Self-Organized Bioelectricity via Collective Pump Alignment
Publication-ready output (workflow example)
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Core claims:
- Fluctuation-driven collective pump alignment
- Emergent membrane-scale electrochemical potential
- Micro-to-macro ordering mechanism hypothesis

Validation status: low-medium confidence (pending replication)

Source preview excerpt:
Self-Organized Bioelectricity via Collective Pump Alignment: Physical Origin of Chemiosmosis Ryosuke Nishide and Kunihiko Kaneko arXiv:2602.16171v1 [physics.bio-ph] 18 Feb 2026 Niels Bohr Institute, University of Copenhagen, Jagtvej 155 A, Copenhagen N, 2200, Denmark Chemiosmosis maintains life in nonequilibrium through ion transport across membranes, yet the origin of this order remains unclear. We develop a minimal model in which ion pump orientation and the intracellular electrochemical potential mutually reinforce each other. This model shows that fluctuations can induce collective pump alignment and the formation of a membrane potential. The alignment undergoes a phase transition from disordered to ordered, analogous to the Ising model. Our results provide a self-organizing mechanism for the emergence of bioelectricity, with implications for the origin of life. Fig.1 Coupling between directional ion transport across a membrane and the generation of an electrochemical potential difference is essential for living cells[1]. Mitchells chemiosmotic theory established that electric currents operate at the source of life: nonequilibrium ion currents across membranes drive cellular energy transduction, including ATP synthesis[24]. Through this coupling, living systems are maintained far from equilibrium by sustained directional ion fluxes across membranes. At the origin of life, the emergence of sustained nonequilibrium ion flows across membranes is thought to have been a critical step. Phylogenetic evidence indicates that early life already synthesized ATP through membrane-potentialdriven processes[5, 6], and chemical and geological studies suggest that early cells may have emerged by exploiting natural proton gradients associated with alkaline hydrothermal vents[7, 8]. However, cells can autonomously generate membrane potential through ion transport, even in the absence of preexisting ion gradients, leaving the origin of such mechanisms unresolved. Therefore, to elucidate the origin of life or protocells, it is necessary to understand how ion pumps could collectively generate and sustain membrane potential. Although studies on the origin of life have examine