A quantum recipe for life

Sixty years on, Erwin Schrödinger's prediction that quantum mechanics would solve the riddle of how life started has not been fulfilled. But the appeal of using quantum theory to solve the mystery persists.

Paul Davies

One of the most influential physics books of the twentieth century was actually about biology. In a series of lectures, Erwin Schrödinger described how he believed that quantum mechanics, or some variant of it, would soon solve the riddle of life. These lectures were published in 1944 under the title *What is life?* and are credited by some as ushering in the age of molecular biology.

In the nineteenth century, many scientists thought they knew the answer to Schrödinger's rhetorical question. Life, they maintained, was some sort of magic matter. The continued use of the term 'organic chemistry' is a hangover from that era. The belief that there is a chemical recipe for life led to the hope that, if only we knew what it was, we could mix up the right stuff in a test tube and make life in the lab.

Most research on biogenesis has followed that tradition, by assuming that chemistry was a bridge — and a long one at that — linking matter with life. Elucidating this chemical pathway has been a tantalizing goal, spurred on by the famous Miller–Urey experiment of 1952, in which amino acids were made by sparking electricity through a mixture of water and common gases. But the concept has turned out to be something of a blind alley, and further progress with prebiotic chemical synthesis has been frustratingly slow. The origin of life remains one of the great outstanding mysteries of science.

To take up Schrödinger's suggestion, a radical solution to the problem, 'What is life?' could be that quantum mechanics enabled life to emerge directly from the atomic world, without the need for complex intermediate chemistry. Life must have a chemical basis: organic molecules provide the hardware for biology. But what about the software?

When Schrödinger asked, 'What is life?' he could already glimpse the central significance of the cell's information storage and replication processes, even though the role of DNA and the genetic code was yet to be discovered. Today, the cell is regarded not as magic matter but as a computer — an information-processing and replicating system of astonishing precision.

When life is viewed in terms of information processing, the problem takes on a different complexion. Biologists have always regarded reproduction — one of the defining characteristics of life — as being about replicating structures, whether they be DNA molecules or entire cells. But to get life started all you need is to replicate information.

Information can be processed at the quantum level orders of magnitude more rapidly than it can be processed classically, which is why the race is on to build a quantum computer. Furthermore, quantum systems can make use of phenomena such as superposition, entanglement and tunnelling to enhance their performance.

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Finding the atomic Adam: quantum mechanics may have allowed life to emerge without the need for complex intermediate chemistry.

A quantum replicator need not be an atomic system that clones itself. Indeed, there is a quantum no-cloning theorem that forbids the replication of wavefunctions. Rather, the information content of an atomic system must be copied more or less intact — not necessarily in one step, but maybe after a sequence of interactions. This information might well be in binary form, making use of the spin orientation of an electron or atom for example. Quantum mechanics thus provides an automatic discretization of genetic information.

What is this atomic Adam, this quantum replicator that begets life? I confess I haven't a clue about the best environment in which to find such a thing, although I know it would not be in a traditional primordial-soup setting. It might even be a frigid location such as an interstellar grain. Wherever it was, once a population of information replicators became established, quantum uncertainty provided an inbuilt mechanism for variation. Throw in a selection mechanism and the great darwinian game could begin.

How, then, did organic life arise? Information can readily be passed from one medium to another. At some stage, quantum life could have co-opted large organic molecules for back-up memory. Eventually the organic stuff would literally have taken on a life of its own. The loss in processing speed would have been offset against the greater complexity, versatility and stability of organic molecules, which in turn would have enabled organic life to invade many environments.

Something is missing from the account so far — complexity. Replicating a single bit of information is one thing; generating and replicating long concatenations of bits is quite another. How complexity emerges in quantum systems is a subject still in its infancy, but the principles involved could be illuminated by applying algorithmic complexity theory to quantum information theory.

When Schrödinger published his book, quantum physicists were flushed with the success of explaining the nature of matter. Life is, after all, just a state of matter, albeit a weird one. Sixty years on, Schrödinger's expectation has not been fulfilled. Molecular biologists are content with ball-and-stick models based on classical concepts. But so long as they cling to that, the origin of life will remain mysterious.

Even if we can't reconstruct the precise details of life's emergence, knowing the general principles would be a huge advance. Proving a quantum-mechanical theorem that puts a bound on the probability that such-and-such a system can replicate to a certain accuracy, and evolve to a particular level of complexity, might answer astrobiology's burning question: was the origin of known life a freak accident, or the expected outcome of intrinsically bio-friendly laws of physics? Momentous implications would flow from the answer, as the issue addresses one of the deepest questions of existence: is life a cosmic phenomenon, or are we alone in the vastness of the Universe? ■

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