Classic Text 13: What is Life?


Erwin Schrödinger (1887 - 1961) Austrian Physicist and Philosopher dilettante who contributed much to the foundations of quantum theory including the wave equation named after him. Schrödinger was awarded the Nobel Prize for Physics in 1933 and the Max Planck Medal in 1937.

"What is life?" is both a question that has occupied philosophers since antiquity and the name of a little book written for the lay reader by the Austrian Nobel Prize winning physicist Erwin Schrödinger. The latter will form the basis of the discussion in this study unit and is available for free download here. Although its central prediction has turned out to be wrong, since it predates the independent discovery of DNA by both James D. Watson and Francis Crick in 1952 by less than a decade, never the less both authors "acknowledged the book as a source of inspiration for their initial researches." (Wikipedia: What Is Life; Derry, 2004)

Although today every high school biology student is familiar the basic molecular machinery of life such as replication, transcription, protein synthesis as well as the Krebs cycle of cellular respiration and the Calvin cycle in Photosynthesis, most are at a loss when pressed with the question: "So what is life?" For the reductionist, life just is the sum total of such reactions while for Vitalists such as Henri Bergson the life-principle is essentially non-material. Between either extreme is Aristotle's theory of **Hylomorphism**, according to which, all things are a combination of matter and form and that the form of a living thing is its soul or **psyche** from the Greek ψυχή (psūkhē), of which there are three types: vegetative, animal and rational, quite unlike the *res cogitans* of Descartes' *Meditations*.

We shall not examine these alternatives just yet, but before reading Schrödinger classic text we should remind ourselves of the seven characteristics of living things:

1. **Homeostasis**: from the Greek ὅμοιος (homoios) 'similar' and στάσις (stasis) 'standing still' to refer to "the property of a system in which variables are self-regulated so that internal conditions remain stable and relatively constant."
2. **Organisation**: Living things display a high degree of order and complexity compared to their environment.
3. **Metabolism**: from the Greek: μεταβολή (metabolē) 'change' to refer to the set of life-sustaining chemical transformations within living organisms. Viruses, in this sense, are not considered to be alive because they have to hijack the metabolic processes of their host cell in order to replicate.

4. **Growth**: Increase in the size of all its parts due to its metabolism. Crystals, in this sense, are not regarded as living either because they merely passively accumulate chemical matter of the same sort.
5. **Response to stimuli**: Detectable environmental changes, whether internal or external, will elicit a response from a living organism, such as the turning of a plant towards the sun (phototropism) or the movement of a cell such as a spermatozoon along a chemical gradient (chemotaxis). A stone rolling down a hill is not regarded as living in this sense because its motion is not due to a detectable change in its environment; it is merely being accelerated by the force of gravity.
6. **Reproduction**: The potential ability of an organism to produce new individuals of the same kind, either on its own (asexually) or together with another organism of the opposite sex (sexually). An organism that may not in fact reproduce, one way or the other, is never the less considered to be living because it retains (or once retained) the *potential* to do so.
7. **Adaptation**: The ability of an organism and its decedents to change in response to its environment. While individual organisms may not be able to adapt anatomically or genetically to environmental pressures, the change in inherited characteristics of living populations over successive generations allows for **evolutionary change** to occur. Lineages that are unable to evolve, at a rate that keeps pace with changes in their environment, typically become **extinct**.

Unfortunately having a “laundry list” like this of life’s characteristics doesn’t answer the question of what life actually is - a question all the more urgent to philosophers, because ultimately we want to know about the weighty derivative questions such as: whether or not life is meaningful, whether some lives matter more than others and whether we have the right to take one life or a duty to save another… *etc.*

In preparing to read *What is Life?* we should remind ourselves of the historical and intellectual context of those public lectures delivered by Schrödinger in February 1943 at Trinity College, Dublin. The world was at war and there was, at the time, no end in sight. According to Margulis & Sagan (1995 p. 1) the lectures attracted an audience of about 400, who were warned “that the subject-matter was a difficult one and that the lectures could not be termed popular, even though the physicist’s most dreaded weapon, mathematical deduction, would hardly be utilized.”

The Modern Evolutionary Synthesis between Mendelian genetics and gradual evolution by means of natural selection that we take for granted today had only just been summarised by Julian Huxley under the title of *Evolution: The Modern Synthesis* (1942) which, at the time, was not popularly known. Schrödinger, as he freely acknowledges in his book, was no biologist but a world renowned physicist, having been awarded the Nobel Prize for Physics together with Paul Dirac in 1933 “for the discovery of new productive forms of atomic theory.” The sub-discipline of Statistical Physics which was a particularly productive at the time, strongly informs the text. Indeed quantum mechanics, which is essentially statistical in nature, was co-founded by Schrödinger. (Wikipedia: What Is Life?)

Notwithstanding, as you will gather, Schrödinger read and consulted widely with the leading biologists of his time. Although the American geneticist and Nobel laureate Hermann Joseph Muller had, as early as 1922, “already laid out all the basic properties of the ‘heredity molecule’ (then not yet known to be DNA)", Schrödinger was apparently "to re-derive… 'from first principles' in What is Life?"

Early in his career, Schrödinger became interested Philosophy, particularly the work Arthur Schopenhauer, who, in his own words, "introduced me to the Unified Theory of the Upanishads." (Schrödinger, 1960) Despite having been raised Christian, he professed to be an atheist, although he was strongly attracted to Eastern mysticism and by **pantheism** in particular (the belief that the Universe is God or that God is everything[1]).

Although the question of "What is life?" is potentially a wide-ranging one, Schrödinger confined himself, in the subtitle of his book to: "The physical aspect of the living cell." Here was physicist trying to make sense of the physical aspect of a living phenomenon. In these lectures, however he focused on one important 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?" which is really as much a philosophical questions as it is a biological one. (p.2)

Please do not be alarmed by the bizarre epilogue. We shall try to quell the "crazy". Now would be a good opportunity to actually read the book (only 37 pages!) If you haven't a copy yet, you can download it for free here.

Commentary

We will ignore Schrödinger's arguments in favour of the "*aperiodic crystal*" being "*the material carrier of life*" not because they are uninteresting but because, as we now know, their conclusion to be factually incorrect. Instead we will focus on those that inform the "one important question" above.

Chapter 1:

Schrödinger begins with an admission that the Physics and Chemistry of his day could not account for the "one important question," however that their obvious inability to do so "is no reason at all for doubting that they can be accounted for by those sciences" and that their inability to do so at the time was "amply accounted for." (p. 2)

After putting the scale of the debate into perspective, Schrödinger proceeds to explain that most macroscopic laws, which are orderly and regular, depend upon events at the microscopic scale which are seemingly random and can only be described statistically. This he calls the "**order-from-disorder principle**." One type of event he mentions, by way of example, is the process of diffusion which is described at the macroscopic level by an elegant mathematical equation but whose underlying action is due to the seemingly random motion of individual molecules "sometimes towards the higher, sometimes towards the lower, concentrations, sometimes obliquely." However, the reason that eventually such molecules diffuse from a region of higher to lower concentration is that there are more molecules on the higher side, engaged in their own random motion, to buffet them about. The conduction of heat behaves after the same fashion and is indeed described by the same mathematical law. (P. 7.)

[1] Not to be confused with the Pauline doctrine of **panentheism** that God is *in* all.

When a system becomes sensitive to the impact of weaker and weaker forces such, as the ever more delicate torsional balance "the impacts of the heat motion of the surrounding molecules … began to perform an incessant, irregular 'dance' about its equilibrium position…" Therefore as the measurement of the numbers of molecules involved becomes constrained, the behaviour of the system becomes *more* random, hence practical limit on the accuracy of measurement.

Though we need not be too concerned to quantify the limits on error of a living system as Schrödinger does with the $\sqrt{n}$ rule, we can see that for the master code of a living organism it has to consist of a very large number of atoms. Indeed as we have learned, there are some 204 billion atoms involved in a double strand of a human's approximately 3 billion base pairs of DNA, only 1-2 % of which actually code for $\pm$ 20 000 genes. (Wikipedia: Gene)

Chapter 2:

From the foregoing discussion the 'naïve physicist' would expect "… that the organism may, so to speak, have sufficiently accurate physical laws on which to draw for setting up its marvellously regular and well-ordered working. … [so as] to involve such enormous numbers of single atoms and single atomic processes that all the relevant laws of physics and physical chemistry would be safeguarded even under the very exacting demands of statistical physics in respect of 'large numbers'; this demand illustrated just now by the $\sqrt{n}$ rule." (p. 8-9) Today we know this to be false: An abundance of molecules, far too small to display exact statistical laws, control large-scale observable features in the course of development (ontogenies) as well as, "important characteristics of its functioning; and in all this very sharp and very strict biological laws are displayed." (p. 9)

We shall gloss over the examples used to illustrate this point in the remainder of the chapter because they are familiar enough to every former high school biology student who cared to pay attention. What we must emphasise however, is the three short sections with which Schrödinger concludes this chapter: the "maximum size of a gene," "small numbers" and "permanence."

From the two estimates cited, "he finds the volume of a gene equal to a cube of edge 300 Å." This is not a far out ball-park figure, given that the outer diameter of the DNA helix is a mere 20 Å and that different genes span different numbers of nuclear base pairs, with some truly "big" genes spanning 500 kilo-bases pairs (kb) or more. (Wikipedia: Gene) And that, according Schrödinger's calculations, "about a million or a few million atoms … is much too small (from the $\sqrt{n}$ point of view) to entail an orderly and lawful behaviour according to statistical physics - and that means according to physics", could not have been foreseen at the time. Moreover, not only is there sufficient elbowroom for orderly behaviour on a molecular level, there is a great deal of redundancy too at the heart of the genetic code.

We have already encountered the question of permanence in Classic Text 10 in Dawkins' *Selfish Gene*. Recall the two unique insights in Ch. 3, "Immortal Coils," that stood out from the customary textbook descriptions, namely that:

1. A body is the genes' way of preserving the genes unaltered... [and that]… natural selection favours replicators that are good at building survival machines, [and] genes that are skilled in the art of controlling embryonic development. A survival machine is a vehicle containing not just one gene but many thousands. The manufacture of a body is a cooperative venture

of such intricacy that it is almost impossible to disentangle the contribution of one gene from that of another.

2. The combination of genes that is any one individual may be short-lived, but the genes themselves are potentially very long-lived. Their paths constantly cross and recross down the generations. One gene maybe regarded as a unit that survives through a large number of successive individual bodies. (Dawkins 2006 p. 23-24)

Even when the basic molecular machinery of heredity was worked out, less than a decade after these lectures, the question of permanence must have seemed a “marvel” as Schrödinger puts it on p. 13, until that is, one assumes the “genes’-eye view” of the mortal phenotype as a vehicle in service of potentially immortal genes; that “A body is the genes’ way of preserving the genes unaltered...” The second marvel that “we, whose total being is entirely based on a marvellous interplay of this very kind, yet possess the power of acquiring considerable knowledge about it” does indeed seem miraculous but not “…beyond human understanding” as Schrödinger concludes. (*l.c.*)

Certainly, we have not found a gene or genes that code for metacognition, language, or a pervasive theory of mind or any of the other faculties that appear to make us human. What we have found are pre-adaptations in the fossil record and in reconstructions of ancient DNA, as well as structures and potential biochemical pathways that have made such adaptations possible such as: the phylogenetic descent of the larynx that allows the vocal tract above it to assume the shapes necessary to produce speech sounds, or the duplication of the SRGAP2 gene thrice in the human genome which “allows faster migration of neurons… and… slows the rate of synaptic maturation and increases the density of synapses in the cerebral cortex.” (Wikipedia: SRGAP2)

<u>Chapter 3:</u>

Like the previous chapter, this one begins with a summary of what is familiar to high school students today concerning mutations: that they are all or nothing events that appear to be “quantum jumps” rather than “small, continuous, accidental variations” that Darwin foresaw. We know this to be the case because mutations involve some induced or spontaneous molecular change to DNA or its chromosomal arrangement. In the case of an incorrect base pairing during replication, for example, or a chromosomal inversion, either the event occurs or it does not - there are no intermediary outcomes. That is not the same as claiming that mutations are of a “quantum mechanical” nature, such as the jump of a hydrogen atom’s electron from one energy level to another, even though both events are discreet and that those at the quantum level give rise to larger scale processes that are not apparently quantized. (See however FIRST AMENDMENT on p.22) So as not to confuse the two, we shall reserve the adjective “quantized” to refer to processes at quantum mechanical level and refer the “jump like” character of mutations as being “discrete.”

The rest of the chapter is par for the course today, however it is remarkable how far we have come in education that “the brief, but highly technical statement” on p. 17 can be meaningfully grasped and explained by high school biology students. Even the arrangement of the orbitals and the *Aufbau* principle describing the electron configuration of an atom or molecule is now covered in the Grade 10 syllabus (without the maths.)

Chapter 4:

In this chapter Schrödinger argues that, based on the previous estimates on the upper size of the gene "of the order of 1,000 [atoms] and possibly much less," we cannot account for its "most regular and lawful activity" or permanence by classical physics, but that we can do so using quantum theory. He goes on to suggest that there are molecules which are stable, even if they consist only of a few atoms and that this stability is due to the discrete nature of quantum mechanics. Again the idea of mutation is liked to that of a quantum jump. (Wikipedia: What Is Life?)

Actually, what Schrödinger proposes in the FIRST AMENDMENT on p.22 is more of an analogy than a direct link, in which different configurations of an isomeric molecule represent a different 'alleles' in the same 'locus' and a quantum jump represents a mutation. The two factually correct amendments to this "interpretation," as he calls it, are important because they allow for wholesale quantization at every level while allowing for '[t]he term 'next higher level' to be understood as meaning the next level that corresponds to a relevant change of configuration." (*l.c.*)

This is because the ground state or lowest energy level "… is followed by a crowded series of levels which do not involve any appreciable change in the configuration as a whole, but only correspond to those small vibrations among the atoms…" This will allow for the low energy bombardment of the molecule by heat motion and other forms of low energy radiation without doing any significant "harm." Schrödinger does not place very much store in these amendments, regarding them as "not very serious…" however they do help to account for the high level of stability of the genetic material at the relatively high temperature of bodies, as well as the necessity and rarity of mutations. The fact that, what we today call, "activation energy" in the SECOND AMENDMENT is need in transitioning from one to another stable isomeric configuration only reinforces the argument above.

Chapter 5:

In this chapter, Schrödinger directly presents his reasons for believing the heredity material to be a molecule that forms an aperiodic crystal, *i.e.* one that does not repeat itself. Although his conclusion turned out to be wrong, one can still read this chapter with profit because, as so often in the history of ideas, one can still be wrong in an interesting or enlightening way.

In his "scheme of 'equations':

molecule = solid = crystal

gas = liquid = amorphous,"

Schrödinger redraws the distinction between the different states of matter. Accordingly true solids, which are also permanent, are crystals, with a small molecule representing 'the germ of a solid.' On the other hand "so-called amorphous solids are either not really amorphous or not really solid." In which case, "Where we find no crystalline structure we have to regard the thing as a liquid with very high 'viscosity' (internal friction)." Now there are two ways of building up a crystal from a "germ of a solid": one, just more of the same in the same figuration in all directions, the other "that of building up a more and more extended aggregate without the dull device of repetition" *i.e.* the aperiodic solid. (p. 25-26)

In the section “THE VARIETY OF CONTENTS COMPRESSED IN THE MINIATURE CODE” Schrödinger realises and even quantifies how efficient a code consisting of only some few “letters” can be. In his own words, “What we wish to illustrate is simply that with the molecular picture of the gene it is no longer inconceivable that the miniature code should precisely correspond with a highly complicated and specified plan of development and should somehow contain the means to put it into operation.”

What would have surprised and then shocked him, in that order, is that that number of “letters” in the “gene script” turned out to be just four (to his example of five in the section above) and yet the overwhelming proportion of most organism’s genomes are either redundant or non-coding: over 98% in the case of humans,’ as we have mentioned. As for the approximate correctness of the calculations involved in this and the previous section, they are not fortuitous but based on the sound Physical Chemistry theory of the day.

Chapter 6:

This chapter contains, in retrospect, a second mistaken prediction and the one nugget of insight which, according to Schrödinger, “I confess, was my only motive for writing this book.” The former concerns “‘other laws of physics’ hitherto unknown,” none of which were required in the discovery of DNA, and the latter “…a rather subtle line of thought, open to misconception in more than one respect.” (p. 29)

According to the “order-from-disorder” principle: “Life seems to be orderly and lawful behaviour of matter, not based exclusively on its tendency to go over from order to disorder, but based partly on existing order that is kept up.” (p. 29) In other words Life evades the **second law of thermodynamics** (or the **entropy principle**) ….the decay to thermodynamical equilibrium.

When is matter said to be alive from the physical perspective?

> When it goes on ‘doing something’, moving, exchanging material with its environment, and so forth, and that for a much longer period than we would expect of an inanimate piece of matter to ‘keep going’ under similar circumstances.

And when it is not alive?

> When a system that is not alive is isolated or placed in a uniform environment, all motion usually comes to a standstill very soon as a result of various kinds of friction; differences of electric or chemical potential are equalized, substances which tend to form a chemical compound do so, temperature becomes uniform by heat conduction. After that the whole system fades away into a dead, inert lump of matter. A permanent state is reached, in which no observable events occur. The physicist calls this the state of thermodynamical equilibrium, or of ‘maximum entropy’. (p. 29)

Without any knowledge of Physics or Chemistry we know that any system, left to itself, tends to go over into disorder over time: embers cool, clocks wind down, things fall apart, or as the Bard observed:

> SINCE brass, nor stone, nor earth, nor boundless sea,
> But sad mortality o'ersways their power,
> …

O how shall summer's honey breath hold out
Against the wreckful siege of battering days,
When rocks impregnable are not so stout
Nor gates of steel so strong, but Time decays?

(Shakespeare: *Sonnet 65*)

This is not merely a poetic reflection. It is a fundamental *law* of Nature. How is it then that living things appear to evade this law? In the past, non-physical or supernatural forces, a *vis viva*, *entelechy* or *élan vital* were postulated as the source of self-organisation within the organism, but this only explains the obscure by the more obscure. The obvious answer, for Schrödinger, is: "By eating, drinking, breathing and… assimilating. The technical term is *metabolism*. The Greek word (μεταβολή) means change or exchange. Exchange of what? Originally the underlying idea is, no doubt, exchange of material. (*E.g.* the German for metabolism is *Stoffwechsel*.)" But, as he points out in the same paragraph, this is absurd. "Any atom of nitrogen, oxygen, sulphur, *etc.*, is as good as any other of its kind; what could be gained by exchanging them?... What then is that precious something contained in our food which keeps us from death?" (p. 30)

The answer is not so much a thing as a process.

> Everything that is going on in Nature means an increase of the entropy of the part of the world where it is going on. Thus a living organism continually increases its entropy - or, as you may say, produces positive entropy - and thus tends to approach the dangerous state of maximum entropy, which is of death. It can only keep aloof from it, *i.e.* alive, by continually drawing from its environment negative entropy - which is something very positive as we shall immediately see. What an organism feeds upon is negative entropy. Or, to put it less paradoxically, the essential thing in metabolism is that the organism succeeds in freeing itself from all the entropy it cannot help producing while alive. (*l.c.*)

Entropy is not some makeshift construct or stopgap option. It is a definite physical quantity (S) measured in Joules per Kelvin ($J.K^{-1}$) or calories per Celsius ($cal.C^{-1}$) if your country has not moved over to S.I. units yet. Entropy is a measure of the number of specific ways in which a thermodynamic system may be arranged. As the number of ways increases, so does the **disorder** of the system, therefore the entropy of a system is a measure of its disorder. *E.g.* a flawless crystal at absolute zero (0^o K or ≈ - 273 ^{0}C) has 0 $J.K^{-1}$ entropy because it is perfectly ordered. Heat it or disarrange it to some extent (which amounts to the same thing) and its entropy will rise. To quote Schrödinger's example: "when you melt a solid, its entropy increases by the amount of the heat of fusion divided by the temperature at the melting-point." Hence the units of entropy: heat/temperature *i.e.* cal./C or J/K.

But Schrödinger also gives entropy (S) a statistical treatment such that it is also given by

$$S = k_b \log D,$$

where k_b is Boltzmann's constant (= 1.3806×10^{-23} $J.K^{-1}$ or 3.2983×10^{-24} cal./C as it appears in the text) and D is a quantitative measure of the disorder of a system. So clearly as a system becomes more disorganised the quantity D increases and so does the entropy (S), because S increases with $\log D$.

If death is the decay into a state of thermodynamical equilibrium or of ‘maximum entropy’ then life must overcome, or at least postpone this eventuality, while it may. It must literally feed upon negative entropy, “attracting, as it were, a stream of negative entropy upon itself, to compensate the entropy increase it produces by living and thus to maintain itself on a stationary and fairly low entropy level.” (p. 31) In symbols, if D is measure of disorder within a system then $1/D$ can be regarded as a measure of its order and since $1/D$ is just negative log $(1/D)$ we can rewrite Boltzmann’s equation as:

$$-S = k_b \log\left(\frac{1}{D}\right)$$

According to Schrödinger, “the awkward expression ‘negative entropy’ can be he replaced by a better one: entropy, taken with the negative sign, is itself a measure of order.” (p. 31) What Schrödinger may not have been aware of at time of preparing his lectures is that negative entropy is equivalent to **information** (unit bit) because it resolves uncertainty. We shall return to this detail in the discussion. The point he wants to make here is that metabolism causes a fairly high local increase in disorder and that if an organism is not to succumb to that disorder it must pay for the upkeep of its own “fairly high level of orderliness (= fairly low level of entropy)” by “continually sucking orderliness [or negative entropy] from its environment.”

> Indeed, in the case of higher animals we know the kind of orderliness they feed upon well enough, *viz.* the extremely well-ordered state of matter in more or less complicated organic compounds, which serve them as foodstuffs. After utilizing it they return it in a very much degraded form - not entirely degraded, however, for plants can still make use of it. (These, of course, have their most power supply of ‘negative entropy’ the sunlight.) (p. 31)

This insight explains numerous biological phenomena, such as why we are warm-blooded or why we can’t utilise coal for food. In the case of the former: all the better to dump excess entropy into the environment that results from our fairly high rate of metabolism (about 80 Watts at rest.) Besides which, up to a point, higher temperature speeds up the rate of most metabolic reactions, beyond after which they cease. As for coal, even though it is very energy dense (≈ 30 Mega Joules per kilogram) we can’t utilise it because “if you allow the reaction, the burning of the coal, to take place, a great amount of heat is produced. By giving it off to the surroundings, the system disposes of the very considerable entropy increase entailed by the reaction, and reaches a state in which it has, in point of fact, roughly the same entropy as before.” (p. 31) So, there is no net decrease in entropy to be gleaned.

Chapter 7:

In this chapter, Schrödinger again predicts that as far as living matter is concerned, “we must be prepared to find it working in a manner that cannot be reduced to the ordinary laws of physics.” (p. 32) In all the intervening years of accumulated knowledge concerning biological processes, right down to their most basic chemical reactions, we have not found living matter to behave according to a different set of physico-chemical processes to that of ordinary matter. In that sense Schrödinger prediction has turned out contrary to his expectations. If however we stress the word *reduced* in the quotation above then, surely, he was correct.

Reductionism, as it applies to Life, is the philosophical position that holds that living systems are nothing but the sum of their parts, and that a complete account of life can be reduced to an account of its individual constituents, right down to its constituent atoms if necessary. There is a trivial sense in which a mechanical toy can be said to reduce to the causal operations of its constituent parts. Living systems however, display a level of complexity that gives rise to emergent phenomena including self-organisation, natural selection and adaptation on the macroscopic level all the way down to quantum mechanical properties of ions within voltage gated ion channels. (See Summhammer *et al.* 2012 for example)

Indeterminacy* vs. *Determinism

These terms are not antonyms. A system that is governed by a deterministic set of equations may display indeterminacy, in that it is *necessarily* impossible to give a complete physical description of the system. Examples include the position and momentum of an electron around an atom or the timing of irregularly dripping tap, both of which are fully determined physical systems. The word "**stochastic**" (from the Greek στόχος for "an aim" or "shot") however, is better reserved for processes that are non-deterministic and therefore truly random.

Life therefore is a phenomenon that spans many orders of magnitude and complexity including the fundamental property of **quantum indeterminacy** at the minutest extreme. The latter refers to "the apparent *necessary* incompleteness in the description of a physical system, that has become one of the characteristics of the standard description of quantum physics." (Wikipedia: Quantum indeterminacy) It follows therefore, that life is not merely contingently irreducible at the fundamental level but *necessarily* so. (See box right.)

In summing up, Schrödinger reminds the reader that "there are two different 'mechanisms' by which orderly events can be produced: the 'statistical mechanism' which produces order from disorder and the new one, producing order from order." The first "which is actually followed in Nature and which alone conveys an understanding of the great line of natural events, in the first place of their irreversibility." The second "the 'order-from-order' principle. You would not expect two entirely different mechanisms to bring about the same type of law - you would not expect your latch-key, to open your neighbour's door as well." (p. 33) In keeping with the "latch-key" metaphor it is as if Schrödinger has unwittingly uncovered the skeleton-key for both doors, in Chapter 6, only to restate his incredulity in his own discovery in this one. At the very end, he throws in: "… the Lord's quantum mechanics" without argument or justification. What are we to make of this?

Epilogue:

The epilogue concerns Schrödinger's "own, necessarily subjective, view of the philosophical implications" of determinism, free will, and the mystery of human consciousness. He believes that he has to reconcile the following two true premises:

> (i) My body functions as a pure mechanism according to the Laws of Nature.
>
> (ii) Yet I know, by incontrovertible direct experience, that I am directing its motions, of which I foresee the effects, that may be fateful and all-important, in which case I feel and take full responsibility for them.

The first premise is true but not very well nuanced. The use of the word “mechanism” brings to mind all sorts of unintended false associations such as “the body as a machine” *etc.* however we can let the premise stand as it is so long as we don’t fall into any such traps.

The second premise is also true but requires qualification. Yes, we know that it is we who control the motion of *some* parts of our own bodies, such as the skeletal muscles but not others such as our intestines. Yes, in part, we can also foresee the consequences of *some* of our actions and so if we are wise, we avoid acting recklessly. If moreover we are mature, we “take full responsibility for them” even when events do not turn out the way we might have foreseen them.

The claim that: “The only possible inference from these two facts is, that I … am the person, if any, who controls the ‘motion of the atoms’ according to the Laws of Nature” (p. 36) is problematic. Either we control the ‘motion of the atoms’ which is magical thinking or the ‘motion of the atoms’ act ‘according to the Laws of Nature’ as they always have done and could not have done otherwise. The free choice to flex one’s wrist say, is determined by a brain state that sends a motor impulse down a nerve in the arm causing a muscle to contract.

A seminal paper by Benjamin Libet (1985) describes an experiment in which participants were asked to flick their wrist at any random time of their choosing while noting when they became aware of the intention to do so. They were able to judge the time by watching a fast moving second hand on a clock and reporting where it was when they became aware of their intention. At the same time Libet measured the associated activity in the subjects’ brain. Interestingly, he found that their brains exhibited a “readiness potential[2]” a full half second before they reported becoming aware of the intention to flick their wrist.

Libet’s paper has been vigorously debated however; the one simple lesson for students of Philosophy is that there is no “I” controlling the ‘motion of atoms’ in the brain, thereby directing behaviour. There is no *Mini-Me*, no *homunculus* at the helm. The sense of agency that is the “I” that we regard as the “doer” of our deeds is as much a product of our brain as are our myriad percepts of sight, sound, texture and so on. By the time we become consciously aware of a decision to flick our wrist; our brain has already set in motion the neural chain of events that will ultimately lead to that movement. In a very trivial sense we do control the ‘motion of the atoms’ because when we decide to perform a movement, trillions upon trillions of atoms within our body are indeed moved. However, the decision to do so and the neural events signalling the move are not caused by our “sense of self,” but by our brain and the body’s effectors. The neural origins of our actions precede the “I” that later takes ownership of them. It is as if the “I” is sensing, “Yes, that action, that’s me doing it. There I go flicking my wrist, just as I intended.” To reiterate: the causal engine of free choice is one of the countless functions of brain, not the sense of self. (We will return to this debate in the Study Unit on Freedom *vs.* Determinism.)

That we have evolved such a faculty is awesome (literally: awe-inspiring) but not magical or mysterious. Whatever inspired Schrödinger in the Upanishads to make the claim he does for the “I” is not a factual one. Indeed, had anyone less than the Nobel prise wining co-founder of Quantum Mechanics made such a claim, he would have been regarded as delusional. Instead the concept of

[2] The readiness potential is merely “a spike in the electrical activity of the brain that happens when a person gets ready to move one arm, leg, or foot.” (Wikipedia: Lateralized readiness potential)

Maya as illusion to which he refers on p. 37 is more appropriate to that of the “I” as understood by Buddhism: “that the self is not as real as it thinks, yet, to the extent it is inside the illusion, real enough to warrant respecting the ways of the world.” (Wikipedia: Maya (illusion) Mahayana.)

Three Theories of Life

Dualism:

We have devoted Classic Text 06 to Dualism as a theory of mind; however it also applies to that of Life in general. Accordingly, there are two fundamental substances: inanimate matter of which the body is composed and life giving spirit (*vis vitae* or *élan vital*) which animates matter. The spirit enters the zygote at conception and departs at the moment of death. Various religions and traditions have stories about where spirits come from and where they go to after death. Dualism with regard to Life is as strong believed by most people as dualism with regard to mind. Unfortunately for believers it suffers from the same defects as mind-body dualism, namely:

- A lack of parsimony. Why postulate multiple substances rather than the one we know?
- Failure to explain how bodies and spirits, which are of different substances, can possibly causally interact.
- Postponement of the question. Invoking spirits doesn’t answer such questions, it simply delays them.
- We have amassed a stupendous amount of knowledge concerning life processes including Biochemistry, Genetics, Neurobiology and so on, while we have learned nothing concrete about spirits. Indeed we are as ignorant of spirits today as our forebears in the last ice age.
- Following on from the previous point; once cannot explain the obscure by appeal to the more obscure.

For these and other reasons the pendulum of Scientific Opinion has swung to the opposite extreme.

Reductionism:

To recap: according to reductionism, a complex system such as a life is nothing but the sum of its parts, and that an account of it can be reduced to accounts of its individual constituents. (Wikipedia: Reductionism) In the case of a complex machine we only have to reduce it to its constituent parts and establish the causal relations between them to arrive at a complete description of the whole functioning system. Of course some systems such as the internet are so vast and so complex that no one person could ever comprehend it fully; however that does not stop us from learning about exchanges, DSLAMs, servers, switchers, routers *etc.* and exclaiming “this is how it works… just hundreds of millions of times over.”

Reductionists believe that if we can just reduce all of life to an immense but finite web of chemical and physical causal reactions we shall have understood it, if not by one person or persons, but at least in principle, then we shall have answered the question: “What is Life?” by gesturing at just such a collection of reactions and causal relations and saying: “Well, there you have it. Life is the sum total of all and only these reactions and relations.” It is of course highly unlikely that any scientist actually believes in such an extreme version of reductionism because:

- It suffers from being exceedingly unparsimonious and inelegant.

- Many of the reactions and physical processes that occur in living systems are also found in lifeless systems.
- Even if we could describe every life-form known today at the molecular level, they are changing and evolving before our very eyes.
- Most of the life forms that have ever existed are now extinct and we will never have an opportunity of studying them, except in the form of rare fossil remains. Moreover, of those species alive today, we know of only fraction here on Earth and nothing at all about other potential life forms on other worlds.

Given that neither of these extremes is either tenable or warranted, it may be instructive to conclude with a brief consideration of one ancient theory that is neither dualistic nor reductionistic; one that is at the same time deterministic, materialist and gives central place to what we today we would call information. According to Aristotle's theory of **Hylomorphism** (from the Greek ὕλη (hyle) for "wood or matter" and μορφή, (morphē) for "form"), being comprises of matter *and* form.

The fundamental difficulty that most people have in understanding Hylomorphism might be called the "cookie cutter" simile. According to this representation, matter is like some amorphous clump of cookie dough and form is like a cookie cutter that stamps out shapes out of the dough, thus giving them form and order. Aristotle had nothing of the sort in mind. On the contrary he was developing his own position with regard to form (from the Greek ἰδέα for "form" or "pattern") as distinct from that of his teacher Plato, which was essentially dualistic.

For Aristotle, **matter** is a relative term so that X's matter is defined as "that out of which X is made."[3] "For example, letters are the matter of syllables."[4] It does not matter whether the letters are speech sounds or whether they are written down or indeed today, whether they are encoded on a memory stick. The point is that they are "that out of which syllables are made" and hence relative. Similarly, "clay is matter relative to a brick because a brick is made of clay, whereas bricks are matter relative to a brick house." (Wikipedia: Hylomorphism)

When matter undergoes change, it is literally "trans-formed" - it undergoes a change in form. Thus, when a lump of bronze is shaped into a statue, bronze is the matter, and this matter loses one form (that of a lump) and gains a new form (that of a statue.)[5] However, again the "cookie cutter" simile should be avoided because we are dealing with more than a mere change in shape. There are besides instances of subjective, conscious experience involved (**qualia**) such as appearance, texture, and odour. [6] (Wikipedia: Hylomorphism)

One of the chief differences between Plato and Aristotle, with regard to form, is that for Plato there exist eternal, transcendental forms, quite apart from matter, in which the human mind can participate. For Aristotle however, matter and form cannot exist apart. It may be that the form of a statue or house exists long before either are realised in bronze or brick, however those forms are first realised within the material brain of the sculptor or architect respectively. On a more fundamental level, mass-energy within the Universe, so far as we know, never exists simply as

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[3] Aristotle: *Physics* 194b23-24
[4] Aristotle: *Physics* 195a16
[5] Aristotle: *Physics* 195a6-8 and *Metaphysics* 1045a26-29
[6] Aristotle: *On the Soul* 418a11–12

indeterministic chaos (from the Greek χάος (pronounced like the same word in Afrikaans) for "the formless or void state preceding the creation of the cosmos.") Either it exists as discreet particles with a given form and/or as energy fields that evolve according to discoverable laws, often elegantly described by deterministic equations.

For Aristotle, the **soul** is that which makes a living thing alive.[7] Life itself is a property of living things, just as knowledge and health are.[8] Therefore a soul or psyche, from the Greek ψυχή (psūkhē) is the form of a living thing.[9] This soul then is related to the body as form is to matter.[10] Hylomorphism therefore is not saddled with the difficulty of explaining the unity of body and soul the way that dualism is. Accordingly, just as a bronze statue requires its bronze and its form to be a certain statue so a living organism consists of a body with the property of life, which is its form (Wikipedia: Hylomorphism)

Yet again, we have to be careful of the cookie cutter simile. If one simply identifies the soul with the physical structure of a body, then the body is alive merely by virtue of its structure. On the other hand, the property of life or the soul is something in addition to the body's structure. According to Timothy Robinson, a running car, by analogy, is running not simply by virtue of its structure but also because of the activity of its engine. By analogy, a living body is alive not only by virtue of its structure but also because of an additional property: that of the soul, without which a suitably organized body cannot live. (Robinson 1995, p. 46) Of course in the case of the car, if there are any critical structural defects, the car may not be able to run. Similarly, the body needs high level of structural integrity in order to live, which is why we cannot reanimate Frankensteinian monsters, because their bodies are cobbled together from parts that lack any structural integrity.

One solution to the problem set out in the following paragraph from the Wikipedia article on Hylomorphism is suggested by what we have read in Schrödinger's "What is Life?" Consider:

> Some scholars have pointed out a problem facing Aristotle's theory of soul-body hylomorphism.[11] According to Aristotle, a living thing's matter is its body, which needs a soul in order to be alive. Similarly, a bronze sphere's matter is bronze, which needs roundness in order to be a sphere. Now, bronze remains the same bronze after ceasing to be a sphere. Therefore, it seems that a body should remain the same body after death.[12] However, Aristotle implies that a body is no longer the same body after death.[13] Moreover, Aristotle says that a body that has lost its soul is no longer potentially alive.[14] But if a living thing's matter is its body, then that body should be potentially alive by definition. (Wikipedia: Hylomorphism)

Christopher Shields however, points out that our bodies are constantly loosing old matter and gaining new. (Shields 2007, p. 293) What then makes your seven year old self the same self as your

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[7] Aristotle: *On the Soul* 413a20-21
[8] Aristotle: *On the Soul* 414a3-9
[9] Aristotle: *On the Soul* 412a20 and 414a15-18
[10] Aristotle: *On the Soul* 412b5-7; 413a1-3 and 414a15-18
[11] Shields, 2007 p. 290-93
[12] Shields, 2007 p. 291
[13] Aristotle: *On the Soul* 412b19-24
[14] Aristotle: *On the Soul* 412b15

seventy year old self is your property of life, that is your soul, not just the matter out of which your body is composed at any one time. This is where Schrödinger's insights come in concerning "The Physical Aspect of the Living Cell" as the subtitle of his book. At the most basic level, we consume water and other matter with a relatively high level of potential energy in the form of food and oxygen and excrete urine, faeces and carbon dioxide with lower potential energy. The net difference in matter that we harvest from this exchange is incorporated into the body by the process of assimilation, while the positive energy balance is used to drive our metabolic processes.

All of this however crates an overall increase in entropy that would otherwise overwhelm our bodies, as it does in death. We have two mechanisms to cope with this: firstly, we are constantly dumping entropy into the environment in the form of heat energy; secondly we extract negative entropy from our food. This negative entropy is the same physical quantity as information which is "already supplied by the special structure or organization of the system in which energy is stored." (Ho, 1994) Living organisms then are literally information sinks, with information stored in the highly ordered structure of their bodies. From the level of organelle upwards, in all forms of life, this structure comprises of a series of compartments, separated by membranes, with some kind of electro-chemical potential being maintained across them.

The most obvious features of dead bodies, on the other hand, are that they are: firstly, (not to be facetious) cool - they are no longer able to get rid of excess entropy in the form of heat loss; secondly, they rapidly approach a state of maximum entropy or equilibrium with the environment in which no significant information is encoded within the matter of the mortal remains: In death all membrane potentials go to zero.

This discussion has taken us far beyond the hylomorphic theory of Life that Aristotle developed, but can we restate it in terms that an educated ancient Athenian would have understood? Certainly they had the vocabulary. Consider:

- The difference between a live rabbit and a dead rabbit is ψυχή (psyche) or a soul. In other words the soul is that set of properties that distinguish a living thing from a non-living thing.
- The soul is the ἰδέα or form of the body, and ὕλη (hyle) or matter is that out of which the body is made.
- The soul confers upon the matter of the body its living form - It literally *in*-forms it.
- Neither the soul nor the body can exist alone, any more than a sphere can exist apart from its property of roundness.
- The soul draws on ἐνέργεια (energeia) "activity" and μεταβολή (metabolē) "change" of the body, via metabolism, to maintain κόσμος (kosmos) "order" within the body.
- If the matter of a body succumbs to θόρυβος (thorubos) "disorder" or "noise" or if the body loses too much mater at once, it will no longer be able to maintain its living form and will go over to death and hence change until it is of the same form as τὰ περιόντα (ta perionta) "the environment."

Task:

Essay question: "Has Schrödinger made good on his promise to answer the question of 'What is Life?' in his book of the same title?"

Feedback:

There is no model answer or rubric to this question. You need to say what you believe to be the case in the light of what is present in the text of Schrödinger's book, not some other book or article. You should substantiate your response by means argumentation and an appeal to the facts, so far as they are known today or were understood at the time of writing. You will not succeed in convincing your reader, one way or the other, if you do not actually personally believe in the case you are trying to put forward. Yes, you may introduce other theories or sources but only to the extent that they corroborate your answer. Finally, be specific. If you try and expound upon the question of Life in general rather than Schrödinger's take on it, you will end up answering some other question.

Once again you will have to seek feedback from someone else who has also read this study unit or who is already familiar with the material. Remember, you cannot be completely objective about your own writing, which is why even the most seasoned authors, including philosophers, rely on editors and peer reviewers.

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