

EXOSELECTROGENS

Bacteria that 'Breathe' Electricity

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EXOSELECTROGENS are a group of anaerobic microbes that obtain energy by oxidising organic compounds coupled with the reduction of extracellular metal oxides or anodes of electrical cells. They mimic the action of batteries that discharge electric current and are said to "breathe electricity." Also known as anode respiring bacteria and electricigens, they transfer electrons removed from organic compounds to the cell exterior by a process called Extracellular Electron Transfer (EET). Although EET in microbes has been recognised for several decades and a few exoelectrogens have been harnessed for bioremediation, the mechanism involved remains largely unexplained.

A team of researchers led by Ajo-Franklin of Rice University, in collaboration with those at the University of California, recently delineated the mechanism of EET and showed that the phenomenon is more widespread in nature than previously thought. They also elucidated how organisms, such as the well-studied *E. coli*, can be nudged to thrive in oxygen-free environments with the help of extracellular respiration and generate an electric current. The work was published in the April 2025 issue of the journal *Cell*. According to one of the authors, "Our research not only solves a long-standing scientific mystery but points to a potential widespread survival strategy in nature."

Most extant higher organisms are aerobic, i.e., they use oxygen to respire. There, however, exist niches such as deep-sea vents, guts of higher animals, and deep underground, where oxygen availability is low or absent (anaerobic conditions). A variety of simple forms of life thrive in these niches by generating energy using the well-studied pathways, such as lactic acid/ethanol fermentation. A few also survive with the help of EET. Fermentation pathways and aerobic oxidation have been studied in detail, but the pathways by which certain anaerobes obtain energy through extracellular respiration are incompletely understood.

EET Differs From Fermentation and Aerobic Respiration

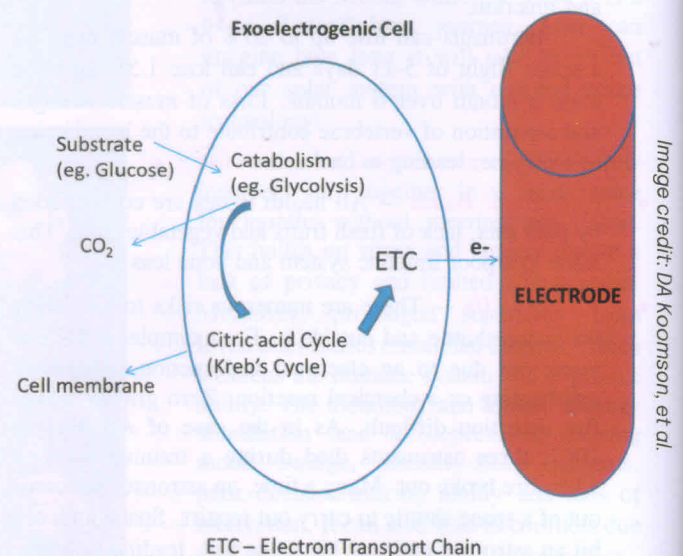
Respiration is the process through which living organisms extract energy from food for their sustenance. Energy-rich and reduced organic carbon compounds, which form the food of most living beings, release energy by the process of oxidation during respiration. Oxidation reactions do not occur in isolation but require specific partners that can be reduced. The energy released in an oxidation reaction is the difference between the reduction potential of the oxidant and that of the reductant. In the redox reactions, oxidation refers to the loss of electrons (from the reductant) and reduction refers to their gain (to the oxidant).

Oxidation of food inside the cell releases a large quantum of energy, which is assimilated by living beings, by dividing the process into multiple small transformations, each releasing

a manageable amount of energy. Energy released during some of the reactions is assimilated in the form of ATP within the cell. Oxygen is an excellent acceptor of electrons, and aerobes derive most of their energy by finally transferring electrons to it. During fermentations that take place in the absence of oxygen, electrons removed from food are transferred to other molecules with a lower oxidation potential present within the cell.

For over a billion years following the origin of life on Earth, the atmosphere had no oxygen, and organisms relied on anaerobic respiration alone for their energy needs. Lactic acid fermentation and ethanol fermentation are typical examples of anaerobic respiration. During lactic acid fermentation, foods such as glucose undergo multiple-step reactions and produce lactate, which is lower in energy and more reduced in nature compared to the sugar. Part of the released energy is assimilated by the cell during this process. Electrons are removed from the intermediate metabolite glyceraldehyde-3-phosphate and transferred to pyruvate, which in turn is converted into lactate. The coenzyme NAD⁺ carries electrons from glyceraldehyde-3-phosphate to pyruvate. The entire process of lactic acid fermentation takes place inside the cell, resulting in the consumption of glucose and net accumulation of lactate.

After oxygen became abundant in the atmosphere about 2.5 billion years ago, several organisms adapted to aerobic respiration. Aerobic respiration leads to complete oxidation, the release of energy from glucose and its conversion to CO₂. Oxygen is a powerful acceptor of electrons (a strong oxidant) and readily accepts electrons removed from food. In the presence of oxygen, more energy is released from the pyruvic acid, formed from glucose, during its conversion to CO₂. This



A schematic diagram of the catabolic and respiratory pathways in exoelectrogens