Redundant God? Christian Faith in the Light of Evolution

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By

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This book is dedicated to all those
who taught me what love might mean:
to my parents Odile and Ralph, my brother Mick,
my wives Valerie, Lesley and Anne,
my daughter Lauren,
and those who guided my first steps in the Christian faith,
opening my eyes to glimpse the breadth and length
and height and depth of God's love.

Consider the lilies, how they grow: they neither toil nor spin; yet I tell you,
even Solomon in all his glory was not clothed like one of these.
[Luke 12:27, NRSV].

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PREFACE

This book looks at Christian faith through the lens of evolution. As a professional biologist—and before that, as an amateur botanist since childhood—I live and breathe a discipline permeated through and through by evolution. That doesn't make me an expert on evolutionary theory, but the evidence in favour of evolution by natural selection is overwhelming, and there is no alternative paradigm that makes coherent sense of the living world around us. Part 1 of this book reviews some of that evidence, using examples and case-studies that particularly appeal to me. Doubtless others could have been adduced, perhaps to greater effect, but this is my own selection—laced with a few personal anecdotes. I make no apology for using technical jargon-words, which are usually italicised and briefly defined at their first appearance. An extended glossary seems redundant, since interested readers can check online for more nuanced meanings of these terms. Though I have omitted many details in my chosen examples, I have tried not to oversimplify *too* much—since the interpretations offered are always subject to revision, expansion or occasionally disproof. Readers from faith backgrounds who may have opened this book in the hope of finding a rebuttal or alternative to evolution will be sorely disappointed. I am not trying to defend a sandcastle of faith against the surging tides of scientific materialism, but rather to ask what kind of God might be *consistent* with the current evolutionary world-view. My provisional answers, developed in outline through part 2 of this book, are surprisingly consonant with the kingdom teaching of Jesus in the gospels. It is this belief which allows me to keep faith as an ordained Anglican priest, ministering from a liberal theology yet preaching the good news of Jesus Christ with evangelical zeal, without denying or betraying my evolutionary convictions. To many this will seem a contradiction in terms, and doomed from the outset. Even so, I believe the attempt is worthwhile, and where I have fallen short, I trust that others will rise to the challenge and will find new ways of holding Christian faith and evolution in creative tension.

Like most biologists, I use the word *function* as a kind of shorthand—to describe what a gene or protein or cell or organism actually *does*. Inevitably, such functional descriptions are incomplete; multi-functionality is the norm rather than the exception. But in common parlance, the word

function has at least two additional senses that most biologists would eschew, as noted by Daniel Dennett (2017, pp. 34-38). When applied to a human artefact, function implies both *design* (and thus a designer) and *purpose*. Despite appearances, this does *not* concede the core argument of the Intelligent Design (ID) school. The designs that evolve in biology, however astonishing in their intricacy and aptness, have been crafted not by some (divine) Intelligent Designer, but rather by an undirected evolutionary process of endless trial and error, with natural selection relentlessly winnowing out the failures. Whereas William Paley (1802) used *design* in nature to argue for a beneficent divine designer—based on the analogy of a watch and its human watchmaker—Richard Dawkins pointedly entitled one of his books "*The Blind Watchmaker*" (1986). Dennett (2017), for one, is more relaxed about using the language of *design* and even *purpose* in biology, so long as we remember that these are produced by undirected, non-intentional processes of evolution. And that, for many religious believers, seems to deny any notion of a divine Creator. I will return to this question and offer a few pointers in chapter 8; suffice it to note here that *non-interventionist* does not inevitably imply *uncaring*, and that the topsy-turvy world of kingdom values, to which the gospels attest, points us to a loving God who never coerces us (Oord, 2015).

It is often claimed that science cannot answer "*why*?" questions, yet Dennett (2017, p. 38) distinguishes two senses of "*why*?" that science can indeed address: *how did this come to be the way it is?* and *what is it **for**?* Both are central to evolution, and each of these senses can illuminate the other. To take one familiar example that will be revisited in chapter 3, the function of wing feathers in (most) birds is to facilitate flight. Even in fossil precursors showing clear reptilian features, such as *Archaeopteryx*, a typical avian arrangement of cross-linking barbs, barbules and barbicels was already present, enabling these *pennaceous* feathers to act as aerodynamic vanes (for insight into the underlying biomechanics of wing feathers, see Matloff *et al.*, 2020). But complex structures such as flight feathers could not possibly have arisen in one step. During the evolution of modern birds from theropod dinosaurs, the earliest feather-like structures were single keratin filaments, then multiple filaments, which later became attached to a central axis (*plumaceous* or down feathers). None of these could conceivably have served to enable flight, and most likely they functioned as insulators in thermoregulation, since birds are (and many dinosaurs were) warm-blooded; this function is still retained by the down feathers in juvenile or flightless birds. We will meet with further examples of evolutionary co-option for new functions (*exaptation*) later in chapter 3.

The story of how flight feathers evolved ("*came to be the way they are*") therefore implies several answers as to "*what they are* (and *were*) ***for***".

The tale is told of a child who asks both parents where the rain comes from. Mum—who is both religious and busy—replies that "*God makes the rain*". Dad, by contrast, launches into a long account of the sun's heat, evaporation from the seas, rising air currents and the condensation of water droplets. The child returns to mum and confronts her with a slightly garbled account of where the rain *really* comes from; "*yes*", she responds, "*that's how God makes the rain*". A wise answer, if the parents wish to avoid being played off one against the other, but equally it's an answer that begs far too many questions. I suspect many middle-of-the-road Christians believe something similar about evolution—that it's the process whereby God creates all the myriad varieties of living things on this planet. But is that really a sufficient answer? One underlying problem is that evolution is both indifferent to suffering and incredibly wasteful. For most organisms, only a fraction of one percent of the viable offspring produced will actually survive to adulthood and produce offspring of their own. True enough, this percentage increases significantly among those birds and mammals that carefully nurture their young—and especially so among humans. But even so, it is hard to reconcile this relentless struggle for survival with a loving God who wills only good for creation. Because of the close evolutionary ties linking humans with other animals, this cost of evolution cannot be glibly dismissed as a mere illusion, as though only human beings matter to God. Nor can we pursue an ascetic line that decries the body and its sufferings, but glories in an immaterial soul or spirit— since modern neurobiology seems inconsistent with such a dualism (see chapter 5). An impersonal God, indifferent to the suffering and wastage attendant on evolution, has only limited appeal; why would such an entity merit devotion and worship? As a Christian, what makes all the difference for me is my conviction that in Jesus, Godself enters into the pain and suffering of this world (which can also be viewed in evolutionary terms), and even suffers death on behalf of—and in solidarity with—all human beings, and perhaps all living things. I cannot prove beyond reasonable doubt that Jesus really *was* God incarnate, nor that he rose again from the dead, but I can at least try to outline how such a God could be interpreted in ways more consistent with an evolutionary world-view. Here I am not so much seeking to convert atheist scientists to faith (though I would ask them to read this book with an open mind), but rather to open the eyes of Christians to evolution and the hard questions it raises for theology.

It is a truism that death is an inevitable corollary of life: galaxies and stars, as well as species and individuals, all succumb to death—eventually. The second law of thermodynamics cannot be defied forever. All living organisms manage to do this temporarily by taking in energy to counteract *entropy* (increasing disorder)—but sooner or later errors creep in, leading to senescence and finally death. As Ecclesiastes 3:1-2 (NRSV) states: "*For everything there is a season, and a time for every matter under heaven: a time to be born, and a time to die*". On our geologically active Earth, environmental change is unavoidable, and on occasion this will prove catastrophic, precipitating the demise of individuals and of whole species, or rarely mass extinctions (§ 3.4). Lucas Mix (2020) argues that most if not all of the suffering and wastefulness usually blamed on evolution is in reality caused by the attrition of entropy in all organised systems. We cannot hope for evolution to redeem itself by defying entropy; such a hope lies in the gift of God alone (§ 8.5.2) and is beyond the scope of science.

The welfare of animals is a fairly recent concern, coming to the fore only since the 19th C CE, at least in Britain. Are we then projecting 21st C sensitivities onto the costliness, suffering and wastage entailed by entropy and evolution, whereas people in earlier centuries would have seen nothing untoward in this? In what ways are human sensations of suffering or pain (a useful warning system, in evolutionary terms) applicable to animals, let alone plants. or even microbes? Among higher vertebrates, comparable experiences of pain can be inferred—but is a plant wilted by drought "suffering" in any real sense? And yet, there is accumulating evidence that plant root systems are able to "communicate" via networks of mycorrhizal fungal symbionts, extending to warnings of predator or disease attack, and even sharing nutrients. This suggests unanticipated levels of co-operation and interactivity even among plants. Little wonder that many Christians are appalled by the seeming callousness of evolution—summarised in Tennyson's eloquent phrase "*nature red in tooth and claw*" from his 1849 poem "*In Memoriam*" (McGrath, 2011, p. 167), which predated Darwin's "*Origin of Species*" by a decade. Jesus came to the sheep of his fold so "*that they may have life, and have it abundantly*" (John 10:10, NRSV), which hardly squares with a world in which so many lives—human and especially non-human—are cut short and left unfulfilled. The question remains unanswered: where can God's love be discerned under the harsh spotlights of entropy on the one hand and evolution on the other?

I will doubtless be taken to task for making common cause with ultra-Darwinists such as Daniel Dennett and Richard Dawkins, who have become *bêtes noires* among Christians. However, my reasons for doing so

are straightforward, since these authors both provide plausible Darwinian accounts of how uniquely human traits such as consciousness, free will, language and culture could have arisen through conventional evolutionary processes. Much of this is speculative, to be sure, but at least it seeks for continuities rather than *dis*continuities between ourselves and all other living things on this planet. The question I am pursuing here is whether such an evolutionary perspective is *inevitably* fatal to belief in God. If evolution is as all-embracing as its atheist proponents claim (and I believe it is), then there is no obvious *necessity* for a Creator, either to set the ball rolling ("light the blue touch-paper and retire to a safe distance": the deist position) or to guide the whole process. My tentative answer is to suggest that the interfering, micro-managing, all-powerful God of traditional belief is indeed redundant, but that the forgiving, non-coercive, counter-intuitive God of love to whom Jesus bears witness in his gospel teaching is not only plausible, but is desperately needed in this beleaguered world we share.

One of the most characteristic and possibly unique of human traits is our innate predilection for story-telling. Our species has been aptly dubbed *Homo fabulans*—"tellers and interpreters of narrative" (Currie, 1998, p. 2). Michael Dowd (2007, pp. 103-106) draws a useful distinction between *day talk*, based on rational evidence and facts (the very essence of science)—and *night talk*, couched in the allusive and emotionally charged language of myth, metaphor and poetry. The former is handled in large part by the left half of the human brain, the latter by the right half (McGilchrist, 2009). But we should not let this neat categorisation blind us to intermediate possibilities—what we might term *sunset talk* or *dawn talk*. The former draws highly selectively on facts and rationality to propose an ideology—political or religious—that tries to lead us down the narrator's preferred path towards conclusions that do not necessarily follow from the facts. I have tried to avoid this trap, as far as possible, by separating the evolutionary science in part 1 from the more speculative theology in part 2. My hope is that this tactic comes closer to *dawn talk*—where a broader perspective on the facts might lead us to consider alternative possibilities, as *non-exclusive* ways of understanding the intricate narrative of evolution.

Scientists each tell that story in slightly different ways, choosing their own personal selections of examples and illustrations, even if tinged with a flavour of whatever ideology they might adhere to (whether atheist or religious, secular or spiritual, political or philosophical). Rather different readings of the story of evolution are given by Richard Dawkins, by Stephen Jay Gould, and by Simon Conway Morris—to take just three writers who have all brought evolution to a wider readership in recent

decades. All base their arguments on the same underlying set of facts, but the examples used and the interpretations offered take the reader on quite different journeys. Even successive books by the same author offer subtle contrasts in emphasis, often with different questions or audiences in mind. There is nothing wrong in this—no one account is necessarily "correct" and the others false (despite bluster to the contrary!). All are provisional, and all may be mistaken or distorted in some respects, while also offering insights that help us glimpse afresh the sheer scope, variety and subtlety of evolution. We don't have a complete understanding of the process, so of necessity all these accounts are *partial*—in both senses of the word. That is one reason why part 2 of this book explores the possibility of different readings, both of scripture and of history, that do not simply play into the tired and obsolete myth of inevitable conflict between science and faith. It is all too easy to portray evolution as a triumphal progress culminating in human beings as some sort of pinnacle or ultimate achievement—"*the crown of all creation*" (quoted from Eucharistic Prayer G, Archbishops Council "*Common Worship*", 2000, p. 201), or as "the universe become conscious of itself" (cf. Dowd, 2007).   That is far too hubristic and anthropocentric a view. We cannot presume that the universe (or multiverse) has not evolved intelligent beings elsewhere, nor indeed that humanity is the final word for evolution on planet Earth. Our singular power to reflect consciously on ourselves and on the universe around us seems to be matched only by our capacity for heedless destruction of other humans and of our environment. In some ways *Homo sapiens* is a misnomer for our species, since wisdom seems in short supply in many of our dealings with each other and with the natural world.

It will be noted by both scientists and theologians that in part 2 of this book I treat scriptural quotations as pieces of *evidence*—but not, I trust, as proof texts. This somewhat cavalier approach to scripture glosses over much Biblical scholarship: textual and form criticism, and hermeneutics—of which I am aware but have no space to explore in detail. Rather, I employ the risky approach that most preachers use in a Sunday sermon—which is to take the words of one or more scriptural passages and try to unpack what they might mean for an audience in the 21st C CE, some 2000 years after they were written down. Of course, words change their meanings and associations over time, but it is dangerous to assume that in any given text there is only one clear and immutable meaning, fixed for all time. Unpeeling the many different layers of meaning and ambiguity in scripture is, to me, more fruitful, more challenging and more illuminating. To emerge after a sermon saying "I'd never thought of it that way before" can be a sincere tribute to inspirational preaching—unless of course the

interpretation offered was so bizarre and implausible that this phrase is said with a regretful shake of the head or a dismissive shrug of the shoulders! That too can happen when preachers start riding one of their pet hobby-horses. I am well aware that conservative Christians and biblical scholars will think this is precisely the trap I have fallen into in part 2 of this book. The world-views available to people back in the first century CE were not touched in any sense by evolution nor even by science as we currently understand it. But science and evolution so dominate contemporary culture and thinking, at least in the West, that Christians must needs accommodate to this reality—perhaps seeing things we thought we knew in a fresh light, as if for the first time. Otherwise, we retreat into alternative realities that operate by their own local rules—an option followed by fringe sects and by fundamentalist streams within all major religions. Though prevalent and superficially attractive—thanks to the apparent certainties it offers—I believe that option to be profoundly misguided and even dangerous. We all inhabit planet Earth and must husband its dwindling resources as best we can, yet many fundamentalists vehemently deny human responsibility for climate change and refuse to accept evolution or many other scientific inferences. But science and faith co-exist within the same physical reality, underlining the urgency of finding realistic contact-points between them.

In terms of this book's structure, chapter 1 offers an outline of cell and molecular biology; non-biologists may find this tough going, but without it much of the rest of part 1 will make little sense. Chapter 2 addresses the core topic of Charles Darwin's 1859 book "*The Origin of Species*", asking how diverse and distinct life-forms arise through evolution by natural selection. Chapter 3 expands this perspective through the vast epochs of geological time—focussing mainly on animals over the past 600 million years—pointing to the ominous refrain of mass extinctions that have punctuated the earth's fossil history. Chapter 4—doubtless also daunting to non-biologists—returns to the molecular and genetic themes of chapter 1, exploring how genes co-operate to establish *pattern* in developing animal embryos, and the hints of "*deep homology*" that suggest how evolution generates endless variety and innovation by tinkering with ancient genetic modules. Chapter 5 looks at humanity from a scientific perspective, ranging widely from DNA and brains to the remarkable rise of culture that seems unique to our species. In Part 2, chapter 6 offers a selection of *ambiguous histories*—where digging down into apparently straightforward stories reveals unexpected layers of complexity—in music, in the history of evolution, and in biblical texts. This provides a prelude to chapter 7, where I review the thought of four very different "key thinkers" who have wrestled with the conundrums of evolution and

Christian faith: the Jesuit Pierre Teilhard de Chardin, the evangelical R.J. (Sam) Berry, the Roman Catholic Celia Deane-Drummond, and the liberal Anglican Arthur Peacocke. Chapter 8 is an attempt to state my own position as clearly as I can set it out, without pretending that I have answers to every question. Chapter 9 offers a brief evolutionary exegesis of a personal selection of biblical texts, exploring how the words used (at least in modern English) can find new resonances in the light of evolution—but without suggesting that the original writers penned these phrases with any such interpretation in mind! Lastly, in chapter 10, I return to the theme of mass extinctions covered in chapter 3. Global warming—largely anthropogenic in origin—is triggering a sixth mass extinction among the myriad other species with whom we share this planet, exacerbated by expanding human populations and overexploitation of resources. Unless we can curb our greed and find the inner spiritual motivation to live more sustainably, our future looks bleak.

Though this book offers a personal take on its subject-matter—its core arguments developed over many years while leading a double life as an academic biologist and ordained priest—it could not have reached fruition without the input and enthusiasm of many others. I would like to take this opportunity to thank my colleagues and friends who suggested extra reading or read chapters in draft: from the University of Nottingham, Jerzy Behnke, Ian Duce, Kate Durrant, Markus Eichhorn, Francis Gilbert and Paul Scotting; among fellow members of the Society of Ordained Scientists, David Atkinson, Pan Conrad, Tom Lindell, Colin Price, Roger Pullin, Simon Lumby, Mark Gallagher, Keith Suckling and Roger Yates; from New College at the University of Edinburgh, Michael Fuller, Mark Harris, Anja Klein and Helen Bond. Help with chapter 3 was generously provided by my geologist brother Mick, with contributions from Simon Conway Morris, Alexander Liu, Jean-Bernard Caron and Sarah Gabbott. I am particularly indebted to Adrian Armstrong, Michael Fuller and Jeff Patrick for reading through most or all of my text—pointing out omissions and non-sequiturs as well as typographical errors. This book has benefitted greatly from all their suggestions and comments. I take full responsibility for the inevitable errors, misapprehensions and omissions that remain. Most illustrations are my own, since copyright permission is such a vexed issue; readers will be left in little doubt about my enthusiasm for plants! As for diagrams, I opted for the familiarity of Powerpoint, despite its limitations. In both parts, I refer extensively to popular presentations of evolution and theology, but part 1 also draws widely on the primary scientific literature. This reflects my own background as an academic biologist, whereas I have no comparable foundation in academic theology.

I have endeavoured to update many of the stories I cite with the latest plot-twists and question-marks from papers published in the last year or so. But I am aware that this provides no assurance of security—as only time will tell which advances will prove fruitful and which lead nowhere. Science is always provisional—aiming for *verisimilitude* rather than absolute truth.

PART 1

CHAPTER 1

OF MOLECULES AND CELLS

Summary

§ 1.1 outlines the basic reasoning, reporting and reliability of science. § 1.2 deals with cell structure, and how bacterial cells (prokaryotes) differ from those of higher organisms (eukaryotes). § 1.3 describes how genetic information is encoded in DNA, copied (by replication), and expressed via RNA (transcription) into protein (translation), using the triplet genetic code. § 1.4 compares the regulation of gene expression in bacteria (Jacob-Monod model) with the multi-level modular control systems employed in eukaryotes, using protein transcription factors, DNA looping, RNA splicing and other mechanisms. § 1.5 looks in brief at inheritance patterns from cross-breeding (Mendelian ratios), genetic mixing through recombination during gamete development, together with the various types of mutation that can alter the DNA sequence and introduce genetic novelty. § 1.6 describes how the prolonged use of pyrethroid insecticides has encouraged specific resistance mutations to emerge among target pests. § 1.7 considers the origin of life, and explores the possibility of an "RNA world" that preceded the emergence of cellular life based on DNA, RNA and proteins. Lastly, § 1.8 considers the success of scientific reductionism, but asks whether there might also be "emergent properties" of the whole that cannot readily be predicted from the properties of its component parts.

1.1 Preamble: the process of science

Part 1 of this book claims to be scientific in its approach, yet many non-scientists have asserted that evolution is non-falsifiable and is therefore not truly a scientific theory. It is always risky to infer a general truth from specific instances—for instance if staking a claim that *all swans are white*—yet this is the way that scientists often work. Such a statement may hold true for all swans encountered in the northern hemisphere, but is immediately disproved by the occurrence of black swans in Australia. Our original sample (northern swans) was too limited in scope and diversity,

and thus our generalisation was misleading; we need a broader zoological definition of what defines the group of birds known as swans (§ 2.3). Karl Popper proposed that science works (for the most part reliably) on the basis of *falsifiability*, whereby any scientific hypothesis can in principle be *dis*proved through thorough testing of its key predictions and showing one or more of them to be demonstrably false (Popper, 1968). At first sight, evolution provides a remarkably protean and flexible explanation for the history of life on earth, with a capacity to absorb major setbacks or to find alternative explanations whenever its key tenets come under challenge. But that doesn't mean that it is *in principle* unfalsifiable: when asked what evidence might disprove evolution, J.B.S. Haldane flippantly but pointedly replied "Fossil rabbits in the Precambrian". Similarly preposterous claims (e.g. of "human footprints" among dinosaur footprints at Paluxy River) have never yet been proven scientifically, but in principle they *could* be.

However, another philosopher of science, Thomas Kuhn, pointed out that science works mostly within over-arching paradigms that represent the accepted consensus in any given field. These paradigms are sometimes false (e.g. the phlogiston theory of combustion before the discovery of oxygen) or at least incomplete (e.g. Newtonian physics before relativity and quantum mechanics). The transition from one paradigm to another (a so-called "*paradigm shift*") is a time of challenge and re-evaluation, when accepted models and explanations are brought into question and often rejected as inadequate (Kuhn, 1962). Such paradigms also feature as *core assumptions* that cannot be abandoned without undermining an entire programme of scientific research, in the model proposed by Imre Lakatos (1978). It is certainly true that evolution provides the current over-arching paradigm and core assumption within the biological sciences; Theodosius Dobzhansky (1973) entitled an influential essay "*Nothing in biology makes sense except in the light of evolution*". But there have been opportunities a-plenty for this evolutionary paradigm to be undermined if not overturned over the past half-century: the genetic code might not have proved universal (so denying the descent of all living things from a common ancestor; this chapter), and genome sequencing in a wide range of organisms might have flatly contradicted rather than broadly supported the inferred evolutionary basis for traditional *taxonomy* (the classification of life; chapter 2) and *phylogeny* (the fossil history of life; chapter 3).

The application of *scientific method* has proved immensely successful in making sense of the world around us. It makes the tacit assumption that the universe is indeed understandable and that we can apply reason as well as observation to the process of understanding it. Many have argued that

this has arisen primarily in the Christian West through its view of God as *guarantor* of natural laws (Aquinas). Scientific reasoning proceeds in two directions: first *inductively*, building models and hypotheses on the basis of our observations; and second *deductively*, making predictions of what we should *expect* to observe under certain (ideally experimental) conditions if our model or hypothesis is correct, and then testing those predictions. There is thus a to-and-fro process of model building and refinement driven by ever more extensive and precise experimental or field observations. This works on the basis of what Lucas Mix (2015, pp. 48-50) has termed *mutual observables*: if I were to conduct an experiment in my Nottingham laboratory, then the same (or very similar) results should be obtainable in a replicate experiment conducted anywhere else in the world on another occasion. Needless to say, there are several caveats to this sweeping generalisation: both experiments would need to use identical conditions, with the same materials and equipment. Another key limiting factor is statistical. Ideally one might wish to measure every single instance of a particular phenomenon, but in practice this is impossible—and we have to content ourselves with measuring a subset or *sample* of the total instances. This can also introduce *sample bias*—particularly if the sample has been selected using criteria that skew the outcome. This can often be inadvertent, but occasionally it is done deliberately. Inadequate sample size is another important limitation. If you toss a coin 5 times, it would not be especially surprising if heads turned up 4 times and tails only once. But if you tossed the same coin 100 times, an outcome of 80 heads to 20 tails would suggest the coin had been tampered with. In general, the larger the sample size, the more confident we can be that our sample is representative of the whole population, giving us tighter *confidence intervals* (often stated as 95% CIs).

Critics claim that "evolutionary" explanations for specific adaptations often amount to little more than wishful "*Just-So Stories*"—on a par with Rudyard Kipling's fanciful account of how the leopard got his spots (etc.). This is more than a little unfair; most such explanations *do* make testable predictions about the mechanisms or pathways by which these adaptations arose, and since most have arisen multiple times in different groups of organisms (by convergent evolution; § 3.5 and 3.6), they are both testable and in principle falsifiable. Daniel Dennett (1995) draws a useful distinction between *skyhooks*—instances of irreducible complexity which defy evolutionary explanation and so necessitate an Intelligent Designer—and *cranes*, where such complexity is built up gradually by plausible small-scale evolutionary steps. By definition, science prefers to work with cranes rather than posit a "miraculous" skyhook. Even where the latter might seem more likely at first sight, it always remains vulnerable to crane

attack. The Intelligent Designer (Behe, 1996) is therefore liable to become an ever-shrinking "*God of the gaps*" (compare Behe, 2007).

In practice, science works by proposing rational hypotheses and models within the prevailing paradigms, such that key predictions made by a given hypothesis or model can be tested—for preference through experiments under carefully controlled conditions—so that it can be either rejected or retained. Experimental findings consistent with the model or hypothesis can never *prove* its validity, since future tests might come to an opposite conclusion. But once falsified through experimental testing, any hypothesis ought to be discarded as inadequate, and alternatives (or at least modifications) sought. In practice, as pointed out by Popper (1968), scientists can waste inordinate amounts of time and effort defending a favourite "wrong" hypothesis, sometimes on the dubious grounds that it is far too good an idea *not* to be true! Occasionally that stubbornness pays off and a controversial hypothesis is eventually vindicated, as with Alfred Wegener's evidence suggesting continental drift (Dudman, 2003), but far more often contrary evidence accumulates till the idea has to be jettisoned.

The process of scientific publication deserves brief comment here. Scientists usually describe their findings and the methods used to obtain them in the form of a paper submitted to a scientific journal, which may be prestigious and broad in scope (like *Nature* or *Science*), or alternatively quite narrow in terms of its remit. After determining its suitability for that journal, the paper is sent out for anonymous *peer review*, conducted by two or more scientific experts in that field. Reviewers can accept or reject a paper outright, but the former at least is unusual. More commonly, sundry criticisms are raised, often requiring extra controls or experimental tests, or sometimes proposing an alternative interpretation, and very frequently recommending additional explanations, cuts, references or textual clarifications. Many authors acknowledge that the final published paper has been greatly improved through this peer review process, though it can all take an unconscionably long time (months to years). However, the system is only as good as the quality of its reviewers, and the time and energy they are willing to devote to this unpaid task amid the pressures of their own careers. There are cases where poor-quality papers slip through the net and get published, not to mention an acknowledged problem of fraud—ranging from selective presentation of data through to outright falsification of results. This detracts from the reputation of science, and is time-wasting for scientists trying to repeat or develop the fraudulent work, though this can often help unmask the fraudsters. Despite these problems, peer-reviewed papers should at least meet basic scientific standards of competence; however, that does not prevent biased or simply erroneous

papers from being published. The quest for scientific novelty can lead to corners being cut, or claims may be made that are later contradicted by new data. The proper procedure in such cases is for the original authors to publish a retraction, but this isn't always done; I did so once myself (de Pomerai *et al.*, 2006) in *Nature* after identifying a key confounding factor.

Science deals with repeatable observations and experiments, subject always to the technological limitations of its equipment, and viewed through the interpretative lens provided by current models and paradigms. It does *not* deal with absolute truths, but rather aims to provide the most accurate achievable description of reality (*verisimilitude*). Its conclusions are necessarily provisional and subject to revision in the light of new understanding, but it is neither arbitrary nor easily set aside as mere "interpretation". Despite the innate conservatism and inertia of mainstream science, paradigm shifts can and do occur; during my own life, these have arisen from the advent of plate tectonics, molecular biology and genomics. Science is *not* wasting its time trying to paper over inadequacies in the evolutionary world-view. Likewise, the vacuous bubble of post-modern deconstructions of the whole scientific enterprise has been convincingly pricked (Sokal & Bricmont, 1998). Human societies depend on the reliable out-workings of applied science: thus antibiotics combat bacterial diseases, vaccines protect against infections, antiretroviral drugs control HIV/AIIDS (despite all rumours and conspiracy theories to the contrary!), and airliners full of trusting humans keep flying—thanks to the laws of aerodynamics.

1.2 Cells and organisms

Readers may question why this book, ostensibly on evolution and Christian faith, opens with a brief primer on genes and cells. Practising biologists often assume that "everybody knows" most of what follows, at least in broad outline, but public knowledge about genes and proteins tends to be very sketchy. It is thus all too easy to miss the clear evolutionary implications of the ways in which organisms function at a molecular level. If we set aside typical viruses—which are genetic parasites rather than independent life-forms—then all living things are composed of *cells*. These vary in size from micrometres to centimetres—indeed the egg-yolk of a bird is in reality a single huge cell. The internal contents of a cell (*cytoplasm*) are separated from the external environment by a *lipid bilayer membrane*, within which embedded proteins control (among other things) the uptake of nutrients and other molecules, and removal of waste-products etc. Often this membrane is reinforced by an external cell wall, as for instance in plants, fungi and bacteria. The *prokaryotic* cells of bacteria are

generally much smaller and simpler than those of "higher" *eukaryotic* organisms—which include both single-celled and multicellular forms. In unicellular prokaryotes, genetic information is carried on a circular piece of DNA (*chromosome*), though often this is supplemented by smaller DNA circles called *plasmids* that can readily transmit traits such as antibiotic resistance between bacterial cells, even across species barriers (Fig. 1-1A).
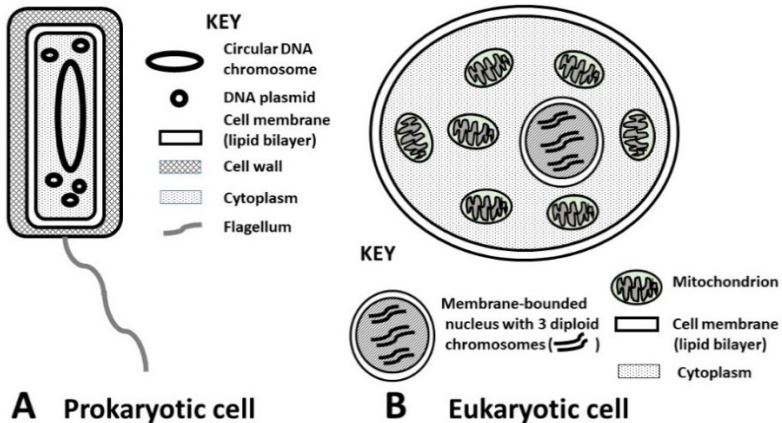

Figure 1-1. Outline of prokaryotic versus eukaryotic cell structure. Part A, prokaryotic cell with a circular DNA chromosome, small DNA plasmids, a cell wall outside the lipid bilayer membrane, and 1 or more flagellae (not present in all bacteria); this structure applies both to Bacteria and Archaea. Part B, eukaryotic cell with a membrane-bounded nucleus containing diploid linear chromosomes, and multiple mitochondria. The outer cell membrane is supported by a cell wall in plants, algae and fungi, or by a fibrous extracellular matrix in many animal cells. If drawn to scale, B would be very much larger than A.

In eukaryotic cells, the genetic material comprises several linear but vastly longer pieces of DNA that are packaged with histones and other proteins to form *chromosomes*; these are usually enclosed in a membrane-bounded *nucleus* (Fig. 1-1B). Most sexually reproducing eukaryotes are *diploid* (2N)—meaning that their nuclei contain two sets of chromosomes derived respectively from the male and female parents. Before a diploid cell divides into two, it first become *tetraploid* (4N) through chromosome duplication (§ 1.3 below), such that each daughter cell receives an identical diploid (2N) set of chromosomes—a process known as *mitosis* (Fig. 1-2A). During the development of sex cells (animal ova or sperm; plant ovules or pollen), a different type of division called *meiosis* reduces the number of chromosome sets from four to two to one, such that each sex cell or *gamete*

carries only a *haploid* (N) or single set of chromosomes (Fig. 1-2B). When a new organism is reconstituted genetically via *fertilisation*, the fusion of male and female gamete nuclei restores the diploid 2N state (*karyotype*).
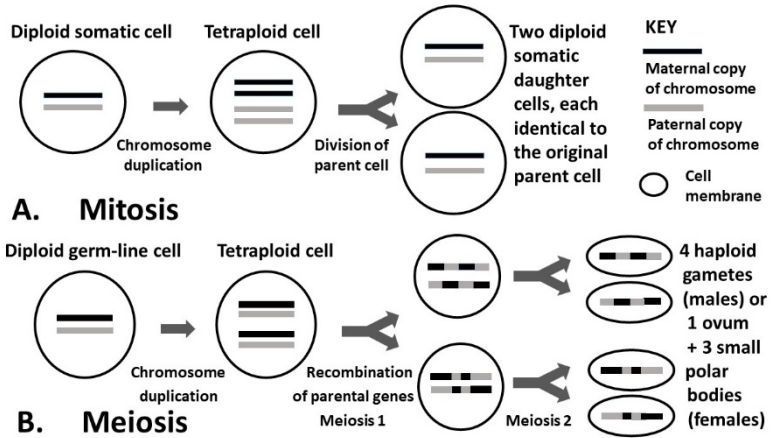

Figure 1-2. Mitosis and Meiosis. Part A, mitosis for diploid tissue (somatic) cells: both chromosomes (one from each parent) are duplicated, and when a cell divides, each daughter cell receives a set of chromosomes identical to the original cell. Part B, in germ-line cells that generate gametes (sex cells), a different type of division—termed meiosis—occurs: the diploid germ cells undergo chromosome duplication as in mitosis, but the number of chromosome sets is reduced from 4 to 2 to 1 (haploid) through 2 reduction divisions, meiosis 1 and 2. In addition, recombination between homologous chromosomes at the tetraploid stage ensures a mingling of genes from the paternal and maternal chromosomes (see § 1.6).

Eukaryotic cells contain a variety of other subcellular membrane-bounded structures termed *organelles*, in addition to the nucleus. These include the *mitochondria* in animal cells (Fig. 1-1B), and also *chloroplasts* in plants—both of which arose from ancient intracellular symbioses between different types of prokaryotic cell (the *endosymbiont* hypothesis of Lynn Margulis, 1970). Both organelles retain at least some of their own genetic information in the form of circular (sometimes linear) DNA that replicates independently of the nuclear chromosomes, though many key genes have been ceded to the nucleus. Mitochondria, derived originally from α-proteobacteria, may be compared to cellular batteries, producing energy in the form of adenosine triphosphate (ATP) to fuel the complex metabolic and other activities of cells. There are many advantages, but also some disadvantages, to this endosymbiotic arrangement (Youle, 2019). Plant chloroplasts undertake *photosynthesis* using the green pigment