Erwin Schrödinger's "What is Life?"

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Erwin Rudolf Josef Alexander Schrödinger also known as Erwin Schrodinger, is a Noble laureate Austrian-Irish physicist who played an important role in the field of quantum theory. He developed the Schrodinger equation which provides a way to calculate the wave function of a system and how it changes dynamically in time. To biologists, his name is connected with a little book, entitled 'What Is Life?'.

In the winter of 5 February 1943, the physicist Erwin Schrödinger invited the Dublin public to hear him deliver a series of lectures which he described as difficult, and that could not be termed popular. Schrödinger offered his views on how physics could shed light on the puzzling ability to live organisms to maintain molecular order and organization in the face of what seemed to be the randomizing forces of nature. The lecture attracted an audience of 400 people. Schrödinger's lectures were collected and turned into a book known as, ***What Is Life?*** published in 1944. Some consider it one of the most influential scientific books of the twentieth century. The book attracted scientists from other fields to the study of genetics and the molecular mechanisms of life, among them physicists Francis Crick, Maurice Wilkins and Seymour Benzer, chemist Gunther Stent and zoologist James Watson. The book also faced some critiscism but it has had a major impact in molecular biology in that generation as well as for later generations.

Erwin Schrödinger was born on August 12, 1887, in Erdberg, Vienna, Austria. Schrodinger was the only child of Rodulf Schrodinger and Georgine Emilia Brenda Schrödinger. He shared a close relationship with his father, Rudolf, who played an important role in his childhood and teenage years. There were frequent scientific discussions between father and son. Schrodinger was able to learn English at an early age because his maternal side was from England, which helped his decision of going to Oxford . Schrödinger studied at the University of Vienna under the physicists Franz S. Exner and Friedrich Hasenohri. He received his doctorate at Vienna under Hasenöhrl in the year 1910. He also conducted experimental work with Karl Wilhelm Friedrich Fritz Kohlrausch.

In 1911, Schrödinger became an assistant to Exner. In his lecture "*Mind and Matter*" he said that "*The world extended in space and time is but our representation*." In 1914 Erwin Schrödinger achieved his habilitation, a qualification which is usually awarded by German speaking universities after one's PhD by demonstrating significant research work post PhD. In 1920 he became the assistant to Max Wien, in Jena, and in September 1920 he attained the position of ao. Prof. (ausserordentlicher Professor), roughly

equivalent to Reader (UK) or associate professor (US), in Stuttgart. In 1921, he became an o. Professor (ordentlicher Professor), in Breslau (now Wroc?aw, Poland).

The theory of wave mechanics was formulated later in 1925 and was at once acclaimed by the scientific community. Between the year 1926-1927, Schrodinger was offered the chair at Berlin as a successor to Max Planck and was invited on a lecture tour of the United States. In Berlin, he found several distinguished colleagues to his liking, including Einstein, Planck, Hertz, and Otto Hahn. In 1933, Schrödinger decided to leave Germany and became a Fellow of Magdalen College at the University of Oxford as a guest professor. It was while at Oxford that Schrödinger was awarded the Nobel Prize jointly with Paul Direck, in the year 1933 for ***the discovery of new productive forms of atomic theory***. In 1934, he visited Princeton and later Spain, lecturing in English and Spanish respectively. In 1936, he accepted a professorship at Graz, but in 1938 he moved once again to Rome, and finally to Dublin to head the School of Theoretical Physics, which was part of the newly established Dublin Institute for Advanced Studies. During his 16 years in Ireland, Schrödinger wrote *Statistical Thermodynamics, What Is Life?* and *Nature and the Greeks*. In 1956, he accepted a professorship in Vienna. For his inaugural lecture, he chose the topic "*the Crisis of the Nuclear Concept*".

Let us now look into What is life? in more details.

The book mainly draws attention on two topics of biology: ***(a) the nature of the hereditary material*** and ***(b) the thermodynamics of living systems.*** One of Schrödinger's key aims was to explain how living things defy the second law of thermodynamics – according to which all order in the universe tends to break down.

Firstly, Schrödinger explains that most physical laws on a large scale are due to chaos on a small scale. He calls this principle ***order-from-disorder***. As an example, he mentions diffusion, which is caused by random movement of atoms or molecules that can be modelled as a highly ordered process. He states that life greatly depends on order and that a naïve physicist may assume that the master code of a living organism has to consist of a large number of atoms. The main principle involved with "order-from-disorder" is the second law of thermodynamics, according to which entropy only increases in a closed system (such as the universe). Schrödinger explains that living matter evades the decay to thermodynamical equilibrium by homeostatically maintaining negative entropy in an open system.

Secondly, he summarizes what was known at this time about the hereditary mechanism. Schrodinger wrote, "*It is these chromosomes, or probably only an axial skeleton fibre of what we see under the microscope as the chromosome, that contains some kind of code-script, the entire pattern of the*

individual's future development and its functioning in the mature state. Every complete set of chromosomes contains the full code; so, there are, as a rule, two copies of the latter in the fertilized egg cell, which forms the earliest stage of the future individual." Schrödinger suggested that one can predict the precise phenotype from the code-script.

He also elaborates on the important role mutations play in evolution. He concludes that the carrier of hereditary information has to be both small in size and permanent in time, contradicting the naïve physicist's expectation. Much of Schrödinger's discussion in *What Is Life?* was based on an article by Timofeef-Ressovsky et al. (1935) on the mutation rate induced by X rays in Drosophila melanogaster. It was then concluded that mutations are quantum transitions resulting from either random thermal fluctuations or the absorption of radiant energy. Spontaneous mutations arising predominantly from thermal fluctuations rather than from natural radiation. Schrödinger, however, failed to mention the discoveries of H. J. Muller on radiation-induced mutagenesis or the important role of complementariness in the specific attraction between molecules and their enzymatic synthesis, which was already suggested by Haldane (1937) and Pauling and Delbruck (1940).

Schrödinger also introduced the concept of "***aperiodic crystal***" that contained genetic information in its configuration of covalent chemical bonds. In the 1950s, this idea stimulated enthusiasm for discovering the genetic molecule. Although the existence of some form of hereditary information had been hypothesized since 1869, its role in reproduction and its helical shape was still unknown at the time of Schrödinger's lecture. In retrospect, Schrödinger's aperiodic crystal can be viewed as a well-reasoned theoretical prediction of what biologists should have been looking for during their search for genetic material.

At a time when it was thought that proteins, not DNA, were the hereditary material, Schrödinger argued the genetic material is the nucleic acid because he suggests that the genetic material should have a non-repetitive molecular structure. He also stated that this structure comes from the fact that the hereditary molecule must contain a code-script that determined the entire pattern of the individual's future development and its functioning in the mature state. From this statement it is clear that gene contain some code-script. Pauling wrote, "*It is accordingly justified … to say that Schrödinger, by formulating his wave equation, is responsible for modern biology*".

The final chapter in *What Is Life?* is entitled "*Is life-based on the laws of physics?*". Schrödinger suggested that the gene is a linear one-dimensional crystal, which lacks the periodic repeat, i.e., an aperiodic crystal following the argument that in crystals, the same pattern is repeated periodically in three dimension and continuity of chemical bond extending over large distance. Under the influence of the theoretical physicist Ludwig Boltzmann (1886), Schrödinger concluded, "*We are faced with a mechanism entirely different from the probabilistic one of physics, one that cannot be reduced to the ordinary laws of*

physics …. Living matter, while not eluding the laws of physics is likely to involve other laws of physics that are unknown."

These lectures were delivered in February 1943, and the book was published in 1944. It was successful beyond the author's expectations. It was translated into seven languages, and the total sales exceeded well over 100,000. Schrödinger wrote that, contrary to the opinion held by some physicists, quantum indeterminacy plays no biologically relevant role in the space-time events in the body of a living being, except perhaps by enhancing the purely accidental nature in mutation, meiosis, and so on. The two major premises considered by Schrödinger are ***(a) the body functions as a pure mechanism according to the laws of nature***; and ***(b) we also know that we are directing its motions, knowing fully the consequences of our actions and taking responsibility for them.***

With the application of quantum theory to biological phenomena, Schrödinger (1944) attempted to elucidate gene structure and function in terms of a hybrid paradigm. It is often at the intersection of two or more disciplines that innovative scientific progress takes place. The impact of this book lies more in its spirit than its substance. Schrödinger presented the problem of life as a puzzle posed to no single discipline.

During his last years, he wrote his autobiographical account, ***My Life***, and My View of the World. He died on January 4, 1961 suffering from tuberculosis.
