amount of nitrate in the soil		Development done but not released
Potassium	Soil quality	Soil	The amount of potassium in the soil		Development done but not released
Skatole	Food quality	Pork	Associated with boar taint/off-smell on pork		Development done but not released
Androstenone	Food quality	Pork	Associated with boar taint/off-smell on pork		Development done but not released
Calcium	Food quality/soil quality	Food/soil	The amount of calcium in the food or soil sample		Development done but not released

THC/CBD



CBN



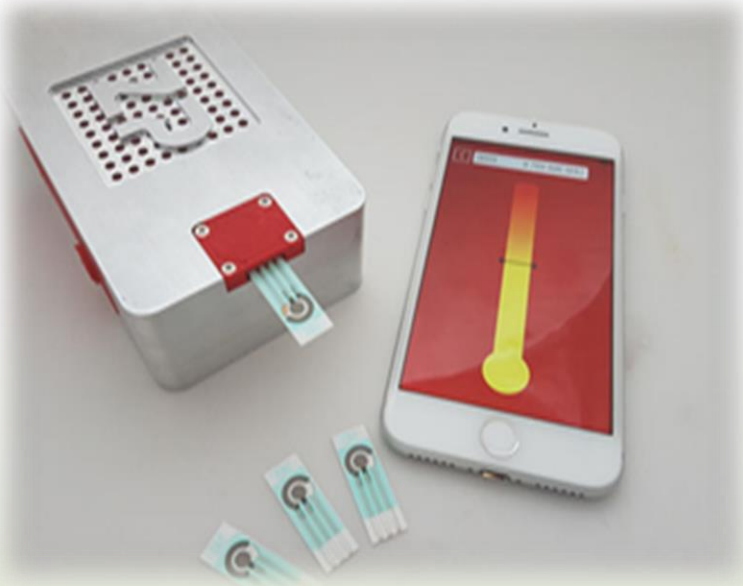
Zimmer & Peacock

Background

Zimmer & Peacock

Sensor Manufacturing and Technology

Idea

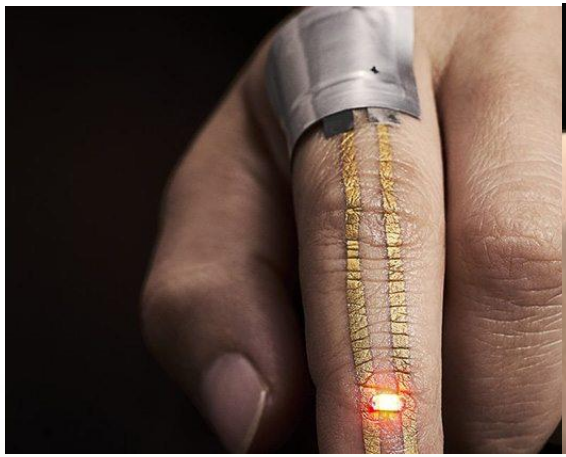


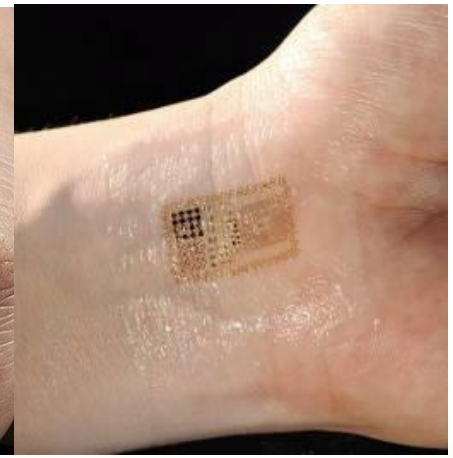
Technology trends in the sensor world IVD

LAB

POC

WEARABLE





ELECTRONIC SKIN

Invasive and Minimally Invasive

Not just medical

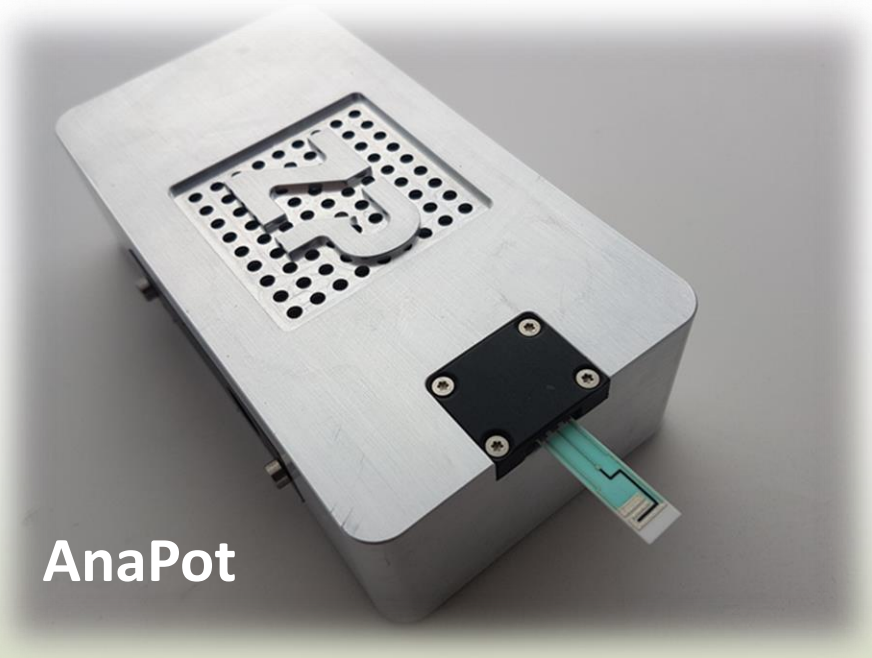
Not just the sick

Zimmer & Peacock

World wide media interest

Zimmer & Peacock

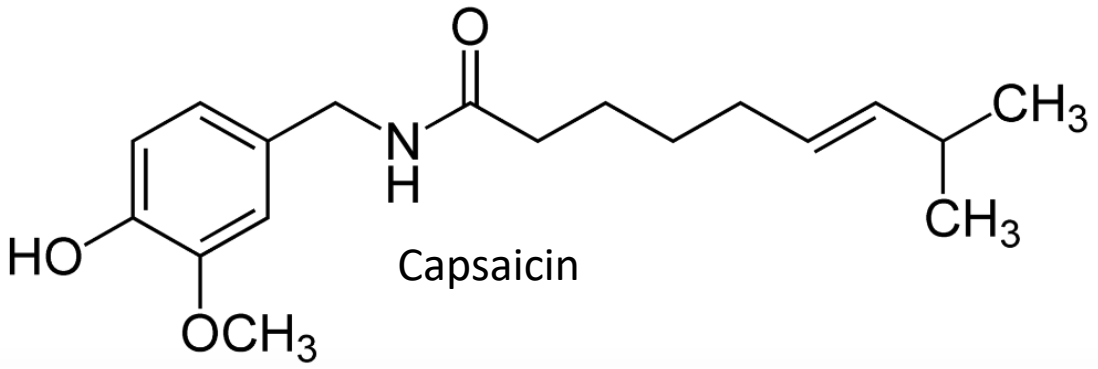
Quiz – spot the difference



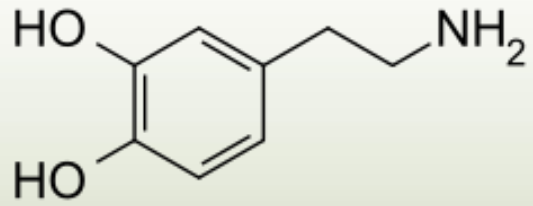
Zimmer & Peacock

Case studies – Chilli Sensor

- Hotness measurement



Capsaicin



Dopamine

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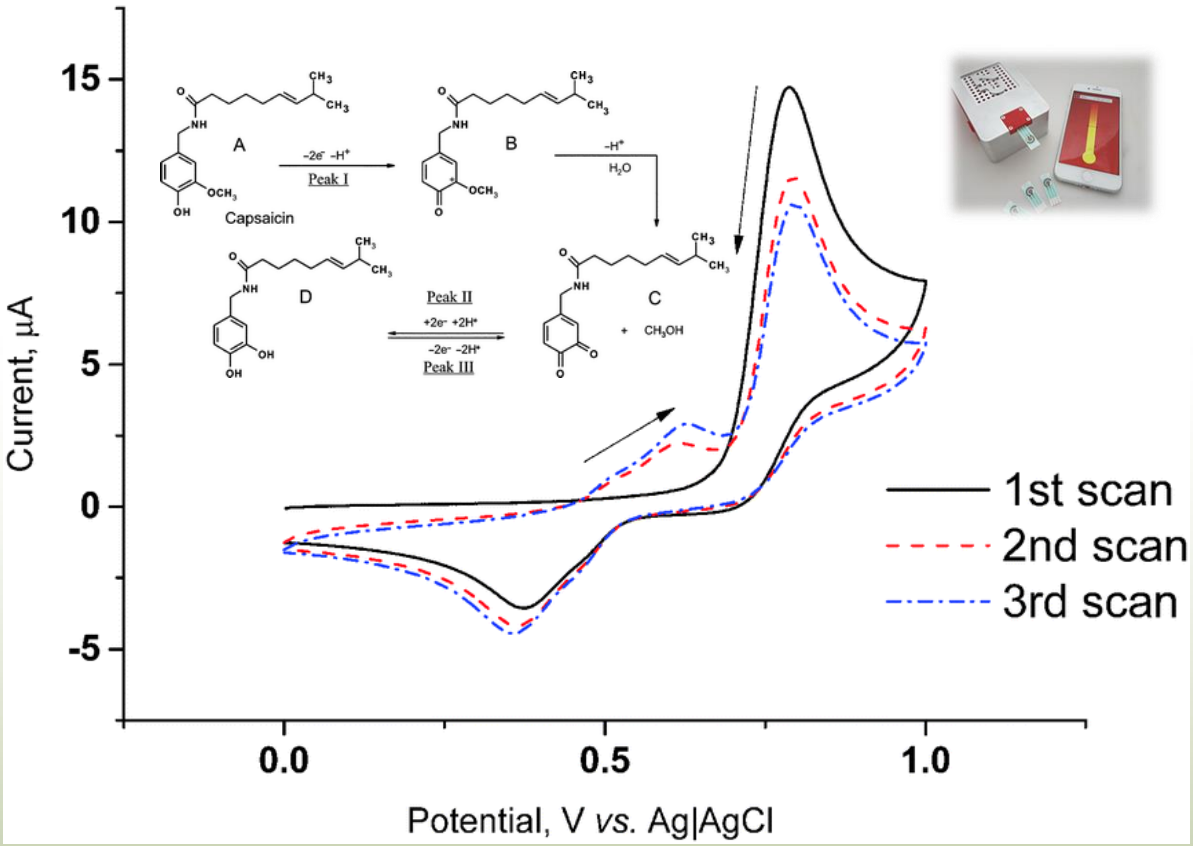
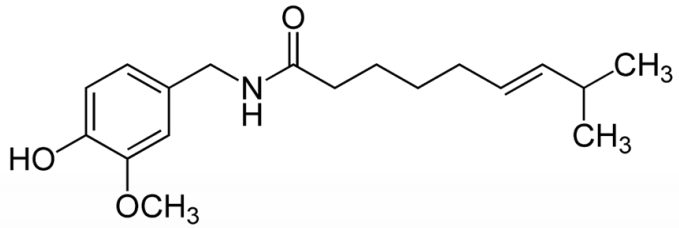
What we do – the science





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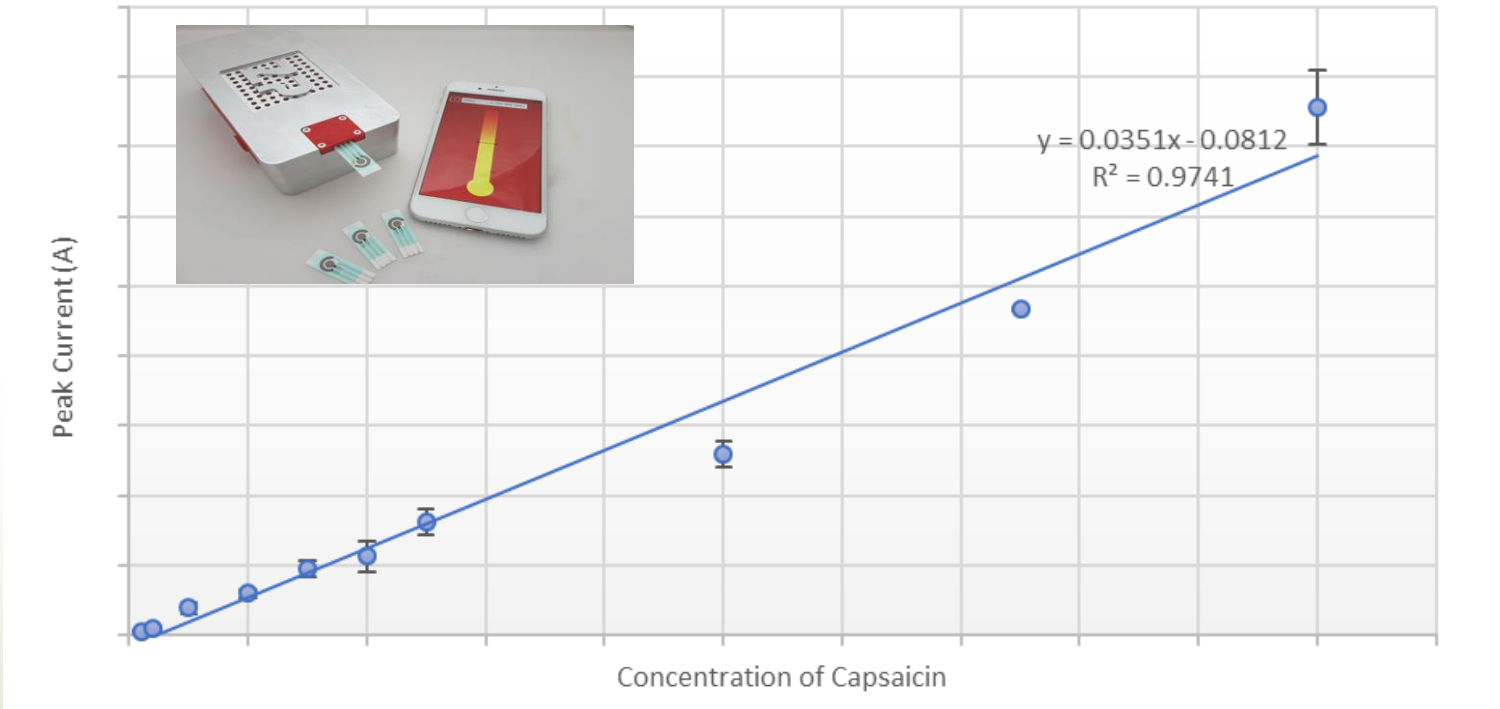
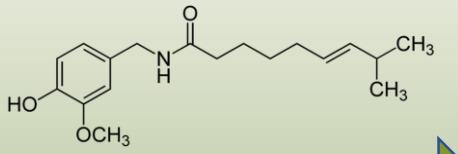
Signal to user friendly number

Signal





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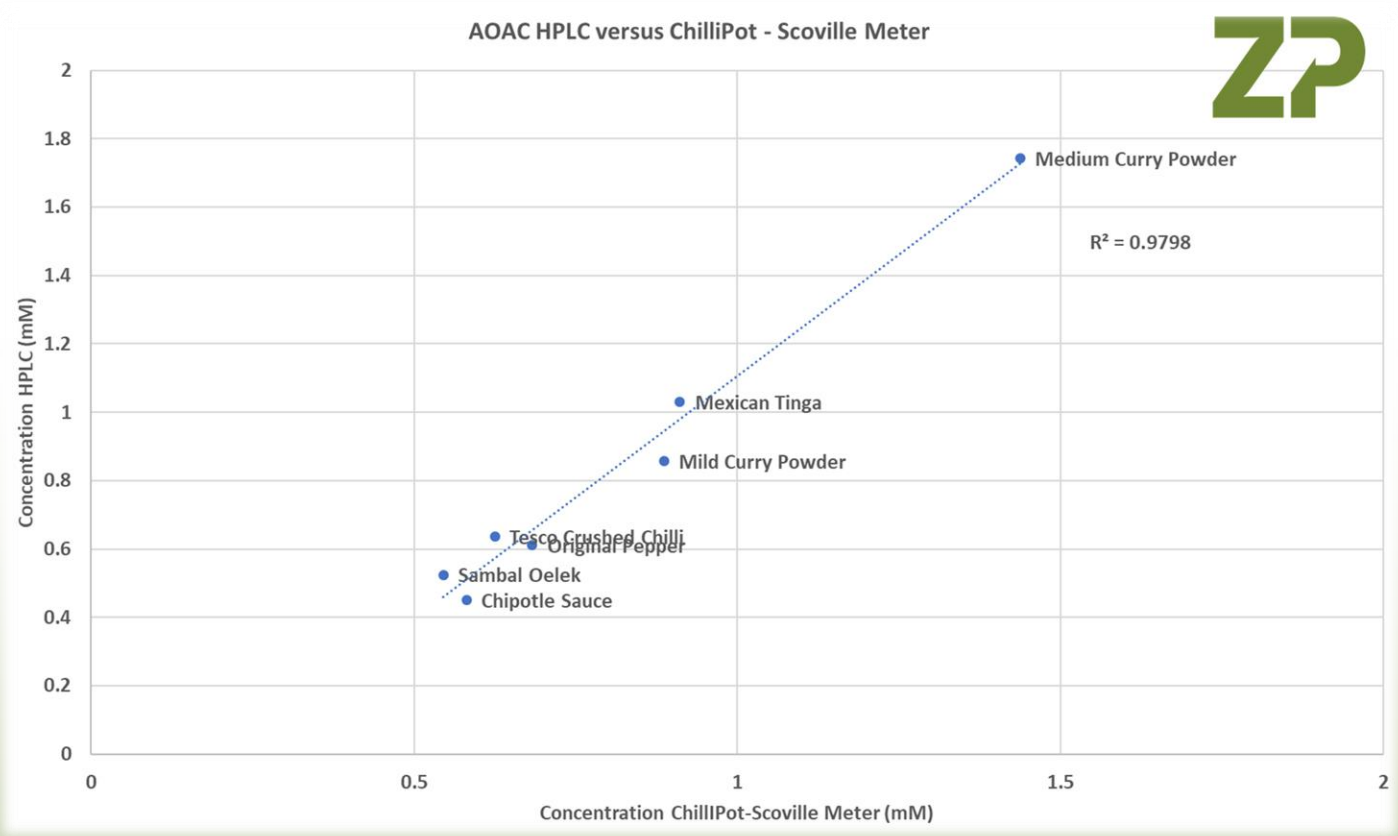
Our shopping list

Zimmer & Peacock

Validation of shopping list

HPLC method



Electrochemical Method

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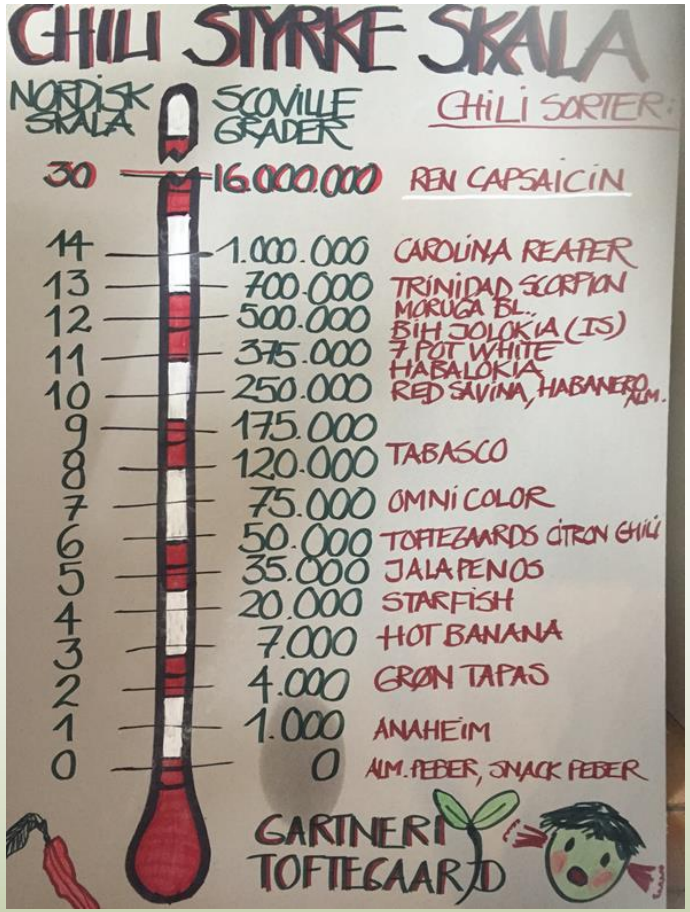
Scoville score



Zimmer & Peacock

Two Demos

- AnaPot
- FoodSense

Our connections to USN

- Bachelors
- Masters
- PhDs
- Employees

Universitetet i Sørøst-Norge

Zimmer & Peacock

Summary

https://www.zimmerpeacocktech.com/2020/02/05/usn-introduction-to-biosensors/

Thank you

Zimmer & Peacock