What enables efficient long-range charge transport across protein layers?

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For molecular layers only $\approx$ 1-2 nm thick, coherent tunneling is a widely accepted mechanism of charge transport. We have studied such systems systematically, including molecules with reversibly switchable asymmetric tunnel barriers [1] and chiral molecules exhibiting structure-dependent spin selectivity [2].

Protein multilayers extend this problem into a qualitatively different length regime, with layer thicknesses reaching several tens of nanometers. For multilayers of the protein bacteriorhodopsin (bR), we find a mono-exponential attenuation of conductance with bR layer thickness up to 16 nm, with a small attenuation coefficient of $\beta \approx 0.8$ nm^{-1} [3]. This weak, exponential length dependence is surprisingly reminiscent of non-resonant tunneling. Indeed, together with the observed temperature behavior, it is consistent with tunneling through the thin protein-protein and protein-electrode interfaces. However, the microscopic (quantum) mechanism underlying the apparently efficient long-range electron transport through the *protein interior* remains elusive and calls for new theoretical approaches.

[1] J. M. Dlugosch et al., ACS Appl. Mater. Interfaces 14, 31044−31053 (2022)

[2] A. N. Nalakath et al., arXiv:2603.17707

[3] D. Chryssikos et al., Adv. Funct. Mat. 34, 2408110 (2024)