

Preface

A landmark event in the history of science was the publication in 1944 of Erwin Schrödinger's book *What is Life?* Six decades later, the question remains unanswered. Although biological processes are increasingly well understood at the biochemical and molecular biological level, from the point of view of fundamental physics, life remains deeply mysterious. Schrödinger himself drew inspiration from his seminal work on quantum mechanics, which had so spectacularly explained the nature of matter, believing it was sufficiently powerful and remarkable to explain the nature of life too. These dreams have not been realized. To be sure, quantum mechanics is indispensable for explaining the shapes, sizes and chemical affinities of biological molecules, but for almost all purposes scientists go on to treat these molecules using classical ball-and-stick models. Life still seems an almost magical state of matter to physicists; furthermore, its origin from non-living chemicals is not understood at all.

In recent years, circumstantial evidence has accumulated that quantum mechanics may indeed, as Schrödinger hoped, cast important light on life's origin and nature. In October 2003, the US space agency NASA convened a workshop at the Ames Laboratory in California, the leading astrobiology institution, devoted to quantum aspects of life. The workshop was hosted by Ames astrobiologist Chris McKay and chaired by Paul Davies. In this volume we solicit essays both from the participants in the workshop, and from a wider range of physical scientists who have considered this theme, including those who have expressed skepticism. The over-arching question we address is whether quantum mechanics plays a non-trivial role in biology.

We believe it is timely to set out a distinct quantum biology agenda. The burgeoning fields of nanotechnology, biotechnology, quantum technology and quantum information processing are now strongly converging. The acronym BINS, for Bio-Info-Nano-Systems, has been coined to describe the synergetic interface of these several disciplines. The living cell is an information replicating and processing system that is replete with naturally-evolved nanomachines, which at some level require a quantum mechanical description. As quantum engineering and nanotechnology meet, increasing use will be made of biological structures, or hybrids of biological and fabricated systems, for producing novel devices for information storage and processing, and other tasks. An understanding of these systems at a quantum mechanical level will be indispensable.

To broaden the discussion, we include chapters on “artificial quantum life,” a rapidly-developing topic of interest in its own right, but also because it may cast light on real biological systems. Related mathematical models include quantum replication and evolution, von Neumann’s universal constructors for quantum systems, semi-quantum cellular automata, and evolutionary quantum game theory.

Finally, we include the transcripts of two debates:

- (1) “Dreams versus reality: quantum computing” hosted by the *Fluctuations and Noise* symposium held in Santa Fe, USA, 1–4 June 2003. The panelists were Carlton M. Caves, Daniel Lidar, Howard Brandt, Alex Hamilton (for) and David Ferry, Julio Gea-Banacloche, Sergey Bezrukov and Laszlo Kish (against). The debate chair was Charles Doering.
- (2) “Quantum effects in biology: trivial or not?” hosted by the *Fluctuations and Noise* symposium held in Gran Canaria, Spain, 25–28 May 2004. The panelists were Paul Davies, Stuart Hameroff, Anton Zeilinger, Derek Abbott (for) and Jens Eisert, Sergey Bezrukov, Hans Frauenfelder and Howard Wiseman (against). The debate Chair was Julio Gea-Banacloche.

The second debate represents the topic of this book and a new reader to the area may find it beneficial to jump directly to Chapter 16, as this will help the reader navigate some of the competing arguments in an entertaining way. The first debate, in Chapter 15, is on whether useful man-made quantum computers are possible at all. Placing these two debates side by side exposes interesting conflicting viewpoints of relevance to this book:

- (1) Those who would argue for quantum processing in various biological

systems have to face the difficulty that useful man-made quantum computers are extremely hard to make, and if they are fodder for debate then the biological proposition would appear to be on even weaker ground; (2) Those physicists who are working towards realizing large scale man-made quantum computers, when faced with skepticism, are on occasion tempted to appeal to biology in their defence as can be seen in Chapter 15. This therefore creates an exciting tension between the opposing viewpoints, namely, that on one hand pessimistic experience with man-made quantum computers is used to cast doubt on quantum effects in biology, whereas on the other hand an optimistic view of quantum effects in biology is used to motivate future man-made quantum computers. Physicists with a vested interest in realizing quantum computers often find themselves in a strange superposition of these orthogonal viewpoints, which can only be finally resolved if more detailed experiments on biomolecules are carried out.

Finally, it is our hope that at the very least this book will provoke further debate and help provide motivation for more experimental research into nature's nanostructures. If experiments can shed further light on our understanding of decoherence in biomolecules, at scales where equilibrium thermodynamics no longer applies, this may provide the required foundation for greatly accelerating our progress in man-made quantum computers.

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