# Biology and Belief

## Andrew Miller - Molecular biologist

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The area of science in which I work is variously called biophysics, biochemistry or molecular biology. It is the application of the methods of physics and chemistry to living things in order to find out how they work. We want to explain the function of living things in terms of the atoms and molecules of which they are composed.

The last thirty years have seen dramatic progress in molecular biology. The first half of the twentieth century saw revolutionary changes at the foundations of physics in relativity theory and quantum mechanics. The second half of our century is likely to be remembered for the transformation in biological sciences. This has completely modified both our understanding of living things and our ability to control or manipulate them. My aim in this chapter is to give a brief account of this progress and to discuss some implications.

When Einstein formulated his theories of special and general relativity, their impact on the popular mind was that they implied a radical revision in our view of the world. Much more radical, however, was the nature of the quantum mechanics revolution in our mode of thought, since it seemed to indicate that quantum events were uncaused, and even now extensive debate is taking place on its significance for our thinking. While the revolution in biological science is perhaps not so profound conceptually as those in physics, the impact on our perception of ourselves is likely to be just as great.

In all living organisms there are three kinds of large molecules or macromolecules with molecular weights ranging from thousands to millions. These are the proteins, the nucleic acids and the polysaccharides; I will discuss the first two. Each of these three macromolecular types are long chain polymers composed of linear strings of smaller molecules called monomers, which act as subunits. These molecules all consist of only a few different chemical elements—carbon, hydrogen, oxygen, nitrogen and phosphorus and somewhat less of several other elements.

Proteins are the molecules which make up the bodies of animals. Muscle, skin and tendons, ligaments, hair and feathers are all proteins. Proteins also are the molecules which make biological catalysts called enzymes. The enzymes are crucial biological macromolecules which enable chemical reactions which would normally require high temperatures or long times to occur rapidly at body temperatures. Other proteins have different but very important functions of transport, control and regulation of reactions, conversion of chemical energy to mechanical work or conversion of energy in light to chemical energy.
Proteins are polymers of amino-acids. There are some twenty different kinds of amino-acids with differing size and electrical properties. It is the order in which these different amino-acids occur along the protein chain which defines first how the protein molecule folds up to form a well defined three-dimensional structure and second, how that well defined structure is able to perform the specific function—enzyme, transport, light-harvesting, etc—of the protein in the organism.

Let us take a specific protein, an enzyme called lysozyme, as an example. Lysozyme occurs in human tears where it acts as a mild antiseptic by catalysing the breakdown of the molecules which make up the protective outer coat of certain bacteria. All molecules of lysozyme (apart from genetic variations—more about this later) are exactly the same size, contain the same array of amino-acids in the same order along the protein chain, and this chain always folds up into precisely the same three-dimensional structure. By applying the rather complex technique of X-ray crystallography to crystals of lysozyme, this precise threedimensional structure was worked out and represented by a molecular model which shows the positions of atoms in space. This model in turn reveals how the enzyme is able to carry out its function of attacking the bacterial walls. In general, enzyme structures contain a binding site, usually a cleft in the structure, which recognises the substrate by a snug geometrical fit. Once enzyme and substrate are fitted together, a so-called active site in the enzyme is brought into close proximity to the chemical bonds to be broken in the substrate and the fission can take place. Any influence which alters the structure of the protein usually results in loss of protein function, and this is readily understood since the precise geometrical fit of recognition is no longer possible. This also explains why an enzyme can be very selective in what it attacks.

By the time of writing, the structures of around 300 different proteins have been determined by X-ray crystallography, and once these structures are known they immediately suggest mechanisms whereby the proteins carry out their function. We now have well developed mechanisms for how haemoglobin and myoglobin control the oxygen level in blood and in muscles respectively, how a large number of different enzymes perform their variety of catalytic functions, how sunlight is harvested in plant leaves by the reaction centre complex, how chlorophyll works, how antibodies recognise foreign materials in human plasma and how vaccines inactivate viruses. A whole new subject called structural molecular biology has blossomed and is currently expanding at a very fast rate. Structural molecular biology shows that living things function at the molecular level by a precise geometrical positioning in space and a high degree of synchronisation in time. This accuracy of positioning in space and time is crucial for a single event like enzyme action, but within the cells of plants and animals millions of such events must further be orchestrated in space and time so that the whole cell functions properly, and of course the cell also plays a defined role in a specific tissue (liver, brain, muscle, etc) which in turn has its specific role in the organism.

In summary, we are now beginning to see how the variety and specificity of all living things is fundamentally dependent on molecular recognition. Below the level of molecules, the atoms of living things are the same as the atoms of the inorganic world. In the biological molecules, however, there occur three-dimensional arrangements of atoms that are highly specific and allow molecular recognition to take place. The cells of living things then appear as vast assemblies of inter-related and interacting three-dimensional jigsaws which result in delicately controlled functions of the cell. This cellular function integrates with the function of millions of other cells, also under molecular control, to serve the overall function of the organism.

How do living organisms construct proteins with such precise structure? The answer lies in a second set of biological macromolecules, the nucleic acids. The nucleic acids are polymers in which the monomers are four different kinds of nucleotide. The function of the nucleic acids is principally to store and transmit information. They therefore make up the genes which are passed on through generations of organisms. There are two kinds of nucleic acid—deoxyribonucleic acid (DNA) and ribonucleic acid (RNA). The four kinds of nucleotides in DNA are adenine (A), thymine (T), guanine (G) and cytosine (C). In RNA, T is replaced by uracil (U).

In 1953, Crick and Watson made the key discovery by X-ray diffraction that the structure of DNA was a double helix. Two DNA chains are wound around each other rather like two strands of a two-strand rope. However, the crucial feature of the DNA double helix is the relation between the nucleotides in one strand and those in the other. In the central core of the double helix where the two strands touch, the A nucleotide of one strand pairs with the T nucleotide of the other, while the C nucleotide of one strand pairs with the G nucleotide of the other. So, if in one strand the order of the nucleotides was

C G T C A T G A T    then the other strand would be
G C A G T A C T A

Crick and Watson wrote the memorable words. ‘This immediately suggests a copying mechanism for the genetic material.’ For if the double helix unwound, each of the two separate strands could coil a second chain around itself to form two double helices, each with the same order of nucleotides as in the parent double helix. And the mechanism whereby A only pairs with T, and C only pairs with G is again molecular recognition. More precisely, the distribution in space of the atoms in A and T allowed them to pair by forming internucleotide hydrogen bonds in a way that was impossible between A and C, A and G, T and C or T and G. Only A—T and C—G pairs are geometrically feasible except for some rare cases. Molecular recognition is thus the basis of the mechanism whereby genes of parents may be copied into genes of offspring.

This, of course, does not yet explain how proteins are formed. By the early 1960s the steps in protein synthesis became clear. Double helical DNA unwinds and is copied into complementary strands of RNA. (In DNA, A, T, C and G produce in RNA U, A, G and C, respectively.) Then the order of nucleotides in the RNA is scanned by cellular organelles called ribosomes. The RNA nucleotides are read three at a time and each triplet corresponds to one specific amino-acid which a messenger molecule brings to the ribosome and adds on to the growing protein chain. The ‘dictionary’ which relates triplets to amino-acids is called the genetic code. For example, if UUC occurs in the RNA, the amino-acid serine is added to the protein, or if GCA occurs in the RNA then alanine is the added amino-acid. The twenty different amino-acids each have their own triplet coding for them (with quite a generous redundancy since four different nucleotides taken three at a time yield sixty-four different triplets which is more than enough to define the twenty amino-acids that occur in the body; some amino-acids can be produced by up to four different triplets).

So let us summarise again. The order of nucleotides in the DNA (the genes) can be copied from generation to generation (with high though not precise fidelity and with complex mixing particularly in organisms which reproduce sexually). This order of nucleotides in DNA determines the order of nucleotides in complementary RNA which, in turn, defines the order of amino-acids in the protein chain. This, in turn, determines the way in which the protein folds up into a well defined three-dimensional structure and this structure gives the protein its ability to function.

Incidentally, the unwinding and rebuilding of DNA as well as the reading of RNA all require specific enzymes which, of course, are proteins. This raises the question ‘What came first: proteins (enzymes) or nucleic acids?’ The discovery of a type of RNA with apparent enzyme activity, called ribosymes, suggests that nucleic acids came first.

With this general background we can now interpret many well known but previously incomprehensible features of biology and medicine.

On a personal note, I cannot forget the day in Oxford when my research group discovered a curious periodicity in the amino-acid sequence of the collagen molecule which immediately explained how molecular recognition between collagen molecules leads them to self-assemble into fibres of tendon. Collagen is the most abundant protein in mammals, accounting for one-third of human protein. It makes up tendons, skin, cartilege, cornea of the eye, the filtration system of the kidneys and the organic component of bone. The molecules are over 1,000 amino-acids long and have a triple helical structure. We could trace an unbroken set of causal links from gene (DNA) through RNA, protein sequences, protein helical structure, molecular assembly into fibrils and fibril assembly into visible tendon fibres. It was also instantly clear that the important biological fibres such as muscle and keratin will assemble in an analogous way.

The DNA-RNA protein framework also suggests mechanisms for protein evolution and for the molecular origin of certain diseases. It has yielded a powerful tool for intervention and control in medicine and agriculture leading to the new subjects of molecular medicine and molecular agriculture.

As described above, the DNA double helix suggests the mechanism whereby genes are passed on through generations. In order to work adequately the copying mechanism must be of high fidelity. However, the fidelity is not 100 percent; errors do creep in leading to alterations or mutations in the newly formed DNA, and hence altered amino-acid sequence in the proteins. When these mutations occur irregularly, and we do not know their exact cause, we call them ‘random’. Sometimes these mutations produce proteins that are unable to form or to function and they are termed ‘lethal’ if the organism cannot survive. However, many mutations are neutral and it has been noted that the number of differences in amino-acids of proteins is clearly proportional to their ‘evolutionary distance’. For example, the proteins cytochrome c from humans and primates are much more similar than those from humans and insects. It is possible by using the differences between the amino-acid sequences in proteins to construct evolutionary trees which correspond well with such trees constructed on the basis of fossil and other evidence. Thus we find the new wealth of information on protein structure fits in with general ideas of evolution and suggests a mechanism whereby evolution may occur. If a mutation happens to produce an enzyme which is more stable or more effective, then a reproductive advantage can be given to the bearer of that mutation and to its progeny. It should be said that this does not yet explain the increase in complexity which we seem to see in evolutionary history, but it throws a lot of light on one aspect of what is going on.

Mutations can also lead to genetic diseases, many of them the result of well recognised molecular defects which account for the manifestations of the disease. The best known historical example is perhaps the widespread incidence of haemophilia in Queen Victoria’s descendants, though she did not have the disease herself.

In the last few years a dramatic new technique has been developed which enables new proteins to be rationally designed. The method is called site-specific mutagenesis and is carried out now in scores of biochemistry and molecular biology laboratories. If a protein structure is known, it is possible to inspect it and decide to design a new protein in which a specific amino-acid is selectively replaced by another chosen amino-acid. This is done to investigate the effect of this site-specific change on the protein. The new protein is made by isolating the gene which codes for the original protein then, by using synthetic short sections of nucleic acids, to produce a new DNA with a chosen altered nucleotide sequence. The new DNA is then incorporated into the ‘gene’ of a bacterial culture and the synthetic mechanism of the bacteria produces the new protein in vitro. In this way, proteins have been engineered with altered enzyme activity, with improved heat stability and with stronger antibody-antigen binding. The next few years will almost certainly see a wide range of specifically engineered proteins for industrial, agricultural and medical purposes. Bacteria will also be used to produce large quantities of valuable proteins which occur naturally only in tiny quantities. Unfortunately, while we are learning a lot about human (and plant and animal) genetics and the modification of genes in disease, we are not yet able to replace deleterious human genes so that they function normally, though it is not unreasonable to expect such developments in the next few decades.

A major project in molecular biology, the achievement of which will require international collaboration, is the determination of the nucleotide sequence of a human genome. The resulting information would be comparable in bulk with that in the Encyclopaedia Britannica. The scientific techniques required are available, though high quality management and co-ordination will be essential for the success of the project. It has also been suggested that systematic efforts be made to determine the structures of all the (available) proteins. The availability of such an encyclopedic natural history of biomolecular anatomy would provide a secure basis for the development of molecular medicine. However, rather more subtle and original probes of the driving forces and controls behind the molecular machinery will also be required.

## Living beings

Of course, the account of molecular biology I have just given is grossly simplified and no proper idea is given of the immense range of biological problems which have been clarified. The reader interested in learning more is directed to the appropriate textbooks. However, I hope I have conveyed the general flavour of the profound revolution that is still taking place in our understanding of living things. A large number of difficult problems remain.

For example, we do not really understand the essence of living things—I mean scientifically, not philosophically. Organisms metabolise, reproduce and evolve. But why? Can life be explained fully in terms of physics and chemistry? The most direct approach to this central question has been taken by Manfred Eigen. The complex structure and functioning of proteins, nucleic acids and other molecules is fascinating and will produce a very powerful tool for manipulating the biological world. But what is the rationale of the whole interlocking show we call 'life'? Living things behave, as we say, with a life of their own. James Lovelock has even suggested that the entire biosphere on earth seems to act as a self-controlling unity he has called Gaia. Eigen is trying to analyse living systems in terms of hypercycles. Hypercycles are cyclical sequences of linked reactions in which the products of one reaction act as reactants for the next. Such cycles are familiar to biochemists who have established the existence of metabolic cycles and chains of reactions in organs such as liver and muscle. These metabolic cycles are mechanisms whereby we extract chemical energy from food and use it to construct essential molecular components in specialised organs of the body. Metabolic cycles are similar over a wide range of organisms but there are also striking differences. Eigen's hypercycle idea is broader than that of metabolic cycles. He is analysing the physico-chemical self-establishment and stability of these hypercycles and seeing if the computer-generated simulated behaviour of such cycles corresponds at all with how living things actually behave. The aim is to see if the apparent self-determination and goal orientation of organisms can be accounted for fully by physics and chemistry. Molecular biology will always be more than just physics and chemistry—there will be essential boundary conditions. Contingency will be evident.

Yet another approach is to ask whether or not some recent ideas on the properties of so-called chaotic systems are relevant to biology. In some systems it is well known that order can arise from disorder in a spontaneous fashion. These systems are not running contrary to the second law of thermodynamics since they are open systems with energy input. Crystal formation from solution is a simple example of such a system, but there are many other examples with a wide range of complexity. Some interesting principles emerge of how chaotic or disordered systems could spontaneously produce order. Could living cells be special cases of these principles? Perhaps living cells are not so dependent on the vagaries of history in evolution but represent the best stable assemblies of matter quite apart from natural selection which, of course, may still have a role to play.

So the new subject of biotechnology has recently appeared. To be more precise, biotechnology has recently burgeoned since we have had traditional biotechnologies of cooking, brewing, dyeing, and so on for millenia. But molecular biology is leading to a revolution in biotechnology. This practical success is raising serious problems in how to cope with it—economic, administrative, legal and ethical. But we should be clear that we still do not know how life arose, or what the explanation is of the extraordinary stability coupled with fragility and plasticity of the biosphere. There remain major problems, such as how cells differentiate, how the forms of organisms develop, what cancer involves, and so on, which seem extremely difficult but probably tractable. Over all hangs the problem of consciousness.

## Belief in God

There are several points mentioned above at which the emerging structural biology impinges on the Christian faith, but here I will discuss only one—belief in God. Although some of the picture I have sketched is fairly new, the general pattern has been evident since the early 1960s and has been commented upon by some of the scientists who created the picture—Monod, Crick, Jacob, Lwoff, Medawar and by skilful writers such as Richard Dawkins, Stephen Gould and Peter Atkins. Several of these writers conclude that theism is no longer tenable in the light of recent discoveries in biology. It is not possible to discuss all the arguments presented but I will try to give the main drift.

Dawkins says that before 1859 it was reasonable to believe in God because there was no other convincing explanation of the complexity of living things. After 1859, natural selection provided the explanation so (although, as the blurb on the cover of Dawkin's Blind Watchmaker says, there may be other reasons for belief in God) biological complexity is no longer a good reason for theism. He quotes Paley's well known argument of the watch as evidence for the design in the living world.

The argument from design ('There is design so there must be a designer') and its relative, the cosmological argument ('The fact that there exists something rather than nothing requires an explanation'), have a long history. The argument from design was used in the New Testament by Paul to the Romans '[God's] invisible attributes ... have been visible to the eye of reason, in the things that He has made' (Rom 1:20). The same argument was known to the pre-Christian Cicero who rejected it, but it was taken up in the second century AD by Tertullian on the Christian side. Varieties of the argument from design in the physical world to a Creator were used by most natural philosophers (the term 'scientist' was not used until 1834) up to the middle of the nineteenth century.

Then, in the nineteenth and early twentieth centuries, several influential thinkers explained God away. Durkeim pronounced God as a projection of society as a whole. Freud maintained that God was a projection of the father figure and that religion was a collective neurosis of society, while Marx held that religion, an ideology to bolster a type of production economy, was the opium of the people. Feurbach said that God was the product of wishful thinking and Nietzsche proclaimed the death of God. The Tubingen theologian Strauss applied historical analysis to the New Testament and wrote a Life of Christ which was supposed to abolish Christianity within a generation (of 1835). Of course, so many different explanations for God was clearly overkill. As a whole, though they contributed to the eventual secularisation of society, they were not widely convincing and more than a century later a professionally conducted opinion poll in the UK (December 1989) found 70 per cent of adults claiming to believe in God. Over the same century dramatic changes have taken place in psychology, sociology, Marxism, history and New Testament criticism. The real damage to theism was supposed to have been done by Hume in the eighteenth century. He argued that all perceptions of the human mind are either impressions of experience or ideas; whereas the relations between ideas can be known with certainty, the facts of reality cannot be established. Belief in the natural world (though a practical necessity) and in the existence of God, cannot be proved by reason. The problem there is that Hume's apparently cogent argument also implied that science should not work either. Philosophy is not always a sound guide to reality.

It is important to be clear that although the work of eighteenth- and nineteenth-century thinkers were strong influences, leading to the secularisation of a Christendom which had lasted for 1,500 years, the design argument for theism was much wider than Paley's example of order in the biological world. The design argument lay in considering the basic regularities in nature and reflecting on their origin and implications. Paley's arguments from biology were a special case of this wider argument. Paley's argument is now unconvincing since it involves details of mechanism within the universe; he brought in a 'God of the gaps' to explain gaps in our understanding—a God who therefore shrinks with our increase in knowledge. The original design argument is really untouched by Darwin since it was based on regularities in the whole of physical science as well as biology. When we try to clearly indicate the difference between theism and atheism the fundamental question is whether or not the universe has a purpose. Does the universe have a personal Creator and hence a purpose or is it entirely the result of mindless forces?

The fact that we are here obviously means that there has been a bringing into being, a creation. Leibnitz' question 'Why is there something rather than nothing?' calls for an explanation of creation, and cosmologists are actively engaged in trying to provide one. Scientific theories which involve the creation of matter out of nothing have been proposed and some (apparently at present) have been falsified.

At present, some cosmologists are looking for a theory of everything (TOE) which, from several basic principles, will explain the emergence of the universe and the present distribution of matter within it. Some theories even imply a sort of natural selection between possible universes. These cosmologists have not yet succeeded so, as in the case of biology before 1859, it would still be possible, following Dawkins' logic, on present scientific knowledge to say, 'It could be God.' But this would be the 'God of the gaps' of Paley's argument. The real reason that leads to belief in God is more fundamental than our inability to see how things work or how they came about.

Let us take the case of gravitation. The laws of gravitation, together with those of dynamics, are adequate to explain with considerable precision the movements of the celestial bodies and of lunar and solar system probes sent from earth. The fact that we can predict accurately the behaviour of gravitational and inertial masses in no way rules out a purposive God as the Creator of these laws.

Christians (and others) see the activity of God in the parts we understand as well as those that we do not. God is the ground of our being. We may know the laws of physics which allow us to calculate and often predict events in nature, but it is not the laws of physics which make events happen. These laws describe the events and their regularities. God is the Author, the Creator in the usual terms, of the world. It is very difficult to decide whether or not observed order originates from personal purpose or not. Purpose involves the idea of intentionality. Was such and such consciously planned or the result of unconscious forces?

Monodgot close to the heart of the debate in a book published in French in 1970, and in English as Chance and Necessity in 1972, when he contrasted what he called animist religions with the secular, objective view of the world. However, it is wrong to classify Christianity as animism. A.N. Whitehead, H. Butterfield, R. Hookyaas and others have pointed out that a key development of Christian thought beyond earlier Greek ideas was the de-deification of nature, a development which, it has plausibly been argued, provided the appropriate intellectual environment for the development of modern science. In Christianity, the Creator and his creation are quite distinct. The creation is not worshipped and may be investigated, as Francis Bacon put it in the seventeenth century, 'For the relief of man's estate'. In fact, this very concept has been suggested as the root cause of the thoughtless exploitation of nature and of our present environmental crisis. Exploitation, however, is not a Christian concept, for the idea of man's stewardship under God is the dominant feature of the biblical attitude towards the natural world—a view that today could be described as being as green as you can get.

However, in spite of our awareness that the Paley arguments taken by themselves are no longer convincing, some reflection on what we know about the route by which life developed shows it to be so remarkable that there seems to be more to it than just physical chemistry. Let me say immediately that I am not thinking of vital forces. I am not saying that because I can't see how it came about, it must be God. How I wish some writers, once they have got over the excitement of what we know, would be just as open about the vast areas of puzzlement and ignorance which still exist in biology. It is flying well ahead of the evidence and counter to much of experience in the history of science to say that we know that it is all going to be explained by our present-day concepts. It is worth recalling that James Clerk Maxwell, perhaps the greatest nineteenth- century physicist, said in 1872 that 'The ether is the largest and most evident body of which we have knowledge'. Within some twenty-five years the ether no longer 'existed'. Young scientists are motivated by the challenge of the great unknown and it is not productive to forget this.

When we think of the host of coincidences which had to occur to produce life, even once the Big Bang was safely over, they are remarkable. The relative sizes of the moon and the earth are, as far as we know, unique, with the implication that monthly regularities are imposed on the earth in a way that almost certainly was essential to get the rhythm of life going. Our moon is the right size to set up a joint system with the earth which produces a terrestrial magnetic core with properties which favoured the development of life.

I have no space to describe further the 'luck' which this earth has enjoyed to allow life to develop, but it is so remarkable that either one says 'Well, it has happened so a physical explanation is all we need look for', a sort of atheism based on personal credulity, or to admit that it might reflect an underlying purpose. To say that natural selection is an anti-random device, a pattern generator, or a probability augmentor, is close to vital force sort of obfuscation. Natural selection can be shown to produce order in a comprehensible way on a very modest scale indeed, and to extrapolate to the whole show is clearly wishful thinking, and not scientific. Of course, scientists must back their hunches, but it is important to be open and perceptive of the situation. It has been said, correctly, that at present we are not in a position to know whether the development of life was inevitable (ie, highly probable) or a lucky accident (highly improbable). It is difficult to be more uncertain.

But biology does not stand on its own. In contrast to the writings of the biologists mentioned above, physical scientists writing on their subject often naturally use the word 'God'. I am thinking of Hawking, Davies, Polkinghorne, Freeman-Dyson, Squires, Josephson, Cottrell, Lovell, Pippard and Coulson. We cannot write off scientists of this calibre as a loony fringe any more than we can the biologists.

All of these physicists except Hawking, who is ambivalent, appear to believe in God; but this is not the point I wish to make here. My point is that they deal in concepts analogous to those of theism. Analysis of modern physical theory shows that ideas based on our everyday experience are not trusty guides to all parts of the physical world. The key criterion in physical theory, as in theism, is empirical testing: 'Seek and you shall find'; 'Taste and see that the Lord is gracious.' Our ideas must be regulated by reality and not vice-versa. Some biologists tend to be so impressed by the success of a particular idea that they become intoxicated and see it as the global answer to everything. Gould's stimulating Wonderful Life is a bit like this. He is thrilled at the totally different species which occur among the fossils of the Burgess Shale. He decided, with rather little quantitative evaluation and contrary to the conclusions of other paleontologists, that there is a greater diversity of species in the Burgess Shale than in these phyla now. He then magnifies this idea up to a revolutionary new insight into the nature of life and the meaning of existence. He wildly theorises on the result of rewinding and playing back a recording of evolutionary development and he discovers that contingency is a concept that is needed. This is heady stuff, with full marks for enthusiasm and originality, characteristics much needed these days. However, careful critical testing will have to be carried out in order to separate the durable from the ephemeral. In the meantime, we wait and see.

Furthermore, there remains consciousness, the great mystery of biology which strongly suggests that surprises are in store for future scientists. Many new concepts are offered to help understand the phenomenon of consciousness, including the notion that we should not talk about it at all in scientific discussions. In fact, we do not have a theory of consciousness. There is no need to invoke the God of the gaps here or even to think we are forced to a mind/body dualism. My own view is that we will build up a natural history of consciousness. We will learn what kinds of electronic circuitry in the neurones can result in consciousness and which ones cannot. Obviously, it will not be easy technically to get this sort of information, and even more difficult (perhaps impossible) to set up falsifiable or verifiable tests for consciousness. Assuming these problems could be overcome, consciousness would take on the same status as gravity, inertial force or magnetism. It might even be possible to think of a theory which 'explained' consciousness in terms of dynamic electronic circuitry.

Recently, it has been emphasised that determinate physical systems can readily develop into chaotic systems where predictability is no longer possible. The development of weather patterns is an example of this. It has been suggested that this kind of indeterminacy may allow the intervention of a Creator or a Mind to nudge physical systems in the direction of the Creators's or the Mind's will. This is too close to a God (or a Mind) of the gaps for my liking. At present there is no theory that even approaches the problem of the relation between mind and matter. Roger Penrose, a leading theoretical physicist, has recently published The Emperor's New Clothes, a superb account of present-day physical theory and at the same time a fascinating analysis of the mind/body problem. He carefully distinguishes between the ideas of determinism, predictability and computability in physical theory. One of his conclusions is 'The present picture of physical reality, particularly in relation to the nature of time, is due for a shake-up.' Note the total absence of the hubris which characterises the biologists. It is as if the biologists didn't know they didn't know. Penrose believes that 'Consciousness is associated with seeing necessary truths', and 'The hallmark of consciousness is a non-algorithmic forming of judgements.' We are clearly in for some interesting surprises in this area. Not all physicists will follow Penrose's controversial view that mind is non-algorithmic, but he refreshingly admits the state of uncertainty in our understanding of the problem.

## Summary

In this chapter I have tried to make three points. First, recent advances in molecular biology are producing a powerful biotechnology which will bring benefits, but also social, legal and ethical problems. Second, despite this dramatic advance in our understanding of biology, we are still a long way from a full understanding of life and it is premature to insist that there are irresistible philosophical or theological conclusions to be drawn at this stage. Third, to suggest that recent advances in our understanding of life rules out belief in God is only valid against a very simplistic, though once popular concept of a 'God of the gaps'. The major religions, Christianity in particular, have held a more serious concept of God as Creator, Sustainer and Upholder of all that there is. This is not a recent idea but is biblical and found throughout historic Christianity. The biologists, in coping with their subject, can work with a rather ball-and-spoke model even of biological macromolecules and hence a fairly mechanistic view of life. Physicists find themselves forced to deal with concepts which are less mechanistic and much more analogous to those of theism.

It is certainly not a scientific matter to decide whether or not there is a God, whether or not there is a fundamental explanation of everything in the personal will and purpose of a Creator. It is a decision of a type which is usually called metaphysical. But this does not diminish the importance of the decision. We all, atheists, agnostics and theists alike, make metaphysical decisions, consciously or unconsciously, which involve what we regard as reasonable presuppositions or value judgements; they are unavoidable and we live by our metaphysical decisions. Most of us believe that torture is wrong, that there is truth to be discovered about the natural world, that there is an external world independent of our subjective awareness, that other people have subjective awareness just like our own, and so on. However, justification of these beliefs is not easy. Powerful arguments have been deployed by philosophers purporting to show that justification of these beliefs is not possible. However, these beliefs are not at all arbitrary, but are based not only on empirical evidence, but also considerations of coherence, fruitfulness, comprehensiveness, adequacy and intelligibility as well. On the basis of these criteria and in the light of contemporary biology, belief in God is reasonable.