Quantum technologies beyond computation: Mimicking and controlling physiology via quantum degrees of freedom

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At the Quantum Biology Tech (QuBiT) Lab, we are quantum engineers interested in how quantum physics informs biology at the nanoscale.

Substantial experimental results suggest that quantum effects involving spin might underlie biological phenomena as varied as magnetic field detection for animal navigation, metabolic regulation in cells and optimal electron transport in chiral biomolecules. In particular, recent evidence indicates that sensing (both endo- and exogenous) magnetic fields (MFs) might be more widespread and impactful for physiology than previously assumed. Weak MFs were demonstrated to regulate: the production of reactive oxygen species in mice and human cells; mitochondrial respiration and glycolysis rates in human cells; stem cell growth in planaria; and yield of DNA repair. These are all fundamental disease markers. Relevantly, all these results are consistent with spins mediating the interaction of the specimens with the weak MF.

At a chemical level, it was established decades ago that MFs can alter the final products of chemical reactions involving both electron and nuclear spins. The leading hypothesis to explain spin-mediated 'biosensing' depends on the same holding true in vivo which, if true, means that organisms are, for a short time, behaving as 'living quantum sensors'. Astoundingly, in certain ways, these quantum sensors appear to even surpass humankind-made devices, despite being embedded in a noisy, hot and wet biological environment, rather than a shielded cryostat at near-zero temperature. Thus, not only could established quantum protocols be used to study and control the effect, but it might also be possible to: use the unequivocal choices of natural selection for advancement of technological quantum sensors (*e.g.*, excellent noise resilience); and harness quantum degrees of freedom to commandeer and drive physiology.

Our research aims to utilize tools from the coherent control of open quantum systems to, for the first time, realize the latter prospects at the nanoscale. In our group, we design quantum-inspired instrumentation to control biological spins *in vivo*. In this talk, I will describe both our vision and some of the novel instrumentation we are currently developing, which include microscopes (lattice light-sheet and total internal reflection) with single-photon/nanosecond/single-molecule resolution capabilities, coupled to a radio-frequency nanochip. The unusual crossover between biophysics and spin physics (a.k.a. 'quantum sensing') is the fundamental strength of our projects.

Can coherent spin physics be established – or refuted! – to account for physiologically relevant biological phenomena, and be manipulated to technological and therapeutic advantage? This is the broad, exciting question that the Quantum Biology Tech (QuBiT) Lab at UCLA wishes to address.