Introduction of "Crystal Souls—Studies of Inorganic Life"[1]

by the translator

Alan L. MACKAY

Department of Crystallography, University of London,
Malet Street, London WC1E 7HX, U.K.

"The central problem of biology is the form problem"—
"form is simply a short time-slice of a single spatio-temporal entity"
—Joseph Needham (1936)

"Dann im Kristall und seiner ewigen Schweignis"
Erblicken sie die Oberwelt Ereignis"[2]
—Goethe (Faust II:4)

We live in a period in which molecular biology has developed very strongly. We may count the new epoch rather arbitrarily from 1953, the year in which the double helix of DNA had been published and Stalin died-ideologies had suddenly changed.

Following the revolution in molecular biology, the role of the component molecules has been emphasised and "explanation" of structures and phenomena in biology has usually meant explanation in terms of constituent molecules (themselves explained in terms of their combining atoms).

However, it is now time to reconsider morphogenesis, the appearance of form, and the topic of form has become increasingly popular as aspects of the generation of natural forms and shapes have come within the ambit of science. The chemistry of homogeneous soups is moving on to the development of a chemistry of structures in space. The apparent conflicts of our time between molecular biology (often labelled "reductionism") and the study of whole organisms, societies, etc. (often labelled "holism" and now "organicism") are really artificial. The most fundamental physics (work by Aspect, Bell, Bohm, etc.) has confirmed that all parts of the universe are indeed connected to each other, often in ways which are counter-intuitive and only to be discovered by subtle experiments. Since we simply cannot consider everything simultaneously we have to try to select what is important, (bearing in mind that at critical junctures very small influences may be decisive)—the eigenvectors corresponding to the largest eigenvalues of the all-embracing interaction matrix, although this metaphor implies a linear approximation and nature is, in general, definitely non-linear. We have to suit our strategies to the problems, but have also to be prepared to find that we have asked the wrong question in the wrong place and have

to move to a different arena. If we have not picked out the significant variables, then our analyses will not fit the facts and we will have to begin again.

Major issues of science, in Haeckel's time (about 1850–1900) and now, include particularly, the origin of life, the appearance of form (morphogenesis), the mind/matter relationship and the mechanisms and processes of evolution. Liquid crystals, particularly in the self-organisation which they exhibit, bear on these issues. Along with the pictures by Maurits Escher to be seen on the walls of students' rooms, there are often to be found the engravings of symmetrical Radiolaria and other marine organisms made by Ernst Haeckel (1834–1919) and his etcher Adolf Giltsch (1852–1911)[3] from specimens collected by the famous "Challenger" expedition (1873–1876), the lavishly illustrated reports of which are now collectors' items. Haeckel's pictures of naturally constructed organisms immediately excite, as they were designed to do, questions about their creation, growth and formation. They represent an attractive bridge between biology and engineering[4]. In his time, the second half of the nineteenth century, Haeckel was a highly visible figure, immersed in scientific and social controversy, and was responsible for promoting in Germany Darwin's views on evolution and the origin of species, although Darwin was himself not enthusiastic over the support which both Karl Marx and Ernst Haeckel found from his work for their own political programmes.

In 1888 F. Reinitzer had discovered liquid crystals, a striking form of self-organisation, in which directional order appears spontaneously in a homogeneous liquid, not incrementally, as in the growth of the familiar crystals layer by layer at the surface, but simultaneously throughout a substantial volume. In 1904 Otto Lehmann published a book about his researches pointing to liquid crystals as being intermediate between living and non-living matter. Haeckel was greatly stimulated by this discovery. J. Lorch[5] has traced the prevalence of the idea of crystals as a model for the simplest form of life from Maupertuis, Schwann, Schleiden, Unger, Herbert Spencer, to Weismann, so that Haeckel was the inheritor of strong tradition in this notion.

Today, liquid crystals[6] are to be found widely used in the displays of text and pictures in the screens of lap-top computers and are an active major branch of science. The Radiolaria too are now being studied with the latest techniques and the remarkable ingenuity of natural structures is being revealed. As plankton, they are of great economic importance. The regular crystals which have preoccupied crystallographers, and which still have their secrets, are extremely simple in comparison. The objective of creating life *ab initio* is being approached, but is still some distance away, and the hubris described in Goethe's "Faust" is still worth the attention of molecular biologists[7] intent on achieving fame and wealth in the global economy[8]. It is probably only a matter of time now before a recognisably living system will be assembled from non-living components[9].

The junction of the forms assumed by non-living "soft matter" (P. de Gennes's term for liquid crystals, plastics, liquids, etc.) and those occurring in micro-organisms is approaching and this is our justification for calling attention to Haeckel's long-forgotten book. If we are to create, *ab initio*, a living structure, we need, not only DNA and its technology, but also an understanding of the inorganic processes involved in the liposomes and micelles, chains, sheets and fabrics[10] which are used by living systems to make their spatial structures. By symbiosis, living systems have taken over, as prokaryotes evolved to eukaryotes, not only organelles, but also significant phenomena of physics, especially

materials, the shapes of which are determined by surface tension. For example, at the earliest stage in the formation of an embryo the spherical cell assembly turns inside out (gastrulation) as the curvature of its surface is controlled by the molecules composing it. The "use" of magnetic particles by magnetotactic bacteria, now the centre of the controversy as to the existence of life on Mars, is just one other such process. Simple physical laws or relationships can have complex consequences.

The discovery of liquid crystals was noticed by several people concerned with the origin of life[11], then a very topical issue because of Charles Darwin's theory of evolution by natural selection and the origin of species (published in 1859). In Britain, D'Arcy Wentworth Thompson (in Dundee) produced his masterpiece "On Growth and Form" (1916); a little earlier, James Bell Pettigrew (1834–1908)[12] in St. Andrews had compiled three huge volumes on "Design in Nature" (1908) and in 1917 Ernst Haeckel in Jena issued the small book "Crystal Souls" which we now discuss. These books were very different from each other. D'Arcy Thompson's book was an application of straightforward mathematics and physics to several different aspects of biology then suitable for such treatment. It has proved to be of lasting value in its approach, in some of the actual analyses, and in its scholarship and style. Curiously, Thompson hardly mentions Pettigrew (and vice versa) although they were at neighbouring universities, and prudently, it being Calvinist Scotland, Thompson does not open questions as to the existence of God, but probably, as for many people living in a quasi-theocracy, "he had his doubts". D'Arcy Thompson clearly also had doubts about Haeckel—writing—"If we may safely judge from Haeckel's figures"—and other people questioned Haeckel's scientific integrity more forcefully. Thompson's treatment of the whole question of the architecture of Radiolaria is more mature and greatly superior to Haeckel's and forms a good basis for present day investigations with far more refined techniques. Living in Scotland, noted for its engineering, Thompson is reluctant to enter metaphysics and is unwilling to countenance a vague "Gestaltungskraft" or "facultas formatrix"[13] as accounting for liquid crystal properties while ordinary mechanisms might be sufficient. He concludes, very reasonably, that the resemblances between the geometric forms of Radiolaria and crystals are the result of analogous, but not identical, phenomena and that deeper detailed investigation is necessary.

Pettigrew's work draws attention to mechanical and geometrical design in nature but the author rejects evolution and, although he sets out alternative theories and considers them at length, settles for the theory of divine creation and the continual intervention of a Creator, in accordance with the prevailing orthodoxy of the pious Scotland in which he must have been brought up[14]. He takes many pages to castigate Haeckel and his views[15] but gives them an honest airing. Pettigrew was a descriptive anatomist with wide interests, having, for example, pertinent observations on the flight of birds, but unfortunately his profusely illustrated book has almost vanished. He was a connoisseur of design in Nature, having dissected hundreds of bodies, human and animal[16]. Pettigrew, expert as an observer and collector, gave an extensive account, with very long quotations, of the controversies of the Victorian period around the topics of evolution and the origin of life. He presents the arguments of Darwin, Haeckel and others at length before totally rejecting them. The 2000 illustrations, while not as good as those of Haeckel, who almost became a professional artist himself, are of great interest. They recall the pre-scientific drawings of Leonardo da Vinci in their concern to apprehend or comprehend the flowing of water, the flight of birds

and the operation of muscle, all of which are essentially three-dimensional structures changing with time. Such preliminary understanding must precede formulation of the differential equations of modern hydro- and aero-dynamics

Ernst Haeckel, aged 83 at the time of writing his book, had a life of controversy behind him. Having rejected the supernatural[17], he espoused a kind of materialism where matter and spirit co-existed in everything[18]. He was clearly influenced by Leibnitz. Haeckel's philosophic outlook was formed in the atmosphere of German Naturphilosophie (which contrasted with the clear rationalism of the French Enlightenment and with English empiricism and included at a lower level, the spirits of the traditional German folk beliefs which saw the world as populated by invisible gnomes, kobolds, changelings[19], water witches and so on who looked after wind, water, rocks etc.). Haeckel was also engaged in German politics and would certainly have been a television personality if there had been television then. He had successfully invited Bismarck to Jena[20] University in 1892 for a special honorary degree in "phyletics" devised by himself and he enthusiastically supported Bismarck in his struggle (the "Kulturkampf") with the Catholic Church. Haeckel's earlier book, "The Riddle of the Universe" (1899) sold some half a million copies in various languages and was for long a weapon of the rationalist movement[21], although it must have baffled many a would-be simple atheist with its mystical accounts of the physical world. Nevertheless, Haeckel said very clearly[22]: "Man creates God in his own image". Some of "The Riddle of the Universe" reappears in "Crystal Souls". Going back to 1900 we can see that, as people's knowledge of the world widened, and it was realised that other civilisations had other religions, so that there existed belief systems different to what one was brought up to believe, there was a rising interest in mysticism, theosophy[23], Indian gurus such as Vivekananda, and so on. In 1901 Jagadis Chandra Bose (1858–1937), the first Indian scientist to achieve general recognition (he demonstrated radio microwaves and studied the growth and senses of plants) lectured at the Royal Institution. He, like Haeckel believed in the continuity of life down to the atomic level and demonstrated "the death agony of a poisoned tinfoil and cured another with drugs" but there were Europeans present who were eager for immortality, like the metallurgist Robert Austen (of austenite) who asked Bose: "I have all my life studied the properties of metals. I am happy to think that they have life... Can you tell me whether there is a future life—what will become of me after my body dies?"

In 1917 Bose founded the Bose Institute of Science in Calcutta and dedicated it to the "search for the ultimate unity which permeates the universal order and cuts across the animal, plant and inanimate lives"[24]. There has long been an affinity of German thought with Indian mysticism, the swastika of the Aryans was current in Germany before Hitler, and this fascination has continued, a recent example being the careers of the Indologist Agehananda Bharati (né Fischer) and his illustrious predecessor Max Müller.

Naturphilosophie is still with us and takes new forms[25]. Theodore Schwenk's book, "Sensitive Chaos", about water, written in the Naturphilosophie tradition as propagated by Rudolf Steiner, is a modern example. The "Whole World Catalog" school of environmentalists, the "Greens", the Scientific and Medical Network, Rupert Sheldrake[26] and such movements continue aspects of Naturphilosophie. Nevertheless sympathetic observation, however sensitive, is not enough. "Nature is not human-hearted" (as Lao Tze put it for the ancient Chinese culture). Critical experiments, the *experimenta crucis* of Francis Bacon,

are necessary. Questions must be put to Nature formulated so as to require a clear distinction between possible outcomes. Feeling at one with Nature does not in itself produce understanding and engineering is a better guide than religion to the behaviour of water. There are obvious practical criteria for judging the success or otherwise of engineering theories. Brian Goodwin has recently given a modern scientific account of the evolution of shapes, influenced by the Goethean outlook. The problem of developing a "language of shape" is being intensively studied by many research groups. Often complex shapes can appear by the operation of very simple rules and the topic has been greatly advanced by the advent of cheap computing. The "life game" invented by J. H. Conway has been of great scientific as well as of popular influence.

The present book by Haeckel appeared in Leipzig in the middle of the Great War of 1914–1918[27] and thus remained obscure. It represents Haeckel's reaction to the discovery of liquid crystals which he connects especially with the Radiolaria resulting from the Challenger Expedition of 1873–76 which he studied, having earlier made himself, through many expeditions, an expert in the questions of the creatures in plankton. In very recent times liquid crystals and Radiolaria are again very active scientific topics and questions of morphogenesis generally are being pursued with the new scientific tools of microscopy, and synthetic and computational chemistry. Liquid crystals are now being used to catalyse the formation of Radiolaria-like structures from silica. "Soft matter" presents hard problems. It is worthwhile to look back at Haeckel's book from our present position partly because of its scientific content but also because it reminds us that the struggle between the scientific and religious views of the world continues and indeed has recently sharpened[28]. It emphasises also the importance of differences for science in the intellectual traditions of Britain and Germany, both different again from that of France. A more lively, and today still very pertinent, discussion in the French tradition, by one of the actual makers of the Enlightenment, is to be found in Denis Diderot's scandalous *jeu d'esprit* "D'Alembert's Dream" (about 1762, but not published until very much later) which deals, inter alia, with the sensitivity of matter. However, the French tradition was not greatly concerned with evolution.

Haeckel's use of the word "soul"[29] excites justified suspicion in a scientific context and, since Haeckel was concerned with opposing his concept of monism to the mind/matter dualism then current, it is probably better to regard Seelen as minds or even programme or organising principle, or blue print, rather than as souls[30] (I have here translated the word soul as psyche[31]). He also uses the words "psyche", "psychom" and "psychomatics". Our modern terminology might try rules of operation, Bauplan, programme, psyche, etc. *Seelenkunde* is still a current, although now old-fashioned German term for psychology and does not necessarily continue theological connotations[32]. Alfred Gierer, a recent exponent of mathematical approaches to morphogenesis, for example, can discuss the soul without embarrassment and it is clear that in German culture "the soul" can relate to mental activities without implications of immortality and religious usage. In Britain the soul seems to remain a serious issue in some places[33]. Haeckel struggled to describe properties emerging as more complex assemblies of atoms organised themselves through their mutual interactions. In this he tried to take over from the Catholic Church the concept and word of "soul" as the organising principle, but the attempt was too presumptuous and the consequent failure simply causes some confusion and suspicion. The concept of the

continuity of all structures in a hierarchy from atoms to mankind permeates the book. Thus, if men have minds and a mental life so, in vestigial degree, do even atoms have mentation[34]. If Haeckel felt that he himself had a "soul" then so must the simplest bacterium. It would be anachronistic to equate the mind of an atom to its wave-function but it is nevertheless a reasonable retrospect. "Soul" is seen as something which accompanies matter. The present-day division into hardware and software is also a possible attitude. Haeckel, as a biologist and naturalist, locked into his particular time and place (as is the case for all of us), applied his experience of structures of his own scale, visible with a microscope of the period, to domains—the microcosmos of atoms and molecules—which only began to become visible with the development of X-ray crystallography (1912) and the electron microscope (our own decade). However, there is no substitute for the actual experimental examination of the relevant structures and phenomena and the aged Haeckel, confined to a Germany locked in the Great War, was unable to do this and could only speculate[35]. The whole position has since been completely changed with the modern understanding of the operation of DNA/RNA , the dialectical[36] relationship between DNA and protein and the whole mechanism of heredity, not in terms of "soul" or "psyche" or such indeterminate concepts, but as carried out by molecular machinery following physico-chemical laws. The components generated by protein synthesis then operate and interact to give the appearance of "Gestaltungskräfte" or the "facultas formatrix". The present-day discussion on the emergence of "intelligence", "soul" and "consciousness" from the complexity of computers is on quite another level but, with the flood of new data, this is proceeding very actively.

Even the Papacy now seems to accept the unity of material nature, living and non-living, being forced back step by step by the advance of science, but still claims the existence of a separate immortal soul. About 25 October 1996 a statement[37] by the Pope (John Paul II) was issued, accepting the reality of evolution of the human body from living matter which pre-dates it, but still claiming jurisdiction over the soul[38]. It is not acceptable to the Papacy for Catholics to believe that "the spirit is also a product of matter". However, the nature of consciousness is one of the areas being now very actively investigated by scientific methods, particularly those, like NMR and PET (positron emission tomography) which enable the living brain to be seen in operation. The soul itself is under investigation[39].

Some of Haeckel's writings appear to be nearly nonsense[40]. Indeed some of his contemporaries, such as Virchow, said as much at the time. However, his descriptions of Radiolaria and single-cell organisms are still fundamental to specialists in this area, although, if much weight is to be put upon specific pictures, modern confirmation would be prudent. Haeckel was a central figure in the development of biology, affecting his scientific and political successors, and it is necessary to try to see what he did. He carried on the discussion, arising from Democritos and Lucretius in classical times, through the Enlightenment when La Mettrie had raised the issue of "Man, a Machine" and Holbach had written "The System of Nature" rejecting any place for God in the operation of nature, to his own period where concepts of evolution had to be assimilated into the general Weltanschauung. Haeckel kept the issues of the origin of life and the processes of evolution before the public eye. He raised questions as to how life could have arisen from non-living systems without a divine spark or a vital principle However, in retrospect, he muddied the discussion by the introduction of mystical concepts uncongenial to the British mind to

which Leibnitz appears unconscionably complicated.

J. D. Bernal, in his book "The Origin of Life" (1967) wrote: "To a scientist of the last century speculating on the origin of life, the first task as he saw it, was to produce something that gave the forms of what seemed to be characteristic of primitive life; to imitate life by means of various precipitates of inorganic or organic substances; to show that even silicates could produce globular and filamentous forms which mimicked many of the features of life as did, for instance, Leduc's algae and mushrooms". This characterised Haeckel accurately and indeed many of his illustrations came from Leduc's book. Today chemistry is concerned with spatial structure and thus with form, as well as with the composition of homogeneous solutions[41]. The episode in the mid 1950s when, following the work of Nagy, Meinschein and Hennesy[42] which reported life-like structures in the carbonaceous Orgueil meteorite, it was thought for a time that life must have existed on other planets, emphasises Haeckel's attention to the life-like products of non-living processes. That this episode is repeating itself in 1996 in relation to artifacts observed in a meteorite originating on Mars, shows that Haeckel's ideas in this respect, were not so fanciful but, not much being then known about the atomic mechanisms, he mistook the external form for the substance. Living systems are immensely more complex than he imagined.

The prospect of finding the non-living mechanisms which produce the forms of life and which are incorporated into living organisms is now much more realistic. Chemistry is now developing from the study of homogeneous solutions, through crystallography, to the study of the formation of much more general and complex spatially ordered structures. Mathematics has recently shown the development of very complex spatial forms from very simple mathematical conditions. Chemistry is now beginning to emulate this and classical crystallography is not enough for dealing with the resultant structures. The quasi-crystal affair has shown the first step away from the tyranny of the formalism of the 230 space-groups of symmetry and Bernal's goal of a "generalised crystallography" is within sight. In 1866 Haeckel, in his "General Morphology of Organisms", called for a "crystallography of organic forms", but this was a premature aim and was too narrow a perspective. With the formation of inorganic structures around liquid-crystal templates, we perhaps even see the beginnings of an informational system, although, with the atomic force microscope and its derivatives, the human informational system has now penetrated to the atomic level. Concern with structure passes to concern with process and on to the information which defines the route of the process. In any case, we believe that the theoretical tools for handling the "form problem" are now developing rapidly. Ideas arising from geometrical structure now meet those coming from the study of complexity. The interface between mathematics and chemistry is proving as important and as complex as that between oil and water. Computer science has even adopted the genetic algorithm (where a mathematical structure alternates dialectically with its description, like protein sequence and gene) for searching configuration space. Evolution by variation and mutation followed by natural selection now takes place *in vivo, in vitro* and *in machina*[43].

Biology could not have become the science it is today until the properties of atoms and molecules had been investigated. Science has its own structure and some parts have to be unwrapped before others. Newton's researches into chemistry were fruitless because the groundwork was simply not then available. Lavoisier had not then carefully weighed and measured chemical reactions. Newton could elucidate the mechanics of the solar system

from the measurements then available, but the behaviour of chemicals was at a level then inaccessible. (Isaac Newton, having determined "the motions of the planets, the comets, the Moon and the sea", was unfortunately unable to determine the remaining structure of the world from the same propositions because) (as he said) "I suspect that they may all depend upon certain forces by which the particles of the bodies, by some causes hitherto unknown, are either mutually impelled towards one another, and cohere in regular figures, or are repelled and recede from one another. These forces being unknown, philosophers have hitherto attempted the search of Nature in vain, but I hope the principles laid down will afford some light either to this or some truer method of philosophy" (Preface to the Principia ...). Haeckel also knew nothing about chemical bonding and, therefore, also could make little progress.

The dialectic interaction between the genetic material and the protein molecules which perform the actions necessary for life is now apparent and we understand many of the processes of molecular evolution. A topic of immediate interest is how the solid-state reactions of inorganic chemistry interact with the biochemical pathways of living material. Even in the field of mathematics there is great activity, promoted by the increasing availability of computer graphics, in the geometrical patterns which can be generated by conditions suggested by chemistry. Biochemistry has profited by the attention of engineers to the mechanics of DNA helices, lipid vesicles, foams, shells, ropes and fabrics which, after all, are just engineering structures on a small scale.

Haeckel was living in a time of religious belief which has not yet died away, as might have been expected with scientific knowledge and the increasing connectivity of different cultures. Religions are now engaged chiefly on the social and political fronts and science is largely left to the scientists except when science, as for example with the invention of an oral contraceptive, intrudes into domains where religions claim authority. Science still represents the world outlook of only a small minority[44]. Indeed the popular understanding of the technological bases on which our civilisation stands is decreasing and claims are pressed for equality between rationality and irrationality. We have witnessed the rise of "creationism" and Christian, Jewish and Islamic "fundamentalisms"—not to mention faiths and cults categorised even by these groups as "superstitions"—in the face of the increasing uncertainties of the modern world. Haeckel's opposition to religion was only one of his driving motivations and he did not offer a completely materialistic view of living matter.

Like Wilhelm Ostwald[45] and later Fritz Haber[46], Haeckel was strongly involved in political activities[47], many of which would now be considered reprehensible. He was a creature of his place and time[48], which lay between the appearance of the Imperial German state and the take-over of Germany by the Nazi Party. Nationalism was in the air. Ostwald said, at the beginning of the First World War, "We or rather the Germanic race, have discovered the factor of organisation. Other peoples still live under the regime of individualism, whereas we live under the regime of organisation". That the strand of German culture which encouraged "Blut and Boden" and "thinking with your blood" led through Haeckel[49] should not lead to his retrospective condemnation. Germany is still one of the few countries which defines nationality genetically ("by blood") and people born in Germany are not automatically German citizens. However, although aware of this side, just as we are aware of the genocidal crimes of Western 'Civilisation', we will neglect this and

concentrate on Haeckel's concerns with morphogenesis. The decisions to promote and finance physical and ideological weapons are taken by politicians[50] not scientists. The views, for example, of Haeckel's contemporary Friedrich Engels (1820–1895), on Darwinian evolution and its social implications, as evinced by his "Dialectics of Nature" (published only very much later) show that there were several quite different traditions which co-existed with Haeckel's. Sociobiology today has inherited elements from both these traditions.

It is a feature of the present period that exponential increase in human population of the Earth is, with increasing inter-communication, becoming apparent to most of the inhabitants of the Earth and is producing friction and competition which cannot always be avoided as before by migration. We are not concerned here with the ways in which groups in human society appear and categorise themselves and others or with the various scenarios which may be envisaged as ending the exponential growth characteristic of the expansion into an ecological niche. Haeckel promoted the concepts of evolution for his own ends. The eugenic movement cannot be understood without his contribution and the problems of world population, for example, are still very topical and ever more pressing. Sooner or later eugenic decisions will again have to be taken[51]. Sociobiology raises material issues which cannot be deconstructed away. The concept of altruism, which appeared in arguments against over simple interpretations of Darwin, can now be formulated and demonstrated in quantitative form[52]. Real scientific understanding is steadily improving and environmental movements have increasingly a solid basis. That evolution takes place in populations of bacteria and of insects has implications for human ecology.

Charles Darwin summed up his exposition of evolution, driven by "superfecundity", in the last paragraph of "The Origin of Species" (6th. Ed., 1872): "these elaborately constructed forms, so different from each other, and dependent on each other in so complex a manner, have all been produced by laws acting around us. These laws, taken in the largest sense, being Growth and Reproduction.; Inheritance which is almost implied by reproduction: Variability from the direct and indirect actions of the conditions of life, and from use and disuse: a Ratio of Increase so high as to lead to a Struggle for Life, and as a consequence to Natural Selection, entailing Divergence of Character and the Extinction of less-improved forms. Thus, from the war of nature, from famine and death, the most exalted object which we are capable of conceiving, namely, the production of the higher animals, directly follows."

Thus the predictions of Malthus[53] remain with us and, although human beings now have the knowledge and ability to avoid the struggle for existence[54], there is little sign yet that we will be able successfully to escape from it. Socialism is a concept whereby human beings can collectively escape from the struggle with each other for existence but the present global economy requires from us competition rather than cooperation and socialism must remain in abeyance until it is rediscovered in a more satisfactory form than that of the Soviet Union. The timescale of the population explosion, a doubling time of 30 years, is instantaneous in comparison with the period of evolution of the plants and animals and their exquisite inter-relationships. Only bacteria can evolve faster. The problems of eugenics, bio-technology, genetics[55] and population limitation remain to be confronted. The situations in India and China make it urgent and the collapse of the USSR has shown that the four horses of the Apocalypse are still waiting only for an opportunity[56].

Evolution through natural selection is undoubtedly the most powerful concept for understanding ourselves and our place in the universe. This has been given a new twist by John Maynard Smith and Eörs Szathmáry (Nature 14 Nov. 1996) who as biologists envisage the consequences of the evolution of cosmology through the variation and competition of black holes. Thus ideas of evolution, developed from a consideration of the meso-cosmos of human life, can be extended upwards to the macrocosmos and even down to the microcosmos, since David Mermin says: "It is because nothing required us to apprehend atomic structure during our evolutionary development that we are incapable of understanding what it is that quantum physics describes" (Nature). There is still more mileage in the concepts of evolution through natural selection and important intellectual movements[57] are still trying to discredit it.

Haeckel is much more readily characterised as a field naturalist than as a scientist. He collected, observed and systematised and his phyletic trees and his classifications remain useful[58]. He had learnt crystallography (reported to be his weakest subject) from C. S. Weiss (Berlin) (of the "Weiss zone law") and later L. Sohncke was his colleague in Jena, but his handling of physical science was anecdotal rather than quantitative. We have only to compare Haeckel's vestigial ideas of crystallography with the great textbook of Paul Groth, "Physikalische Krystallographie"[59] (Leipzig, 1895) to see how far Haeckel was from the forefront of German physical science, which then led the world in this as in other fields. Serious crystallographic studies of the Radiolaria and such organisms are now in progress, but the marvel of their construction is increased rather than diminished. Haeckel seems not to have designed and executed much in the way of critical experiments which would have decided between one theory and another[60] and he was also averse towards mathematical analysis. He named things and coined words in great profusion. There are some 300 references to Haeckel in the Oxford English Dictionary. A few of his coinages, especially the word "ecology" have stuck. Most others died with him. Unfortunately his secondary schooling in Merseburg had emphasised Greek and Latin above mathematics and that above natural science, so that his writings are overloaded with neologisms which conceal rather than promote understanding. Naming is stamp-collecting and pre-science but much of biology was at that stage of development and names were needed for objects and processes.

Haeckel himself admitted (with reference to the language of his "General Morphology") that, the style "makes the overloading with neologisms, the sharp polemic and the strongly eccentric tone of the often personal and ill-judged attacks, something less than attractive"[61]. T. H. Huxley and Charles Darwin set out to translate the "General Morphology" into English, omitting the whole philosophical part and the various polemics, but this English edition never appeared. Edwin Ray Lankester[62] (one of the two Fellows of the Royal Society to attend the funeral of Karl Marx), although a fluent German speaker, also suffered pains in the translation of Haeckel's "Generelle Morphologie", but the book was then thought to justify the labour expended upon understanding it. It is indeed opaque and unrewarding although Huxley had said that it was one of the greatest scientific works ever published[63].

The sad saga of the last years of Linus Pauling and his pursuit of universal remedies is a modern reminder of the effects of age on him, on Haeckel and, in due course, on all of us. Haeckel died of influenza in the pandemic[64] of 1919 following the end of the Great War.

He had written nationalist polemics in condemnation of Britain for forcing Germany into the disastrous war for "Lebensraum"—territory in France, Russia and Africa. During that war he had, like almost everyone else, been carried away by the flood of tribal enthusiasms but was appalled by the slaughter and saddened that his country and that of Darwin were enemies. The present book, since it was published in Germany in the middle of the Great War, did not circulate widely and has not been translated or been seriously discussed before. The topic of liquid crystals, with which it deals, is now, however, most topical both in the technical and in the biological fields. It is indeed seen as one of the keys to morphogenesis.

We see in science the steady replacement of mystical notions by concrete physical mechanisms. About 1950 Grey Walter demonstrated his rather simple electro-mechanical tortoises which, especially considering that they had only a few "tropisms" (move towards a light; reverse away from a touch; choose a random direction, for example) showed remarkably complex and unpredictable behaviour. They recall the popular complaint: "this supermarket trolley has a mind of its own". Grey Walter's tortoises, (which he called "machina speculatrix"), not unlike supermarket trolleys, had vestigial minds of their own. Richard Gregory marvelled that so little information could produce so much behaviour. Since then, with the availability of enormous numbers of circuit elements in computers, the behaviour of automata has become more elaborate and questions of the emergence of intelligence, mind, consciousness and self-consciousness become more pressing. There is a convergence too with the improving understanding of actual biological brains from those of the smallest organisms to the largest. The whole wiring diagram and the whole course of development of every cell in Caenorhabditis elegans (a very small nematode worm) has now been worked out. It carries through its whole life cycle with a brain of some few hundred neurons. The concerns of philosophers and psychologists are becoming outflanked by molecular biology and actual experiments and observations on sub-systems of the brain. The mind/matter dualism is disappearing. The mystical outlooks of C. G. Jung and Sigmund Freud on the soul/brain/mind/psyche area are at last slowly being replaced by proper science as methods of access to its workings develop[65]. Peter Medawar, rather cruelly, suggested that "psychoanalysis... is an end product, like a dinosaur or a zeppelin; no better theory can ever be erected on its ruins which will remain for ever one of the saddest and strangest of all landmarks in the history of twentieth century thought". The theories of Jung, Freud and Haeckel as regards the soul or psyche predict nothing, are not subject to experimental verification and are thus only peripheral to science.

When in 1934/35 Joseph Needham and others of the Club for Theoretical Biology in Cambridge drew up proposals to the Rockefeller Foundation for the establishment of an Institute for Physico-Chemical Morphology, they foresaw the application of physical methods in biology and the creation of molecular biology with a prescience which has left their manifestos still a source of stimulation[66]. In these proposals J. D. Bernal also saw liquid crystals as the key example of purely physical self-organising structures which were "used" in biological systems. Even earlier, Wilhelm Roux, whose ideas Needham developed, wrote of "The developmental mechanics of organisms, an anatomical science of the future"[67]. Real science is now developing rapidly on these lines and morphogenesis is a fashionable topic but Haeckel's book still possesses some interest as a specimen of the thought of its time and place.

In the socio-political field, not to mention the media, there are many groups in positions of power who have active interests in preventing people in general from understanding the operation of the world, not that they really have this understanding themselves, so that deceptions and concealment of all kinds of knowledge are being steadily propagated[68]. Education and information (and their opposites, obscurantism and dysinformation) are weapons in the struggle for power. Haeckel's career is an intriguing mixture of scientific and mystical elements interacting with the hard realities of political power, so that it still has many lessons for us. Haeckel's mode of thought and its relation to material facts is fortunately one which has largely died out in the scientific world, but not in the political world. The influence of C. G. Jung (1885–1961) and of Sigmund Freud (1856–1939) which was of the same type is fortunately also decreasing[69] although the mystification caused by the more recent deconstructionists increases the confusion between the real world and the imagined world to the benefit of those who try to manipulate us. Nevertheless, Haeckel was a serious enemy of superstition and especially of the Roman Catholic Church so that, particularly in Germany where there is a Blasphemy Section (section 166) of the Criminal Code, information about him has been suppressed and distorted. He wrote: "Enlightenment and education remain the mightiest weapons (against the Church); the safest way to achieve them is the unprejudiced study of and knowledge about nature and especially of its most recent and most magnificent fruit—the theory of evolution. When, during this fierce fight, the shout 'Peoples of Europe, safeguard your highest possessions' is to be heard in our days—to us, from our standpoint, this can only mean defending reason against superstition" (1907, Postscript to 10th. Ed. of The Riddle of the Universe).

On the scientific side, Haeckel over-emphasised his "basic biogenetic law"—ontogeny recapitulates phylogeny[70], but this is still a topic for controversy[71]. S. J. Gould has devoted a whole book to the problem and there is a huge literature. Haeckel greatly underestimated the complexity of the protoplasm and his equation of protoplasm with liquid crystals was invalid. His style of propagating science was polemic and partisan. He made a bad mistake, through carelessness or over-enthusiasm, and used the same pictures for three different embryos and seems not to have withdrawn or apologised. This contrasted badly with the modesty and self-criticism of Darwin, who wrote in his Autobiography: "I had, ... during many years, followed a golden rule, namely, that whenever a published fact, a new observation or thought came across me, which was opposed by general results, to make a memorandum of it without fail and at once; for I had found by experience that such facts and thought are far more apt to escape from memory than favourable ones".

J. W. V. Goethe (1749–1832) was one of Haeckel's heroes[72], and he is still claimed, with considerable exaggeration, as having been one of the last to be a master of all knowledge, before our culture fragmented, but his place in the history of science is, in fact, rather slight. The liquid crystal episode and Haeckel's last book, are mainly of importance for the light cast on the different modes of thought of different cultures[73] at different times. Crystallography is an apparently harmless subject concerned with the forms of crystals, but in fact research on crystals has now led, most notably through the discovery of the double helix of DNA, to a new, more adequate, understanding of ourselves and of the real world outside, different from that dreamed up by philosophers, theologians and literary people. We have neglected Haeckel's political activities. But just as religious ceremonies carried

out by an immoral priest are deemed still to be valid, so research by a scientist is also not invalidated by his personal character and beliefs. In the case of science validation rests on other criteria, principally on replicability. The test of truth in science is that any other interested person, furnished with the appropriate physical and intellectual equipment, should come to the same results. This distinguishes scientific "truth" from religious "truths" deriving from anecdotal and non-replicable "revelation" to apparently privileged people.

Altogether, Haeckel's contribution was to draw attention to the regularities of natural structure and to ask for rational explanations. He asked how life could have arisen on Earth and looked for a non-religious answer. He actually discovered thousands of new organisms in the realms opened up by his Zeiss microscope. He identified the "form problem", but liquid crystals were only the simplest example of self-organisation and did not take the solution very far. He called for "a crystallography of organic forms", but admired the system of crystallography rather than the understanding of structure underlying the systematisation and thought of structure like an old-time grammarian, rather than like an engineer. He realised that in the growth and evolution of organisms some kind of dialogue between organised matter and organising principle was necessary, but sought the organising principle from the domain and vocabulary of religion, rather than from the material world. His analogy with the dialogue between kinetic and potential energy was perceptive. He must have seen that structure is not self-sufficient and that structure must related dialectically to description. Haeckel's emphasis on the unity of nature (including mankind) was certainly correct, but then few people could have doubted it.

The material nature of the necessary description did not become clear until 1953 with the double helix and the demonstration that both structure and description were made of the same atoms subject to the same laws of chemistry. Software is ultimately also material. Paradoxically Haeckel called his philosophical outlook "monism", because he wished to dissociate himself from the body/soul dualism of the Christian religion, but he expressed himself continually in terms of the dualism between structure and soul, which we have here transcribed as "psyche" to distinguish the concept from that of the Christian soul. In November 1997, for example, the complete genome sequence of the bacterium Bacillus subtilis, the immortal "soul" with 4,214,810 base pairs, which controls its structure and its life cycle and embodies its evolutionary history was published. Knowledge of the human genome, the human soul, cannot be far behind. The crystal soul was only the first idea.

REFERENCES

Anderson, O. R. (1983) *Radiolaria*, Springer, New York.
Bernal, J. D. (1967) *The Origin of Life*, Weidenfeld and Nicolson, London.
Cairns-Smith, A. G. (1996) *Evolving the Mind*, Cambridge University Press.
Crick, F. C. (1990) *The Astonishing Hypothesis: The Scientific Search for the Soul*, Simon and Schuster, London.
Demus, D. and Richter, L (1980) *Textures of Liquid Crystals*, 2nd. Ed., VEB Deutsche Verlag f. Grundstoffindustrie, Leipzig.
Desmond, A. *The Politics of Evolution.*
Desmond, A. and Moore, J. (1991) *Darwin*, Michael Joseph, London.
Diderot, D. (1966) *D'Alembert's Dream*, (trans. L. W. Tancock), Penguin Classics.
Driesch, H. (1905) *Der Vitalismus als Geschichte und als Lehre*, J. A. Barth, Leipzig.
Driesch, H. (1909) *Philosophie des Organismen* (2 vols.), Wilhelm Engelmann, Leipzig.

Engels, F. (1954) *Dialectics of Nature*, FLPH, Moscow.
Gasman, D. (1971) *The Scientific Origins of National Socialism*, Macdonald, London.
Gellner, E. (1992) *Postmodernism, Reason and Religion*, Routledge, London.
Gierer, A. (1985) *Die Physik, das Leben und die Seele*, Piper, München.
Goodwin, B. C. (1994) *How the Leopard Changed Its Spots*, London.
Gould, S. J. (1977) *Ontogeny and Phylogeny*, Belknapp Press, Harvard University Press, Cambridge, Mass.
Greenfield, S. A. (1995) *Journey to the Centre of the Mind*, W. H. Freeman, New York.
Gregory, R. L. (ed.) (1987) *The Oxford Companion to the Mind*, OUP.
Haeckel, E. (1866) *Generelle Morphologie der Organismen* (2 vols.), G. Reimer, Berlin.
Haeckel, E. (1929) *The Riddle of the Universe* (translated by Joseph McCabe), The Thinker's Library, Watts, London.
Hildebrandt, S. and Tromba, A. (1996) *The Parsimonious Universe: Shape and Form in the Natural World*, Springer.
Krausse, E. (1984) *Ernst Haeckel*, BSB B. G. Teubner, Leipzig.
Leduc, S. (1910) *Théorie physico-chimique de la Vie*, Translation into English by W. D. Butcher, "The Mechanism of Life", Rebman Ltd., London (1911).
Lester, J. (1995) E. Ray Lankester and the Making of Modern British Biology (ed. P. J. Bowler), British Society for the History of Science.
Mann, S. and Ozin, G. A. (1996) Synthesis of organic materials with complex forms, *Nature*, **382**, 313–318.
Mermin, D. (1996) Review of *Beyond Science* by J. Polkinghorne, CUP, 1996, 131 pp., *Nature*, **383**, 772.
Needham, J. (1936) *Order and Life*, MIT Press, 1968.
Oliver, S., Kuperman, A., Coombs, N., Lough, A. and Ozin, G. A. (1995) Lamellar aluminophosphates with surface patterns that mimic diatom an radiolarian microskeletons, *Nature*, **378**, 47–50.
Pettigrew, J. Bell. (1908) *Design in Nature* (3 vols.), Longmans Green, London.
Raff, Rudolf. A. *The Shape of Life: Genes, Development and the Evolution of Animal Form*, Chicago University Press.
Richardson, M. K. (1995) Heterochrony and the Phylotypic Period, *Developmental Biology*, **172**, 412–421.
Richardson, M. K., Hanken, J., Gooneratne, M. L., Pieau, C., Raymond, A., Selwood, L. and Wright, G. M. (1997) There is no highly conserved embryonic stage in the vertebrates: implications for current theories of evolution and development, *Anat. Embryol*., **196**, 91–106.
Smith. J. Maynard and Szathmáry, E. (1996) On the likelihood of habitable worlds, *Nature*, **384**, 107.
Thompson, D'A. W. (1916) *Growth and Form*, 2nd Ed., 1942, 2 vols., Cambridge University Press.
Wilcock, J. R., Perry, C. C., Williams, R. J. P. and Mantoura, R. F. C. Crystallographic and morphological studies of the celestite skeleton of the acantharian species Phyllostaurus siculus, in *Proc. R. Soc. Lond*., **B233**, 393–405 (1988) and **238**, 223–233 (1989), **238**, 203–221 (1989).
Report of the ÖVoyage of H.M.S. Challenger, HMSO (1887) (Zoology, Vol. XVIII, 2 vols + vol. of plates.)
Urey, Harold C. *et al.* (1962) Life forms in meteorites, *Nature*, **193**, 1119–1133.

Notes

1. For the present day position in this field, which prompted me to look back at Haeckel, see a review by Stephen Mann and Geoffrey A. Ozin, *Nature*, **382**, 313–318 (25 July 1996).
2. (*In the eternal silence of a crystal they may see the happenings of the world outside*)
3. Drawings in the first part of Haeckel's *Die Radiolarien* (1862) are due to Wagenschieber and seem to have been made with the impression that a mesh of hexagons could cover a spherical surface. In later etchings acknowledged to Giltsch this mistake does not seem to occur.
4. Stimulated by Haeckel's drawings of Radiolaria, a 25m span geodesic dome was constructed for the Zeiss Planetarium in Jena (Haeckel's home town) in 1925/26 (first version 1923), long before Buckminster Fuller. It survived the air-raids. The metal framework was embedded in concrete, only 6cm thick, so that the steel network became invisible. Similar domes had been built in various cities, including Chicago (1930) by the Zeiss-Dywidag System. See, for example: "Jena und Umgebung", VEB Tourist Verlag, Berlin-Leipzig (1977), p. 83.
5. The charisma of crystals in biology, J. Lorch, in *The Interaction between Science and Philosophy*, ed. Y. Elkana, Humanities Press, 1975.
6. For example: G. W. Gray, Molecular Structure and Properties of Liquid Crystals, Academic Press, New York, (1962). One of the key substances, p-azoxyanisole, was studied by J. D. Bernal and D. Crowfoot (*Trans. Faraday Soc*., **29**, 1032 (1933)) (and later in more detail by other workers in the Crystallographic Laboratory of Birkbeck College, London, so that concerns with liquid crystals were always present there). C. H. Carlisle and C. H. Smith, The structure of p-azoxyanisole, *Acta Cryst.*, **B27**, 1068–1069 (1971).
7. ... and the "cold fusion" people!
8. Es wird ein Mensch gemacht. / ... nun lässt sich wirklich hoffen, / Dass, wenn wir aus viel hundert Stoffen / Durch Mischung—denn auf Mischung kommt es an—/ den Menschenstoff gemächlich komponieren (A human being in the making ... Look, There's a gleam—/ Now hope may be fulfilled, / That hundreds of ingredients, mixed, distilled—/ And mixing is the secret—give us power / The stuff of human nature to compound;—Faust, II.ii. trans. Philip Wayne). Today's Nature (27. 2. 97) brings news of a sheep cloned from a single mature cell!
9. *Methanococcus jannaschii* has 1738 genes for living purely from non-living material. (M. W. Grey, *Nature*, **383**, 299–300, 26 Sept. 1996).
10. Structures with dimensionalities, 0,1,2 and 3 respectively.
11. Haeckel is sometimes accused of believing in the spontaneous generation of life (discredited by experimental work in the mid-19th century). He did indeed believe, as is generally believed among scientists in the present period, that life on Earth had at one time in the remote past evolved from non-living matter, but did not, I think, believe that life arose easily in everyday conditions.
12. It is worthwhile to reproduce *in extenso*, Pettigrew's footnote about Otto Lehmann:

    "Professor O. Lehmann, at a concourse of German physicians and physicists held at Stuttgart, endeavoured to prove that no hard and fast line can be drawn between the living and the dead. He contended that crystals of numerous substances showed all the characteristics of life as revealed in certain of the lowest organisms; that substances which crystallise do so in a specific form and resemble many plants; that crystallisation requires a germ to start with; that some crystals are capable of growth, while others poison themselves by absorbing substances contained in the medium investing them. He challenged the statement that living things are always fluid or partially so, and that crystals are invariably solid. In support of this last proposition he maintained that liquid crystals can now be produced, and that as many as fifty varieties are already known. Those of soft soap afford a good example. Professor Lehmann directed attention to some remarkable crystallic forms occurring in viscous fluids which, under the microscope, are seen to be in a state of constant motion; others being found in clear fluids each drop of which consists of a crystal; a third form resembling a bacterium where the crystals are linked together and occasionally exhibit spiral serpentine movements. These after a time are said to break up and re-form after the manner of bacteria. The views of Professor Lehmann have, of course, to be subjected to the most severe criticism on the part of physicists and biologists before they can be accepted as forming even the basis of a working hypothesis." Pettigrew, I, p. 181.

    This account is significant in that it indicates that it was Lehmann and not Haeckel who originated the idea of living crystals.

13. The expression due to Johannes Kepler emerging from his consideration of the "The six-cornered snowflake" (1611 and Oxford 1966) and his explanation of the shapes in terms of the packing of atoms. Haeckel coined the term "molethyn" to correspond roughly with the "*facultas formatrix*".
14. Pettigrew was a distinguished and honoured member of society in his time but his scientific work is now forgotten. It is, however, astonishing that his religious view are still shared by the principal leaders of the states of America, Britain and Germany. For example, Mrs Margaret Thatcher, despite her scientific education in Oxford, declared to the General Assembly of the Church of Scotland that "We were made in God's image" (Guardian, 23 May, 1988), almost Pettigrew's belief, although Pettigrew, while attributing creation to a Creator, did not go so far as to suggest that the Creator had a human image. Nowadays, almost all scientists, except those brought up in America and in theocratic Islamic states, believe that God was created by man in his own image as an instrument of social administration.
15. "Haeckel's wild speculations are not supported by even a tittle of evidence which is worthy of the name" Pettigrew, I. p. 202.
16. His collection of dissections, preserved in jars of formalin and alcohol, went to the Royal College of Surgeons but was probably destroyed in the air-raids of the second World War.
17. Haeckel answered "die Gretchenfrage" (Margarete's question to Faust) "Glaubst du an Gott?" (do you believe in God?") with a much more decisive "no" than did Faust. Haeckel deduced that God must be a "gaseous vertebrate".
18. Joseph Needham's comment is relevant: ".. the characteristic European schizophrenia or split-personality. Europeans could only think in terms either of Democritean mechanical materialism or of Platonic theological spiritualism. A *deus* always had to be found for a *machina*. Animas, entelechies, souls, archaei, dance processionally through the history of European thinking." Science and Civilisation in China, II. p. 302. Needham sees Leibnitz (ibid. p. 498 et seq.) as a bridge-builder reconciling theological idealism with atomic materialism into an "organicism" congenial to biologists.
19. Some of these had serious foundations. E.g. *kobolds* had bewitched the ore and turned silver into cobalt; *Wechselbalg* a changeling, was a defective child probably with Down's syndrome.
20. In the Carl Zeiss Stiftung, Jena had a unique scientific/industrial complex (making optical equipment) where science, industry and labour cooperated, and shared in the profits of the enterprise. Ernst Abbe developed the theory of the resolving power of the microscope and developed other inventions which made this scientific industry the world leader in the field. The Jena glass works (Jenaer Glaswerkes Schott & Gen. opened in 1884) was also famous.
21. Modern heretical letters, political as well as religious, Ketzerbriefe, are published by Ahriman Verlag, PO Box 6569, D-79041 Freiburg with an internet site at http://www.ahriman.com
22. "Der Mensch schafft Gott nach seinem Bilde" (Generelle Morphologie, p. 174, 1866).
23. Theosophy was a strong organisation then and built the building which is now the headquarters of the British Medical Association. We may recall also Madam Blavatsky's "Occult Chemistry".
24. Ashis Nandy, "Alternative Sciences" (2nd. Ed.), Oxford University Press (1980/1995).
25. It is not necessary to document the rise of mysticism in modern society but one could point to the astrology, prevalent even in the highest circles in America and to the "metaphysical stores" selling magic crystals, to the "holistic" and "alternative" medicines, etc.
26. R. Sheldrake, "The Rebirth of Nature" (1990), quotes Haeckel, Goethe, etc. Sheldrake's postulated morphogenetic fields are not unlike the concepts of Haeckel associated with the "soul" and with "molethyn" the latter being seen as a special force to account for self-organisation in liquid crystals. Sheldrake's example of "morphic resonance" in crystals is dealt with in the paper by J. D. Dunitz and J. Bernstein, "Disappearing polymorphs", *Acc. Chem. Res.*, **28**, (4), 193–200 (1995).
27. "Grandfather, who won the war?" "It is too early to say" (Guardian, 1997).
28. I happen to have (Old) Moore's Almanack for the year 1828. The monthly observation for July reads: "Much has been said by my predecessors about the downfall of the Pope, and I have, accordingly been very assiduous in my endeavours by inspecting the aspects and positions of the stars for the present year, which are the basis from whence the structure in judgment is to be raised; and I have, moreover, made use of the best glasses in my possession; yet such is the weakness of my intellects, that I cannot see one glimpse of the downfall of the Pope, at least for the present. Indeed the Pope is a subtle, sturdy old fellow; if he sinks he will not go down far; if he staggers, he will not fall."
29. The Encyclopaedia Britannica (9th. Ed., 1910), contains a long article "Metaphysics" (**19**, 225–253) by

Thomas Case, evidently himself a believer in God, which lays out the various viewpoints of the time, including that of Haeckel and people he quotes.

30. We may think of Bernard Shaw’s play “Misalliance” where Tarleton says: “I’ve got a soul: dont tell me I havnt. Cut me up and you cant find it. Cut up a steam engine and you cant find the steam. But, by George, it makes the engine go”.
31. Joseph McCabe who translated “The Riddle of the Universe” (Thinker’s Library, 1929) uses the word **soul** throughout.
32. Gustav Theodor Fechner (1801–1887) also wrote about the soul in: “Nanna, oder das Seelenleben der Pflanzen” (1848) and “Über die Seelenfrage” (1861), although his book “ Elemente der Psychophysik” (1860) was very influential and founded the influence of the exact sciences in psychology. See the essay on Fechner by E.G. Boring in “The World of Mathematics”, (2) 1148–1166 (1956).
33. Nature (**386**, 567, 10 April 1997) notes a new edition of “The Evolution of the Soul” (Revised Edition), Richard Swinburne, Oxford University Press, 1986/1997 quoting the author as saying “mental states are states of a soul, a mental substance in interaction with the body”.
34. Freeman Dyson wrote much more recently: “But I, as a physicist, cannot help suspecting that there is a logical connection between the two ways in which mind appears in my universe. I think our consciousness in not just a passive epiphenomenon carried along by chemical events in our brains, but is an active agent forcing the molecular complexes to make choices between one quantum state and another. In other words, mind is already inherent in every electron, and the processes of human consciousness differ only in degree but not in kind from the processes of choice between quantum states which we call ‘chance’ when they are made by electrons. “*Disturbing the Universe*”, Harper and Row, New York, 1979.
35. He also wrote about the war.
36. A. J. P Taylor explained Hegel’s development of dialectics: “he laid down how change came about. A principle or idea—the thesis—was challenged by its opposite—the antithesis. From their conflict there emerged not the victory of one side or the other, but a combination of the two — the synthesis.. Hegelian philosophy was a stroke of enlightenment. For the first time thinkers made their peace with movement instead of insisting on a static universe. They were in fact fumbling towards the idea of evolution, which was perhaps the greatest creative idea of the nineteenth century” (Introduction to “The Communist Manifesto”, Penguin, London, 1967).
37. Available from the Internet on the Vatican Web Site http://www.vatican.va.
38. “Q. What is the Soul? A. The soul is a living being without a body, having reason and free will.” The Roman Catholic Catechism (qu. Francis Crick).
39. A dramatic episode has been described by Dannie Abse. During brain surgery on a conscious patient, when a particular area of the brain was stimulated, the patient cried out “leave my soul alone” (see: “Poems of Science”, ed. John Heath Stubbs and P. Salman, Penguin (1984), p. 297). “The Oxford Companion to the Mind”, edited by Richard Gregory (OUP 1987) provides a wide-ranging modern exposition of views and facts on the mutual relationships of mind, brain, soul and body.
40. The word *biopoesis* (which suggests an associated word *biopoetry* which might be applied to much of Haeckel’s work) was coined by N. W. Pirie, (Discovery, **14**, 238, 1953). When dealing with books which are apparently mystical rubbish we have to ask “what are these people really talking about?” For example, the Tibetan books, the Tanjur and Kanjur, appear to be nonsense but it has been shown that some of the accounts are in fact about the behaviour of mercury and sulphur while the authors had no appropriate vocabulary for the description and had to use words from the domains of religion and sex. The same is the case for many books about alchemy. Haeckel did not have our present-day vocabulary of concepts such as: “information”, “software”, “programme”, let alone the mathematical descriptions of chemical bonding. I. A. Richards wrote in “Science and Poetry” (1926). “Nobody before Sir Ronald Ross knew what the consequences of thinking about malaria in terms of influences and miasmas instead of in terms of mosquitoes”—Haeckel was just emerging from the Magical View of the World, discussed by Richards, and the age of “malaria”, “influenza” and “miasmas”.
41. A recent important Royal Society Discussion meeting dealt with biominerals: Phil. Trans., RS London, **B 304**, 409–588 (1984).
42. B. Nagy, W. G. Meinschein and D. J. Hennesy, Ann. N.Y. Sci., **93,** 25–35 (1961).
43. Eduardo Mitrani’s phrase.
44. Atheists, (like the present author), who deny the existence of God(s), have to explain why they are in a

minority and point to the frequency with which religious affiliations are apparently inherited. This indicates that children do not have a free choice but are imprinted, in the manner explored by Konrad Lorenz, with the views of their parents. It takes considerable work and thought to escape from this imprinting. The case of Salman Rushdie shows the physical sanctions applied to apostates. The value of religious affiliation for the survival of individuals and societies is obvious but does not have any connection with the truth or otherwise of the doctrines imprinted. Charles Darwin knew this: "Nor must we overlook the probability of the constant inculcation of the belief in God on the minds of children having an effect that makes it difficult for them to throw off a belief in God, as for a monkey to throw off its instinctive fear and hatred of a snake" (seems not to be in Autobiography). Ernest Gellner (1992) has stated a point of view to which I can completely subscribe.

45. "Die Welt der Form, Entwicklung und Ordnung der gesetzlichschönen Gebilde, gezeichnet und beschrieben von Wilhelm Ostwald, 4 vols. Leipzig, 1922–1925. Ostwald was an active member of the Monist League, but was also concerned with **form** and many other topics.
46. The divisional history of the 15th Scottish Division, mentioned in the later footnote, quotes the divisional GS diary for July 1917: "On July 19 the enemy introduced a new form of "frightfulness" — to wit, "mustard gas". On the 13th the following entry occurs in the Fifteenth G. S. Diary: "At night, between 10 p.m. and 1 a.m., between 3000 and 4000 gas-shells were fired against battery positions, causing many casualties" Fritz Haber was the chief originator of the use of gas which was first released on the Western Front on 22 April 1915. The conflicts between duty to Germany and to humanity in general must have been enormous and the night before the first gas attack Haber's wife committed suicide.
47. Pettigrew reminds us that in 1904 Arthur Balfour, a noted politician who became Prime Minister of Britain, gave the Presidential Address to the British Association for the Advancement of Science on "Reflections Suggested by the New Theory of Matter". In those days the professions of politics and of science overlapped far more than they do today. For example, Marx and Engels feuded with Lord Kelvin and P. G. Tait on the scientific question of the tides raised by the Moon. Intellectuals then were supposed to be *au fait* with both cultures.
48. In many ways it was a remarkable time, with many key people in contact with each other, for example: Darwin (1809–1882); Haeckel (1834–1919); E.Ray Lankester (1847–1929), Marx (1818–1883); Spencer (1820–1903); Engels (1820–1895); Schorlemmer (1834–1892); Maxwell (1831–1879); Virchow (1821–1902); Wallace (1823–1913); Kelvin(1824–1907); Babbage (1791–1879).
49. This book by Haeckel was published in 1917 when my father was a lieutenant in the 11th Argyll and Sutherland Highlanders in Belgium on the Western Front taking part in the disastrous Battle of Ypres ("Third Ypres") against the German Army. In his war diary he wrote (for 22 August 1917): "Zero hour was at 4.45 a.m. and was a sight I will never forget. God knows how anybody got over at all" He never did forget the sight and made sure that I should not forget either so that I must mention it here. The official history of the 15th Scottish Division, writing about the attack on 22 August 1917, where whole companies disappeared in the mud: "On the right the fate of the leading companies of both the 13th Royal Scots and the 11th A & S Highlanders will never be known". My father noted in the margin "They perished, nearly all" That the peoples of Britain, Germany, France and Russia could suffer such things has left Europeans with a profound distrust of German militarism The Germans are an enduring problem and something like Desmond Tutu's "Truth and Reconciliation Commission" is necessary. We live in the same world with them and, more than ever, it is of importance to know how they think. The pushes for "Lebensraum" in 1870, 1914–1918 and 1938–1945, capturing Paris two out of three times, are seen as part of the "struggle for existence" and Haeckel was one who assimilated concepts of Darwinism to the ideology of power politics
50. But technicians and scientists are not blameless. A British surgeon in Peshawar wrote: "There's an appalling number of paraplegics. It always amazes me that there are people calling themselves human beings who spend their lives designing weapons which maximise soft-tissue injury." Guardian, (12 Nov. 1987). (These are, for example, bullets with the centre of inertia displaced, designed to evade the Geneva Convention outlawing Dum-Dum bullets, reminding us of the Medieval concept of "round bullets for Christians: square bullets for Turks".)
51. Already many decisions about apportioning resources between young and old are being made.
52. The inimitable and irreligious J. B. S. Haldane, said (New Scientist, 8 Aug. 1974, p. 325) "I would lay down my life for two brothers or eight cousins".
53. "An Essay on the Principles of Population" (1798) which, of course, stimulated both Darwin and Alfred

Russell Wallace. "Population, when unchecked, increases in a geometric ratio. Subsistence only increases in an arithmetic ratio".

54. The struggle for existence was more evident in 1870 when Edwin Lankester, M.D., (Coroner for Central Middlesex, and father of Sir Edwin Ray Lankester, FRS) could write in his booklet "What shall we teach?" "Half the population of every town in England dies before it is five years old, and half this death arises from want of knowledge on the part of mothers and nurses how to feed children" (qu. Mary P. English, "Victorian Values", Biopress, Bristol, 1990, p. 151).
55. Insurance companies are now becoming engaged with genetics in an economy where man is the servant of money, rather than money the servant of man.
56. The reduction of 10 years in the expectation of life is equivalent to a holocaust of 15M people.
57. A recent account of these is to be found in "Darwin's dangerous idea" by Daniel C. Dennett, Penguin (1995).
58. The Phyletic Museum in Jena, founded by Haeckel, continues and its exhibits have been brought up to date in the light of more recent discoveries, especially that of the double helix of DNA.
59. Groth's textbook describes the optical microscope with a heated stage which Otto Lehmann used for his liquid crystal work.
60. "Even Haeckel had once done some experimental work" (Gould, p. 430).
61. E. Krausse, p. 79.
62. Lankester, who studied in Germany and Austria, was an important interface between German and British biology. He knew Haeckel, had worked in Jena and translated some of Haeckel's books.
63. qu. Gould (p. 76) from McCabe.
64. In which, it is said, more people, weakened by malnutrition, died than in battle.
65. There is some way to go. Susan Greenfield use the concept of a "neuronal Gestalt" which is: "a highly variable aggregation of neurons that is temporarily recruited around a triggering nucleus" (p. 112).
66. Joseph Needham, "Order and Life" (1936).
67. "Die Entwicklungsmechanik der Organismen, eine anatomische Wissenschaft der Zukunft" (Vienna, 1890).
68. "Die herschenden Ideen, die Ideen der Herrschenden sind"—K. Marx. (The ruling ideas are the ideas of the rulers.)
69. Scientific American, Dec. 1996, pp. 74–79.
70. Adam Sedgwick, writing the article on embryology in the 1910 edition of the Encyclopaedia Britannica wrote "when we look for the facts on which it is based we find that they are non-existent" and scorns to mention Haeckel by name. Von Baer's law is also "open to serious criticism".
71. Charles Darwin, in his Autobiography wrote: "Hardly any point gave me so much satisfaction when I was at work on the *Origin*, as the explanation of the wide difference in many classes between the embryo and the adult animal, and of the close resemblance of the embryos within the same class. Within recent years several reviewers have given the whole credit to Fritz Mueller and Haeckel, who undoubtedly have worked it out much more fully."
    Whether anything is recapitulated is not evident but it is clear that in generating a complete organism more fundamental structures must be laid down before those developed later—the foundations must be built before the roof.
72. W. A. Coupe, (Penguin Companion to European Literature) writes: "The central idea in Goethe's thought is the concept of organic development. His botanical and zoological writings revolve around his theory of evolution from certain primary forms (*Urphänomene)* and the principle of metamorphosis is held to be the basic law of all existence; the whole of nature is seen as being in a constant state of dynamic change and development. In his view of nature there is no dualism: God does not exist outside of nature but is in-dwelling, and apparent conflicts serve only to produce heightened development ("*Polarität und Steigerung*"). The ethical task of man is to fit into this pattern of harmonious development: the Faustian principle of activity is in harmony with the dynamism of nature itself and, with external nature, man must learn to 'die and become'; above all, however, he must learn, like Wilhelm Meister, to recognise and respect the limits of his own physical and spiritual being."
73. The BSE (*bovine spongiform encephalitis*—mad-cow disease) crisis exhibits clearly the differences between scientific and political truth (see The Economist, 22 Feb. 1997, pp. 25–26).