Profile of a Polymath

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A Life of Erwin Schrödinger
Walter Moore
Canto Paperbacks, Cambridge
University Press, 1994

Among the many geniuses who carried physics through the quantum revolution, none possessed a more complex personality than Erwin Schrödinger. He was truly also a polymath – "one who knows many arts and sciences." His greatest achievement, the discovery of wave mechanics in 1925–26, occurred, as Weyl said, "during a late erotic outburst in his life." Considering that he was then 38 years old, an age at which, generally, theoretical physicists of such calibre are past their prime, we see the truth in Feynman's assessment that "Schrödinger rose to the occasion in meeting the challenge of developing his version of quantum mechanics."

Walter Moore's *Schrödinger: Life and Thought*, published in 1989, was soon recognised as a deftly handled portrait of an extraordinarily gifted, yet complex genius. His *A Life of Erwin Schrödinger* is an abridged version, retaining all the charm and readability of the original.

Erwin Schrödinger was born into a relatively affluent family in Vienna in 1887. Being an only child, and in an environment of doting aunts and nurses, he grew up with definite attitudes towards women and a need for attention. His feelings about formal religion and morality were formed early, in a Vienna with rich cultural, literary and scientific traditions and yet a brittle brilliance. He became the finest product of the Viennese school, with a deep feeling for statistical principles, and a taste for elegance in scientific work.

Schrödinger's reading of Schopenhauer brought him very early in touch with the Upanishads and Vedantic philosophy; at one stage he seriously considered making philosophy rather than physics his vocation. He saw active duty during World War I. His early scientific work was shaped by the interests of the Vienna school which, in spite of the legacy of Boltzmann, was somewhat away from the mainstream.

Throughout his career, Schrödinger moved continuously from one university to another – first the game of musical chairs among German universities, then longer stays at Zurich and Berlin. His longest tenure, from 1939 to 1956, was in Dublin. It was at Zurich that he caught up with current developments and, at a resort in the company of a Viennese girlfriend, rather like "the dark lady of the sonnets," created wave mechanics. No other work of his came near the magnitude of this one. His own contribution to the inter-

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pretation of quantum mechanics consisted largely of a critique of the conventional Bohr–Heisenberg view. In 1933 he shared the physics Nobel Prize with Dirac. As a rule he dealt only with basic issues and avoided applications, and did not collaborate much with others.

Women – indeed, many of them – played an important role throughout Schrödinger's life. His condescending, male supremacist attitude towards them may have been the result of early unrequited love. His marriage to Anne-Marie Bertel in 1920 soon became a mutually agreed cover for affairs on both sides. His own, all passionate and most of them brief, even included one with the wife of an obliging junior colleague.

He had no regard for conventional social norms or morality, and on occasion displayed not a little conceit. His yearning for a son was never fulfilled, and each of his three daughters was born of a different affair.

All this contrasts sharply with his Vedantic world view and his deep belief in the unity of minds and consciousness. In some ways this philosophical stance, reinforced by his own wave mechanics, influenced his attitude to science in general. Yet his intellectual pursuits remained so, a world apart from his romantic affairs and unintegrated with actions and relationships. His eloquence and command of language, the persuasive quality of his writing and the ability to distil the essence of a subject into a few pages, remain unsurpassed. His range of interests, revealed in his writings – *Nature and the Greeks, My View of the World, Space Time Structure, Mind and Matter, What is Life?, Statistical Thermodynamics*, among others – each one a jewel of exposition, is astonishing.

Moore treads a delicate path, and combines tact, sympathy and honesty in his account. His delineation of Schrödinger's philosphical views is accurate and a pleasure to read. In assessing and reacting to this unique personality, a good guide is Max Born's statement: "His private life seemed strange to bourgeois people like ourselves. But all this does not matter. He was a most lovable person, independent, amusing, temperamental, kind and generous, and he had a most perfect and efficient brain". And the biblical injunction: "Judge not, that ye be not judged."

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Erwin Schrödinger, "What is Life? The Physical Aspect of the Living Cell"

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Erwin Schrödinger, 'What is Life? The Physical Aspect of the Living Cell'
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Science Paperbacks Edition (1992)

Exactly fifty six years ago, during February 1943, the theoretical physicist Erwin Schrödinger gave a set of three lectures at Trinity College, Dublin under the auspices of the Dublin Institute for Advanced Studies (DIAS) on the subject "What is Life?" Coincidentally Schrödinger himself was fifty-six then, and the subject of quantum mechanics, whose wave mechanical form he had discovered in 1926, was in its teens. These lectures were published in 1944, and have long since become a classic of popular science. They have been reprinted a number of times, and have been reviewed, praised and criticised on scores of occasions. In 1993 a meeting was organised at Trinity College to celebrate the fiftieth anniversary of the original lectures. Quite a record for a tract of barely a hundred pages.

The background to these lectures is interesting. Schrödinger fled his native Austria for neutral Ireland (via Oxford) in 1938, and was to remain there as the Professor of Theoretical Physics at the DIAS till 1956. In the early 1940's the theoretical physicist P P Ewald brought to Schrödinger's attention a 1935 paper by Timoféeff–Ressovsky, Zimmer and Delbrück titled "The Nature of Genetic Mutations and the Structure of the Gene". There was also an obligation for the DIAS to arrange an annual public lecture. Schrödinger was so fascinated by the 1935 paper and his own thinking and reading on the subject that he gave the three lectures "to an audience of about four hundred, which did not substantially dwindle". He further explains that he was inspired by the need to preserve the universality of knowledge. In this age of great specialisation, once in a while someone well versed in one area should attempt to build bridges to others, even at the risk of being accused of having inadequate background.

The book consists of seven short chapters, and an epilogue on Schrödinger's Vedantic philosophical views. Right at the start he poses his basic question – "How can the events in space and time which take place within the spatial boundary of a living organism be accounted for by physics and chemistry?" – and immediately gives his conclusion: "The obvious inability of present-day physics and chemistry to account for such events is no reason at all for doubting that they can be accounted for by those sciences". In developing this answer the discussion keeps hovering between physics and biology.

The aim of the first Chapter is to show how a physicist, trained in the Boltzmann–Gibbs tradition of classical statistical mechanics, would approach this problem. Faced with the ubiquitous presence of heat noise or random atomic motions, reliable and stable patterns of behaviour appear in a statistical manner only in systems composed of very large numbers of atoms – the $\sqrt{n}$ law of fluctuations is illustrated via several examples (paramagnetism, diffusion, Brownian motion ...), and is also invoked to explain why we are so much bigger than individual atoms. Chapter 2 then immediately shows that such classical arguments are invalid in the biological realm. The basic mechanisms of heredity – cells, their sizes and chromosomal content, the processes of mitotic and meiotic division with cross-over – are briefly and lucidly explained, and the sizes of genes estimated. The upshot is that, far from a value for n of the order of 10^{23}, biology creates and uses molecular structures with no more than about a million atoms, already overcoming heat noise and displaying stable and orderly behaviours. The following Chapter 3 devoted to mutations, both natural and artificially induced, further reduces the size estimate of the gene to the range of about a thousand atoms. So the great puzzle is: how can an object consisting of just a thousand atoms, may be even less, show such great permanence and regularity of behaviour overcoming heat noise?

For this, Schrödinger turns in Chapter 4 to the quantum theory, with its basic nonclassical features of discrete states, energy gaps and quantum jumps. By now he is able to declare – “In the light of present knowledge, the mechanism of heredity is closely related to, nay, founded on, the very basis of quantum theory” – a striking statement which could have come only from one of the creators of quantum mechanics! The basic recognition is that the nature of the chemical bond is intrinsically and unambiguously a result of quantum mechanics, and that holds the key. The picture emerges of the gene as an “aperiodic crystal”, a concept and phrase brought in earlier. Delbrück’s contribution to the 1935 three-man paper mentioned earlier was his model of the gene as a large molecule governed by quantum mechanics and possessing many isomeric states, with transitions between them – mutations! – determined by energy differences and temperature. This model is taken up in Chapter 5 and an effort is made to show that its main features explain available data on mutation rates, both natural and induced, quite satisfactorily.

Having approached the problems of gene stability, mutations and orderliness in this way, the question that remains for Chapter 6 is: how do biological processes ‘evade’ the Second Law of thermodynamics, and retain and reproduce existing order? Again Schrödinger points to a consequence of quantum mechanics, the Nernst heat theorem, which shows that the entropy of any system vanishes at the absolute zero of temperature. He contrasts two ways of creating order and stability: from disordered heat motion to order by the classical statistical mechanical

"$\sqrt{n}$ route"; and from order to order by retention as exemplified by life processes, thanks to quantum mechanical principles. Indeed he concludes by referring to chromosomes as "cogs of the organic machine", and as for the gene: "the single cog is not of coarse human make, but is the finest masterpiece ever achieved along the lines of the Lord's quantum mechanics".

Schrödinger's account is many decades old, and enormous progress has taken place since then in the areas and questions he touched. He has often been criticised for major omissions: his knowledge of genetics was from a very narrow set of sources; he ignored the roles of enzymes, catalysts and complementary structures; and "what was true in his book was not original, and most of what was original was known not to be true even when it was written" (Perutz). Much later, in his own `Tarner Lectures' on 'Origins of Life' , Freeman Dyson appreciatively points out that Schrödinger restricted himself mainly to the problem of replication, and avoided linking it up to metabolism, or even asking the question (wisely at that juncture) of how life arose in the first place.

But Schrödinger spoke (and wrote) to convey his fascination for the subject, and to express what seemed important to him at that time as a physicist. Two of his original ideas have become – after the discovery of the structure of DNA in 1953 – parts of modern biology: that the gene is best viewed as an aperiodic polymer, and that its message for development and reproduction is expressed in some code. And while the degree of influence may vary from person to person, he seems to have inspired many (physicists included) to turn to problems of modern biology: Maurice Wilkins, James Watson, Joshua Lederberg, Seymour Benzer, Francis Crick.... Compared to Niels Bohr's expectation that the Complementarity Principle of quantum mechanics would become indispensable for the understanding of life (which thought turned Max Delbrück from physics to biology), Schrödinger's general ideas seem to have come much closer to modern biology, and had a more tangible impact. He succeeded in showing that some of the basic questions of biology could be phrased in the language of physics – and so eloquently too – and this was invaluable.

Schrödinger has also been criticised for having treated his interest in this subject as a passing fancy – he got deeply involved in it for a while, expressed his views to a general audience, but did not seriously follow up what he had begun and instead turned to other interests. But then, such is the nature of a polymath functioning to preserve the universality of knowledge. Who today would wish to say that 'What is Life ?' should not have been written ?

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What Is Life? – Reconsidered*

Raghavendra Gadagkar

Origins of Life
by Freeman Dyson
Cambridge University Press, 1985.

The problem of the origin of life is a very old one. While there have been some distinguished supporters for theories suggesting extra-terrestrial origin and subsequent transport of life to earth, the remaining scientific community has built up a progressively more convincing, if more complex, reconstruction of the possible events leading to the origin of life on primitive earth. As it happens so often, our present beliefs about the origin of life on earth go back to Charles Darwin in whose inimitable style "But if (and oh, what a big if) we could conceive in some warm little pond, with all sorts of ammonia and phosphoric salts, light, heat, electricity, etc., present, that a protein compound was chemically formed ready to undergo still more complex changes, at the present day such matter would be instantly devoured or absorbed, which would not have been the case before living creatures were formed." More sophisticated theories embodying this basic idea were formulated by A I Oparin and by J B S Haldane in the 1920's. The experimental demonstration of abiological synthesis of complex biological molecules including amino acids in simulated primordial earth conditions by Stanley Miller in 1953 gave a major boost to these theories. Since then there have been innumerable extensions and modifications of the Miller experiment and impressive theoretical leaps into imagining how these chemically formed molecules might have got together to form a primitive cell. The discovery of DNA as the genetic material and the advent of molecular biology quite naturally shifted attention to the pre-biotic chemical synthesis of nucleic acids and their precursors and more importantly, to the possible ways in which primitive nucleic acids may have undergone some crude form of replication without the aid of enzymes. It was soon realized that RNA rather than DNA was likely to have been the more primitive carrier of genetic information. The problem of the non-enzymatic synthesis and replication of RNA in the pre-biotic world has thus virtually become synonymous with the problem of the origin of life.

In the delightful little book under review, which is based on his Tarner lecturers at Trinity College, London, the well-known physicist Freeman Dyson brings in a breath of fresh air. Dyson correctly attributes the present-day replication-centered pre-occupation of molecular biology to Erwin

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Schrödinger's advice to biologists to investigate the molecular structure of the gene. But then why did Schrödinger call his book *What is life*?. Because, says Dyson, Schrödinger equated life with 'replication' and neglected to worry about 'metabolism' (perhaps wisely at that time, as Mukunda has argued in the accompanying review of Schrödinger's book). But Dyson argues convincingly that the time has now come to once again ask "What is life?" and focus this time around on 'metabolism' rather than replication.

Origins of Life is full of virtues. It has new ideas, provides a plausible solution to a long-standing problem and even has a mathematical model whose results are not only largely consistent with known facts but also suggest new approaches to experimentalists. Dyson's style makes the book a pleasure to read; he never overstates his case and always cautions the reader on the boundary between fact and hypothesis. In addition Dyson does a masterly job in setting his hypothesis in a historical and philosophical perspective. All this in just 77 pages – what more can one ask for?

Dyson's main thesis is that life originated twice, not just once. First he makes a very convincing case for the distinction between what he calls *replication* (= nucleic acid) and *metabolism* (= protein). Borrowing on von Neumann's analogy, he equates nucleic acid to *software* and protein to *hardware* and reminds us that hardware logically comes before software. So in Dyson's hypothesis (he is not willing to call it a theory), metabolism or proteins evolved first, and once this crude hardware was available, nucleic acid or the software evolved in a second step. In today's organisms nucleic acids are needed for protein synthesis and proteins are needed for nucleic acid synthesis. So which came first, the chicken or the egg? Dyson clearly prefers the chicken (= metabolism or protein) for step one and argues that a primitive form of life consisting only of protein must have arisen first, growing, metabolising and reproducing in some crude fashion before nucleic acids came along in step two. Apart from its logical reasonableness, this sequence makes sense of what has long been an acute embarrassment to experimentalists. The accumulated wisdom of the variations of the Stanley Miller experiment has been that amino acids are formed readily in simulated pre-biotic conditions but nucleic acid bases, let alone nucleotides, are much harder to come by. If only proteins needed to have been produced pre-biotically and nucleic acids originated inside primitive 'cells' already containing proteins, the experimental findings make perfect sense.

But how did the primitive 'protein' organism get along without nucleic acids? Dyson recognises that they must have been beyond the reach of Darwinian natural selection because they could not have reproduced with any level of precision. He therefore uses Kimura's neutral theory of evolution to deal with these primordial 'cells'. But it is Dyson's treatment of the subsequent evolution of RNA as a parasite that is most appealing in the context of present-day evolutionary biology. If RNA (or DNA) is the software it can exist as a parasite on the hardware without contributing anything in return. That is precisely what most present-day viruses do. The primitive RNA must have started off as a parasite until the protein-based life "learned to make use of the capacity for exact replication which the chemical structure of RNA provided" and "The primal symbiosis of protein-based life and parasitic RNA grew gradually into a harmonious unity, the modern genetic apparatus".

Recent findings that RNA molecules can sometimes have enzymatic properties and can possibly catalyze their own replication have led some biochemists to believe that the chicken and egg problem has finally been solved in favour of RNA but I would hazard a guess that such a conclusion is too premature – the logic in Dyson's arguments (in favour of protein) is so compelling that we need to tread here with caution. At the very least, more biochemists should read Dyson

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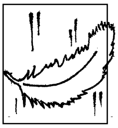

The way to solve the conflict between human values and technological needs is not to run away from technology. That's impossible. The way to resolve the conflict is to break down the barriers of dualistic thought that prevent a real understanding of what technology is – not an exploitation of nature, but a fusion of nature and the human spirit into a new kind of creation that transcends both. When this transcendence occurs in such events as the first airplane flight across the ocean or the first footstep on the moon, a kind of public recognition of the transcendent nature of technology occurs. But this transcendence should also occur at the individual level, on a personal basis, in one's own life, in a less dramatic way.

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