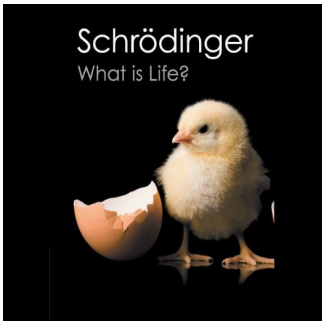
28 August 2022

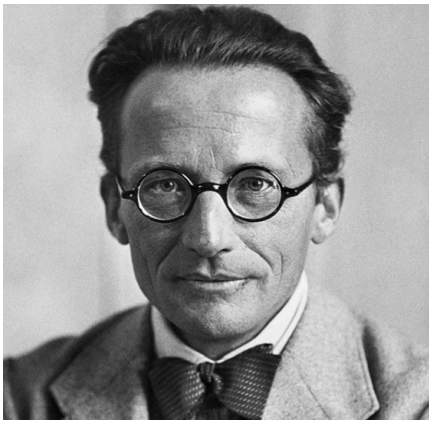
Notes and comments on “What is Life “ by E. Shrödinger

By Yossi Karov: www.edu-multimedia.com



Wikipedia:

Erwin Schroedinger, was a Nobel Prize-winning Austrian-Irish physicist who developed a number of fundamental results in quantum theory: the Schrödinger equation provides a way to calculate the wave function of a system and how it changes dynamically in time.



In addition, he wrote many works on various aspects of physics: statistical mechanics and thermodynamics, physics of dielectrics, colour theory, electrodynamics, general relativity, and cosmology, and he made several attempts to construct a unified field theory. In his book What Is Life? Schrödinger addressed the problems of genetics, looking at the phenomenon of life from the point of view of physics. He paid great attention to the philosophical aspects of science, ancient, and oriental philosophical concepts, ethics, and religion.[4] He also wrote on philosophy and theoretical biology. In popular culture, he is most known for his "Schrödinger's cat" thought experiment.[5] [6] Schrödinger's personal life caused him some problems as he lived with both a wife and mistress. In his journal, he also documented sexual liaisons with other women and his self-described "predilection for teenage girls".

Spending most of his life as an academic with positions at various universities, Schrödinger along with Paul Dirac won the Nobel Prize in Physics in 1933 for his work on quantum mechanics, the same year he left Germany due to his opposition to Nazism. In his personal life, he lived with both his wife and his mistress which may have led to problems causing him to leave his position at Oxford. Subsequently, until 1938, he had a position in Graz, Austria until the Nazi takeover, when he fled finally finding a long-term arrangement in Dublin where he remained until retirement in 1955. He died in Vienna of tuberculosis at the age of 73.

Chapter 1: The classical physicist's approach to the subject

About this book (an Introduction)

- This book is about how can life and processes that constitute and represent life be explained and described by physics and chemistry. The preliminary answer that Shrödinger gives is: 'Our inability to describe and explain life is temporary, in the future we will be able to do so. '

- Shrödinger strategy is: Propose a 'naive physicist' view/model and compare it to biological facts. Amend and edit the original model to fit the biological facts.

- The laws we use in physics and chemistry are of statistical nature. They apply to very large aggregates of atoms and molecules and describe the average behaviour of that aggregate. The fundamental behaviour of a single atom or molecule is random, disordered vibration and movement (in liquid and gas).

- For an organism to exist, and employ life-supporting processes such as metabolism, the organism must not be a random and disordered entity. Such an entity would not have space and time permanency and unable to execute purposeful activities needed to sustain life.

- The structure, (that is the atomic arrangement), that is found in an organism is fundamentally different from the structures that the chemist and physicist study and describe with the laws of chemistry and physics.

- Chromosomes are perhaps the key part of a living cell. Chromosomes can be described as 'aperiodic crystals'. Aperiodic crystal presents the physicist with much greater difficulty than the periodic crystal of most solids.

Questions

- Shrödinger asks why our bodies (and other objects of human civilization) are so much larger than an atom. Why does life require millions and millions of atoms and molecules?

- Shrödinger asks, why our brain needs to consist of millions of atoms (organized in neurons) to be able to think? If we were to become sensitive to a single atom event, such as an atom impingement, would we be able to think at all?

Order ► disorder

- Regarding 'thinking', according to Shrödinger thoughts are "an orderly thing" and are applied to (or used for) our perception and experiences. These too, are orderly processes.

- Shrödinger posits that an organism that has thoughts (*he means us, humans*) has to be himself an ordered entity.

- Interaction between an organism and the outside has to have some kind of order and therefore can be described by the laws of physics.

Comments

1. Not clear how the structure and none structure state affect the 'statistical' laws of physics? The

aperiodic crystal has a higher structural and more complex order. But the basic laws describing the periodic crystal should still describe at least parts of the aperiodic crystal.

2. What are the fundamental differences between matter and life? Clearly, life is built from matter, is it just an inevitable step of evolution that matter becomes organized in such a way that it becomes an entity that can extract energy from its environment, can grow in size and can duplicate or propagate? Does this new level of matter require a 'spark', divine or other, or is it just a natural progression of matter formation and arrangement? What will be the next evolutionary step? Is consciousness the quality that distinguishes life from matter? Is it a characteristic of a living organism or is it something that living organisms can access, and tap into it? Are there different levels of consciousness? Are we, humans progressing towards a higher level of consciousness? What will it be? Perhaps consciousness is some cosmic connectivity, some metaphysical thing that coexists with our physical world, or is it an integral part of our world, something like time and space?

Summary

An organism must have a relatively gross structure (= be comprised of many, many atoms and molecules) to follow fairly accurate laws and to carry out in a reproducible way, life-supporting activities such as metabolism and maintaining homeostasis. It can not be just a few atoms in size as its existence would be a constant random change imparted by impinging atoms of the environment.

Add on comment

But what about a microorganism such as bacteria? It is alive, it performs the essential interactions with the environment and is roughly 10^{10} atoms in size. That may be a large enough number of atoms to provide the bacteria immunity against its chaotic disordered environment. Bacteria are impacted by their immediate environment, its movement depends, perhaps relies on the watery environment currents. Its metabolism and exchange of goods with the environment depend, I think, on diffusion processes. Perhaps microorganisms are actually utilizing the random and disordered millennia to execute life-supporting processes? Having a boundary (such as a cell membrane) facilitates exchanges between disordered and ordered entities. In other words, having a boundary around an ordered creation is sufficient for that entity to carry on and exist despite the constant chaotic events such as the thermal vibration of water molecules around. Such an organism would be preoccupied with keeping the disorder "outside", and its sophistication would be limited.

Chapter 2: Hereditary mechanism

Chromosomes and genes

- According to Shrödinger , a more recent knowledge in biology (*as of 1944 when this book was written*) and in particular in genetics had shown that chromosomes, which have relatively small structure and **do not** contains a very large number of atoms, play a central role in life evolution and propagation. Thus the argument presented in the first chapter by the 'naive' physicist is incorrect, life does not require a very large number of atoms.

- Chromosomes contain instructions (a code) on how to build an organism, they control the evolution of the organism with time. Chromosomes also (according to Shrödinger) participate directly in the building of the organism and not just provide instructions on how to.

Permanency

- Regarding permanency, Shrödinger sees 'great' permanency of genes,(*almost absolute?*). He points out that genes faithfully reproduce the four-dimensional pattern of an organism, its phenotype as well its change with time. Shrödinger marvels that we, the product of gene permanency are able to learn about genes and suggests that our capacity to do so may be beyond human understanding.

Comments

1. Not sure if chromosomes contribute directly to the building of tissues of the growing and evolving organism?

2. The fact that every cell of an organism, no matter what kind of tissue it is, does contain chromosomes, suggests that chromosomes perform some vital role in the living organism. Perhaps support collaborations between cells?

3. Genes are segments of chromosomes that contribute (direct?/ perform?) to processes that support living. How they do that can not be explained by classical physics because these genes are too few atoms in size, to be described by laws of physics that are statistical. Later in the book Shrödinger talks about how the organized entity such as an organism rose from a preexisting order. Shrödinger, (I gather), is referring to chromosomes being the source of this newly ordered entity we call an organism. Shrödinger thinks that we need new physics, new principles to describe a living organism and even hints about supernatural attributes of life.

4. Shrödinger is baffled by the fact that we humans are able to study the things that made us and designed us. Is Shrödinger reminding us about the limits of our perceptions and understandings?

Summary

- Life does not require a very large number of atoms.
- Chromosomes contain instructions (a code) on how to build an organism and create life.
- Chromosomes and genes show great permanency and that is an essential feature for creating and supporting life.

Chapter 3: Mutations

Shrödinger assertions

- Transitions from one gene configuration to other gene structures can be seen as quantum jumps in gene molecules.

- Mutations are due to quantum jumps in genes
- Mutations are rare, if they were frequent, the injurious mutations, those that impact negatively the next generations would be dominant and species evolution would be compromised.

- Mutations do not happen by the accumulation of small changes. Darwin was mistaken in proposing that continuous accidental variations drive evolution. These small variations are not inherited.

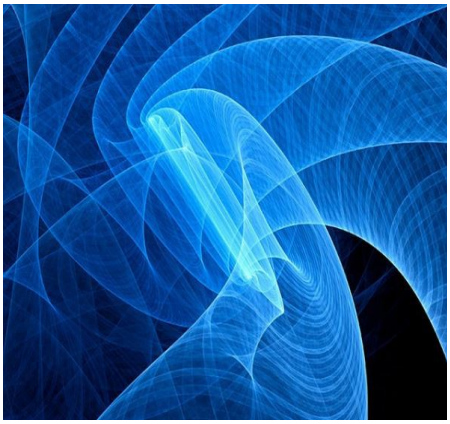
Comments
Today a chemist would point out that a gene is not exactly a molecule. The molecule in chemistry is the smallest unit that has the substance characteristics. We could perhaps say that organism is a kind of substance and a gene is a molecule that it is made of. Not really! Genes are NOT the building blocks of the organism, they furnish instructions on how to build the various tissues and organs. However, the permanency of genes is similar to molecule stability.

Summary
- Gene stability (which is a critical characteristic for life to exist) is comparable to the stability of a molecule. The mutation is a change in gene structure.
- Energy differences between two different gene structures are quantum jumps.

Chapter 4: Quantum mechanical evidence

Stability
- Life requires stability of shape and structure in space-time. And that is in contrast to the fundamental randomness we find in the micro-world.

Different configurations
- Quantum theory posits that (at least at the level of atoms and subatomic particles) nature exists in discreet rather than continuous states. Energy and other characteristics are quantized.



- When atoms form a system such as a molecule; that system has a limited number of configurations and corresponding states that can be characterized by their 'energy' (*which is a measure of stability and permanency*). Each particular configuration will have a different energy. The transition from one configuration is the 'quantum jump' that Shrödinger is referring to.

- The probability of an atomic aggregate (molecule, a gene) to be transformed to the next discreet energy level can be measured by the average time we will have to wait until this jump occurs. S hrödinger calls this a 'time of expectation' and it is a function of delta E/kT, where delta E is the energy jump and kT is related to the thermal energy of an atom in the molecule.

Comments
1. Stability of an aggregate of atoms requires that change to it would require energy. In a world without energy barriers, aggregates of atoms would be in flux and constant change, and there would be no permanency in structure, spatial shape and as a result, probably no processes that support life, such as metabolism. Life would not exist, at least not in the form of life we see here on our planet.

2. For life to 'be', (if we accept Shrödinger story so far), the time expectation needs to be equal to

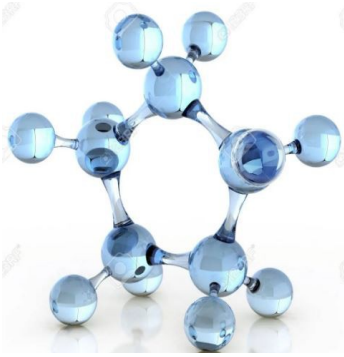
many years to provide the permanency that life needs to exist.
*Time expectation = Constant * Exp (del E/kT); constant is of order 10^{-13} or 10^{-14} seconds and is related to the vibration period of the aggregate, del E is the energy jump to another configuration of the aggregate (molecule or a gene).*

Summary

- At the atomic and subatomic levels nature exists in discreet rather than continuous states.
- Each particular configuration of a molecule or a gene will have a different energy. The transition from one configuration to another is the 'quantum jump' to which Shrödinger is referring.
- Expectation time, the time one has to wait before a transition occurs is a measure of the stability of a molecule or gene. It needs to be of an order of years for high organisms such as humans to exist.
- ----------

Chapter 5: Dellbrück's model

Gene viewed as a molecule

- 

  Shrödinger suggests that we can see the gene, the fundamental inheritance element as a molecule (*at least from the point of view of stability?*). It is an aggregate of relatively few atoms that can have several configurations (*atomic arrangements*) that differ in energy level, hence having energy barriers between the different configurations. These energy barriers are high enough to ensure that mutations (= change in configurations) are rare as required for evolutionary progress. This model is due to the German physicist M. Delbrück.

- Shrödinger argues that since we can observe a gene or ascertain it exists it must be stable which implies that the activation energy required to change gene configuration (proposed to be modelled as a molecule) must be about 50 times larger than kT. Shrödinger proposes to view genes as 'aperiodic solids'.(I*n the sense that they have a stable shape, with the internal arrangement of atoms being not periodic.*)

Genes - organs

- The question of how a small aggregate of atoms can provide instructions to the many diverse organs and tissue is easy to answer. Shrödinger points out that there is an almost infinite number of configurations of the genes and assuming there is a relation between gene configuration (structure/ arrangement of atoms) and the instructions on how to build organ or tissue – it should be possible to build many organs and tissues.

Genes – mutations

- The natural mutation rate is not caused by natural radiation. Only a small portion of natural mutation can be explained by natural radiation.

- In general, mutations are as stable as the original forms, but there are some exceptions. Injurious mutations can not be too frequent as that would lead to the demise of the organism.

Comments

1. A gene is just a segment of a DNA strand, it is not a separate molecule. However, the comparison to a molecule-like stability is still useful.

2. If we picture gene as a kind of molecule (at least in terms of stability) then the activation energy for a transition from one configuration of the gene to another, needs to be at least 50kT.

Summary

- A gene, the fundamental inheritance element can be viewed as a molecule (*at least from the point of view of stability*). Its stability would depend on a high enough energy barrier.
- The energy barrier needs to be at least 50kT, 50 times the average energy of atoms that constitute the molecule (or the gene)
- There is almost an infinite number of gene configurations; the large number of gene configurations are needed to provide different sets of instructions for the different organs and tissues.

Chapter 6: Order, Disorder and Entropy

Gene -how it operates

- Debrüch's model of a gene suggests that the miniature code in genes has one to one relationship to the development of different organs and tissues of a complex organism. However, the mechanism, and how it is done, are not explained.

What is an organism

- Shrõdinger suggests that a living organism is a macroscopic system that is behaving in part purely mechanical (like a clock) as opposed to a thermodynamic behaviour.

- Shrõdinger defines a living entity as something that moves, exchange material with the environment and does it for a time much longer than inanimate matter. Living organism avoids a rapid decay into an inert state of equilibrium by metabolism. Metabolism increases the Entropy (*apparently?*) of the nearby environment. Our metabolism increases our entropy. Eating is a process in which we dismantle an order in our immediate environment (for example well ordered carbohydrates in form of a piece of bread). Shrõdinger describes it as sucking a negative Entropy (= order) from the environment.

- The living organism itself achieves maximum entropy when it ceases to live. While we are alive we maintain order.

Mathematical expression for Entropy

- Shrõdinger explains the connection of a degree of disorder to Entropy. Entropy increases in a logarithmic fashion:
- S =k*logD; where S is entropy, k is the Boltzmann constant related to lattice vibration and has an approximate value of 10^{-13} and D is a measure of disorder. (*Not clear how one assigns a value to D? it seems just a qualitative relationship?*).
- Shrõdinger also defines a measure of order as minus Entropy: order = -S = k*log(1/D).

Comments

1. Shrõdinger point is that our physics: quantum mechanics, Newtonian physics or the macro physics of relativity can not adequately describe the life and life-supporting processes.

2. According to Shrõdinger there are two kinds of matter behaviour: mechanical such as the pendulum or the planet motion and thermodynamic in which change with time and space is characterized by energy change and the increase in Entropy. A living organism is predominantly a mechanical one.

3. Any change that happens is increasing the total entropy. That is the fundamental claim of thermodynamics (which I think is the study of energy flows, processes that cause a change in space and time). We have created the concept of Entropy to study the stability and change in our world. We have come up with the concept of energy for the same reason as a characteristic of stability, change and probability of change. It is a much-needed concept and a useful one, to describe our world. But is it true property and the real behaviour of our world or merely a descriptor of the way we see the world?

4. Entropy is in part the latent heat, the energy that is added to an entity per one degree of temperature and summed up for the temperature interval. It is the integral of delta W/T between T1 and T2: $\int \Delta W/T \, dT$.
The physical meaning of latent heat is (I think) the energy that is sustaining thermal vibration. My understanding is that this is the energy, the heat, that can not be taken out of the system, it is a kind of energy reserve that an entity has to have to exist at a given Temperature.

5. My understanding is that a living organism reduces the order of its immediate environment by converting food to energy (basically heat). That is, as Shrõdinger puts it, equal to feeding on negative Entropy. That may explain why higher animal existence does not contradict our accepted fundamental claim that any change, any happening leads to increased entropy. But what about a growing plant, it is a thing that creates order and space-time-specific shape and evolution. Is it not a creation of order out of disorder!??

6. Do we, animals, emit heat to control Entropy level, to keep some order which is in essence the requirement for life?

Summary

- Debrüch's model of a gene suggests that the miniature code in genes has one to one relationship to the development of different organs and tissues of a complex organism.
- A living organism is a macroscopic system that is behaving in part purely mechanical (like a clock) as opposed to a thermodynamic behaviour.
- A living entity is something that moves and exchanges material with the environment.
- Living organism avoids a rapid decay into an inert state of equilibrium by metabolism. Metabolism increases the Entropy of the nearby environment. Our metabolism increases our entropy.

Chapter 7: Is life based on laws of physics?

Physics of life

Shrödinger says that we should be prepared to accept the idea that 'living matter' can not be described by ordinary laws of physics because the structure of a living matter is very different from structures found in the none animated world like solid crystals, gas molecules or liquids.

The life cycle of an organism is a show of regularity and orderliness that are not found in inanimate matter. Organism formation and time evolution are controlled by an ordered aggregate of atoms - the genes. The number of atoms in genes is relatively small. Mutations in genes constitute a change in

the location of some atoms (= *change in atom arrangement*) and result in a change in the organism. The change can be in appearance, internal organs, cognitive capabilities, or life-supporting processes such as metabolism. A living organism maintains itself and maintains orderliness and produces orderly events.

Creation of an organism

Shrödinger stresses the difference in the creation and the maintenance processes of an organism. The building of an organism is guided by a mechanism that is entirely different from the probability mechanism in physics. It is a unique process, and it can not be described by current physics (*current in 1944, perhaps we have made some progress since?*).

Two physics – examples

Shrödinger says that an ordered entity can arise in two ways. From a disorder, for example, the diffusion process is on a macro scale orderly, it has direction and follows some rules (*the equations of diffusion; but on an atomic scale diffusion is a random and disordered proces*s). The other way to create an ordered process or a 'thing' is by using an ordered predecessor like a gene. The laws of physics will not be the same and some new physical laws are needed to describe this second mechanism.

Shrödinger revisits his claim from chapter 1 that all physical laws are statistical. He points out that planets orbit stars in orderly reproducible manner described by Newtonian physics, which is not statistical physics. (*which I understand describes atom and subatomic behaviour?*) Shrödinger posits that there are two fundamental kind of events: mechanical and statistical.

The organism as a machine

Shrödinger compares an organism to a mechanical clock, both are created from an ordered substance, genes in the case of an organism and solid materials in the case of machines like a clock and both are functioning despite the vibration of atoms and molecules due to latent heat.

Comments

An important question to ask is how the mechanical order such as the motion of planets arose from the initial disorder and chaos? What happens seems to be a process of creating order out of disorder, and that would be a reduction of Entropy. Maybe our assumption that every change in our world/universe has to and is accompanied by an overall increase in Entropy; is artificial, untrue.

Summary

- Living matter can not be described by ordinary laws of physics because the structure of a living matter is very different from structures found in the none animated world.
- The life cycle of an organism is an example of regularity and orderliness that are not found in inanimate matter.
- Organism formation and time evolution are controlled by an ordered aggregate of atoms - the genes.
- Living organism maintains itself and maintains orderliness and produces orderly events.
- The process of building an organism is guided by a mechanism that is entirely different from the probability mechanism in physics.

- Shrödinger posits that there are two fundamental kinds of events: mechanical and statistical.
- An ordered entity can arise from a disorder, for example, the diffusion process or from an already ordered predecessor like the gene.
- Shrödinger compares an organism to a mechanical clock

Epilogue: On determinism and free will

Determinism

- Shrödinger posits that space-time events that take place in a living organism's body, including thinking and self-conscious actions are mostly deterministic.
- Shrödinger suggests that a self-conscious organism is like a god because by moving his/its body it moves atoms that constitute it.

Consciousness, self and reality

- Consciousness is singular, not plural (*not shared with other people or organisms ?*) The position that there is a plurality of consciousness leads to the idea of souls, questions about immortality and the independent existence of souls from bodies.

- The reality that one experiences is what one's consciousness sees. That is the individual experience we have with the outside world. Consciousness mediates the experience with the outside, and it is subjective. While comparing one's reality with the reality of another person we will see mostly similar world and experiences but there will be some differences.

- What is I? A collection of experiences and memories. The 'ground' staff (*meaning the influential experiences?*)

'What is Life' - a very concise Summary

I think Shrödinger is saying that life and the life processes that support life are deterministic. By that, he means non-random, mechanical in the sense that life and the life-supporting processes (such as metabolism) are processes that are ordered, reproducible and machine-like. As such, life can not be described by the present physics which is statistical and describes an average behaviour of many, many small constituents (atoms and molecules). Shrödinger sees gene as a kind of molecule, an ordered entity able to maintain its structure in a sea of thermal fluctuations and atomic impingement. Shrödinger sees genes as the 'creator' (or a blueprint) of life. The process of building life is a process of building order from preexisting order (an organism created from genes). In the epilogue, Shrödinger proposes that life and a living organism are an expression of a godlike control of the body's fundamental constituents, the atoms. Perhaps he means that life is a manifestation of some Universe's creativity?
Shrodinger talks about consciousness and argues that it is not plural. (I think he means that it is not shared and that it is individual). Shrödinger posits that 'I', the self is a container of personal experiences and memories.

A few important questions are reiterated here:
What are the fundamental differences between matter and life? Clearly, life is built from matter, is it just an inevitable step of evolution that matter becomes organized in such a way that it becomes an entity that can extract energy from its environment, can grow in size and can duplicate or propagate? Does this new level of matter require a 'spark', divine or other, or is it just a natural progression of matter formation and arrangement? What will be the next evolutionary step? Is

consciousness the quality that distinguishes life from matter? Is it a characteristic of a living organism or is it something that a living organism can access, and tap into it? Are there different levels of consciousness? Are we, humans progressing towards a higher level of consciousness? What will it be? Perhaps consciousness is some cosmic connectivity, some metaphysical thing that coexists with our physical world, or is it an integral part of our world, something like time and space?

Acknowledgements:
Created by Yossi Karov (http://www.edu-multimedia.com)
based on E. Shrodinger book: 'What is Life'

Images and video credits:
https://www.thefinancialphilosopher.com/2009/01/we-are-all-naive-scientists.html
https://blogs.biomedcentral.com/on-biology/2021/04/23/dna-day-quiz-2021/
https://www.weka.io/blog/biology-and-artificial-intelligence-part-i/
https://www.nature.com/articles/d41586-019-01101-0
https://www.vecteezy.com/video/2016117-abstract-rainbow-balls-in-random-movement