Development of Electrochemical Methods for Differentiation of the Catecholamine Neurotransmitters

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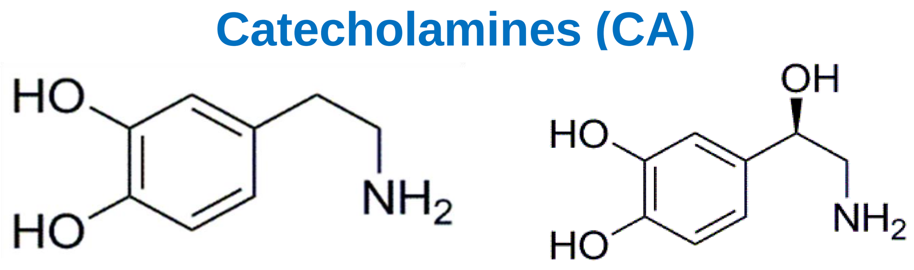
INTRODUCTION

- ❑ Imbalances in catecholamine concentrations are often linked to neurological disorders such as Parkinson's disease, schizophrenia, and substance addiction.
- ❑ Technology is being advanced to monitor catecholamines (CA) to facilitate direct observation of their mutual interactions in brain functions.

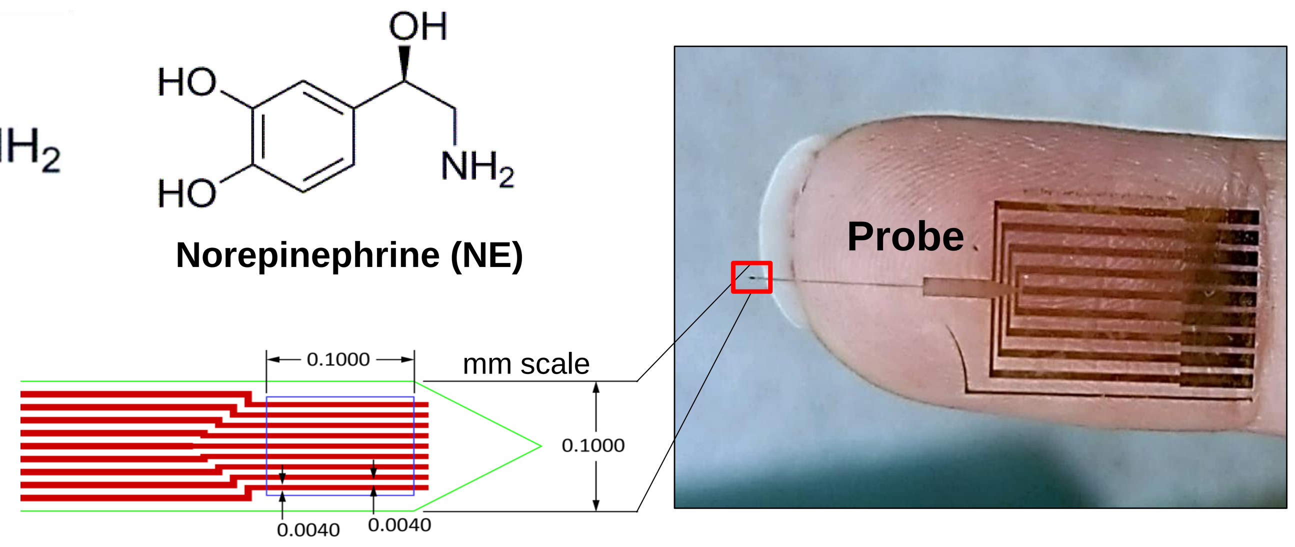
Catecholamines (CA)



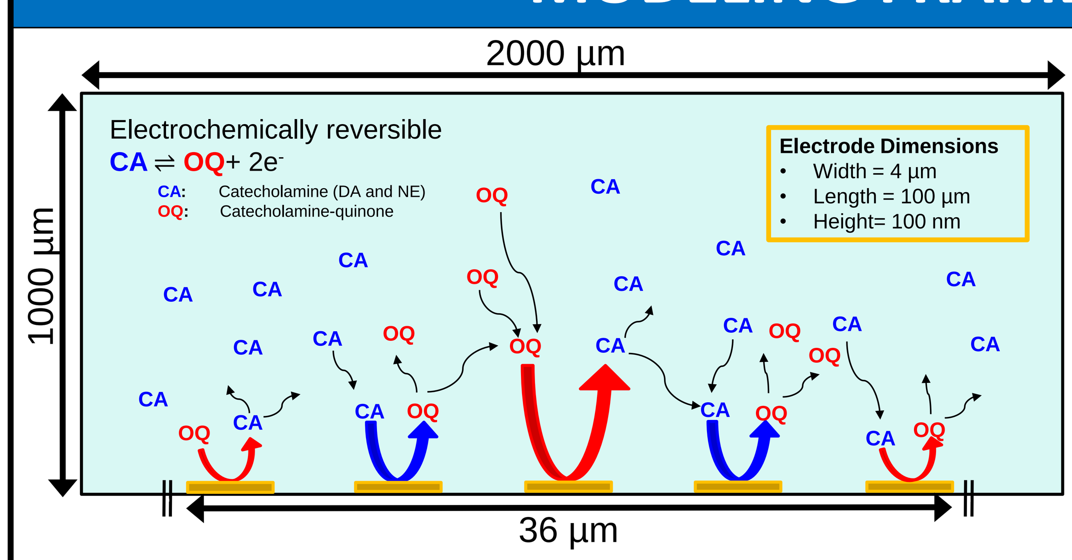
Dopamine (DA) Norepinephrine (NE)

Probe design

- 9 electrodes
  4 µm wide × 100 µm long × 4 µm gap



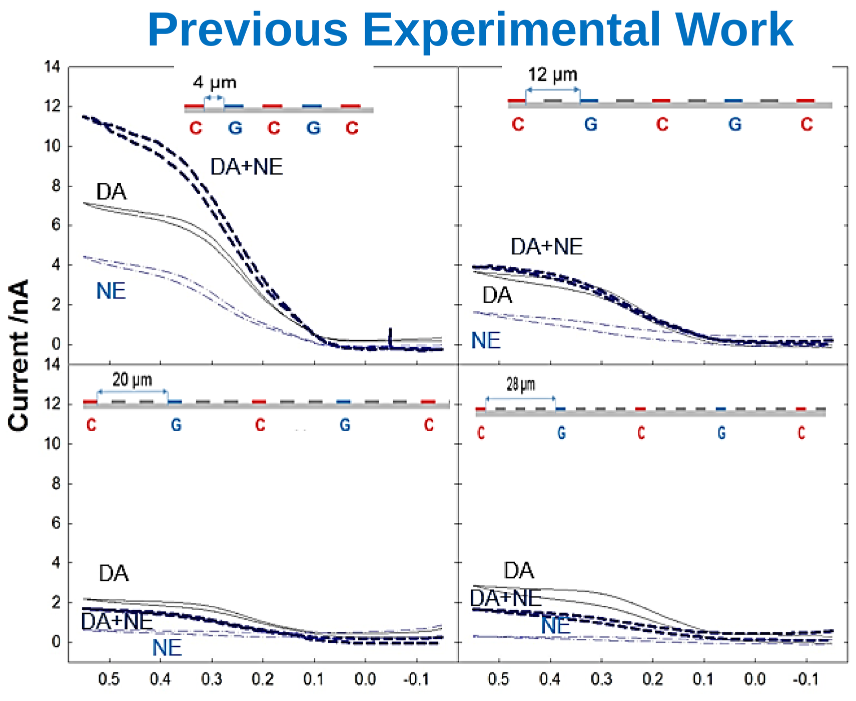
MODELING FRAMEWORK



CGCGC configuration of electrodes.

These closely-spaced electrodes take advantage of the reaction kinetics and mechanisms for the differentiation of each catecholamine.

Previous Experimental Work



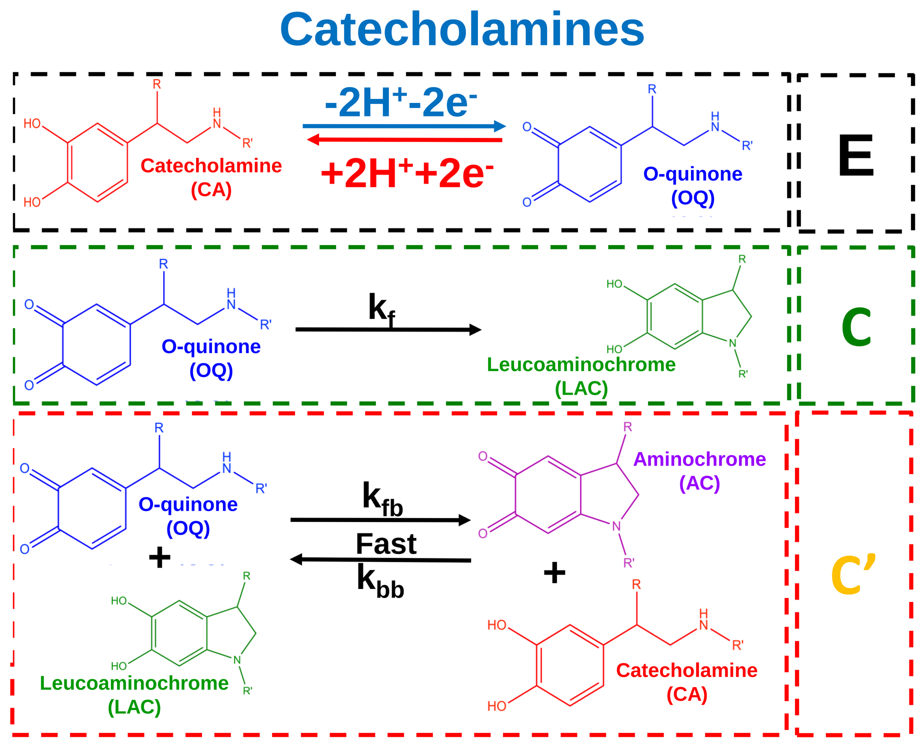
Detection of catecholamines:

- **G** -0.15 V→+0.55 V, 0.02 V/s,
- **C** -0.01 V

With the increasing gap width:

- NE **Collector** current becomes silent
- LAC form reacts with OQ form
- Mixture current falls below DA current

Redox Cycling of Mixtures of Catecholamines



k_f (s-1) at pH=7.4	
DA	0.13±0.05
NE	0.98±0.52

COMPUTATIONAL METHODS

- ❑ The Electroanalysis interface implements chemical transport equations for reactants and products of the redox species using Fick's Second Law (extended to 2D) to describe the chemical transport of DA and NE.
- ❑ The Chemical Engineering interface uses the reaction nodes to account for the consumption and production of the species throughout the chemical reaction.

Initial Conditions:

$C_{CA}(x,y,0) = C^*_{CA} = 0.01\,mM$

$C_{OQ}(x,y,0) = 0$

$C_{LAC}(x,y,0) = 0$

$C_{AC}(x,y,0) = 0$

Boundary Conditions:

$C_{CA}(\infty,\infty,0) = C^*_{CA} = 0.01\,mM$

$C_{OQ}(\infty,\infty,0) = 0$

$C_{LAC}(\infty,\infty,0) = 0$

$C_{AC}(\infty,\infty,0) = 0$

Definitions:

$C_1 = [C_{CADA}(x,y,t)]$ $C_5 = [C_{CANE}(x,y,t)]$

$C_2 = [C_{OQDA}(x,y,t)]$ $C_6 = [C_{OQNE}(x,y,t)]$

$C_3 = [C_{LACDA}(x,y,t)]$ $C_7 = [C_{LACNE}(x,y,t)]$

$C_4 = [C_{ACDA}(x,y,t)]$ $C_8 = [C_{ACNE}(x,y,t)]$

$$\frac{\partial C_1}{\partial t} = D\nabla^2 C_1 - k_{bb}C_1C_4 + k_{fb}C_1C_3 - k_{bb}C_1C_8 + k_{fb}C_2C_7$$

$$\frac{\partial C_2}{\partial t} = D\nabla^2 C_2 - k_f C_2 + k_b C_3 + k_{bb}C_1C_4 - k_{fb}C_2C_3 + k_{bb}C_1C_8 - k_{fb}C_2C_7$$

$$\frac{\partial C_3}{\partial t} = D\nabla^2 C_3 + k_f C_2 - k_b C_3 + k_{bb}C_1C_4 - k_{fb}C_2C_3 + k_{bb}C_5C_4 - k_{fb}C_6C_3$$

$$\frac{\partial C_4}{\partial t} = D\nabla^2 C_4 - k_{bb}C_1C_4 + k_{fb}C_2C_3 - k_{bb}C_5C_4 + k_{fb}C_6C_3$$

$$\frac{\partial C_5}{\partial t} = D\nabla^2 C_5 - k_{bb}C_5C_8 + k_{fb}C_6C_7 - k_{bb}C_5C_4 + k_{fb}C_6C_3$$

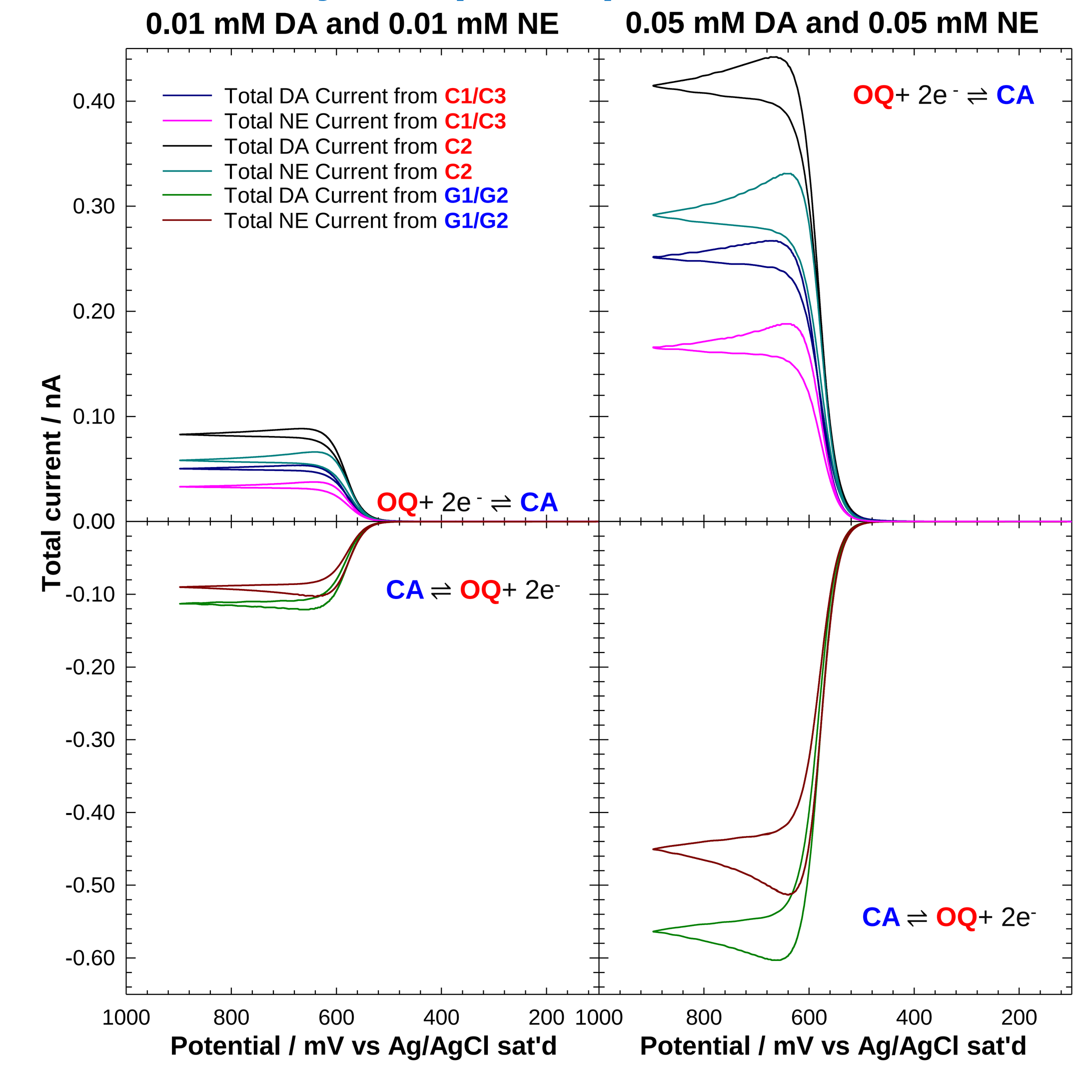
$$\frac{\partial C_6}{\partial t} = D\nabla^2 C_6 - k_f C_6 + k_b C_7 + k_{bb}C_5C_8 - k_{fb}C_6C_7 + k_{bb}C_5C_4 - k_{fb}C_6C_3$$

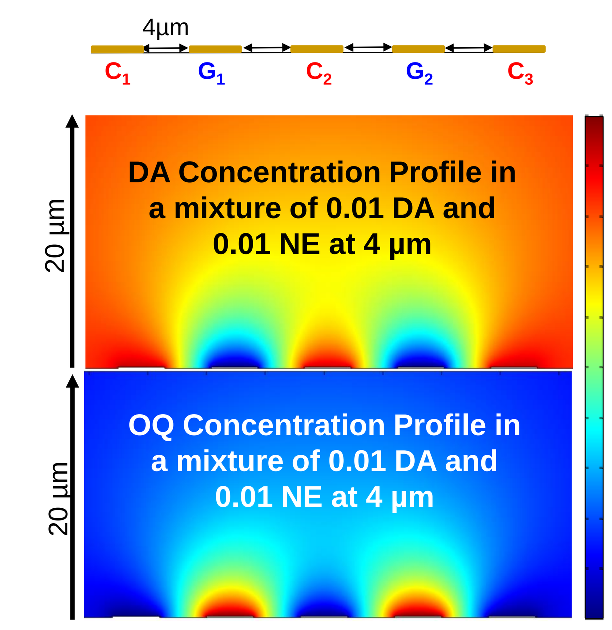
$$\frac{\partial C_7}{\partial t} = D\nabla^2 C_7 + k_f C_6 - k_b C_7 + k_{bb}C_5C_8 - k_{fb}C_6C_7 + k_{bb}C_1C_8 - k_{fb}C_2C_7$$

$$\frac{\partial C_8}{\partial t} = D\nabla^2 C_8 - k_{bb}C_5C_8 + k_{fb}C_6C_7 - k_{bb}C_1C_8 + k_{fb}C_2C_7$$

RESULTS

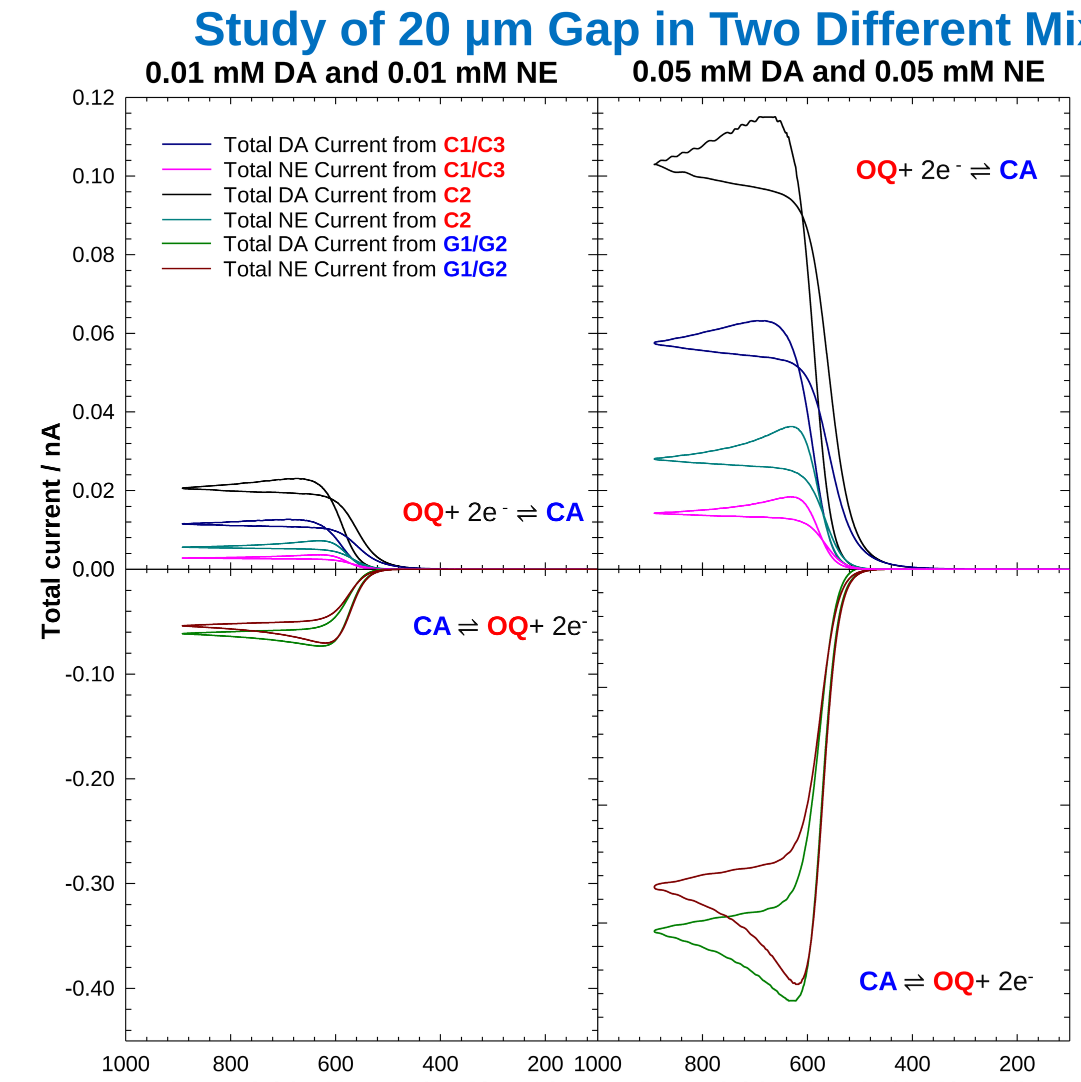
Study of 4 µm Gap in Two Different Mixtures of DA and NE

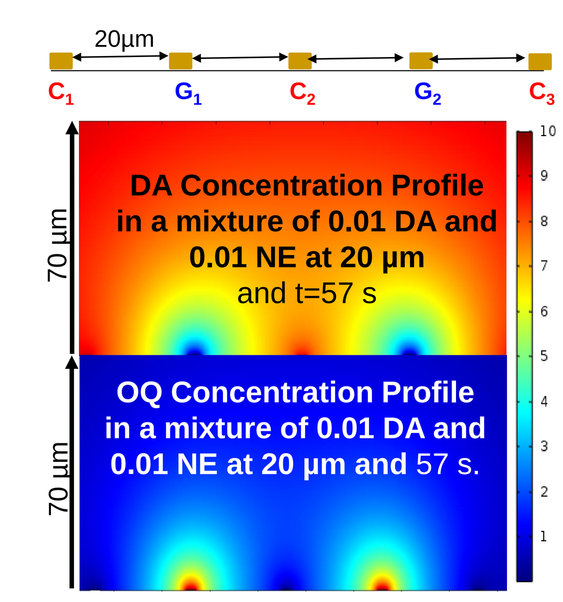




DA and NE cannot be differentiated at a gap of 4 µm.

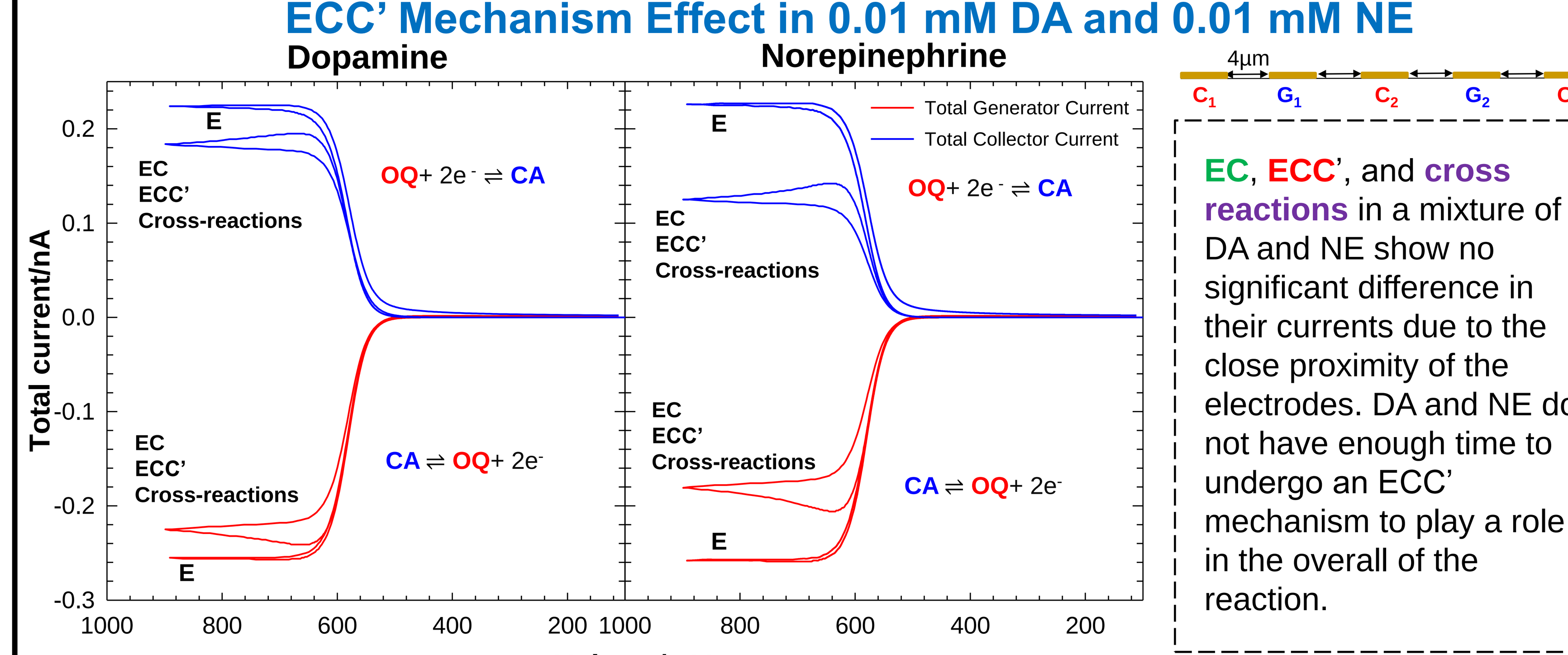
Study of 20 µm Gap in Two Different Mixtures of DA and NE





The differentiation of the catecholamines becomes possible at a gap of 20 µm and 0.01 of DA and NE.

ECC' Mechanism Effect in 0.01 mM DA and 0.01 mM NE



EC, **ECC'**, and **cross reactions** in a mixture of DA and NE show no significant difference in their currents due to the close proximity of the electrodes. DA and NE do not have enough time to undergo an ECC' mechanism to play a role in the overall of the reaction.

CONCLUSION AND FUTURE WORK

- ❑ The catecholamines can be distinguished based on their different cyclization rates by redox cycling methods
- ❑ Additional studies are being developed to further minimize the gaps between the electrodes to achieve lower detection limits.

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ACKNOWLEDGMENTS

❖Fritsch Research Group
❖Research was supported partially through the National Science Foundation (Grant CHE-1808286), the University of Arkansas Women's Giving Circle, and the Arkansas Biosciences Institute, the major research component of the Arkansas Tobacco Settlement Proceeds Act of 2000.