Life Electric: What can microbes teach us about electron transport, energy, and sustainability?

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Electron Transfer (ET) is the stuff of life. The stepwise movement of electrons within and between molecules dictates all biological energy conversion strategies, including respiration and photosynthesis. With such a universal role across all domains of life, the fundamentals of ET and its precise impact on bioenergetics have received considerable attention, and the broad mechanisms allowing ET over small length scales in biomolecules are now well appreciated.

In what has become an established pattern, however, our planet’s oldest and most versatile organisms are now challenging our current state of knowledge. With the discovery of bacterial nanowires and multicellular bacterial cables, the length scales of microbial ET observations have jumped by 7 orders of magnitude, from nanometers to centimeters, during the last decade alone! This talk will take stock of where we are and where we are heading as we come to grips with the basic mechanisms and immense implications of microbial long-distance electron transport. We will focus on the biophysical and structural basis of long-distance, fast, extracellular electron transport by metal-reducing bacteria. These remarkable organisms have evolved direct charge transfer mechanisms to solid surfaces outside the cells, allowing them to use abundant minerals as electron acceptors for respiration, instead of oxygen or other soluble oxidants that would normally diffuse inside cells. From an environmental perspective, these microbes are major players in global elemental cycles. From a technological perspective, microbial extracellular electron transport is heavily pursued for interfacing redox reactions to electrodes in multiple renewable energy technologies.

But how can an organism transfer electrons to a surface many cell lengths away? What molecules mediate this transport? And, from a physics standpoint, what are the relevant length, time, and energy scales? We will describe new experimental and computational approaches that revealed how bacteria organize heme networks on outer cell membranes, and along the quasi-one-dimensional filaments known as bacterial nanowires, to facilitate long-range charge transport. Using correlated electron cryo-tomography and in vivo fluorescent microscopy, we are gaining new insight into the localization patterns of multiheme cytochromes along nanowires as well as the morphology and the formation mechanism of these structures. In addition, we will examine the fundamental limits of extracellular electron transport, down to microbial energy acquisition by single cells. These findings are shedding light on one of the earliest forms of respiration on Earth while unraveling surprising biotic-abiotic interactions.