Dielectric Responses of Living Organisms

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A LIVE CELL HAS AN EXTRAORDINARILY HIGH INTRACELLULAR charge density owing to the presence of negatively charged proteins, such as actin and other biomolecules. An applied electric field will displace charges in the extracellular medium and inside each cell, leading to a finite dipole moment. Recalling that the polarization vector **P** is the dipole moment per unit volume, and that the dielectric susceptibility is proportional to **P**, a live cell suspension has an extremely high dielectric constant at low frequencies. We observe relative dielectric constants greater than 10^7 for fission yeast suspensions with 10^8 cells/ml, and somewhat lower values for various species of bacteria. The dielectric response falls rapidly with increasing frequency since the charges move through a highly viscous aqueous medium. Potential applications include the detection of biological warfare agents inside sealed containers, biosensors to search for subsurface life on Mars, and basic research on live cells.

More recently, we have begun to study the frequency-dependent dielectric responses of biological proteins. In particular, tubulin is a protein that self-assembles, or polymerizes, to form microtubules. These tube-shaped structures play an enormous role in all higher organisms, comprising a major component of the cellular cytoskeleton and proving heavily involved in motility, intracellular transport, mitosis (cell division), and neuronal information processing. Tubulin comes in several forms, or amino acid sequences, the most predominant of which are α- and β-tubulin. These two monomers combine to form the α-β tubulin heterodimer, which has a strong intrinsic electric dipole moment. The α-β tubulin heterodimers, in turn, polymerize into microtubules.

We find that the dielectric response of a suspension of tubulin heterodimers changes during microtubule polymerization. Figure 1 shows a plot of the dielectric response vs. frequency of a tubulin suspension slightly above 0°C. After 1.5 hours, the dielectric response is seen to decrease significantly. We attribute this reduction in dielectric constant to the fact that, as the tubulin dimers polymerize into microtubules, their orientational motion is “frozen out,” thus preventing them from contributing to the dielectric response.

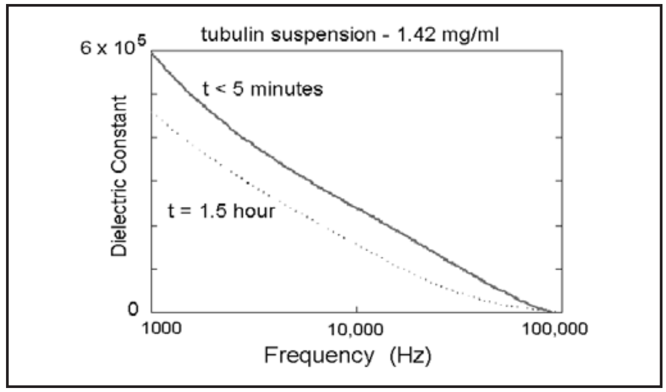

Figure 1. Relative dielectric constant vs. frequency for a suspension of α-β tubulin heterodimers shortly after warming above 0°C and after 1.5 hours. As the tubulin dimers self-assemble to form microtubules, the concentration of tubulin dimers free to rotate is reduced, leading to a decreased dielectric constant.

Additional ongoing studies include the time-dependent electrical responses of live cell suspensions, some of which suggest collective charge dynamics similar to that seen in certain condensed matter systems, such as charge density waves. Participating UH students include Nawarathna-Mudiyanselage D. Nawarathna, Vijayanand Vajrala, Hugo Sanabria, and Gustavo Cardenas.

Publications

Prodan, C., F. Mayo, J. R. Claycomb, J. H. Miller, Jr., and M. J. Benedik. “Low-Frequency, Low-Field Dielectric Spectroscopy of Living Cell Suspensions,” *J. Applied Physics* 95 (2004): 3754-56.

Presentations

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Funding and proposals

Miller, J. H., Jr. “Dielectric Spectroscopy for the Detection of Chemical and Biological Warfare Agents, DARPA - Naval Surface Warfare Center, Dahlgren Division, April 23, 2003-April 22, 2005, $348,525.

Miller, J. H., Jr. “Dielectric Spectroscopy of Chemical and Biological Systems,” Robert A. Welch Foundation, June 1, 2004-May 31, 2007, $165,000.

FUEL CELLS—Dr. John H. Miller, Jr., Associate Professor of Physics and a faculty member of the Texas Center for Superconductivity and Advanced Materials (TCSAM) specializes in the development of fuel cells. Reducing the nation’s use of fossil fuels is a goal of fuel cell research which has applications in home heating and cooling and in automobile production.