Chemistry Departmental Colloquium

Thursday, October 26, 2023
4:30 p.m. ~ WTHR 104

"The Chemistry and Physics of Water-Dissociation Catalysis in Bipolar Membranes"

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and the Materials Science Institute
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Bio: Boettcher is a Professor in the Department of Chemistry and Biochemistry at the University of Oregon. His research is at the intersection of materials science and electrochemistry, with a focus on fundamental to applied aspects of energy conversion and storage. He has been named a DuPont Young Professor, a Cottrell Scholar, a Sloan Fellow, and a Camille-Dreyfus Teacher-Scholar. He is a 2019-2022 ISI highly cited researcher (top 0.1% over past decade) and in 2023 was the Blavatnik National Award Laureate in Chemistry. In 2019 he founded the Oregon Center for Electrochemistry and the first graduate program in Electrochemical Technology in the USA.

Abstract:

Bipolar membranes (BPMs) are ionic analogues of semiconductor pn junctions and consist of an anion-selective ionomer membrane laminated with a cation-selective ionomer membrane. BPMs generate pH gradients under bias by driving water dissociation (WD) into protons and hydroxide at the interface between the two different ionomers. In BPM water electrolysis, this feature enables devices that drive proton reduction in locally acidic conditions, where electrode kinetics are fast, and water oxidation in locally basic conditions where efficient earth-abundant catalysts are stable. In electrodialysis, BPMs generate acid and base from salt water on demand for wastewater treatment/reuse, CO_2 capture from the air or ocean, and niche applications like food/drink processing. As the predominant H^+/OH^- ion flow is out from the center of the BPM, in electrosynthesis BPMs mitigate deleterious cross-over of reactants and products.

The key factor traditionally limiting the use of BPMs to niche applications, has been the low operating currents and high voltage losses (~0.4 V at 0.1 A/cm2). We have isolated the voltage loss in BPMs to kinetics of the water dissociation (WD) reaction, nominally $H_2O \rightarrow H^+ + OH^-$. We invented physical electrochemical platforms to study the basic factors and mechanisms that control the kinetics of WD, discovering how tuned metal-oxide nanoparticles provide surfaces with (controllable) proton-absorption sites that catalyze WD while also focusing the interfacial electric field across the BPM junction and thus further speeding the WD rate (e.g. Science 2020, Nature Comm. 2022). Temperature-dependent measurements show the WD catalysts do not primarily lower the activation energy for WD, but instead dramatically increase the number of water configurational microstates poised for the proton-transfer elementary steps in WD (Joule, 2023). These discoveries enable BPMs that operate at least 20-times better voltage efficiency than the commercial state of the art, and at current-densities of 4 A/cm2, opening tremendous new application space.

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