PLS Sloan Alumni Seminars
"What is Life?"
Introductory Discussion
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In developing an informed and critical engagement with contemporary life science from the standpoint of Catholic faith, or any philosophical or religious position, it is important to set the discussion for these seminars in a larger context. We are today dealing with a powerful historical convergence of genetics, evolutionary biology, molecular biology, cognitive neuroscience, embryological development theory, nanotechnology, and instrumentation, now being carried out in the framework of "big science" practiced in research universities and research medical schools, and also in major separate interdisciplinary institutions of research. This is a convergence that has generally taken place only in the last fifty years, and it now dominates research in the life sciences. This work is also supported by massive governmental and private funding. The Human Genome Project, which pursued the goal of sequencing the entire human genetic structure, is one manifestation of how this convergence has played out in the last two decades. On the horizon is the emerging Human Brain Project, which is being coordinated internationally and has as its goal the understanding of thought and the workings of the human brain through a molecular biology of consciousness.

The challenges of this kind of integrated life science research to a philosophical and theological anthropology that seeks to move beyond reductive materialism are potentially enormous and they must be seen as multi-factor—we cannot think simply of genetics, or stem-cell research, neurobiology, or evolution, without seeing that there is a larger interaction occurring with the potential of delivering a completely reductive view of the human person. Even though this reductionism may be conceived by some as only "methodological," meaning that it is simply a result of the methodology of science, this easily slips in "ontological" reductionism that assumes this is the truth about reality. It requires little comment to realize how routinely this image is being delivered by the mass media, discussions on NPR, NYT *Science Times*, and programs on NOVA.

I have assigned as a general text for the seminar the *Phenomenon of Life* by Continental philosopher Hans Jonas (1903-1993), a former student of Heidegger who taught at the New School for Social Research in New York from 1955-1976. These lectures in part emerge from a course he taught with that name, but also include other materials. I will ask you to focus on the Foreword and First Essay ("Life, Death," omit Appendices), the Second Essay ("Darwinism," including Appendix), the Fifth Essay ("Cybernetics and Appendix") , and the Seventh Essay ("Image Making") and the "Transition from Philosophy of Organism."

The remarks in the following essay are intended to give us some perspective on these developments and a framework for discussion of issues by reaching back into history for some grasp on the strands leading into this current disciplinary convergence and its philosophical extensions. Our seminars, in true PLS style, will be discussions of primary documents and not lectures by me. But these remarks may help us get a common vocabulary and reference framework for more productive discussions.

Our opening readings will explore two options for viewing the living state that have interacted historically since Antiquity in some way. One is the reductionist and analytical point of view, sometimes termed a "mechanistic" conception of life, although the latter label covers a variety of approaches that need to be distinguished. This assumes that living phenomena can eventually be explained from the "bottom up" through processes, concepts, and laws of the physical sciences. A typical recent statement to this effect is that of DNA-structure co-discoverer Francis Crick who appeals back to the quantum revolution in physics for support:

> The ultimate aim of the modern movement in biology is in fact to explain *all* biology in terms of physics and chemistry. There is a very good reason for this. Since the revolution in physics [i.e. quantum mechanics] in the mid-twenties, we have had a sound theoretical basis for chemistry and the relevant parts of physics.
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> * * * * * * *
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> Thus eventually one may hope to have the whole of biology "explained" in terms of the level below it, and so on right down to the atomic level.
>
> (Francis Crick, *Of Molecules and Men* 1966)

It can be argued that this perspective is that which has governed much of life science over the last fifty years, although we will see new ways of looking at these claims on Day Three.

The other option is a non-reductionist perspective, in some formulations representing what has been termed a "vitalist" position, but one that is more often articulated today less controversially as a "holistic" or "organismic" conception of life. This position claims that there is something besides physical processes needed to understand living beings. The following discussion will give us some background and vocabulary for discussing these issues.

Our inquiry logically opens with a discussion of Aristotle's biological thought and of his most theoretical work on living nature, his *On the Soul*. This work has been enormously influential on discussions in western Christianity and science up to the present.

Aristotle is important for our discussion for three reasons. **First**, he is the one non-medical author from Antiquity whose texts have survived into the modern era who offered detailed consideration of the issues of classification, comparative anatomy, and developmental biology, exemplified in such works as his *Parts of Animals*, *History of Animals,* and the *Generation of Animals*. For this reason, his arguments have affected a long tradition of scientific reflection up into the twentieth century, and there are many philosophers, even secular philosophers of biology, who would still argue that his analyses of these issues are the most viable in dealing with the range of philosophical issues encountered in contemporary biological science (e.g. philosopher Marjorie Grene). **Second**, even if one is not an Aristotelian of some variety, Aristotle's formulations enable us to see more clearly several issues related to questions of teleology, organism, vitality, and the relations of form and function. **Third**, through the long tradition of commentary by the great Scholastics like St. Thomas Aquinas, and the developments of modern Neo-Thomism, reworked Aristotelian foundations underlie much of the reflection on natural law theory and Catholic ethical principles that are in play in Catholic responses to issues such as IVF and embryonic stem cell research.

A first set of concepts that the reading of Aristotle introduces into our discussions concern **causality, form, function,** and **teleology** in biology. Aristotle's discussions of form and function can be situated against his more general discussions of causation that receive their best known formulation in Book II, chp. 3 of the *Physics* (—you may want to read these if unclear). There he distinguishes four kinds of causes: efficient, material, formal, and final. These differences in the *Physics* are primarily expounded through examples that only work partially for our consideration of the organism—e.g. that of a sculptor working on bronze to create a statue. Such examples assist us in making some clear distinctions among kinds of causes, but they are not easily mapped onto the phenomena immediately of concern to our discussions—the processes of living organisms.

For a more relevant example that will fit the discussions of the Aristotle readings and our subsequent discussion of biological topics much better, we can use the example of a developing organism. For a long tradition, the development of life, including human life, was conceptualized through the paradigmatic example given by the development of the chicken. This was easily grasped empirically through a simple experiment described in the Hippocratic writings utilizing eggs incubated in a dung heap and opened serially over 21 days. In this way one could follow how a fertilized egg developed through an ordered series of stages into a fully-formed chicken. The categories for explaining this process were readily supplied for the western tradition until the seventeenth century by Aristotle and his conception of the four causes. The **material cause** in a developing organism can be considered to be the material of the egg itself. For Aristotle, this was in a chicken simply the yolk and egg-white. In mammalian generation (*G.A.* I, 19), the material cause was the menstrual blood. Contemporary biology would describe this material component in highly sophisticated terms, referring to various proteins, DNA and RNA molecules, lipids, cell membranes, microsomes, and other complex chemical components. But this is a matter of detail, not of conceptual difference, in specifying the material cause—that out of which something is made.

The **efficient cause**, that which gives the driving force to the process, for Aristotle would be the incubating heat and also the dynamic energy supplied by "soul" discussed below. We would today speak of the chemical energy contained in complex biochemical molecules, especially the high-energy phosphate bonds contained in ATP (adenosine triphosphate). The expenditure of the energy contained in such biochemical structures gives the motive power for structural complexification and temporal organization according to known physical principles, such as the conservation of energy. But in most general terms the Aristotelian efficient cause—that which drives the process—can be understood in modern terms. Much of the framework of discussion and analysis of developmental and molecular biology today assumes processes that can be translated into material and efficient causes in Aristotle's sense, and in this respect such explanatory frameworks are in keeping with the forms of analysis found in physics and chemistry. Explanation of development, for example, is therefore typically reductive and from efficient and material causes acting from the "bottom up."

But such forms of explanation are not exclusively those encountered in contemporary life science. The difficult problem presented for modern biology, and particularly for developmental biology, is the persistent use of forms of explanation that involve what Aristotle terms ***formal*** **cause**, and to a lesser degree, ***final*** **cause**. Explanation of phenomena through such causes was explicitly abandoned in physical science since the seventeenth century by such authors as Bacon, Galileo and Descartes. But in life science the problem has proven more intractable.

To illustrate the issue by use of the classical example of the development of the chicken, the egg develops into a chicken under the action of efficient and material causes, but it does this through a regular series of stages that seem to be goal directed in a way that does not accord with the physical laws and least-action principles that would explain why rivers run downhill or why entropy increases in a physical system. In other words it shows **teleological directedness.** Why is this? For Aristotle, such goal directed behavior cannot be explained simply on the basis of material and efficient causes, since these seem unable to account for the regular way in which this process is normally occurring, nor do they account for the *specific ordering* of the sequence of events that result in the temporal production of a fertile, adult organism of an identifiable species membership able to reproduce its like. For Aristotle this is explained by something inherent in the chicken, a "nature" or in his term "form" (*eidos*), which is passed on through generation and is manifest in the developing chicken as its "soul."

Aristotle on "Soul"

The notion of "soul" (Gr. *psuche;* Lat. *anima*), encountered in Aristotle's *On the Soul*, is an important concept to understand, and in this principle is contained the Aristotelian account of formal, final, and even efficient causation of organic life. In his account of soul, there are some important things to highlight. First, "soul" serves as the dynamic ordering principle, or efficient cause, of life. Second, the relation of soul to body is that of **form to matter**. It is **not** a relation involving the addition of an external immaterial principle to an otherwise inert material. This is why Aristotelian understandings of the soul-body relationship do **not** reduce to what is typically called "vitalism." To explicate this fully would be a complicated discussion and it is connected to Aristotle's hylomorphic conception of substance developed in detail in his *Metaphysics*. But a few summary comments can be made here.

An initial point is that Aristotle conceives of an intimate relation between the dynamism and activity of living beings—the fact they move, eat, reproduce, respire, grow, decay, die—and the presence of "soul." "Soul," it should be emphasized, is **not** meant in a theological or dualistic (e.g. Platonic, Cartesian) sense.[1] As we see from the reading in *De Anima* Book II, "soul" is the "form" (*eidos*) of the body in a living thing, intimately related to the body like "seeing" to the "eye." It functions as "form" in his theory of substance (*ousia*). This means that it is intimately associated with "matter" to comprise the composite of form and matter that underlies Aristotle's theory of substance. Form or soul in this sense is the integrating principle that **unites** the formal, final, and efficient causes of life into a single dynamic principle. Hence living beings differ from non-living because they have the principle of motion *within* themselves, indicative of the presence of soul. In some important respects, "soul" in Aristotle's writings is more a designation of the dynamic functional activity of a living being than it is a specification of a separable principle that moves in and out of matter. This also differentiates Aristotle's account from modern "vitalisms."

A second general point is that for Aristotle, the relation between "form" and "matter," or "soul" and "body" in an organic being, goes "all the way down" and involves the integral union of form and matter in his complex 'hylomorphic" concept of substance from the initial beginning of life. It is not a reading supported by the Aristotelian texts that there is an immaterial "form" or soul *added* at some later temporal point following fertilization to otherwise inert "matter" that gives it these dynamic powers of goal-oriented development. Sexual fertilization (*Generation of Animals*) involves an immediate union of form and matter. On Aristotelian grounds, a strong argument can

[1] The classic theological discussion in the Catholic tradition that has sought a reconciliation of Aristotle's account of soul with the Christian notion of a separable and immortal soul have been commentaries on his additional concept of the separable "active" intellect at *De Anima* III:v. 430a.15. See St. Thomas Aquinas, *Commentary on Aristotle's De Anima*, trans. K. Foster (Notre Dame: Dumb Ox Press, 1994).

therefore be made for the existence of significant human life from the moment of conception.

Some confusion was introduced into the interpretations of Aristotle by the commentary traditions of the Middle Ages that have come to bear on issues involved in contemporary debates over stem cell use and the first beginnings of human life. Through attempts in the Middle Ages to synthesize Aristotle and Plato with the theories of medical writers such as Galen, there was introduced into Aristotle's account of the functional levels of soul the concept of a *serial addition* or successional development of different kinds or forms of "soul"—vegetative, animate, rational—in time. The interpretations of the Aristotelian tradition through the lens of these historical revisions have generated a substantial recent literature that has utilized these claims in the stem cell and abortion debates in favor of a concept of "delayed hominization."[2] However, this is not the conclusion we draw from a careful reading of Aristotle's texts.

A third observation is that soul-as-form is something other than empirical shape. A dead body has a shape, but presumably as dead it does not have the dynamic principle of life involved with soul. For this reason a developing being would not have to achieve a particular "shape" to be in possession of its substantial "form."

Fourth, soul-as-form is individuated in the thing. There is not some "soul in general" that animates members of a natural kind. Nonetheless, there is a basis for the concept of a natural kind in which the members all have the same form or soul as individuated in these individuals as a specific principle of life. The form-in-the-thing is connected to the universal in thought, language, and classification, by a complex process that we will not try to explicate in this summary. This means that the universal *Homo sapiens* can genuinely refer to the essential principle in a specific human being. This can have some bearing on whether individuals which may lack some normal properties of a species may nonetheless share in that species. These issues become important for analysis of ethical issues related to embryos, fetuses, and stem cells and also for the notion of a species in biology.

Although Aristotle's own formulations are limited by their antiquity and involved merely naked eye observations, the central concepts involved can be translated into contemporary discussions in developmental biology without considerable difficulty. One can reformulate the concept of **formal** cause for our purposes more simply in terms of the *specificity* of the underlying genetic "instructions" contained in the specific

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[2] These often draw upon Thomas Aquinas *Summa contra gentile* Bk. II, Chp. 89, Para. 9-11. See for historical review J. F. Donceel, "Immediate Animation and Delayed Hominization," *Theological Studies* 31 (1970): 76–106. See also M. Johnson, "Delayed Hominization: Reflection on Some Recent Catholic Claims for Delayed Hominization," *Theological Studies* 56 (1995); 743- 63 and response by Jean Porter, "Individuality, Personal Identity, and the Moral Status of the Preembryo: A Response to Mark Johnson," *Theological Studies* 56 (1995): 763–70.

sequence of bases in the DNA molecules in the cell. This "instructional program," as it might be termed, would be that expressed phenotypically through the complexities of the linkage from DNA sequence to protein synthesis. Even though a modern biology paper or textbook would not speak of the action of formal causes, we can identify implicit appeals to formal causation in the pervasive teleological language of much of biological discussion referring to "functions," and in the use of concepts like "code," "program," "system," and "information." The Marjorie Grene reading develops these points for us.

Final Cause in Aristotle's Biology:

Finally, we must consider the **final** cause. In the example from *Physics II*, it is the ultimate end for which the sculptor made the statue. For Aristotle this is the ultimate explanation of why the three other causes in fact operate, and is the ultimate or final end for which a thing exists. In the case of an organic being, its final cause is the end of generating more like itself so that its species may be eternal (*De Anima* 415a), with the goal of achieving this eternity of the species serving to order all other processes that places this within a larger final cause of nature itself. Final cause in this sense refers to a larger natural teleology of life, a teleology that can be imposed from without, as maintained in later Judeo-Christian tradition in the concept of creation. For Aristotelian biology, final cause of a more limited kind is realized from within through the drive of an organism to perpetuate itself and fulfill its various functional ends to achieve this.

In laying out these very summary remarks on Aristotle's philosophical biology, the intent is to help explicate some points that may not be familiar to those not acquainted with his writings. Although they involve reflections substantially predating modern life science, they deal with the perennial philosophical problems of modern biology.[3] Most modern biology textbooks will simply present a kind of "mundane" mechanistic reductionism as its framework of exposition and explanation in biochemistry, cell biology, genetics, and embryology without suggesting that other kinds of causes may be relevant. The mainstream of contemporary analytic philosophy of biology generally would hold more deliberately that traditional notions of formal and final cause are eliminated from the life sciences through a combination of molecular biology and evolutionary theory which in company eliminate the need for formal and final causal analysis in the Aristotelian sense, along with other forms of "vitalism."

But the philosophical issues surrounding form, cause, teleology, and the nature of life in developmental biology raised by the Aristotelian tradition are persistent. The debates over the moral status of the human embryo force new attention to these questions. The

[3] See M. Grene and D. Depew, *The Philosophy of Biology: An Episodic History* (Cambridge: Cambridge University Press, 2004).

revival of systems biology and the reemergence of holistic and organismic biology in such areas as evolutionary-developmental biology have also required new attention to these matters from within scientific inquiry itself.[4]

Mechanism in Biology

The main historical source of the modern "mechanistic" approach to life can be traced to the writings of the French philosopher Réné Descartes (1596-1650). In his analysis of the living state, developed particularly in our reading from his posthumous *Treatise on Man* (1664), which in many respects was the first "textbook" in the mechanistic approach to biology and was used as such in major medical schools in the seventeenth century, the machine model is obvious and the organism is likened to an inorganic mechanism working simply by mechanical action without vital principles or a soul in the Aristotelian sense. But it should also be observed that this is accomplished by moving the formal and final causes of life to an external domain—the actions of a creator who designs this machine for certain ends much as a watchmaker would design a watch. To this machine, but **only** in humans, will then also be added a separable immaterial soul that can move and interact with the machine. This gives us a strong **dualistic** model of the soul-body relationship that will have a complex career in philosophy and the sciences up into the twentieth-century. There are, for example, contemporary neo-Cartesians, such as the neurophysiologist John Eccles (1903-1997), who won the Nobel Prize in Physiology and Medicine in 1963. But much of modern neurophysiology, molecular biology, and biophysics has rejected this option, and has moved, either explicitly or implicitly, to endorse a materialist interpretation in which higher properties simply emerge from states of matter.

The term "mechanism" is also used in other ways in discussions of the life sciences. Although the Cartesian model covers attempts to explain the organism by analogues of of clocks, computers, and servo-mechanisms, other meanings are encountered. Commonly "mechanism" means the explanation of biological processes from some kind of deterministic cause akin to those used in physics and chemistry without the interaction of other causes—in other words solely through material and efficient causes. Another meaning of mechanism commonly encountered is the explanation of organisms as analogous to some kind of organized biochemical system with energy input and output governed by conservation principles, such as the conservation of energy. In all of these various uses, there is presumably no appeal being made to immaterial principles, souls, forms, or vital forces as explanations.

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[4] For some sampling of these issues see A. Ariew, R. Cummings, and M. Perlman, eds., *Functions: New Essays in the Philosophy and Psychology of Biology*. (Oxford: Oxford University Press,2002). These topics are explored in some depth, with an extensive overview of contemporary literature, in the dissertation by James Barham, "Teleological Realism in Biology," Ph.D. Dissertation, Program in History and Philosophy of Science, Notre Dame, 2011.

Recent Mechanism-Vitalism Conflicts:

We will not attempt to deal with a long and complex history of these questions after Descartes and simply jump to a more recent debate taking place a century ago that began in the sciences and then spilled over into philosophy and theology. This originally centered around developmental biology and then moved into more general discussions of the nature of life. One of these approaches, popularized in the influential lecture of physiologist Jacques Loeb (1859-1924) adopted an analytic and reductive perspective, and the other represented in our reading by Hans Driesch (1867-1941) adopted a holistic perspective that owed a good deal to Aristotle.

The debate first emerged from experimental embryology carried out by the German embryologist Wilhelm Roux (1850-1924), founder of what came to be known as "developmental mechanics" (*Entwicklungsmechanik*). Roux's perspective, summarized briefly in the Driesch reading, has in some important ways come to dominate a long tradition that in a loose sense might be called a "mechanistic" approach to embryology. This put forth a "mosaic" theory of development in which the embryo is formed of separable component parts, each with its own deterministic development, with the whole explained as a composition of these components. This was originally grounded upon Roux's experiments that seemed to show that damaging the embryo in its early stages led to only partial formation of the adult, suggesting that the organism is simply a conglomerate of individual parts with some inherent instructions that led to the development of the organism as a mosaic of parts. Loeb will draw on aspects of this in his popular lecture we will be reading.

In response to the claims of Roux, and then later to Loeb, the second option was first developed by Hans Driesch (1867-1941). Driesch was led by his inquiries as a young scientist in developmental biology to move from biology to philosophy, and he ended his career as a major philosopher at the University of Leipzig. As Driesch's views developed, he became the foremost theorist of what he himself termed "neo-vitalism." On the basis of his experiments on developing sea-urchin eggs, Driesch concluded that the original cells of the embryo were much more plastic, and that they could, up to a certain point, even overcome the effects of damage to attain an end goal by multiple means, what he termed "harmonious equipotentiality." This concept is closely similar to the notion of "robustness" frequently encountered in contemporary literature of biological theory.[5]

Particularly at issue in the conflict between the tradition of Roux-Loeb and that of

[5] For an influential recent statement see H. Kitano, "Towards a Theory of Biological Robustness," *Molecular Systems Biology* 3 (2007): article number 137.

Driesch was the nature of development and its causes. Did the organism form by the independent action of component cells, each with an independent career determined by some kind of internal material properties (this was before the "gene" concept was formulated), as Roux would argue from his experiments? Or is development governed by some kind of more general organizing power or force, named by Driesch with explicit reference back to Aristotle, the *entelechy*, which would lead undifferentiated cells to develop in specific ways, and even achieve a developmental end by alternative routes?

The controversy that began in the 1900s flowed into a larger philosophical controversy in the early decades of the last century concerning the role of vital properties and the adequacy of a "mechanistic" approach to the organism that involved such individuals as Jacques Loeb, Kurt Goldstein, Niels Bohr, Pascual Jordan, Erwin Schrödinger, Conrad Waddington, Joseph Needham, and many others.[6] We will not attempt to survey this controversy except to point out the existence of a debate nearly a century ago concerning the nature of the organism, the reality of teleological properties and forces in organisms, and the adequacy of "mechanistic" and "vitalistic" approaches to developmental biology to deal with the phenomena at hand. Many of these issues were removed from discussion by the combination of philosophical critique, the strong development of gene theory, and the growth of molecular biology since the 1930s.

Schrödinger and What is Life?

As our third major reading, we will consider some of the arguments of Nobel-Prize winning theoretical physicist Erwin Schrödinger (1887-1961) presented in his popular *What is Life?* lectures delivered in Dublin during World War II in 1943 and published in 1944. Although Schrödinger had no credentials as a biologist and presents in many ways views that were outdated and even naive for the biology of his time, these lectures proved highly inspirational for a dynamic group of physicists, mathematicians, and biophysicists after WWII who entered biology in many ways under the inspiration of these lectures. James Watson, the co-discoverer of the structure of DNA, for example, read the Schrödinger book as part of the "great books" curriculum at the University of Chicago. His co-worker, Francis Crick, also was inspired by these lectures to move from physics into biology. Most of the great founding names of "molecular" biology cite similar readings of Schrödinger in their background. It has been a very influential document, although the reading of it is more complex than it appears and there have been divergent readings of what its conclusions are that will surely arise in our own discussions.[7] The following general outline may be useful if you do not have time to read the entire book:

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[6] I have discussed aspects of this in my "How Was Teleology Eliminated in Early Molecular Biology?" *Studies in History and Philosophy of Biology and Biomedical Science* 43 (2012), 140-151.

[7] See Daniel McKaughan, "The Influence of Niels Bohr on Max Delbrück," *Isis* 96 (2005): 507-529.

Schrödinger's *What is Life* ?

Basic Outline of the Argument

Chp. 1:

Basic concepts of Boltzmann-Gibbs interpretation of Classical Mechanics.

-- Macroscopic order is a product of underlying atomic disorder

--The determinate character of physical laws only approximate

--This precision of physical laws a mass-action effect

Chp. 2:

--Organisms appear to violate the assumptions of classical mechanics in this sense

--Governed by entities located on the chromosomes

--The size of these entities, estimated by cross-over and linkage experiments very small. The "gene" estimated by this means at $3x10^{-6}$ cm^3

--On the basis of statistical mechanics, structures of this size could *not* manifest such high degree of order and continuity over time.

Chp. 3:

True-breeding character of genes suggests that only by discontinuous mutations (DeVries) can their order or structure be changed.

--All experiments display these to be rare events

--The work of Timoféeff-Ressovsky, Zimmer, and Delbrück with X-ray induced mutations (1935) shows linear relation of mutation and energy.

--By x-ray target theory, size of gene can now be reduced to a volume of $1x10^3$ atoms

Chp. 4:

The preservation of genetic order and continuity at this size compounds the problem of stability of size and violates statistical mechanics.

--But new quantum mechanics, asserting energy exists in discrete packets or quanta suggests alternative solution.

--Chemical bond is understood in terms of quantum mechanics: both strong ionic and weak (Heitler-London) bonds.

--The alterations of micro-atomic states is not continuous, but involves quantum-discontinuities between stable energy configurations.

--This gives a means for understanding how complex organic molecules of very small size can be stable, and changes are only introduced either by spontaneously degrading to a lower energy level, or by being "lifted" to a higher level.

Chp. 5: These considerations give a way to understand the gene and its stability

--On assumption that it is a complex molecule, or "a-periodic solid," it can be in a stable energy configuration. Isomeric forms can be stable alternatives.

--The concept of "information" and "code" introduced. The "information" of the gene can be understood as the result of the large number of permutations and combinations of isomeric atomics arrangements of simple elementary atoms.

--This gives a plausible way to understand the nature of the gene and mutation.

Chp. 6: How these considerations bear on the second law issues

--Organisms are able to maintain order from order relations through generation

--This seems to biolate the second law of thermodynamics, which states that order will always degrade to disorder (entropy)

--Organisms do this by extracting order (negentropy) from their enviroment. They do not violate the second law because they excrete more highly disordered byproducts.

Chp. 7: Are Organisms governed by special laws?

--This was expected by those who saw violations of second law and statistical mechanics

--But in terms of quantum mechanics, the preservation of order from order is explicable

--At the ordinary temperatures at which life proceeds, they are governed by non-statistical laws which makes order-preserving properties possible.

Consequently, the problem to be solved--how can the uniqueness of life be explained by physics--has been answered.