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Electrochemical Detection of the Molecules of Life

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Introduction

All forms of life on Earth contain cellular machinery that can transform and regulate chemical energy through metabolic pathways. These processes are oxidation-reduction reactions that are performed by four key classes of molecules: flavins, nicotinamaides, porphyrins, and quinones. By detecting the electrochemical interaction of these redox-active molecules with an electrode, a method of differentiating them by their class could be established and incorporated into future life-detecting missions. This body of work investigates the electrochemistry of ubiquitous molecules found in life and how they may be detected. Molecules can oxidise or reduce the surface of an electrode - giving or receiving electrons - and these interactions are represented by changes in current with respect to an applied voltage. This relationship varies with: electrolyte type and concentration, working electrode material, the redox-active molecule itself, and scan rate. Flavin adenine dinucleotide (FAD), riboflavin, nicotinamide adenine dinucleotide (NADH), and anthraquinone are all molecules found intracellularly in almost all living organisms. An organism-synthesised extracellular redox-active molecule, Plumbagin, was also selected as part of this study. The goal of this work is to detect these molecules in seawater and assess its application in searching for life on Ocean Worlds.

Methods

Redox-active molecules were independently added to Synthetic Sea Water solutions (SSW) with increasing concentrations from 1nM to 1mM. SSW solution was degassed using nitrogen gas for 10 minutes before running electrochemical experiments. An AgIAgCl reference electrode and Pt wire counter electrode were used. The working electrode was a Glassy Carbon Electrode that was pretreated with mechanical polishing, electrochemical etching at 1.2V in 1M NaOH for 45s, and sonication for 5min in deionised water. Differential Pulse Voltammetry (DPV) was used to determine the electrochemical features of the molecules of interest with a scan rate of 10mV/s. Peak analysis and baseline measurements were performed in OriginLab software.

Applications

The chemically-dynamic environments of Ocean Worlds render them suitable candidates for future life-detection missions. In context of our solar system, Europa and Enceladus are of significant interest for future spacecraft missions because of their favourable conditions that could encourage life to exist, and - perhaps - sustain itself. The introduction of electrochemical sensors into a science payload for these missions would generate valuable data as to whether life-created redox-active molecules are present in a sample and aid in identifying their class. This work demonstrates a useful limit of detection for glassy carbon electrodes in screening for molecules of life, and similarly how to differentiate them (Fig 2,Table 1). The successful integration of these sensors into a microfluidic channel has shown a relatively simple yet effective application of this technology (Fig 3).

Results

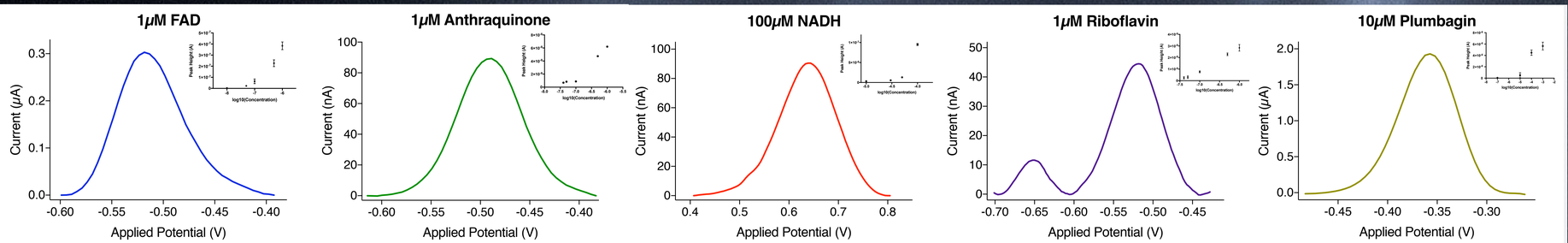

Fig 1. DPV of Redox-Active Molecules in Synthetic Sea Water Solution with Concentration vs Peak Height.

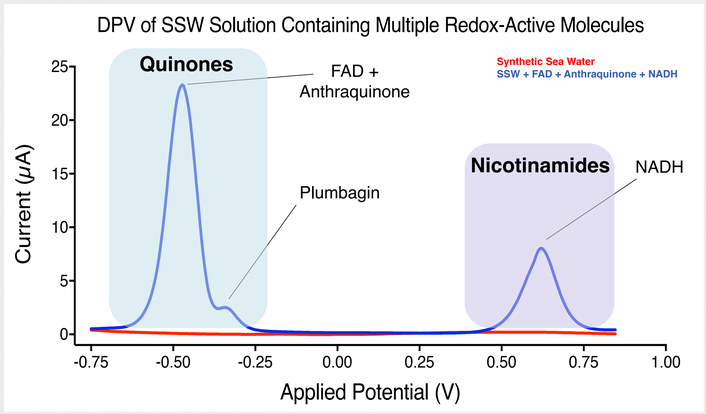

Fig 2. DPV of Synthetic Sea Water containing 25μM FAD, 25μM Anthraquinone, 25μM Plumbagin, and 25μM NADH.

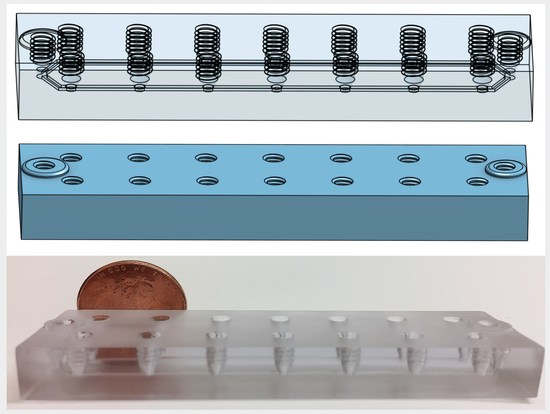

Fig 3. CAD Models with 3D-Printed Microfluidic Channel.

Table 1. Limits of Detection in Synthetic Sea Water.

	Limit of Detection
FAD	10nM
Riboflavin	30nM
Plumbagin	100nM
Anthraquinone	30nM
NADH	10uM

Conclusion and Future Work

This project demonstrate that it is possible to detect naturally-synthesised redox-active molecules in synthetic sea water. The glassy carbon electrodes detected a relatively low concertation of these molecules, and could be readily incorporated into a 3D-printed microfluidic channel. A limitation for further investigation of these ubiquitous molecules is that most of them exist intracellularly, and so future studies could be directed at the lysis of cells so that the sensors can directly access these molecules. Similarly, the scaling-down of the glassy carbon macro electrode to a micron scale may prove valuable in decreasing the limit of detection. Investigating other carbon-based electrode materials such as diamond-like-carbon and boron-doped diamond are also of future interest for their wide electrochemical range and robust properties. This is important for detecting porphyrins, where a low applied voltage is needed.