Synthetic Neural Interface

via electrically controlled ion pump

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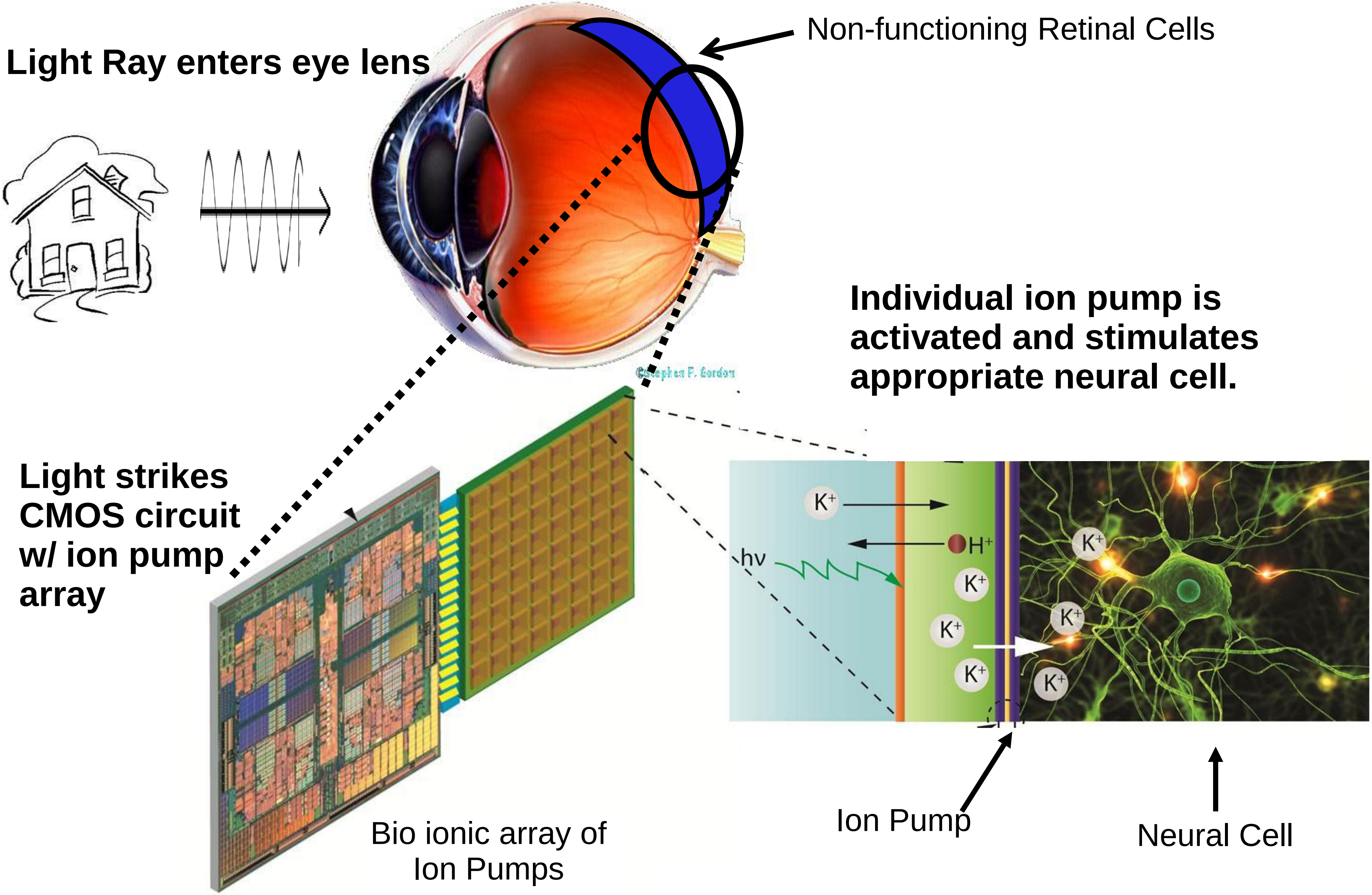
The Big Picture

- Restore vision in patients that have retinal degenerative conditions
  - Deterioration of the retina caused by eventual death of the retinal cells
  - One of the major causes of blindness
  - Can be caused by:
    - Complications from diabetes
    - Macular Degeneration due to aging
    - Various hereditary diseases

How it works



Light Ray enters eye lens

Non-functioning Retinal Cells

Individual ion pump is activated and stimulates appropriate neural cell.

Light strikes CMOS circuit w/ ion pump array

Bio ionic array of Ion Pumps

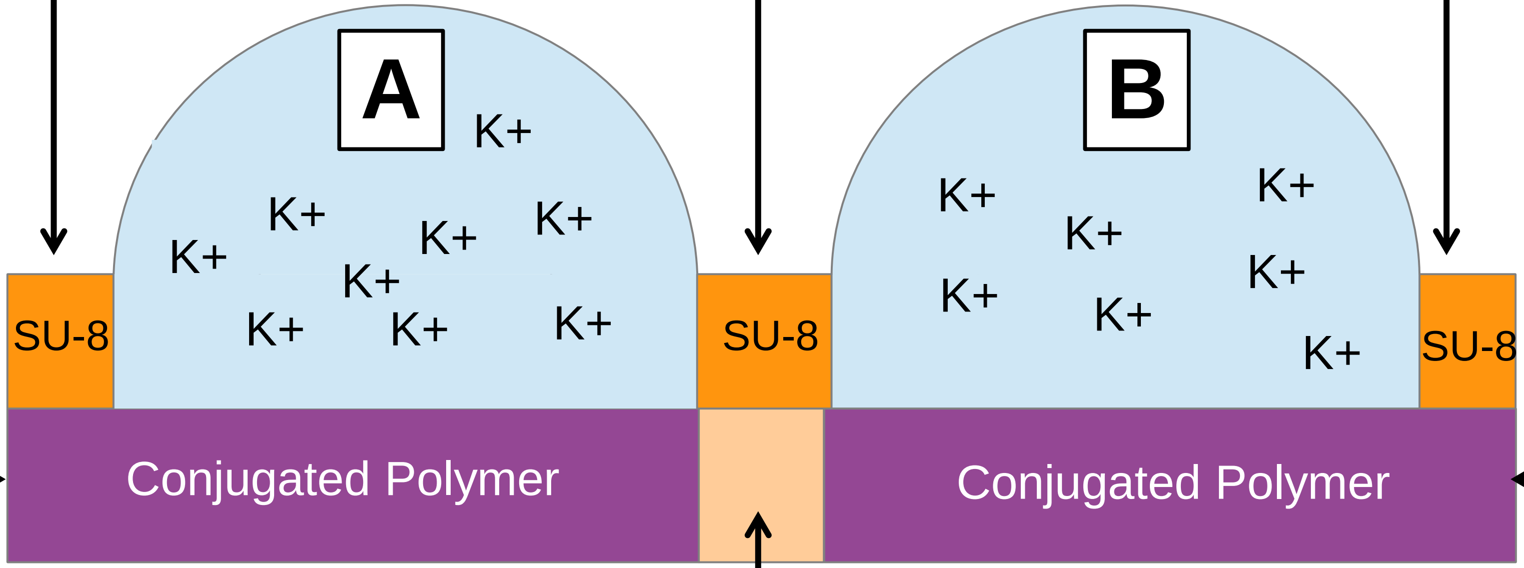
Ion Pump

Neural Cell

Ion Pump Components

Conjugated Polymer: A polymer that is electrically conductive.

SU-8: Viscous polymer with high stability.
Keeps reservoirs separate.



Intermediate Region Area connecting both conjugated Polymers and keeps them electrically/ionically separate.

<u>2 Types:</u>

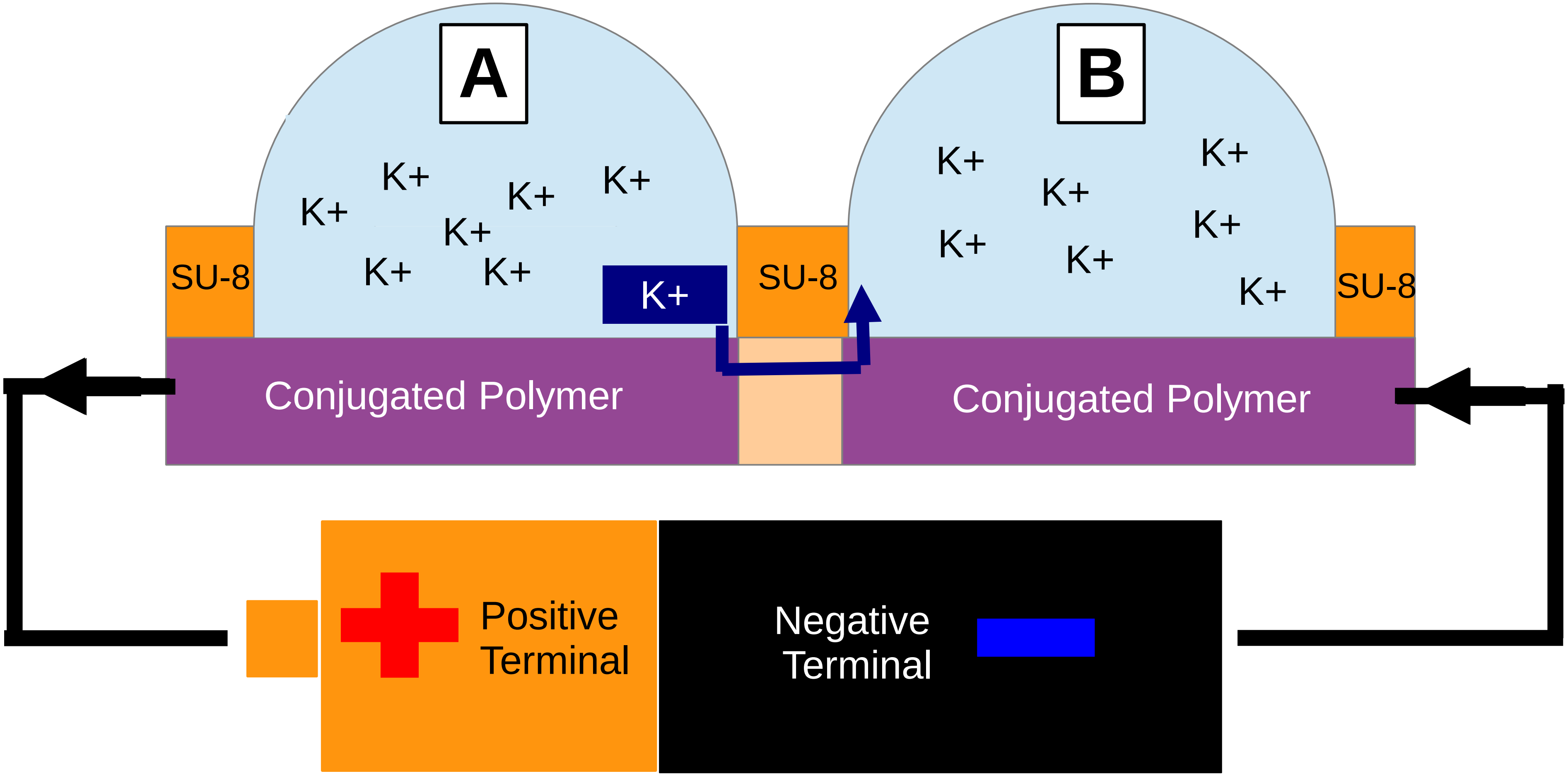
- Electrically Non-conductive but ionically permeable
- Electrically Conductive but ionically selective

Ion Pump Operation

1 Initially there is no flow of Potassium Ions (K+) from A to B side to the other.

2 When a voltage is applied across the pump, K+ ions are attracted by intermediate layer's electric field.

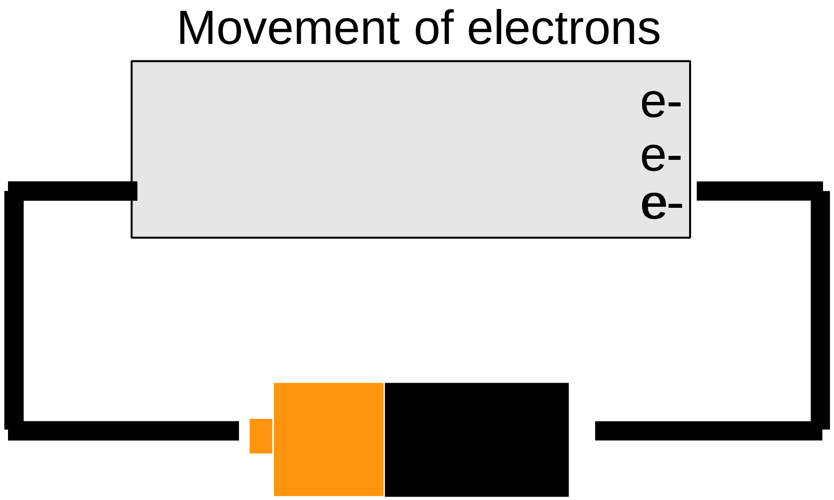
3 As a result of this attraction Potassium ions (K+) travel from reservoir A to reservoir B.

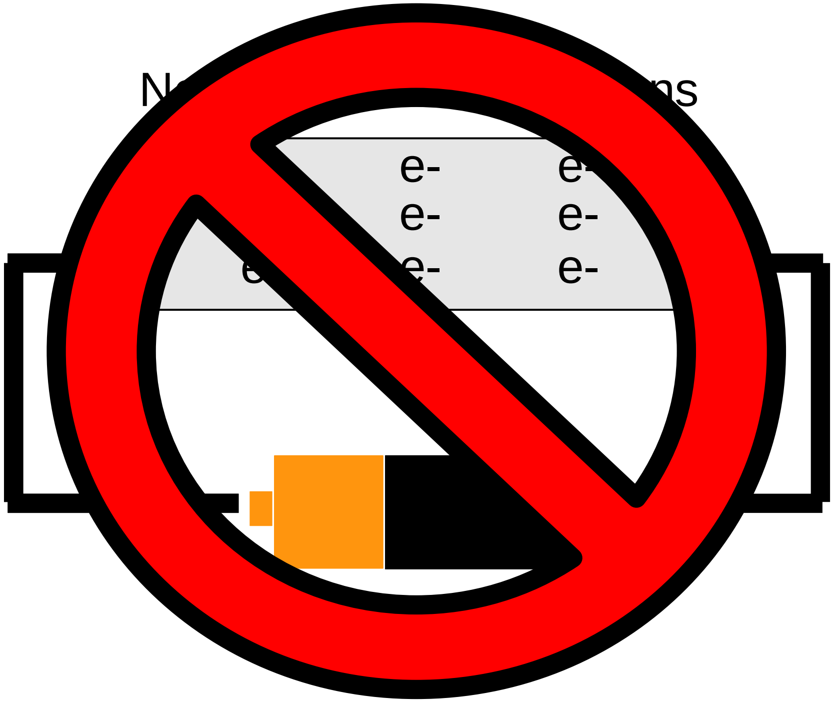


Research Goals #1

Testing various conjugate polymers for the following properties.

1 Polymer must be electrically conductive.



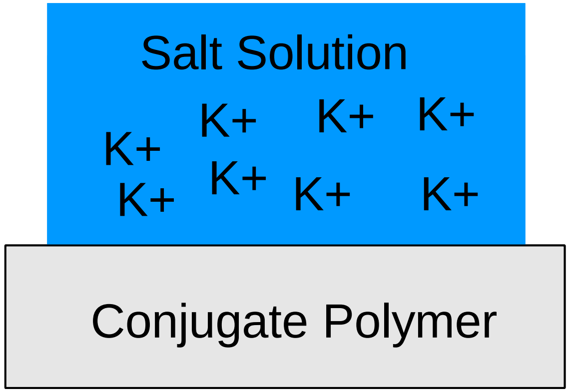


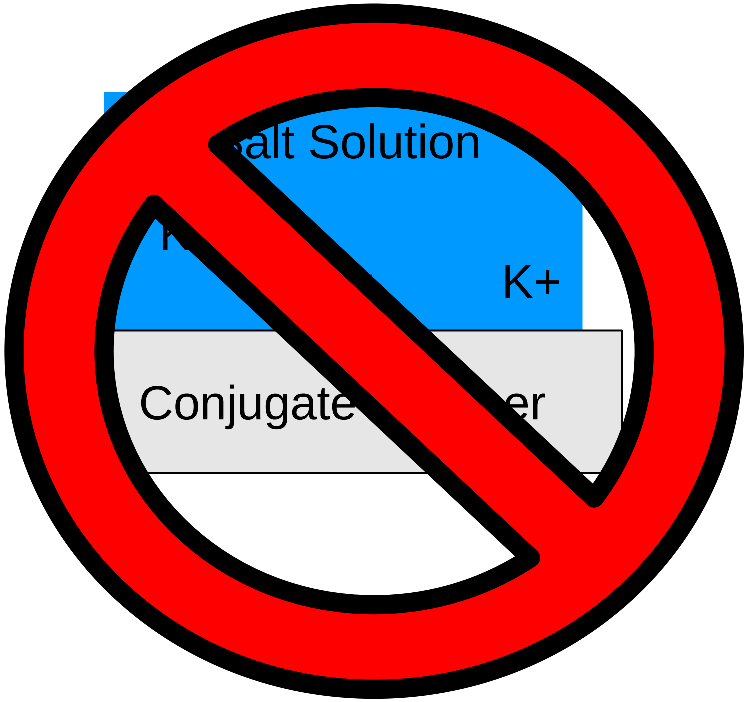
Research Goals #1

Testing various conjugate polymers for the following properties.

1 Must be electrically conductive.

2 Must be permeable to Potassium ions.





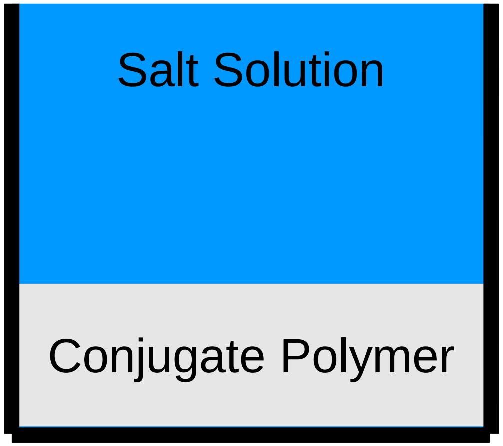
Research Goals #1

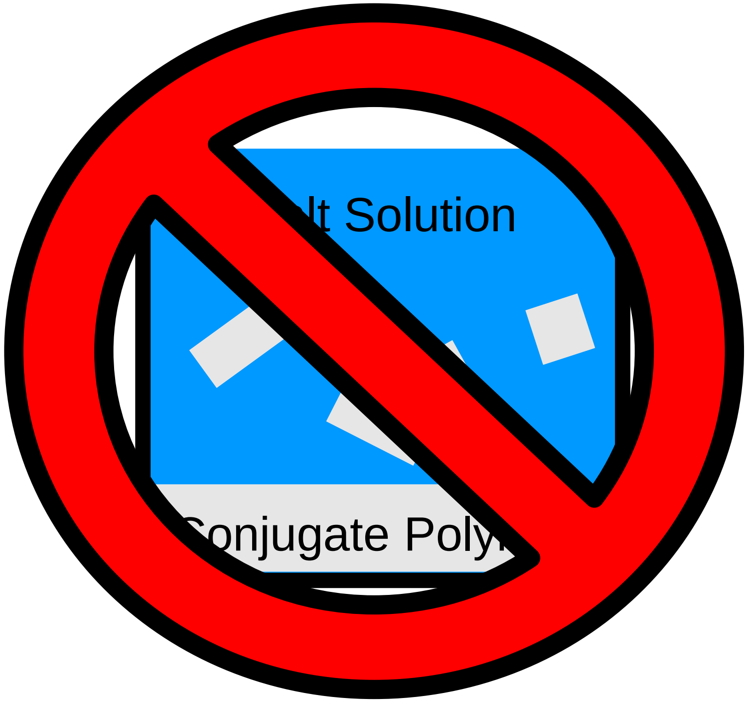
Testing various conjugate polymers for the following properties.

1 Must be electrically conductive.

2 Must be permissible to Potassium ions.

3 Must remain insoluble in salt solutions.

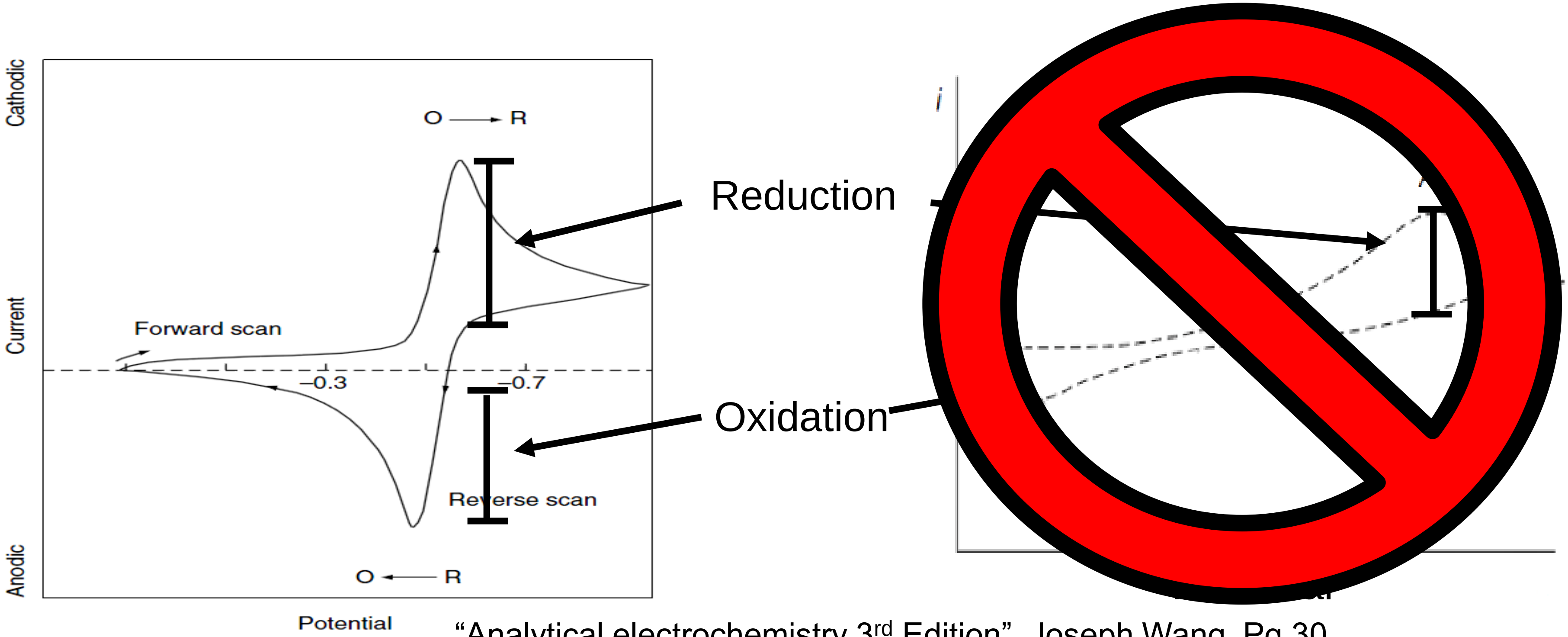




Research Goals #1

Testing various conjugate polymers for the following properties.

- 1 Must be electrically conductive.
- 2 Must be permissible to Potassium ions.
- 3 Must remain insoluble in salt solutions.
- 4 Must Have reversible oxidation and reduction reactions.



“Analytical electrochemistry 3rd Edition”, Joseph Wang, Pg 30

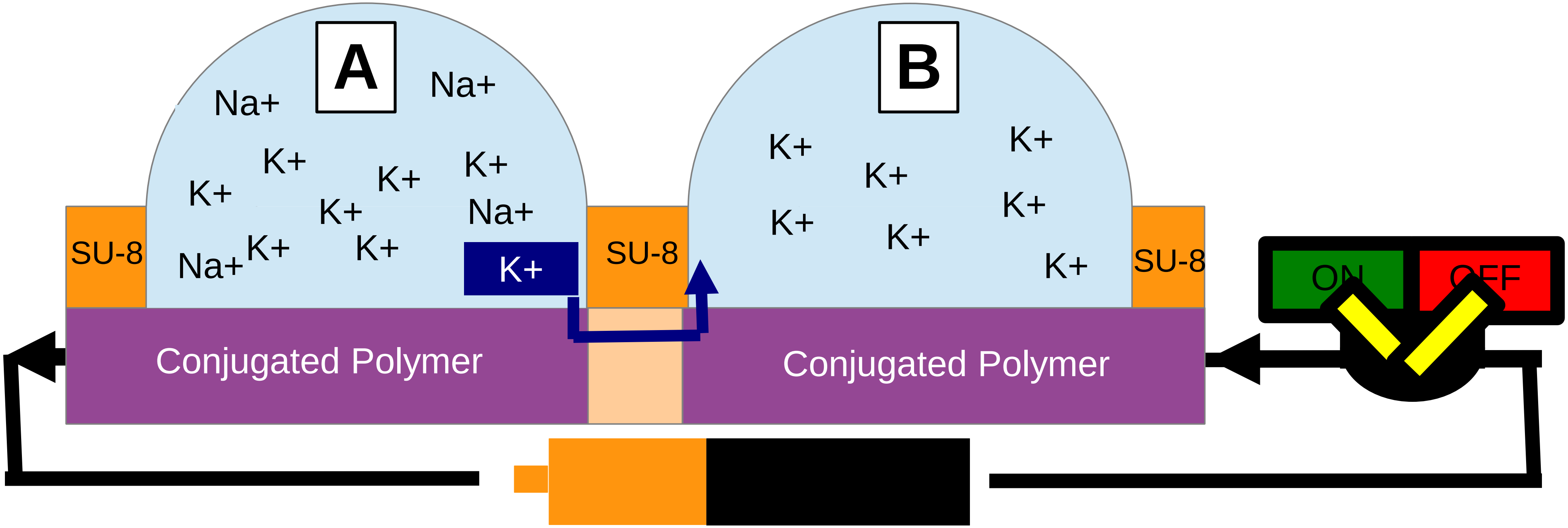
Research Goals #2

Test the various designs of the ion pump to ensure it follows the following specifications.

1 Ensure Potassium ions (K+) don't travel from A to B when pump is off.

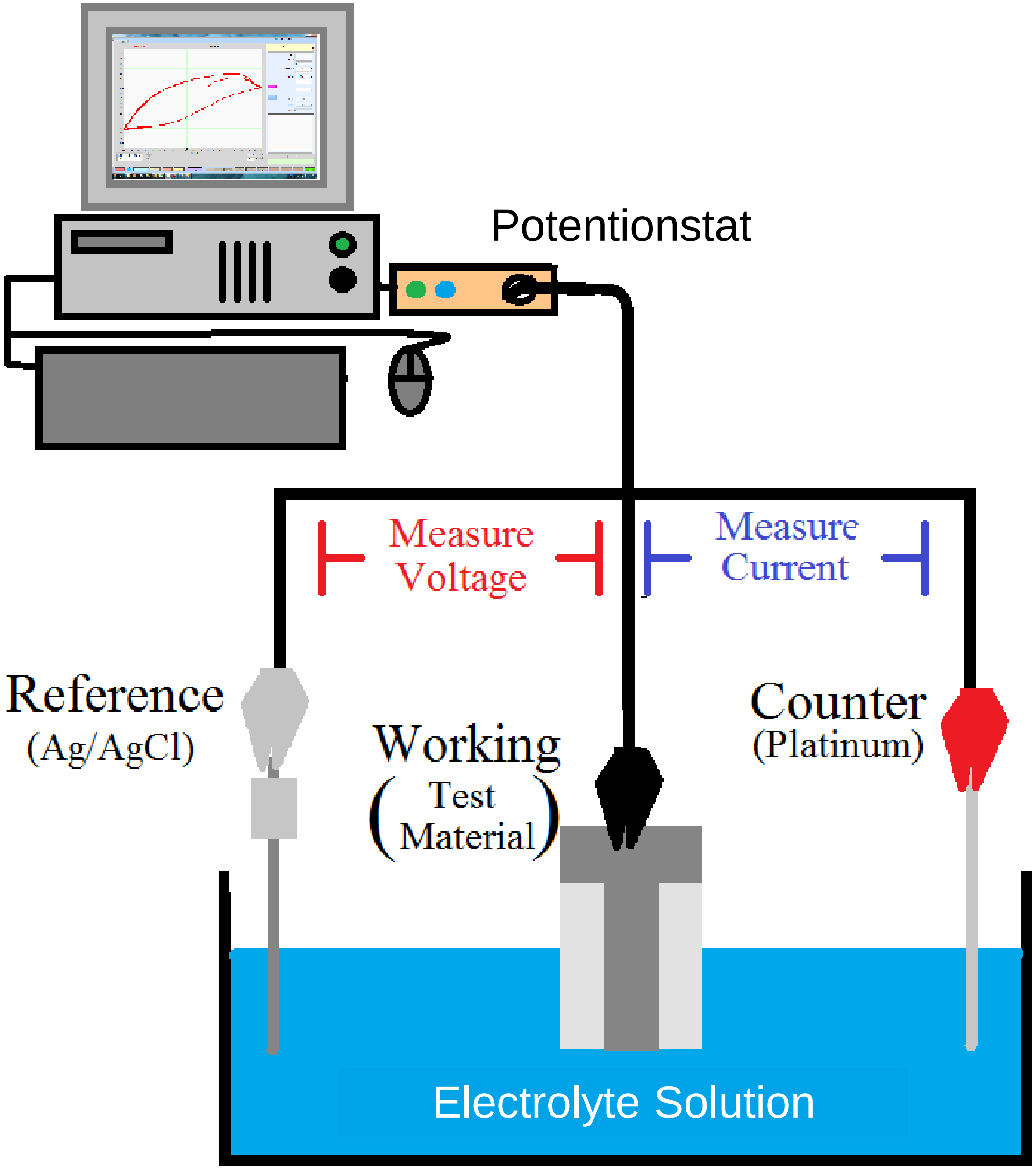
2 Measure flow of ions when pump is switched on

3 Ensure only Potassium ions (K+) travel from A to B



Research Methods

Cyclic Voltammetry Setup:

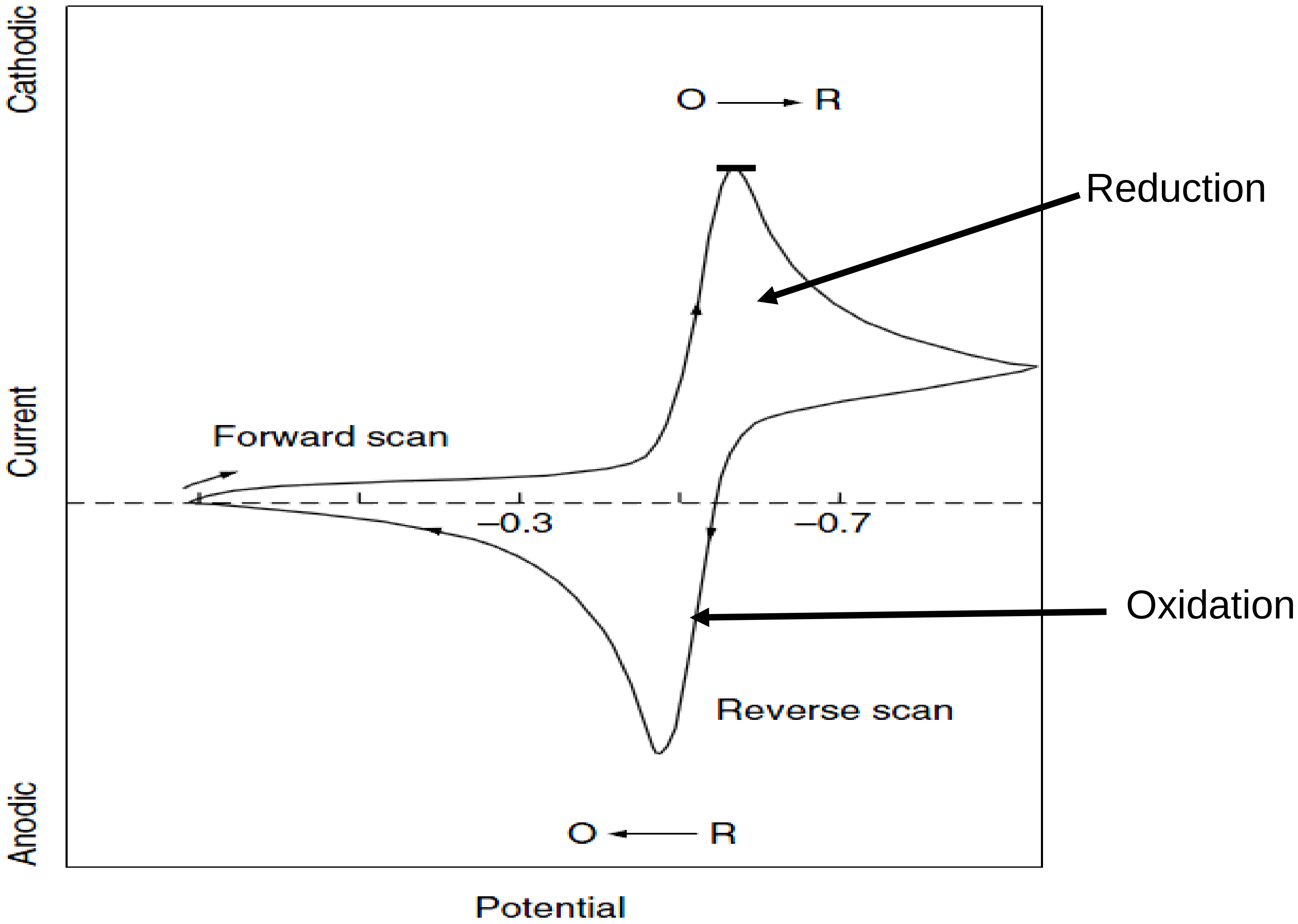


What it does:

- Determines degree of reversibility of oxidation / reduction cycles.
- Current measured at Working Electrode
- Cycles from user determined min and max potential
- Creates graph of current vs voltage
  - X axis is voltage
  - Y axis is current

Current Vs Voltage

Example graph of ideal CV results



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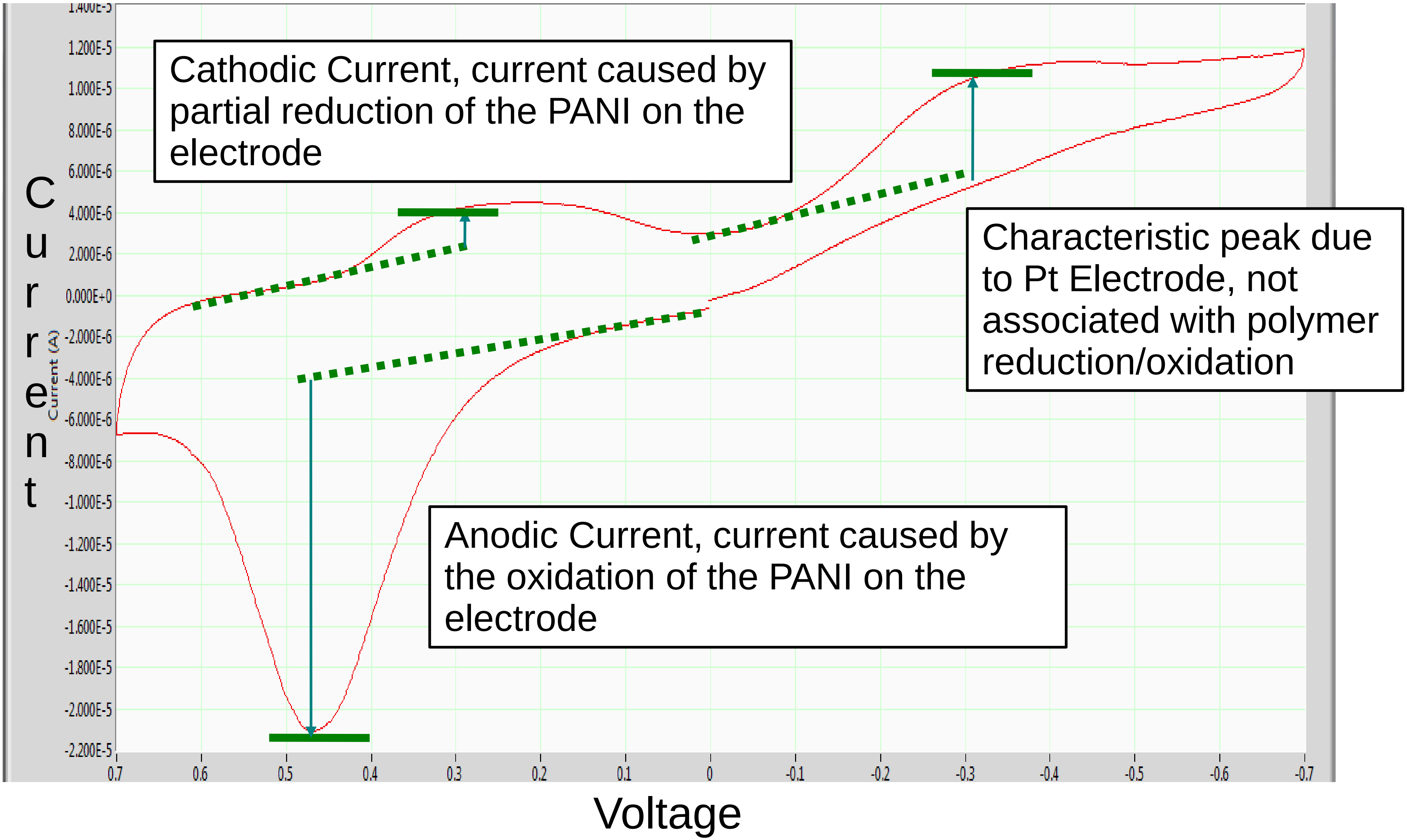
Current(Amps) vs Voltage (Volts)

Example of Semi-reversible Process with PANI on Pt Electrode



Cathodic Current, current caused by partial reduction of the PANI on the electrode

Characteristic peak due to Pt Electrode, not associated with polymer reduction/oxidation

Anodic Current, current caused by the oxidation of the PANI on the electrode

Research Results

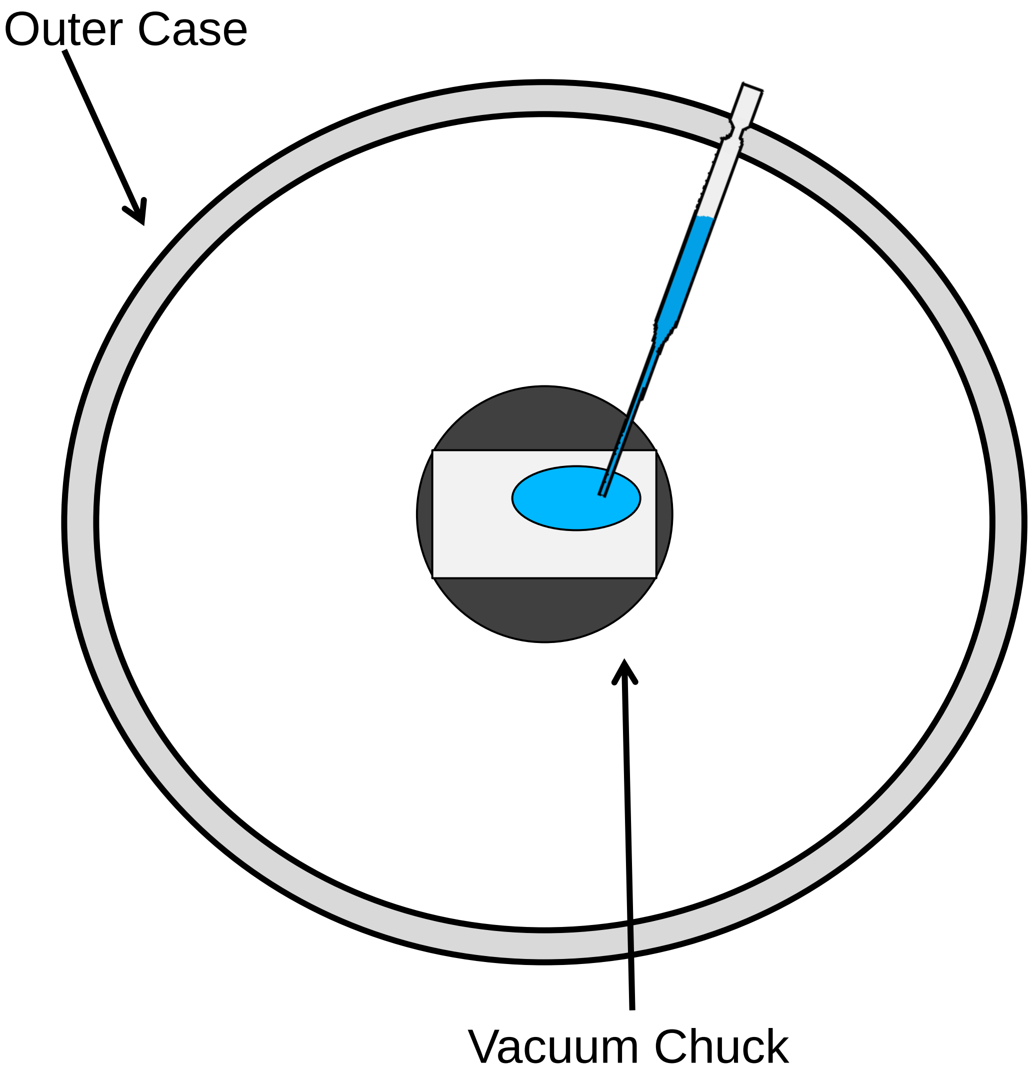
PEDOT:PSS w/ Silquest is Polymer of choice

	Conductive	**Insoluble**	**Reversible Cycle**
Polyurethane	✗	✓	✗
Polyurethane w/ TCNQHE	✓	✗	✗
PEDOT:PSS	✓	✗	✗
PEDOT:PSS w/ Silquest	✓	✓	✓
Polyaniline	✓	✗	✗
PEDOT/PANI Copolymer	✓	✗	✗
PANI Plated On PEDOT	✓	✓	✗

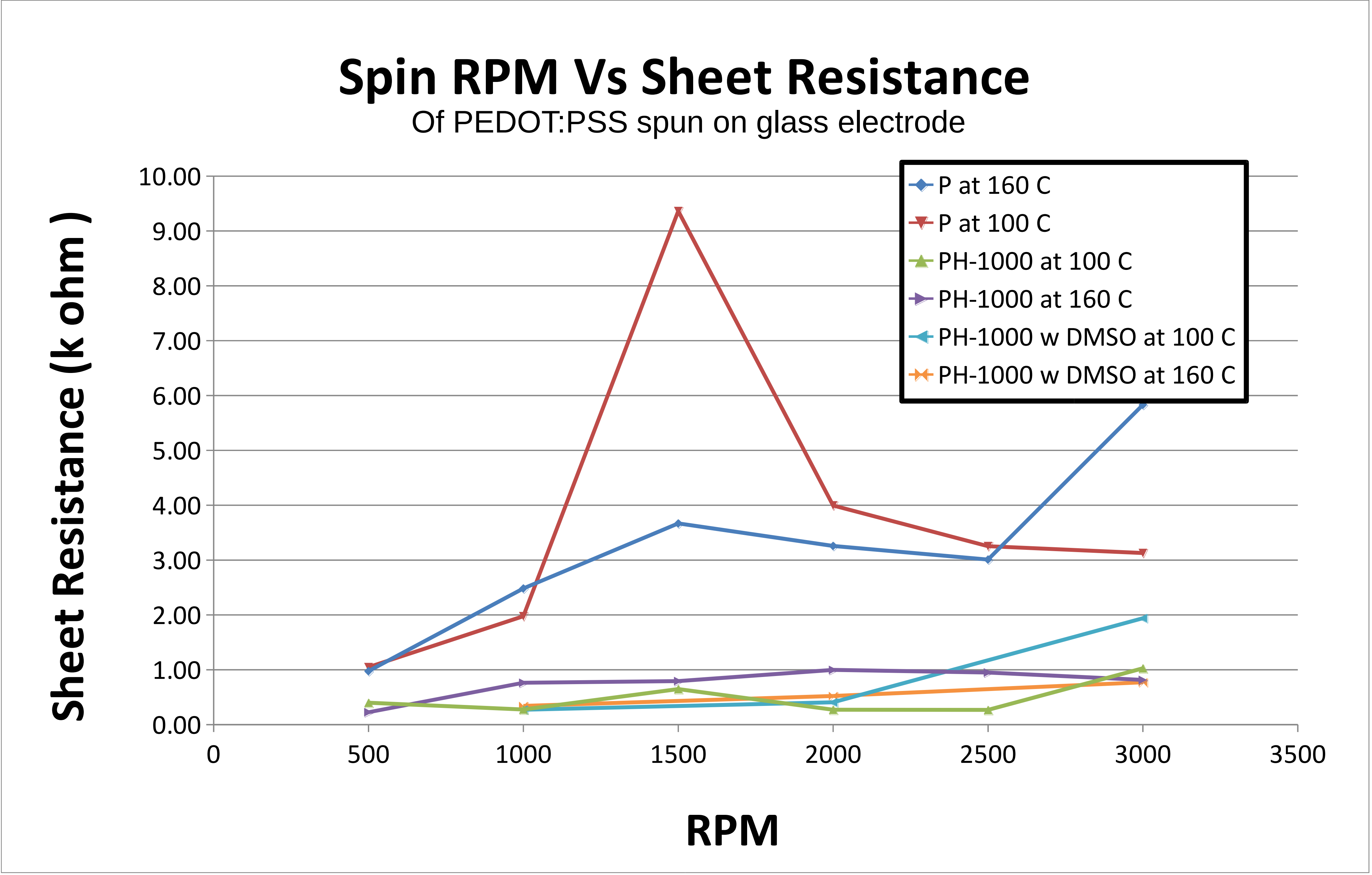
* K+ Permeability has not yet been tested and thus is excluded from results.

Research Methods #2

Methods for varying polymer thickness



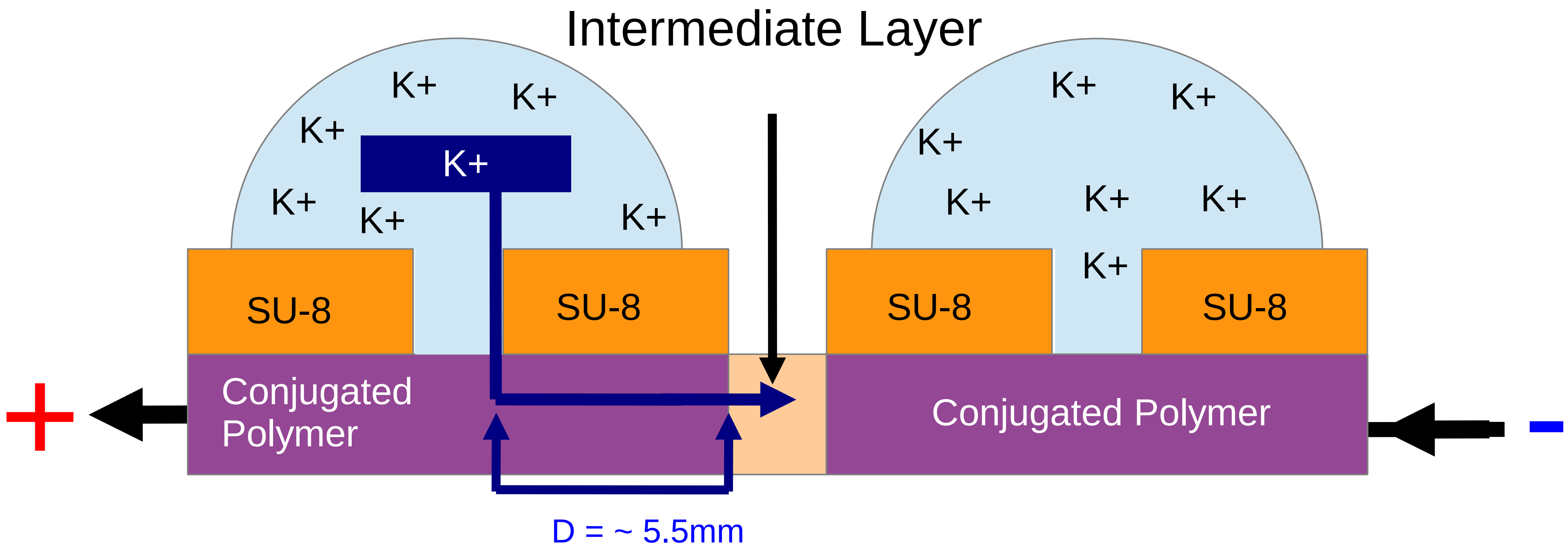
1. Place Glass Slide on spinning device. Vacuum engages and secures slide on surface.
2. Use dropped to spread polymer solution across glass surface.
3. Once sample is entirely covered, set spin speed and close lid.
4. Activate Spinner.
5. Once spinner stops, remove sample and place in oven or hotplate.
6. Repeat Process, varying spinning speed, duration, bake time, and bake temperature.
7. 3 Variations on PEDOT:PSS were tested
   - Clevios P
   - Clevios PH-1000
   - Clevios PH-100 w/ solvent(DMSO)



Most consistent low sheet resistance is from Clevios PH-1000 brand PEDOT:PSS baked on at 100 C for 10 mins.

What we've Learned so far..

Problems with old pump design



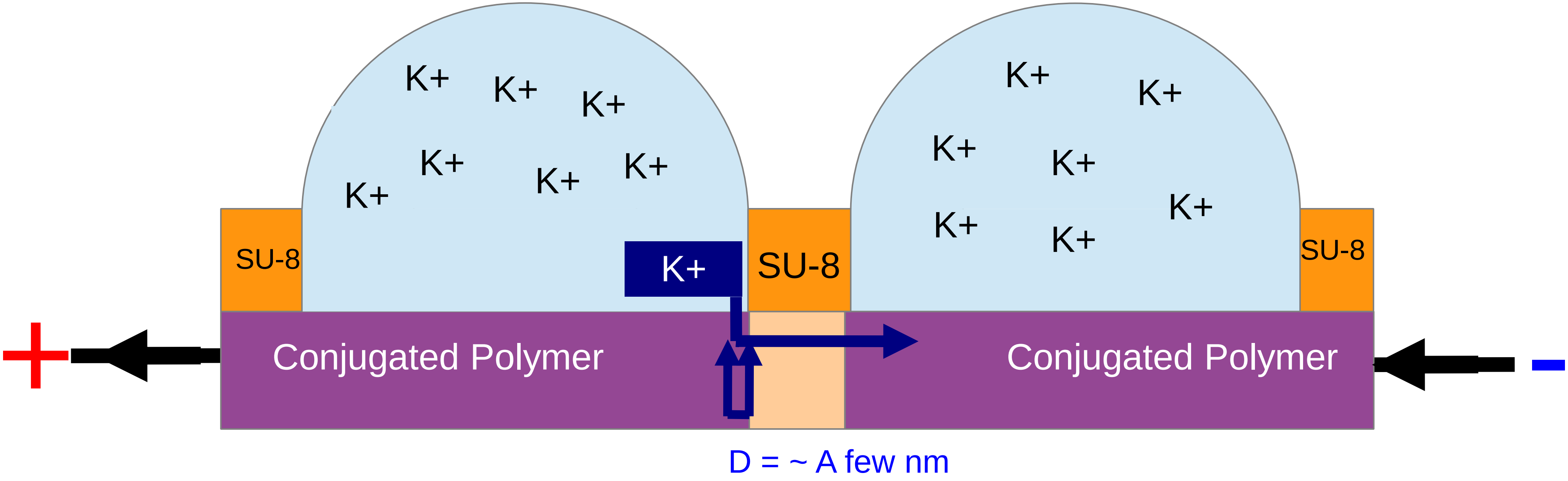
Ion pump did not transfer ions

Diffusion rate through Polymer is too slow for ion to quickly move across a large distance.

Attraction from intermediate layer electric field decreased due to distance of Potassium ions(K+) from layer.

Future Plans

Look at alternative pump designs

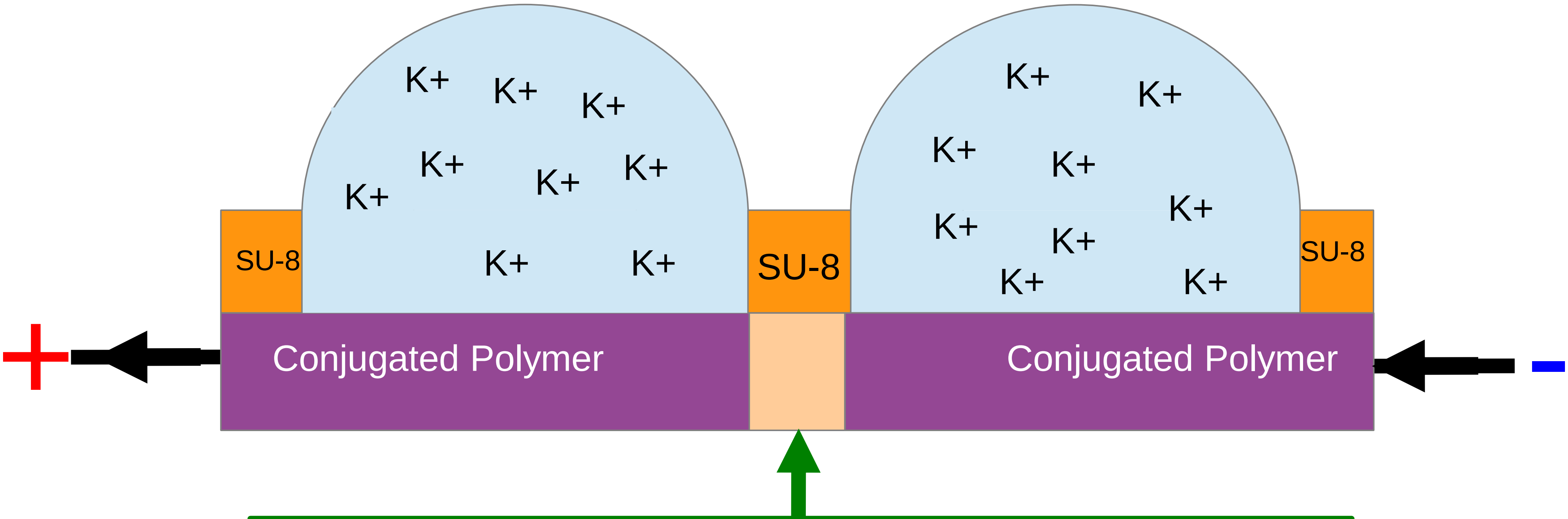


Proposed Solution

Expand reservoir size to decrease distance from cations to intermediate layer.

Future Plans

Test ion selectivity of intermediate layer



Fabricate nano-pores in aluminum material and fill nano-pores with ion-selective crown ether.

Test to ensure it allows only Potassium ions(K+) to pass.

Future Plans

Long term goals

- Fabricate 3-D stack version of pump
- Fabricate pump at nano level
- Test different ways to attach one side of the pump to neural cells.
- Test pump in live trials

Acknowledgments

- NSF, INSET, and INSET Coordinators and sponsors
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  - For their guidance and knowledge
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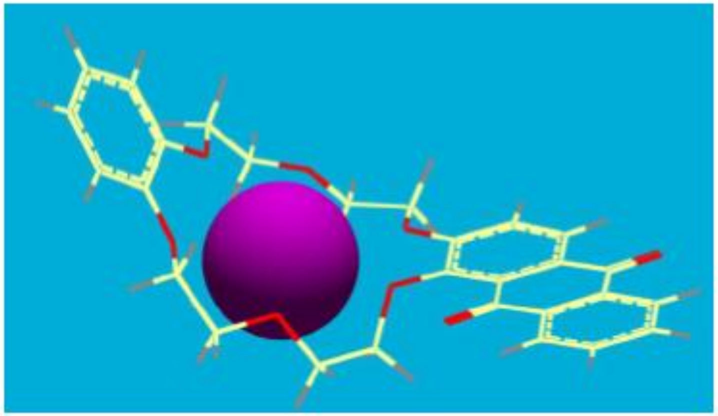
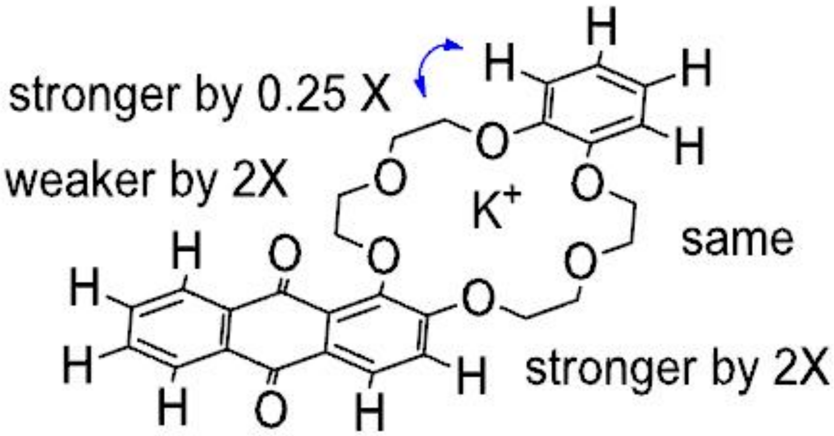
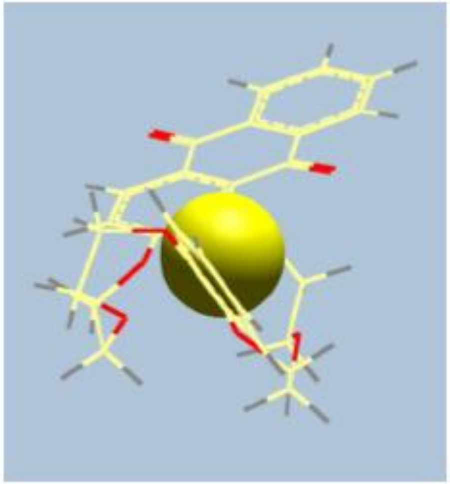
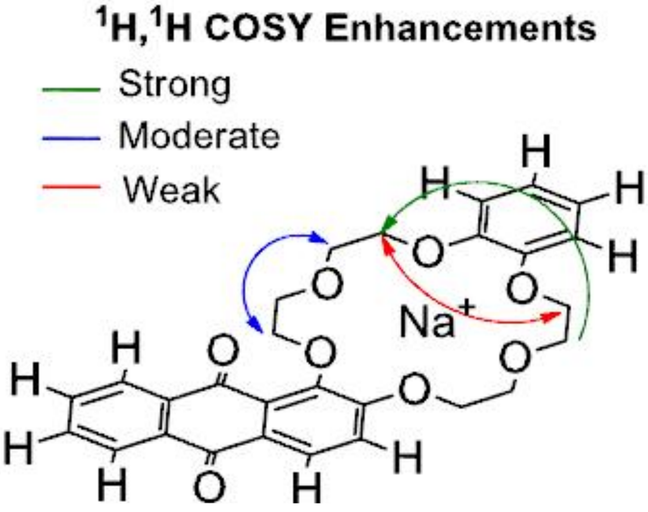
  - For their PEDOT:PSS coating guides
- Joakim Isaksson, Peter Kja, David Nilsson, Nathaniel D. Robinson, Magnus Berggren AND Agneta Richter-Dahlfors
  - For their paper on initial ion pumps research

Ion Selective Crown









Graph Peak Potentials

Current Peak amplitude:

$$i_p = (2.69 * 10^5) n^{3/2} ACD^{1/2} v^{1/2}$$

A = electrode area, D = diffusion coefficent

v = Scan rate, C = concentration

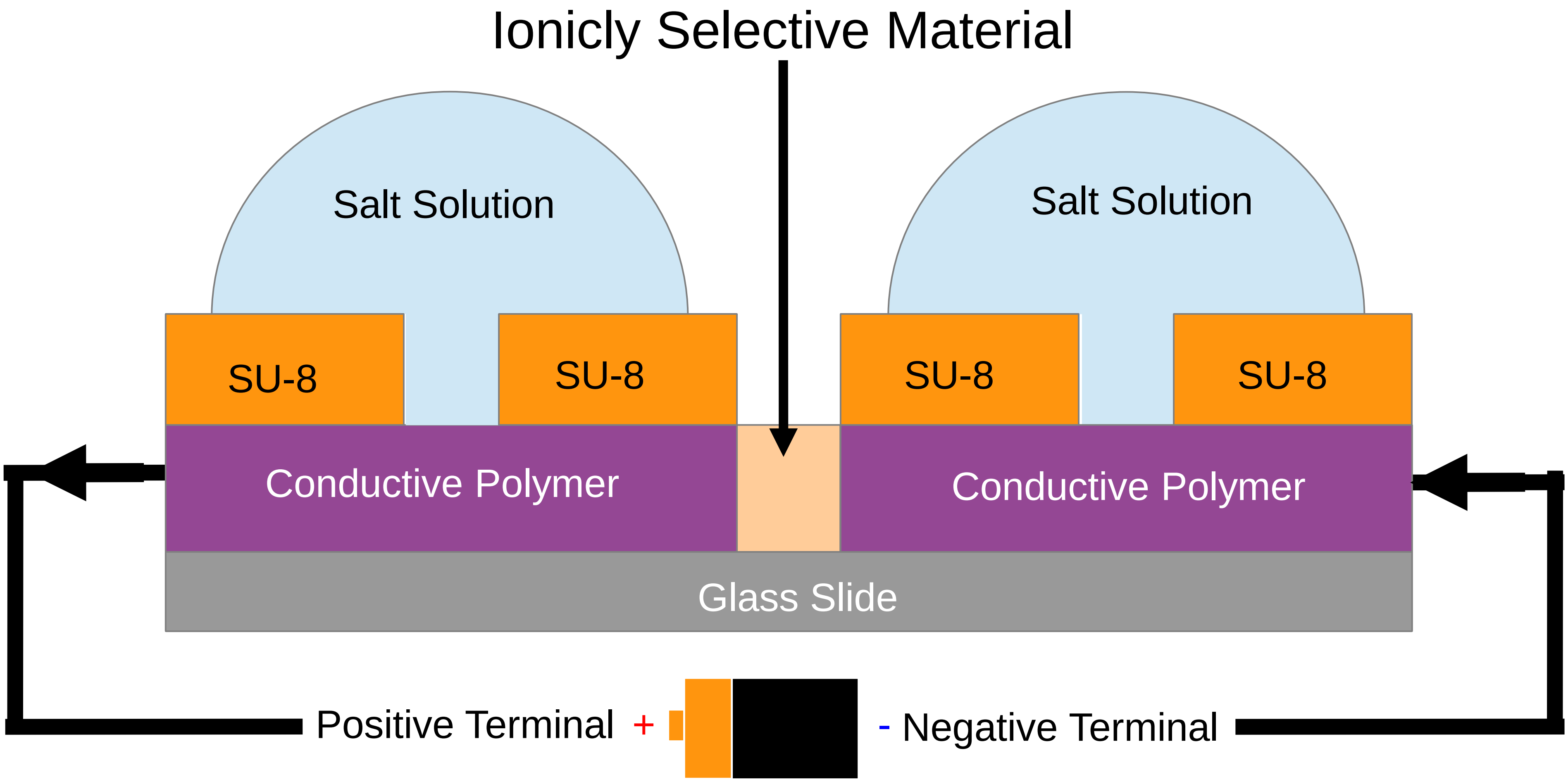
Peak Positions with relation to formal potential:

$$E^0 = \frac{E_{pa} + E_{pc}}{2}$$

Seperation of Peak Potentials:

$$E_{pa} + E_{pc} = \frac{0.059}{n}$$

Ion Pump Design



Anode is Oxidized

PEDOT + M(PSS)

↓

PEDOT:PSS + M + e

Cathode is Reduced

PEDOT:PSS + M + e

↓

PEDOT + M(PSS)

What we've learned so far..

	Conductive	**Insoluble**	**K+ Permissible**	**Reversible Cycle**
Polyurethane	🟥	🟩	⬜	🟥
Polyurethane w/ TCNQHE	🟩	🟥	⬜	🟥
PEDOT:PSS	🟩	🟥	⬜	🟥
PEDOT:PSS w/ Silquest	🟩	🟩	⬜	🟩
Polyaniline	🟩	🟥	⬜	🟥
PEDOT/PANI Copolymer	🟩	⬜	⬜	🟥
PANI Plated On PEDOT	🟩	🟩	⬜	🟥
SPAN	⬜	⬜	⬜	⬜

From tests PEDOT:PSS w/ Silquest bonding agent is best choice.

🟩 Test successful

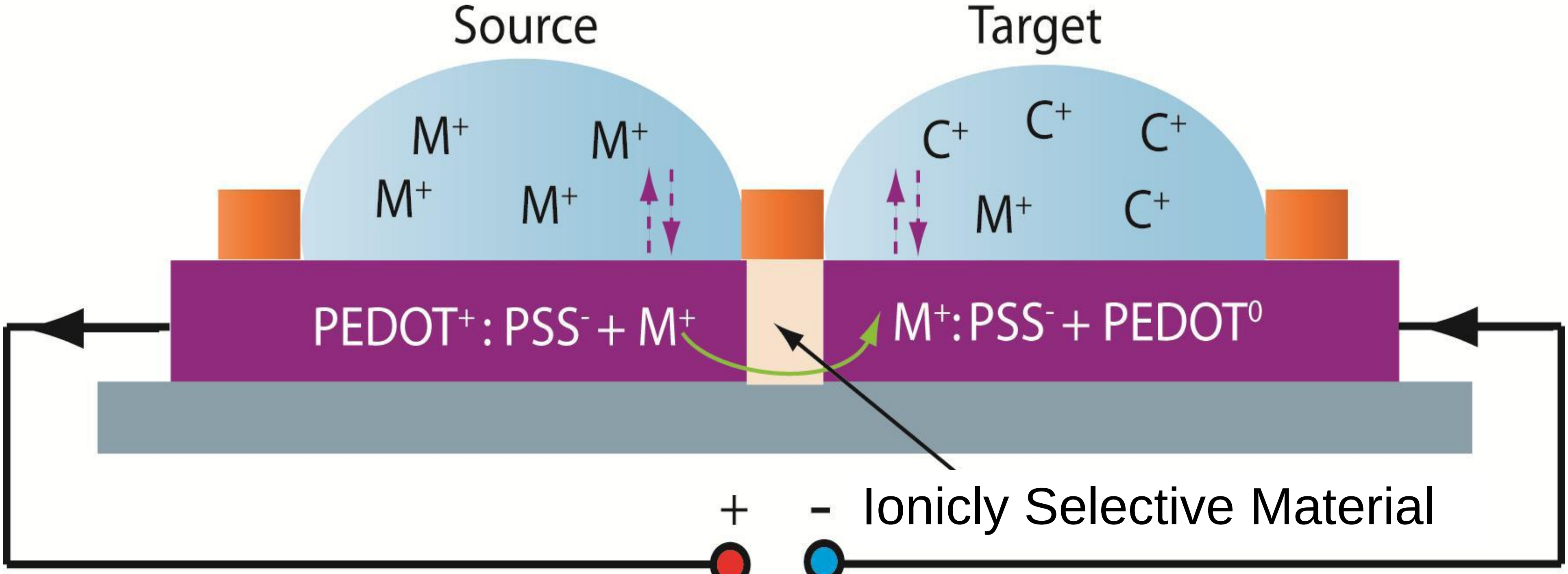
🟥 Does not posses property

⬜ Un-Tested

Research Goals

- Assist in developing an artificial ion pump
  - Fabricate and test Conjugate Polymer
    - Electrically conductive
    - Remain insoluble in aqueous salt solutions
    - Permeable to potassium ions
    - A reversible reduction/oxidation cycle
  - Test prototype pumps
    - Presence of electron/ion flow when pump is on
    - No ion leakage when pump is turned off
    - Ensure only potassium ions pass selective layer

Why the Polymer Matters



J. Isaksson et. al, Nature Mater. 6, 673 (2007)

Anode is Oxidized

PEDOT + M(PSS)

↓

PEDOT:PSS + M + e

Cathode is Reduced

PEDOT:PSS + M + e

↓

PEDOT + M(PSS)

Research Results

- Polymers Tested
  - Poly(3,4-ethylenedioxythiophene) poly(styrenesulfonate) (aka PEDOT:PSS)
  - PEDOT:PSS with glass adhering epoxy
  - Polyurethane Doped with TCNQHE
  - Polyaniline
  - PEDOT:PSS and Polyaniline co-polymer
- Tests Used
  - Cyclic Voltammetry
  - Solution submersion
  - Measurement of sheet resistance

Research Methods Continued

- Ag/AgCl electrode
  - Potential remains stable in 1M Cl solution

$$E = E^O - \frac{RT}{F} \ln [\mathrm{Cl}] \text{ (where [Cl] = 1 and ln [Cl] = 0)}$$

- 1M Electrolyte soln
  - Necessary for Ag/AgCl electrode to remain potentially stable
  - Allows transport of electrons from one electrode to another

Ion Pump Layered View